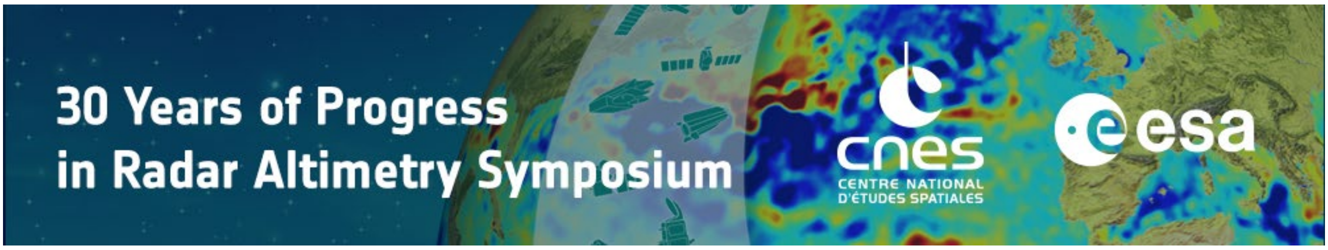

"30 YEARS OF PROGRESS IN RADAR ALTIMETRY" SYMPOSIUM

Le Corum - Place Charles de Gaulle | Montpellier, France

2-7 September 2024

ABSTRACT BOOK

(Draft7 – 2024-07-15)

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ABSTRACTS

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OBSERVING WAVE-AFFECTED MARGINAL ICE ZONES IN SOUTHERN OCEAN BY SATELLITE RADAR ALTIMETER SYNERGY

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Marginal Ice Zone (MIZ) is an integral part of the Antarctic sea ice cover and usually associated with intensive air-ice-ocean interactions. Wave-affected MIZs form due to the wind wave/swell propagation into the ice pack, the ice breaking, the pronounced ocean mixing, as well as the potential positive feedback to the sea ice cover. However, great challenges exist for the satellite-based observations of the MIZ, mainly due to its small temporal and spatial scales. In this talk we introduce recent advances of observing MIZs with radar altimeters. Circumpolar remote sensing of Antarctic MIZs is carried out through the synergy of multiple satellite campaigns, with July of 2017 as the sample period of study. We show that, the wave-affected MIZ can be effectively retrieved with radar altimeters through the waveform properties, which is modulated by both sea ice and the wave's modulation. Furthermore, the synergy of multiple radar altimeters greatly improves the temporal and spatial representation of the underlying MIZ. Hot-spots of MIZs are revealed around the Antarctic, especially around Ross/Amundsen Sea and Weddell/Riiser-Larsen Sea. Related topics, including the swell attenuation in the MIZ, are also discussed.

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ASSESSMENT OF SENTINEL-6 MF SAR MODE AND REPROCESSED JASON-3 LRM SEA LEVEL MEASUREMENTS OVER GLOBAL COASTAL OCEANS

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With dedicated coastal processing strategies and advanced Delay-Doppler technique, the quality of altimeter data from Low-Resolution Mode (LRM) and Synthetic Aperture Radar (SAR) mode altimeters in coastal areas have been greatly improved. In this study, we present a new 20-Hz along-track sea level anomaly (SLA) dataset of Jason-3 within 100 km to the global coastlines using the modified SCMR (Seamless Combination of Multiple Retrackers) processing strategy. The new reprocessed Jason-3 dataset, along with Sentinel-6 Michael Freilich (MF) SAR mode data, are evaluated and validated over global coastal oceans. The evaluation results show that the modified SCMR has significantly increases the data availability by 16%–67% for Jason-3 when compared to the official SGDR MLE4 dataset, especially in the last 5 km to the coast. The resultant data availability retains more than 90% beyond 5 km to the coast and 80% within 5 km to the coast, which is slightly higher (2%–10%) than that obtained by the Sentinel-6 MF. Most importantly, the modified SCMR can mitigate the hump artifacts observed for the SLA spectrums of LRM altimeters and make the noise level of 20-Hz SLA estimates from Jason-3 (5.52 cm) comparable with that from Sentinel-6 MF (5.42 cm). This result demonstrates that the modified SCMR strategy would improve the LRM altimeters' capability of monitoring the mesoscale eddies. The evaluation results also show that the Sentinel-6 MF SAR mode data obtain higher data precision but lower data availability than reprocessed Jason-3 LRM data, especially in the 0-5 km coastal strip and mid-to-high latitude (>40°N or <40°S) regions. Although the quality of altimeter data in the 0-5 km coastal strip has been significantly improved, the validation results against tide gauges demonstrate that the degraded performance still occurs when compared to the results beyond 5 km offshore. The significant discrepancy between tide gauge records and altimeter data is found in places such as sheltered bays and archipelagos where the land contamination is severe, and thus the development of dedicated coastal retrackers for SAR mode altimeters is still of great importance. Finally, the good consistency between reprocessed Jason-3 LRM and Sentinel-6 MF SAR mode altimeter datasets has been found by examining the inter-mission SLA biases (−0.12±0.01 m).

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THE HORIZON2020 OPEN CLOUD FOR RESEARCH ENVIRONMENT PROJECT'S HIGH-RESOLUTION ALTIMETRY DATA FOR COASTAL ANALYSIS

Ponce De Leon Alvarez S[1], *Orrù C*[2], *Iesué M*[2], *Orlandi M*[2], *Rivolta G*[2], *Restano M*[3], *Benveniste J*[4]
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This work details the processing of CryoSat-2 and Sentinel-3 data through the SARvatore services for CryoSat-2 & Sentinel-3, which are key components of the ESA Altimetry Virtual Lab (https://eo4society.esa.int/resources/earthconsole-altimetry-virtual-lab/). Both services allow for the selection of a "Coastal Zone" profile, specifically designed to generate thematic coastal altimetry products that are crucial for detailed coastal studies.

The generation of this high-resolution altimetry database was undertaken within the framework of the European Union's Horizon 2020 research and innovation program, specifically under the Open Clouds for Research Environments (OCRE) grant, facilitated through the ESA Altimetry Virtual Lab on Earth Console®. This initiative has led to the creation of a pioneering assessment of renewable wave energy resources in coastal areas, a project entitled "Assessment of Renewable Wave Energy Resources in the Coastal Zone Using High- Resolution Altimetry Products."

A key feature of these services is the integration of a customizable unfocused SAR processor coupled with the advanced SAMOSA+ coastal retracker. This combination is instrumental in providing high-quality coastal zone data. The choice of SAMOSA+ was motivated by its superior performance in retrieving a higher number of valid estimates in coastal areas when compared to the SAMOSA2 open ocean retracker used to produce o\icial ESA CryoSat-2 & Sentinel-3 SAR ocean altimetry products. This distinction highlights the tailored approach of our methodology, specifically optimized for coastal altimetry applications.

Overall, this work marks a significant advancement in the field of altimetry, o\ering valuable insights into the potential of renewable wave energy resources in coastal regions.

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WAVE CONTRIBUTION TO SEA LEVEL IN THE FRENCH FAÇADE OVER 2002-2021 INFERRED FROM HIGH-RESOLUTION SIMULATIONS AND ALTIMETRIC OBSERVATIONS.

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In coastal regions, local sea level (SL) fluctuations are subject to a variety of influences, with wind-generated waves being a significant factor. Understanding these variations is essential, particularly in terms of the dual impact of wave setup and swash.

To delve deeper into the role of waves in coastal SL dynamics, we have conducted a comprehensive analysis of time-series data, encompassing significant wave height (Hs), both altimetric and in situ sea level measurements, and wave setup, spanning the years 2002 to 2022. The aim is to precisely assess the impact of waves on coastal SL alterations, with a focus on seasonal and interannual timescales.

Our approach integrates high-resolution numerical simulations with a diverse array of observational data. We place special emphasis on various extreme events known to induce rapid, high-frequency changes, potentially affecting coastal SL. Through this approach, we aim to unravel the critical influence of waves in driving sea level changes in coastal environments.

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ASSESSMENTS OF WAVE RESOURCES USING THE HORIZON2020 OPEN CLOUD FOR RESEARCH ENVIRONMENT PROJECT'S HIGH-RESOLUTION ALTIMETRY DATA IN THE ATLANTIC FRENCH AND PORTUGAL

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In light of the current energy crisis, wave energy conversion emerges as a viable and sustainable alternative for energy generation, significantly contributing to the advancement of the Blue Economy. This study focuses on the potential of wave energy resources across various coastal regions, with particular emphasis on overseas marginal territories and European coastal zones. Our research utilizes high-resolution satellite altimetry sea state data, including significant wave height and backscatter coefficient, sourced from the European Space Agency's CryoSat-2 mission and processed using the advanced SAMOSA+ retracker algorithm tailored for coastal areas. The analysis spans over a decade, from January 2011 to December 2022, employing an empirical model to calculate wave power density.
Autumn, when sea state conditions are less harsh for extraction activities, appears to be the most favorable season for harnessing wave energy. According to the estimated positive trend in wave power density, the wave resource is abundant along the nearby coasts of the French façade and mainland Portugal, showing promising potential for future exploitation.
The Azores, a group of nine islands located about 1200 km west of Portugal, also show considerable wave energy resources, particularly in areas not near the shore. Our results indicate that the northwest of the Azores Islands, specifically Flores and Corvo, have the most substantial wave resources. In contrast, the Central Group of Azores islands experience a decrease in wave resources, although it remains an area where extraction would be easier. According to our findings, the Wave Power Density in the central Azores region is approximately 27 kW/m, consistent with results obtained by other authors. This result aligns with previous studies using altimetry (Timmermans et al., 2020; Passaro et al., 2021).
This study highlights the importance of innovative methodologies and the role of satellite data in enhancing the accuracy of wave energy assessments.

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COASTAL SEA LEVEL RISE IN THE GULF OF MEXICO

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In the context of the ESA Climate Change Initiative (CCI) Coastal Sea Level project, a complete reprocessing (including retracking of the radar waveforms) of high resolution (20 Hz, i.e. 350 m) along-track altimetry data of the Jason-1, Jason-2 and Jason-3 missions over January 2002 to July 2021 was performed along the world coastal zones. This reprocessing has provided valid sea level data in the 0-20km band from the coast. This led us to define a network of 1183 virtual coastal altimetry stations corresponding to the location of the first valid point along the track (with an average distance of 3.8 km from the coast). Sea level anomalies time series together with associated coastal sea level trends have been computed over the 2002-2021 time span. In the Gulf of Mexico the rate of sea level rise significantly exceeds the global mean sea level rise, amounting about 6 mm/yr over the satellite altimetry era (1993-present). At some coastal sites in the Gulf, tide gauge records corrected for GPS-based vertical land motion show even larger rates (up to 10 mm/yr in the Mississippi delta). In this region, the reprocessed high-resolution along-track altimetry data show a sea level rise increase from 6 mm/yr offshore to 8 mm/yr (uncertainty of 1 mm/yr) in the last 4km to the coast over 2002-2021. This is in good agreement with the tide gauge data. River runoff data available at a few sites along the Mississippi channels nearby the delta indicate a positive trend over the past 15 years. We estimated the contribution of the river runoff trend to the observed coastal sea level rise and found it can explain about 1 mm/yr of the excess coastal sea level rise compared to offshore.

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SWOT'S CONTRIBUTION TO THE STUDY OF COASTAL OCEAN CIRCULATION, AND MORE SPECIFICALLY THE NORTH CURRENT (NW MEDITERRANEAN SEA)

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The monitoring of ocean currents is a key component in many coastal applications, ranging from biogeochemical resources to marine pollution or search and rescue. During the last three decades, satellite altimetry has played an essential role in the understanding and monitoring of ocean currents at global scale. But its use is still limited in coastal areas due to a poorer data quality as we approach the coast, and a spatio-temporal data resolution considered as sparse relatively to the scales of coastal dynamical features.

However, many recent studies addressing the different issues related to the derivation and exploitation of altimeter-derived coastal current velocities have shown that they efficiently complement coastal velocity fields derived from in-situ data (e.g., hydrographic observations, surface drifter and moored or ship-based acoustic Doppler velocities) or from shore-based HF radars. Indeed, one of the major advantages of this measurement technique is to provide long time series (i.e. > 30 years) of spatially and temporally homogeneous information about the circulation and to be available at near-global scale. The data quality problem can be partially overcome thanks to dedicated processing with adequate corrections. Additionally, merging data from multiple missions has been shown to improve the spatial and temporal resolution. But few data sets including coastal processing and several altimetry missions still exist.

The SWOT mission represents the beginning of a new class of altimeters. Associated to substantial improvements in terms of spatial resolution and altimetry data accuracy, it could considerably change the situation in terms of coastal applications. In this study, we study and quantify the ability of SWOT to observe coastal currents compared with conventional nadir missions on a case study: the Northern Current (NW Mediterranean Sea). In particular, we take advantage of the 1-day repeat orbit during the Fast Sampling Phase as a prototype to explore what future altimetry based on such temporal resolution could bring in coastal oceanography.

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COPERNICUS POD SERVICE: STATUS OF COPERNICUS SENTINEL SATELLITE ORBIT DETERMINATION

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The Copernicus Precise Orbit Determination (CPOD) Service delivers, as part of the Ground Segment of the Copernicus Sentinel-1, -2, -3, and -6 missions, orbit products and auxiliary data files for the operational generation of the science core products in the corresponding Production Services (PS) at ESA and EUMETSAT, and to the external users through the newly available Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu/).
Since April 2014, the CPOD Service has been supporting the Copernicus program as soon as the different Sentinel satellites were launched. GMV is responsible for the operations of the CPOD Service, and together with the CPOD Quality Working Group (QWG), is in charge of the POD system evolutions. The CPOD QWG is integrated by some of the leading institutions in POD in the world such as AIUB, CNES, DLR, ESOC, JPL/NASA, TU Delft, TU Munich, TU Graz and GFZ, among others, and they provide support to the quality control of the POD products, as well as helping with the inclusion and validation of new algorithms and standards. The CPOD Service has achieved a remarkable level of performance for the POD products over the years, both in terms of state-of-the-art accuracy (obtaining consistency below 1 cm in 3D RMS with the non-time-critical products produced by the centres of the CPOD QWG) and

timeliness (generating products in less than 5 minutes to support near-real time processing, in the most demanding case).
The CPOD Service has been recently involved in the analysis of the impact of the seasonal geocenter motion modelling, making use of the new model proposed in the frame of the latest ITRF20 standards. This work has entailed the assessment of the different solutions provided by the centres of the CPOD QWG in Centre of Mass (CoM) and Centre of Network (CoN) realisations, and how it impacts the orbit comparisons and the orbit combination strategy, which are part of the CPOD Service responsibilities. Other analyses that have been conducted lately in the Service involve the improvement of the Sentinel-3 short-time critical products by using single-receiver ambiguity fixing strategies, and the update of the Sentinel-6 macro-model modelling.
This contribution aims at showing the current POD product performance of the CPOD Service, focusing on the results obtained in the latest analyses. In addition, upcoming evolutions with the aim of continuous improvement of the POD products will be presented.

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DORIS PROCESSING USING FOCUSPOD

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GMV has recently developed a new Flight Dynamics and geodesy library called FocusPOD, written in modern C++ and python from scratch. This library supports several projects led by GMV, including the operational provision of Precise Orbit Determination (POD) products of the Copernicus Sentinel satellites in the frame of the ESA Copernicus POD (CPOD) Service contract, the simulation of GNSS and SLR data for Galileo 2nd Generation (G2G) System Test Bed, or the maintenance of a catalogue of orbit debris.
With the objective to make FocusPOD a reference SW in geodesy, DORIS processing has been incorporated into the library. This contribution will describe how the DORIS observables are modelled and which parameters are estimated, using as a real showcase Sentinel-3 and -6 real DORIS observations. The achievable accuracy will be shown by comparing LEO POD orbits based on DORIS with the current state-of-the-art combined solution generated by the CPOD Service. Other processing metrics such as empirical accelerations and residuals will also be analysed. Particular attention will be paid to the treatment of the DORIS receiver clock reconstruction. In this line of investigation, the CPOD Service has proposed to provide GNSS-based receiver clock series to the IDS Working Group on Sentinel clock modelling and will also assess how the GNSS clocks fit into the DORIS processing, analysing how the different GNSS clock generation strategies impact the results.

This contribution will present the implemented DORIS processing strategy in FocusPOD, and the achievable accuracy for the Copernicus Sentinel-3 and -6 satellites. Moreover, the results of the GNSS receiver clock analysis integrated with DORIS will be shown. Next evolutions in terms of DORIS processing will be highlighted, focusing on enhancing the receiver clock treatment and also adding more geodesy capabilities to the library, like the estimation of Earth Orientation Parameters and station coordinates.

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DREAMING - FROM DESERTS TO RIVER BASINS

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For many decades, satellite altimeters have collected data over land surfaces. Monitoring inland water is a well-established application. Also extracting soil moisture has been attempted since the SMALT Study initiated by ESA 15 years ago. What is the State-of-the Art today? Can altimeter data contribute to sol moisture monitoring?

The main challenges in deriving soil moisture estimates are the complex and intricate changes in the underlying surface composition and roughness on a range of spatial scales.
The approach taken here is to craft DREAMs (DRY EArth Models) using multi-mission satellite data and ground truth to model the response of a completely dry surface to Ku band nadir illumination. Initially crafted over deserts and semi-arid terrain, this approach has been extended to include river basins. New DREAMs over Africa now extend the coverage to more than 80% of the continent, encompassing more than 30 river basins including the Congo, Niger, Okavango, Zambezi and Volta. DREAMs have also been crafted over parts of Australia, the Amazon basin and Arabia.

This paper presents results using multi-mission altimeter data over these DREAM models. Envisat, ERS-1/2, Jason-1/2, CryoSat-2 and Sentinel-3A altimeter data were utilised in this study, together with a database of over 86000 graded altimeter River and Lake height time series. Soil moisture estimates were generated and validated over a range of surface conditions.

The main outcomes are summarised here.
The highest data retrieval rate over river basin DREAMs is found over 'river' and 'wetland' pixels, with lower percentages over 'soil' pixels where soil moisture estimates can be generated. This is an expected outcome, as targeting 'soil' pixels selects for rougher topography. Within the constraints of satellite orbit and repeat period, data can be successfully gathered over the majority of these overflown DREAM surfaces. Very detailed DREAM models are required to capture the intricate structure in river basins. Smaller tributaries in

the Congo and Amazon basins are below the current 10 arc second spatial resolution of the DREAMs, and are classified with their surrounding terrain as wetland pixels. The ability of nadir-pointing altimeters to penetrate vegetation canopy gives a unique perspective in rainforest areas.
Of prior missions, ERS-2 and Envisat performed best, successfully retrieving data over DREAMs even in rough terrain. The Sentinel-3A OLTC mask is found to preclude monitoring of the vast majority of 'soil' pixels over all DREAMs.
Along-track time series of surface soil moisture can be generated at the spatial resolution of the underlying DREAM, currently 10 arc seconds. The major constraint, as with altimeter height measurements, is the spatio-temporal sampling, so use is envisaged in combination with other remote sensed and in-situ data. However, DREAMing provides a valuable independent dataset which can also be used to assess soil moisture estimates from other techniques.

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VARIABILITY OF WATER LEVELS, AREAS, AND VOLUMES OF THE SOUTHERN CHILEAN LAKES THROUGH SATELLITE ALTIMETRY AND ITS INTERACTION WITH CLIMATE

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Understanding the dynamics of freshwater bodies like lakes is crucial for assessing the impacts of climate variability and human activities on water resources. This study presents a comprehensive methodology for monitoring and analyzing the water volume variability of two major lakes in Chile, Llanquihue and Villarrica, using a combination of satellite altimetry, remote sensing, and climatic data.

The methodology comprises five phases: (1) data collection and preprocessing, (2) Water volume variation estimation (3) accuracy verification with in-situ data (4) Water and flow balance (5) analysis of correlation between water levels. volume data and climate variability, focusing particularly on the phases of the El Niño Southern Oscillation (ENSO).

Satellite imagery from Sentinel-2, Landsat-5, and Landsat-8, along with altimetry data from ENVISAT, provided insights into the temporal variations of lake surface area and water level. Challenges such as limited altimetry data availability and cloud cover affecting satellite imagery were encountered, particularly for Llanquihue Lake.

Integration of altimetry and satellite imagery allowed for the preliminary estimation of volumetric variations in Villarrica Lake, indicating notable seasonal anomalies.

Preliminary bathymetric results show maximum depths of 160 meters for Villarrica and 324 meters for Llanquihue. Satellite imagery from Sentinel-2, Landsat-5, and Landsat-8, along with altimetry data from ENVISAT, provided insights into the temporal variations of lake surface area and water level. Challenges such as limited altimetry data availability and cloud cover affecting satellite imagery were encountered, particularly for Llanquihue Lake.

Integration of altimetry and satellite imagery allowed for the preliminary estimation of volumetric variations in Villarrica Lake, indicating notable seasonal anomalies. Variations in surface area for Villarrica Lake ranged from 171 to 177 km^2, with distinct annual cycles peaking in June-July, suggesting potential climatic implications.

However, limitations in data availability restricted the analysis, particularly for Llanquihue Lake, where a marked annual cycle was not evident due to cloud cover issues. Despite challenges, preliminary volumetric variation analysis for Villarrica Lake revealed significant positive anomalies in 2004 and 2005, indicating a 50% increase in volume approaching spring. Similarly, negative anomalies in 2007 and 2008 showcased volumetric decreases of 60% and 30%, respectively.

Further efforts are required to expand altimetry data sources, validate results with in-situ measurements, improve surface area estimation using better-quality satellite imagery, and integrate climatic factors like ENSO phases, PDO, or SOI index, for a comprehensive understanding of lake dynamics in response to climate variability.

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ESTIMATION OF THE QUALITY DIFFERENCE BETWEEN SENTINEL-6 AND

JASON-3 USING THE TANDEM PHASE OVER POLISH RIVERS USING A HYDRODYNAMIC MODEL AND GAUGING STATIONS

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The development of altimetry missions such as Sentinel-6 and SWOT enables higher-quality measurements and new applications. This study aims to assess the differences in the accuracy and precision between Sentinel-6 and its predecessor Jason-3 over Polish rivers. A reliable quality assessesment of water levels from satellite altimetry is essential for further exploitation. To achieve this, water levels are validated with in-situ stations and compared with the IMGW-HD hydrodynamic model. Here, modeled water levels are computed for specific river mileage on specific days and times and then compared with water levels from Jason-3 and Sentinel-6 provided by DAHITI. In addition, factors influencing altimetric measurements such as river

characteristics and environmental factors will be investigated.

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WET TROPOSPHERIC CORRECTION FOR ALTIMETRY: PROGRESS MADE SINCE THE BEGINNING OF ALTIMETRY ERA AND CHALLENGES TO COME

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Since the beginning of the altimetry, more than thirty years ago, microwave radiometers have flown on almost all altimetry missions to provide an accurate wet tropospheric correction.
This correction has improved significantly since the early 1990s. Instruments have improved in terms of precision, spatial resolution and stability of brightness temperatures. Inversion algorithms have also evolved with the development of more sophisticated statistical or physical methods such as neural networks or variational methods. The use of additional parameters during the inversion and direct coupling with altimeter measurements are particularly noteworthy. The number of calibration and validation methods or data has increased (new in-situ measurements, more sophisticated diagnostics involving sea surface height estimations, new vicarious calibration methods,…). Finally, a great deal of effort has gone into detecting any instrumental drift, so as not to degrade the estimation of the global and regional mean sea level. In parallel, models (analyses or reanalyses) have also been significantly improved, with more efficient assimilation methods and assimilation of more and more diverse data.
Despite this, the wet troposphere correction remains the most important contribution to the error budget of the altimetry system, and radiometers are needed more than ever to correct the altimeter range to the level of accuracy, spatial resolution and stability required for today's altimetry applications.
In this presentation, we will detail the most significant improvements developed over the last 30 years and present the challenges for the coming decades, in particular those relating to the resolution and stability of the wet tropospheric correction.

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ASSESSMENT OF AN ADAPTIVE SUBWAVEFORM COASTAL RETRACKER (ASCR) OVER GLOBAL COASTAL OCEANS FOR SAR ALTIMETRY

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To improve the data availability of SAR-mode altimeters in the coastal zones, we propose a new Adaptive Subwaveform Coastal Retracker (ASCR) and include the empirical coastal retracker ITAS and the full-waveform coastal retracker MSCR in this study. The Sentinel-3A/B altimeter data during the period between January 2021 and December 2021 are reprocessed by these coastal retrackers. The performance of the coastal retrackers, as well as the official Ocean retracker, is intensively assessed over global coastal oceans within 100 km to the coastline. The results show that the coastal retrackers outperform the Ocean retracker in the 0-5 km distance band, with the data availability increased by up to 7%, and the data precision increased by 25%−42%. The ASCR retracker achieves overall better performance than both ITAS and MSCR retrackers. The power spectrum analysis further demonstrates that the noise level within 5 km to the coast is about 35% higher than that offshore. Moreover, about 10%−20% of data loss is observed in the same distance band, which may be because the on-board altimeter fails to record the ocean returns reflected from the nadir sea surface. Finally, the crossover analysis and validation against tide gauges prove that the coastal retrackers can achieve better or at least comparable data qual-ity with official Ocean retracker over global coastal oceans.

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EXTENDING THE CORSICA FACILITIES UP TO SWOT SWATH

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Initially developed for monitoring the performance of TOPEX/Poseidon and follow-on Jason legacy satellite altimeters, the Corsica geodetic facilities that are located both at Senetosa Cape and near Ajaccio have been developed to calibrate successive satellite altimeters in an absolute sense. In anticipation of SWOT, a first phase of extension of the reference surfaces of the Corsica site was carried out in June 2021 (378 nautical miles) and the second in May 2022 (508 nautical miles). The measurements were carried out simultaneously using the instruments developed by DT-INSU as part of FOAM project (CalNaGeo and Cyclopée), which showed very good consistency (a few mm on average and ~20 mm standard deviation). GNSS processing using different software (track, MIT, differential mode / GINS, CNES, iPPP mode) and using the GPS and Galileo constellations jointly or separately have been analyzed. The high degree of consistency, both at processing level and at instrumental level, demonstrates the great maturity acquired thanks to the synergy of the FOAM group. We will present in details, the different phases of processing and preliminary results of the resulting reference surface local (“Mean Sea Surface”) covering the SWOT swath of pass #001 (60km along-track and 50km across-track)

Preliminary Calibration and Validation results of both KaRIn and nadir altimeters will be also presented.

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CHANGING PATTERNS IN THE GULF STREAM OVER THE LAST THREE DECADES AS OBSERVED IN THE ALTIMETRIC RECORD

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The Gulf Stream transports warm waters from low to high latitudes in the North Atlantic Ocean, impacting Europe's climate. This study investigates the changing pattern of the Gulf Stream over the last three decades as observed in the altimetric record (1993–2022) using monthly-averaged altimetry maps together with the outputs from an ocean reanalysis product. The seasonal and yearly evolution of the coordinates (destabilization point) where the Gulf Stream starts to meander and to convert from a stable to an unstable detached jet is investigated. At seasonal scale, the location of this destabilization point presents zonal shifts displacing the Gulf Stream path to the north in summer and fall; and to the south in winter and spring. In addition, it presents variations at interannual scale and has varied by more than 1400 km in longitude showing meridional shifts of 300 km over the altimetric era: it exhibits a low-frequency remarkable shift westward and southward between 1995 and 2012. From that year, the destabilization point displacement inverses exhibiting a previously unreported migration eastward and northward that translates into a larger fraction of the stable detached jet in detriment of the unstable meandering jet. Changes in the Gulf Stream path impact both associated mesoscale Eddy Kinetic Energy and waters transported towards the subpolar North Atlantic. The observed shifts of the path destabilization point seem to be linked to North Atlantic Oscillation variability during winter that may play an important role: it presents a negative trend associated with a shift from a positive to a negative phase between 1995 and 2011; and an opposite behavior from a negative to a positive phase from that year until 2020 in agreement with the associated south-westward and north-eastward observed migration of the destabilization point.

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COMPREHENSIVE ASSESSMENT OF SEA-ICE THICKNESS DATASETS: THE ESA SIN'XS PROJECT

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Sea-ice thickness is a crucial parameter for a variety of scientific disciplines, including climate science, oceanography, and ecology. It plays a vital role in regulating exchanges of heat, and moisture and momentum between the polar oceans and the atmosphere, influencing ocean currents, and affecting local cloud cover and precipitation. Considerable progress has been made in estimating sea-ice and snow thickness using space-based observations, mainly using spaceborne radar and laser altimeters. The simultaneous availability of CryoSat-2, Saral/AltiKa, and Sentinel-3 radar altimetry data, SMOS passive microwave thin ice thickness data, and IceSat-2, high resolution laser altimeter data, as well as the coincident ESA/NASA Cryo2Ice project has opened opportunities for the development of many new sea ice thickness data products. However, all retrieval algorithms rely on many assumptions, e.g. with regard to snow loading and radar snow penetration, and are subject to large uncertainties. Therefore, an intercomparison of the different available ice thickness products among each other, as well as with model, reanalysis and validation data is of utmost importance in order to better understand uncertainties and to agree on observed ice thickness variability and change. This work will also contribute to the preparation of the CRISTAL polar altimeter, which will be able to simultaneously measure sea-ice and snow thickness.

This will be pursued by the ESA-funded project SIN'XS led by NOVELTIS, in close collaboration with AWI, LEGOS, and UCL, with contributions by the international sea ice thickness research and stakeholder community, as well as the WMO Global Cryosphere Watch (GCW). The SIN'XS project aims to comprehensively assess available sea-ice thickness and snow thickness products and their uncertainties. Its ultimate goal is to provide a reconciled and comprehensive sea-ice thickness estimate. We are building up a database of large-scale datasets (satellite-based and models) as well as reference datasets (in-situ, airborne, moorings, etc.) to better understand the variability and change in observed ice thickness in both hemispheres. A web portal (https://sinxs-tools.noveltis.fr) enables users to interactively explore and to analyze data.

After a short project overview, we will report on the most recent progress, mostly the launch of the SIN'XS data submission portal and first results of the ice thickness product intercomparison interface and science studies. We will encourage the ice thickness community to submit data to our website and to contribute to joint protocols for the intercomparison of ice thickness products and their validation, using established approaches from the GEO/CEOS Quality Assurance framework for Earth Observation

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SENTINEL-3 LAND STM: PERFORMANCE OF THE S3A AND S3B SURFACE TOPOGRAPHY MISSION OVER LAND ICE

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Sentinel-3 is an Earth observation satellite series developed by the European Space Agency as part of the Copernicus Programme. It currently consists of 2 satellites, Sentinel-3A and Sentinel-3B, launched on 16 February 2016 and 25 April 2018, respectively. The satellites carry a radar altimeter among the onboard instruments to provide operational topography measurements of the Earth's surface. For land ice, the main objective of the Sentinel-3 constellation is to provide accurate measurements of the polar ice sheet topography to support ice sheet mass balance studies. Compared to previous missions embarking on conventional pulse-limited altimeters, Sentinel-3 measures the surface topography with an enhanced spatial resolution, thanks to the onboard SAR Radar ALtimeter (SRAL), exploiting the delay-Doppler capabilities.

To ensure the mission requirements are met, the Sentinel-3 Mission Performance Cluster (MPC) oversees the monitoring of the instrument and core product performances. Here, the MPC Land Ice ESLs (Expert Support Laboratories) presents the current performance of the satellites over the Antarctic and Greenland ice sheets.

Further improving the performance of Sentinel-3 Altimetry products is also a core element of the MPC. Hence, ESA and MPC recently developed specialized delay-Doppler and Level-2 processing chains over (1) Inland Waters, (2) sea ice, and (3) Land Ice areas. The objective was to provide users with new dedicated "thematic products" for the three surfaces mentioned. For land ice, delay-Doppler processing with an extended window has been implemented to enhance the coverage of the ice sheet margins. The full-mission reprocessing of S3A/B data was finalized in 2023 and is now operational.

This full-mission reprocessing shows excellent stability and homogeneity between S3A and S3B; this addresses the Land Ice community's demands for consistency in deriving ice-surface elevation changes. Significantly, we've streamlined this process exclusively through Sentinel-3, distinguishing it as the go-to mission for deriving essential climate parameters. Our presentation highlights Sentinel-3's recent performance over land ice, showcasing surface elevation change results derived solely from its thematic product. To validate our findings, we compare results with CryoSat-2 and ICESat-2, providing a benchmark for future evaluations. This reinforces Sentinel-3's reliability in a landscape with fewer polar radar altimeters, ensuring sustained and accurate assessments of land ice dynamics. As part of the Copernicus program, the Sentinel-3 mission will provide continuous operational observations of the cryosphere until at least 2030.

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30 YEARS OF ARCTIC SEA LEVEL FROM RADAR ALTIMETRY: ASSESSING THE CLIMATE CHANGE IN THE ARCTIC REGION

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The Arctic is undergoing an unprecedented warming, surpassing low- and mid-latitudes. This has triggered significant transformations, marked by a rapid decline in sea ice and an expanded open ocean. Consequently, oceanic waves intensify, and wind conditions shift, impacting upper ocean dynamics and intensifying river outflow into the Arctic Ocean, further modifying its composition.

This study delves into sea level changes using the European Space Agency's (ESA's) radar satellite altimeters. Recent advances enhance our ability to investigate climate-related phenomena. We present a 30-year time series of Arctic Ocean sea-level measurements, focusing on the dynamic Arctic. Emphasizing the last one and a half decades, we employ a case study approach, analyzing the Beaufort Gyre region and the Russian Shelf and examining Arctic Ocean circulation patterns.

The sea-level dataset, part of the ESA Climate Change Initiative (CCI) Sea level budget closure initiative, is updated with enhanced CryoSat-2 processing through the ESA G-POD SARvatore Data Repository. Our research unveils substantial Arctic changes, leveraging a comprehensive sea-level dataset and advanced satellite altimetry. This sheds light on key drivers, offering insights into the intricate dynamics of the Arctic Ocean system amid climate change.

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14 YEARS OF CRYOSAT DATA QUALITY CONTROL: CURRENT STATUS OF THE ICE AND OCEAN PROCESSORS

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Launched in 2010, the European Space Agency's (ESA) polar-orbiting CryoSat satellite was specifically designed to measure changes in the thickness of polar sea ice and the elevation of the ice sheets and mountain glaciers. To reach this goal, the CryoSat products have to meet the highest data quality and performance standards, achieved through improvements of the Instrument

Processing Facilities (IPFs). Processing algorithms are improved based on feedback and recommendations from Quality Control (QC) activities, Calibration and Validation campaigns and the Scientific Community.

Since launch, CryoSat QC activities have been performed by the Telespazio UK led Quality Assurance for Earth Observation (IDEAS-QA4EO) service, on behalf of ESA/ESRIN. IDEAS-QA4EO routinely monitors all CryoSat ice and ocean products generated operationally, to detect anomalies, support investigations, and prevent the distribution of poor-quality data to users. QC activities also provide a valuable input to CryoSat processor evolution and all anomalies identified are investigated, tracked, and later resolved in an updated IPF.

Since September 2021 the CryoSat Ice products are generated with Baseline-E. This major processor upgrade brought improvements to all Near Real Time and Offline ice products, including improved sea surface height anomaly interpolation, provision of an improved snow depth correction, improvements to land-ice retracking, and the addition of pseudo-LRM estimates to the L1B products. The Ice Baseline-E reprocessing campaign recently reprocessed the full mission dataset (July 2010 – September 2021) to Baseline-E, thereby providing a consistent high-quality dataset to users. The IDEAS-QA4EO team played an important role in the reprocessing campaign, providing best practice guidance and knowledge transfer to the reprocessing team, checking output data products and monitoring processing failures.

Going beyond its original ice-monitoring objective, CryoSat is also a valuable source of data for the oceanographic community. The CryoSat Ocean products are currently generated with Baseline-C. A major upgrade to the Ocean IPFs is expected later in 2024, which will bring significant improvements to the CryoSat Ocean products. The main evolutions include the implementation of an updated SAR/ SARIn SAMOSA retracker (v2.5), an improved Sea State Bias model, improved wind speed and sigma-0 solutions, an upgraded surface type mask, and updated models and corrections.

This poster provides an overview of CryoSat QC activities performed by the IDEAS-QA4EO team on operational and reprocessed CryoSat data products. The main evolutions and improvements implemented in the Ice Baseline-E and Ocean Baseline-D processors are also presented.

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TOWARDS SYNTHETIZATIONS OF THE SATELLITE ALTIMETRY SEA SURFACE HEIGHT ANOMALY AND NCEI IN SITU DART® AND TIDE GAUGE OBSERVATIONS IN THE IMPROVEMENT OF THE GRIDDED PRODUCTION USING MACHINE LEARNING TECHNIQUES

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The NOAA National Centers for Environmental Information (NCEI) provides data stewardship for the Jason-2 and Jason-3 mission products and manages a complex sea level archive of over 300 Deep-ocean Assessment and Reporting of Tsunamis (DART®) records and high-resolution tide gauge records from NOAA tsunami-ready network. DART® records represent the pressure of the water column above the bottom pressure recorders (BPR) and the effect of the atmospheric pressure at the ocean surface. The DART® measurements of the depth equivalent ocean bottom pressure gives an estimate of open-ocean sea-level height and provide essentially continuous sampling in a one-minutes time frame. Currently the gridded sea surface height anomaly (SSHA) maps are produced from independent satellite altimetry using traditional optimal interpolation (OI) and face the challenges from an irregular space-time sampling and very large missing data rate on a daily scale due to the sensors' characteristics and the satellite limited time repeating track, which may lead to high mapping errors in regions with rapidly-evolving mesoscale features. Therefore, synthetizations of in situ and satellite observations using the machine learning (ML) techniques may provide a notable improvement of accuracy and resolution of gridded SSHA. In our previous comparison studies, we investigated the representativity of the DART® observations to the water level variations by comparing them to the satellite altimeter and tide gauge data. We documented a good agreement of DART® SSHA with the altimeter SSHA and coastal or island tide gauge records in regions where DART® SSHA characterizes the open-ocean water level variations in the high frequency. For the lower frequency variations, DART® systems do not record the long-period pressure variations due to the plastic deformations of the alloy containers with the BPR sensors on the ocean floor. Based on the ML techniques developed in NCEI for estimating offshore wind speed profiles from satellite-derived surface (Frech et al., 2024) and producing a global surface temperature dataset (Huang et al., 2023; Yin et at., 2024), this study will use ML to synthetize the satellite SSHA, DART® and tide gauge observations. Our primary goal is to explore the methods for improving SSHA gridding maps with a combination of satellite and in situ observations and estimate the effectiveness of the altimeter sampling where the oceanic mesoscale is energetic. The preliminary results will be presented in the meeting.
References:

- Frech, J., et al., 2024: Offshore Wind Profile Maps Developed using Machine Learning Techniques over the USA Coastal Region. The 104th AMS Annual Meeting, Jan 28- Feb 1, Baltimore, MD, USA.
- Huang, B., et al. 2023: ERSSTv6 with new methods and validations., submitted to Journal of Climate.
- Yin, X., et al., 2024: NOAAGlobalTemp version 6: An AI-based global surface temperature dataset; to be submitted to Bulletin of the American Meteorological Society (BAMS).

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ICE COVER AND EDDIES IN LARGE DEEP SEASONALLY-FREEZING EURASIAN LAKES: INSIGHTS FROM SATELLITE REMOTE SENSING AND FIELD OBSERVATIONS

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Large Eurasian lakes are an integrator of climate processes at the regional scale and a good indicator of climate changes. Variability of ice and snow regime is important for their physical, chemical and biological properties, and for human activity.

We present studies of ice and snow cover and water dynamics for the lakes Baikal and Teletskoye (Russia) and Hovsgol (Mongolia). We address the formation of giant ice rings and eddies under ice in lakes Baikal, Hovsgol and Teletskoye. Multi-mission satellite observations make it possible to monitor ice cover evolution and water dynamics in ice-free period with high spatial and temporal resolution. We have used satellite imagery in the visible, near-infrared, shortwave and thermal infrared (MODIS Terra/Aqua, Sentinel-2, Landsat-8, PlanetScope), complemented by active microwave observations (Sentinel-1 SAR, Jason-3 radar altimeter). We also complement these observations with in situ data from our field campaigns and loggers.

We also address drivers and patterns of eddy generation during ice-free season before and after vertical overturning. Eddies generated between autumnal vertical overturning and ice formation continue to exist under ice cover and may lead to ice melting and destabilisation, leading to surface manifestation as giant ice rings. Better understanding of eddy dynamics and continued monitoring help to improve safety for people travelling or working on the ice. There is a need for timely communication of results for non-scientific audience - fishermen, tourism agencies, tourists, journalists and local administration.

This research was supported by the CNES TOSCA Lakeddies, TRISHNA and SWIRL projects, P.P. Shirshov Institute of Oceanology Project N FMWE-2024-0016) and Institute of Water Problems Project N FMWZ-2022-0001.

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SATELLITE ALTIMETRY-BASED EXTENSION OF GLOBAL-SCALE IN SITU RIVER DISCHARGE MEASUREMENTS (SAEM)

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Freshwater, a fundamental resource for life, demands accurate monitoring to address global water challenges. River discharge, a pivotal metric reflecting the volume of water flowing through rivers, plays a crucial role in freshwater monitoring. However, its monitoring faces a significant challenge marked by a decline in the number of operational gauges globally. Reducing monitoring capabilities, especially in regions crucial for understanding water dynamics, emphasizes the need for alternative solutions. Remote sensing offers a unique possibility to overcome this challenge. Using satellite altimetry, we present a new dataset to extend river discharge measurements for globally available in situ gauged river discharge data. Our dataset is entitled: Satellite Altimetry-based Extension of global-scale in situ river discharge Measurements (SAEM). SAEM includes altimetry-based river discharge with an uncertainty estimate and quality metrics.

In addition to the river discharge time series, SAEM dataset comprises three more products, each contributing a unique facet to a better understanding of river discharge dynamics: (1) The foundation of the SEAM dataset is a catalog with Virtual Stations (VSs), defined based on certain predefined criteria. This catalog, on top of each station's coordinates, provides information on satellite altimetry missions, distance to the discharge gauge, and relevant quality flags. (2) The altimetric water level time series of those VSs, for which we ultimately obtained good-quality discharge data. The water level time series are sourced from both existing level-3 water level time series and newly generated ones within this study. The level-3 data are gathered from pre-existing datasets including Hydroweb, the Database of Hydrological Time Series of Inland Waters (DAHITI), the Global River Radar Altimeter Time Series (GRRATS), and HydroSat. (3) SAEM's third product is rating curves for the defined VSs: The transformation of water level time series into discharge data is modeled through rating curves, derived using a Nonparametric Stochastic Quantile Mapping Function approach.

SAEM dataset deals with the limitations of existing river discharge datasets by utilizing satellite altimetry and river gauges, providing a comprehensive, and globally applicable solution. This dataset is instrumental for informed water resource management, sustainable development, and addressing the challenges posed by climate change.

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ENHANCING ALTIMETER OBSERVATIONS THROUGH COMPARISON AND ANALYSIS OF WIND AND WAVE DATA WITH OCEAN RESEARCH STATION DATA

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Satellite-based observations play an important role in ocean research; however, validating such data through on-site measurements is often hindered by insufficient observational records. This challenge is particularly pronounced in oceanic studies, where on-site data is primarily concentrated in coastal areas, posing difficulties in securing continuous, long-term datasets.

Within the Yellow Sea, the Korean government operates three strategically positioned ocean research stations—namely, the Ieodo Ocean Research Station (IORS), Gageocho Ocean Research Station (GORS), and Socheongcho Ocean Research Station (SORS)—each dedicated to real-time monitoring of oceanic, meteorological, and environmental parameters. The IORS, established in 2003, serves as Korea's pioneering ocean research station, providing comprehensive marine observations. GORS and SORS, established in 2009 and 2014 respectively, further contribute valuable insights, covering the southern and central regions of the Yellow Sea.

With an average depth of 44 meters in the Yellow Sea, a unique opportunity arises for altimeter performance validation in relatively shallow and narrow waters compared to the open sea. This study capitalizes on this distinct setting, focusing on the passage of two to three typhoons annually, and analyzing wind and wave fields along their trajectory. The comparison of altimeter data with ocean research station records enhances our understanding of altimeter observations, particularly in extreme weather conditions.

Furthermore, the central-southern region of the Yellow Sea currently hosts operational offshore wind farms, with expansion plans underway. Despite this, comprehensive wind observations for offshore wind energy are lacking. This research addresses the existing gap by exploring remote sensing methods for both wind and waves—crucial components for ensuring the stability of offshore structures. The findings aim to provide valuable insights to the scientific community, particularly in advancing observations for offshore wind energy initiatives.

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THE AVERAGE IMPULSE RESPONSE OF A SEA SURFACE AT THE OBLIQUE SENSING

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The altimeter performs measurement at the nadir sensing and the backscattered signal contains important information about the properties of the sea surface. During processing, the waveform of the reflected impulse is analyzed and the developed retracking algorithms make it possible to determine the significant wave height (SWH), the mean sea level (MSL) and the backscattering radar cross section (RCS). The RCS is used to retrieve the near surface wind speed along altimeter track.

The well-known retracking algorithms are based on a theoretical model for the waveform of the reflected impulse developed by Brown and in further improvement by Amarouche. However, analytical formulas were obtained for the vertical sensing, so information may be retrieved only along the motion trajectory. To form a wide swath with high spatial resolution, it is necessary to use oblique sensing.

In this research the operation of an altimeter when sensing the sea surface at small incidence angles was considered.

In the Kirchhoff approximation the theoretical task about waveform of the reflected impulse at oblique sensing was considered. Within the framework of the two-scale model (TSM), sea waves are divided into large-scale waves and small-scale waves (ripples), relative to the radar wavelength. Properties of the backscattered signal depend on the large-scale waves. In the region of small incidence angles (< 12°), backscattering occurs on facets of the wave profile oriented perpendicular to the incident electromagnetic waves. In the result of the investigation the analytical formula for the waveform of the reflected impulse for oblique sensing at the small incidence angles (< 12°) for a microwave radar with a narrow antenna beam was obtained. The dependence of the waveform of the reflected impulse on the width of the antenna beam, the SWH, the incidence angle and the distance from the radar to the sea surface was investigated. It is shown that the waveform of the reflected impulse depends on the SWH and this parameter may be measured.

It should be noted that at the small incidence angles, the precision of measuring the MSL will be much lower than with vertical sensing.

The new model opens up the possibility of measuring (retrieving) the SWH in the wide swath with high spatial resolution.

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RECONCILING GLOBAL AND REGIONAL SEA LEVEL CHANGES FROM 30 YEARS OF ALTIMETRY AND 20 YEARS OF GRACE AND GRACE FOLLOW ON OBSERVATIONS.

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Understanding the causes of sea level changes is imperative, especially in the context of closing the sea level budget. Recent analyses have sought to harmonize data from GRACE (Gravity Recovery and Climate Experiment) and its successor, GRACE-Follow On, with steric-corrected altimetry data and terrestrial/ice contributions to ocean mass. Despite these efforts, studies by Wang et al. (2022) and Barnoud et al. (2022) have uncovered inconsistencies within the mass and sea level budgets, suggesting potential gaps in our global sea level monitoring system or our comprehension of Earth's mass dynamics.

Building upon the groundwork laid by Ludwigsen et al. (2014, Nature Communications), which utilized GRACE-independent land surface mass change estimates to corroborate two decades of GRACE data, our study broadens this analysis to encompass the entire 30-year altimetry record and identifies the causes of both transient (from seasonal to decadal) and long-term causes for altimetry-observed sea level change on a global and regional scale.

Our findings, as detailed in Ludwigsen et al. (2024), reveal a substantial alignment between ocean mass reconstructions and GRACE data up until 2020. Post-2020, discrepancies become apparent, notably a pronounced increase in ocean mass as per the reconstruction compared to GRACE measurements. This discrepancy is attributed primarily to an underestimation of precipitation over Western Africa in the ERA5 reanalysis data, which is frequently employed by hydrological models for assessing terrestrial water storage changes. Validation through GRACE land mass data confirms this underestimation, indicating a closer alignment between models and observations when excluding the sub-Saharan African region.

The comparative analysis of GRACE data with GRD (Gravitational, Rotational, and Deformational) influenced ocean mass changes reveals a consensus, suggesting that previously identified discrepancies between GRACE data and steric-corrected altimetry chiefly stem from inaccuracies within the ARGO float system. Specifically, a 'salinity drift' and errors associated with the wet path delay caused by radiometer drift in the Jason-3 satellite are identified as primary contributors to the divergence observed post-2016. Other minor differences may be attributed to Glacial Isostatic Adjustment (GIA) effects and/or biases in the Argo data.

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COMPARISON OF CERES AND ERA5 PRODUCTS FOR THE EARTH RADIATION PRESSURE MODELLING OF COPERNICUS SENTINEL SATELLITES

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Earth radiation pressure (ERP) modelling is an important part of the non-gravitational force modelling in precise orbit determination (POD) of low Earth orbiting satellites. Mainly impacting the radial component of the orbit it is in particular important for the orbit determination of altimetry satellites. ERP depends on the Earth's outgoing radiation and consists of two parts, the Earth albedo (reflected visible spectrum) and the thermal radiation of the Earth in the infra-red (IR) spectrum. Several data sets are available to be used for the ERP modelling, e.g., the CERES (Clouds and the Earth's Radiant Energy System) and ERA5 (5th generation of ECMWF atmospheric reanalysis) products. In the POD processing of the Copernicus Sentinel-1, -2, -3, and -6 missions as it is done in the frame of the Copernicus Precise Orbit Determination (CPOD) Service an average over more than 17 years of CERES monthly products is used for the ERP modelling.
The CPOD Service is part of the respective Ground Segments and delivers orbit products and auxiliary data files of the Copernicus Sentinel missions for the operational generation of the science core products in the corresponding Production Services (PS) at ESA and EUMETSAT, and to the external users through the newly available Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu/).
The impact of exchanging CERES averaged monthly products by ERA5 monthly or even hourly products in the ERP modelling of the NTC (not-time critical) POD processing at the CPOD Service is the topic of this study. This is in line with current trends of other processing centres like CNES (Centre Nationale d'Etudes Spatiales), who are updating the ERP modelling to use ERA5 hourly products in the upcoming POE-G standards for altimetry satellites, including Sentinel-3 and -6.
Differences between the CERES and ERA5 products are presented and Sentinel-3 and -6 orbit determination

results and processing metrics are compared using either the CERES or the ERA5 products. Feasibility in terms of orbit product quality w.r.t. the larger housekeeping effort of using the hourly instead of monthly files is assessed.
In addition, a first assessment on the ERA5 forecast products is done. It is analysed if they are usable for the ERP modelling in the generation of NRT (near real-time) and STC (short-time critical) POD products.

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ASSIMILATION OF WIDE SWATH SATELLITE ALTIMETRY TO MAP GEOSTROPHIC AND INTERNAL TIDE SIGNALS OF THE OCEAN DYNAMICS

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Mapping Sea Surface Height (SSH) from satellite altimetry is key to many scientific and operational applications. At the fine scales observed by SWOT, SSH variations are primarily driven by two types of dynamics - nearly geostrophic Balanced Motion (BM) and wavy motion due to the Internal Tide (IT). These two processes differently affect ocean dynamics. The IT does not affect the surface horizontal transport of passive tracers (oil spills, plastics, algae…) unlike BM, but has a significant contribution to the vertical transport of heat, salt and nutrients. Separating BM and IT contributions to SSH variations will be essential in the mapping process. To a different extent, this separation is now common practice with high-frequency outputs of numerical simulations. Yet it is still an unresolved challenge for SSH maps computed with satellite observations like SWOT, which are sparse in space and time.

This study introduces an innovative method to separate BM and IT components from SSH altimetric observations including SWOT. The method is based upon a data assimilation system combining two models - quasi-geostrophic for BM and linear shallow-water for IT. The inversion is performed with a weak-constraint four-dimensional variational (4DVar) approach, with two different sets of control parameters adapted to each component. A major, expected benefit of this approach lies in the potential to capture the non-stationary part of the internal tide component. The method outputs hourly SSH and surface velocity fields over a domain for both components.

The work focuses on the North Pacific Ocean, because this zone has a strong mesoscale and submesoscale activity, including the two dynamics of interest. Observing System Simulation Experiments (OSSEs) are carried out over 20°x20° domains surrounding the SWOT crossovers. The experiments include both conventional Nadir and wide-swath SSH measurements, that are interpolated from the LLC4320 MITgcm simulation. The mapping algorithm performances are evaluated by comparing the outputs with the MITgcm referenced fields. The first results indicate that the assimilation system is able to separate the two targeted components, including the non stationary part of the internal tide. As this study is part of a PhD, the latest results available will be presented at the conference.

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EFFECT OF BUILT INFRASTRUCTURE ON WATER REGIME OF ARCTIC RIVER FROM SYNERGY OF SATELLITE ALTIMETRY AND HYDRODYNAMIC MODELLING.

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Sentinel-3 SAR altimetry have demonstrated high potential for studies of different aspects of river water regime. Combination of altimetric water level observations with hydrodynamic modelling allows for more deep understanding of the hydraulic functioning of complex rivers systems, such as confluence nodes or large floodplain reaches. Sentinel-3A data product of enhanced up to 50 m spatial resolution (obtained via the SARvatore processor available from the Earth Console ESA Altimetry Virtual Lab https://earthconsole.eu/virtual-labs/) was used for investigation of specifics of water level temporal and spatial variability within 65 km long reach of the Middle Ob River. The reach is characterised by wide swampy 25 km floodplain cut by road embankments in many places. STREAM_2D hydrodynamic model was forced by synthetic discharge estimated from gauges acquired 600 km upperstream. The upper and lower model boundary conditions were assigned using Sentinel-3A altimetry measurements. We found that the seasonal amplitude of the water level in the small river branches is higher than in the main Ob R. channel. Moreover, according to altimetry measurements, during open water period the water level in southern river branches is several tens of centimetres lower than in the northern ones. These hydraulic conditions were also successfully reproduced by the hydrodynamic model. Water level seasonal amplitude of 1-1.5 m retrieved from altimetry for natural oxbow lakes was also simulated by the model. The satellite measurements and the model agree that the water level amplitudes in ponds bordering the infrastructures differs significantly from that in natural ponds due to backwatering by roads. Numerical experiments revealed that the effect of infrastructure on water heights in the main river channel propagates up to 5 km upperstream from the bridge.
The study is supported by RNF N_22-27-00633 AltiMo(2022-2023) grant and by the Governmental Order to WPI RAS, Theme FMWZ-2022-0001.

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KUROSHIO EXTENSION'S ROLE IN THE MID-LATITUDE NORTH PACIFIC CLIMATE VARIABILITY BASED ON 30-YEAR SATELLITE ALTIMETRY MEASUREMENTS

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Kuroshio Extension (KE) is the wind-driven North Pacific subtropical gyre western boundary current after the Kuroshio separates from the coast of Japan. Over the past 3 decades when high-precision satellite altimetry data are available, the KE system has been observed to vacillate between a stable and an unstable dynamic state with a preferred period of ~10 years. Our past analyses have found that this decadal vacillation resulted from a delayed negative feedback process involving the KE variability, its impact upon the overlying stormtracks, the basin-scale wind-forced main thermocline adjustment, and the response of the KE system to the westward-propagating thermocline anomalies. In August 2017, the Kuroshio south of Japan developed into a large meander (LM) path which has persisted over the past 7 years. By analyzing the multi-mission sea surface height data and by adopting a wind-forced linear vorticity model, we demonstrate that the on-going persistent LM is maintained by an exceptionally stable dynamic state of the KE that is both forced by wind stresses across the Pacific basin and by the occurrence of the Kuroshio LM. Through the nonlinear mutual enhancement between the KE and its upstream LM, the KE system has entered a new regime with a super dynamic stability in which the basin-scale air-sea interaction appears also different from the delayed negative feedback loop prevalent during the decades prior to 2018.

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REMOTE SENSING-BASED EXTENSION OF GRDC DISCHARGE TIME SERIES - A MONTHLY PRODUCT WITH UNCERTAINTY ESTIMATES

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The quantification of river discharge is essential for understanding a broad range of scientific questions focused on hydrology, hydraulics and water resource management. However, the Global Runoff Data Center (GRDC) data set has faced a decline in the number of active gauges since the 1980s, leaving only 14% of gauges active as of 2020. For extending the discharge estimates of inactive GRDC stations, we develop the Remote Sensing-based Extension for the GRDC (RSEG) data set that can ingest legacy gauge discharge and remote sensing observations.

First, we evaluated the feasibility of extending discharge estimates of gauges in the GRDC dataset benefiting from river water height time series obtained from satellite altimetry missions (2000--2020) and river width estimates obtained from Landsat 4-8 mission images (1984–2020). Then we employ a stochastic nonparametric mapping algorithm to extend the discharge time series for inactive GRDC stations, benefiting from satellite imagery- and altimetry-derived river width and water height observations. Finally, we conduct a rigorous quality assessment on our discharge estimates, involving statistical validation, tests and visual inspection, resulting in the salvation of discharge records for 3377 out of 6015 GRDC stations with an average discharge exceeding 10 m^3/s. The quality of discharge estimates for the rivers with a large or medium mean discharge is quite satisfactory (average KGE value > 0.5) however for river reaches with a low mean discharge the average KGE value drops to 0.33. The RSEG data set regains monitoring capability for 83% of total river discharge measured by GRDC stations, equivalent to 7895 km^3/month, providing valuable insight into Earth's river systems with comprehensive and up-to-date information.

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THE BIN-SPACE-TIME (BIST) RETRACKING METHOD: A PARADIGM SHIFT IN RETRACKING METHODS

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In the 30 years of its existence, satellite altimetry has established itself as an important tool for understanding the Earth system. Originally developed for oceanography and geodesy, it has also proven valuable for monitoring lakes and rivers. However, when using altimetry for inland waters, there is always a game breaker: retracking, i.e. the procedure in which the range from the satellite is (re)estimated from reflected signal energies. The current retracking methods heavily rely on single waveforms, resulting in a high sensitivity to every individual peak in the waveform and a strong dependency on the waveform's shape. Here, we propose the Bin-Space-Time (BiST) retracking method that moves beyond finding a single point in a 1D waveform and instead seeks a retracking line within a 2D radargram.

The retracking line divides the radargram into two segments: the left- (Front) and right-hand side (Back) of the retracking line. Such a segmentation approach can be interpreted as a binary image segmentation problem, for which spatiotemporal information can be taken into account. We approach this by applying a probabilistic graphical model, the Markov Random Field (MRF). Here, we explicitly model two energy functions: 1) the bin-space energy function defined between neighbouring pixels of a radargram being labelled as Front and Back and 2) the temporal energy function of a pixel for labeling Front or Back given its overall temporal evolution. The total energy being the sum of the bin-space and the temporal energy functions is then minimized through the max-flow algorithm, leading to obtaining an optimal labelling in radargram and consequently obtaining the retracking line.

We applied our method to both pulse-limited and SAR altimetry data over nine lakes and reservoirs in the USA including Mendota Lake, Waubesa Lake, Kegonsa Lake, Lake Michigan, Rathbun Lake, Lake Mohave, Abiquiu Reservoir, Lake Boca and Lake Maumelle with different sizes and different altimetry characteristics. The resulting water level time series are validated against in situ data, demonstrating significant improvements in terms of correlation and RMSE compared to different 1D retracking methods. Our proposed retracker, operating in bin, space, and time domains, exhibits robustness to unexpected waveform variations, allowing improvements of water level time series over diverse inland water surfaces.

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VALIDATION OF THE SATELLITE RADAR ALTIMETRY FROM ERS-1, ERS-2 AND ENVISAT FOR INLAND WATER THEMATIC DATA PRODUCT

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Inland water monitoring is essential to quantify the available and accessible water resource and assess the amount useful for meeting human needs. It has an essential role for both society and the environment, and because of the many problems with ground hydro-monitoring networks, the measurements of inland water represent a political and economic challenge. A viable alternative for deriving surface water information at large scale involves satellite Earth Observations, and in recent decades, satellite altimetry has proven to be an established method for providing water level measurements. The large availability of satellite sensors guarantees a continuous and comprehensive coverage in time and space, but often the harmonization among different missions is difficult and most of the time is reduced to a bias correction. With this purpose, here the Inland Water Fundamental Data Records are generated within the FDR4ALT project to produce the Inland water Thematic Data Products based on the exploitation of measurements acquired by the altimeter onboard the ESA ERS-1, ERS-2 and ENVISAT missions.

In this work, we present the results of the project for the rivers, showing the analysis of the different retrackers (Ice1, Ice3, MLE3, TFMRA, Adaptive) during a continuous period of the year. A Round Robin analysis is carried out to evaluate the performances of each retracker with the final goal to detect the best retracker able to describe the inland water flow to be implemented at global level. The global validation is carried out through a valuation of the performances calculated against external measurements from reliable ground-based measurements and using datasets from other altimetry sources freely available on the web (Theia Hydroweb, Dahiti, HydroSat). In general, quite accurate long time series of altimetry water level have been reconstructed from 1993 to 2010 by merging ERS-1, ERS-2 and ENVISAT data.

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LONG TERM ANALYSIS OF GLOBAL SURFACE WATER VOLUME CHANGE USING REMOTE SENSING DATA

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The availability and variations of continental water storage are of great importance for society, as they influence agricultural, industrial, and domestic water use. Among the water storage components, terrestrial surface water specifically lakes and reservoirs are essential for wildlife and human habitats as they store freshwater in the most accessible way, control seasonal floods and generate hydropower. Despite the importance, the estimation of surface water storage variation at a global scale is usually obtained from simplified models due to the absence of necessary gauge and remote sensing measurements.

In this study, we produce monthly water volume anomaly time series of 182260 global lakes and reservoirs larger than 1 km² for 1985-2018. To do so, water area time series of lakes and reservoirs are obtained from the Joint Research Center Global Surface Water data set. We gather all publicly available in situ water level time series and generate water level time series using satellite altimetry data from various missions and data sets. For the remaining lakes and reservoirs, water height information is extracted from the TerraSAR-X digital elevation model.

After collecting the required data, first, the empirical water area-level model is developed for each object and then the water volume variation time series are estimated. With this data set, we can investigate the temporal and spatial variations of surface water stored in lakes and reservoirs from 1985-2018 on a global scale. This study aims to answer these fundamental questions: 1) What are the temporal behaviors of surface water volume variations in different river basins? 2) Does water volume variation trend agree with other hydrological parameters' temporal variation, And 3) what are the major natural and anthropogenic factors that explain the long-term water volume variation?

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EXPLORING SIAMESE NETWORK TO ESTIMATE SEA STATE BIAS FOR WIDE-SWATH ALTIMETRY

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Sea State Bias (SSB) is one of the key errors in sea surface height (SSH) measurements for satellite altimetry, whether for the nadir-looking altimetry or wide-swath altimetry. Currently, SSB estimation is primarily based on parametric or non-parametric models, using parameters related to the sea surface such as wind speed, significant wave height or mean wave period. However, the significant differences in SSH measurements between the nadir-looking altimetry or wide-swath altimetry, including interferometric measurement and wide-swath coverage, result in that the SSB estimation model should be reexamined. Parameters including the cross-track distance and mean wave direction are worth considering in the SSB estimation. Considering these, our study proposes a novel deep-learning-based SSB estimation model, named Siamese Network for SSB (SNSSB). Using the latest SSH data measured by the Surface Water and Ocean Topography (SWOT), training and testing experiments are conducted across the global ocean. The experimental results demonstrate that the proposed SNSSB model can further improve the accuracy and explained variance of SSB estimation. And another major advantage of the SNSSB model is that more parameters can be incorporated to estimate SSB while ensuring the computational efficiency. In the context of the increasing application of artificial intelligence in oceanographic research, it is anticipated that more accurate SSB estimation can be achieved with the help of deep learning, thereby further improving the accuracy of SSH measurements for wide-swath altimetry.

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RECONSTRUCTION OF OCEAN TEMPERATURE AND SALINITY PROFILES IN THE NORTHWESTERN PACIFIC USING SATELLITE SSH AND ARGO FLOAT DATA

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Reconstructing temperature and salinity structure from sea surface parameters obtained from satellites and other sources is an important issue and is used in operational-based ocean data assimilation systems. Sea surface height (SSH) is the most important parameter in the estimation of hydrographic structure because it is the integral information of temperature and salinity. In this study, we used the multiple linear regression method (Guinehut et al., 2012) and the vertical coupled mode of the temperature-salinity empirical orthogonal function (EOF) (Fujii and Kamachi, 2003). An estimation method that combines both methods is also investigated based on the evaluation of the characteristics of errors due to SSH anomaly (SSHa). ARGO float data were used to calculate the regression coefficients and create the vertical mode of EOF. The period was from 2001 to 2020, and the area was from 120°E to 180° and 0° to 60°N.
Calculation of regression coefficients and creation of vertical mode of EOF were performed separately for each ocean area. For ocean area classification, we performed unsupervised classification using a Gaussian Mixture Model (GMM) on the ARGO float data, with reference to Guillaume et al. (2017). Based on the knowledge of ocean current systems and water masses, the Northwest Pacific was divided into seven areas: subarctic circulation, mixed water region, subtropical circulation, Kuroshio recirculation, subtropical countercurrent, north equatorial current, and tropical circulation.
Climatology of WOA18 was used as a first guess, and the deviations from the climatology were estimated using the two methods. The method using EOF modes had a slightly smaller error. As a result of error evaluation, it was confirmed that the error of the method using EOF increases as the SSHa increases. This was thought to be due to the difficulty in reconstructing the steep changes in the stratified structure caused by eddies.
In order to incorporate eddy information, a high-pass filter was applied to create a SSHa map, and the correlation between the SSHa and the errors was investigated. A relatively high correlation was confirmed in the depth of the eddy core. Temperature and salinity were re-estimated using the multiple linear regression method for the errors of the method using EOF and adding them to the original reconstructed profiles. The error using the combined method was reduced by about 8% for temperature and by about 2% for salinity. The error reduction rate for temperature in the subtropical circulation was the highest at 11%. In the subarctic circulation, the error of salinity was reduced by about 9%, which was about the same as that of temperature by 8%. In this study, we use the high-pass filtered SSHa created from multiple nadir altimeter observations to investigate correlation with the errors. It is thought that by using SWOT data with high spatial resolution, it will be possible to more appropriately capture the relationship between eddies and the stratified structure.

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TOWARDS A COMMON PROCESSING CHAIN FOR THE OPEN AND POLAR OCEAN ON SENTINEL-3: LOOKING FOR THE "MAGIC" ALONG-TRACK WEIGHTING WINDOW.

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More than 30 years ago, the Hamming weighting window was directly applied on-board ERS-1 in the across-track dimension in order to transform the Point Target Response (PTR) from a sinc² function to a Gaussian function, that was easier to handle during the retracking algorithm that is used to retrieve the geophysical parameters. The same strategy was then chosen for ERS-2 and ENVISAT. The missions from the Poseidon family (Topex/Poseidon, Jason-1, Jason-2 and Jason-3) use a rectangular window and therefore keep the PTR as a sinc² function, which is retrospectively preferable as it allows to keep the original signal and handle it afterwards on-ground, thus preserving the resolution of the instrument.
Moving forward, a new dimension was added with the development of the Delay-Doppler (SAR mode) processing with Cryosat-2 and then the Sentinel-3/6 missions, that improve the along-track resolution. No Hamming window is applied in the across-track dimension, but another issue was identified in the along-track dimension: the SAR altimeter processing is not optimal on specular regions because of the along-track PTR that is also a sinc² function with relatively strong secondary lobes. For specular returns, energy spreads into these secondary lobes leading to leakage in the off-nadir beams. Eventually, this leads to perturbations on the Level-1B SAR waveforms significantly degrading performance in the polar oceans. To fix this issue, the well-known Hamming window was tested and was proven very efficient to reduce these off-nadir spurious, improving greatly performances over specular surfaces. This solution was therefore implemented for the ESA Cryosat-2 Baseline E Ice products as well as for the ESA Sentinel-3 Sea-Ice and Hydrology Thematic products.
For the EUMETSAT Sentinel-3 Marine products, that cover the global ocean, including polar regions, this solution is not fully satisfactory. Indeed, over open ocean, the Hamming window degrades the performance and more specifically the along-track resolution, thus preventing the agency from using one single processor over global ocean (which would also contribute to continuity between the oceans).
In the frame of the COPAS project, a study was conducted to investigate other weighting windows, to find the "magic" weighting window that could be applied on open ocean and leads without degrading performance on either surface. After a bibliographic inspection, different weighting windows have therefore been implemented in the CNES/CLS Sentinel Processing Prototype (SPP), and then tested on real Sentinel-3 data to be assessed and compared over open ocean and specular areas.
The first part of this talk will be an overview of the different candidates for the weighting windows from a theoretical point of view, using [Smith,2018] "Spectral windows for satellite radar altimeters" as the principal source to support the investigation. Then, the details of the implementation and processing will be presented. This talk will finally focus on the assessment performed over real data using the most promising windows that were selected in our study, including a Cal/Val analysis over one full cycle of Sentinel-3 on the open ocean at Level-2, as well as an assessment on the resulting Level-1B echoes over specular areas.

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A DEEP LEARNING APPROACH TO SEPARATE BALANCED AND UNBALANCED MOTIONS FROM SEA SURFACE HEIGHT SNAPSHOT

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Separating balanced geostrophic motions (BM) and unbalanced wave motions (UBM) from sea surface height (SSH) observations obtained by the Surface Water and Ocean Topography (SWOT) mission holds great significance in enhancing our understanding of ocean dynamic processes. However, SSH observations derived from wide-swath altimetry are characterized by high spatial resolution while relatively low temporal resolution, thereby posing challenges to separate these two motions from an instantaneous SSH snapshot. To address this issue, our study proposes a deep learning model called the BM-UBM Network, which takes one SSH snapshot as input and generates the projections corresponding to the BM and UBM. Using SSH data from a realistic simulation, training experiments are conducted both in the Gulf Stream where the BM is stronger than the UBM and the South China Sea where the UBM is stronger than the BM. Choosing different regions, namely different dynamical regimes, helps demonstrate the effectiveness of the BM-UBM Network. Three metrics are considered to diagnose model's outputs, including the root-mean-square error (RMSE), the wavenumber spectrum, and the wavenumber-frequency spectrum. Results show that the effective separation scale of the BM-UBM Network is roughly comparable to the resolution can be resolved by the SWOT (15-30km), and the BM-UBM Network has the capability to capture both the spatial and temporal characteristics of ocean dynamics. These favorable results highlight the potential capability of the BM-UBM Network to process SSH measurements from wide-swath altimetry at submesoscale wavelength. We also expect that the BM-UBM Network will contribute to the study of multiscale oceanic motions in the era of SWOT mission.

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IMPROVED INLAND WATER LEVEL MEASUREMENTS WITH SENTINEL-6 FULLY-FOCUSSED SAR PROCESSING

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The observation of small to medium inland water targets is currently limited by the along-track resolution of UnFocused Synthetic Aperture Radar altimetry, which is approximately 300 m. In this study, we analyse the benefits of the sub-meter along-track resolution provided by Fully-Focused Synthetic Aperture Radar altimetry applied to Sentinel-6 Michael Freilich data over a collection of small to medium targets in the Ebre basin, Spain. Moreover, we evaluate the application of extended water masks, which exploit across-track and nadir measurements to increase measurement acquisition. The obtained water level estimations over a 2-year period are compared to in situ data. We achieved a median absolute deviation of 1.9 to 6 cm, with an average of 3.78 cm, in comparison to an average of 11.1 cm for UnFocused Synthetic Aperture Radar (UFSAR) with the Offset Center of Gravity (OCOG) retracker and 15.0 cm with the ocean retracker. In addition, FFSAR allows us to analyse small targets (sub-300) where UFSAR might not retrieve measurements. Finally, we showed that extending water masks in the across-track direction from the satellite's nominal track provided a notable increase in valid measurements, specifically we observed an average increase of 36.6% for UFSAR, and 47.7% for FFSAR.

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PRELIMINARY ASSESSMENT OF SWOT L2 LAKE PRODUCTS OVER SMALL WATER BODIES IN THE ALSACE AND LORRAINE REGIONS (FRANCE)

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Launched on December 16th, 2022, the innovative SWOT mission provides observations of inland water bodies at unprecedented resolution and accuracy. The surface water areas estimated shall have a relative error smaller than 15% for water bodies exceeding 250*250m²), and the height accuracy shall be 10 cm or better for water bodies exceeding 1km2) and 25 cm or better for water bodies between 250*250m2 and 1km2. The preliminary results obtained over the Rhine Tier 1 CalVal site are within the requirements with margin.
An assessment of SWOT HR L2 Lake products has been carried out over a set of 20 lakes, with sizes ranging from 7 to 0.03 km² and varying topographic settings: steep-sided reservoirs, lowland lakes near the Rhine River, step-sided lakes surrounded by forest…).
A preliminary work consisted in setting up a database containing water surface dynamics based on 6 years of Sentinel-2 images, water elevation from historical data from institutes, municipalities, state agencies (VNF, DREAL, EDF, …), and the installation of limnimetric scales (OECS initiative), and leveling of these stations through ICESat-2 data and field campaigns.
The analysis of SWOT products generated daily during the Cal/Val phase was done as follows:
- Evaluation of the accuracy of the PIXC classes (water only, land and water, dark water, etc.).
- Exploitation of Bright Land and Dark Water flags.
- Comparison of the in situ water elevations and the ones provided by the L2 SWOT lake products.
- Comparison of water area provided by the SWOT product and the ones derived either from quasi-synchronous VHR Pleiades and HR Sentinel-2 data

In terms of lake water level, based on daily SWOT data, it was possible to follow the reservoir behavior (drainage or stability) with a wse error (1sigma) of 6 to 11 cm. It was also possible to obtain information on very small water bodies (e.g. Vert Lake & Forlet < 0,1 km²).
For lake water surface area, a slight overestimation is observed with respect to the reference water surfaces, with a relative area error (1sigma) between 7 and 11%.

These preliminary analyses show wse and area errors lower than the SWOT requirements, highlighting the high accuracy of the SWOT products and their limitations for very small water bodies, which are often overlooked. These results have been consolidated and extended to other lakes during the science phase

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COMPARISON OF METHODS TO DERIVE THE HEIGHT-AREA RELATIONSHIP OF SHALLOW LAKES IN WEST AFRICA USING REMOTE SENSING

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In West Africa, lakes and reservoirs play a vital role as they are critical resources for drinking water, livestock, irrigation and fisheries. Given the scarcity of in situ data, satellite remote sensing is an important tool for monitoring lake volume changes in this region. Several methods have been developed to do this using water height and area relationships, but few publications have compared their performance over small and medium-sized lakes. In this work we compare four methods based on recent data from the Pleiades, Sentinel-2 and -3, ICESat-2 and GEDI missions over 16 lakes in the Central Sahel, ranging in area from 0.22 km² to 21 km². All methods show consistent results and are generally in good agreement with in situ data (height RMSE and volume NRMSE mostly below 0.30m and 11% respectively). The obtained height-area relationships show very little noise (fit RMSD mostly below 0.10m), except for the Sentinel-3-based method which tends to produce higher dispersion. The precision of the estimated water height is about 0.20m for Pleiades Digital Surface Models (DSMs) and less than 0.13m for the other methods. In addition, fine shape patterns are consistently observed over small height amplitudes, highlighting the ability to monitor shallow lakes with non-linear bathymetric behavior. Inherent limitations such as DSM quality, temporal coverage of DSM and lidar data, and spatial coverage of radar altimetry data are identified. Finally, we show that the combination of lidar and radar altimetry-based methods has great potential for estimating water volume changes in this region.

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INSIGHT INTO THE DYNAMICS OF SAHELIAN SHALLOW LAKES WITH SWOT KARIN

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In West Africa, lakes and reservoirs are critical resources, providing crucial social and ecosystem services such as freshwater and food supply, natural habitats, livestock watering and irrigation. Given the scarcity of in-situ data, satellite remote sensing is an important tool for monitoring lake volume changes in the region. The recently launched Surface Water and Ocean Topography (SWOT) mission, with its wide swath Ka-band radar interferometer, is capable of observing at least 90% of the inland areas, significantly increasing the number of lakes and reservoirs that can be monitored by the other altimeters. In this work, we evaluate the performance of SWOT for retrieving water surface elevation, area and hypsometric curves. The analysis is carried out on 16 small and medium-sized lakes and reservoirs in the Central Sahel, ranging in area from 0.22km² to 21km². The SWOT products are compared with 1- in-situ water surface elevation observations over 1 reservoir in Burkina Faso and 1 small lake in Niger 2- hypsometric curves derived from in-situ data (8 lakes) and other remote sensing products such as Pleiades Digital Surface Models (DSMs), Sentinel-3 and -6, ICESat-2 and GEDI altimetry data. Pleiades DSMs and Sentinel-2 optical imagery data are also used to assess SWOT-derived water masks. SWOT 2D (Pixel Cloud) and lake-averaged (Lake Single Pass) products from both 1-day (7 lakes) and 21-day (16 lakes) orbits are evaluated for precision and accuracy.

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PRELIMINARY ASSESSMENT OF SWOT L2 RIVER PRODUCTS: CASE OF THE CANALIZED RHINE RIVER (FRANCE)

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A preliminary assessment of SWOT L2 River products has been carried out over the Rhine River, along 180 km of the German-French border exploiting the daily Cal/Val SWOT data (end of March to mid-July 2023). This area is particularly interesting as two hydraulic objects running in parallel can be distinguished. The Western one, the canalized Rhine, is presenting a succession of 10 hydropower dams, i.e. like a succession of gently sloping basins, with 12-14-m jumps, returning to a free river course after the Iffenzheim dam. On the Eastern side, the Old Rhine is flowing in more natural conditions, beginning with a first free segment of 40 km. Then the Old Rhine corresponds to segments of about ten km, very largely entropized, flowing at a lower altitude of about ten meters. The difference in gradient is recovered by a series of metric weirs. At the level of a hydroelectric dam, the North-South offset will be 12-14 meters, with a lateral East-West offset of 8-10 m.
Preliminary work consisted in setting up a database containing water elevation over about 40insitu gauge stations collected from French and German agencies (VNF, DREAL, WSV, LUBW and EDF). Several stand-alone stations plus additional gauges were also installed, as well as few limnimetric scales (OECS). Drone flights were also carried out to measure the water surface elevation and slopes.
The first analysis covered SWOT L2 HR River Node and Reach products using the SWORD V14 river database, but also SWOT HR L2 PIXC (pixel cloud) products. It was done as follows:

- Comparison of the insitu water elevations and the ones provided by the SWOT HR L2River products at the node and reach scales.
- Comparison of the slope provided by the SWOT HR L2 River Reach products and the ones derived from the insitu measurements.
- Comparison of the insitu water elevations and the ones provided by the SWOT HR L2 PIXC product.
- Evaluation of the accuracy of the PIXC classes (water, water near land, dark water, etc.).

For most of the stations, we observed at the node scale a 1-sigma difference between SWOT water elevation and in situ reference data over all Cal/Val cycles of about 10 cm, both on the canalized and the free-running part of the river.
For a proper assessment of the quality of SWOT measurements via SWOT HR L2 River products at local level, it is essential to first evaluate the quality of the

SWORD database. And that by an inaccurate SWORD centerline, which does not respect the true river morphology, that SWOT L2 products is not biased.

For the Rhine River, a customized river database, with a more realistic description of the Rhine's parallel courses, and of the position of structures (dams, locks, weirs), was used to reprocess the SWOT HR L2 River products, using the open source RiverObs tool.

These analyses show water surface elevation errors lower than the SWOT Science requirements, for most of the cases. These results have been consolidated and extended during the science phase

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LEVEL-1 PROCESSING OF UNFOCUSED SAR ALTIMETRY DATA: 15 YEARS OF INNOVATIONS

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During the last 20 years, a new paradigm for radar altimeter instruments has been designed, implemented and exploited to observe the Earth surface. The Synthetic Aperture Radar (SAR) altimeter instruments are able to transmit pulses at high pulse repetition frequency guaranteeing at the same time their coherence. Such instruments allowed to exploit the delay/Doppler processing concept that, by coherent summation of pulses within a burst, achieves an improvement in terms of along-track resolution compared to conventional pulse-limited altimeters. CryoSat, launched in 2010, has been the first satellite radar altimeter to incorporate SAR mode capability. Sentinel-3 is the first altimetry mission operating all over the globe in SAR only, while Sentinel-6 has introduced new capabilities with the open burst chronogram. Similarly, the on-ground processing of the echoes acquired by such instruments has improved to allow for a more accurate estimate of the geophysical variables. Since the first operational Level-1 processing chain developed for CryoSat, different evolutions have been included for the different Missions starting from a variety of R&D activities and a wide effort of the community, under the input of the Agencies. In particular, in the context of the Delay/Doppler processing, investigations have been concentrated on the azimuth windowing (e.g. Hamming, Gaussian, etc), on the focusing operator (e.g. DFT, Chirp-Z, exact vs. approximate methods), on the posting rate (40 Hz, 80 Hz or higher) and on the inclusion of second order effects (e.g. range walk compensation). Additionally, R&D activities have been also devoted to edit and characterize the single-look waveforms prior multi-looking (the so-called stack): for example introducing new stack parameters (e.g. stack peakiness and antenna pitch estimation), extending the range window size, weighting the single looks waveforms (e.g. stack trimming, Antenna Compensation Dilation Compensation, Antenna Pattern Compensation) and masking the Doppler ambiguities.
This abstract is aimed at giving a comprehensive overview of the R&D activities and the evolutions in the past 15 years that have innovated the Level-1 processing of SAR altimeters data, highlighting the performance improvement obtained by implementing novel algorithms in the operational Level-1 processors.

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SYNERGY BETWEEN SATELLITE ALTIMETRY, SEA SURFACE SALINITY AND ARGO FLOAT DATA TO DIAGNOSE MESOSCALE EDDY FLUXES OF SALT

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Mesoscale eddies play an important role in the ocean transport of heat and salt. Eddy fluxes are difficult to observe, however, mainly because of the difficulties in gathering observations with sufficient time and space resolution to resolve the eddy field. In this study, the transport properties of mesoscale eddies are diagnosed from a synergistic use of satellite altimetry, sea surface salinity (SSS) and Argo profile data. Here, we focus on the SSS maximum in the South Indian Ocean (SIO), where mesoscale eddies are believed to play a potentially important role in shaping the ocean's salinity distribution with important implications for climate.

To overcome the problem of poor spatiotemporal resolution of Argo profile data, we utilize the so-called eddy composite analysis. In this analysis, a three-dimensional structure of a "typical" mesoscale eddy in a chosen geographical area is reconstructed by synthesizing all available Argo profiles following the trajectories of mesoscale eddies identified in altimetric sea level anomaly (SLA) maps. The statistics of the horizontal distribution of eddies derived from the SLA maps are then combined with the eddy vertical structure to compute the eddy-induced transport of salt. Satellite SSS data along with the altimetry-derived surface geostrophic velocities are used to calibrate and validate subsurface estimates. The results show that the role of mesoscale eddies in the SIO subtropical gyre is to pump salt out of the gyre. The eddy salt transport is equatorward on the equatorward side of the gyre and poleward on the poleward side. In the vertical, the eddy salt flux "penetrates" as deep as 400 m, closely following the subsurface "river of salt", an important part of the Indian Ocean shallow overturning circulation. The results also show that the eddy salt transport in the subsurface layer can be parameterized using a simple gradient-flux relationship with a diffusivity coefficient given by the mixing length formulation, while all the parameters (r.m.s eddy velocity and length scale) can be estimated from the eddy composite analysis. This parameterization, developed from observations, is used to assess the effect of mesoscale eddies on spiciness variability originated from the SSS maximum region in the SIO.

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DAHITI – MONITORING OF WATER LEVELS AND WATER SLOPES SURFACE USING USING SWOT KARIN MEASUREMENTS OVER INLAND WATERS

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For more than three decades classical satellite altimetry has been successfully used to monitor water levels of inland waters such as rivers, lakes and reservoirs. In December 2022, a new generation of altimeter mission called Surface Water and Ocean Topography (SWOT) was successfully launched. SWOT is equipped with a classical radar nadir altimeter comparable to Jason-3, but also with a new Ka-band Radar Interferometer (KaRIn). KaRIn uses the principle of SAR interferometry, which has the capability to monitor almost every inland water body worldwide because of its 120 km wide swath and its 21 day repeat science orbit.

In this contribution, we present two new approaches to derive hydrological parameters over inland waters. For lakes and reservoirs are water level time series derived. For rivers, however, not only water levels but also time-varying water surface slopes are derived from the high-resolution SWOT pixel cloud dataset. This dataset allows us to monitor water levels of very small targets. We use SWOT data measured on the fast sampling orbit (03/2023 – 07/2023, 1-day repeat cycle) and the science orbit (since 07/2023, 21-day repeat cycle). This contribution also discusses the challenges due to measurement noise, data gaps, and dark water pixels when using SWOT KaRIn data and how the new approach addresses them.

For quality assessment, the resulting time series of water levels and water surface slopes will be validated with in-situ data and compared with other data sets. All time series of water levels and surface water slopes will be freely available on the web portal of the „Database of Hydrological Time Series of Inland Waters„ (DAHITI, https://dahiti.dgfi.tum.de).

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30 YEARS OF WIND AND WAVE ENERGY ASSESSMENT IN THE OFFSHORE AREAS OF CHINA FROM SATELLITE ALTIMETRY

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Energy has always been a major problem plaguing human development. Developing renewable and clean energy sources is crucial in addressing the energy challenge and building a sustainable future. Offshore wind and wave energy exhibit significant potential and can help optimize our energy mix. However, due to the limitation of observation data, there is a lack of effective and accurate assessment of wind and wave energy in the global or local ocean.
Satellite radar altimeters have been providing outstanding contributions to the long-term monitoring of global marine environment. Benefiting from that altimeter can directly measure the key parameters such as wind speed and significant wave height, satellite altimetry has the potential to offer a valuable tool for long-term assessment of offshore wind and wave energy resources.
This research investigates the wind and wave characteristics, the spatial and temporal distribution as well as the long-term trends of wind and wave energy in the offshore areas of China (100°-145°E, 0°-45°N) from 1993 to 2022. The data used is measured significant wave height and wind speed from satellite altimeters (T/P (1993)-Jason-3 (2022)). The data are firstly validated by buoy measurements, and the results showed good consistency. Then the theoretical wind and wave energy in the study area are calculated, and the spatial distributions of the annual, seasonal, and monthly mean wind power density and wave power are presented. The results show that wind and wave energy exhibit significant seasonal characteristics and show long-term increasing trends. The long-term trend of wind energy is relatively stable with subtle growth. In contrast, the wave energy demonstrates a strong growth trend with an average annual growth rate of 0.15 kW/m. Both wind and wave energy are most abundant in winter, followed by spring and autumn, and least abundant in summer. The distribution of energy resources varies across different regions. The wind energy is rich in the Taiwan Strait, Luzon Strait, and the Northwest Pacific Ocean, with a northeast-southeast direction. The annual average wind energy density near the Taiwan Strait exceeds 1000 W/m². Meanwhile, wave energy-rich areas are primarily found in the Northwest Pacific, Luzon Strait and the northeastern part of the South China Sea, and the annual average wave energy in the Northwest Pacific reaches 40 kW/m. Comparatively, the East China Sea coast shows relatively high levels of wind and wave energy.
These results show the potentials for wind and wave energy development, providing scientific references for offshore resources assessment, wind and wave climate prediction, and ocean engineering. The study also demonstrates the capability of satellite altimeter to provide accurate and reliable data for more comprehensive estimates of global energy potential.

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MONITORING KUROSHIO MEANDERS AROUND THE IZU RIDGE BY FERRY-BORN GNSS AND SWOT ALTIMETRY DATA

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Since 2017, the Kuroshio south of Japan has taken a large meandering path. Significant bottom topography of the Izu Ridge is one of the factors affecting generation and degeneration of the large meander, together with variations of the wind stress and eddy activities in the North Pacific. Frequent monitoring of the Kuroshio around the Izu Ridge is therefore required, but short-term variations of the Kuroshio are not well observed due to the absence of proper satellite tracks of conventional satellite altimeters. In this study, we have started Global Navigation Satellite System (GNSS) observations on a ferryboat "Tachibana Maru" (Tokai kisen co. ltd., 5681 ton) sailing between Takeshiba Port, Tokyo, and Hachijo-jima Island, which crosses the Kuroshio over the Izu Ridge twice a day. Among various GNSS positioning methods, Precise Point Positioning (PPP) can provide reasonable daily sea surface height (SSH) variations of the Kuroshio, except near islands. Meanwhile, beta pre-validated SWOT altimeter data can provide a spatial extension of SSH variations observed by the along-track ferry GNSS data, although intermittent in time. Combination of these two SSH data sets enables us to trace movements of small meanders of the Kuroshio around the Izu Ridge. In the upstream of the Izu Ridge, since the Kuroshio turns its direction clockwise due to the large meandering path, significant positive SSH anomaly (SSHA) peaks of approximately 100-km diameter are found at around 33.5° N, with temporal modulations of the amplitude. However, in the downstream of the Izu Ridge, no significant SSHA peaks were found. Instead, the boundary of the positive SSHA areas is present in the coastal area with frequently changing its position in time, which represents movements of the Kuroshio axis in the downstream of the Izu Ridge.

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USE OF GNSS-IR TO DETECT RECENT AND HISTORICAL STORMS SURGES IN HONG KONG

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Hong Kong commonly experiences around 5 to 6 typhoons per year, with an average occurrence of one super typhoon every three years. These extreme weather events pose a significant threat to the region, causing substantial damage and economic loss. Therefore, it is crucial to monitor storm surges to mitigate potential coastal hazards. Tide gauges have traditionally been the primary tool for providing this information; however, they may fail to record the peak water level (i.e., storm surge height) due to breakdown during extreme events. Over the past decade, Global navigation satellite system interferometric reflectometry (GNSS-IR) has been emerging as an in-situ sea-level observing technique. GNSS-IR offers comparable accuracy to conventional tide gauges but has the advantage of being less susceptible to damage during extreme events. This is possible because GNSS-IR stations can be installed at higher locations, such as rooftops, reducing the risk of being damaged or destroyed during the most intense storms. In this study, we employ GNSS-IR to detect typhoon-induced storm surges in Hong Kong from 2009 to 2023. Additionally, we aim to investigate the limitations and challenges that GNSS-IR may encounter in detecting storm surges.

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ARE NEAR-COASTAL SEA LEVELS ACCELERATING FASTER THAN GLOBAL DURING THE SATELLITE ALTIMETRY ERA?

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Impact and risk assessments in coastal areas are informed by current and future sea level rise and acceleration, which demands a better understanding of drivers for regional sea level acceleration. In our study we analyze the near-coastal sea level acceleration compared with global values during satellite altimetry (1993–2020) and discuss the potential drivers of regional sea level acceleration. We estimate regional sea level acceleration using high-resolution satellite altimetry sea surface height anomalies. Our study reveals a wide range of regional acceleration estimates, varying from −1.2 to 1.2 mm/yr², which can be up to 20 times larger or smaller than the global mean sea level acceleration of 0.07 mm/yr². Notably, sea level acceleration near the global coastline is calculated at 0.10 ± 0.03 mm/yr², exceeding the global mean sea level acceleration by 40%. Regional patterns of sea level acceleration are in good agreement with acceleration patterns calculated from the steric sea level. However, the magnitude of acceleration is only partially explained by the changes in steric sea level, with increasing contributions from the non-steric component.

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GLOBALLY TRAINED LSTM MACHINE LEARNING-BASED APPROACH TO ESTIMATE RIVER DISCHARGE USING THE GLOBAL RUNOFF DATA CENTRE (GRDC) RIVER DISCHARGE AND INLAND ALTIMETRY WATER LEVEL DATA

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Estimation of river discharge is essential from the perspective of river basin management and disaster risk management, as well as from the fundamental science perspective - to better understand our hydrological cycle. However, the number of publicly available river discharge monitoring station data has been gradually declining over the past decades. In recent times, supervised machine learning-based approaches, such as the LSTM machine learning models (using hydrometeorological predictor datasets), have been used to estimate river discharge (Kratzert et al., 2018; Feng et al., 2020; Arsenault et al., 2023). Notably, these models have reportedly outperformed traditional conceptual hydrological models. Furthermore, these data-driven models, when trained on a global dataset, have shown potential for river discharge estimation in ungauged basins. The progress in data-driven river discharge prediction has even led some to question the role of hydrological theories and conceptual hydrological models (Nearing et al., 2020).

In parallel, the satellite altimetry community has advanced towards inland water level and inland river discharge estimation. While the altimetry-based river discharge estimation typically works well in wide rivers with in-situ observations, altimetric water level-based river discharge predictions in ungauged basins (PUB) is largely limited to the application of Manning-based empirical equations. Such Manning-based empirical equations are not highly reliable. As such, improvements in inland altimetry application in predictions in ungauged basins may be desirable. Furthermore, machine learning-based techniques have not been explored much, alongside inland altimetry data, to estimate river discharge. In this contribution, we explore machine learning-based approaches, such as the LSTM machine learning model, to predict river discharge (at GRDC station locations) when trained with the Global Runoff Data Centre (GRDC) river discharge data and altimetric water level data. We intend to train the LSTM machine learning model on the globally available altimetric water level dataset and the GRDC river discharge dataset. We further intend to validate our results and evaluate the predictive capability of such globally trained LSTM models, trained on altimetric water level and GRDC river discharge data, in ungauged river basins in East Africa. We look forward to presenting early results, as well as the opportunities and challenges of using altimetric observation data in a machine learning framework.

Key References:

- Arsenault, R., Martel, J. L., Brunet, F., Brissette, F., & Mai, J. (2023). Continuous streamflow prediction in ungauged basins: long short-term memory neural networks clearly outperform traditional hydrological models. Hydrology and Earth System Sciences, 27(1), 139-157.

- Feng, D., Fang, K., & Shen, C. (2020). Enhancing streamflow forecast and extracting insights using long-short term memory networks with data integration at continental scales. Water Resources Research, 56(9), e2019WR026793.

- Kratzert, F., Klotz, D., Brenner, C., Schulz, K., & Herrnegger, M. (2018). Rainfall–runoff modelling using long short-term memory (LSTM) networks. Hydrology and Earth System Sciences, 22(11), 6005-6022.

- Nearing, G. S., Kratzert, F., Sampson, A. K., Pelissier, C. S., Klotz, D., Frame, J. M., ... & Gupta, H. V. (2021). What role does hydrological science play in the age of machine learning?. Water Resources Research, 57(3), e2020WR028091.

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DRIVERS OF HALOSTERIC REGIONAL SEA LEVEL INTERANNUAL VARIATIONS

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In addition to the global mean sea level rise associated with ongoing climate change, sea level exhibits large interannual variability, which is known to strongly influence regional sea level trends. Since the launch of Topex-Poseidon in 1992, accurate measurements of sea level variations are available with a $\pm \SI{66}{\degree}$ latitude coverage. A better understanding of the mechanisms leading to the observed patterns of sea level rise is needed to better interpret these measurements.
Although generally smaller than thermosteric regional sea level variations, Argo float measurements show that halosteric sea levels can reach amplitudes comparable to their thermosteric counterparts in several regions, such as the North Atlantic or southwestern Indian Ocean.
The associated variations in salinity may be directly driven by variations in evaporation, precipitation, and river runoff, or by oceanic processes.
In addition, freshwater input to the ocean from melting continental ice may also contribute to regional variability in sea level trends. In this study, we seek to further our knowledge of the mechanisms of halosteric regional sea level variations at the interannual time scale.
To do so, we use a novel framework based on variance budgets, which we applied to full-depth steric sea level from observations and oceanic numerical models to investigate these mechanisms. Using a specially designed eddy-permitting global configuration based on an ensemble approach (OST/ST IMHOTEP project), we further evaluate the contribution to halosteric sea level

from long-term freshwater input due to melting continental ice.

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SEA ICE THICKNESS RETRIEVAL AND IMPLICATIONS FROM SNOW EFFECTS USING CRYOSAT-2, OIB, AND ICESAT-2 IN THE WEDDELL SEA

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Snow overlying sea ice significantly impacts the accuracy of altimetric remote sensing, introducing uncertainties through radar propagation delay due to slower radar speeds in snow and altered radar waveform shapes caused by varying snow morphologies, surface roughness, and mixed surface conditions. This study presents a novel approach to deconvolute and quantify snow scattering effects on the CryoSat-2 (CS-2) waveform, utilizing comparisons with the airborne Ka-band altimeters KAREN. We introduce an enhanced CS-2 freeboard estimation method, calibrated against multiple undertrack Operation IceBridge (OIB) campaigns, which notably improves sea ice thickness measurements. Our analysis reveals a snow-induced bias in sea ice thickness of up to 0.5 m within the CRYO2ICE campaigns. This paper also debuts a pioneering sea ice thickness product for the Weddell Sea derived from CryoSat-2 data. Our findings mark a significant advancement in sea ice thickness retrieval techniques from radar altimeters, offering new insights into the current state of Antarctic sea ice mass. With this improved product, we pave the way for further investigations into the mechanisms and processes driving the recent dramatic losses of Antarctic sea ice.

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GLOBAL TRENDS IN EDDY KINETIC ENERGY OVER THE ALTIMETRIC ERA: ARE THE OCEANS BECOMING MORE ENERGETIC?

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Earth has undergone anthropogenic global warming driven by the emissions of greenhouse gasses released to the atmosphere by human activities since the beginning of the Industrial Revolution. The ocean is Earth's major heat reservoir and has absorbed 90% of the anthropogenic excess heat. Ocean circulation plays a key role in the global climate system by redistributing water masses and their properties, including heat and carbon, throughout the global ocean. At the same time, changes in the climate system have not only warmed the upper ocean but also altered the wind stress, heat, and freshwater fluxes that act as driving forces for ocean circulation. Hence, climate change can modify the intricate system that constitutes the global ocean circulation. The mesoscale circulation (~10-100 km) is an essential component of the global ocean circulation constituted by a steady flow and a time-varying flow (also called mesoscale variability). Mesoscale features exist throughout the global ocean and transport and mix water masses and their properties over long distances and locally in depth, influencing larger and smaller-scale processes. This study aims to evaluate if the global ocean mesoscale variability is increasing or decreasing over the altimetric era. To achieve this goal, we evaluate global trends of eddy kinetic energy (EKE), a widely-used metric for characterizing the intensity of the ocean mesoscale variability. The EKE is computed from altimetric observations provided by a product constructed for climate applications, which includes observations from a consistent pair of altimeters to ensure almost uniform errors over the altimetric era (two-sat). Additionally, we compute the EKE from a product that includes all available altimeter missions (all-sat), whose number generally increases over time. The inclusion of new satellites enhances the capacity to map mesoscale structures, despite the time-variable errors dependent on the number of satellites used. Our investigation reveals that two-sat yields a non-significant global EKE trend over the altimetric era, suggesting (i) that the all-sat positive EKE trends may, at least partially, be induced by the increasing number of satellites and (ii) that two-sat may not completely capture a potential increase in mesoscale kinetic energy due to its lower resolution. However, conducting the same analysis but after 2003, when the satellite constellation was constituted by three or more altimeters, we obtain significant and positive global EKE trends for both altimetric products, revealing that over the period 2003-2022 the mesoscale variability is becoming more energetic. The exact value of the global EKE trend is expected to be between the trends obtained from two-sat and all-sat, due to the intrinsic limitations of each product. Additionally, our results reveal that the regions of the global ocean of intense mesoscale activity (with the highest EKE) are the areas that are becoming more energetic. Providing knowledge on this topic is crucial for predicting the future state of our oceans and their role in the broader climate system.

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FULLY FOCUSED SAR ALTIMETRY AND INNOVATIVE RIVER LEVEL GAUGES FOR COASTAL MONITORING – THE FFSAR-COASTAL PROJECT

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“Fully focused” processing of SAR altimeter data provides opportunities for exciting new applications, as it provides hitherto unachievable along-track resolution and offers the potential to monitor small water bodies.

The objective of the FFSAR-Coastal Project was to evaluate the potential of FFSAR altimeter data to make a significant new contribution to coastal and estuarine monitoring systems.
Two different environments were considered:
• The Severn Estuary and river: A highly dynamic mixed tidal estuary environment.
• The lower Rhone Delta and Camargue: A low lying, flat river delta and wetland environment

DTU Space implemented the SMAP (Standalone Multi-Mission Altimetry Processor) and applied it to Sentinel 3A and 3B altimeter data for the two regions in the study). Different Fully Focused SAR processing options have been implemented and assessed for the two regions. The best performing options were then used to generate time series of data for selected tracks, and these data validated against in-situ data. The in-situ data comprise data from existing tide gauges, but also from four newly installed innovative “micro-gauges” provided by vortex.io, two in each region. Drone campaigns with an embedded LiDAR altimeter were carried out to provide high-resolution sea level measurements, to provide a water level profile between the micro-gauge location and the satellite ground track.

Subsequent analysis has investigated the capability of FFSAR altimeter data to capture small scale physical signals (surface gradients, currents, roughness signatures) in highly tidal regions and to detect and measure tidal asymmetry/gradients across estuaries not seen with conventional altimetry. For the Rhône delta the analysis has focussed on the ability of FFSAR data to accurately map different low-lying channels and filaments. We present results of these analyses and provide key recommendations for further developments and implementation.

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PRECISE SEA LEVEL AND GRAVIMETRIC MEASUREMENTS, ALONG WITH IN-SITU ARGO PROFILES, ENABLE THE ESTIMATION OF CHANGES IN THE GLOBAL WATER-ENERGY CYCLE AND THE CONSTRAINING OF CLIMATE SENSITIVITY.

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Over the past 30 years, the scientific community, space agencies and oceanic institutes have developed a global geodetic and hydrographic observing system to monitor sea level rise and its climatic contributions. The objective was to produce observations that are accurate enough to determine the sea level variations in response to current climate change and enable further studies that evaluate the potential impacts and risks for coastal populations and ecosystems. After 30 years, this observing system composed of 14 satellite altimeters (including the Topex/Jason series and the Sentinel series), 2 space gravimetry missions (GRACE and GRACE-FO) and millions of ocean in-situ temperature and salinity profiles (including XBT, CTD and Argo profiles) has reached a level of maturity and accuracy that enables to estimate sea level variations and their contribution on a monthly basis with quasi global coverage and a stability ≤0,5mm/yr over periods ≥20 years. This unprecedented level of accuracy appears now sufficient for a new scientific application: estimating the ocean storage of heat and water and further constraining the global water-energy budgets to derive more accurate estimates of the global water-energy fluxes that are responsible for climate change and their sensitivity to greenhouse gases emissions. This is a change of paradigm for an observing system that was designed to monitor the impact of climate change and which is used now to evaluate the causes for climate change. With this change of paradigm come new requirements on the accuracy of the observing system and on the determination of the uncertainties. In this talk I will recall the performance of the current sea level observing system. Then, I will show how the sea level observing system can be used to estimate the ocean storage of heat and water and how this information enables to constraint the global water-energy budgets leading to more accurate estimates of the global water-energy fluxes and of the climate sensitivity. In conclusion, I will list a few important scientific questions related to the global water-energy cycle, recall the level of accuracy that is needed in the estimate of the ocean heat and water storage to provide new insights on these questions and then estimate the constraint it places on the sea level observing system to achieve this objective. I will also explain why this new paradigm emphasizes the need of robust, comprehensive and validated uncertainty estimates for the sea level observing system.

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FROM MESOSCALE TO SMALL-SCALE OCEAN VARIABILITY THROUGH SATELLITE ALTIMETRY AND MULTI-PLATFORM INTEGRATION: A REVIEW OF NEARLY THREE DECADES OF RESEARCH

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Over the past three decades, ocean variability research has undergone a transformative journey, evolving from a focus on large-mesoscale phenomena to the exploration of finer-scale features, such as fronts, meanders, eddies, and filaments. These small-scale ocean features, ranging from 1 to 100 km, play a critical role in the distribution of heat, fresh water, and biogeochemical tracers, thus influencing climate dynamics. Integrating our understanding of these processes into climate scales has emerged as a key challenge in Earth observation.

In this presentation, I propose to give a review of 25 years of research devoted to studying mesoscale and small-scale ocean variability through the integration of satellite altimetry and multi-platform observations. I started working with altimetry thanks to an internship during my first year of PhD. I used gridded products combining two altimeters to analyze a mesoscale eddy in the Balearic Sea (western Mediterranean) that reversed the general cyclonic circulation of the basin, a previously undetected feature. After completing my PhD, I conducted postdoctoral research at CLS (France), where I focused on integrating data from various altimeter missions to study global mesoscale variability. Upon returning to Spain, I initiated satellite altimetry projects at our IMEDEA team, fostering international collaborations.

The transition towards studying small-scale ocean variability has been facilitated by the synergy of in-situ and satellite altimetry observations, alongside numerical simulations. Multi-platform field experiments, particularly in the western Mediterranean Sea, have been key in estimating small-scale horizontal and vertical currents. For example, the ALBOREX multi-platform experiment in 2014 focused on studying mesoscale features in the Alboran Sea. In 2018, the PRE-SWOT campaign expanded on ALBOREX's efforts, preparing for the Surface Water and Ocean Topography (SWOT) satellite mission. By combining in-situ and satellite observations with numerical models, PRE-SWOT aimed to enhance our understanding of small-scale ocean structures, particularly in the Balearic Sea. The CALYPSO initiative, spanning from 2017 to 2024 and funded by the Office of Naval Research, has represented a significant milestone in the study of vertical oceanic transport. Through field campaigns and modeling studies in the western Mediterranean, CALYPSO has shed light on coherent pathways for vertical transport. The launch of the SWOT satellite mission in December 2022 marked a significant advancement in ocean observation capabilities. The FaSt-SWOT experiment (April-May 2023) contributed to the calibration and validation of SWOT data by collecting in-situ observations (drifters, glider, ship, cameras, HF radar,...) of a small-scale eddy in the Balearic Sea during the SWOT fast sampling phase. Innovative approaches, combining optimal interpolation schemes with machine learning algorithms, have also emerged to reconstruct three-dimensional ocean states.

These initiatives, spanning nearly three decades, including the validation of all the new satellite altimeter products, highlight the transition from large-mesoscale to small-scale. Looking ahead, continued collaboration, innovation and sustained integrated observations will be essential for advancing our understanding of ocean variability and its impact on climate. The list of co-authors aims to reflect some of the collaborators, students, postdocs, and advisors with whom I have had the privilege of working so far. But the list is incomplete!

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RIVER DISCHARGE DATA ASSIMILATION FROM SIMULATED DAILY WIDE-SWATH OBSERVATIONS IN THE MISSISSIPPI BASIN

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River discharge is a fundamental component for comprehending the hydrological cycle and optimizing various water-related activities, including irrigation, flood forecasting, and dam management. However, accessing discharge data presents challenges due to limited ground observations globally. Considerable efforts have been made to infer discharge from satellite data, particularly altimetry, using established rating curves at local virtual stations. The Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, is providing groundbreaking wide-swath data, allowing innovative approaches to infer discharge from simultaneous SWOT observations of height, width, and slope using hydraulic models and inverse problem methodologies. Notably, SWOT enables the promise of a new discharge product globally available at rivers wider than 50m.

Despite SWOT's dense swath-based spatial coverage, its 21-day repeat cycle remains a challenge in capturing rapidly changing river dynamics, especially during flood events occurring between satellite overpasses. In hope to partially alleviate this challenge, we explore the potential of a high-frequency wide-swath satellite mission combined with hydraulic models and data assimilation techniques. While no such mission currently exists, we propose a preliminary study to evaluate its potential, drawing inspiration from the daily CalVal orbit configuration of SWOT’s first three months of observations to create an Observing System Simulation Experiment (OSSE).

We focus on the Mississippi basin for continental-scale river discharge analysis. Our synthetic truth is reconstructed using data assimilation of available daily USGS in-situ gauges to correct Land Surface Model runoff, performed through the Data Assimilation (DA) capabilities of NASA's RAPID model. A performance assessment among various land surface models ensures a 'synthetic truth' closely aligned with observations, accounting for systematic and random errors from ground measurements and Land Surface Models. This synthetic truth is then resampled using daily SWOT calval orbit to extract idealized discharge observations at SWOT observable reaches.

We investigate the Data Assimilation capabilities of RAPID and their potential in bridging the gap between satellite observations in space. Given the limitations of deterministic DA methods in the presence of high bias in the prior information, we first employ a Long-Term Inverse Routing (LTIR) approach to correct prior runoff bias at and upstream of any satellite observation. Subsequently, we utilize Kalman Filter to further correct runoff variance by assimilating satellite-like discharge.

RAPID DA Capabilities demonstrate promising performance at the continental scale, with discharge estimation showing satisfactory accuracy at and beyond observed reaches. Runoff bias correction significantly reduces discharge bias across the basin, upstream of observed rivers. DA improvement is noted downstream until a corrected river's relative contribution to total downstream discharge diminishes within the network. However, DA estimation remains uncertain in very small rivers ($Q<1m^3/s$), potentially due to limited knowledge of error covariances , hydraulic representation, and equifinality.

Our findings indicate that by observing only 0.7% of the basin, constituting SWOT observable reaches, we can correct up to 30% of the basin's discharge. Future research will delve into SWOT science orbit sampling and assess the uncertainty associated with the SWOT discharge product.

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20-YEAR-LONG SEA LEVEL CHANGES ALONG THE WORLD'S COASTLINES FROM SATELLITE ALTIMETRY: THE NEW ESA CCI DATASET OF COASTAL VIRTUAL STATIONS

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In the context of the ESA Climate Change Initiative (CCI) Coastal Sea Level project, a complete reprocessing (including retracking of the radar waveforms) of high resolutions (20 Hz, i.e. 350 m) along-track altimetry data of the Jason-1, Jason-2 and Jason-3 missions since January 2002 was performed along the world coastal zones. The latest release (v2.3) of this SL_cci coastal altimeter sea level dataset covers the period January 2002 to June 2021 and is now available for the users (https://doi.org/10.17882/74354). A new improved processing of the waveform retracking and computation of the coastal sea level anomalies was developed and a new editing procedure for the coastal sea level trend computation was implemented. This new dataset shows spectacular reduction of the data noise compared to previous versions, both in terms of sea level anomaly time series and trends. We now obtain more than 1200 coastal virtual stations (i.e., the location of the first valid point from the coast along the satellite track) at an average distance from the coast of about 3 km, including more than 200 stations at less than 2 km from the coast. These coastal sea level anomalies and trends of the altimetry-based virtual stations have been validated with tide gauges data where possible. An example is presented in the Mississippi river delta.

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PERFORMANCES OF THE SWATH ALTIMETER SAOOH ON BOARD THE SENTINEL 3 NEXT GENERATION TOPOGRAPHY MISSION

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The Sentinel-3 Next Generation Topography mission, addresses the need for a timely extension of the current Sentinel-3 capability in terms of stability and continuity, while improving performances and increasing the quantity and quality of geophysical products. Sentinel-3 Next Generation belongs to the Copernicus "enhanced continuity" missions of the European Union.
The baseline concept relies on Thales Alenia Space state of the art technology with an altimetry payload composed of Poseidon-5 (POS5) a SAR nadir altimeter for continuity, and SAOOH the Swath Altimeter for Operational Oceanography and Hydrology for enhancing sampling, coverage, revisit, and enhanced topography product. In order to achieve the specified five days revisit time, two satellites will operate simultaneously, on a dawn-dusk sun synchronous orbit, with same ground tracks as for Sentinel 3 First Generation.
SAOOH is currently developed, under ESA contract, by Thales Alenia Space and benefits of heritage from CryoSat (SIRAL), Sentinel-3 (SRAL), Sentinel-6 (POS4), SWOT (KaRin) and Cristal (IRIS) missions. SAOOH improves the spatial/temporal sampling of the ocean and inland waters with respect to nadir altimeters. The products are available over a typical swath of 120 km centred on nadir. Swath altimeters also permit to observe continental water extent, and to measure surface elevation and river slopes. New observation capabilities for significant wave height (SWH), wave spectrum, sea ice and land ice are anticipated as shown by preliminary SWOT data.
SAOOH is a Ka-band multibeam swath altimeter using one transmit antenna and two receive antennas with a 3m interferometric baseline.

The SAOOH antenna design results in high signal to noise ratio (SNR) to comply with the random error requirement while keeping a relatively short interferometric baseline. The thermally regulated low noise amplifier front-ends (LNA) integrated very close to the antenna feeds further maximises the SNR.
It is then possible to accommodate SAOOH without deployment mechanism, leading to a simple mechanical design and excellent antenna stability.
This presentation addresses the SAOOH design with a focus on achievable performances at radar level and the related end-to-end geophysical product accuracies (L2 level). The measurement principle, including the external calibration is addressed. Random errors and systematic errors are also presented and discussed with respect to the mission requirements.

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SENTINEL-3 LAND STM: PERFORMANCES OF THE HYDROLOGY THEMATIC PRODUCTS OVER INLAND WATERS

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Sentinel-3 is an Earth Observation satellite series developed by the European Space Agency (ESA) as part of the European Copernicus Programme. It is currently a constellation composed of 2 satellites: Sentinel-3A and Sentinel-3B, launched on 16 February 2016 and 25 April 2018, respectively. Among the on-board instruments, the satellites carry a radar altimeter system which aims at providing operational topography measurements of the Earth's surface. Over inland waters, the main objective of the Sentinel-3 constellation is to provide accurate measurements of the water surface height, to support the monitoring of freshwater stocks. Compared to previous missions embarking conventional pulse limited altimeters, Sentinel-3 measures the surface topography with an enhanced spatial resolution, due to the on-board SAR Radar ALtimeter (SRAL) which exploits the delay-Doppler capabilities.

ESA and the Sentinel-3 Altimetry Mission Performance Cluster (MPC) recently developed dedicated delay-Doppler and Level-2 processing chains for the generation of Hydro-Cryo Thematic Products over Inland Waters, Sea-Ice, and Land Ice. Since September 2023, Hydrology Thematic Products has become the official Sentinel-3 STM products for inland waters, while previous Land Products stopped being produced. The Hydrology Expert Support Laboratories (HY-ESL) is in charge of monitoring the SRAL performances and making sure that these products meet the mission requirements, but also of proposing evolutions that could potentially be included in the Hydrology Thematic Products in order to improve their performances.

We will first present the main results of routine activities ensuring the quality of the Hydrology Thematic Products. In a second part, our study will be mainly focused on providing the performance assessment of dedicated-water surface retrackers, the sinc²-based model and SAMOSA+ retrackers for rivers and lakes respectively. These retracker algorithms will be applied on Sentinel-3 measurements over specific areas which are monitored by in-situ stations: French rivers (SCHAPI network) and Canadian and American lakes (Wateroffice and USGS networks). Global comparisons will be performed between these retrackers and those currently available for the users in the Hydrology Thematic Products. Statistics based on precision and accuracy will be inferred in order to quantify the performance improvement.

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RECENT UPDATES AT THE GSC DORIS ANALYSIS CENTER

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We discuss updates to the operational series for the GSC DORIS Analysis Center. We describe recent updates that we have implemented, including the reprocessing of all data using DPOD2020, the additional of new satellites, and where appropriate, the adoption of improvements to the nonconservative force modelling, and other background models. Preliminary results for 2023 show that we can improve the WRMS from 8.97 to 7.80 mm by using the new a priori station set (dpod2020_015). We test newly available atmospheric density models, DTM2020, and MSIS2, and report on whether they improve the DORIS satellite orbit determination. We describe updates to our operational series including the addition of newer satellites, such as Sentinel-6A, and the HY-2C & HY-2D satellites. We investigate how to improve the scheme we use to weight each set of satellite in the weekly solutions. We take a new look at the 2nd order ionosphere perturbation in DORIS data, and assess how it might affect DORIS POD and the development of DORIS products.

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INNOVATIVE OFF-NADIR VALIDATION AND PROCESSING APPLIED ON HYDROLOGY THEMATIC PRODUCTS OF SENTINEL-3 LAND STM FOR PERFORMANCE ASSESSMENT OVER RIVERS

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Sentinel-3 is an Earth Observation satellite series developed by the European Space Agency (ESA) as part of the European Copernicus Programme. It is currently composed as a constellation of 2 satellites: Sentinel-3A and Sentinel-3B, launched on 16 February 2016 and 25 April 2018, respectively. Among the on-board instruments, the satellites carry a radar altimeter system which aims at providing operational topography measurements of the Earth's surface. Over inland waters, the main objective of the Sentinel-3 constellation is to provide accurate measurements of the water surface height, to support the monitoring of freshwater stocks. Compared to previous missions embarking conventional pulse limited altimeters, Sentinel-3 measures the surface topography with an enhanced spatial resolution, due to the on-board SAR Radar ALtimeter (SRAL) which exploits the delay-Doppler capabilities.

ESA and the Sentinel-3 (S3) Altimetry Mission Performance Cluster (MPC) recently developed dedicated delay-Doppler and Level-2 processing chains for the generation of Hydro-Cryo Thematic Products over Inland Waters, Sea-Ice, and Land Ice. Over hydrology, the processing chain includes new algorithms, in particular the hamming window and the zero-padding processing. While it has been demonstrated that such algorithms greatly improve the quality of the Hydrology Thematic Products, performance of these products over rivers is still difficult to assess. Indeed, the standard nadir validation of altimetric measurements is often impacted by the river slope, so that it prevents to clearly evaluate the S3 product performances. This limitation is partially overcome when external datasets provide slope estimates, e.g. drone profiles, but it is restricted to a limited number of sites.

In this study, we will propose an innovative validation of altimetric measurements over rivers, for which the effect of river slope is greatly reduced, therefore allowing to assess the global performance of S3 measurements over various type of rivers. The so-called "off-nadir" validation takes advantage of the SAR processing to isolate S3 measurements that are not directly at the nadir of the river monitored by the in-situ station. However, the waveforms at this location still include backscattering signal of the river. We apply this approach over French rivers that are monitored by the SCHAPI network, composed of hundreds of in-situ stations. After selecting in-situ stations nearby theoretical tracks of S3A and S3B, our results suggest that, without external datasets providing slopes, off-nadir validation provides much more reliable Cal/Val sites for performance assessment than the standard nadir selection. Based on these sites on various rivers, we finally apply a sinc²-based model retracker, particularly well-suited for specular waveforms. Comparisons of the precision and accuracy of this retracker with threshold retrackers, like OCOG provided in the Hydrology Thematic Products, will be proposed in order to quantify the performance improvement.

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30 YEARS OF RADAR ALTIMETRY OF THE CASPIAN SEA

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In this paper we follow 30 years of progress in radar altimetry application to the Caspian Sea since the first publications by Cazenave et al. (1997), Vasiliev et al. (2002) and Lebedev and Kostianoy (2005) who showed that satellite altimetry can be successfully used for the investigation of the Caspian Sea level variability in a deficiency of the traditional sea level gauge measurements. Spatial location of the TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 ground tracks at the sea surface makes it possible to investigate different features of hydrological, hydrodynamic and meteorological regimes of the Northern, Middle and Southern Caspian Sea, as well as of the Kara-Bogaz-Gol Bay. In this paper we show capabilities of application of satellite altimetry to monitor sea level, wind speed, wave height, water dynamics, water exchange seasonal and interannual variations in different parts of the Caspian Sea, as well as the Volga River water level. We present the results of verification of the satellite altimetry data with in-situ measurements at gauge and meteorological stations, as well as with numerical modelling of water dynamics in the Caspian Sea.

This research was supported by the Russian Science Foundation Grant N 23-77-00027 «Investigation of the climate variability of thermo-hydrodynamic regime of the Caspian Sea based on remote sensing data», https://rscf.ru/en/project/23-77-00027/.

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A METHOD FOR ESTIMATING DAILY DISCHARGE USING SPACE-BASED DISCHARGE ESTIMATES

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An accurate estimate of river discharge is vital to quantifying the global hydrological cycle and managing water resources. In view of the steadily deteriorating data provision from gauge networks, hydrological monitoring through spaceborne sensors becomes a necessity. The SWOT mission is the first satellite to conduct a global survey of the Earth's surface waters, measuring water surface elevation, river width, and surface slope for estimating discharge. Since SWOT can only sample mid-latitude locations approximately twice per its 21-day cycle, we develop a linear dynamic system for daily discharge estimation over a continuous single-branch river network. The linear dynamic system includes a process model based on a physically-based spatiotemporal correlation and observation equations utilizing SWOT discharge products. We solve this dynamic system through a Kalman filter, which is simultaneously executed in the time and space domain to obtain daily discharge. Since SWOT discharge products are currently inaccessible, we use a perturbed version of synthetic SWOT datasets obtained by Monte Carlo simulation to test the feasibility of our approach. The validation of the estimated discharge against true discharge in the synthetic datasets over all rivers leads to a median correlation as high as 0.95, a median NSE for residuals as high as 0.82, and a median relative bias as high as 5.22%, respectively. Our method delivers promising results and the hope of obtaining daily discharge once the required SWOT data is available.

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HOW MUCH ENSO-RELATED SSH PREDICTABILITY DOES OCEAN DYNAMIC PERSISTENCE PROVIDE IN THE TROPICAL PACIFIC OCEAN?

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Understanding the predictability of El Niño-Southern Oscillation (ENSO) has significant environmental, economic, and societal implications because of the widespread influence of ENSO around the globe. In the tropical Pacific, the variation of upper-ocean heat content preconditions the development of ENSO-related sea surface temperature anomalies (SSTA), thus providing some ENSO predictability. Sea surface height anomaly (SSHA) is a good proxy for upper-ocean heat content in tropical oceans. Therefore, it is important to understand the predictability of tropical Pacific SSHA. Although coupled ocean-atmosphere models can be used to study SSHA predictability, they suffer from initialization shocks that limit the positive contribution of an accurate initial ocean state to ENSO prediction skill. It is not clear how much SSHA predictability an accurate initial ocean state alone can provide without considering post-initialization ocean-atmosphere coupling. Here, we address this question by performing a set of 12-month hindcasts of the 3-D ocean state using a global ocean model. The ocean model is initialized from the initial condition at every month and every year from 1992 to 2017 obtained from the ECCO (https://ecco-group.org) ocean state estimates that are constrained by altimetric SSHA and other observations. During each 12-month hindcast, the atmospheric forcings are set to climatological seasonal forcings. Therefore, any interannual ocean anomaly in the 12-month hindcasts is solely due to the evolution of the initial ocean state without subsequent ocean-atmosphere coupling. We refer to this as ocean dynamic persistence. We show that ocean dynamic persistence provides significant predictability of tropical-Pacific SSHA for several months, owing to the dynamic memory provided by equatorial Kelvin and Rosssby waves as well as the advection of initial steric height anomalies. We also compare the skill of ocean dynamic persistence in predicting SSHA with the statistical persistence. The latter is a common baseline evaluation metrics for predictions where the initial anomalies, e.g., SSHA observed by satellite altimetry, is damped as a function of prediction lead time. Ocean dynamic persistence offers a more stringent metrics for evaluating ENSO prediction skill. It allows the ENSO prediction community to determine how much improvement of the coupled models is needed to claim a skillful prediction. The method is also applicable for studying the predictability of other oceanic phenomena such as marine heat waves.

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THE EVOLUTION OF RADAR ALTIMETRY FROM SEASAT TO SWOT

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The era of satellite oceanography began with Seasat 46 years ago. With only one month's worth of data, the Seasat radar altimeter revealed a blurred view of the global ocean variability of sea surface height (SSH). Seasat also carried a synthetic aperture radar (SAR) that provided images of sea surface features at high resolution. These two measurement techniques have gone separate ways ever since. Radar altimetry has provided a modern record of global sea level change and the large-scale ocean circulation. However, its two-dimensional spatial resolution is limited to ~100 km by the large radar footprint (~10 km), measurement noise, and nadir observations. While SAR provides high-resolution images of many features of the ocean and land waters (e.g. 10 m resolution of Sentinel 1 SAR data), it is difficult to derive the quantitative information needed to study the underlying physical processes. The SWOT Mission has reconciled the strengths of each instrument: using two SAR antennas carried onboard to perform radar interferometry in orbit, the Ka-band radar Interferometer (KaRIn) achieves measurements of SSH at a resolution close to that of SAR. We have analyzed KaRIn data on 250 m grids and identified SSH features as small as 1 km. This represents a breakthrough of radar remote sensing. To illustrate the impact of SWOT, we have calculated the difference between the KaRIn observations and those

from the constellation of conventional altimeters provided by AVISO. This provides a new global view of small-scale ocean variability, which will take years to explore and analyze fully. We will present findings from a survey of selected features across the globe, and demonstrate the ability of SWOT to advance the understanding of small-scale ocean processes and their interaction with larger-scale ocean dynamics and other processes of the climate system.

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MESO AND SUBMESOSCALE DYNAMICS : A NEW APPROACH COMBINING THE AUTOMATIC INFORMATION SYSTEM (AIS) DATA AND SWOT DATA.

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The aim of this study is to characterize the meso and submesoscale dynamics in the western Mediterranean Sea. This region is dominated by a strong current, the northern current, but we can also note the presence of strong fronts than are not detected with the nadir altimetry data, such as Jason or Sentinel. We used the data of the SWOT mission using the fast sampling phase to have the 2D SLA at fine scale. The new SWOT data during the fast sampling phase have a high resolution (~ 2km) and a periodicity of one day. In this work, we combined the SWOT data with AIS (Automatic Information System) data to study the dynamics of the meso and submesoscale currents in this region. The AIS data offer high spatio-temporal resolution of the total current in coastal area and along the main maritime road across the ocean. So it is unique data set, that can be combined with several data such as the in-situ data from the C-SWOT and WEM-SWOT campaign, with several ADCP transects that can be used to validate the currents from the SWOT data. The CMEMS data (combined nadir altimetry product) is also used and compared with the SWOT and AIS data especially for the mesoscale dynamics. Combining these data allows us to study the fronts at submesoscale in this region and also the mesoscale dynamics. We show that the front detected in the SWOT data are comparable to the fronts detected with the AIS data. So the AIS data represent a very useful data set to validate the SWOT data and to study submesoscale dynamics such as fronts in the ocean.

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PERSPECTIVES ON DEVELOPING THE SURFACE WATER OCEAN TOPOGRAPHY MISSION (SWOT) FROM CONCEPT TO REALITY FOR OBSERVING EARTH'S PRECIOUS WATER FROM SPACE

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The Surface Water and Ocean Topography (SWOT) satellite was launched on 16 December 2022, commencing a new era of high-resolution satellite remote sensing of Earth's ocean and inland surface waters. SWOT was developed jointly by NASA and the French space agency (CNES) with contributions from the UK and Canadian space agencies. Using state-of-the-art "radar interferometry" technology, SWOT is measuring the elevation of water to observe millions of lakes and wetlands with surface areas 250 m2 and thousands of rivers whose width exceeds 100 m, while detecting ocean features with unprecedented resolution, accuracy, and spatial coverage.

The primary science payload, a novel Ka-band Radar Interferometer (KaRIn), is the first in-flight demonstration of wide-swath (2, 50Km swaths) SAR interferometry for more accurate and comprehensive mapping of Earth's ocean and surface water from space.

SWOT is expected to revolutionize hydrology and oceanography, providing a set of observations for nearly all surface waters on planet Earth, allowing scientists to determine changing volumes of water across the globe. SWOT will also significantly advance climate and ocean sciences by detecting ocean features with 10 times better resolution than present technologies. The higher resolution will reveal small-scale ocean features that contribute to the Earth's fundamental cycles of heat, energy, carbon, moisture, and nutrients.

SWOT measurements are key to understanding surface water availability, informing water-resource management, preparing for important water-related hazards such as floods and droughts, improving ocean circulation forecasts, and benefiting ship and offshore commercial operations, along with coastal planning activities such as flood prediction.

Parag Vaze will provide a retrospective and prospective on how two decades of activities lead to the groundbreaking measurements being provided by SWOT today. The talk will describe the programmatic and technical challenges to conceive, develop, launch, and operate one of the most complex Earth observing space systems. An overview of the calibration/validation activities and initial results will also be provided along with the applications potential that SWOT enables.

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SHORT-TERM SUBMESOSCALE EDDY VARIATIONS OBSERVED IN SWOT KARIN SLA FIELDS

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In this study, we present a series of typical submesoscale eddy short-term variations revealed by SWOT KaRIn sea level anomaly (SLA) fields. First, several representative cases demonstrate SWOT's capacity to continuously track submesoscale signals (<80 km diameter) over multiple days. By comparing with eddies detected based on traditional merged SLA fields with 0.25° spatial resolution, it is observed that SWOT can well resolve the process of eddy generation and dissipation. The unique morphological, kinematic, and dynamical characteristics of eddies during this process will be investigated. Second, the study validates the effectiveness of SWOT in resolving complex eddy-eddy interactions of merging and splitting which are often ambiguous in data merged from multiple altimeters, especially in high latitudes. Then, the vertical structures of SWOT-derived submesoscale eddies are revealed by combining with Argo observations. Results indicate that these submesoscale eddies can induce strong temperature and salinity anomalies, and also exhibit vertical biochemical signatures (e.g., chlorophyll, backscattering coefficient of particles). A BGC-Argo float was trapped by an anticyclonic eddy for nearly 2 months in the Northwest Pacific, revealing that the vertical temperature anomaly of the eddy had a double-core structure with a warm (cold) core in the upper (lower) layer during its generation phase. In addition, the submesoscale eddy features detected by SWOT are further verified by chlorophyll and sea surface temperature data. This study demonstrates the robust submesoscale resolving ability of new-generation altimetry and its advantage in capturing rapidly evolving signals. Such insights are invaluable for advancing our understanding of submesoscale eddies and energy cascading from meso- to sub-mesoscale processes.

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PROMOTING & EXPLAINING A NEW TECHNOLOGY: SWOT OUTREACH

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Swot KaRIn instrument is a completely new concept. Some pieces of explanations existed through the CNES space technology training courses, some had been posted on the JPL & Cnes project web pages, but more could be done and made available -- and has been, with a major focus on hydrology, but not forgetting the ocean, and the complementarity with currents techniques, including nadir altimetry. Series of ppt slides have been developed and released during the past 5 years, they have now been updated with real Swot data, and will continue to be.
With those data available, a portfolio of the early images is posted and updated on Aviso web site.

Communication on results, articles and other publications is also done, in order to promote Science Team work, and also to get would-be users familiar with the data, pinpoint their differences with classical and delay-Doppler altimetry alike and give glimpses of what new uses and applications could be developped from those data.

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INTERANNUAL VARIABILITY OF WATER LEVEL IN LADOGA AND ONEGA LAKES BASED ON RADAR ALTIMETRY

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Regional climate change affects the state of inland water bodies and, first of all, their water balance, which is determined by a number of hydrometeorological and hydrogeological factors. An integral characteristic of changes in the water balance is the behaviour of the level of lakes and reservoirs, which not only largely determines the physical and ecological state of water bodies, but also significantly affects the coastal infrastructure and socio-economic development of the region. The paper investigates the interannual variability of the level of Ladoga and Onega lakes, two largest lakes in Europe, located in the northwest of Russia, according to satellite altimetry data for 1993-2020. For this purpose, we used three specialized altimetry databases: DAHITI, G-REALM, and HYDROWEB. Water level data from these altimetry databases were compared with in-situ records at water level gauge stations. Information on air temperature (1945-2019) and precipitation (1966-2019) acquired at three meteostations located at Ladoga and Onega lakes was used to investigate interannual trends in the regional climate change. Finally, we discuss a potential impact of the lake level rise and regional climate warming on the infrastructure and operability of railways in this region.
This research was supported by the Russian Science Foundation Grant N 21-77-30010 (2021-2024) "System analysis of geophysical process dynamics in the Russian Arctic and their impact on the development and operation of the railway infrastructure".

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SEASONAL AND INTERANNUAL VARIABILITY OF WATER EXCHANGE THROUGH THE KERCH STRAIT BASED ON RADAR ALTIMETRY

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In this paper we propose new methodology for calculation of water exchange anomalies between the Sea of Azov and the Black Sea. To analyze changes in water exchange through the Kerch Strait, altimetry measurements from the TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 satellites were used. Calculation of water exchange anomalies was carried out according to the methodology developed for the Caspian Sea (Lebedev, Kostianoy, 2019). The analysis of the variability of water exchange through the groundtracks is based on the analysis of the variability of surface velocity anomalies, which are calculated through sea level anomalies determined from satellite altimetry data. The positions of 007 and 042 tracks of the TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 satellites are optimal for analyzing water exchange between the Black and Azov Seas. To do this, it is necessary to consider a part of the 042 track from the Crimean coast to the point of intersection with track 007, and then a part of the track 007 to the coast of the Taman Peninsula. In this part of the Black Sea, limited by groundtracks 007 and 042, there is no river runoff, and most of water fluxes are determined by water exchange through the Kerch Strait. To calculate water exchange, the time interval was taken from October 23, 1992 to September 22, 2016. Processing and interpretation of satellite altimetry data were carried out using the Integrated Database of Satellite Altimetry (IBDSA) software developed at the Geophysical Center of the Russian Academy of Sciences.
Maximum current velocity anomalies associated with water exchange between the Black and Azov Seas through the Kerch Strait are observed at the track 042 closer to the coast. In this area, geostrophic velocity anomalies exceed 20 cm/s. Temporal variability of water exchange anomalies between the Black and Azov Seas through the Kerch Strait shows seasonal and interannual variability of its values. The maximum amplitudes of water exchange anomalies reach more than 4 km^3. The maximum values of water exchange anomalies were observed in 2000, 2003 and 2015. From 2001 to 2013, water exchange through the Kerch Strait decreased at a rate of 0.082±0.264 km^3.
A.G. Kostianoy was partially supported in the framework of the P.P. Shirshov Institute of Oceanology RAS budgetary financing (Project N FMWE-2024-0016).

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STILL IMPROVING THE ERS-1, ERS-2 AND ENVISAT ALTIMETER AND RADIOMETER HISTORICAL DATASETS: TOWARDS A NEW VERSION OF THE FDR4ALT PRODUCTS

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In the framework of the European Heritage Missions Program, aiming at generating innovative Earth system data records named Fundamental Data Records (basically level 1 altimeter and radiometer data) and Thematic Data Records (basically level 2+ geophysical products), the European Space Agency (ESA/ESRIN) launched a reprocessing activity of the ERS-1, ERS-2 and ENVISAT altimeter and radiometer datasets. A large consortium of thematic experts has been formed to take in charge these activities which are to 1) define thematic products including the long, harmonized record of uncertainty-quantified observations, 2) define the most appropriate level 1 and level 2 processing, 3) reprocess the whole times series according to the predefined processing and, 4) validate the different products and provide them to large communities of users focused on the observation of the atmosphere, ocean, coastal, hydrology, sea ice, ice sheet regions. The project reached its end in 2023 and the FDR4ALT products have been finalized and delivered to ESA. An overview of the available products has been presented in Puerto Rico at the 2023 OSTST, and the products will be made available to the public during the first semester of 2024. Following the paper related to the Sea-Ice TDP recently published (https://doi.org/10.5194/tc-17-3013-2023), several papers will be submitted in 2024 on the performance assessment of the Radiometry FDR, the Inland Waters TDP and the Land-Ice TDP.
Following the success of the FDR4ALT project, ESA decided to continue the project for an additional 3 years follow-on activity, in order to deliver a new version of the FDR4ALT products in 2026 by following the most recent recommendations and up-to-date algorithms, allowing the end users to continue the exploitation of this 21-years long time series that is extremely valuable for climate studies. Different technical activities are planned that should lead again to great improvements, such as an innovative relocation technique for Land-Ice, an up-to-date hydrological targets database for Inland Waters, investigations about the SSE correction linked to wave groups, new orbits for ERS-1/2, new wet tropospheric corrections (GPD+ and 1DVAR), updated geophysical corrections and new SSB solution for the Ocean & Coastal, investigations about ERS-2 data beyond the tape recorder failure … and a long list of other planned improvements.
The first part of this talk will remind the context and give a global overview of the FDR4ALT project and products. Then, this talk will focus on the follow-on activities, by introducing the new consortium and especially present in details the planned evolutions for the second version of the FDR4ALT products.

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ASSESSING THE ACCURACY OF SENTINEL-3A ALTIMETRY-BASED WATER LEVELS OF THE ODRA RIVER USING UAV PHOTOGRAMMETRY

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Aerial Imagery belongs to most important sources of data in the Earth sciences. Acquisition methods have changed significantly over last decade. Currently, in addition to satellite and traditional aerial photographs, also low-altitude images from unmanned aerial vehicles (UAV) are commonly used. The state-of-the-art of unmanned technologies allows for the installation of various sensors onboard UAVs, including highly specialized ones, but the most popular are still the visible light cameras (RGB). The usage of RGB images and photogrammetric products, as the reference data for other measurement methods, is extremely valuable, low-cost and easy to obtain.

In frame of the project no. 2020/38/E/ST10/00295 ("Forecasting water levels at ungauged river sections using satellite altimetric data"), financed by the National Science Centre of Poland, we tested various approaches to delineate the river coastline, and one of them was based only on low-altitude aerial photos taken by unmanned aerial vehicles (UAVs) with RGB camera. Subsequently, water levels were estimated based on the delineated coastline.

In many research fields the problem of water detection is extremely important. It can be successfully solved with the use of specialized sensors, such as multispectral or thermal cameras. However, these sensors are not as common as traditional RGB cameras. The problem of water detection on UAV-based RGB images or orthophotomozaic has not been fully solved yet. We tested several methods for detecting the boundary between water and land, using only RGB images. The detected lines were used to determine water levels at eight virtual stations (places, where the satellite passes the river) in the Odra river channel (western Poland). These data are the reference for water levels determined by altimetric measurements of the Sentinel-3A. The river coastlines, and thus water levels, were estimated based on close-range UAV data from 40 UAV field campaigns, carried out when Sentinel-3A overpassed virtual stations. Mapping with the use of UAV covered an area of approximately 2 x 0.5 km in the vicinity of each virtual station, including the area of ground track shifts. The measurements were conducted in various hydrological situations. Water levels on UAV-mapped sections of the channel were obtained by intersection of the delineated coastline with following digital elevation models (DEMs): (1) national, (2) UAV aerial images (close-range photogrammetry with the Structure-from-Motion algorithm), (3) UAV LiDAR based, (4) high-accuracy field surveying with total station and GNSS receiver. We compared water levels from UAV photogrammetric data with water stages from Sentinel-3A measurements. The preliminary verification of altimetric measurements of water levels, carried out at one of the eight virtual stations, has shown that the accuracy of altimetric measurements in relation to the reference, obtained from photogrammetric data, is of approximately 0.5 m.

The research is supported by the National Science Centre, Poland, through the project no. 2020/38/E/ST10/00295.

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THE CNES-CLS 2024 FREE AIR MARINE GRAVITY ANOMALY MODEL: A PRELIMINARY GLOBAL SOLUTION.

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The determination of this first global model of free air gravity anomalies follows the solution strategy applied in the 2022 calculation over the Mediterranean, which showed a level of accuracy similar to the two reference solutions, USCD and DTU.
This new model is based on Mean Profiles of the Exact Repeat Missions sampled at 1 Hz along track (T/P, J1, J2, J3, ERS-2, EnviSat, SARAL, GFO), and on high-resolution data that are provided by the Cryosat-2 (20 Hz) and SARAL (40 Hz) missions in the geodetic/drifting phase. A particularity of the colocation method implemented is that it allows for different types of uncertainties and cross-correlation functions. All these parameters are adjusted locally to improve the result.
A validation of this new solution based on a comparison with existing altimetry-inferred models (the most recent releases of the UCSD and DTU models), as well as with ship data, is presented.

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PRELIMINARY PERFORMANCE ASSESSMENT OF THE WATER SURFACE ELEVATION OF HR SWOT PRODUCTS BASED ON COMPARISONS WITH IN-SITU NETWORKS AND IN-FLIGHT NADIR ALTIMETRY MISSIONS

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The Surface Water and Ocean Topography (SWOT) mission, conducted by CNES and NASA was successfully launched on 16 December 2022. It provides unprecedented 2D observations of the sea-surface height and mesoscale structures as well as water surface elevation, water stock estimates and discharge over continental water surfaces. An interferometric SAR altimeter, the Ka-band Radar Interferometer (KaRIn), is designed to cover two 50-km cross-track swaths. In terms of repeat time, the SWOT mission has two main phases: the 7-month Calibration/Validation (Cal/Val) phase, during which daily measurements are provided over limited areas, and the nominal Science phase with its 21-day repeat cycle and global spatial coverage up to 78° latitude. Both mission phases are relevant for Cal/Val purposes.

The High Rate (HR) mode of KaRIn, dedicated to hydrology, provides several HR SWOT products. Their performance assessment is achieved through comparison with reference measurements. Although specific in-situ Cal/Val sites have been equipped for the validation of HR SWOT products over lakes and rivers, existing in-situ networks are essential, especially for statistical validation that requires a significant number of comparisons. As an extension of this, the use of measurements from current nadir altimetry missions (Sentinel-3A/B, Sentinel-6, ICESat-2, etc.) has also the potential to generate reference measurements over a large number of lakes and rivers, or to perform levelling of existing gauges.

Our analysis is part of the global assessment of the HR SWOT products during the Cal/Val and the first part of the Science phases. In particular, we address the use of ICESat-2 measurements to level in-situ water surface elevation measurements of lakes provided by the USGS (USA) and MELCCFP, Hydro-Québec, and ECCC (Canada) networks, comparing also with data from the BAFU network (Switzerland) that is already accurately levelled. Similar analysis is carried out over rivers based on the SCHAPI network (France). The use of measurements from nadir altimetry mission to include water bodies that are not monitored by in-situ networks will also be described. We will first focus on lakes and rivers, observed daily by SWOT during the Cal/Val phase to assess the performance of HR SWOT products for monitoring short timescale variation of the water surface elevation. In a second step, we will take advantage of the global spatial coverage of the SWOT mission during the Science phase for broader statistical analysis.

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ADDED VALUES OF GEODETIC DATASETS OF SATELLITE ALTIMETERS FOR INLAND WATER RESEARCH

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Satellite radar altimetry has attracted much attention in hydrology over the past two decades. Unlike imagery that quantifies the water dynamics from the horizontal dimension, altimetry observations deliver vertical information about water dynamics. With such information, hydrological changes and water resources can be estimated for inland water bodies. Compared with altimetry datasets of exact repeat missions, geodetic datasets such as CryoSat-2, SARAL/AltiKa, as well as the end-of-life phase of Jason-1/-2, were less used by the hydrology community, but contributed considerably to oceanographic and cryospheric studies. Spurred by the successes of oceanographic studies using geodetic altimetry datasets, this study aims to augment such data for hydrological research and to bring awareness to its potential applications.
We demonstrate the values of CryoSat-2, Saral/AltiKa, Jason-1 GM, and Jason-2 GM in terms of large-scale lake monitoring, retrieval of local geoid undulation over large lakes, as well as the construction of time series of river levels. The preliminary results show that geodetic datasets are more useful if lake dynamics at large scales is of interest instead of the detailed variations in a few certain lakes. The combined use of more geodetic datasets allows us to resolve much finer geoid undulations. Last but not least, with such datasets, we are able to retrieve time series of river levels at a higher temporal resolution that is better than the resolution of any of the four geodetic missions.
The findings of the current study will draw the attention of hydrologists and engineers to make use of such data for various purposes.

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INLAND WATER MONITORING USING CRYOSAT-2 DATA: ADVANTAGES AND LIMITATIONS

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Fresh water is an essential resource for both society and environment. The significant stress on this resource is constantly increasing. Monitoring inland water stocks is thus a political, environmental and economical challenge. The use of altimetry to measure surface water height is a well-established technique that has evolved over the past three decades. With the launch of CryoSat-2 in 2010, carrying the first Synthetic Aperture Radar (SAR) altimeter, an along-track sampling of 300 m has allowed accurate measurement of smaller targets, and the dense ground track sampling has allowed substantially more lakes and rivers to be monitored in comparison to repeat orbit missions.
Outside the altimetry community, hydrologists benefit from an along-track altimeter product, which is used to estimate river discharge and hydraulic modelling through data ingestion, parameter calibration and flow validation along the water course. Nevertheless, the current along-track products are not easy to use for non-expert users and require a detailed understanding of the altimetry system.
An activity called Cryo-TEMPO (CryoSat-2 ThEMatic PrOducts) was launched by ESA to better exploit the CryoSat-2 measurements. The overarching aim of Cryo-

TEMPO is to develop agile, robust and state-of-the-art CryoSat-2 products, which are dedicated to specific Thematic Areas, and which are accessible to – and can easily be used by – a broad range of scientific and service users, beyond the traditional altimetry experts. To achieve this aim, the main technical objectives of the study are as follows:
- To implement dedicated, state-of-the-art processing algorithms over each thematic domain.
- To develop agile, adaptable processing workflows, that are capable of rapid evolution and processing at high cadence.
- To create products that are driven by, and aligned with, user needs; thereby opening up the data to new communities of non-altimetry experts.
- To deliver transparent, traceable uncertainties associated with each thematic parameter.
Thus, as part of the ESA Cryo-TEMPO Project, the inland water Thematic Data Product (TDP) is designed to be a state-of-the-art Geophysical level (L2-type) product for users outside the altimetry community and it will include water levels based on the most appropriate retracker. In this poster, we present the retrackers that will be analysed (MLE4, OCOG, TFMRA, SAMOSA+) over different water bodies such as rivers and lakes of different sizes and environments during a 10-year period and considering the three different acquisition modes of the CryoSat-2 radar instrument (LRM, SAR and SARin). Results of the validation phase are also presented referring to the comparison against ground recorded water level for some stations over rivers and lakes.

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MEAN SEA SURFACE STATE OF THE ART OVER THE LAST 30 YEARS.

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The Mean Sea Surface is by definition the steady state of the ocean over an arbitrary period which is used as a reference field for altimeters calibration and for oceanographic and geophysical studies. Determining the MSS is multiple challenging, goal is to provide the best compromise between the removal of seasonal and interannual ocean variability and an accurate mapping of the shortest wavelengths of the topographic structures. The first component is theoretically available only from repetitive missions (T/P, ERS-2, Jason-1/2/3, EnviSat, SARAL, and Sentinel-3A/B) whereas until SWOT, the finest structures smaller than 20 km were only available from geodetic or drifting phases such as Cryosat-2 and SARAL, sampled at 20 Hz and 40 Hz respectively. An overview of the evolution of the precision and of the spatial resolution of the MSS is proposed, from the late of the 1990s to the most recent models.

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ASSESSING THE PERFORMANCE OF SWOT ALTIMETRY AGAINST TIDE GAUGE OBSERVATIONS IN THE WESTERN MEDITERRANEAN SEA

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The coastal region of the Western Mediterranean Sea exhibits particular oceanographic features influenced by its semi-enclosed nature, complex bathymetry, and circulation patterns of the basin characterized by the presence of energetic mesoscale structures. As a result, the region is equipped with a network of tide gauges provided by the Copernicus Marine Service In Situ Thematic Centre (INS-TAC) that ensures a robust dataset providing continuous water level observations that are crucial for assessing coastal hazards and sea level changes. This dataset can be also used to validate altimeter Sea Level Anomalies (SLA) in the coastal zone. Thus, this is an optimal region to (i) validate the capabilities of KaRIn swath and nadir altimeter data, which offers unprecedented 2D maps of water levels, and (ii) to assess SWOT data quality in the coastal and nearshore environments of the Western Mediterranean.

In this context, this study aims to conduct a comparison between the Level-3 (L3) high-resolution SLA retrieved by the SWOT mission and Sea Surface Height (SSH) from 21 tide gauges located along the Western Mediterranean coasts during the 90-day daily Cal/Val mission phase, spanning from April to July 2023. To have SSH measurements closer to SLA from the SWOT mission, the atmospherically induced sea level changes due to atmospheric pressure and wind were removed from the tide gauge residuals after subtracting the tidal signal. In addition, the capabilities of the SWOT nadir altimeter are assessed through the comparison with other altimeter missions in the region (e.g., Cryosat-2, SARAL/AltiKa, Jason-3 and Sentinel-3 series). Preliminary results indicate strong correlations and low RMSD, demonstrating the effectiveness of the SWOT mission in capturing sea level anomalies in coastal regions.

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THE EOLIS DATASET: MONITORING LAND ICE FROM CRYOSAT-2 SWATH PROCESSING

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Satellite radar altimetry has been routinely used to monitor land ice heights since the 1990s. However, the launch of CryoSat-2 - the first altimetry mission to carry a synthetic aperture radar interferometer on board - has allowed several technical breakthroughs and led to many new applications that were previously unforeseen. One such breakthrough is Swath processing of CryoSat's SARIn mode, making full exploitation of the information contained in CryoSat's waveforms and leading to one to two orders of magnitude more measurements than the conventional so-called Point-Of-Closest-Approach (POCA) technique.
Following on from the early demonstration of the technique and of its potential impact, the CryoTEMPO EOLIS (Elevation Over Land Ice From Swath) dataset now routinely provides information of elevation over land ice at high resolution on a monthly basis. The dataset allows the use of radar altimetry in new environments such as the more complex terrain over glaciers and ice caps, as well as new applications thanks to the superior spatial and temporal resolution, such as the more precise quantification of subglacial lake drainage events. Currently, the EOLIS dataset is provided at monthly intervals over both ice sheets as well as all larger glacier regions, with future developments such as the expansion of the dataset to the ice shelves and new gapless annual DEMs over the two ice sheets coming soon.
With the aim of making CryoSat-2 altimetry data available to non-altimetry experts and encouraging its use more broadly by the community, the platform CS2EO (cs2eo.org) provides advanced data access to the EOLIS suite datasets. In CS2EO, users can query coincident data with other altimetry sensors, as well as explore and download custom elevation change time series over desired areas on ice sheets and glaciers, without having to download the EOLIS data first.

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A FACET-BASED NUMERICAL MODEL TO RETRIEVE ICE SHEET TOPOGRAPHY FROM SENTINEL-3 ALTIMETRY

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Sentinel-3 is an Earth observation satellite series part of the Copernicus program. The mission provides operational topography measurements of the cryosphere since the launch of Sentinel-3A in 2016. In this study we present a facet-based model simulating the Sentinel-3 UnFocused-Synthetic Aperture Radar (UF-SAR) waveforms. To this end, the backscatter radar signal is calculated over the 10 m facets of the Reference Elevation Model of Antarctica (REMA). A dedicated level-2 processing was developed, taking advantage of the numerical modelling to geolocate the Sentinel-3 altimetry measurements in the radar footprint. The end-to-end software, named the "Altimeter data Modelling and Processing for Land Ice" (AMPLI), provides topography estimations posted at ~330 m along the satellite track.

Sentinel-3A and Sentinel-3B acquisitions made over the Antarctic ice sheet in 2019 and 2022 were processed with the AMPLI software. Using ICESat-2 as a reference mission, we demonstrate that AMPLI provides significant performances improvements in comparison to surface height measurements delivered in the ESA Land Ice Thematic Products. In terms of elevation precision, there is more than a factor 10 improvement over the ice sheet margins, where surface slope exceeds 0.5°. In terms of elevation accuracy, the median bias between Sentinel-3 and ICESat-2 ATL06 remains on average below 50 cm over the whole ice sheet. While with the ESA Land Ice Thematic Products it can reach several meters. We finally assess the capability of Sentinel-3 to monitor Surface Elevation Change (SEC) over the Antarctic ice sheet. The comparison between 2019-2022 SEC maps from Sentinel-3 AMPLI and ICESat-2 ATL15 shows a Pearson correlation of 0.92. Future processing improvements will focus on correcting the snow volume scattering effect, which biases the Sentinel-3 ice sheet elevation at the decimetre scale.

The study highlights the benefit of radar signal modelling, in synergy with high resolution Digital Elevation Model (DEM), for improving the measurement geolocation over ice sheet. The results emphasize the potential of the Sentinel-3 constellation for ice sheet mass balance studies. Complete time series of Sentinel-3A and Sentinel-3B AMPLI "Demonstration Products" are planned to be publicly released by ESA and CNES in Q3-Q4 2024.

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COASTAL HYDROLOGY SUPPORTED BY SATELLITE ALTIMETRY RADAR (CRYOSAT-2)

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This work analyses the capability of the European Space Agency's CryoSat-2 (CS2) satellite (operating in SAR mode) to measure the sea level elevation associated with coastal bulge-like lenses of water from river discharges. We analyse four events of high river freshwater discharges in two river estuaries in Spain: Guadalquivir and Ebro. The orbit configuration of CS2 (non-sun-synchronous with high inclination) provides dense coverage of tracks in the study areas, improving the revisiting time during periods of high river discharges. We estimate the along-track Absolute Dynamic Topography (ADT) during these events and compare them with periods of low discharge conditions. We observe that, during high river discharges, the associated less-salty water bulges increase the sea level between 5 and 10 cm with respect to the sea level observed under low/normal discharge conditions. The lens spreads out far from the estuary mouth (more than 25 km off the coast in the case of the Guadalquivir River and about 50 km for the Ebro River). In addition, auxiliary materials including Red-Green-Blue optical images from MODIS satellites, model-based IBI-ADT/surface circulation, and ERA5-wind model are used to support the observations made by the satellite altimeter in the coastal zones close to river estuaries during strong river freshwater discharges. We analyse the effect of the wind regime and the surface circulation modifying the properties of the bulge-like lens in terms of sea level and plume extension.

This contribution discusses how more accurate fine-resolution sea levels estimated from satellite altimeters might help in understanding interactions between river outflow waters and shelf waters, and in determining the fate and transport of materials associated with river discharges. We also conclude that more efforts are still needed to improve the quality of satellite altimeter data in coastal waters significantly close to the estuary mouths. This could enhance the characterisation of high freshwater discharge events close to the coast and in surrounding waters affected by the spread of lower salinity river waters.

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USE OF ALTIMETER DATA IN A COUPLED DATA ASSIMILATION SYSTEM

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Altimeter information is currently used in ocean data assimilation (DA) system as sea level anomalies (SLA). These anomalies are subject to several geophysical corrections, including one related to the atmospheric delay. The atmospheric delay correction is similar to the ground-based GPS Zenith Total Delay (ZTD) measurements, which are assimilated in atmospheric DA systems and provide column integrated water vapour information.

Recent developments in coupled DA, linking the ocean and atmospheric DA components more closely, suggest the assimilation of quantities coming from instruments that are sensitive to both earth system components. Altimeters are such instruments.

The main idea of this work is to explore the potential of advancing the use of altimeters in a coupled DA system and in particular advance the use of altimeters for Near Real Time applications for Numerical Weather and Ocean Predictions. This is implemented by assimilating a new quantity derived from altimeter range (without atmospheric delay correction) which is sensitive to both the sea surface height above the geoid (SSH) and the atmospheric delay. This quantity, called here the sea surface to satellite delay (S3D), is equal to ZTD minus SSH and is being assimilated in the atmospheric 4D-Var. To do that, SSH is incorporated and estimated in the atmospheric 4D-Var system as an extended control variable.

Preliminary results show that by assimilating S3D, the SSH analysis is more consistent with the CMEMS daily mean analysis by about 1 cm, compared to the ocean forecast SSH background field. The next, currently on-going step is to strengthen the coupling/communication between the two DA systems and feed the outcome of the S3D assimilation back in the Ocean DA system.

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IMPROVING SAR ALTIMETER PROCESSING OVER THE COASTAL ZONE, THROUGH IMPLEMENTATION OF INNOVATIVE PROCESSING ALGORITHMS AND ASSESSMENT OF A NEW COASTAL ZONE DATA SET. RESULTS FROM THE ESA HYDROCOASTAL PROJECT

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The objectives of the HYDROCOASTAL project, funded by the European Space Agency under the EO Science for Society programme, were to enhance our understanding of interactions between the inland water and coastal zone, between the coastal zone and the open ocean, and the small scale processes that govern these interactions. The project also aimed to improve our capability to characterize the variation at different time scales of inland water storage, exchanges with the ocean and the impact on regional sea-level changes.

To achieve these aims, the HYDROCOASTAL project team has developed and implemented new SAR altimeter processing algorithms for the coastal zone and inland waters, and with these processed Sentinel 3A, 3B and Cryosat-2 data to generate an initial 2-year Test Data Set for selected regions. The performance of these new algorithms has been evaluated, by statistical analyses and comparison against in situ data. From this analysis, the best performing algorithms were identified and a processing scheme implemented to generate a global scale coastal zone and inland water altimeter data set, over 24 regions. The source data were Sentinel 3A and Sentinel 3B SRAL L1a data, for all the operational mission to 30/09/2022 (S3A from 01/04/2016 to 30/09/2022, S3B from 11/05/2018 to 30/09/2022) and Cryosat-2 SAR mode FBR data, for all the operational mission available in Baseline D (from 06/09/2010 to

21/08/2021). U Porto have provided new dry and GPD+ wet troposphere corrections, and these have been merged with the final products.

The University of Bonn STARS re-tracker and the DTU MWaPP (Mult-waveform Persistent Peak) re-tracker were selected and implemented to generate Level 2 along track data for the coastal and estuary regions. The DTU re-tracker was implemented to provide continuity with the HYDROCOASTAL inland water level data sets.

A series of case studies were implemented to assess these products in terms of their scientific impact in the coastal zone. These studies included: The Severn Estuary; Baltic, German Bight and Elbe Estuary; Northern Adriatic Sea; Saline Intrusion in the Ebro delta; Data Assimilation Study in the Southern North Sea.

All the produced data sets are available on request to external researchers, and full descriptions of the processing algorithms available via the project web-site (https://www.satoc.eu/projects/hydrocoastal/).

We will provide a short introduction to the project, before presenting the results from the coastal zone impact assessment case studies, and key recommendations for future implementation in SAR altimeter processing.

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IMPROVING INLAND WATER ALTIMETRY BASED ON ANALYZING DUAL-FREQUENCY ALTIMETER WAVEFORM DATA

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Satellite altimetry has revolutionized our understanding of inland water due to its frequent sampling and global coverage. However, its application in inland water is limited by interference from land and calm water within the altimeter and radiometer footprint. Various dedicated retracking solutions have been proposed and tested in recent years to mitigate the influence of altimeter footprint contamination. Nevertheless, effectively separating the water body components of the waveform remains challenging.

In this study, we conduct a systematic analysis comparing Ku-band and C-band waveforms from Jason-1, Jason-2, and Jason-3 radar altimeters in inland water. Due to the differing backscatter coefficients of water bodies and land for different radar frequencies within altimeter footprints, dual-frequency waveforms exhibit high correlation in inland water bodies. As the distance from the shore decreases, contamination of waveforms by land increases, resulting in significant disparities in the correlation between waveforms of Ku- and C-band. Based on this analysis, we propose establishing a model to fit the relationship between dual-frequency waveforms. By analyzing the relationship between dual-frequency waveforms of water bodies, we are able to distinguish segments containing water and non-water components. The classical open ocean Brown model is then modeled using the least squares method to characterize it. Different weights are allocated to the water and non-water components to reduce contamination from non-water body land in waveform retracking.

We evaluate our method on a limited number of lakes and reservoirs and validate the results against in situ water level data. Our results demonstrate that our method has the potential to reduce the influence of footprint contamination and improve the accuracy of water level estimation.

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IMPROVING SAR ALTIMETER PROCESSING OVER INLAND WATER, THROUGH IMPLEMENTATION OF INNOVATIVE PROCESSING ALGORITHMS AND ASSESSMENT OF A NEW INLAND WATER DATA SET. RESULTS FROM THE ESA HYDROCOASTAL PROJECT

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The objectives of the HYDROCOASTAL project, funded by the European Space Agency under the EO Science for Society programme, were to enhance our understanding of interactions between the inland water and coastal zone, between the coastal zone and the open ocean, and the small scale processes that govern these interactions. The project also aimed to improve our capability to characterize the variation at different time scales of inland water storage, exchanges with the ocean and the impact on regional sea-level changes.

To achieve these aims, the HYDROCOASTAL project team has developed and implemented new SAR altimeter processing algorithms for the coastal zone and inland waters, and with these processed Sentinel 3A, 3B and Cryosat-2 data to generate an initial 2-year Test Data Set for selected regions. The performance of these new algorithms has been evaluated, by statistical analyses and comparison against in situ data. From this analysis, the best performing algorithms were identified and a processing scheme implemented to generate a global scale coastal zone and inland water altimeter data set, over 24 regions. The source data were Sentinel 3A and Sentinel 3B SRAL L1a data, for all the operational mission to 30/09/2022 (S3A from 01/04/2016 to 30/09/2022, S3B from 11/05/2018 to 30/09/2022) and Cryosat-2 SAR mode FBR data, for all the operational mission available in Baseline D (from 06/09/2010 to

21/08/2021). U Porto have provided new dry and GPD+ wet troposphere corrections, and these have been merged with the final products

The DTU MWaPP (Mult-waveform Persistent Peak) re-tracker was selected and implemented to generate Level 2 along track data for the inland water regions, and from these data, Level 3 water level time series were generated by different schemes implemented by DTU and AltiHydroLab. Finally Level 4 River Discharge time series were generated for a subset of the inland water regions by CNR-IRPI and NUIM.

A series of case studies were implemented to assess these products in terms of their scientific impact on inland waters. These studies included: The Rhine River and Lake Constance; Discharge validation and the River Po outlet; Lake size and riverbank configuration study, Republic of Ireland; A hydraulic model of the Amur River informed with ICESat-2 elevation.

All the produced data sets are available on request to external researchers, and full descriptions of the processing algorithms available via the project web-site (https://www.satoc.eu/projects/hydrocoastal/).

We will provide a short introduction to the project, before presenting the results from the inland water impact assessment case studies, and key recommendations for future implementation in SAR altimeter processing.

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CRYOSAT MISSION: 14 YEARS OF CALVAL AND SCIENCE FOR EARTH'S CRYOSPHERE—AND MORE

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Launched in 2010, the European Space Agency's (ESA) CryoSat mission was the first polar-orbiting satellite flying a SAR Interferometric altimeter dedicated to the cryosphere, with the objectives to monitor precise changes in the thickness of polar ice sheets and floating sea ice. After 14 years in orbit, CryoSat remains one of the most innovative radar altimeters in space and continues to deliver high-quality data, providing unique contributions to several Earth Science and application domains. The mission is funded to be operated until the end of 2025 with the scope to achieve important scientific objectives and to extend the synergy with other missions by further strengthening international cooperation.

Routine CalVal activities are fundamental to evaluate the accuracy of CryoSat measurements, to monitor the long-term stability of the altimeter, and to characterise uncertainties on the final geophysical retrievals. Here, we present the CryoSat mission status and show results from several CalVal activities currently in place, e.g., acquisition over transponders, comparison of sea level at tide gauges and exploitation of data collected during polar field campaigns. We then provide an overview of the ever-growing CryoSat data portfolio, with a special focus on the state-of-the-art thematic data products, so-called "Cryo-TEMPO", enabling the full scientific and operational exploitation of CryoSat data.

We discuss the importance of international cooperation in CalVal and Science activities from the perspective of the ESA-NASA CRYO2ICE campaign, aligning CryoSat orbit to the one of ICESat-2, and the Sea Ice Thickness Intercomparison Exercise (SIN'XS) project, aiming to provide reconciled sea ice thickness estimates in both hemispheres. Finally, we discuss how current and future CryoSat activities are crucial to prepare for the upcoming Copernicus CRISTAL mission which will provide coincident measurements at Ka and Ku bands.

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COASTAL ALTIMETRY PRODUCTS: FROM HISTORICAL 1 HZ ALONG-TRACK DATA TO VIRTUAL TIDE GAUGES

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The Center of Topography of the Oceans and the Hydrosphere (CTOH) has been involved in major advances in coastal altimetry and to its coastal applications. One of its contributions has been the development of the X-TRACK processing software (developed in collaboration with LEGOS), dedicated to improving the quality and coverage of altimetry data in coastal regions. X-TRACK has now evolved into a mature product distributed worldwide by AVISO+ (https://www.aviso.altimetry.fr) and which has been used in many scientific publications. It provides long time-series of sea level anomalies (SLA) along the tracks of many altimetry missions, processed homogeneously, and also empirical tidal constants derived from these series, offering valuable data for regional/coastal ocean analysis, tidal studies, and model validation.

A new stage in bringing altimetry data closer to the coastline has been completed at CTOH/LEGOS with the ESA Climate Change Initiative Sea Level project. in close collaboration ESA, TUM, CLS, NOC and SKYMAT. By combining the Adaptive Leading Edge Subwaveform (ALES) Retracker and the X-TRACK software for the first time, 19.5 years of sea level anomaly data (Jan. 2002 to Jun 2021) from the Jason missions have been reprocessed at a high frequency level (20 Hz). This has led to the development of a new coastal sea level product called X-TRACK/ALES, which significantly extends the spatial coverage of sea level altimetry data in the coastal direction, now reaching a distance of 1.2-4 km from the coast on average (Birol et al., 2021). This is an unprecedented coastal coverage for any long-term altimetry data set, and a significant contribution to the coastal research community.

Based on this dataset, a network of virtual altimetry-based stations has also been derived within a 20 km coastal zone, providing new information on how long-term sea level trends change as it approaches land (see Cazenave et al 2002).

Following the same approach of Cazenave et al 2002, the concept of virtual tide gauge, already used for continental hydrology, has been derived. It corresponds to the 20Hz altimetry measurement points closest to the coast, averaged to construct a single point of SLA time series at each intersection between one altimetry track and the coastline. This work reveals the significant contribution that we can expect from altimetry in terms of coastal sea level monitoring in all the regions with little or no tide gauge observations.

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SEA LEVEL RISE FROM ALTIMETRY: CLIMATE BELLWETHER AND IMPLICATIONS FOR FUTURE MISSIONS

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The era of precise satellite altimetry is generally regarded to start with the launch of TOPEX/Poseidon in 1992. Since then, a continuous series of missions, Jason-1, -2, -3 and Sentinel-6 Michael Freilich have been monitoring global and regional mean sea level from what is called the "altimetry reference orbit" at 1336 km and with a 66º inclination. Many consecutive improvements in satellite instrumentation, satellite design, as well as to the precise orbit determination systems on-board contributed to an increasing accuracy and precision. By flying the successive missions in tandem with a separation of 30 seconds to 30 minutes, it was possible to cross-calibrate those missions to within a few millimeters or better, thus ensuring the long-term stability of the now 32 years record.

Other external factors have also contributed to the continued success of the altimetric sea level record. The ever increasing precision and accuracy of the atmospheric and other geophysical modelling, and the availability and maintenance of a number of tide gauges against which any drift of the altimetric sea level measurements can become evident.

But the most overlooked source of critical validation of the reference missions as well as contributors to the long-term record have been nine other missions that have operated during the same time from a much lower altitude (ERS-1, ERS-2, Envisat, GFO, CryoSat-2, SARAL/AltiKa, Sentinel-3A and -3B, and SWOT), generally in Low Earth high inclination sun-synchronous orbits, conditions that were widely thought to prohibit an accurate retrieval of global mean sea level.

During the course of time, technologies, background models, and orbit determination have evolved. For example, on the reference orbit, Sentinel-6 makes the transition to High Resolution altimetry that is intrinsically more precise, while also providing continuity Low Resolution measurements on the reference orbit. Sentinel-3 also introduced global High Resolution altimetry on the polar orbit and deviating slightly from the previous polar orbits of the ERS/Envisat/SARAL heritage.

That poses the following questions:

- How well can we currently determine sea level rise and its acceleration?
- Is there a distinction between the reference and polar altimeters?
- How relevant is the selection of the orbit for the continuation of the sea level record?
- What does this all mean to the design of the Next Generation altimeter missions?

This presentation makes a statistical analysis and highlights the results of the altimetric sea level rise measurements, summarises some of the essentials to their success and discusses the way forward to maintain this record for the next decades with the Sentinel-3 Next Generation Topography Mission and Sentinel-6 Next Generation.

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SWOT VALIDATION IN THE WESTERN MEDITERRANEAN SEA WITH HIGH-RESOLUTION OBSERVATIONS AND MODELLING DURING THE FAST-SWOT FIELD CAMPAIGNS

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The FaSt-SWOT field campaigns sampled the western SWOT pass in the western Mediterranean cross-over region of the fast-sampling phase. Two campaigns took place between 25-28 April and 7-10 May 2023, with the aim of collecting multi-platform in-situ observations of meso- and submesoscale ocean structures in the area covered by the SWOT satellite during its initial fast-sampling phase. The data collected during the campaigns included both using multi-scale ship-based instruments (CTD, Moving Vessel Profiler, thermosalinograph, ADCP and GoPros), autonomous platforms (surface drifters and gliders), and satellite observations (SST, ocean colour and altimetry). This data was complemented with a model simulation at a spatial resolution of 2 km and including data assimilation, providing another view of the fine-scale surface dynamics.

The sampling first focused on a small (~20 km in diameter) anticyclonic eddy detected under the swath of the satellite thanks to satellite imagery and drifter trajectories. Several cross-sections of the ship-based instruments, namely the Moving Vessel Profiler, and underwater gliders provided insights into the structure of temperature and salinity fields and the associated signals in chlorophyll and dissolved oxygen. This allowed the comparison of the in-situ measurements with the observation of this small-scale eddy by SWOT. Two gliders were programmed to perform back-and-forth sections during a 3-week time with a 1-day delay between them. This gives us the opportunity to evaluate the temporal variability of the ocean fields at the same frequency as SWOT's fast-sampling phase repeat cycle time. The second campaign started 9 days after the end of the first one. A 48-hour dense radiator-like pattern was performed by R/V SOCIB, allowing to characterize the evolution of the small eddy observed during the first leg. 45 surface drifters were deployed during the two phases to evaluate in-situ surface currents and their associated convergence and divergence in the vicinity of the eddy. This dataset brings further insights into the observability of fine-scale structures by SWOT. While conventional altimetry was not able to properly represent the sea level signature of the observed eddy, initial SWOT measurements indicate an improved detection capability by the new satellite. In addition, high-resolution numerical simulations reproduce a small anticyclonic eddy with similar characteristics as that of the observed eddy. These simulations are used to provide a more general understanding of the situation, and helps us to evaluate SWOT observations before/after the field campaigns.

We provide here an overview of the whole FaSt-SWOT dataset, including both observing and modelling components, and a multi-platform perspective to the validation and comparison of the SWOT fast-sampling observations with in-situ, remote sensing and modelling efforts in the region, at the ocean surface. The data obtained during the FaSt-SWOT project, in addition to helping with SWOT's cal/val activities, will help to improve the characterization and understanding of the fine-scale dynamics, thanks to the combination of in-situ multi-platform and satellite data with high-resolution numerical models.

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SARMAT: SAR ALTIMETRY MATLAB SOFTWARE PACKAGE FOR LEVEL 1 AND LEVEL 2 PROCESSING

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SARMat provides a user-friendly graphical environment to catch and work with satellite altimetry data and delve into intermediate steps in L1B and L2 processing. The software is open source and the codes are developed in Matlab.
A key feature is the Level 1-A to Level 1-B processing pipeline in SARMat. SARMat employs Unfocused and Fully-Focused SAR techniques to generate waveforms and radargrams. The package also incorporates Level 2 processing, with the current version (V1.0) implementing the OCOG retracking method, SAMOSA retrackers, and the recently developed algorithm by GIS the so-called Bin-Space-Time (BiST) retracking method.
SARMat is an easy-to-use application that gives you the power to: directly download satellite datasets from the available FTPs and data hubs, select specific regions of interest for subsequent analysis, explore files, allow users to crop data to desired boundaries, and facilitate efficient handling of large datasets.
SARMat facilitates analysis and visualization of results upon processing through built-in plotting tools. The generated data is saved with system time tagging, ensuring traceability and organization for subsequent analyses.
SARMat aims to contribute to the accessibility and understanding of SAR altimetry data processing techniques. The software's modular design allows for future expansion and the incorporation of additional retracking methods, fostering collaboration and advancement within the altimetry research community.

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INLAND WATER EXTENT MEASUREMENTS FOR THE CRISTAL MISSION

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The CLEV2ER LI+IW (CRISTAL LEVel-2 procEssor prototype and R&D - Land Ice and Inland Water) aims at developing, implementing, and supporting the evolution of the CRISTAL Level-2 product and algorithms, which are associated with the thematic Ground Processor Prototypes (GPP's) over Land Ice and Inland Water surfaces. Within this framework, one of the objectives is to study the potential and exploit the development of valuable FF-SAR applications [1] to estimate inland water bodies extent using FF-SAR waveforms. We have chosen to utilise Sentinel-6 data, acquired in open-burst mode (and thus minimising the impact of secondary lobes effects) in order to better assess the applicability and benefits of such method.
Fully-Focussed SAR (FF-SAR) algorithm allows the focusing of whole target observation echoes in a fully coherent way, achieving improvement of the along-track resolution down to the theoretical limit and

statistically reduction of waveforms contamination, facilitating the estimation of water bodies extent. Within this scope, the study introduces the methodology for geo-referencing and estimating the size of inland water bodies, such as reservoirs or lakes, located on unambiguous across-track targets, using Fully-Focussed SAR (FF-SAR) processed altimetry data. Indeed, a FF-SAR Ground Prototype Processor (GPP), developed by isardSAT and based on the backprojection algorithm, has been used to generate FF-SAR radargrams of off-nadir inland targets located within certain observation constraints. Cloud coverage does not have an impact on the measurements as radar signals can penetrate clouds without being altered, allowing for consistent and continuous data collection. Post-processing techniques were then implemented to enhance the contrast between water and non-water pixels before classification. The filtered FF-SAR radargrams were segmented using unsupervised techniques, such as K-means clustering, to classify pixels based on shape or intensity similarities and extract the corresponding water regions. Subsequently, the obtained water pixels were projected onto the ground to estimate the total extent of the water bodies.
The performance of the technique was evaluated through a validation process, which involved comparing the FF-SAR water extent measurements derived from Sentinel-6 data against optical measurements from Sentinel-2 as well as in-situ observations. The results demonstrate the capability of the method to estimate the size and spatial distribution of inland water bodies, making it ideal for monitoring water targets with substantial seasonal extension variability.

[1] A. Egido and W. H. F. Smith, 'Fully Focused SAR Altimetry: Theory and Applications', IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 1, 2017, doi: 10.1109/TGRS.2016.2607122.

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FAULT TOLERANT APPROACH TO REGENERATE LEVEL 1B SAR ALTIMETRY WAVEFORMS FOR ENHANCING LEVEL 2 RETRACKERS PERFORMANCE

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This study deals with identifying and retrieving anomalous waveforms generated in the Level 1B processing chain of satellite altimetry over coastal areas and inland water bodies. Efficient identification of anomalous waveforms greatly improves the retracking performance, leading to the generation of precise water level time series that serve as vital inputs for hydrological studies. Abnormal behaviour in waveforms may be an indication of environmental changes, instrument malfunctions, or other critical factors. To find abnormal waveforms, our framework utilizes an unsupervised machine learning technique. We categorise different parameters of the satellite's altimeter like AGC parameter, tracker range, and features related to the shape of waveforms for instance waveform's skewness, number and location of peaks, and so on for each sample in the dataset. Then we identify abnormal waveforms using a two-step density distribution probability analysis.
The secondary purpose of this study is to propose a robust strategy to retrieve abnormal waveforms in the level 1B SAR processing chain. This step is vital for narrow rivers and small inland water bodies, in which a low number of measurements on related cycles cause missing water level variation. In contrast to previous studies focusing solely on investigating L2 waveforms to determine precise retracking gates for multipeak and noisy waveforms, we propose an additional step in the L1B processing chain, specifically tailored to coastal and inland waters, enabling the retrieval of abnormal waveforms. In both fully focused and unfocused SAR processing, the final waveform is formed through the combination of various beam looks from the altimeter during fixed illumination time in stacks to the desired point on the surface, certain looks in the stack may exhibit undesirable patterns due to variations in environmental characterization, antenna footprint, and sidelobe gain. The proposed methods will mitigate the presence of undesirable waveforms in the stack before generating the final waveforms.
We applied the proposed methodology for Sentinel 3-A, 3-B and Sentinel 6-MF datasets over different inland waters and validated our results against in-situ data. The results demonstrate that the water level time series, obtained by regenerated waveforms have significantly improved. The results show the potential of our proposed framework for detecting and retrieving anomalous waveforms leading to robust water level estimates from satellite altimetry data.

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CHANGES IN WATER LEVELS, EXTENT AND STORAGE OF THE TITICACA LAKE USING SWOT DATA

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Lakes are considered as sentinels of climate change. Water stored in lake is an important component of the land water cycle. Earth Observations offer a unique tool to monitor lakes extent, water levels variations, and hence changes in water volume combining these two variables or one of them with lakes bathymetry. Lake Titicaca, the second largest lake in South America with an area of 197,000 km², located in a high semi-arid plateau between Peru and Bolivia, has been experiencing an ENSO-related drought of an exceptional intensity starting in 2023. In this study, SWOT data (i.e., surface water levels, extent and storage anomalies) will be evaluated against in-situ (i.e., water levels, bathymetry filled with water levels) and other sateliite data (i.e., water levels from LRM and SAR altimeters, surface water extent from Sentinel-1 and 2 and MODIS, surface water anomalies derived from the combination of surface water extent and levels). Current drought intensity will be compared to the previously experienced ones observed during the Earth Observation period (e.g., the 1997-1998 ENSO). For instance, a minimum water level of 3,808.7 m was recorded in November 2023 using radar altimetry measurements compared to the previous minimum of 3,808.9 m derived from radar altimetry in December 1996.

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A BOTTOM-UP METROLOGICAL UNCERTAINTY ASSESSMENT OF SEA ICE THICKNESS MEASUREMENTS FROM SATELLITE AND NON-SATELLITE SYSTEMS

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The Committee on Earth Observation Satellites (CEOS)-endorsed Quality Assurance Framework for Earth Observation (QA4EO) encourages a metrological uncertainty assessment for satellite-derived data products. ESA has led the way in applying formal metrological uncertainty analysis to observational data through its 'fundamental data record' (FDR) and 'fiducial reference measurement' (FRM) programmes. Initially established for passive sensors, these methods have more recently been applied to radar altimetry data products in projects such as FDR4ALT, St3TART and ASELSU.

Here, we describe a bottom-up metrological uncertainty assessment of sea ice thickness products developed within the FDR4ALT and St3TART projects. Our analysis encompasses both the satellite radar altimeter data series and the FRMs used during the calibration and validation of satellite products. Sea ice thickness poses many unique challenges, including its dynamic movement, non-homogeneity and the intricate conversion process from the measured parameter (such as Ku-band radar freeboard) to the desired quantity (sea ice thickness). This conversion relies on numerous assumptions and approximations related to, for example, ice densities, snow thickness and radar penetration through snow layers.

Despite these inherent difficulties, our systematic application of the '5-steps to an uncertainty budget' methodology, with its tools such as the 'uncertainty tree diagram', has yielded valuable insights. Additionally, the uncertainty tree diagram has provided a structure for conducting a thorough literature review of the methodologies and information available on these auxiliary parameters used in the conversion to ice thickness. Furthermore, our comparative study between Monte Carlo and the law of propagation of uncertainty approaches to uncertainty assessment, has shed light on effectively assessing uncertainties within this highly sensitive system.

In this presentation, we will present the scientific findings, including the uncertainty assessment and results from our quantitative studies involving various satellite data records and FRMs. Additionally, and as a reflection from these early experiences of integrating metrological uncertainty assessment into sea ice thickness estimates, we will summarise the practical experiences, building on insights from our own work, and from the outcomes of a workshop organised by the Sea Ice Intercomparison Exercise (SIN'XS) project. That workshop provided a forum for diverse perspectives on the application of metrological methods, ranging from enthusiastic support to scepticism. In this presentation we reflect on that breadth of viewpoints and provide our conclusions on how metrological approaches can benefit the assessment of historical data sets and the preparation for future missions.

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THE JASON-3 ERROR BUDGET PERFORMANCE

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From TOPEX/Poseidon to Sentinel-6 MF, a long record of high-precision ocean altimetry data has been acquired over the same historical ground track. From 2016 to 2022, Jason-3 was the reference mission orbiting this ground track before giving up its role to Sentinel-6 MF. Nowadays, it keeps orbiting and contributing to the better understanding of the ocean, while before then its instrumental stability has allowed the accurate calibration of Sentinel-6 MF during their tandem phase (another one is planned to prepare the future missions).
Thanks to the CNES SALP (Système d'Altimétrie et Localisation Précise) project, CLS has provided the long-term monitoring of the various Jason altimetric missions on the CNES behalf. This activity provides an assessment of the missions' performances for oceanic applications such as climate studies.In particular, as TOPEX/Jason/Sentinel-6 have all been reference missions used in operational applications and in delayed time studies (especially for the Global Mean Sea Level monitoring), the main focus of this activity has been the long-term stability of their Global Mean Sea Level (GMSL).
To ensure the most reliable content to all scientists involved in climate change studies as well as operational oceanography, it is essential to precisely observe Jason-3 data quality and errors. This characterization is necessary to evaluate the impact of the instruments'

ageing, the performance of the geophysical corrections and the performance of the retracking methods.
This presentation aims at providing an error budget for the Jason-3 mission at different spatio-temporal scales:

- high-frequency errors through a spectral analysis and an analysis of the standard deviation of 20Hz data;
- low-frequency errors through the evaluation of the mission performance at mono-mission crossovers and along-track;
- long-term errors through the comparison with other missions;

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OCEAN TIDES IN THE COASTAL REGION: INSIGHTS GAINED FROM SWOT

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Studying ocean tides from satellite altimetry has traditionally been difficult in coastal regions, mainly due to the complexity of tides in these regions, limited spatial coverage, and land contamination of the radar returns. Significant efforts have been made by modellers to better resolve the ocean tides closer to the coast by employing enhanced retracking algorithms for coastal altimetry and leveraging more accurate bathymetry products. In late 2022, the SWOT satellite launch introduced the Ka-band Radar Interferometer (KaRIn), marking a significant leap beyond traditional altimetry by offering high-resolution, two-dimensional sea surface measurements. Starting with a 90-day Cal/Val phase featuring a 1-day repeat cycle, followed by a science phase with a 21-day repeat cycle, SWOT enables observation of geophysical phenomena over several days. Additionally, it enhances the geophysical record with significantly better spatial resolution and coverage, offering an excellent opportunity to expand our knowledge of the spatial variability of ocean tides. This is particularly interesting in complex coastal regions, such as fjords or coastal inlets, where conventional altimetry missions have previously struggled to provide reliable measurements. This opens the door for improving tide estimations and studying nonlinear tidal effects, which play a substantial role in the tidal dynamics of specific regions and provide a serious challenge to accurate tidal prediction within these regions. In this presentation, the current state-of-the-art tide models are contrasted to tidal estimations made from the KaRIn products of SWOT in two complex coastal areas: the Bristol Channel and the Great South Bay. Conclusions are then made about the usability of SWOT for tidal estimation, and recommendations are provided for research to further improve the reliability of tidal estimations.

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GLOBAL OCEAN DATA QUALITY ASSESSMENT OF SARAL/ALTIKA'S GDR-F PRODUCTS

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The SARAL mission was successfully launched on February 25th 2013. Its Ka-band altimeter and dual frequency radiometer have been delivering high quality sea surface topography measurements since. On July 4th, 2016 an orbit maneuver was performed to move the spacecraft to a new orbit where the satellite altitude is no longer maintained, starting the so-called drifting phase. Following the loss of one of the platform's reaction wheels on September 13th 2014 and star tracker on February 3rd 2019, the pointing accuracy is degraded from 2019 onwards.

We present the current mission performance status of the SARAL/AltiKa mission over ocean, based on the analysis of the latest GDR version data (GDR-F).

The main objective of this study is to assess quality of the SARAL/AltiKa's product over the whole series. Several Cal/Val metrics are presented to document data availability and overall mission performance. Cross-comparisons with other altimetry missions show the still excellent performance of SARAL/AltiKa.

The aim of this work is also to provide an overview of SARAL/AltiKa's data quality at different scales: climate, mesoscales, high latitudes...

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LOW WATER MAPS OF GROUNDWATER TABLE USING MULTISATELLITE DATA IN THE INNER NIGER DELTA (IND) OVER THE PERIOD 2000-2022

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The Earth's largest reservoir of liquid freshwater is situated within groundwater, comprising 30% of the planet's freshwater supply.This reservoir plays a crucial role in both hydrological and biogeochemical cycles. Its significance extends to agriculture, with approximately 43% dedicated to irrigation, contributing to global food security as the primary freshwater source for around 2 billion people worldwide. As climate change and human activities intensify, the demand for freshwater is projected to rise. Traditional water sources, such as surface water, are becoming less reliable due to contamination and depletion. Therefore, effective management of these resources necessitates vigilant monitoring of the groundwater reservoir both spatially and temporally. However, the current lack of comprehensive spatial data inhibits global assessment of changes in reservoir dynamics, particularly in areas with limited accessibility. Remote sensing from space emerges as a potential solution to address this challenge. This study aims to assess the spatio-temporal variability of the groundwater table from 2000 to 2022 using multi-satellite datasets over the Inner Niger Delta (IND), located in Central Mali between 3-5° W and 13-17° N. The IND, Africa's second-largest wetland, forms a crucial hydrological network within a flat and sandy basin. The Niger River, entering through Ke-Macina, and its principal tributary, the Bani, entering through Sofara, originating from the South, on the high plateau of Guinea at the base of the Tingi Mountains. Subject to seasonal rainfall from the West African Monsoon, the IND experiences a wet season with flood events occurring between August and December (maximum flood extent of 30,000 km²). During flood periods, water levels rise significantly by 4.5 to 7 meters compared to low-water periods. Previous studies have shown that minimum water level maps can estimate the groundwater table during low-water periods (Pfeffer et al., 2014). To achieve this, our methodology employs water level maps derived from MODIS sensors' multispectral imagery (with a spatial resolution of 500 m and temporal resolution of 8 days) and virtual stations created from radar altimetry. This method involves interpolating altimetry-based water stages over inundated pixels using an inverse distance weighting technique. Consequently, water level maps were generated monthly from 2000 to 2022 with a spatial resolution of 500 meters. Priliminary findings are promising, revealing spatial pattern changes over the years, with temporal variations seemingly correlated to cumulative rainfall variations. This study marks the first time spatial-temporal variations in groundwater base level have been observed over a 20-year period.

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SYNERGY OF FINE-RESOLUTION REGIONAL MODEL AND SWOT MEASUREMENTS TO STUDY COASTAL DYNAMICS

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Satellite altimetry has revolutionized the study of ocean dynamics as well as the monitoring of the global mean sea level. Despite its significant contributions, traditional altimetry measurements encounter challenges near the coast due to land proximity and the complexity of the coastal processes. In this challenging front, the SWOT (Surface Water and Ocean Topography) altimetry mission utilizing Ka-band SAR has made remarkable advancements in resolution, coverage and overall observability. While traditional nadir altimetry offers valid ('good' quality flag) observations up to roughly 30 km from the coast, SWOT extends this range to approximately 3-5 km. Although SWOT's primary objective is to monitor both open ocean and inland water bodies at an unprecedented spatial resolution, its potential application in coastal regions appears promising. However, fine scale SWOT measurements in the coast faces two major challenges regarding fine scale geophysical correction and coastal dynamic processes.
In order to improve the geophysical correction related to tides and dynamic atmospheric correction, a fine resolution regional tide and surge model based on SCHISM (Semi-Implicit Cross-scale Hydroscience Integrated System Model) (Zhang et al., 2016) is being developed in the coastal region of Pertuis Charentais, located in the Bay of Biscay, France. This area is situated under LR (Low Resolution) and HR (High Resolution) coverage of SWOT swath and covered by several long-term tide gauge stations, making it an ideal site to validate SWOT measurements in a macro-tidal coastal region. The importance of a regional tide and surge model in a semi-closed system like Pertuis Charentais has previously been demonstrated for traditional nadir altimetry (Tranchant et al., 2021). This study aims to improve the existing regional tide model by refining spatial resolution and bed roughness characterization, employing better tidal forcing, and aligning it with SWOT swath coverage to enable local reprocessing of tide and atmospheric correction for both LR and HR measurements. The model and SWOT observation will be validated using available tide gauges as well as several pressure gauges deployed within the SWOT coverage. Additionally, this study will utilize the planned in-situ campaigns along SWOT swath using an innovative unmanned marine drone, PAMELi (Plateforme Autonome Multicapteurs Pour l'Exploration Du Littoral), to validate the model and the altimetry data. With improved geophysical correction, this study will eventually investigate the fine scale coastal dynamics observed by SWOT, which are typically not resolved from traditional altimetry.

Reference:
Tranchant, Y.-T., Testut, L., Chupin, C., Ballu, V., & Bonnefond, P. (2021). Near-Coast Tide Model Validation Using GNSS Unmanned Surface Vehicle (USV), a Case Study in the Pertuis Charentais (France). Remote Sensing, 13(15), Article 15. https://doi.org/10.3390/rs13152886
Zhang, Y. J., Ye, F., Stanev, E. V., & Grashorn, S. (2016). Seamless cross-scale modeling with SCHISM. Ocean Modelling, 102, 64–81. https://doi.org/10.1016/j.ocemod.2016.05.002

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DEEP STERIC SEA LEVEL VARIABILITY INFERRED FROM SATELLITE OBSERVATIONS, OCEAN REANALYSIS AND DEEP ARGO PROFILES

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Monitoring and predicting sea level change is of great importance as nearly 10% of the world population lives at an altitude within 10 meters above sea level. Regional sea level change has been largely investigated for years using complementary observing systems including satellite altimetry, GRACE/GRACE-FO and Core Argo floats profiling the upper 2000-m. However, the contribution to sea level of the deep ocean below 2000-m remains poorly understood as historical data consist mostly of CTD profiles from oceanographic campaigns along sections with limited repeatability, and generated uncertainties in regional-to-global deep sea level are comparable to the signal.

In this study, we investigate regional steric sea level change at subannual to interannual time scales using an integrative approach. First, we analyze ocean reanalysis (available from Copernicus Marine Service) and compare the results with geodetic observations (based on satellite altimetry and space gravimetry). We will highlight common hot spots of large deep steric sea level variability at subannual and interannual time scale detected in western boundary currents and in the ACC, and describe regions of large discrepancies between ocean reanalysis and geodetic estimates. We will further investigate deep steric sea level change by comparing ocean reanalysis and space geodetic approach with quality-controlled Deep Argo profiles collected in the North Atlantic Ocean. Using Deep Argo data as the ground truth, we will describe performance and limitations of space observations and ocean reanalysis to estimate variability in deep-ocean steric sea level.

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COASTAL PROCESSING USING SAR INTERFEROMETRIC MEASUREMENTS

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Coastal zones present unique challenges for altimetry studies, aiming to obtain precise geophysical data of the ocean surface, including Sea Surface Height (SSH), Significant Wave Height (SWH), and wind velocities. Various factors affect the quality of these scientific parameters in coastal environments. These factors include coastal topography, the angle of attack of the ground track concerning the coastline, the specularity of water surfaces near the coast or high-return ground targets, sea state conditions, onboard operational mode, science chronogram, and other variables.
Efforts have been made over time to manage undesired interferences within coastal zone science datasets. One effective strategy involves isolating the ocean signal segment of the echo, significantly enhancing data quality by filtering out most interferences.
In the CryoSat-2 Plus for Ocean (CP4O) project, funded by ESA, isardSAT proposed a method for coastal altimetry processing with SAR interferometry (SARin) data. This approach leverages SARin capability to determine the across-track angle of arrival for all echoes' range bins, which has not been utilised in any ESA altimetry mission since CryoSat-2 (CS2). The CP4O coastal processor employs a method that identifies a segment of the original science echo characterised by high coherence and power and a low angle of arrival. It assumes that the nadir backscattering represents the ocean signal during overflight, utilising SARin capabilities effectively.
In the second phase of the CP4O project, an enhanced version of the SARin retracker was introduced, broadening its capabilities to distinguish coastal environmental interferences in modes other than SARin. By incorporating the Window Delay parameter, the coastal processor can be tailored to accommodate any altimetry mission requirements.
Later significant enhancements were made to the coastal processor, rebranded as CORS, considering new retracking processing modifications. Validation exercises were conducted after adapting the model to Copernicus missions Sentinel-3A/B (S3) and Sentinel-6 (S6), funded by ESA.
This presentation explains recent validations conducted on CryoSat-2 (CS2) data over a SARin mode area around the Cuban archipelago coasts, integrating CP4O SARin-specific and CORS methodologies. They validated SSH and SWH parameters through various means, resulting in SSH noise reduction and improved PSD function across all wavelengths. However, rough sea states tend to exacerbate these outcomes.
The upcoming CRISTAL altimetry mission, first in incorporate SARin mode since CS2, will benefit from the validation efforts presented here, facilitating the future development of coastal processor solutions tailored for the mission.

(Ray et al. 2015) SAR altimeter backscattered waveform model. IEEE Trans.Geosci. Remote Sens. 53, 911–919. https://doi.org/10.1109/TGRS.2014.2330423.

(Garcia et al. 2018). SARin mode, and a window delay approach, for coastal altimetry. Advances in Space Research, 62(6), 1358-1370. https://doi.org/10.1016/j.asr.2018.03.015.

(Makhoul et al. 2018). Evaluation of the precision of different Delay-Doppler Processor (DDP) algorithms using CryoSat-2 data over open ocean. Advances in Space Research, 62(6), 1464-1478. https://doi.org/10.1016/j.asr.2018.04.004.

(Garcia et al. 2022): The CORS processor outcomes. Improving the Coastal Ocean SSH & SWH series from the Copernicus altimetry constellation. 2022 OSTST Meeting.
https://ostst.aviso.altimetry.fr/fileadmin/user_upload/

OSTST2022/Presentations/COA2022-Coastal_Processing_from_the_Copernicus_Altimeters__the_CORS_processor_outcomes.pdf.

(Garcia et al. 2023), HYDROCOASTAL CCN2 Technical Note. Coastal and FF-SAR processing of S6 data. https://satoc.eu/projects/hydrocoastal/docs/Hydrocoastal_isardSAT_TN_CCN2_Final.pdf

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ADVANCEMENTS IN MAPPING SURFACE CURRENTS WITH DOPPLER OCEANOGRAPHY: HISTORICAL DEVELOPMENT AND INSIGHTS FROM OSCAR AIRBORNE DATA DURING THE BIOSWOT-MED CAMPAIGN

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The study of ocean surface currents has gained significant attention in recent years, driven by the need to better understand the complex interactions between the ocean and atmosphere, as well as the crucial role these currents play in marine ecosystems and global climate. In this context, Doppler Oceanography has emerged as a promising field of research, leveraging advances in satellite remote sensing to directly measure ocean surface motion from Doppler shifts in microwave radar signals. This abstract provides a historical perspective on the development of Doppler Oceanography, its complementary nature to altimetry, and recent insights derived from the OSCAR (Ocean Surface Current Airborne Radar) instrument during the BioSWOT-Med campaign.
Doppler Oceanography origins traced back in the 1970-80s, with first airborne demonstrations. Since then, the technique has evolved, with notable advancements achieved through analysis SAR data from missions such as Envisat-ASAR, TerraSAR-X, and Tandem-X. These developments have fueled renewed interest in the capabilities of ocean Doppler signals to measure surface currents from space, opening up new opportunities for oceanographic applications.
The Doppler shift can be measured using two primary techniques: Along-Track Interferometry (ATI) and the Doppler Centroid Anomaly (DCA) method. The large and stable Envisat satellite platform has played a significant role in advancing our understanding of the geophysical information contained in ASAR Doppler signals. As the prospect of accurate Doppler signal measurements from space gains maturity, a wealth of satellite mission concepts are emerging to measure ocean surface currents, including SKIM, Harmony, SeaSTAR, OSCOM and ODYSEA.
In addition to satellite capabilities, airborne instruments have been developed as demonstrators of satellite concepts. Among these, OSCAR provides 3-look direction SAR images at 8m resolution, from which a synoptic 2D view of ocean and atmosphere dynamics, including currents, waves, and winds, at fine scales over a 5km swath is derived. The success of OSCAR has been demonstrated in various campaigns, such as the SEASTARex campaign held in May 2022 over the Iroise Sea in Brittany, France, where it showed excellent performance against various measurements, including marine radar, ADCP, and HF radar in a macro tidal environment.
Building on OSCAR's success, a campaign was organized in May 2023 to coincide with the BioSWOT campaign, during which OSCAR flew together with SWOT over an area known for its meso- and submeso-scale dynamics. The BioSWOT-Med cruise focused on the Western Mediterranean Sea, aiming to investigate the role of fine-scale circulation as a driver of plankton diversity. Initial comparisons between OSCAR and satellite data, spanning remote sensing instruments like SWOT, SAR imagers, and optical sensors, showed a high level of agreement.
OSCAR Doppler and scatterometry capabilities offer a fresh perspective on dynamic processes, particularly at fine scales, bridging the gap between in-situ point measurements and space-based sensors. The ongoing synergy between OSCAR and satellite data holds potential to advance our understanding of oceanic and atmospheric phenomena, addressing critical challenges related to climate, weather, and marine ecosystems, which are relevant for past, present, and future missions like Harmony, Copernicus Sentinel-1 NG and Sentinel-3 NG.

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TOPEX GDR-F AND SWOT NADIR: CALIBRATION OF TWO NEW DATASETS FROM THE BEGINNING AND END OF THE 30 YEARS OF ALTIMETRY TIME SERIES

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DGFI-TUM has been performing multi-mission crossover analysis (MMXO) for many years. This methodology allows for a cross-calibration of all available nadir altimeter missions and reveals possible systematic differences between the systems, such as offsets, drifts, and geographically correlated errors. Such harmonization is a prerequisite for any long-term, multi-mission sea level analysis.
This contribution presents crossover validation results for two recently released datasets of the very first modern altimetry mission (TOPEX) and the most recent one (SWOT nadir). For TOPEX, the newly released GDR-F dataset is independently evaluated to quantify the improvements over older datasets and to analyze the consistency with other missions. In particular, biases between the different altimeters on board (Side A, Side B, and Poseidon) are evaluated, as well as potential remaining drifts, large-scale orbit errors, or systematic

errors in the geophysical corrections. For SWOT, nadir data from both mission phases (1-day repeat and 21-day repeat) are analyzed. In particular, the consistency with other missions, such as Sentinel-6A, is investigated, and the mission is checked for possible systematic effects.

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INSTRUMENTAL CALIBRATION OF COPERNICUS ALTIMETERS

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The Sentinel-3A, 3B, and 6 missions configure a constellation of Copernicus altimeters, all working in the enhanced Synthetic Aperture Radar (SAR) mode to continue the legacy of a long ESA altimetric series, now with improved performances. The crucial importance of the instrumental calibration when processing the altimeter data, in order to produce reliable and accurate geophysical retrievals, such as sea surface height, significant wave height, or wind speed over the oceans, is well known.

isardSAT is responsible for monitoring the calibration parameters during the Sentinel-3A and B missions, first within the ESA S3 Mission Performance Center, and now fort the Sentinel-3 Land Altimetry Mission Performance Cluster Service and the EUMETSAT Copernicus Altimetry Service.

In addition, isardSAT designed and implemented the complete L1B processing algorithms of the Sentinel-6 mission, which include the calibration processing chains, and is still monitoring the Sentinel-6 altimeter calibration data. For the CRISTAL altimetry mission, planned for launch in 2027, isardSAT is responsible of the design and implementation of the L1B processing algorithms,

This presentation gives an overview of the most recent calibration monitoring data acquired from the altimeter instruments of the three aforementioned current missions. Internal delay, power, transfer function, burst power and phase, USO clock frequency and thermal behaviour variables are depicted among other instrument characterisation performances.

When available, a comparison with other ESA altimetry missions (e.g. Envisat, CryoSat-2) is shown, so we can have a wide picture of ESA altimeters in-orbit performances, compared to each other. The impact of the new digital architecture and the new SAR altimetry mode can be clearly depicted in these combined representations.

In addition, a specific investigation from Sentinel-3A and B Moon Calibration orbital measurements is addressed. Its aim is to build an orbital instrument characterisation during the operational phase, already available for the Sentinel-6 mission (Echo CAL mode), but not for the two Sentinel-3 units, which activate the calibration measurements over specific geographical areas. If the orbital excursions of a particular calibration parameter are not negligible, an additional calibration model can be proposed to increase the level of accuracy of the final geophysical data.

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HYDROLOGICAL DYNAMICS OF THE FLOODPLAIN IN THE CUVETTE CENTRALE (DEMOCRATIC REPUBLIC OF CONGO) USING SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT) MISSION

Normandin C[1], *Frappart F, Bourrel L, Zeiger P, Salameh E, Peña Luque S, Ygorra B, Betbeder J, Gond V, Kitambo B, Papa F, Riazanoff S, Wigneron J*
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Climate change is impacting all the different compartments of the Earth, and in particular the surface water reservoir (lakes, rivers, floodplains, wetlands). Within this reservoir, wetlands, which include floodplains, play a major role in regulating river flows by storing large quantities of water for periods of up to several months, modulating air temperatures and increasing evapotranspiration. However, the spatio-temporal dynamics of floodplains are still poorly understood at regional and global scales. The main reasons for this are the lack of multi-year measurements of the extent and height of flooded areas, and the limited inclusion of these variables in hydrological and hydrodynamic models. To address this issue, the Franco-American (CNES/NASA) Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, will provide for the first time direct measurements of the extent and height of surface water on floodplains, at spatial resolutions of 100 m and temporal resolutions of 21 days. My study focuses on the monitoring of the Cuvette Centrale floodplain, based on the first data obtained from the SWOT mission. To do this, I'm first looking at the backscattering coefficients derived from the radar altimeter to identify surface water, and comparing these results with data from the Sentinel-1 satellite. Preliminary results are currently being processed. Next, I will focus on the study of the coherence and water level maps. The study area is the Cuvette Centrale, located in the center of the Congo Basin in Africa. The Cuvette Centrale is a large floodplain covering an area of 1,176,000 km², ranging from latitudes 3 to 5°N and longitudes 16 to 22°E. In this area, the main river, the Congo River, meets its two main tributaries, the Ubangi River and the Sangha River. This area is dominated by a tropical climate, with heavy seasonal rains occurring at two distinct times of the year: a peak in October and another in March. Thus, the central basin is subject to a bi-modal flooding pattern, with a maximum peak in November-December and another in May-June. In contrast, low-water periods occur in August and February-March (Betbeder et al., 2014).

References:
Betbeder, J., Gond, V., Frappart, F., Baghdadi, N. N., Briant, G., & Bartholomé, E. (2013). Mapping of Central Africa forested wetlands using remote sensing. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 7(2), 531-542.

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EXPANDING THE USE OF COPERNICUS MARINE ALTIMETRY DATA: EUMETSAT USER SUPPORT AND TRAINING ACTIVITIES

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Following the successes of the first phase of the European Commission Copernicus programme, EUMETSAT is continuing and expanding its offer of data access services, marine data products, as well as marine training activities and user support services, under phase two. EUMETSAT operates the Sentinel-3, Sentinel-6 and Jason-3 satellites, and provides level-1, level-2, level-2p and level-3 marine data products for altimetry science and applications. User support services include data access tools, web-based technical information about products, as well as a help-desk available to answer a full range of user queries on the products and their use.

EUMETSATs approach to user engagement and training revolves around open source tools and resources showing how marine data is relevant for a broad range of applications. This is achieved through the use of Python based Jupyter Notebooks and various thematic case studies relevant to current topics and initiatives such as the UN Ocean Decade. Interactive training courses are designed to accommodate a diverse range of audiences, both research and operational, putting trainee needs and interests at the centre of learning objectives. A focus on co-development of resources and participant-led learning interventions allows participants to tailor their own experiences towards development of the skills and knowledge that will help them in their own applications and work tasks. Building on four years of successful general courses, EUMETSAT now seeks to develop further specialised training and advanced courses for the marine community.

This presentation will showcase existing services and resources, and provide information on planned training events for 2024 and beyond. It will expand on our training approaches and provide further information on opportunities for collaboration with the wider marine community, during the UN ocean decade.

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ASSESSMENT OF SWOT KARIN SPECTRAL PERFORMANCE AND ERROR REQUIREMENTS DURING THE 1-DAY REPEAT ORBIT

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The launch of the Surface Water and Topography Mission (SWOT) in December 2023 represented a major breakthrough in satellite altimetry. SOWT Ka-band radar interferometer (KaRIn) provides surface ocean topography measurements at the km resolution over a swath of 120 km, enabling the possibility to observe ocean processes at spatial scales well below those from the current nadir altimeter constellation.

The novelty of the KaRIn instrument compared to current nadir altimeters, and the move from 1-dimensional to 2-dimensional surface ocean topography observations represent also a main paradigm shift for Cal/Val activities. Furthermore, as opposed to other altimeter missions, SWOT KaRIn error requirements are specified in a spectral form in order to be able to resolve ocean signals down to 15 km in wavelength. All these aspects make the assessment of KaRIn performance a particularly challenging task.

Along-track wavenumber spectra are a common diagnostics to investigate altimeter noise levels. Here we present a spectral assessment of KaRIN performance and error requirements using LR observations from SWOT one-day repetitive orbit Cal/Val phase (Jan to July 2024). 1-day SSHA difference spectra were obtained by subtracting the SSHA observed over the same track over two consecutive days. Since those spectra include ocean variability and decorrelated 1-day KaRIn errors, ocean variability spectra were also estimated via independent approaches that combined SWOT KaRIn with SWOT Nadir observations, as well as those from other altimeters. The resulting spectra of KaRIn errors evidenced good performance, in line with the expectations.

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NAVIGATING UNCERTAINTIES: OPTIMIZING SWOT ASSIMILATION FOR RIVER DISCHARGE ESTIMATION

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Rivers play a pivotal role in the global hydrological cycle, yet a substantial portion remains inadequately monitored, hindering comprehensive understanding and sustainable management of water resources. The emergence of the Surface Water and Ocean Topography (SWOT) satellite in December 2022 offers a groundbreaking opportunity to enhance river discharge estimation through precise measurements of water surface elevation (WSE). However, the integration of SWOT observations into hydrological models, especially on a global scale, presents multifaceted challenges. This study introduces a novel data assimilation framework, known as CTRIP-HyDAS (Total Runoff Integrating Pathways - Hydrological Data Assimilation System), which effectively incorporates SWOT observations into a high-resolution (1/120) river routing model utilizing the Local Ensemble Transform Kalman Filter (LETKF). Through rigorous systematic assessment, we scrutinize the assimilation of SWOT-derived WSE and river discharge, addressing fundamental research questions regarding their efficacy and realism within the modeling framework. Our methodology encompasses a comprehensive delineation of the hydrological modeling system and experimental conditions to ensure robustness and reliability of the results. The findings of this study reveal significant enhancements in global-scale river discharge estimates across diverse hydro-climatic contexts, underscoring the transformative potential of SWOT observations in refining our understanding of river system dynamics within the broader framework of the continental water cycle. By harnessing SWOT altimetry data and employing innovative assimilation methodologies, this research contributes to bridging critical gaps in global hydrological modeling, highlighting the paramount importance of satellite-based observations in advancing sustainable water resource management practices. Upon the release of real SWOT discharge products, the methodologies developed in this study could be instrumental in producing the first assimilated continuous spatio-temporal simulations at the global scale. These insights hold considerable promise for informing policy-making and facilitating more effective decision-making processes aimed at ensuring the resilience and sustainability of water systems worldwide.

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COLLABORATIVE DATA CHALLENGE FOR SEA LEVEL AND SURFACE CURRENT MAPPING: REVIEW OF OPERATIONAL PRODUCTS AND EMERGING METHODS

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Collaborative data challenges have emerged as open comparative platforms in the field of oceanography, facilitating the evaluation and enhancement of data processing methods and products. By bringing together multidisciplinary teams and leveraging diverse datasets, these challenges enable a comprehensive assessment of operational products and the exploration of innovative methodologies.
Through various projects (CMEMS Service Evolution SLICING project, CNES and ESA funded projects), collaborative data challenges were created to allow researchers and operational centers to compare and evaluate a wide range of ocean data processing techniques, leading to continuous improvements in product accuracy and reliability. These challenges serve as catalysts for innovation, fostering the development of novel approaches and algorithms through open science for extracting meaningful information from satellite observations and in-situ measurements.
In this presentation, we propose a comparative review of emerging methods and products in sea level and surface current mapping. This review stems from two main collaborative data challenges: WOC-ESA surface current and SLICING global altimetry data challenges. By comparing new developments to operational products, we aim to identify strengths, weaknesses, and areas for improvement, ultimately contributing to the refinement of operational sea level and surface current data products.
Concurrently, the use of open and collaborative data challenges can extend beyond gridded product evaluation, already playing a role in improving SWOT preprocessing techniques, they could also be central to the design of future satellite missions, such as the upcoming S3NG ESA mission.
Finally, following the overarching spirit of the Digital Twin of the Ocean initiative, the argument is made in this presentation that both product users and operational centers would strongly benefit from users having a better knowledge and a more direct access to the operational data streams through, for instance, access to cloud-deployed data production processes.

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CTOH PRODUCTS TO EXTEND THE RANGE OF ALTIMETRY APPLICATIONS OVER THE OCEAN AND CONTIENTAL SURFACES

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The Center for Topography of the Oceans and Hydrosphere (CTOH) is a French Observation Service created in 1989 and dedicated to the dissemination of satellite altimetry products and knowledge. It focuses on the development and improvement of approaches to processing altimetry data for emerging research domains (coastal ocean, mesoscale/sub-mesoscale ocean dynamics, continental surface water). It works in close relationship with space agencies (mainly CNES and ESA) at different levels of satellite altimetry missions: preparation, definition of the user's needs, CAL/VAL studies, signal analysis & data reprocessing, development of thematic products, teaching and outreach.

In terms of data distribution, the CTOH maintains a global GDR data base for almost all altimetry missions since Topex/Poseidon. All the products are made homogeneous by providing up to date altimetry corrections to historical missions. All products are in NetCDF format.

For the hydrology community, this poster presents the latest developments of the AlTiS software, which enables the easy computation of sea level time series over rivers, lakes, flood areas, starting from Level 2 altimetry products. We also present the development of the new virtual station product based on SINC retracker developed at CTOH.

For the coastal community, we present the multi-mission X-TRACK L2P product, based on the latest altimetry standards for the Topex/Jason-1/Jason-2/Jason-3, ERS/Envisat, Sentinel, Geosat and HaiYang-2A missions. The X-TRACK along-track tidal constant product is presented as well. The latter provides independent synoptic data on the coastal ocean for tidal studies, validation of tidal models or assimilation into tidal models.

For open-ocean applications, the CTOH distributes also a multi-satellite Southern Ocean fronts product, providing information on the position of the three main fronts of the Antartic Cicumpolar Current, which was updated in early 2024.

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ACHIEVING SIGMA0 CONSISTENCY FOR THE ENTIRE TOPEX/JASON RECORD

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The normalised backscatter, sigma0, measured by radar altimeters is normally interpreted as just a simple monotonic function of wind speed. However the precise value recorded depends subtly on wave height, sea surface temperature, and other factors, contingent upon the particular choice of retracking algorithm used. Furthermore the development from conventional low-rate mode (LRM) altimetry to SAR mode produces a much smller footprint, and thus the variability between Ku- and C-band is increased as there is much less areal averaging. These factors have been codified to produce empirical adjustments in order to generate the best possible agreement between the dual-frequency observations at Ku- and C-band. This enables clear discrimination of long-term changes and correction for instrumental differences. The resultant datasets are then better suited for long-term climate studies of wind speed (including extremes), rainfall, air-sea gas transfer and the occurrence of slicks on the sea surface. With temperature having an appreciable effect on the backscatter signal, a temperature-dependent correction may be necessary before a universal wind speed algoirthm is applied, else rising values of SST may be conflated with changes in wind speed.

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VALIDATION OF THE SWOT CROSS-OVER CALIBRATION OVER LARGE LAKES

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The Surface Water and Ocean Topography (SWOT) mission, conducted by CNES and NASA was successfully launched on 16 December 2022. It aims at providing unprecedented 2D observations of the sea-surface height and mesoscale structures as well as water surface elevation, water stocks estimates and discharge over hydrological areas. A SAR-interferometry wide-swath altimeter, namely the Ka-band Radar Interferometer (KaRIn), is designed to cover two 50-km cross-track swaths with a 21-day repeat cycle. Considering the need of different spatial scales for observations, dedicated processing methods are used to generate Low Rate (LR) products for oceanography and High Rate (HR) products for continental hydrology.

The specificity of the interferometric-SAR technique leads to several errors included in the KaRIn measurements that must be considered. The uncalibrated systematic errors, for example the roll and phase errors, are the main components of the total error budget in hydrology. The objective of the so-called cross-over calibration is to isolate these systematic errors impacting the quality of the KaRIn measurements to obtain a residual error within the performance requirements. This approach proposes a correction based on models over ocean crossovers that is further extrapolated over continental areas. The quality assessment of such correction is therefore mandatory to validate SWOT swath measures over inland waters.

Our analysis proposes an evaluation of the Level-2 and Level-3 cross-over corrections over large lakes. Both LR and HR data are used to evaluate XCAL L2 and L3 solutions. We will take advantage of external datasets providing reliable estimates of the water surface elevation. Particularly, in-situ measurements from the Swiss (BAFU) or the American (USGS) networks are used. Comparisons are also performed with conventional altimetry (Sentinel-3A/B and Sentinel6) and ICESat-2 missions providing reliable references of the water surface elevation.

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CYCLOGEOSTROPHIC INVERSION FOR ESTIMATING SEA SURFACE CURRENTS FROM SWOT ALTIMETER DATA

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The spatial resolution of the Sea Surface Height (SSH) observations provided by the SWOT mission opens unprecedented perspectives for estimating ocean near surface circulation at scales <100km. The geostrophic balance, which relates the pressure gradient, the current velocity, and the Coriolis force, is commonly employed to estimate Sea Surface Currents (SSC) from SSH. This equation represents a drastic approximation of the Navier-Stokes equations adapted to mesoscales and larger scales ocean dynamics, which neglects in particular the velocity advection term. However, it is known that at the scales allowed by SWOT's observations, the advection term can no longer be neglected in the leading order balance, especially in highly energetic regions. But solving the cyclogeostrophic balance equation, which includes the advection term, can not be achieved analytically, and requires the use of numerical methods. Still, (1) existing iterative approaches are known to diverge, and ad-hoc procedures are required to avoid local discontinuities; (2) publicly available implementations are missing.

To overcome these limitations, we propose a new Python package, named jaxparrow. jaxparrow formulates the cyclogeostrophic balance as a variational problem and solves this problem using state-of-the-art optimization procedures. Its implementation heavily relies on JAX, a Python library which brings together automatic differentiation and just-in-time compilation. In this presentation, we will describe the variational formulation of the cyclogeostrophic balance inversion and demonstrate the performance of this approach with high resolution ocean model data. We will then illustrate how global estimates of cyclogeostrophic SSC can be obtained from SWOT altimeter data by combining jaxparrow with existing SSH mapping techniques. Finally, we will validate how cyclogeostrophic corrections may improve our ability to estimate SSC using measurements from drifters released during the 2023 C-SWOT campain.

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PHYTO- AND ZOO-PLANKTON RESPONSE TO EDDIES IN THE NORTH ATLANTIC

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The North Atlantic Ocean is region with two contrasting regimes. A northern area (circa 35-50oN) contains the Gulf Stream, the Azores Current and many energetic eddies, and undergoes pronounced wintertime mixing replenishing the nutrient pool. In contrast, a region within the North Atlantic Subtropical Gyre (10-25oN) has little mesoscale variability and the generally weak winds lead to permanent stratification and low productivity in these oligotrophic waters. Cyclonic and anticyclonic eddies derived from altimetric sea level anomaly fields can be combine with synoptic ocean colour and SST data to show the contrasting behaviour of these eddies on surface variations of temperature and chlorophyll concentration. By collating profiles from Biogeochemical Argo floats, we can explore how the chlorophyll concentration varies with depth in eddies in these regions. The raising/lowering of isopycnal surfaces due to the eddy-pumping mechanism is shown by both isotherms and the depth of the deep chlorophyll maximum (DCM); however the associated changes in nutrient supply and vertical advection of plankton lead to increased concentrations of chlorophyll at the DCM in cyclones, but elevated concentrations reaching deeper in anticyclones. Taking advantage of multiple towed zooplankton surveys in the northern region, we can establish that zooplankton numbers are significantly higher at the edges of anticyclonic eddies than at their centres. Given that these zooplankton are incapable of swimming large distances, these findings show that the conditions on the edge of anticyclonic eddies are better suited for zooplankton growth. This confirms the link between distributions of megafauna (seabirds and turtles) and mesoscale oceanic structures.

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GLOBAL EVALUATION OF LAKE WATER HEIGHT AND VARIABILITY USING ICESAT-2 SATELLITE ALTIMETRY

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Satellite altimetry has emerged as a powerful tool for monitoring water bodies on a global scale. In this study, we present a comprehensive assessment of lake water height and variability worldwide utilizing satellite altimetry data. We used data from the Ice, Cloud and land Elevation Satellite-2 mission (ICESat-2) ATL13 version 6, from October 2018 to June 2023. It provides high-resolution measurements of water levels across various lakes globally, enabling a robust analysis of temporal and spatial variations. Our methodology involves the preprocessing of satellite altimetry data to extract water level measurements over lakes. We analysed the temporal patterns of water height changes throughout the whole time period. Preliminary results provide average water level height for more than one million lakes around the world. Additionally, our analysis reveals distinct variabilities in lake water levels, potentially driven by precipitation, evapotranspiration, and hydrological inputs. Overall, our study demonstrates the efficacy of LiDAR satellite altimetry in evaluating lake water height and variability on a global scale. The findings provide valuable insights into the dynamics of lakes worldwide and underscore the importance of satellite-based remote sensing for water resource management and climate research.

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USING SPATIAL ALTIMETRY TO CALIBRATE AND VALIDATE SURFACE WATER STORAGE MODELLING IN THE FLOODPLAINS OF THE AMAZON BASIN

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Inland surface waters in tropical environments play a crucial role in both global water and biogeochemical cycles and are critical for water resources management. However, spatiotemporal dynamic of freshwaters in floodplains are still widely unknown and are still not consistent both at local and large scales. In this study, we used a transposable methodology coupling in situ observations, remote sensing, and modelling tools to better assess the alluvial functioning of the whole Amazon basin, more particularly over its floodplain system at a daily time step between 2000 and 2018. We used the semi-distributed hydrologic Soil and Water Assessment Tool (SWAT) model with a new hydraulic module for water routing, as well as a new floodplain module. The floodplain is implemented either as a simple reservoir or as a continuum where the water can flow along the floodplain network. In the SWAT-FlooPlain model, L-band passive microwaves (SMOS) data were used for floodplain delineation as inputs which corresponds to the maximum water bodies extension. Spatial altimetry (Jason 2-3 and Sentinel-3A) data were applied both to rivers and floodplain areas between 2009 and 2018 over the whole Amazon basin to validate the floodplain module of the model. SWAT-FloodPlain offers relevant modelling of surface waters in floodplains both at local and large scale. The calibrated model for discharge gauging stations shows a mean R^2 ² and NSE of about 0.83 and 0.74 for the whole basin and means R^2 / RMSE of 0.63 ± 0.14 / 0.75 ± 0.32 for the 1,100 Jason 2-3 river stations and 0.75 ± 0.14 / 0.65 ± 0.14 for the 3800 Sentinel-3A river stations. Concerning the floodplain virtual stations, there are 840 Jason 2-3 stations with means R^2 / RMSE of 0.61 ± 0.16 / 0.72 ± 0.28 and there are 2570 Sentinel-3A stations with average scores of R^2 and RMSE of 0.75 ± 0.14 / 0.65 ± 0.81. As so, surface water storage in the floodplains of the Amazon Basin is about 1800 km3 per year, or one third of the average discharge at the outlet. The Negro/Branco and Madeira river Basins are the main contributors in terms of water storage, with respectively 480 km3 and 312 km3 of water stored each year between 2000 and 2018.

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INDUS BASIN WATER STORAGE VARIATION ESTIMATION COMBINING ALTIMETRY AND GRAVIMETRY DATA SETS

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At global scale, South Asia's rivers are one of the main sources of freshwater to the oceans. However, their temporal variability and the causes of these variations are still subject to considerable uncertainty. Among these basins, the Indus, a transboundary river, is characterized by a lower discharge at its outlet than other major rivers in the region (such as the Ganges-Brahmaputra, Mekong, Irrawaddy and Godavari), despite a larger drainage area. This difference can be explained not only by the hydrology of the basin, but also by an a priori higher level of anthropization (numerous reservoirs along the river network) than other basins in the region. However, even though there are several in situ water level/discharge stations in this basin, there is a lack of freely accessible data to characterize the spatio-temporal variability of water stored in the Indus and its sub-basins.
Remote sensing data can help to fill this observation data gap at basin scale. In this study, we compute river discharge and lake volume change over the Indus basin from 30 years of altimetry data (Topex/Poseidon, ERS-2, Jason1, Envisat, Jason2, Saral/Altika, Jason3, Sentinel3A, Sentinel3B, Sentinel6 and SWOT) and compare them with the total terrestrial water storage from 20 years of gravimetry data (GRACE, GRACE FO)

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DEEP TOPOGRAPHIC PROFILE REGRESSION USING SATELLITE RADAR ALTIMETRY OVER ANTARCTICA

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Between 1992 and 2020, the Antarctic Ice Sheet (AIS) lost approximately 2671 ± 530 billion tonnes of ice, contributing to a global sea-level rise of 7.4 ± 1.5 mm. Continuous and detailed monitoring is crucial for tracking these processes.

Our understanding of how ice sheets are changing is largely informed by satellite observations, with the longest continuous record coming from the technique of satellite radar altimetry. While satellite radar altimetry provides valuable data, current methods for extracting elevation measurements have limitations, especially over complex topography like the Antarctic coast and Peninsula.

Leveraging deep learning, we present a novel approach for estimating across-track surface topography directly from the detected power waveform, without the need for conventional L2 processing steps such as retracking and echo relocation. This is done using Synthetic Aperture Radar Interferometric (SARIn) mode observations from CryoSat-2 (CS2) and the Reference Elevation Model of Antarctica (REMA). By interpolating REMA within the illuminated footprint of each CS2 observation, we obtain a 15 km-wide, 30-point target topographic profile for each 1024-bin waveform. Filtering based on a rudimentary waveform simulator and balancing across topographic complexity, we obtain a final dataset comprising 1,000,000 labelled observations from 2014-2017.

Utilising ResNet-RS, a modified ResNet-D architecture, we achieve a preliminary Root Mean Square Error (RMSE) of 26.3 ± 9.23 m. While this is large, we highlight that performance is limited by the fact satellite radar altimetry is a 1D process, meaning there exists a distribution of possible topographic profiles for each waveform. Therefore, our model provides insights into the mean of the distribution of topographic profiles for each waveform, with future work aiming to model the underlying distributions themselves. Despite these challenges, our analysis demonstrates that our model successfully captures the large-scale topographic profile geometry in the vast majority of cases.

In summary, this preliminary study underscores the potential of deep learning approaches in advancing our understanding of Antarctic ice sheet dynamics, offering a pathway for more detailed and robust monitoring strategies in the context of ongoing climate change.

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THE LONGEST SINGLE SATELLITE ALTIMETRY RECORD FOR OCEANS: CRYOSAT OCEAN PRODUCTS VALIDATION AND SCIENCE

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14 years since ESA launched the innovative Synthetic Aperture Interferometric Radar Altimeter (SIRAL) onboard CryoSat-2, the data continue to update our understanding of how the oceans work. By exceeding its expected lifetime, CryoSat-2 provides the longest data record of the sea surface height anomaly (SSHA), significant wave height (SWH) and wind speed (WSP) measurements from a single instrument. CryoSat-2 pioneered the use of delay doppler (SAR) altimetry that has since been adopted for subsequent ESA nadir altimeters.

Since 2014, a dedicated ocean processor has provided CryoSat Ocean Products (COP) at different latencies (near-real time, a few days and about a month); here we only consider the approximately 30-day latency Geophysical Ocean Product (GOP). 2024 sees the implementation of an improved operational processor and the release of new operational products (Baseline D), followed by a full mission reprocessing. This reprocessing will further improve the quality of the global and regional mean sea level timeseries available, alongside timeseries in SWH and WSP.

This study is part of a larger ESA funded project concerned with ensuring the quality of the SIRAL data (CryOcean-QCV) including routine daily and monthly quality reports (available from https://qras.earth.esa.int/?mis=CryoSat&ins=SIRAL). Beyond presenting the validation of COP we look at additional work on a longer time-series including comparisons of SSHA/SWH/WSP trends regionally and globally. We incorporate additional data sources and comparisons to extend the assessment of the data (e.g. comparison with additional tide gauges or ERA5 wind speed).

Finally, we present findings of novel local/regional studies on the utility of SIRAL data for investigation of specific oceanographic features.

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OPERATIONAL LAKES AND RIVERS WATER LEVEL MONITORING IN NEAR REAL TIME USING THE SATELLITE ALTIMETRY NADIR CONSTELLATION: CONTRIBUTIONS FROM HYDROWEB AND COPERNICUS GLOBAL LAND SERVICES

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With the increasing demography, inland water face mounting pressures to meet population needs presenting both a crucial resource and a significant societal risk for local populations. It is also a fundamental element for industry and agriculture, therefore becoming an economic and political stake. The monitoring of inland water level, proxy to surface freshwater stocks, conditions of navigability on inland waterways, discharge, flood risk management, is thus an important challenge. With the decreasing number of publicly available in situ water level records, the altimetry constellation brings a powerful and complementary alternative.

The HYSOPE software was designed by Legos and Cnes to operationally process altimetric data and to generate water level timeseries products with their associated uncertainties over rivers and lakes worldwide. Thanks to the combined support of CNES (THEIA Hydroweb) and the European Copernicus program it provides the Water Level timeseries since 2017 in the Copernicus Global Land Service. The number of operational products is in constant augmentation as a result of evolutions to successively integrate the Sentinel-3A, Sentinel-3B missions. This allowed to define new targets as well as Sentinel-6MF to ensure continuity of the historical Jason series. Successive upgrades of Open Loop Tracking Commands onboard the satellites are also valued by continuously adding new rivers and lakes targets. This yields to an operational monitoring of more than 22000 virtual stations over rivers and 250 lakes worldwide (as of February 2024).

The accuracy of reconstructed water level timeseries from nadir altimetry can be affected by various factors, among which is the satellite excursion within a 1km deadband (requirement for the Copernicus missions) around its theoretical ground track. The last evolution of the HYSOPE processing workflow integrates a river slope correction to account for such satellite excursion effects, exploiting river slope databases derived from IceSat2 data (IRIS) and will soon benefit from slopes estimates from SWOT data.

This presentation will detail the validation and benefits of this algorithmic evolution, then comparing the timeseries of the virtual stations with that of in situ gauging stations (e.g. French network Schapi), as well as results from the regular quality assessment of the produced water level timeseries.

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SEA-ICE DETECTION FROM SWIM OFF NADIR BEAMS: FOCUS ON WAVE FORECASTING IN POLAR OCEANS

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An algorithm based the analysis of SWIM off nadir beams has been developed to detect sea ice presence (Peureux et al.2022). The algorithm uses geophysical Model Function (GMF) for NRCS signatures over open water and sea ice. The probability of sea ice presence is estimated by comparing the observed sigma0 profiles with GMFs using a Bayesian approach. The results of this algorithm have been validated in comparison with OSI-SAF sea ice products and show a good consistency.

Since the beginning of 2023, this algorithm is operated on a daily basis and the output files are broadcast via AVISO website. A global gridded sea ice product with a resolution of 0.5°x0.5° is also available as a demonstrational datasets covering the whole mission period (2019-present).

More than 5 years of sea ice probability jointly with directional wave spectra from SWIM are available to investigate wave-ice interactions, which are not accounted in most of the climate models.The SWIM sea ice data have been used as a forcing in the wave model MFWAM in order to evaluate the impact on the wave forecast in polar oceans, particularly in the Marginal Ice Zone of Antarctica. Several model runs are performed in Austral and boreal summer. Validation of wave parameters such as Significant wave height from model runs has been performed with Sentinel-3 altimeter wave data. Comparisons of model integrated wave parameters with available drifting wave buoys have also been investigated.

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SHELF/DEEP-OCEAN INTERACTIONS IN THE SW ATLANTIC

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This presentation summarizes the main achievements of our efforts to characterize the interactions between the shelf and the deep-ocean circulation in the southwestern Atlantic. This region is one of the fundamental sources for the primary productivity cycle of the Southern Ocean. The SW Atlantic shelf is the largest continental shelf area in the Southern Hemisphere, exporting highly fertilized waters into the Southern Ocean. In this presentation we summarize the characteristics of these flows (volume transport, detrainment location, temporal variability, etc.) and identify their dynamical drivers. We show that the boundary currents surrounding the continental land mass (ACC, Malvinas and Brazil currents) regulate the shelf/deep-ocean exchanges by entraining, on the one hand, deep-ocean waters onto the northern and southern portions of the shelf and detraining, on the other hand, shelf waters from its middle region. These interactions generate a frontal system that extends from the shelf to the deep-ocean and which has no equivalent in any other region of the world ocean. Besides the transports of nutrients, the cross-shelf exchanges also carry large volumes of fresh water into the South Atlantic, thus creating a region with large SSS gradients. This presentation combines synergistic analyses of different types of satellite data, in-situ observations and model data produced by a suite of dedicated numerical experiments. Our analysis also considers the impacts of climate changes on the circulation and shelf/deep-ocean interactions of this region.

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ANALYSIS OF FINE-SCALE DYNAMICS IN THE BALEARIC SEA THROUGH HIGH-RESOLUTION IN-SITU OBSERVATIONS, MODELLING, AND SWOT SATELLITE DATA

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The FaSt-SWOT experiments aim to integrate SWOT measurements with in-situ observations from two high-resolution multi-platform field campaigns and advanced data assimilative models. The goal is to evaluate the satellite's performance, characterize fine-scale dynamics (10-100 km), and quantify associated horizontal and vertical transports. The FaSt-SWOT experiments were specifically designed to collect multi-platform in-situ observations within the swath of the SWOT satellite for validation, focusing on the area around the Balearic Sea. The campaigns took place in April and May 2023 and involved the simultaneous use of various ship-based instruments (CTD, Moving Vessel Profiler (MVP), thermosalinograph, ADCP, GoPros), autonomous platforms (surface drifters and gliders), and satellite observations (SST, ocean color, altimetry). The sampling location was defined a few days before the first experiment based on the presence of a remarkable small-scale anticyclonic eddy (~20 km diameter) detected in SST imagery and in the trajectory of a drifter within one of the SWOT swaths north of the Ibiza Island. Subsequent SST and ocean color maps showed the temporal evolution of the sampled eddy, which evolved into finer-scale features. Therefore, the context was ideal for analyzing SWOT's capability to detect this type of small structures.

This poster will present the results of a data integration approach that combines high-resolution in-situ observations collected during the FaSt-SWOT experiments, utilizing a Moving Vessel Profiler (MVP), a rosette CTD, an ADCP, and two gliders that conducted back-and-forth transects along the satellite swath. In particular, we will discuss the processing of ~ 1000 MVP profiles of temperature and salinity, along with the cross-calibration performed between CTD, MVP, and glider measurements. This step is crucial to ensure the provision of accurate and reliable quality-controlled observations. The integration also includes altimetric measurements, with a specific focus on the SWOT data provided during the experiments. Additionally, numerical models, such as the WMOP, with resolutions reaching up to 650 m, have been incorporated into the analysis.

The analysis and reconstruction of the field using these diverse datasets provide an overview of fine-scale dynamics in the study area, revealing detailed spatial and temporal patterns.

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THREE DECADES OF ALTIMETRY DATA RECORDS AND PROGRESS: GLOBAL WATER MEASUREMENTS OF SURFACE ELEVATION OVER LAKES, RESERVOIRS, WETLANDS, AND RIVERS

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The Global Water Measurements (GWM) system and web portal is a NASA/USDA funded program which offers recent and historical products of surface elevation variation for lakes, reservoirs, river reaches, and wetland zones. These are provided by a suite of satellite-based radar altimeters and potentially span up to 31 years in length. The program fulfills NASA requirements of creating long-term, high-quality, Earth Data Records, but also serves stakeholders including the USDA/Foreign Agricultural Service (for the Global Reservoirs and Lakes Monitor or G-REALM) applications), the US Geological Survey, USACE/NGA, and various Wetland-related organizations.
Progress to improve the surface elevations measurements over inland water bodies and the along track resolution (minimum water body width) includes exploration of: i) use of the Open Loop acquisition (DEM) mode, ii) the high resolution (Doppler) radar altimetry Range estimates, iii) the FF-SAR Range measurements, and iv) the high-resolution microwave radiometer-based wet tropospheric correction. Ongoing surface acquisition checks and feedback to the CNES continues to focus on the success or failure of the Sentinel-6 and Sentinel-3 on-board DEM's. This is done on a case-by-case basis, contributing to the improved DEM which is being updated once per year, though the potential of a new ICESat-2/GEDI DEM is being explored for a more global approach.
In addition, more recent observational parameters from the laser-based ICESat-2 mission, and the enhanced SWOT KaRIn instrument and the SWOT profiling radar altimeter (RA), are also being explored to meet various end user requirements and provide new products via the GWM and G-REALM portals. The profiling SWOT RA is to be integrated into G-REALM as per USDA's request to increase the number of lakes and global coverage being monitored. The ICESat-2 data continue to be used as a validation tool for radar-derived surface elevation products, but the laser measurements will be integrated into the GWM system for more high-latitude targets, to address complex lake dynamics (water storage variability) and river dynamics (discharge variability). It will further showcase the advantages of fusing lidar/radar datasets and test if SWOT/KaRIn data can be used to cross-validate the ICESat-2 measurements.

The resulting GWM measurements will be a combination of surface water level and slope, surface water extent, water storage and basin bathymetry, with a suite of Status Indicators which highlight deviations from long-term and seasonal averages. While ongoing Level3+4 surface water products are being directed by end user requirements, the overriding NASA objectives are to continue with the successful formation of high-quality Earth Data Records from multiple instrument platforms.

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MAPPING THE DIRECTIONAL SEA SURFACE SLOPES WITH SWOT AND ICESAT-2

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Over 70% of the world is covered by oceans, from which we for the most part lack high-resolution bathymetry maps, achievable from sonar. Observations from satellite altimeters are thereby a key part of the global mapping of the marine gravity field and bathymetry. Monitoring sea surface heights and sea surface slopes from conventional satellite altimetry enables us to determine the marine gravity field to a few mGals, however, improvements are challenging.

One major challenge lies in the sampling geometry, as conventional satellite altimetry observes along-track sea surface heights and relies on several passes to determine across-track sea surface slopes. This results in the north-south direction being better determined than the east-west direction. Therefore, being able to determine the directional sea surface slopes, we would achieve a large improvement in the ability to map the marine gravity field. With the new swath-altimetry achieved from the KaRIn instrument on the Surface Water and Ocean Topography (SWOT) satellite, we obtain 2-dimensional observations of the ocean surface. From these observations, it is possible to determine the directional sea surface slopes for a single pass.

Using this new SWOT level 2 data, we present directional sea surface slopes associated with underwater seamounts and observe major improvement in resolution with the use of SWOT data. To characterize these, we use observations from the ICESat-2 satellite. We utilize the geometry of the ICESat-2 satellite, which due to its three parallel beams is also able to characterize the across-track sea surface slopes. We determine the difference in sea surface height between the parallel beams to achieve along-track and across-track sea surface slopes. With this method, we achieve promising results, and we can therefore compare the two satellites SWOT and ICESat-2 at crossover points to determine the relative performance. The characterizing and validation of the new swath-data from SWOT is of major importance for the improvement of the global mapping of the marine gravity field.

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30 YEARS OF SEA LEVEL MULTI-MISSION REPROCESSED TO IMPROVE CLIMATE AND MESOSCALE SATELLITE DATA RECORD

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Since the launch of TOPEX/Poseidon 30 years ago, more than 15 other Altimetry missions were launched. They are operated by different agencies with different instruments and orbit. We learn a lot from these differences by comparing them all together. Our goal is to inter-calibrate all missions and provide as much as possible the same up to date corrections. It allows us to build a precise sea level at mesco-scale for level 3 CMEMS (Copernicus Marine Service) products and to have consistent time series in the last 30 years at climatic scales for C3S (Copernicus Climate Change Service).

30 years of sea level multi-mission were reprocessed and released early 2024. We present here the last improvements on sea level corrections (ocean tide, mean sea surface, ...), improvements on instruments algorithms (including level 2 reprocessing of most reference missions, among others). We show the inter-calibration method used to reduce regional inter-mission bias, and the contribution of the new regional reference mission Copernicus mission Sentinel-6A/Jason-CS. We show here how continuity of sea level observations is ensured into a fourth decade.

In the frame of the SALP (Service d’Altimétrie et de Localisation Précise) project supported by CNES (Centre National d’Etudes Spatiales) and of the Sentinel Marine Altimetry L2P-L3 Service (in cooperation agreement with EUMETSAT in the frame of the Copernicus Programme funded by the European Union) level 2P data are available to users for all the altimeter missions (TOPEX/Poseidon, Jason-1/2/3, ERS-1/2, Envisat, Saral/AltiKa, Sentinel-3A/B, Sentinel-6A, GFO, Cryosat-2, HY-2A/B, SWOT Nadir) on AVISO+(https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html) and L3 on CMEMS catalogue (https://marine.copernicus.eu).

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HOW FAR DOES RIVER FLOODING CHANGE THE MORPHOLOGY OF A FLOODPLAIN? A CASE STUDY USING UAV IMAGES ANALYSIS RELATED TO SENTINEL-3A SATELLITE ALTIMETRY ON THE ODRA RIVER, POLAND.

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This study is a part of a larger research project that includes regular Odra River observations at the virtual stations of the Sentinel-3A satellite. The fact that a flood event occurred in early 2024 provided an opportunity to observe how morphology of the Odra River floodplain changed.
In its middle section, the Odra River is a lowland river with small channel slope. Historically, its course was marked by a meandering pattern along almost the entire length of the valley. Nowadays, it is a regulated river with numerous anthropogenic, hydrotechnical structures within the channel and in its vicinity. The construction of flood embankments has prevented flooding of large areas. As a result, flood waves are shorter and water level on the floodplain between the embankments is higher. This increase in dynamics has a negative impact on the structure of the riverbed, floodplain, the banks and their nearest surroundings. Material carried by the river is accumulated in the flooded areas, the sections of the river with river groynes, may also be subject to small bank erosion, deepening of flood channels and dynamic sediment deposition into the bays between the groynes.
Regular (2021-2024) field campaigns were carried out on eight two kilometre-long sections of the river, which are ungauged river sections. As part of the field campaigns, close-range visible-light (RGB) aerial images were taken by unmanned aerial vehicles (UAV). The photogrammetric material was collected for the selected area and the preliminary studies were carried out. A number of numerical terrain models were created for the observed areas. An attempt was made to compare the elevation data. It was used as a starting point for investigations into changes in floodplain morphology. The results were compared with altimeter measurements to see if altimetric data captured the flood event. An attempt was made to compare the elevation data was a relationship with flood events. It was also investigated whether the changes were more pronounced after such an event. Initial studies show that altimetric water level measurements can help to determine from what water level height we can expect to see modifications in the floodplain morphology.
The research has been conducted in frame of the project no. 2020/38/E/ST10/00295 within the Sonata BIS programme of the National Science Centre, Poland

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THE OPERATIONAL FRAMEWORK OF THE SURFACE WATER AND OCEAN TOPOGRAPHY RIVER DISCHARGE

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The Surface Water and Ocean Topography (SWOT) mission, launched on December 16th, 2022, marks a significant milestone as the first satellite mission designed to monitoring Earth's continental waters. After a successful launch, SWOT started operations in its daily calibration-validation orbit for an initial 3-month period before transitioning to its scientific orbit, with a 21-day repeat cycle. This satellite mission holds the promise of revolutionizing hydrological science by providing crucial insights into river dynamics such as simultaneous water surface elevation, width, slope, as well as discharge, particularly for rivers exceeding widths of 50 meters. Notably, SWOT has unprecedented accuracy at reach-scale levels, achieving precision levels of 10 centimeters, 15%, and 17 millimeters per kilometer for elevation, width, and slope measurements, respectively. One of the most valuable outcomes of SWOT is the global product of discharge. It is estimated using SWOT discharge algorithms, which combine its measurements with ancillary global databases while leveraging various hydraulic approaches and advanced inverse methods.

To ensure timely production of these estimates at a global scale, discharge algorithms have been implemented on the Confluence computational engine, which runs the entire production chain on Amazon Web Service. Tests on the SWOT data have been performed on CalVal sites to assess its performance in capturing daily dynamics. Since SWOT discharge algorithms are applied at individual or contiguous sets of reaches between tributaries, Integrators are designed to harmoniously "integrate" reach-scale results across extensive river networks.

Acknowledging the diverse applications of SWOT discharge data, two distinct branches of discharge estimates will be disseminated: "gage-constrained" and "unconstrained" discharge. The "gage-constrained" discharge will be complemented by in-situ measurements, ensuring enhanced accuracy and reliability. Conversely, the "unconstrained" discharge will solely rely on SWOT measurements, providing valuable insights into ungaged basins where conventional in-situ measurements may be lacking. These two branches of discharge data aim to cater to a diverse range of applications, each meeting specific requirements in terms of accuracy and applicability.

With its unprecedented capabilities, SWOT promises to unlock new frontiers in hydrology. The new data will contribute to significant advancements in various fields and foster sustainable practices for the benefit of present and future generations.

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CLEV2ER: THE CRISTAL LEVEL-2 PROTOTYPE PROCESSORS AND R&D FOR LAND ICE AND INLAND WATER

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Satellite radar altimetry has provided a near-continuous record of Earth's topography for over three decades, delivering invaluable measurements of Earth's ice and inland water surfaces. From the pioneering measurements of ERS-1 in the early 1990s to the latest observations acquired by CryoSat-2 and the Copernicus Sentinel-3 satellites, this unique record has transformed our ability to monitor Earth's surface dynamics, leading to significant advances in our understanding of the environment under a changing climate. Scheduled for launch towards the end of this decade, the Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission represents the next generation of polar-orbiting radar altimeters. As such, it will introduce a number of innovations relative to its CryoSat-2 heritage, including a dual-frequency Ku-Ka radar altimeter, comprehensive Ku interferometric SAR acquisitions over ice surfaces, an increased bandwidth, and Open Loop tracking. These innovations will, ultimately, drive improved measurements and monitoring of various Earth system components, including sea ice thickness, ice sheet and glacier elevation, inland water level and ocean surface topography.

This presentation will introduce early results from the 'CRISTAL LEVel-2 procEssor prototype and R&D (CLEV2ER): Land Ice and Inland Water' study, which aims to (1) design and build the Level-2 thematic processor protoypes for land ice and inland water surfaces, and (2) support the further development, implementation and evolutions of the CRISTAL Level-2 product and algorithms, through the targeting of outstanding scientific and technical questions relating to these specific domains. Here we will report the progress achieved during the first year of the project, and also present preliminary findings from a number of the dedicated R&D studies. This work will support the continued development and increased scientific readiness of CRISTAL in the years leading up to launch and operations, as the mission progresses through Phase C/D/E1.

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ENHANCED ICEBERG MEASUREMENTS FROM CRISTAL MISSION

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The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission, planned to be launched in 2027 has as main payload a dual Ku/Ka-band altimeter, interferometric in Ku, with specific transmission pulse sequences designed to enhance the performances over sea and land ice. The mission plans to have OB (Open Burst) SARIn acquisitions over sea ice and iceberg zones, taking onboard heritage interferometric capabilities from CryoSat-2, and continuous transmission-reception pulse by pulse from Sentinel-6 Michael Freilich. Thanks to the open burst, Fully Focused processing can be incorporated into the operational L1 production yielding enhanced along track resolution capabilities.

For iceberg measurements, with reference to the current methods described in [Tournadre et al. 2008], CRISTAL will have clear capabilities. The use of Fully Focused (FF) waveforms instead of Unfocused opens the door to improved retrieval of the shape of the icebergs. This can be already explored in Sentinel-6 data over icebergs. Fully Focused Multilooked waveforms can be generated at very high along-track resolution, for instance every 10 metres, whereas the unfocused SAR waveforms will have the nominal 300 metres resolution. This increase in resolution will help address both iceberg detection and volume change user requirements. The combination of FFSAR and interferometric acquisition at Ku band allows in principle the estimates to be extended in the across-track direction, and further R&D activity is foreseen to exploit the Ka band waveforms together with FFSARin waveforms at Ku band.

Within the CLEV2ER Sea Ice and Icebergs project for the design and implementation of the Ground Prototype Processor (GPP), state-of-the-art algorithms for iceberg detection and volume estimation are being included in the GPP as part of the first development iteration. This allows an early assessment of the performance of these algorithms with data simulated or adapted from other missions. These algorithms will be further tuned to CRISTAL data, and detection and estimation methods suitable for FF-SARIn data will be developed.

In this work we will present the assessment of the CRISTAL iceberg detection and volume estimation performances based on the combined use of CyoSat-2 and Sentinel-6 together with CRISTAL simulated data.

[1] Tournadre, J., K. Whitmer, and F. Girard-Ardhuin (2008), Iceberg detection in open water by altimeter waveform analysis, J. Geophys. Res., 113, C08040, doi:10.1029/2007JC004587.

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CRYO-TEMPO: EXPANDING THE RADAR ALTIMETRY PORTFOLIO WITH CRYOSAT-2 THEMATIC PRODUCTS OVER LAND AND SEA ICE, POLAR AND COASTAL OCEANS, AND INLAND WATERS

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Since its launch in 2010, CryoSat-2 has continued the long-term radar altimeter record, and provided over a decade of measurements with which to monitor and understand our changing planet. With its unique orbit and payload, not only has CryoSat-2 far exceeded its primary mission objectives over both land and sea ice, but it has also delivered scientific and methodological advances across a diverse range of applications. Although these datasets have historically been processed by ESA to Level-2, following consultations with the wider community, it has become increasingly clear that there is significant untapped value that can be realised by expanding the user-base through the development of dedicated L2P Thematic Products. Crucially, this requires simplified, agile and state-of-the-art products and processing flows, which deliver an easy-to-use dataset whilst maintaining the native along-track sampling of the original Level-2 products. Thus, ESA has embarked on a new path towards developing CryoSat-2 Thematic Products, which aim to drive further innovation and exploitation, and have created a model that has now been replicated across other radar altimeter missions.

Here, we present the latest results from Cryo-TEMPO, an ESA-funded study that began in October 2020 with the goal of delivering a new era of innovative CryoSat-2 Thematic Products over five domains; land ice, sea ice, polar ocean, coastal ocean and inland water. The over-arching objectives of Cryo-TEMPO are (1) to implement dedicated, state-of-the-art processing algorithms over each thematic domain, (2) to develop agile, adaptable processing workflows, that are capable of rapid evolution and processing at high cadence, (3) to create products that are driven by, and aligned with, user needs; thereby opening up the data to new communities of non-altimetry experts, and (4) to deliver transparent and traceable uncertainties associated with each thematic parameter. In this poster presentation we shall provide an overview of the project, a review of the current generation of these thematic products, and a look forward to the evolutions that are being implemented within the next phase of the study.

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A 30-YEAR RADAR ALTIMETRY RECORD OF ICE SHEET ELEVATION AND MASS CHANGE

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The response of the ice sheets to changing environmental conditions is a key climate variable and critical to determining the ice sheet contribution to global mean sea level. The UK Centre for Polar Observation and Modelling (CPOM) has been at the forefront of this endeavor, monitoring ice sheet elevation, volume and mass changes over Greenland and Antarctica using the long term record of satellite radar altimetry spanning ERS-1, ERS-2, Envisat, CryoSat-2 and Sentinel-3. Here, we present the comprehensive datasets generated by CPOM using satellite radar altimetry within the context of the UK's Earth Observation Climate Information Service, and provide analysis of the ongoing changes of Earth's ice sheets.

In this presentation, we provide an overview of our datasets, including data sources, spatial and temporal coverage, and potential applications. Our ice sheet-wide datasets over Greenland and Antarctica span three decades enabling the identification of long-term trends. We make use of the latest satellite altimetry products, including ESA's CryoSat ThEMatic PrOducts (Cryo-TEMPO), the Sentinel-3 Thematic Ice Sheet product, and the ERS-1, ERS-2 and Envisat Fundamental Data Records for Altimetry (FDR4ALT) products, in order to quantify ice sheet elevation and mass change over the past three decades. We also utilise the elevation change datasets to demonstrate how other important geophysical information can be retrieved, such as estimates of seasonal elevation change and runoff that have been developed within ESA's Earth Observation for Surface Mass Balance and 4D-Greenland projects.

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A FAST-TIME COMPLEX CORRECTION FOR THE END-TO-END RANGE IMPULSE RESPONSE OF THE SENTINEL-3 AND SENTINEL-6 ALTIMETER SYSTEMS

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Continuing the work presented at 12th Coastal Altimetry Workshop by Abileah & Vignudelli [1], we studied a fast-time complex correction to the end-to-end range impulse response (RIR) of the Sentinel-3 and Sentinel-6 altimeter systems.

This complex correction can calibrate any instrumental and antenna distortions out over the whole mission time (like RIR asymmetries, RIR main-lobe widening, antenna imperfections, etc.) and hence is expected to improve the quality and fidelity of the end-to-end RIR of the altimeter system.

The first step of this correction consists in the estimation of the amplitude and phase distortions of the CAL1 internal path. This is performed by means of the CAL-1 SAR I/Q calibration data, estimating the fast-time (i.e. in range) amplitude and phase distortions over the mission time and comparing it with the ideal PTR amplitude and phase.

The impact of the CAL1 component is very different between the SRAL and POS4 cases. Given the digital architecture of POS4 altimeter, the POS4 CAL1 phase distortions are (as expected) negligible and steady in time, with a peak-to-peak error in Ku-Band of around 1 degree. In the case of SRAL, the CAL1 phase distortion resembles a steady (in time) parabolic-shape curve, with peak-to-peak error in Ku-Band of around 10 degrees [2].

The second component of the end-to-end correction is composed by the antenna amplitude and phase distortions, as these have been measured in the pre-launch antenna characterization test reports. The final end-to-end complex correction is computed as the inverse of the estimated CAL1 + antenna amplitude and phase distortions.

This final complex correction has been applied to a theoretical squared sinc function (i.e. ideal RIR) and compared to the end-to-end RIR currently observed over corner reflector (CR) in Fully-Focused SAR, once this latter one has been averaged for several CR passes.

The performances over CR and natural targets (Salar Uyuni, Etosha Pan) will be presented to demonstrate the improvements provided after the correction is applied.

The findings of this study lead to revisiting the internal calibration strategy for future altimeters, and to reevaluate the current processing approach for CAL1 in the on-ground processors.

[1]: R. Abileah, S. Vignudelli: A phase error in Sentinel-3 Individual Echoes, and how to correct the error in post processing, 12th Coastal Altimetry Workshop, Cadiz, 2023

[2] Salvatore Dinardo; Ron Abileah; Stefano Vignudelli; Walter H.F. Smith; Bruno Lucas; Remko Scharroo. A Fast-Time Amplitude and Phase Correction for the Global Range Impulse Response of the Sentinel-3 Altimeter System, 8th Sentinel-3 Validation Team Meeting, Darmstadt , December 2023

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COASTAL EVALUATION OF THE FIRST THREE YEARS OF SENTINEL-6MF HIGH-RESOLUTION WET TROPOSPHERIC CORRECTION

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In orbit for more than three years, Sentinel-6 Michael Freilich (S6MF) satellite carries the Advanced Microwave Radiometer for Climate (AMR-C) for the estimation of the wet tropospheric correction (WTC) of S6MF altimeter observations, with channels at 18.7, 23.8 and 34 GHz. Compared to the previous reference missions, this instrument contains additionally a High-Resolution Microwave Radiometer (HRMR) with channels at 90, 130 and 166 GHz, allowing a better spatial resolution for enhanced measurements of atmospheric parameters in coastal zones. The current S6MF radiometer products in baseline F08 provide two different WTC fields: amr_wet_tropo, computed from AMR measurements alone, and rad_wet_tropo, computed from the combination of AMR and HRMR measurements.
Motivated by this new high-resolution WTC, this study aims at inspecting the differences between the two provided corrections and evaluating the actual impact of the HRMR in the retrieval of the WTC over coastal regions. For this task, S6MF Climate-quality AMR Level 2 NTC (Non-Time Critical) Products, at 20 Hz, from EUMETSAT Data Store have been used, available since the start of mission. This study includes three main parts: 1) assessment of the availability of each WTC; 2) analysis of the differences between them, mainly function of distance to the coast; and 3) evaluation of these differences when compared with independent data, e.g., from GNSS coastal stations and with a GPD+ WTC.
Regarding the availability of the WTC computed with a combination of AMR and HRMR over coastal zones (coastal processing), the data analysis shows that about 10% of the rad_wet_tropo estimates are derived only with AMR data (rad_wet_tropo equals amr_wet_tropo), which means that the remaining about 90% of the S6MF coastal measurements incorporate HRMR data.
Concerning the differences between the two provided corrections, the global differences are small, however with a maximum RMS value of 0.9 cm for distances to the coast in the range 5-10 km. For distances to the coast smaller than 5 km or larger than 100 km, this RMS is 0.3 cm or less.
Additionally, an independent non-collocated comparison with GNSS-derived WTC is performed over coastal regions. This comparison reveals that, for distances from coast in the range 0-5 km, the two S6MF-derived WTC are not significantly different, and for distances to the coast in the range 5-20 km the correction with HRMR shows an improvement, when compared to the corresponding correction using only

AMR data. This independent comparison reinforces the previous inter-comparison, showing that the most significant impact of including the HRMR occurs for distances to the coast ranging from 5 to 20 km. Comparisons with an updated GPD+ WTC are also shown, evaluating the small land impact still present in the two S6MF WTC.
The current assessment of the new S6MF WTC, during its first three years in orbit, confirms the better performance of AMR-C, mainly at coastal zones, attributed to the better spatial resolution provided by the HRMR. In spite of these improvements, both S6MF WTC reveal a small land contamination for the distances to coast smaller than 10 km, not observed in GPD+.

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PRODUCING ICE SHEET SURFACE ELEVATION CHANGE TIME SERIES WITH KALMAN FILTERING

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Generating accurate estimates of ice sheet surface elevation change (SEC) is crucial to our understanding of the impact that ice sheets have on sea level rise. The 30-year radar altimetry record is one of our best resources for assessing these continental-scale changes spanning multiple decades. Conventionally, altimetry-derived SEC time series for ice sheets are computed by fitting a polynomial model to repeated measurements within small ice sheet regions for a single satellite mission. However, with the presence of multiple synchronously orbiting altimeters, there is now the opportunity to employ more advanced statistical methods capable of assimilating measurements from various sensors while acknowledging disparities in uncertainties. Here, we display results from work to develop one such approach, which employs Kalman filtering to fuse data from multiple sources.

The Kalman Filter is a recursive algorithm for estimating the states of dynamic systems where the true state is unobservable. This is achieved by integrating state predictions with noisy observations over time, thereby providing optimal estimates of a system's state. First devised in the late 1950s, the Kalman Filter and its extensions have found widespread use in various fields, including Earth System Science. Four-dimensional local ensemble transform Kalman filters have been used in atmospheric science for generating time series of spatiotemporally chaotic systems, and we aim to employ a similar technique for our applications to the cryosphere.

In this study, we present a novel approach for generating ice sheet SEC time series from radar altimetry data, utilising spatially localised Kalman filtering/smoothing and Gaussian mixture model approximations. We demonstrate this technique using CryoSat-2 radar altimetry measurements over the Greenland Ice Sheet from the European Space Agency's Cryo-TEMPO Baseline-B dataset. The results will be assessed with two case studies over areas with different climatological regimes: (1) Greenland Summit and (2) Russell Glacier, making intercomparisons with existing approaches and validating against in situ observations. If successful, we hope this work will form the basis of a new framework for assimilating other current and historical missions to produce a single collective time series of SEC over ice sheets.

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30 YEARS OF CALIBRATION WITH TRANSPONDERS

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From ERS-1 to Sentinel-6, altimeter missions progressively utilise ground transponders for calibration and validation during commissioning and routine operation. These systems are crucial for verifying performance and maintaining altimetry product quality through regular monitoring with independent data.

Over 30-years, significant advancements have been made in transponder technology that have made it possible to extend the Cal/Val network.

The Svalbard transponder was developed by RAL in 1987 to investigate the feasibility of using a transponder with the Geosat altimeter, in preparation for ERS-1. Although its feasibility was confirmed, it wasn't part of the ERS-1 altimeter calibration campaign. Instead, it was utilized by RAL for scientific research before being stored. Years later, it was refurbished at ESTEC and relocated to Svalbard in 2005. Prior to the CryoSat launch, it was briefly used for Envisat passes, highlighting the importance of transponder-altimeter polarisation alingnment. Following the CryoSat launch failure, it was stored in Longyearbyen until shortly before the CryoSat-2 launch.

Crete and Gavdos islands have become the Permanent Facility for Altimeter Calibration (PFAC) following the Fiducial Reference Measurement Standards. Back in 2003, the first transponder, property of the Austrian Academy of Sciences (AAS), was deployed in Gavdos (Dias) in support of ERS-2, Envisat and Jason. Data processing was carried out by a team from the AAS, Technical University of Crete (TUC), ESA and CNES. In 2013, a second transponder was manufactured by TUC. It was initially installed near the university and moved to its permanent Crete (CDN1) site in 2015. It has been the main absolute Cal/Val site for Sentinel-3A and 3B for range measurement and for CryoSat-2, Jason-2&3 and Sentinel-6. Finally in 2021, a new range & σ0 transponder, manufactured by Space Geomatica, was installed in Gavdos (GVD1) to replace the old one and enhance the calibration of Sentinel-6 and Sentinel-3A.

Also in 2021, the Catalina transponder, developed by JPL, incorporated the innovative approach to calibrate both Ku and C bands at the same time, for both range and σ0. It has been used primarily to calibrate Sentinel-6 and Jason-3 and can also cover Sentinel-3A and SWOT Nadir Altimeter.

Finally, the σ0 transponder, designed at ESTEC/ESA in 2001, and used during the Envisat Commissioning phase (March – December 2002) in the Nederland, for σ0 absolute calibration. Successively, it was operated by Sapienza University of Rome in two different phases: 2004-2005, it was moved around four sites near Rome each time Envisat overpassed them, and then between 2006-2010, it was installed in a permanent site over the centre of the city. It was refurbished by RAME in 2019 and it has been used for both Sentinel-3A and 3B, firstly during a preliminary campaign in 2020 and since February 2023 in the permanent location near Leonessa, Italy.

This presentation will give comparison between the different sites, systems, and the results that they have been providing for the different missions. By examining how calibration systems have changed over time, we can understand our past achievements and anticipate future capabilities in calibrating altimeter measurements, showcasing its significance.

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SYNTHESIZING NADIR ALTIMETRY AND SST USING DEEP LEARNING IMPROVES THE RESOLUTION OF GLOBAL SSH MAPS

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In recent years, there has been an intense community effort to improve the resolution of gridded (L4) altimetry products derived from multi-mission nadir altimetry. The linear interpolation algorithms used in the creation of existing operational products (e.g. DUACS) smooth the mesoscale eddy field both in space and time owing to the sparsity of nadir observations. Among the recently-proposed algorithms for improved SSH mapping, two families of methods have emerged as particularly promising avenues: (i) data-driven methods that allow the optimal mapping to emerge objectively from the data, and (ii) methods that exploit synergies between altimetry and other surface ocean tracers (e.g. SST) to reconstruct eddies between altimeter tracks. Deep learning methods can exploit both (i) and (ii) and have proven especially effective in regional proof-of-concept studies. However, it remains to be demonstrated that this impressive performance in regional studies can be translated into improved global altimetry products. Global mapping poses a significant challenge to deep learning approaches since they need to be able to generalise across the wide range of dynamical regimes present in the global ocean.

Here, we present a new global SSH product that uses deep learning to synthesize SSH and SST observations to better map mesoscale eddy dynamics. We trained a deep learning neural network to map SSH from nadir altimetry and SST using real-world observations alone, with no pre-training on synthetic observations from numerical simulations. We demonstrate that the resulting data-driven global SSH maps have lower mapping errors and higher effective spatial resolution, resolving wavelengths up to 30% smaller than DUACS in eddy-rich regions. This enhanced resolution reveals a strong seasonality of eddy dynamics in the small mesoscale range with an associated seasonal upscale kinetic energy cascade. In the subtropics, qualitatively different eddy dynamics emerge in our maps compared to DUACS, with a strongly interacting eddy field rather than a uniform westward propagation of eddies. Further, we show that exploiting the SSH-SST synergy significantly improves the altimetry mapping for periods when only 2 nadir altimeters are operational, as was the case for most of the 30-year altimetry era. We also propose a new metric that relates the spectral characteristics of the mapped signal to an equivalent coarse-graining filter, aiding the interpretation of coarse-graining analyses (e.g. for kinetic energy cascade diagnosis). This study demonstrates that deep learning approaches can significantly enhance operational global gridded altimetry products which will help to shed new light on ocean eddy dynamics.

Associated pre-print: Martin, S. A., Manucharyan, G. E., Klein, P., "Deep Learning Improves Global Observations of Ocean Eddy Dynamics", under review, https://doi.org/10.31223/X5W676

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COMBINING FULLY FOCUSED AND SWATH PROCESSING FOR GLACIER APPLICATIONS

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High PRF altimeters transmit pulses at a high pulse repetition frequency thus making the received echoes suitable for coherent processing on-ground.

Conventional delay-Doppler processing (commonly called Unfocused SAR-UFSAR or High Resolution) coherently integrates echoes in a burst-by-burst basis to provide single look waveforms referred to a specific ground location, which after being correctly aligned (compensating for the slant-range migration, among others) can be incoherently averaged, increasing the performance in terms of the speckle reduction and the along-track resolution compared with the traditional Low Resolution Mode and in turns in terms of geophysical retrieval.

The Fully Focused SAR processing (FFSAR) moves one step ahead and intends to coherently integrate the echoes over a time longer than a burst to get an even higher along-track resolution with an improved speckle reduction with respect to UFSAR.

The Open Burst (or interleaved) transmission mode to be implemented in Sentinel-6 and the Copenicus polaR Ice and Snow Topography Altimeter (CRISTAL) missions makes more suitable the exploitation of the FFSAR thanks to the uniform along track sampling of the scene. However, in the conventional Closed Burst mode (like in CryoSat-2), replicas induced by the non-uniform sampling of the Doppler spectrum will be mixed with the main echo and, in most cases, will not be able to be filtered out.

Swath mode processing has been used to monitor elevation of areas with complex topography such as over ice sheet margins, ice caps and mountain glaciers, improving upon the resolution of conventional radar altimetry. Swath mode relies on an accurate angle of arrival of the measured echo, this is obtained from the SAR Interferometric mode of CryoSat-2 and CRISTAL and post-processing strategies resolving the ambiguous nature of the phase measurement.

The CRISTAL Mission will include Open Burst and Interferometric capabilities. It will be the first altimeter to be able to combine both methodologies to increase both the along and across-track resolutions improving the current performances of CryoSat-2 over small glaciers that can't be observed properly.

In this poster we present the first results from the assessment and impact of the combined Fully Focussed and Swath solution within the CLEV2ER Land Ice & Inland Water project.

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GLOBAL MARINE GRAVITY RECOVERY USING SWOT WIDE-SWATH ALTIMETRY

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[1]Ucsd

The Surface Water and Ocean Topography (SWOT) is a wide-swath satellite radar altimetry mission observing global water body elevation with unprecedented detail. Over the ocean, each SWOT cycle can deliver gravity anomalies with an accuracy of 2.7 mGal and a spatial resolution of 14 km. Our analysis of 90 repeat measurements, collected during the 1-day repeat orbit phase, demonstrates a substantial improvement in resolution (8 km) and accuracy (1.2 mGal) after stacking 60 repeat passes [Yu and Sandwell, in review, 2023].

There are two issues with the current SWOT L2 data products that result in less than optimal global gravity recovery. The first issue is only 88% of the oceans are covered because the outer edges of each swath have strong filter edge effects. The second issue is that the cross-track sea surface gradient is contaminated by systematic variations associated with the antennae phase screen. We have developed methods to improve both issues, achieving 98% ocean coverage at better than 2 mGal accuracy. The results will be presented as a new high-resolution global grid of vertical gravity gradient (i.e., ocean surface curvature) to reveal previously uncharted details of the seafloor, including thousands of uncharted seamounts.

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CRISTAL SEA ICE AND ICEBERG L2 PROCESSING: BASELINE APPROACH AND NEW DEVELOPMENTS

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The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) is a satellite system developed as part of the European Union Copernicus program expansion activities. Main objective of the CRISTAL mission design is to measure and monitor variability of Arctic and Southern Ocean sea ice thickness and its snow depth.

Built on the heritage of CryoSat, the CRISTAL instrument technical solution is based on a dual-frequency synthetic-aperture radar altimeter with interferometric capabilities at Ku-band and a second Ka-band frequency. Moreover, CRISTAL will be equipped with a passive microwave radiometer to aid in atmospheric corrections and surface-type classification.

The features of the CRISTAL instrument will enhance our ability to estimate geophysical parameters: (i) better precision for sea ice freeboard and along-track resolution, exploiting the open-burst chronogram and the FFSAR processing on-ground, (ii) the capability to detect leads across tracks through interferometric acquisitions and (iii) retrieval of snow thickness by analysing scattering range at both Ku- and Ka-bands.

The CRISTAL Level-2 ground processor prototype in the sea ice domain will implement the geophysical retrieval algorithms for the following variables: sea ice freeboard, sea ice thickness, snow depth over sea ice, ice shelves thickness, iceberg distribution and volume. To achieve the Mission performance objectives, advanced geophysical retrieval algorithms for sea ice and icebergs are needed to be defined so that the CLEV2ER activity will carry on R&D studies to support the definition and implementation of the retrieval algorithms. Such R&D studies are geared towards addressing current scientific inquiries regarding sea ice retrieval in the context of CRISTAL: (i) evaluating variations in sea ice thickness derived from Ku-band and Ka-band altimetry resulting from differing penetration depths in snow cover on sea ice, (ii) enhancing the quantity of sea surface height measurements in regions covered by ice through the utilization of multi-peak waveform retracking and swath processing, and (iii) expanding the capacity to retrieve geophysical data in challenging sea ice conditions

As part of the activity, a Transcoding tool has been developed in order to adapt L1B data from other altimeter into the CRISTAL L1B format so their products can be used to emulate L2 products and derive the performances.

This presentation will detail the overall project approach, status and the expected outcomes from the research tasks.

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A PERFORMANCE ASSESSMENT TOOL (PAT) TO EVALUATE CRISTAL END-TO-END PERFORMANCES

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The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) Expansion mission, planned to be launched in 2027, will incorporate a dual Ku/Ka-band interferometric altimeter with specific transmission pulse sequences designed to enhance the performances over sea and land ice. The open burst mode will enable the generation of Fully Focussed products over sea ice with snow depth retrievals derived from the Ku/Ka range differences instead of taking them from external auxiliary data. In the same way as in CryoSat-2, the closed burst interferometric mode over land ice will allow the generation of swath elevations for the full Greenland and Antarctica, improving the current coverage of the CryoSat-2 swath products that are only produced in the ice margins.

At this stage of the mission design, the expected performances are being evaluated against the requirements to verify the effectiveness of the mission configuration and assess its compliance. In this framework, an end-to-end validation environment has been designed. It is composed of the System and Instrument Simulator (SIS), in charge of generating datasets for the different scenarios relevant for the mission performance assessment, the Ground Processor Prototype (GPP), including L1 GPP and geophysical retrievals (GR) to process the simulated data and the Performance Assessment tool (PAT), designed to test and verify the scientific requirements.

The PAT closes the end-to-end chain as it will cross-check each geophysical parameter generated by the GPP against the corresponding requirement, starting from the knowledge of the simulated parameters, assessing and validating the end-to-end performance chain.

Firstly, the PAT uses specific algorithms to read the variables of the different input files (L1A, L1B, GR, and auxiliary). Secondly, five scenario modules analyse the five types of scenarios: point target, land ice, sea ice, open ocean, and inland waters. Finally, the PAT generates a csv file containing the information of all the requirements which are being checked for the current validation scenario under analysis.

Each module has a list of possible requirements to be checked and from those, only the ones indicated in the Validation Plan are checked for the corresponding scenario. Examples of parameters analysed are: for the point target module, the range and dation bias of LR, HR and L1B-S products or peak power side lobes ratio for Fully Focussed products; for the land ice module, the along-track resolution for glaciers and ice sheets and elevation uncertainty; fort the sea ice module, sea-ice thickness along-track resolution, first-year ice thickness uncertainty, width lead elevation, or iceberg freeboard; for open ocean, SSH uncertainty, σ0 and range random error, or wind speed uncertainty, and for inland waters only water surface height uncertainty.

The poster will describe the PAT design and provide some example outputs for the analysis of different TDS validation.

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CRISTAL PERFORMANCE ASSESSMENT: AN END-TO-END SIMULATION APPROACH

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The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) Expansion mission, planned to be launched in 2027 will incorporate a dual Ku/Ka-band interferometric altimeter with specific transmission pulse sequences designed to enhance the performances over sea and land ice. The open burst mode will enable the generation of Fully Focussed products over sea ice with snow depth retrievals derived from Ku/Ka waveforms comparison instead of taking them from external auxiliary data. In the same way as in CryoSat-2, the closed burst interferometric mode over land ice will allow the generation of swath elevations for the full Greenland and Antarctica, improving the current coverage of the CryoSat-2 swath products that are only produced in the ice margins.

At this stage of the mission design, phase C/D, the expected performances are being evaluated against the requirements to verify the effectiveness of the mission configuration and assess its compliance.

In this framework, an end-to-end validation environment has been designed. It is composed of the System and Instrument Simulator (SIS), the Ground Processor Prototype (GPP), and the Performance assessment tool (PAT).

Following the validation plan defined during the first stage of the project, the SIS will be in charge of generating datasets for the different scenarios that are foreseen to be of interest for the mission performance assessment (e.g. point targets, sea ice with different snow properties, ice sheet with small slope and uniform snow and ice characteristics, glaciers with different size, slope, and orientations, ocean tracks with different SWH and wind conditions, river and lakes for specific size and geometry)..

The GPP will process the instrument science data packets using different processing chains to ensure compliance with the functional and performance requirements. It is composed among others of Level1 Calibration chains, Level1 Low Resolution chains (LR-RMC, LR Over-Sampled, and the conventional LR), Level1 Delay Doppler chain, Level1 Fully Focussed chain, Level2 retrackers module (compilation of different retrackers tailored for the different thematic surfaces), Level2 Geophysical corrections and retrievals (translating the information from the retrackers into sea ice, land ice, ocean and inland waters measurements). Calibration data measured during the instrument characterisation can be processed and analysed to ensure the quality of the point target response echoes.

The PAT is in charge of closing the end-to-end chain: it will cross-check each of the geophysical parameters generated by the GPP against the corresponding requirement, starting from the knowledge of the simulated parameters, assessing and validating the end-to-end performance chain.

This presentation will give an overview of the expected performances of the CRISTAL mission based on the end-to-end validation activity carried out in this project.

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INVESTIGATION OF SWOT ALTIMETRY FOR THE IMPROVED MARINE GRAVITY FIELD OFFSHORE THE WESTERN AUSTRALIA

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Before the SWOT satellite altimetry mission, the marine gravity field relied heavily on conventional altimeters' geodetic phases. Compared to conventional altimeters, SWOT is more efficient and brings cross-track geoid gradients due to its high resolution and two-dimensional sea surface height observations. We investigated the marine gravity field using so far available cycles of SWOT L2 and L3 data products over the Indian Ocean offshore the Western Australia. The deflections of the vertical (DOV) in north and east directions were determined by multi-direction geoid gradients and then used to determine gravity anomalies by the Inverse Mening Meinesz formula. The results show that there are obviously residual errors in SWOT L2 data, which affect the DOV estimates, especially roll errors affecting the east-west DOV component. The SWOT long-wavelength error, appearing in the along-track (or nearly north-south) direction, predominates the DOV components.The residual instrumental error seems to have been corrected in SWOT L3, and the error does not appear in the SWOT L3-based DOV estimated. The DOV and marine gravity anomalies are improved by using multi-directional geoid gradients, which reveal small-scale details of seafloor in the study area.

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CONGO RIVER BASIN'S HYDROCLIMATOLOGY AND ITS LINK WITH CLIMATE VARIABILITY UNRAVELED FROM SPACE

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As the second-largest watershed and tropical forest worldwide, the Congo River Basin (CRB) is of global significance for biodiversity and the water and carbon cycles. However, it remains among the least studied regions globally due to the lack of adequate in situ observations over space and time.
Therefore, CRB's hydroclimatology, its freshwater availability, distribution and variability remain relatively unknown. Here, we characterize the CRB's surface hydrology using a robust approach based on a multi-scale combination of in situ and remote sensing measurements, in particular altimetry-derived observations, along with hydrological modeling.
First, we built an extensive database (a total of ~2,300 virtual stations) of long-term time series (more than 20 years) of water levels (WL) from satellite altimetry, validated using an unprecedented in situ database across the basin (root mean square error varying between 10 cm to 75 cm across the altimetry missions). This unique dataset revealed the great spatial and temporal variability of CRB's surface hydrology, especially its annual amplitude of surface water levels across the entire basin and sub-basins. We estimate, for the first time, using time-lag time correlation, the water time travel across the basin and the relative contribution of each sub-basin to the outlet of the basin, characterized by a bimodal hydro-climatic regime. In parallel, Surface Water Extent (SWE) from the Global Inundation Extent from Multi-Satellite (GIEMS-2) in the basin are assessed in the Cuvette Centrale and large wetlands of the Lualaba sub-basin. Secondly, the combination of altimetric water levels, SWE and digital terrain models enabled to estimate interannual variations of Congo basin's surface water storage (SWS) over the period 1992 to 2015. The mean annual amplitude of the monthly SWS anomaly over wetlands, floodplains, rivers and lakes in the CRB has been estimated at ~101 km3. Furthermore, we are able to characterize the impact of extreme events on freshwater resources in the CRB. The illustration of the exceptional drought of late 2005 and early 2006 showed significant negative anomalies of SWS, with a deficit of up to ~40% compared to the long-term SWS average. Water level's time series confirm the extension of these extreme negatives anomalies up to the lower Lualaba basin.
Finally, building on the previous results, this study helped the development of a calibrated hydrological-hydrodynamic MGB model over 1981 to 2020 at daily scale that can be updated to present. This provides a >40-year reconstruction of hydrological simulation over the entire CRB offering an unprecedented representation of hydrodynamics at different spatial and temporal scales of the basin. This long-term series has enabled us to establish the teleconnections between extreme drought and flood events, and large-scale processes such the variability sea surface temperatures and El Niño phenomena.
These results contribute to a better understanding of the overall functioning of the Congo Basin and its links with large scale processes and demonstrate the capacity of remote sensing coupled with hydrological modeling to further improve the management of the basin's water resources.

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A KALMAN-BASED APPROACH TO SIMULTANEOUSLY ESTIMATE REGIONAL VERTICAL LAND MOTION AND MISSION-SPECIFIC SYSTEMATIC ERRORS USING COMBINED ALTIMETER, TIDE GAUGE, AND GPS RECORDS

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Many studies have sought to integrate absolute sea-level from altimeters (ASL, ALTs) and relative sea-level from tide gauges (RSL, TGs) to investigate vertical land motion (VLM) along the coastlines. Previous studies often assume the VLM is linear and regional geographically correlated errors in altimetry records are negligible. We developed a Kalman filtering and smoothing approach to simultaneously quantify the TG-specific VLM and altimeter-specific systematic errors at regional-scales. We assimilated specific datasets from multi-mission altimeters, long-running TGs, and permanent GPS sites since the early 1990s wherever available. We did this while including the space-time covariances and time-correlated errors within the observational series of altimeter minus TG, tandem and dual crossovers, and GPS heights. We evaluated the performance of three variations of the approach to study regions including the Baltic Sea, Australia, and South America expanding to the Antarctic Peninsula. We quantified the long-term variability of VLM across the TG lifespans in the Baltic Sea and around Australia, typically ~1.1 mm/yr (but up to ~4.5 mm/yr), that otherwise cannot be inferred from spatially interpolated GPS velocities or from predicted GIA rates. We examined the capabilities of the method in determining time-variability in VLM in terms of co- and post-seismic deformation in the Chilean subduction zone, and ongoing ice-mass loss in the Antarctic Peninsula. We detected small but significant trends in systematic errors in the regional altimetry data within a typical range of ~0.5-2.5 mm/yr over mission lifespans. Appropriately capturing these systematic errors narrowed the deviation between the ASL estimates inferred from the TG and close by ALT records, reducing the RMSE of the differences by ~40%. Here we review our approach, present the key findings, and discuss potential limitations of the technique including unresolved differential oceanographic signals between the ALT and TG measurement locations that can in part be mitigated by incorporating non-reference-mission measurements close to the TGs. In summary, we found that the developed approach advances the ALT minus TG technique to estimate VLM at TG locations, and places bounds on regional altimeter-specific systematic errors. Our approach further provides the ability to estimate sudden changes and significant non-linear signals in VLM at TGs. Such VLM estimates can subsequently be used to improve geophysical interpretation following their use as new constraints in inverse geophysical modelling applications given the sparsity of early GPS-based VLM records across space and time.

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30 YEARS OF IN SITU ALTIMETER VALIDATION: RESULTS AND PERSPECTIVES FROM THE BASS STRAIT FACILITY

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The Bass Strait altimeter validation facility (~ 40° 39'S, 145° 36' E) has provided cycle-by-cycle estimates of absolute altimeter bias since the launch of TOPEX/Poseidon in 1992. The site has since evolved to provide ongoing in situ validation of the reference missions (now Sentinel-6 Michael Freilich), in addition to Sentinel-3A, Sentinel-3B and SWOT. The facility uses a direct geometric approach to validation that involves maintaining an in situ network of sensors including moored oceanographic instruments, GNSS equipped buoys, a coastal tide gauge and continuously operating GNSS reference stations. Outputs from the facility highlight the need for holistic and sustained observation of the ocean, the solid Earth, and atmosphere in order to probe altimeter performance in this shelf-sea coastal region. Observations made directly at mission-specific comparison points avoid the need for extrapolation and yield highly precise estimates of altimeter bias over time.

Here we review the drivers for in situ absolute validation alongside the relative approach involving the global tide gauge network. We detail our results from Bass Strait for all missions including the latest GDR-F data from TOPEX and the most recent releases of SAR data from the Sentinel-6 Michael Freilich and Sentinel-3A/3B missions. We summarise some of the key lessons learned from 30 years of operation at the Bass Strait facility. We draw on experience across the different nadir missions using both traditional low resolution mode and high resolution SAR mode, as well as from our experience of validating the exciting new SWOT mission over its critical Fast Sampling Phase (FSP).

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PHYSICALLY-CONSISTENT MAPPED ALTIMETRY PRODUCTS ON USER-CUSTOMIZABLE GRIDS

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Mapped sea surface height (SSH) anomaly products from satellite altimetry are an integral part of modern oceanography, widely used in both scientific and operational contexts. However, we note three significant limitations of the present mapped products and distribution system. 1) The correlation function imposed by the most common mapped products is physically unrealistic and inconsistent with the underlying along-track observations. This correlation function artificially steepens spectral slopes in mapped SSH products, significantly smoothing small scale features. 2) Effective resolution, signal covariance, errors, and uncertainties in mapped products are often misunderstood by users, leading to mis-application of altimetry products. 3) Scientists often require the SSH field on a custom grid, and either apply additional interpolation or improvise their own mapping procedures.

We attempt to address these three issues by combining altimetric data and statistical models to ensure the most accurate and useful global multi-satellite record of sea level. Our approach is based on Gaussian process regression methods with a carefully chosen parametric covariance function that is consistent with observations. Covariance parameters (space and time decorrelation scales, spectral slopes, and propagation speeds) are estimated from along-track data, and will be presented as part of the mapped data product. We also introduce an open-source, reproducible tool that allows statistical SSH mapping on custom grids by end users. The final distributed products are fully open source and flexible to meet the needs of scientists.

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30 YEARS OF ALTIMETRY SEA LEVEL L3/L4 PRODUCTS RECORD: MAJOR IMPROVEMENTS IN RECENT DECADES

Pujol M[1], Ballarotta M[1], TABURET G[1], Delepoulle A[1], Vergara O[1], Veillard P[1], Treboutte A[1], Dupuy S[1], Jahdou D[1], Dibarboure G[2], Faugere Y[2]
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The DUACS system (Data Unification and Altimeter Combination System) produces, as part of the CNES/SALP project, Copernicus Marine Service and Copernicus Climate Change Service, high quality multi-mission altimetry Sea Level products for oceanographic applications, climate forecasting centers, geophysics and biology communities. These products consist in directly usable and easy to manipulate Level 3 (L3;

along-track cross-calibrated SLA) and Level 4 products (L4; multiple sensors merged as maps or time series) and are available in global and regional version.
The first DUACS products were released in 1997, few years after the launch of TP and ERS1. Over the years, DUACS processes and products have evolved to adapt to user needs, incorporate the measurement of new altimeters, and take into account the latest technical and technological advances in processing these measurements.
The objective of this presentation is to make a synthesis of the major improvements of the DUACS multi-mission products in recent decades and express the challenge of the coming years.

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DUACS DT-2024: THE NEW REPROCESSING OF THE SEA LEVEL ANOMALY LEVEL-3&4 ALTIMETRY PRODUCTS

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Since 1997, the multisatellite DUACS system (Data Unification and Altimeter Combination System) has been providing high quality multi-mission altimetry Sea Level products for oceanographic applications, climate forecasting centers, geophysics and biology communities. They consist in directly usable and easy to manipulate Level 3 (along-track cross-calibrated Sea Level Anomaly SLA) and Level 4 (multiple sensors merged gridded gap-free) products, for global and regional applications. Initiated as part of the CNES/SALP project, this production is now carried out jointly with the Copernicus Marine and Climate Change Services.
A full reprocessing of these products is carried out almost every 3 years, based on the state-of-the-art Level 2 to Level 4 algorithms. A new version, identified as DT-2024, is now in preparation to cover 31 years of altimetric data (i.e. more than a century of cumulated data using 15 altimetric missions). It is expected to be available in November 2024 and concerns the DUACS product lines distributed via the Copernicus Marine and Climate Change Services. This reprocessing allows the incorporation of the latest L2 reprocessing for various missions (e.g. Sentinel-3, Sentinel-6, etc.), the latest versions of geophysical corrections (e.g. Ocean Tide FES22 model; etc.), and other parameters used in processing, as well as a new multiscale cartography method (i.e. Multiscale Inversion of Ocean Surface Topography from Ubelmann et al. (2021, 2022). All of these developments contribute to an improvement in DUACS products, to be better able to capture oceanic signals, ranging from mesoscale to climate scales.
The objective of this presentation is to present this DUACS DT2024 multi-mission reprocessing with an overview of the different evolutions and expected product quality improvement.

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BATHYMETRY FROM SWOT AND ICESAT-2 – CASE STUDIES IN AUSTRALIA WATERS

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Australia is a continent surrounded by a 200 nautical mile Australian Exclusive Economic (AEE) Zone comprising 8.2 million square kilometres of shallow coastal and deep waters. However, only 25% of the seafloor in the AEE Zone has been measured, and this is mostly at a sparse spatial resolution often to no better than tens or hundreds of km using time-consuming and costly shipboard sounder surveys. Satellite altimetry, a remote sensing technique, has significantly changed this situation. Using the new generation of satellite altimetry sensors, such as ICESat-2 and SWOT, we are investigating and mapping bathymetry in several shallow water bays (e.g., Moreton Bay and Shark Bay) and oceans offshore the Western Australia in the Indian Ocean. ICESat-2 data from 2018 to present and all available SWOT L2 and L3 data have been used. We found that (1) ICESat-2 photon data contribute to estimates of the detailed bathymetry that is missing in the current bathymetry models in shallow waters, and (2) using SWOT L3 data products produces more accurate marine gravity anomalies than L2 data products and then reveals more small-scale details of seafloor.

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IAS PILOT SERVICE FOR SCIENTIFIC AND GEODETIC APPLICATIONS

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Satellite altimetry has evolved into a unique geodetic remote sensing measurement system with multi-satellite missions and constellations generating an unprecedented climate data record since 1993, for three decades and in the decades to come. Satellite altimetry has fostered seminal research in interdisciplinary Earth sciences, contributing to many scientific and operational applications in geodesy, as well as in climate research, including climate monitoring, meteorological and ocean circulation forecasting, coastal hazards, vertical datum realization, Earth's gravity field and its changes, maritime safety, ocean pollution tracking services, inland water level, river discharge, freshwater flux to the ocean, floods monitoring and forecasting, water resources management, energy, and many others.

The IAS (International Altimetry Service) Pilot Service, approved by the International Association of Geodesy (IAG) at IUGG Berlin in July 2023, brings international collaborations together to anticipate and solve geodetic and climate research problems using the community's satellite altimetry expertise. It aims to fill the knowledge 'gaps' between space agencies and scientific/other users of satellite altimetry data and data products from both radar and lidar, and to conduct non-duplicated or complementary efforts to advance validated alternate altimetry data processing algorithms/analytics towards new and even innovative data products. The IAS Pilot Service will provide a platform for open access to information on satellite altimetry and data distributions for scientific, educational and operational applications.

The IAS Pilot Service is implemented as a multi-institutional effort. Critical to activities of the IAS Pilot Service are six clusters (or analysis centers) based on activities of the IAG Satellite Altimetry sub-commission. The clusters will provide products covering, but not limited, the following fields: (1) sea level and geodetic monitoring, (2) altimetry-based information and tools, (3) coastal and inland altimetry, (4) high-resolution altimetry, (5) synergy of satellite sensors' data, in situ data and physical models, and (6) high resolution Mean Sea Surface (MSS), marine gravity field and bathymetry. The clusters/centers have produced different data products and tools.

The IAS has now 32 members from 11 countries: Australia, China (and China-Taipei), Denmark, France, Germany, Indonesia, Italy, Netherlands, Norway, Spain and USA. The IAS is welcoming new members, especially Early Career Scientists. The IAS and its members are a pivotal source of knowledge in altimetry and an excellent forum to support IAG's capacity building altimetry workshops in Geodesy.

IAS Pilot Service Group Members:

Mohammad Al-Khaldi (USA)
Ole Andersen (Denmark)
Lifeng Bao (China)
Jérôme Benveniste (France), Co-Chair
Jean François Crétaux (France)
Xiaoli Deng (Australia), Chair
Denise Dettmering (Germany)
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James Garrison (USA)
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Sinem Ince (Germany)
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Yuanyuan Jia (USA)
Taoyong Jin (China)
Chungyen Kuo (China-Taipei)
Jürgen Kusche (Germany)
Hyongki Lee (USA)
Weiqiang Li (Spain)
Xiaopeng Li (USA)
Marc Naeije (The Netherlands)
Hossein Nahavandchi (Norway)
Jason Otero Torres (USA)
Marco Restano (Italy)
Fukai Peng (China)
Richard Salman (USA)
David Sandwell (USA)
Christian Schwatke (Germany)
C K Shum (USA), Co-Chair
Yohanes Budi Sulistioadi (Indonesia)
Stefano Vignudelli (Italy), Co-Chair
Pieter Visser (The Netherlands)
Xiaoyun Wan (China)

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PROGRESS IN PRECISE ORBIT DETERMINATION OF ALTIMETRY SATELLITES

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Precise orbits of altimetry satellites are a prerequisite for various scientific applications, such as the determination of the mean sea surface, the mean dynamic topography, ocean tides, sea level change investigations, and some others. The accuracy of altimetry satellite orbits depends on the type of observations used (SLR, DORIS, GPS, or combinations of them), corrections applied to the observations, background models of the forces acting on the satellite, reference system realizations, satellite macro-models and other factors.
Significant progress in precise orbit determination (POD) for altimetry satellites has been made in the last 30 years. In this presentation, we review the main improvements in the POD of altimetry satellites in the last three decades. A special focus is put on the level of accuracy which can be achieved by using most-recent solutions of the Earth's time-variable gravity field and the terrestrial reference frame as well as state-of-the-art ocean and atmospheric tide models.

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TOWARDS AN OPERATIONAL GLOBAL COASTAL ALTIMETRY PRODUCT: ALTICAP (ALTIMETRY INNOVATIVE COASTAL APPROACH PRODUCT)

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Although spatial altimetry was originally developed for measurements on the open sea, it can be used in a coastal context, even though this type of use is far more

complex. Part of the problem lies in the land contamination of radar observation in the last few kilometers from the coast. In the last few dozen kilometers approaching the coastline, this problem is further aggravated by the poor quality of some of the geophysical corrections applied. In view of the large number of altimetry applications, the international community and space agencies have been trying to resolve this issue for more than 15 years. Following extensive work and studies, a number of processing algorithms have been developed and a few experimental products have been proposed.
In order to move towards the routine use of sea level altimetry measurements along the coastal strip on a global scale, we have conducted a Round Robin study aimed at comparing 25 algorithms used to calculate sea level anomalies (SLA) from altimetry in low resolution mode (LRM) and targeting the ocean region between 0 and 200 km from the coast. For each one, a significant number of diagnostics was carried out at global and regional levels. The most immediate outcome of this study is the new global AltiCAP altimetry product available on the AVISO+ portal since January 2024. Note that the processing solution which was adopted is a compromise between:

- The capability of each algorithm (correction or parameter) to provide the best SLA dataset over the entire strip between 0 and 200 km from the coast (and not necessarily in the most coastal zone) in order to guarantee continuity with the open ocean.
- The availability of the correction or parameter on several altimetry missions.
- A guarantee of product continuity in the future.

Integrated with the Jason-3 mission in the first instance, this high resolution (20Hz) altimetry product will rapidly include other missions in order to extend the use of the product in time and space, and ensure a long-term implementation. It is provided with different case studies in the form of Python notebooks. Its distribution will also be supported by training workshops for the international community (virtual schools).

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IMPROVEMENTS IN IN SITU INSTRUMENTATION AT THE BASS STRAIT SATELLITE ALTIMETRY CAL/VAL FACILITY TO RESPOND TO THE ADVANCES IN ALTIMETRY PRECISION.

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Responding to the stringent requirements for climate quality sea level monitoring is a challenge. The space agencies have responded with new generations of satellites and instruments with SAR mode, swath altimetry and improved radiometers. To validate the measurements in situ to ensure they are consistent with the requirements has been quite a challenge. The Bass Strait cal/val facility has developed a new generation of in situ instrumentation to respond to this challenge while maintaining the ongoing validation of the reference missions climate record. In this presentation we focus on the analysis of moored oceanographic sensors, specifically our CWPIES in Bass Strait. Our CWPIES instrumentation has been developed over the last 7 years to respond to the Sentinel-6 and SWOT validation requirements. The facility has also developed a new generation of GNSS buoys which allow for longer deployments and provide a stronger tie of in situ mooring data to the satellite reference frame while providing robust datasets to validate the mooring Sea Surface Height consistency.
Here we show how the moored instruments are quality assured and quality checked and validated. A series of experiments with various configurations of in situ array deployment and overlap with “classic” (bottom pressure and dynamic height) moorings and satellite phases allow us to generate a sustained SSH record at centimetre level. We show the results from the new mooring compared to the classic over the Sentinel-6 time series. We also present ancillary datasets produced by the facility to describe the wave field (continuous directional wave spectra besides Significant Wave Height) and currents through the column> from the ADCPs. These extra datasets are available to the community to test the impacts of waves on the radar measurements and validate the currents inferred by the altimetry products.
The Bass Strait facility will now operate continuously with the CWPIES at 3 key sites: the historical Jason-Sentinel-6 comparison point as well as Sentinel-3A and Sentinel-3B crossovers comparison points, all of which are covered by SWOT regularly.

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THE ESA PERMANENT FACILITY FOR ALTIMETRY CALIBRATION IN CRETE: RANGE, SIGMA0, AND SEA-SURFACE CALIBRATION WITH TRANSPONDERS, CORNER REFLECTORS AND COASTAL REFERENCE SITES.

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Two microwave range transponders, one sigma0 transponder and two corner reflectors have been operating on the mountains of Crete and on the island of Gavdos to calibrate international satellite radar altimeters at the Ku-band. In 2023 and early 2024, a couple of corner reflectors in Crete have been established to complete the infrastructure for range and sigma0 calibration of all ESA satellite altimeters. This

ground infrastructure is also supported by four sea-surface Cal/Val sites operating, some of them, for over 20 years. To cover the entire extent of Crete island, two additional such Cal/Val sites are set up in 2024. This ground infrastructure is part of the European Space Agency Permanent Facility for Altimetry Calibration (PFAC), and has been producing continuously as of 2004 (sea-surface) and 2015 (range) a time series of biases for Sentinel-3A, Sentinel-3B, Sentinel-6A, Jason-2, Jason-3 and CryoSat-2.
This work presents a thorough examination of the transponder Cal/Val responses to understand and determine absolute biases in all satellite altimeters overflying this infrastructure based on the principle of fiducial reference measurements. Using various techniques, infrastructure, and settings, the latest calibration results for the Jason-3, the Copernicus Sentinel-3A and -3B, Sentinel-6A and the HY-2B, HY-2C radar altimeters will be described based on six sea-surface, two transponder and two corner reflector Cal/Val sites of the PFAC in west Crete, Greece.

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SENSITIVITY OF CLIMATE SIGNALS TO ALTIMETRY MAPPING.

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Here we evaluate gridded sea level products ability to reproduce climate signals. CSIRO maintains an independent climate Sea Level record using the reference missions that is complementary to the "AVISO" grids, the Copernicus allsat and twosat gridded products as well as new aviso products. We use the sea level modes of variability from the gridded products to reconstruct the ocean heat content from the Argo datasets. The sea level modes of variability are extracted using empirical orthogonal functions. The Argo record is aggregated and extended to a 3d gridding from the spatial patterns of variability using the Reduced Space Optimal Interpolation. The global heat content time series trends are comparable when using the various input sea level variability patterns. However the reconstructed patterns of vertical profiles and inter-annual variability are much better reproduced when using the CSIRO gridded product which only uses the reference mission. We investigate the reasons for this surprising result and point to some mapping process tending to dampen the intermediate spatial scales at which inter-annual heat transfers seem to be prominent.

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MONITORING LAKES AND RESERVOIRS FROM SPACE USING ICESAT-2 AND GRACE FOLLOW-ON MISSIONS

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Since their respective launches in May and September 2018, we have been using data from the GRACE-FO gravity and the ICESat-2 laser altimetry missions to monitor lake and reservoir mass and volume variations. In more details, we use MODIS imagery to estimate the water bodies' surface water extent, and then filter out returns from the ICESat-2 ATL13 inland water products. The conversion from ellipsoidal heights into orthometric heights requires an accurate geoid model. We show the value of replacing the EGM2008 geoid model used in the ATL13 products and highlight the importance of using more recent models to allow a more accurate conversion to ellipsoidal heights. In addition, and as we have done in previous studies, we also show how the ICESat-2 altimetry products can be used to improve geoid models over large water bodies. To validate our water level estimates, we compare them to available state-of-the-art radar altimetry products and in-situ measurements when available.

In addition, we derive lake and reservoir mass variations from high resolution time-variable gravity solutions (mascons) from the GRACE and GRACE-FO missions. The main limitation of the gravimetry products is due to the spatial resolution of the GRACE & GRACE-FO solutions, and the quality of the hydrology models used to correct for the other continental water storage components. In spite of the limitations, we show that a good agreement between the water volume changes computed from ICESat-2 and MODIS and the mass changes deduced from space gravity missions can be obtained.

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TESTING OCEAN CURRENTS GEOSTROPHY USING ALTIMETRY PRODUCTS AND IN SITU DRIFTERS IN A MEANDER OF THE ANTARCTIC CIRCUMPOLAR CURRENT SOUTH OF TASMANIA.

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The Southern Ocean and its main component, the Antarctic Circumpolar Current (ACC), have a key role in the heat and carbon uptake and transport, with hotspots occurring where the current interacts with topographic features. In recent times, more and more studies have pointed out that smaller scale ocean processes, likely to be ageostrophic, have a key role in the Heat and Carbon transfers and cross-frontal exchanges in the ACC.
During the SWOT-ACC validation cruise in a meander south of Tasmania (RV Investigator FOCUS voyage) in November-December 2023, we deployed a set of instrumentation, including 15 SVP drifters. They often

experience surface intensified current that depart from geostrophic balance and represent a reference ground-truth for the validation of near-surface currents and their observability in altimetry observation (nadir altimetry and SWOT). We develop a strategy for mapping SWOT observations in the region by taking profit of its high-latitude coverage and have higher temporal resolution while not degrading the spatial resolution.
With a lagrangian approach, we quantify and partition the ageostrophic contributions to surface drifters velocities (higher-order balance, Ekman current, stokes drift, …), using ancillary ADCP dataset (CTD, shipborne) and altimetric geostrophic currents.
With the help of a regional model and synthetic particles experiments, we quantify errors that can be made on geostrophic velocities by including the signature of unbalanced motions in SSH fields, and discuss their impact on lagrangian trajectories and characteristics in the ACC meander.
In this presentation we evaluate the impact of the SWOT mapping to recover more intense currents compatible with the drifters in situ observation, test the dispersion statistics and regimes and infer diffusivity.

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VALIDATION OF SWOT DATA AND ANALYSIS OF MULTI-SCALE HYDRAULIC SIGNATURES VISIBILITY WITH A WAVELET-BASED ALGORITHM AND IN SITU DATA ON THE MARONI, NEGRO AND TSIRINBIHINA RIVERS

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The SWOT satellite mission launched in December 2022 provides an unprecedented cartographic hydraulic visibility of water surfaces deformations over worldwide rivers, in addition to decades of nadir altimetry and imagery. Here we focus on the informative content of the SWOT pixel cloud (2D in space) and of 1D data (spatial aggregation along rivers centerlines), on the vertical accuracy of water surface elevation measurements and of resulting slopes, on the detection capabilities of spatio-temporal variabilities associated with hydraulic signatures. They reflect variabilities in inflows and/or river-floodplain bathymetry and/or hydraulic friction. We consider data from the SWOT Cal-Val phase, i.e. 1-day revisits without global coverage, and from the final SWOT science orbit with nearly global spatial coverage by 21 days cycles but with sparser temporal revisits over the same spatial location. SWOT data are analyzed on the Maroni, Negro and Tsiribihina rivers against rich in situ datasets, and especially accurate georeferenced water surface profiles and water level time series, including ones especially collected during the SWOT fast sampling phase. SWOT measurement errors are evaluated with in situ data and highlight the unprecedented potential of SWOT to capture longitudinal and temporal hydraulic signatures accurately. The application of our wavelet based denoising and multi-scale segmentation algorithm to the 1D product, enables to preserve multi-scale signatures of hydraulic controls while denoising raw data and to produce meaningfull reach averaged elevation and slope products. The capability to depict flood propagation in a river network with SWOT is analyzed and depends on the spatial orientation of the river network and on the spatio-temporal sampling of measurement, which is dense in space but sparser in time relatively to flows dynamics and associated WS signatures. WS surface signatures indeed reflect hydrological signals variabilities and hydraulic propagation at network scale, hence multi-frequential, multi-scale non linear physical processes that SWOT enables us to observe in a new way.

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FORECASTING RIVER STAGES AT VIRTUAL STATIONS OF SENTINEL-3A: CASE STUDY FROM THE ODRA RIVER (WESTERN POLAND)

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The paper reports on the preliminary results of the project (funded by National Science Centre, Poland, grant no. 2020/38/E/ST10/00295), the objective of which is to issue predictions of water levels at ungauged sites of the Odra/Oder River located in western Poland as well as at the Polish-German border. We developed a hydrologic prediction system that calculates in real time (every hour) forecasts of river stages at virtual stations of the Sentinel-3A altimetry. Since the satellite cycle if of 27 days, we transfer predictions computed for nearest upstream in-situ gauge to a virtual station using the hourly updated gauge-gauge relationship. The water level prognoses issued for in-situ gauges are based on vector autoregression (VAR) supported by our stochastic-deterministic no-data gap infilling method known as LinAR as well as by the dedicated outlier removal approach. The prediction lead time is set to 72 hours, however, we found that forecasts up to 24 hours into the future are the most skillful when anticipating high flows at in-situ gauges. For every gauge, the prognoses are moved from in-situ site to a virtual station using the aforementioned gauge-gauge relationship, the latter being established in real time using the lag correlation approach. Finally, we compute 72-hour predictions of water levels at eight Sentinel-3A virtual stations, with the recommendation that maximum reasonable lead time is much shorter in case of high flow development.

In order to verify prediction accuracy at virtual stations we conduced a long-term fieldwork, consisting of forty 5-day excursions to eight locations along the Odra River in western Poland. During each excursion, we observed virtual stations using airborne LiDAR (light detection and ranging) and high resolution digital camera, installed onboard an unmanned aerial vehicle. Dense point clouds acquired by LiDAR allowed us to delineate river coastline and compute water levels at approximate times when Sentinel-3A was overpassing virtual stations. Such data were used to infer on the accuracy of altimetry-derived water levels and – most importantly – to assess the performance of our hydrologic prediction system designed for ungauged sites.

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SENTINEL-6/MICHAEL FREILICH PERFORMANCES ASSESSMENT OVER INLAND WATERS DURING TANDEM PHASE WITH JASON-3

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The Copernicus Sentinel-6/Michael Freilich mission was successfully launched on November 21st, 2020. Although the primary objective of the mission is to measure sea surface topography with high accuracy, it also allows to monitor water level over inland waters. Freshwater stocks monitoring is of great interest for climate change monitoring studies as well as near real time lakes and rivers monitoring services. This benefits to domains such as flood and droughts risks management, health, agriculture, economic and political activities, transportation. Sentinel-6/MF is another essential brick in the altimetry constellation to support the validation of the recent SWOT mission swath altimetry datasets and prepare for the Sentinel next generation topography missions.

Poseidon-4 altimeter on board Sentinel-6 differs from previous conventional sensors by operating simultaneously in Low Resolution mode (LRM) and in Synthetic Apeture Radar mode (SARM), in a so-called interleaved mode which allows for continuous transmission (also refers as open burst mode). Over one year, December 18th, 2020, to April 7th, 2022, Sentinel-6 was in tandem flight with Jason-3, before this later being moved to another orbit. This configuration allowed comparing Sentinel-6 and Jason-3 data, which is of importance to ensure continuity of downstream services.

This presentation focuses on Sentinel-6 CalVal activities over inland waters exploiting the tandem phase. Comparisons between Sentinel-6 and Jason-3 continental water level retrievals will be presented, as well as assessment of the reconstructed water level timeseries with respect to insitu measurements. Precision and accuracy of water level estimates will be quantified, focusing on the improvements Sentinel-6 brings comparing to Jason-3. The benefits of SAR mode, as well as the Fully focus SAR processing it allows, will be emphasized in terms of unexpected opportunities to now monitor very small water bodies in complex hydrological geometries.

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INFERRENCE OF SPATIO-TEMPORAL PARAMETERS OF BASIN SCALE HYDROLOGICAL-HYDRAULIC MODEL BY VARIATIONAL ASSIMILATION OF MULTI-SATELLITE AND SWOT DATA

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In complement to decades of nadir altimetry and imagery, the SWOT satellite mission launched in December 2022 provides an unprecedented cartographic hydraulic visibility of water surfaces deformations over worldwide rivers. This contribution investigates the informative content of multi-satellite and in situ observations of rivers for estimating unknown or uncertain parameters of basin scale hydrological-hydraulic model. The modeling approach with DassHydro consists in a 1D Saint-Venant differentiable hydraulic model of the river network inflowed by a spatially distributed hydrological model. An automated toolchain (Hydropreprocessor) enables to (1) determine inflow coupling points between the hydrological and hydraulic domains, (2) to generate the 1D hydraulic mesh over the river network using observations of water heights and widths either from SWOT L2 river products or from other EO missions (ICESat-2, Copernicus Sentinels). A variational data assimilation algorithm is used for the first time at river network scale with heterogeneous data cocktails for simultaneously inferring spatially distributed inflow discharge hydrographs, bathymetry and friction parameters of the hydraulic model. This approach is illustrated on the Maroni River basin in French Guyana with assimilation of water level data from altimetry alone or in combination with temporally dense but spatially sparse data from in situ gages. The validation dataset consists of in situ discharge time series and altimetric water level dataset split into two subsets, one for building the model (along with water masks) and one for the assimilation.
The obtained results show that realistic spatially distributed bathymetry-friction and inflow discharges corrections can be inferred with prior information of sufficient quality and respecting flow laws. Frequential inferrability of inflow discharge hydrographs depends on the spatio-temporal visibility of their mixed signatures in the water surfaces downstream in the river network, which corroborates our findings in

previous studies at single river portion scale. Working at network scale with a hydrological-hydraulic model ensures physical consistency in terms of non linear flood propagation and water surface signatures, while global optimization in space and time enables to maximize information extraction from heterogeneous data and to improve the coherence of model internal states. This approach enables information feedback from hydraulics observables downstream to hydrological modeling and can be applied to other basins worldwide and other data cocktails. The differentiable model is usable as backbone for building a learnable spatialized hydrological-hydraulic framework.

References:
[1] DassHydro: https://dasshydro.github.io/

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INLAND WATER LEVEL MONITORING WITH RADAR ALTIMETRY : THE SPECR RETRACKER

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Inland waters are an essential part of the water, carbon and energy global cycles, and river and lake water levels are essential climate variables (ECV) as defined by the Global Climate Observing System. Water resources over the continents, however, have been and continue to be affected by climate change and anthropogenic impact. Monitoring their evolution is essential for risk management and successful water governance policies. Despite the urgent need, the number of publicly available water level temporal series has dwindled in the last decades, making water level databases sparse and very heterogeneous in space and time. By virtue of their global coverage and continuous operation, spaceborne radar altimeters can mitigate the lack of in situ data.

After summarizing the evolution of altimetry retrackers for inland waters, we present one of the most recent retrackers, tailored for historical altimetry missions in low-resolution mode (LRM). This retracker shows very good performance on inland waters and enables the generation of extended water level time series. The Specular waveform retracker for inland waters, uses the fact that there is a high backscatter contrast between inland waters and their surroundings, frequently produces specular waveforms. The physical model used is based on a sinc-squared function, with the novelty that we also take into account radar signal clipping as is often the case with Poseidon altimeters (Jason missions).

We present some case studies in the Garonne and Mississippi rivers, as well as global performance assessment.

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SYNERGIES BETWEEN RADAR ALTIMETRY AND MULTISPECTRAL REFLECTANCE SIGNAL FOR RIVER DYNAMICS DETECTION AND RIVER DISCHARGE ESTIMATION: PROGRESS AND NEXT STEPS

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River discharge is a fundamental variable of the hydrological cycle, necessary for flood forecasting, essential for water resources management, and supporting the identification and adaptation to potential effects of climate change. Its estimation is quite difficult because it is not direct and requires many variables and references measured on the ground. However, due to the difficulty of obtaining a homogeneous and continuous hydro-monitoring network on the ground, the scientific community is looking for the possibility of estimating river discharge from space. Among the satellite sensors, radar altimeters provide important information for river water level monitoring, and the increased accuracy of the sensors encourages their use also for river discharge estimation by traditional methods (rating curves or hydraulic modeling). The main limitation lies in the temporal frequency, which is often too low for classical hydrological applications related to the identification of extreme events in small to medium sized rivers. In this case, a multi-mission approach, i.e. the interpolation of different altimetric river crossings, has the potential to overcome the limitations due to the poor spatio-temporal sampling. Alternative sensors include optical sensors, which due to their frequent revisit time (almost daily) and wide spatial coverage have shown that reflectance change can be a proxy for river discharge variation and can be used for river monitoring. Based on these premises, the synergy between altimeter and optical sensors has proven successful in many cases to overcome the limitations of the individual missions. Recent developments and progress in the combination of the two different sensors are presented here, tracing the results of the advancement of the method, the use of the different sensors available, and the application at different sites with the prospect of achieving global spatial coverage and a time frame of about 20 years.

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ASSEMBLING 30 YEARS OF SATELLITE WAVE MEASUREMENTS FOR CLIMATE SCIENCE : THE SEA STATE CLIMATE CHANGE INITIATIVE CCI TEAM

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Robust long-term sea state information are needed for coastal adaptation, offshore engineering, marine energy production, and marine security, but also to constrain modern global wave reanalysis, which often suffer from the assimilation of uneven dataset. In this context, the European Space Agency is playing an active role through the Climate Change Initiative program, which aims at making the most of historical and current Earth Observation missions in order to produce long term records of Essential Climate Variables (ECV). The sea state ECV has been routinely monitored from space with radar altimeters and synthetic aperture radar imagers over more than three decades. Over this period of time, mission designs and technology have evolved alongside climate change, and the production of seamless multi-mission and multi-sensor climate data record has become more and more challenging. For the second phase of the Sea State CCI project,wave measurements from 16 satellite missions, including altimeters (LRM and SAR) and SAR imagers, will be inter-calibrated to minimize the bias between missions and sensor types, and between satellite, ground truth measurements and models. This study presents the satellite missions, the selected in situ and model dataset, and the inter-calibration strategy developped within the project. The impact on the long-term statistics are finally discussed.

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VALIDATION AND UNDERSTANDING OF SWOT AND COASTAL ALTIMETRIC DATA

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Satellite altimetry has revolutionized the study of ocean dynamics as well as the monitoring of the global mean sea level. Since 2022, the SWOT (Surface Water and Ocean Topography) altimetry mission, employing Ka-band SAR, provides unprecedented spatial resolution over both the open and coastal oceans and inland water bodies. At the coast, traditional processing of radar altimeters measurements used for the open seas are not adapted. Radar altimeters face challenges due to land contamination and complex dynamic processes. Dedicated processing for coastal environments has been developed in recent years to improve the quality of the measurements at the coast (X-TRACK (Birol et al., 2022), ALTICAP (Birol et al., 2023) ...).

Despite the anticipated improvements offered by SWOT, its applicability in coastal regions remains not fully understood. To address this gap, our validation approach relies on in-situ measurements obtained from the USV PAMELi (Plateforme Autonome Multicapteurs Pour l'Exploration Du Littoral) in the Pertuis Charentais coastal zone (located in the Bay of Biscay, France). The objective of these in-situ measurements is to validate and improve both SWOT and coastal nadir altimetric products, with the aim of facilitating cross-calibration with SWOT. Building upon the methodology established by Chupin et al. (2020, 2023), this study will deploy the Cyclopee system on PAMELi along the SWOT swath. Moreover, deploying GNSS buoys and incorporating long-term tide gauges measurements will expand our in-situ network, enriching validation efforts. The use of GNSS buoys will also be used to improve tropospheric correction in the altimetry processing. In validating and improving coastal altimetric products, our study aims to understand and use satellite altimetry and SWOT data in coastal regions.

The validation and calibration process using in-situ measurements play a crucial role in advancing the accuracy and reliability of SWOT and altimetric coastal products. By addressing the challenges associated with coastal altimetry, this study contributes to characterizing coastal dynamics and enhancing the utility of satellite-derived data for coastal research.

Reference

Birol,F., Fuller N., Lyard,F., Cancet, M. Nino,F., Delebecque,C. Fleury,S. Toublanc,F. Melet,A. Saraceno,M. Léger,F. (2022) Coastal applications from nadir altimetry: Example of the X-TRACK regional products https://doi.org/10.1016/j.asr.2016.11.005

Birol, F., Bignalet-Cazalet, F., Cancet, M., Daguze, J.-A., Faugère, Y.,
Fkaier, W., Fouchet, E., Léger, F., Maraldi, C., Niño, F., Pujol, M.-I., and Thibaut, P.
(2023). Round Robin Assessment of altimetry algorithms for coastal sea surface height data.

Chupin, C., Ballu, V., Testut, L., Tranchant, Y.-T., & Aucan, J. (2023). Nouméa: A new multi-mission calibration and validation site for past and future altimetry missions? Ocean Science, 19(4), 1277–1314. https://doi.org/10.5194/os-19-1277-2023

Chupin, C., Ballu, V., Testut, L., Tranchant, Y.-T., Calzas, M., Poirier, E., Coulombier, T., Laurain, O., Bonnefond, P., & FOAM Project, T. (2020). Mapping Sea Surface Height Using New Concepts of Kinematic GNSS Instruments. Remote Sensing, 12(16), Article 16. https://doi.org/10.3390/rs12162656

PAMELI – Plateforme Autonome Multicapteurs pour l'Exploration du Littoral. (n.d.). Retrieved December 20, 2023, from https://pameli.recherche.univ-lr.fr/?lang=en

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ANALYSIS OF HIGH-FREQUENCY SEA-STATE VARIABILITY USING SWOT NADIR MEASUREMENTS AND APPLICATION TO ALTIMETER SEA STATE BIAS MODELLING

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SWOT 1 day-phase provides a unique opportunity for analyzing the high-frequency sea-state variability and its implications for sea state bias (SSB) model development. Time series of sea level anomaly (SLA) and SSB input parameters - comprising significant wave height (SWH), wind speed (U) and mean wave period (MWP) - were constructed using altimeter nadir data. Temporal autocorrelation functions were computed to determine the decorrelation time scales (DT) associated with SLA (≈ 4 days on average) and SSB input parameters (≈ 1-2 days). The latter results, obtained using unprecedented high-frequency satellite data from multiple ocean basins, are consistent with observations from ocean wave model. The computed average DT values also suggest that the current assumptions governing the formation of SSB databases (through the selection of optimally time-differenced data points) should be revisited whenever possible, provided that the orbit's repeat cycle of the mission at hand allows it. In addition, the analysis of the temporal cross-correlations provided a description of the relationships between SSB input parameters (SWH, U and MWP), with distinct behaviors in swell and wind-sea-dominated areas. Finally, it was demonstrated that computing cross-correlations between SLA (before and after it is corrected for SSB) and SSB input parameters, could serve as an additional tool for quantifying the SSB correction performances (which so far mainly relies on variance reduction of SLA differences at crossover points).

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NUMERICAL CONVOLUTIONAL MODEL FOR RETRACKING SENTINEL-6 DELAY/DOPPLER ALTIMETRY DATA

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The analytical form of the delay/Doppler backscattered echo (Ray et al., 2015), currently implemented in the Sentinel-6 (S6) Payload Data Acquisition and Processing (PDAP) retracker, makes multiple approximations of the analytical functions making up the convolutional model in order to obtain a closed form solution. One of this simplifications is the Gaussian approximation of the Point Target Response (PTR). Anomalies in the global mean sea level drift and significant waveheight stimations have been observed with the PDAP retracker implementation, which have been related to the evolution of the main lobe width and secondary lobes asymmetries of the in-flight PTR (Boy et al., 2022). With the aim to reduce the impact of the PTR model approximation, the use of static look-up-tables (LUT) has been exploited. However, fully reliable estimations of the sea level trend can be obtained only if LUTs are regularly updated, which appears to be operationally unfeasible. As an alternative, the convolutional model can account for the measured PTR of the instrument, so that any PTR shape evolution is considered when retrieving geophysical parameters, if the convolution is solved numerically.

This work is devoted to providing a description of the algorithms that comprise a numerical model of the altimetric delay/Doppler backscattered echo that allows for the use of the measured PTR, based on the physical convolutional model in range time - Doppler frequency domain in (Halimi et al., 2014). A circular antenna pattern is assumed in the modeling of the flat surface impulse response, and ocean skewness is considered in the probability density function of the distribution of heights. Prior to multilooking, a stack mask is applied which eliminates bins with spurious information. In addition, the fitting parameters correspond to the solution of a constrained least-squares problem, where lower weights have been given to the range bins with high errors through the use of robust statistics.

The model is implemented in a processor which is fed by Level-1B HR and CAL1 S6 data and provides temporal series of geophysical parameters estimates (significant waveheight Hs, sea surface height SSH and normalized radar backscattering cross section σ0) and quality measures. The results over a study area on the South-West Indian Ocean are analysed in terms of accuracy and precision and compared with Level-2 operational products, showing good performances and suggesting potential uses of the current model for future investigations.

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CONTRIBUTION OF DAILY SURFACE WATERS OBSERVATIONS VERSUS THE CURRENT OPERATIONAL CONSTELLATION OF ALTIMETERS FOR HYDROLOGICAL MONITORING OF UNDER-MONITORED BASINS: THE CASES OF MARONI AND NIGER BASINS

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In the context of climate change, there is an increasing need to understand and monitor inland waters and their

cycles. Additionally, the preservation of natural resources is crucial, as they face mounting pressure from human activities. Traditional monitoring networks face challenges such as conflicts, difficult accessibility, and high maintenance costs, making them inadequate for effective monitoring of continental waters at large scale. This challenge is particularly pronounced in basins like Maroni in French Guiana and Niger, where existing networks are unable to provide information at the necessary time and space resolution,s mostly due to dense forests and political conflicts. Hence, the utilization of current and forthcoming free and accessible datasets from space, integrated into hydrological and hydrodynamic models, can offer crucial information to supplement existing in situ networks.
In this context, incorporating satellite radar altimetry observations of inland waters into hydrological models holds significant promise for enhancing water resource management and flood prediction. This study focuses on integrating water surface elevation (WSE) observations from several altimeters, including SWOT (Surface Water and Ocean Topography) mission's nadir altimetry data with a one-day repetitivity (SWOT-1d), into the MGB (Modelo de Grande Bacias) hydrological model. WSE are converted into discharges using rating curves (RC). The study compares the predictive capabilities of SWOT-1d data with older satellite constellations like Sentinel and Jason, specifically in the Maroni basin (French Guiana), and the Niger basin, where flooding is frequent.
To evaluate the improvements brought by SWOT-1d data, a comparative analysis is conducted among SWOT, Sentinel, and Jason altimeters in terms of their predictive discharge performance within the MGB model. The ensemble Kalman filter (EnKF) method is employed to assimilate discharge data derived from the combination between satellite altimetry data and RC informations into the MGB model. This allows for refining streamflow predictions and assessing the advancements facilitated by SWOT-1d data.
This assimilation approach has been applied over the period from 2000 to 2023 for both basins, enabling the integration of SWOT-1d data into the MGB model. This time span allows the inference of the contribution of the daily observations from April to June 2023 when compared to other years when only the constellation with revisit periods of 10 and 27 days (for Jason3 and Sentinel-6 and for Sentinel3 A&B, respectively) in basins with contrasted hydrological conditions and behaviours.
The results demonstrate the potential for improved streamflow predictions, particularly during extreme events, offering valuable insights into hydrological dynamics and contributing to enhanced water resource management and flood forecasting in these regions. It illustrates the trade-off between the necessary high temporal sampling for fast events monitoring (here provided by the daily observations from SWOT-1d) and the necessity of higher spatial observation capacity (provided by the currently flying Copernicus constellation) for providing a distributed vision of basins hydrological state. And provides insights on the relevance of under discussions constellations of nano satellites such as SMASH.

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WAVE-CURRENT INTERACTIONS IN THE AGULHAS CURRENT: A COMPARATIVE ANALYSIS OF ALTIMETER PRODUCTS AND WAVE MODELS AGAINST DRIFTERS

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Our study exploits in situ data collected in the Agulhas Current and Retroflection region during the One Ocean Expedition 2021-2023 to evaluate the effect of wave-current interactions on wave models and altimetry-derived products. In January 2023, six OpenMetbuoy drifters (Rabault et al, 2022) were deployed in the Indian Ocean, in and around the Agulhas Current. Over approximately two months, these drifters continuously recorded data, enabling the estimation of significant wave height and Stokes drifts along their paths. Additionally, surface velocities were derived from onboard GPS data, providing insights into surface current velocities, as the drifters experienced minimal direct windage due to their high immersion.

The analysis first focuses on surface velocity products. The Copernicus GlobCurrent product combines altimetry-derived geostrophic currents with Ekman drift computed from atmospheric forecasts. We found out that this product tends to underestimate surface velocities exceeding 0.5 m/s. A similar trend of underestimation with greater dispersion was noticed for MERCATOR surface velocity product. Further analysis, incorporating Stokes drift, derived from the Météo France Wave Model (MFWAM) forced by GlobCurrent currents, into the GlobCurrent surface velocity product, showed a marginal effect: on average, Stokes drift contributes less than 10% to the total surface velocity, thereby making its impact very weak. However, during strong wind events, Stokes drifts and subsequent inertial oscillations tended to divert the drifters from their geostrophic paths, leading to circular trajectories.

Further, we compared Stokes drifts and significant wave heights derived from ERA5 reanalysis and MFWAM with the in-situ measurements from the drifters. ERA5 consistently underestimated significant wave heights over 3 m, while MFWAM, demonstrated good agreement with drifter data. Both models tended to overestimate Stokes drifts, with ERA5 showing greater variability. The absence of current data in ERA5, coupled with its coarser spatial resolution (1/2 degree) compared to MFWAM (1/12 degree), likely contributes to the diminished accuracy of ERA5 in areas with strong currents, underscoring the complexities and challenges in accurately modelling wave-current interactions in dynamic regions like the Agulhas Current.

Reference:

Rabault, J, T Nose, G Hope, M Muller, Ø Breivik, J Voermans, L R Hole, P Bohlinger, T Waseda, T Kodaira, T Katsuno, M Johnson, G Sutherland, M Johansson, K H Christensen, A Garbo, A Jensen, O Gundersen, A Marchenko, and A Babanin (2022). OpenMetBuoy-v2021: An Easy-to-Build, Affordable, Customizable, Open-Source Instrument for Oceanographic Measurements of Drift and Waves in Sea Ice and the Open Ocean, Geosciences, 12(3), doi:10.3390/geosciences12030110

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UTILIZING SATELLITE ALTIMETRY TO ENHANCE IN-SITU WATER LEVEL OBSERVATIONS IN LEAST DEVELOPED COUNTRIES

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This contribution presents an approach to enhance water level observations in least developed countries (LDCs) by synergistically integrating satellite altimetry data from various missions (ESA radar altimetry missions, NASA/CNES SWOT, and NASA ICESat-2) with ground-based measurements collected through a free, SMS-based platform. This innovative approach leverages the strengths of both data sources to address the critical challenge of data scarcity in LDCs. By establishing a comparison between satellite and ground-based water level observations, we can validate the quality of manual readings, fostering trust in their application and enhancing the overall reliability of the data. Furthermore, this combined dataset offers valuable insights for optimizing the design and operation of national hydrological monitoring networks, ensuring they effectively capture crucial water level information across diverse geographical regions. To further empower national hydrological services in LDCs, we have developed a user-friendly, centralized platform for data access and visualization. This platform seamlessly integrates altimetry data with in-situ observations, providing a convenient and readily accessible resource for hydrologists. Additionally, we envision incorporating satellite data into existing flood models. This integration has the potential to significantly improve flood prediction capabilities, ultimately leading to more robust flood risk management strategies and enhanced protection for vulnerable communities in LDCs. By fostering collaboration between satellite technology and established ground-based monitoring practices, this project paves the way for a more comprehensive and effective water resource management framework in LDCs.

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SENTINEL 3 ACTIVE RADAR CALIBRATOR GROUND TRANSPONDER DATA ANALYSIS: AN OVERVIEW OF 1.5 YEARS COLLECTED STATISTICS AT FRANK SILVIO MARZANO CAL/VAL SITE IN LEONESSA.

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This abstract is presented in the framework of S3 MPC Service contract serving the Copernicus Sentinel-3 mission, jointly operated by ESA and EUMETSAT to deliver operational ocean and land observation services. In the presentation, Sentinel-3 A and B radar signals, recorded by the Sigma0 ground Active Radar Calibrator (ARC) transponder in the Frank Silvio Marzano Cal/Val site since October 2022 are presented, first explaining the down-conversion and sampling characteristics of the MW and analog received signal elaboration and then introducing the processing implemented on the digitalized data. Through the implemented processing, many Synthetic Aperture Radar (SAR) signal parameters can be estimated during the calibration time such as Ku Radar Burst Cycle (RBC) count, duration and amplitude per single pulse as well as envelope of received pulses. Statistics gathered in the 1.5 years activity are hence discussed, showing observed drifts, trends and correlation with available troposphere conditions. Descending from statistics discussion, conclusion on the impact of ground ARC transponder data for the Radar Altimetry community are drafted, with the aim of leveraging the processing outcomes for improving the quality of the Copernicus Sentinel-3 Data Products.

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C3S: AN INCREASED SPATIAL COVERAGE OF MONITORED LAKES WITH NADIR ALTIMETRY FOR WATER LEVEL PRODUCTS.

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Lakes play a crucial role in retaining and stocking water, and in the context of the significant global environmental changes occurring at several anthropocentric levels, the necessity to monitor water level has increased substantially over the last years, and lake water level is defined as an Essential Climate Variable by GCOS. The water stored in lakes responds to any changes in precipitation and air temperature as well as directly to human use of water resources. Fresh water is a more and more pressured resource for the population needs and a fundamental element for industry and agriculture. It is therefore essential to measure lake water level changes over multi-annual time scales to trace it in the context of climate change and to be used within climate models. Satellite altimetry is widely used to measure lakes and reservoirs water height changes worldwide, and their associated uncertainties. However, strategies and algorithms to calculate this variable are not straightforward and sophisticated approaches have been developed.

Although originally conceived to study open ocean processes, the radar altimeter satellites have nevertheless been shown of great interest to acquire numerous useful measurements of decimetric to centimetric precision over lakes. With this technique, the Lake Water Level is defined as the height of the reflecting surface, in meters above the geoid. Hence, only lakes located along the satellite's ground tracks or within few kilometres can be monitored with nadir altimetry, with a quality of measurement that not only depends on the size of the lake, but also on its surface roughness, possible signal coming from other reflecting targets in its surroundings. Depending on the size of the lake, the satellite data may be gathered and averaged over very long distances. It is thus necessary to correct for the slope of the geoid (or equivalently, the mean lake level profile). The “repeat track technique” is used to solve this problem. The geoid slope is recalculated for each of the track of the satellite and then is averaged over a significative number of cycles. The result of this calculation is a mean vertical profile, along each pass per lake, which serves as correction for geoid. Additionally, many of these lakes, are observed by multiple mission and tracks, requiring a bias correction process.

For small lakes, the variation of the geoid has a negligible impact. A simpler approach can therefore be implemented to use the input L2 altimetry products and will be presented: measurements are extracted within lakes contours (from Hydrolakes dataset) and averaged for each transect. Particular attention was nevertheless required to setup editing criteria to remove possible outliers within the 20Hz input data. Indeed, given the smaller size of this lake sample, the altimeter footprint also covers lake shores and possible surrounding echogenic targets. Using this approach, water level timeseries have been generated over several thousands of lakes worldwide. The validation of the water level time series will be detailed in the presentation, emphasizing on comparisons to external data sets with either in-situ data or other altimetry-based products.

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MULTI-OBSERVATION DATA ASSIMILATION FOR LARGE-SCALE HYDROLOGIC-HYDRODYNAMIC PREDICTION

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Satellite remote sensing improves model predictions by providing information on land and hydrological processes. Although data assimilation techniques have shown promise, standardized and effective approaches for integrating multiple observations simultaneously are lacking. This study presents a novel assimilation framework, the multi-observation local ensemble Kalman filter (MoLEnKF), designed to effectively integrate multiple variables, even at scales different from that of the model. Unlike previous studies focused on one or two products, MoLEnKF employs the LEnKF technique in a large-scale hydrologic-hydrodynamic model. This study evaluates our technique in the Amazon River Basin (ARB) which includes assimilation experiments with water surface elevation (WSE) from radar altimetry satellites, terrestrial water storage (TWS) from the GRACE mission, flood extent (FE) from the GIEMS-2 multi-mission product and soil moisture (SM) from SMOS LERZ. MoLEnKF demonstrates improvements in regions lacking in situ hydroclimatic records when compared to the benchmark which is an uncalibrated version of the model. MoLEnKF outperforms the mean of individual assimilation experiments with notable reductions in discharge and WSE errors of 7% and 12%, respectively. WSE assimilation from radar altimetry outperforms, achieving ~16% reduction in discharge errors and WSE compared to the uncalibrated model. TWS assimilation excels in specific sub-basins. While radar altimetry provides the largest error reductions in the simulations in many regions of the study area, highlighting its importance for the continuation of such missions, this study provides evidence that assimilation of other complementary variables can help improve performance in regions where altimetry does not. MoLEnKF simulations outperform state-of-the-art models in the ARB, demonstrating its potential as a valuable tool for the scientific community. MoLEnKF emphasizes simplicity and elegantly expresses the LEnKF equations. The flexibility of MoLEnKF allows its application with different types of variables, compatible with large-scale hydrologic-hydrodynamic models and missions such as SWOT. Furthermore, its robustness ensures easy replicability in any global basin, facilitating the improvement of prevision, establishing MoLEnKF as a valuable tool for the scientific community in hydrological research.

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IMPACT OF SWOT ASSIMILATION ON MERCATOR OCEAN INTERNATIONAL GLOBAL FORECASTING SYSTEM

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Mercator Ocean International (MOi) has conducted several Observing System Simulation Experiments (OSSEs) to assess the potential of SWOT and more generally swath altimetry for ocean forecasting. The results have shown that the complementarity of SWOT with nadir altimeter data improves the quality of ocean forecasts. The launch of the SWOT satellite took place on 16 December 2023. We use here the first SWOT (Nadir+karin) L3 data sets (21-day orbit) to carry out assimilation tests in our global (1/12°) forecasting system and assess the impact of SWOT data on the quality of ocean analyses and forecasts. A new data assimilation technique with scale separation is used. Adding SWOT observations to those of other nadir altimeters globally reduces the variance of sea level analyses and forecasts by about 20%. Perspectives for improving further the impact of SWOT data are discussed.

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VALIDATION OF LAKE LEVELS FROM SENTINEL-6MF WITH IN-SITU DATA AND OTHER SATELLITE ALTIMETERS

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The importance of satellite altimetry for the monitoring of inland water bodies is increasing, which the addition of Sentinel-6 Michael Freilich (MF) to the satellite altimetry record will help support. With the launch of Sentinel-6MF, we have for the first time high- and low-resolution observations of inland water in parallel. In this study, we validate Sentinel-6MF based low and high-resolution lake water levels, determined with a state-space model. We use data from 124 gauges in 85 lakes, located in the United States, Canada, Sweden and Australia, and additionally estimate the scatter of observations from 1330 globally distributed lakes (greater than 20 km²), and compare with Sentinel-3A and B. At these locations, we determine the performance difference between a physical (ocean) and empirical (OCOG) retrackers, as well as the difference between the low- and high-resolution modes. We see how lake characteristics (size, shape, location), as well as the satellite ground track locations can influence the performance.

Using the gauges as ground-truth, we achieve an unbiased root mean squared error (u-RMSE) of 6.4 cm for Sentinel-6MF (best case, with high-resolution mode, only summer data and using the OCOG retracker). We achieve lowest u-RMSE when using only summer data, to correct for ice-coverage on lakes in the winter. The median standard deviation per transect of lake water levels is found to be 3.7 cm for high resolution, and 8.7 cm for low resolution (OCOG), compared to 6.1 and 6.2 cm for Sentinel-3 (A and B respectively). We achieve generally better performance with the empirical retracker, however the physical retracker outperforms at larger lakes (> 10,000 km²). We see more confidently determined water levels with the high-resolution mode, especially at lakes with a high chance of land contamination in the altimetry footprint. Overall, we achieve good results from Sentinel-6MF and the data from this mission would provide additional value to future inland water level monitoring.

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ASSIMILATION OF SWOT DATA (1-DAY ORBIT) INTO MERCATOR OCEAN INTERNATIONAL'S GLOBAL FORECASTING SYSTEM

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The international Surface Water and Ocean Topography (SWOT) satellite, launched in December 2022, is making high-resolution 2D observations of sea-surface height (SSH) using SAR radar interferometry techniques. Mercator Ocean International (MOi) has carried out the first tests to assimilate SWOT (1-day orbit) data into the global (1/12°) forecasting system. A new data assimilation technique with scale separation has been tested. The results of these studies are presented here. We analyze the impact on SWOT crossover regions and the impact of repetitive observations. The one-day fast sampling phase offers a unique opportunity to assess the model forecast representation of the high frequency phenomena down to 1-day that will be aliased with the 21-day orbit.

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"SWATH PROCESSING" WITH SENTINEL-6: MEASURING DENSELY SAMPLED RIVER ELEVATION PROFILES

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Radar altimeters typically provide water elevations of rivers and lakes only where a target intersects the satellite's ground track, called Virtual Stations (VS). This way, the observations have both limited temporal and spatial resolution, because on one hand such intersections occur by chance and because on the other hand the repeat cycle of the orbit ranges from 10 to 35 days, depending on the mission.

Boy et al. [1] illustrated recently that river signals may also be captured when the river is located at cross-track distances of several kilometers, when utilizing high resolution SAR altimeter products (particularly fully-focused SAR [2], FFSAR). This enables to measure dense longitudinal river profiles, but comes with completely new challenges in the data processing. Based on the initial idea, we developed a novel algorithm to semi-automatically calculate water surface elevations (WSE) of rivers within a ground swath of approximately 14 km width, and with along-track resolutions as fine as 10 m from the Sentinel-6 altimeter signal. All that is needed additionally to the FFSAR-processed signal is an a-priori river polygon or centerline to correct for non-zero cross-track distances.

Our algorithm can provide WSE along most parts of the river that fall within the swath, thus delivering densely sampled WSE profiles instead of a few point measurements over only the nadir crossings (VS). This marks a drastic improvement in the number of available WSE observations and opens completely new research possibilities, as water surface slopes and level changes due to rapids and dams can be studied directly. Essentially, these new Sentinel-6 WSE measurements resemble the river WSE product obtained with the recently launched SWOT mission (albeit with more limited coverage). As such, they can be exploited in similar manners to provide much additional information for hydrological research, e.g. for assimilation in hydrological models and more reliable estimation of river discharge.

We validated the new measurement approach and our algorithm over two rivers in France, the Creuse river and the Garonne river, showing biases that are typically on the order of +-4 cm and random errors on the order of 5 cm, both on 30 m along-track resolution. We currently evaluate a remote case study in Nepal, in which we aim to also compare the results to the SWOT measurements. In our presentation, we will concentrate our attention on the new challenges of the method, including a sophisticated signal detection algorithm, the altered error budget of off-nadir WSE measurements and the limitations due to signal folding, clutter, lacking contrast and the complexity of the scene.

[1] Francois Boy et al. “Measuring longitudinal river profiles from Sentinel-6 Fully-Focused SAR mode”. In: Ocean Surface Topography Science Team (OSTST) meeting. Nov. 2023. doi: 10.24400/527896/a03-2023.3781.

[2] Alejandro Egido and Walter H. F. Smith. “Fully Focused SAR Altimetry: Theory and Applications”. In: IEEE Transactions on Geoscience and Remote Sensing 55.1 (Jan. 2017), pp. 392–406. doi: 10.1109/TGRS.2016.2607122.

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LONG TERM ASSESSMENT OF THE GLOBAL MEAN SEA LEVEL RECORD AND ASSOCIATED UNCERTAINTIES BASED ON NEW L2P DT 24 PRODUCTS

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The Global Mean Sea Level (GMSL) has been measured with radar altimetry satellites since October 1992. This indicator is a natural integrator of Climate Change with two main contributions : ocean heat uptake as more than 90% of the energy kept by the additional greenhouse effect is stored within oceans (IPCC AR6 report, Working Group 1, Chapter 7) and additional mass from ice melt.

A robust description of the GMSL stability uncertainty budget is mandatory to disentangle the physical signals from measurement artefacts and to provide climate users with reliable uncertainties associated with the GMSL parameters. New recommendations for long-term stability have been established by the scientific community on both global and regional scale (Meyssignac, B., Ablain, M., Guérou, A., et al. How accurate is accurate enough for measuring sea-level rise and variability. Nat. Clim. Chang. 13, 796-803 (2023), https://doi.org/10.1038/s41558-023-01735-z). Tackling upcoming climate science questions will require an altimeter record stability to be lower than 0,1 mm/yr (currently ~0,3 mm/yr). To achieve this objective all contributions to the nadir satellite altimetry error budget must be revisited and improved as much as possible.

A new dataset of reprocessed along-track L2P products was released this year (L2P DT 24). It includes several updates with respect to the previous (L2P21) version: updated standards, reprocessed reference missions, new inter-mission biases. In this talk, we present updated GMSL rise and acceleration estimates, along with the associated uncertainty budget based on L2P24 data. This budget reflects new knowledge about errors and uncertainties of the satellite altimetry ocean surface topography observing system. Updated uncertainties on GMSL trends and accelerations are derived and compared to previous estimates based on L2P21 data and uncertainties.

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INCREASING LAKE TEMPORAL COVERAGE WITH DATA FROM ERS-1, ERS-2 AND ENVISAT. TDP INLAND WATER FROM FDR4ALT

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Although originally conceived to study open ocean processes, the radar altimeter satellites have nevertheless acquired numerous useful measurements over lakes. With this technique, the Lake Water Level is defined as the height, in meters above the geoid (the shape that the surface would take under the influence of the gravity and rotation of Earth) of the reflecting surface. It is observed by space radar altimeters that measure the time it takes for radar pulses to reach the ground targets, directly below the spacecraft (nadir position), and return. Hence, only lakes located along the satellite's ground tracks can be monitored, with a quality of measurement that not only depends on the size of the lake, but also on its position over the lake and the reflecting targets in its surroundings such as topography or vegetation.

For climate observations, analysing the causes of variations in lake level and understanding the processes involved in water level variations depend on the availability of observations over long periods of time. In addition to measurements from current missions, observations from past missions are invaluable for identifying seasonal variations in climate trends. In the framework of the FDR4AL project, a Thematic Data Product (TDP) only over inland water targets was generated from measurements acquired by the altimeters on board of ERS-1, ERS2 and ENVISAT. including some useful data as a quality flag, the type of surface and the water occurrence. This dataset allows to increase the temporal coverage for some lakes being monitored by currently missions but where the information on water variation before 2011 was not available as well as the generation of timeseries for some lakes not observed by more recent missions in a different orbit. The results of this increase are used in current versions of climate projects such as Lakes CCI and Copernicus Climate Change Service (C3S).

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ASSIMILATING CRYOSAT-2 FB TO IMPROVE MODELED SEA ICE THICKNESS

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Assimilating CryoSat-2 sea ice thickness (SIT) has shown to improve modeled SIT, but the assimilated CryoSat-2 SIT comes with large uncertainties. This uncertainties are for example due to CryoSat-2 derived freeboard (FB) uncertainties, but also due to the values of snow thickness and sea ice density used when converting CryoSat-2 FB to SIT. Here we present a new approach to assimilate FB directly into a coupled ocean-sea ice model, with a Kalman filter based FB assimilation. For the FB to SIT conversion, model derived values for snow thickness, sea ice density and water density are used. The resulting SIT of a first 3 year pilot study are presented and compared against other CryoSat-2 derived SIT products and SIT in sito observations. Further we analyzed the impact of changing the snow thickness, sea ice density and water density to model values on the FB to SIT conversion and find, in line with prior studies, that the snow thickness and sea ice desnity have the largest impact. We also find that their impact is opposite sign in some key regions, emphasizing that changing the snow thickness estimates from the typically used climatology in the FB to SIT conversion should always go hand in hand with an update of the typically used sea ice density values.

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GLOBAL OCEAN SPECTRAL SLOPES : FROM 1D NADIR ALTIMETRY TO 2D WITH SWOT

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Over the past decades, along-track Sea Surface Height (SSH) observations (1 Hz) have been used to tease out the spectral characteristics of oceanic variability in the meso- to sub-mesoscale wavelength range (wavelength < 100 km). Conventional altimetry reveals how mesoscale slopes vary geographically and seasonally depending on the ocean dynamics, and allow us to quantify the regional and seasonal variations in background noise and ocean observability above the noise. Alongtrack wavenumber spectra have also revealed regime shifts in many tropical and subtropical regions, where a quasi-geostrophic energy cascade changes to a flatter, non-geostrophic dynamical regime at smaller wavelengths. This wavelength scale, where the geostrophic energy cascade becomes dominated by non-geostrophic dynamics (e.g. internal gravity waves including internal tides) is important for using and interpreting SSH-derived geostrophic current data, and to quantify the regions and seasons where the geostrophic assumption breaks down. At higher latitudes, with smaller Rossby radius, this regime shift was not apparent, hidden by the higher conventional altimetry noise at smaller wavelengths.
The SWOT mission, embarking both the revolutionary KaRIn 2D imaging SAR interferometer and a Jason-class nadir altimeter, provides sub-50 km wavelength ocean sea surface height observations allowing us to explore the mesoscale eddy energy cascade at all latitudes. In addition, the SSH images allow us to observe true 2D structure of the mesoscale eddies and the radiating internal tides, and their interaction. With its unprecedented spatial resolution, coupled with an extremely low noise, the SWOT KaRIn observations allow us to characterize ocean dynamics for wavelengths well below the capabilities of conventional nadir altimetry.

In the present study, we characterize and re-assess the spectral slope characteristics at global scale (mesoscale slopes, noise levels, and spectral slope rupture). We use SWOT data from the first months of the mission's 21-day repeat orbit and compare these results against latest model and nadir altimeter estimates. The impact of a coherent internal tide correction on spectral slope estimates is also assessed. Our results can be used as an indicator for the spatial scales of residual internal tides and other ageostrophic signals in the SWOT and alongtrack data. This information is needed as more high-resolution SWOT data become integrated into multi-mission global SSH products and their derived geostrophic currents.

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UNDERSTANDING TROPOSPHERIC VARIABILITY OVER SHORT SPATIAL SCALES IN THE COASTAL ZONE: INSIGHTS FROM THE BASS STRAIT VALIDATION FACILITY USING SWOT SWATH ALTIMETRY

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The unprecedented resolution of wide-swath data from the SWOT mission is providing an exciting new lens into oceanographic processes over short spatial scales. These new data place an increased emphasis on the accuracy of geophysical corrections needed, and on the important yet challenging requirement for robust validation over these spatial scales. This is nowhere more evident than in the coastal zone where there are significant opportunities for the application of SWOT and future wide-swath data, yet many of the corrections required are particularly challenging.

Using an array of multiple GNSS buoys and sub-surface moored oceanographic sensors deployed over a ~80 x 40 km region, the long-term validation facility in Bass Strait is well placed to investigate the performance of swath altimeter data in the coastal zone. Our array of in-situ instrumentation deployed ~6-35 km from the coast for the three-month duration of the SWOT Fast Sampling Phase (FSP) offers a unique insight into the spatial and temporal variability of the wet tropospheric delay and sea surface height. These in situ data enable independent validation of the SWOT observations, corrections, and derived products over this coastal shelf sea region.

Here we present results over the SWOT FSP, with a focus on the variability of the tropospheric wet delay and SSH at short spatial scales up to ~80 km. This is of particular interest in the coastal zone where land contamination biases SWOT radiometer observations, and global models fail to capture the finescale tropospheric dynamics. We conclude with an assessment of the key improvements required for validating swath data in the coastal zone into the future, as well as a perspective on requirements for next generation missions.

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ARCTIC FRESHWATER FLUX FROM ALTIMETRY AND EO DATA.

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Understanding and monitoring the Arctic Ocean freshwater budget is crucial for predicting and adapting to climate change, as the Arctic region is highly sensitive and serves as a flagship area of the Earth's climate system (IPCC AR6, 2021). Variations in freshwater content influence ocean circulation patterns, including the Atlantic Meridional Overturning Circulation (AMOC), which impacts the transfer of heat between the equator and the polar regions. A major challenge in the retrieval of freshwater fluxes in the Arctic Ocean is associated with the lack of availability of in situ observations. Direct measurements are non-homogenous in both time and space and rely on spatial as well as temporal interpolation, resulting in large uncertainties. The ability to estimate freshwater content of the Arctic region indirectly from satellite observations is a major breakthrough.The ESA Arctic freshwater flux project demonstrated the ability of Earth Observation data from the Sentinel satellites and particularly satellite altimetry to determine freshwater fluxes from ocean, rivers and ice-sheets. This presentations illustrate highlight results from the ESA Arcflux project and outlines the path toward a full exploration of the freshwater budget in the Arctic Ocean focusing on how to address key scientific topics related to freshwater changes n the Arctic Ocean in the satellite era.

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CONSISTENT MEAN SEA SURFACE AND SEA LEVEL CHANGE ESTIMATION IN THE ERA OF CLIMATE CHANGE – OUTLOOK TO SWOT.

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Since the beginning of the precision satellite altimeter era in the early 1990s, efforts have been focused on computing the mean height of the ocean surface for use in various geodetic and oceanographic studies. With 30 years of satellite measurements now available, it is time to rethink how we model the mean sea surface (MSS) in the era of climate change.
There are linear changes in the height of the ocean surface due to melting ice and increasing ocean heat content that will not average to zero when computing the mean. Today, there are places in the ocean that are

15 cm higher than they were at the start of the altimetric era some 30 years ago. Today, conventional MSS models like CLS15/22 or DTU15/21 are roughly 5 cm lower than what is observed by present-day satellites like Sentinel6-MF.
We propose that linear sea level changes are estimated simultaneously and consistently with the mean sea surface computation and added to the definition of the MSS, which is tied to a particular date in time. This is possible because the MSS are tied to the 2003.01.01 period for the DTU MSS models.
We also investigated the acceleration of sea surface height but found these small and still unstable [Nerem et al., 2018]. We also found that these are still somewhat dependent on the Side A correction of the TOPEX mission. We conclude that a longer time series is needed before a stable map of the accelerations can be computed and applied.
There is considerable evidence that using a 30-year trend pattern in sea surface height is stable and is driven by the "forced response" of Greenhouse gases and aerosols. These patterns will be reasonably persistent as we move forward in time.
Testing a new DTU24MSS mean surface tailored to the year 2024 to our processing of the recently available 2023 SWOT data, we find this new DTU24MSS reduces the spatial variability of the SWOT data which is important to the processing and particularly the roll-error correction applied to the 2D SWOT sea surface height data. Applying the new DTU24MSS to conventional satellites like Sentinel-3A/B and 6 reduces both offset and spatial variability of the data indicating that the new MSS is actually very close to a "present-day mean"

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INVESTIGATION OF GNSS AND ALTIMETER DERIVED WAVE CHARACTERISTICS AT THE SOUTHERN OCEAN SOFS SITE DURING THE SWOT FAST SAMPLING PHASE

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The wide-swath SWOT satellite altimetry mission provides ocean measurements at unprecedented resolution and precision. These exciting new measurements bring with them significant challenges in validation, requiring a diverse range of approaches across a geographic spread of areas with different oceanographic regimes. The Southern Ocean Flux Station (SOFS) mooring offers in situ measurements of both waves and sea surface height (SSH) derived from Global Navigation Satellite System (GNSS) data, in addition to sub-surface oceanographic instruments observing temperature and salinity through the column. Data from this mooring has proven useful in the validation of previous nadir missions, providing a comparison point of interest in a highly dynamic region of the Southern Ocean where the mean significant wave height is ~4 m, and individual waves are regularly in excess of 10 m.

In this poster, we present significant wave height (SWH) and directional wave spectra derived from GNSS data from the SOFS mooring. We compare these observations to data available from the SWOT satellite during the Fast Sampling Phase (FSP). Finally, we highlight the value and unique insights offered through independent validation from in situ data in this undersampled and energetic location.

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OBSERVING OCEAN MESOSCALE EDDIES : A REVIEW FROM THE GEOSAT ERA THROUGH TO SWOT

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Satellite altimetric sea surface height (SSH) has always detected the most energetic part of the ocean circulation : mesoscale eddies. Early studies with Seasat and Geosat, revealed the global structure of eddy kinetic energy. Geosat crossovers were used to study 2D eddy variance and energy and momentum fluxes, for example in the Southern Ocean. Spectral analyses of these alongtrack data have revealed the seasonal and regional variations in altimetric noise levels and the mesoscale eddy turbulent cascades.

Over the last 30 years, data from multiple altimeter missions allowed a better representation of the mesoscale eddy structures, but for the larger-scale processes greater than 100 km in diameter. Most mesoscale eddy studies have relied on the 2D multi-mission mapped data, revealing the rich structure of the larger mesoscale eddies and jets, and how they evolve in time and space, and in relation to the larger-scale circulation changes. These mapped altimetric data has been used to track the pathways of mesoscale eddies, calculate eddy fluxes, eddy diffusion and Lagrangian stirring of the surface oceanic tracer fields.

Collocated in-situ observations within mesoscale eddies detected from altimetry allow us to better define the eddy's vertical structure, and estimate how eddies are transferring heat, salt and other tracers laterally across oceans, and to estimate eddy heat and salt fluxes.

The anisotropic 2D structure of mesoscale eddies and their interaction with oceanic internal tides are revealed in all their splendor with the NASA/CNES wide-swath SAR-Interferometry SWOT mission, launched in December 2022. SWOT's low noise and full spatial coverage up to 78° in latitude allows us to fully observe all mesoscale eddies, even in high latitudes and coastal/regional seas. SWOT's 1-day Calibration Phase reveals the rapid evolution of ocean eddies. Full global coverage in the 21-day Science Phase of fine-resolution 2D images allow us to re-assess the eddy cascade from wavenumber spectra, to calculate 2D eddy energy fluxes at higher spatial resolution, and to explore the holy grail of calculating the oceanic vertical velocities from surface data alone. This historic evolution will be addressed in this presentation.

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HIGH RESOLUTION ALTIMETRIC GRAVITY FIELD MODELING DEVELOPMENT OVER THE LAST 30 YEARS FROM GEODETIC MISSION ALTIMETRY – WITH AN OUTLOOK TOWARDS SWOT

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Prior to the launch of Cryosat in 2010 the only 2 years of geodetic data available for deriving high-resolution marine gravity fields from Geosat and ERS-1.
With the launch of the second generation altimeters CryoSat and SARAL/AltiKa and the completed geodetic missions from Jason-1 and 2 a new era in satellite altimetry was initiated

Since 2010 the amount of geodetic mission altimetry has nearly ten-doubled. At the same time the signal-to-noise ratio in these new satellite's range measurements is far better than that of Geosat and ERS-1, leading to huge improved resolution of marine gravity anomalies. Today the quality of altimetric marine gravity is 3 times more accurate than 15 years ago and on the order of 1.5 to 2 mGal resolving gravity field features down around 12-15 km depending on region This surpasses what can be obtained from marine gravity in many regions of the world.
The quality and resolution of altimetric marine gravity field will always be limited by the random noise level in the radar range measurement as well as the ground track spacing. Over the years geodesists have made significant advances in retracking algorithms, cutting range error nearly in half, and leading to improvements. With tailored EoL geodetic missions of the Jason satellites we could aim to systematic decrease the groundtrack spacing from 8 km today to 2 km which will will increase the spatial resolution and hence the accurate of altimetric marine gravity field.
SWOT is now providing systematic mapping of altimetric gravity and the first tests point towards improving marine gravity to a spatial resolution of better than 8 km and lowering the accuracy to the 1-mgal level with only a few years of data.

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NEW DEFINITIONS FOR THE HIGH FREQUENCY CORRELATED NOISE IN THE GLOBAL MEAN SEA LEVEL UNCERTAINTY BUDGET USING SWOT CAL/VAL PHASE DATA

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The Global Mean Sea Level (GMSL) record has been measured with radar altimetry satellites since October 1992. The GMSL record is a natural integrator of climate change with contribution from ocean thermal expansion and ocean mass change from ice melt.

A robust description of the GMSL stability uncertainty budget is mandatory to disentangle the physical signals from measurement artefacts and to provide climate users with reliable uncertainties associated with the GMSL parameters. New recommendations for long-term stability have been established by the scientific community on both global and regional scale (Meyssignac, B., Ablain, M., Guérou, A., et al. How accurate is accurate enough for measuring sea-level rise and variability. Nat. Clim. Chang. 13, 796-803 (2023), https://doi.org/10.1038/s41558-023-01735-z). Tackling upcoming climate science questions will require an altimeter record stability to be lower than 0,1 mm/yr (currently ~0,3 mm/yr). To achieve this objective all contributions to the nadir satellite altimetry error budget must be revisited and improved as much as possible.

In its current definition (Guérou, A., Meyssignac, B., Prandi, P., Ablain, M., Ribes, A., and Bignalet-Cazalet, F.: Current observed global mean sea level rise and acceleration estimated from satellite altimetry and the associated uncertainty, EGUsphere, https://doi.org/10.5194/egusphere-2022-330, 2022.), the Altimetry error budget includes two contributions from high-frequency correlated noise. The method used to estimate these contributions is simple and does not separate real uncertainties coming from the measurement errors from high frequency natural oceanic variability leading to an overestimation of these contributions.

Observations from the SWOT one-day repetitive orbit Cal/Val are used to revisit the computation high-frequency correlated noise of nadir satellite altimetry, and consequently to remove the contribution from the natural oceanic variability in the nadir satellite altimetry uncertainty budget. In this presentation, we present new estimates of those high-frequency correlated noise combining SWOT 1 day repeat orbit observations with those from nadir satellite altimetry constellation, and their impact on the estimation of uncertainties associated with the GMSL parameters.

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THE SEVERN ESTUARY TIDAL BORE FROM FAST SAMPLED SWOT DATA

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Satellite altimetry is instrumental in deciphering the dynamics of oceans and coastal regions. It yields indispensable data critical for monitoring global sea levels, predicting wave heights, and charting the courses of ocean currents and river elevations. These insights are pivotal for advancing climate research, ensuring navigational safety, and managing water resources effectively. Nonetheless, in coastal settings, the efficacy of conventional altimetry is constrained by its spatial resolution and the interference of land in the radar signal near the coastlines. These limitations hinder its ability to accurately capture the nuanced characteristics of dynamic and intricate coastal environments.
The launch of the Surface Water and Ocean Topography (SWOT) satellite represents a monumental leap in the technology of satellite altimetry. With advanced high-resolution wide swath altimetry and innovative use of the phase difference between dual onboard antennas, SWOT drastically reduces the limitations of traditional radar altimeters. SWOT provides a 2D measurements grid with a detailed 50m grid spacing not degrading towards the coast. This marks a substantial enhancement compared to the 7-km across-track spacing along a 1D trajectory offered by conventional altimetry.
This enhancement allows for the precise and detailed monitoring of dynamic coastal phenomena such as tides and tidal bores, even in estuaries.
Tidal bores, characterized as sudden and powerful water surges against the river's current, are critical for local ecology, navigation, and flood management. Despite their importance, their dynamic and transient nature has made them challenging to study using conventional methods. The Bristol Channel, with its extreme tidal range and the presence of the Severn Bore, presents an ideal case study to demonstrate SWOT's capabilities.
We use SWOT 50-meter pixel cloud data during the 1-day fast sampling repeat period in April 2023 to study the high-resolution tidal signal in the Bristol Channel - Severn Estuary and the Severn tidal bore. The results demonstrate that SWOT can capture both complex tidal signals associated with wetting and drying close to the coast, but also the tidal bore sweeping up the Severn River from the mouth of the river and some 20 km upstream.

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USING A VECTOR AUTOREGRESSIVE MODEL AND GAUGE RELATIONSHIPS TO PREDICT WATER LEVELS OF THE ODRA/ODER RIVER AT VIRTUAL SITES OF THE SENTINEL-3A SATELLITE

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Sentinel-3 altimetry observations of water levels (WL) of medium and big rivers are characterized by high accuracy, with errors at virtual sites (VS – intersections of satellite ground track with river bed) of approximately 20-30 cm. However, the usefulness of these observations for operational hydrology applications is constrained by a set of factors, including: (1) poor temporal resolution of 27 days, and (2) lower accuracy of Near Real-Time observations (delivered within 3 hours) compared to the Non-Time Critical data (delivered within 1 month).

In this study we propose a new method for forecasting water levels at VS of the Sentinel-3 satellite. The method is based on the hydrological relationship between a VS and a neighbouring upstream gauge. To produce water level predictions at VS, several steps must be taken. First, a prediction is issued for the neighbouring gauge upstream of a VS. Next, in situ WL and VS WL are juxtaposed, taking into account the time lag between the stations studied. The corresponding measurements are then used to calculate a regression, which is used to convert WL predictions at the gauge into water level predictions at the VS. Finally, the predictions are adjusted for the time lag calculated in the previous step.

This approach has been implemented in a real-time prediction system on the Middle Odra/Oder River (W Poland) for 8 VS of the Sentinel-3A satellite. The Vector Autoregressive Model (VAR) has been utilized for WL predictions of lengths up to 72 h, which was built on hourly WL data from 28 gauges within the basin, provided by the Institute of Meteorology and Water Management. Altimetry-based WL are obtained from the Hydroweb database (https://hydroweb.theia-land.fr/, accessed on 28.02.2024) and corrected for the river slope bias. Time lags are calculated using correlations between lagged neighbouring gauge WL time series, and the VS-gauge WL transformation is performed using a classical linear regression. For each VS-gauge pair, the regression is updated when new altimetry data become available.

Since there are no gauge measurements exactly at VS, the validation of predictions has to be performed using altimetry-based WL. Namely, each Sentinel-3A measurement serves as a reference for the predictions issued within the last 72 h. Initial studies reveal good accuracy of short WL predictions (up to 24 h). As new altimetry measurements become available, the VS-gauge regression is updated, which is expected to improve the regression fit and prediction accuracy over time. The research is supported by the National Science Centre, Poland, through the project no. 2020/38/E/ST10/00295.

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POLAR OCEAN MSS DEVELOPMENT COMBINING RADAR AND LASER ALTIMETRY

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Radar altimeters have traditionally been used for the determination of the mean sea surface with a few centimeters accuracy. However close to the coast, the MSS degrades because of the lack of valid altimetry observations and because of the land contamination and the altimeter footprint size.

In 2018, the National Aeronautics and Space Administration launched ICESat-2, a laser altimetry mission equipped with the Advanced Topographic Laser Altimeter System, providing measurements every 0.7 m in the along-track direction. We have investigated the use of ICESat-2 around Greenland and Denmark. Greenland has a highly complex coastline and Denmark has more than 20 GNSS-controlled tide gauges for validation. The aim is to investigate if we can improve coastal MSS from ICESat-2 for the updating of the upcoming DTU24MSS model. In Greenland, we realized that the existing ocean tide model hampers the use of laser altimetry in the fjords as FES2014 does not cover. Hence we developed a novel method that simultaneously determines MSS and ocean tide signal in complicated polar ocean coastal zones

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14 YEARS OF WATER LEVEL CHANGE IN LAKES AND RESERVOIRS OBSERVED BY CRYOSAT-2

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The explorer mission, CryoSat-2, launched in 2010, initiated a new era within satellite altimetry as it is the first altimetry satellite to operate in SAR and SARIn mode. Another key feature of CryoSat-2 is the geodetic orbit ensuring a high spatial coverage for nadir altimetry. The latter is seen as a challenge for inland water applications as virtual stations (locations where the ground track intersects a given target) cannot be formed directly. This is most likely one reason why CryoSat-2 is not applied as much within inland water as the repeat orbit mission. Though challenging, a geodetic orbit is a tremendous gift for hydrology as it enables us to observe a considerably larger amount of lakes, detect spatial signals such as unmodelled geoid signals on large lakes, and outline river elevation profiles.

Here we present a dedicated lake and reservoir data set based on CryoSat-2 that covers 14 years. This data set contains water level time series for more than 5000 lakes and reservoirs with an area larger than 20 km^2. The time series are reconstructed at the time of measurement but additionally, water level time series predicted at regular time intervals (monthly to yearly) are also provided to ease the use in further analysis. Here, we present the workflow for the creation of this data set and address the encountered challenges which among others include erroneous measurements as CryoSat-2 is operating in closed loop mode and that lake mask and geoid errors are affecting the water level time series. To assess the data set we compare it with ICESat-2 in the overlapping period. Finally, we highlight some of the global trends and patterns detected in this important data set. With this data set, we hope to expand and ease the use of CryoSat-2 for inland water applications The data set will potentially also make an important contribution to our overall understanding of climate change.

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ENHANCED WET TROPOSPHERIC CORRECTION COASTAL METHODOLOGIES FOR THE SENTINEL-3 MISSION

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Over coastal regions, the wet tropospheric correction (WTC) derived from Microwave Radiometers (MWR) brightness temperatures (TBs) measurements is inaccurate due to land contamination in the TBs. The retrieval errors increase rapidly with the satellite approach to the coast. In this work, improved methods to compute the WTC over coastal regions for the Sentinel-3 mission are developed. These are based on the Sentinel-3 dual-band MWR TBs and the Synthetic Aperture Radar Altimeter (SRAL) Ku band backscatter coefficient, σ0, together with additional parameters to account for surface effects. In order to mitigate land contamination effects on the MWR TBs and SRAL σ0, modification methods of these parameters are proposed. The impact of these modification methods on the WTC retrieval is first evaluated in terms of the use of modified inputs in an open-ocean algorithm, and, on a second phase, in new developed coastal algorithms. Previous authors have tested similar approaches on three-band MWR aboard the reference missions, on open-ocean algorithms only. This is the first study exploiting these methods for two-band MWR (where the coastal land contamination is a more challenging problem), including its implementation in new coastal algorithms. Independent comparisons are performed against the WTC derived from coastal Global Navigation Satellite Systems (GNSS) stations. In parallel, the evaluation of the three-band MWR-derived WTC against GNSS stations is also performed for the reference missions, in order to place the coastal retrieval errors of the Sentinel-3 mission in relation to these missions. Originally developed for the Sentinel-3 Baseline Collection (BC) 004, significant improvements over the Sentinel-3 MWR-derived WTC operational algorithm have been achieved with the combined strength of modified inputs and coastal algorithms. For BC 004 data, the rms of the differences w.r.t. GNSS are of 3.1 cm between 5 and 10 km from the coast (9.2 cm for the Sentinel-3 operational algorithm) and 3.3 cm up to 5 km from the coast (16.2 cm for the Sentinel-3 operational algorithm). The proposed methods are revisited in terms of the new Sentinel-3 BC 005.02, in order to evaluate whether these methods need further tuning for this new BC.

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POLAR OCEAN TIDES FROM RETRACKED CRYOSAT-2 ALTIMETRY.

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Polar oceans have generally been harder to determine from satellite altimetry because the regions outside the 66 parallel has traditionally only been surveyed satellites in sun-sun-synchronous orbits. With Cryosat-2 this has changed. However, the satellite poses a number of challenges to tidal analysis because of its long groundtrack repeat period (368 days) and its diverse measurement modes, low-rate mode (LRM) over the ocean and synthetic aperture radar interferometric mode (SARin) over ice surfaces and parts of the ocean. Within the ESA CP40 project the SAMOSA+ physical retracker were developed to process the Cryosat-2 data across measurement modes. Being a physical retracker it enables determination of the sea state bias and hence provides more stable sea level estimates compared with traditional empirical retrackers used in the Polar Ocean. Nearly 10 years of Cryosat-2 data have been analysed for residual ocean tides to the FES2014 ocean tide model in the Arctic Ocean and Antarctic Ocean using the response formalism. We use data from the near monthly-repeated subcycle of C2 as this has a favorable alias period for most major constituents. We map long wavelength corrections to the major astronomical constituents M2, S2, K2, N2, K1, O1, P1, and Q1 tides for both the ocean and floating ice shelves domains. In addition, several smaller third, fourth and sixth diurnal tides have been determined. Some of these small compound/over tides does show small but consistent signal across regions like the Weddell sea (South Atlantic) and in the Baffin Bay between Greenland and Canada.

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HIERARCHICAL VARIATIONAL DISCHARGE INVERSION (HIVDI) FROM SWOT DATA OVER RIVERS NETWORKS

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The SWOT mission provides hydraulic visibility of rivers surface el-evation, width and slope, at an unprecedented resolution and accuracy. One mission target is the estimation of global rivers discharge Q(t) which remains a challenging inverse problem with unobservable bathymetry b(x) and friction K(x). The inferrence of the triplet (Q(t); [K, b](x)) is faced with structural and spatial equifinality, and pertains to a double hydrological-hydraulic regionalization problem. Moreover, SWOT data are dense in space but relatively sparse in time compared to diverse frequential aspects of rivers surface signatures triggered by upstream-lateral hydrological inflows.
An improved version of the Hierarchical Variational Disharge Inversion (HiVDI, https://mathhydronum.insa-toulouse.fr/codes_presentation/pres_hivdi/) algorithm applicable to rivers networks is presented here and includes a new parameter estimation methodology based on hybrid Bayesian-Machine Learning and Variational Data Assimilation (VDA) approaches applied to a hierarchy of hydraulic models. This new HiVDI version is the combination of all our knowledge acquired during the past 10 years in the preparation of the SWOT mission in terms of modeling, forward-inverse methods and ancillary databases exploration to constrain the ill-posed problem. Key ingredients are:
- The steady Low Froude model with equivalent bathymetry-friction parameterization of adequate complexity given SWOT visibility scales.
- Hybrid estimation approach for efficient global search and learning of prior parameters from large physiographic and SWOT databases.
- The full 1D Saint-Venant river network model providing physical consistency to simulated flows, especially in terms of wave propagations given hydrological inflows over entire networks.
- Optimal combination of the dynamic flow model and heterogeneous measurements by VDA including regionalization constraint.

The new version of HiVDI has been tested on the benchmark PEPSI cases (42 single channel river portions) but also on river networks in France (Tarn-Garonne) and in French Guyana (Maroni basin, sparsely gauged). To the best of our knowledge, this is the first application of a discharge algorithm on a river network in the context of the SWOT mission. A SWOT signal filtering and river segmentation algorithm is implemented on top of HiVDI in view of operational application on diverse basins.

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PRODEM: AN ANNUAL SERIES OF SUMMER DEMS (2019-2023) FOR THE MARGINAL AREAS OF THE GREENLAND ICE SHEET

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Surface topography within the marginal zone of the Greenland Ice Sheet continually evolves in response to varying weather, season, climate and ice dynamics. However, existing ice sheet Digital Elevation Models (DEMs) usually rely on multi-year data, obscuring these changes over time. We have here developed an annual series (2019-2023) of summer DEMs in 500m resolution for the Greenland ice sheet marginal zone, referred to as PRODEMs. Encompassing all outlet glaciers from the Greenland ice sheet, these PRODEMs result from fusing CryoSat-2 radar altimetry and ICESat-2 laser altimetry using a regionally-varying Kriging method. Validated through leave-one-out cross-validation, they demonstrate accurate representation of surface elevations within the spatially varying prediction uncertainties with a median value of 1.4m.

The PRODEMs capture the recent annual evolution in summer surface topography of all outlet glaciers from the Greenland ice sheet. We observe a general lowering of surface elevations compared to ArcticDEM, but the spatial pattern of change is highly complex and with annual changes superimposed. The PRODEMs offer detailed insights into marginal ice sheet elevation changes, temporally as well as spatially, making them valuable for researchers and users studying ice sheet dynamics under changing environmental conditions.

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CRYOSAT LONG-TERM OCEAN DATA ANALYSIS AND VALIDATION: FINAL WORDS ON GOP BASELINE-C

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ESA's Earth explorer mission CryoSat has an ice-monitoring objective, but is also a valuable source of observations for measuring impacts of climate change over the ocean. In this paper, we report on our long-term ocean data analysis and validation, and give our final words on CryoSat Geophysical Ocean Products (GOP) Baseline-C. The validation is based on cross-comparison with concurrent altimetry and with in-situ tide gauges. Highlights of our findings include GOP Baseline-C showing issues with the ionosphere and pole tide correction. The latter giving rise to an east-west pattern in range bias. Between Synthetic Aperture Radar (SAR) and Low-Resolution mode (LRM) a 1.4 cm jump in range bias is explained by a 0.5 cm jump in sea state bias which relates to a significant wave height SAR-LRM jump of 10.5 cm. The remaining 0.9 cm is due to a range bias between ascending and descending passes, exhibiting a clear north-south pattern and ascribed to a timing bias of +0.367 ms affecting both time-tag and elevation. The overall range bias of GOP Baseline-C is established at –2.9 cm referenced to all calibrated concurrent altimeter missions. The bias drift is not exceeding 0.2 mm/yr, leading to the conclusion that GOP Baseline-C is substantially stable and measures up to the altimeter reference missions. This is confirmed by tide gauge comparison with a selected set of 309 PSMSL tide gauges over 2010–2022: we determined a correlation of 0.82, a mean standard deviation of 5.7 cm (common reference and GIA corrected), and a drift of 0.17 mm/yr. In conclusion, the quality, continuity, and reference of GOP Baseline-C is exceptionally good and stable over time and no proof of any deterioration or platform aging has been found. Any improvements for next CryoSat-2 Baselines could come from sea state bias optimisation, ionosphere and pole tide correction improvement, and applying a calibrated value for any timing bias. Baseline-D data will be released medio 2024 and we do hope to be able to update our findings with analysing available GOP Baseline-D data.

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FIRST RESULTS OF THE CCI RIVER DISCHARGE PRECURSOR PROJECT

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The Global Climate Observing System (GCOS) identified river discharge as an Essential Climate Variable (ECV) (GCOS, 2022). This ESA River Discharge Climate Change Initiative (CCI) precursor project (https://climate.esa.int/en/projects/river-discharge/) aims to takcle this purpose using remote sensing data. However, there is currently no satellite instrument able to directly measure river discharge. It can only be derived indirectly, using three methodologies: (1) the use of multiple satellite radar altimeter long time series of water surface elevation to estimate discharge through a rating curve approach, (2) multispectral sensors data, specifically in the near infrared (NIR) band, are used to compute the ratio between the reflectance of a dry pixel and a wet pixel which is linked to the river flow variations, and (3) the combination of these 2 approaches. The large advantage of the multispectral sensors, compared to radar altimeters, is the sub-daily temporal resolution, however they cannot penetrate clouds (contrarily to radar altimeters). This RD_CCI+ is a proof-of-concept and is therefore not yet global. It aims at providing discharge estimation from at least 2002 to 2022, at 54 locations over 18 river basins. These selected targets cover different climatic zones (from the tropics to the Arctic), different drainage areas (from 50,000 km2 to the Amazon basin), different levels of human activities and in situ observation availability. This presentation will provide an overview of the methodologies used, the computed discharge time series and their validation.

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DAILY MONITORING OF INLAND SURFACE WATERS WITH A CONSTELLATION OF SMALL ALTIMETRY SATELLITES (SMASH)

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At global scale, there is still considerable uncertainty about the spatial and temporal variability of water storage and fluxes at the surface of continents. This is even more critical in the context of global climate change and the increasing human pressure on water resources. Despite this context, the following scientific questions remain difficult to answer, due to the coarse spatio-temporal resolution of current data: what is the global distribution of the heterogeneous change undergone by continental surface waters? What is the impact of anthropogenic pressure on water flows and stocks? What is the impact of these changes on the frequency and intensity of hydrological extremes (high and low waters)? To answer these questions, the Global Climate Observing System (GCOS) has identified river levels/discharges and lake/reservoir levels/volumes as essential climate variables, and recommends daily sampling (GCOS, 2022). Besides, extreme events, such as floods or droughts, cover a wide range of spatio-temporal scales. At present, water volume variations can only be observed by satellite at the coarsest scales (and are therefore of interest only for floods on the scale of the world's largest watersheds). The lack of observation of these events in basins with little or no in situ instrumentation is a major issue to understand, simulate and forecast these events. Observing these events globally, at least on a daily scale, would make it possible to quantify local flooding, thus greatly improving our knowledge of these events.
One of the main issues to tackle these questions is the still rather coarse temporal sampling of current satellite missions, particularly altimetry missions. To overcome it, we are proposing the SMall Altimetry Satellites for Hydrology (SMASH) mission. This is a constellation of around 10 compact Ka-Band nadir radar altimeters optimized to provide daily observations of water levels in rivers, lakes and reservoirs along the constellation tracks. The specifications of the SMASH mission are the following: daily temporal sampling, observe water bodies larger than 100 m x 100 m and rivers as narrow as 50 m, with an accuracy on water elevation ~10 cm, and should provide products in near-real time and over the long term (10 years) in open access (open science and FAIR principles). SMASH requirements and technology are the direct outcome of 30 years of progress in radar altimetry over inland waters, especially it relies on the knowledge from AltiKa/SARAL data analysis.
Combining "high temporal frequency/low spatial frequency" measurements from the SMASH mission with "high spatial frequency/low temporal frequency" measurements from swath altimetry missions (current SWOT or future Sentinel-3 Next Generation Topography missions) would cover unprecedented time and space scales and should open new fields of research.

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CURRENT STATUS OF SWOT PERFORMANCE OVER RIVERS

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The Surface Water and Ocean Topography (SWOT) Satellite Mission is designed to measure water surface elevation and inundation extent in water bodies globally, including in rivers. Because SWOT's Ka-band radar measurements produce novel data over these water bodies, considerable effort to assess SWOT's performance is necessary. This work includes a wide range of activities, including qualitative assessment of SWOT data on its own, quantitative comparison against in situ data collected expressly for the purpose of assessing SWOT performance, and comparison against other already available datasets. In this presentation, we will explore the performance of SWOT over rivers, including its capabilities to measure or estimate inundation extent, water surface elevation, slope, and discharge. Results suggest that SWOT is broadly capable of quantifying all of these variables with high accuracy when compared against state-of-the-art in situ or high resolution remote sensing measurements. There are also a number of sources of error in SWOT river measurements, which include the presence of dark water associated with specular reflectance and other sources, misassignment of SWOT pixels to rivers that were actually collected over other surfaces, and outward propagation of very strong signal collected directly beneath the satellite (termed nadir ringing). While these sources of error do impact SWOT performance in some cases, the overall picture is of a sensor that meets or exceeds performance expected prelaunch.

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THE NEW SENTINEL-3 HYDRO-CRYO (LAND) THEMATIC PRODUCTS: CURRENT STATUS AND FUTURE EVOLUTIONS

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Sentinel-3 is an Earth observation satellite series developed by the European Space Agency as part of the Copernicus Programme. It currently consists of 2 satellites: Sentinel-3A and Sentinel-3B, launched on 16 February 2016 and 25 April 2018, respectively. Among the on-board instruments, Sentinel-3 is measuring the surface topography with the SAR Radar ALtimeter (SRAL), providing high resolution measurements along the satellite track compared to previous conventional altimeters operating in Low Resolution Mode (LRM). This is highly valuable over continental surfaces, considering the heterogeneous surface properties observed at the radar footprint scale.
To further improve the performances of the Sentinel-3 Altimetry Hydro-Cryo products, ESA and the Sentinel-3 Mission Performance Cluster (MPC) transferred to operation in September 2023 specialized and separated delay-Doppler and Level-2 processing chains over (1) Hydrology, (2) Sea-Ice, and (3) Land Ice areas. With these so-called Hydro-Cryo Thematic Instrument Processing Facilities (T-IPF), ESA delivers Thematic products covering these three mentioned surfaces, to address the needs of the different scientific communities.
The objective of this talk is to provide a status of the Sentinel-3 Hydro-Cryo Thematic Products. In a first part, the architecture of the Thematic Processors and the data content will be shortly introduced. In a second part, the talk will focus on the short-term evolutions planned to be implemented in 2024. Mid-terms strategies to further improve the data performance will finally be presented.

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HOW DO MEASUREMENT ERROR AND NATURAL VARIABILITY CONTRIBUTE TO TREND ESTIMATION UNCERTAINTY?

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The Global Mean Sea Level (GMSL) is one of the Essential Climate Variables identified by the Global Climate Observing System. GMSL rise is a direct indicator of a changing climate and is particularly important in climate adaptation as it impacts coastal and low-lying islands communities. We illustrate that estimates of the GMSL trend and its uncertainty require considerations of both measurement uncertainty and natural variability. Building on expert work on both types of uncertainty, we propose a methodology that captures both aspects and propose an estimate of the GMSL trend and acceleration and their uncertainties.

In (Ablain et al., 2019), the authors propose an error covariance matrix for the measurement uncertainties associated with a dataset covering 25 years of 10-days averaged GMSL data from satellite altimetry with a 10-day sampling frequency. We use the data and covariance suggested therein to model the distribution of measurement errors. To understand the natural variability, we build on prior work (Bos et al., 2014) which models the stochastic aspects of the GMSL data series using probabilistic models that include both Gaussian (white noise) effects and autocorrelated effects in the time series. Combining those two previous works and modelling inter-annual variability due to El-Nino/La Nina cycles with a sparse model in a Ricker wavelet basis, we provide estimates and uncertainties for the trend and acceleration of GMSL that consider both measurement uncertainty and natural variability.

Ablain, M., Meyssignac, B., Zawadzki, L., Jugier, R., Ribes, A., Spada, G., Benveniste, J., Cazenave, A., Picot, N., 2019. Uncertainty in satellite estimates of global mean sea-level changes, trend and acceleration. Earth System Science Data 11, 1189–1202. https://doi.org/10.5194/essd-11-1189-2019

Bos, M.S., Williams, S.D.P., Araújo, I.B., Bastos, L., 2014. The effect of temporal correlated noise on the sea level rate and acceleration uncertainty. Geophysical Journal International 196, 1423–1430. https://doi.org/10.1093/gji/ggt481

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ASSESSING THE IMPACT OF ASSIMILATING HIGH-RESOLUTION SLA FIELDS (SWOT) INTO MOVE/MRI.COM-JPN

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Integrating satellite altimetry, particularly the Surface Water and Ocean Topography (SWOT) mission, into numerical models presents a promising frontier in oceanographic research. This study aims to assess the impact of assimilating additional sea level anomaly (SLA) data including SWOT into an operational ocean data assimilation/prediction system. The Japan Meteorological Agency (JMA) has been operating MOVE/MRI.COM-JPN (MOVE-JPN) , which covers the seas around Japan with a horizontal resolution of 2 km, as a system capable of monitoring and forecasting

Kuroshio, sea ice, and other coastal phenomena . MOVE-JPN is now using alon g-track SLA data from CMEMS, which include Jason-3, SARAL, Cryosat-2, Sentinel-3A/B, and HY-2B . SLA is assimilated after the exclusion of two nonsteric components, namely the global ocean mass change and the sea level variations due to the barotropic response to atmospheric forcings. Through comparative analysis against conventional systems and observational datasets, we quantify the benefits of assimilating SWOT data, highlighting enhanced predictive capabilities and improved representation of complex oceanic variability.

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DEVELOPMENT OF ALTIMETRY QUALITY ASSURANCE GUIDELINES

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For over three decades, ESA's Earthnet Programme has provided support to access and exploit ESA and non-ESA Earth Observation (EO) data, from both commercial and public organisations worldwide. In 2018, ESA launched the Earthnet Data Assessment Project (EDAP) to help assess the quality and suitability of Third-Party Missions (TPMs) to be integrated into the Earthnet Programme. As of today, EDAP has provided best practice guidelines for quality assessment of several types of EO data, including data from optical, SAR and atmospheric missions. As an extension to the initial project, EDAP+ plans on providing similar guidelines to assist the quality assessment of satellite altimetry data products.
The initial EDAP project defined a consistent set of criteria by which the claimed mission performance for sensors of all types could be verified. This was done through the 'calibration-validation maturity matrix', which is a high-level colour-coded summary of results of a detailed quality assessment of the data set (including documentation review and detailed validation). A maturity matrix consists of different sections (columns) and sub-sections (rows) and covers all essential aspects in evaluating mission performance.
In the EDAP+ project we are establishing maturity matrices, and the detailed criteria for different scores in each evaluation cell, for satellite altimetry products over sea ice, land ice, and inland water bodies. Here, we present initial results in defining a matrix that is tailored to the needs of the satellite altimetry community, while still being as consistent as possible with maturity matrices for other types of sensors. These preliminary results have been obtained in discussion with a consortium of scientists, data providers and calibration-validation experts for each of the three surfaces and are presented here to obtain further community feedback. The outcome will be published as a QA guidelines report through earth.esa.int.

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IMPROVING THE FILTERING SCHEME OF THE IONOSPHERIC CORRECTION

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The electron activity in the ionosphere, driven mainly by the solar radiations, plays a significant role in delaying an altimeter pulse propagation, leading to errors of up to 10 cm and more in the measurement of the Sea Level Anomaly (SLA). Most altimetric missions account for these errors by computing a ionospheric correction from dual-band observations. However, the correction becomes ineffective, and can even be detrimental to the SLA observation, when its values become of the same order as the background noise.

Filtering the dual-band ionospheric correction is therefore essential to remove the noise present in its high frequency content, and is now part of the GDR-F Standard. On the Jason series, such operation is currently performed iteratively with a composite median/Lanczos filter. Cutoff frequencies used in GDR products have been empirically set to 40 and 50 measurements respectively, i.e. about 231 and 289 km, in a compromise between filtering the noise and preserving the geophysical content. Gaps up to 500km in the filtered solution are reinterpolated using splines.

In this presentation, we propose improvements to this filtering scheme by removing the non-linear and redundant median filter, increasing the Lanczos frequency to 1154km (or 200 measurements) and interpolating missing or spurious coastal measurements in some cases even when gaps are larger than 500km. We show that such changes, tested on Jason-3 as well as Sentinel-3, improve the reliability of the filtered correction, its availability in coastal areas, and the stability of sea surface height differences at crossovers while preserving most of the ionospheric signal in high Total Electron Content (TEC) areas.

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ALTIMETRY AND THE MANY SCALES OF THE OCEAN SURFACE ELEVATION: WAVE HEIGHTS, WAVE GROUPS, SKEWNESS, AND SEA LEVEL "NOISE"

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Satellite altimeters are the only source of measurement for ocean wave that routinely report estimates of the significant wave height above 14 meters. Over the last 30 years, these phenomenal seas (WMO sea state code 9) have become an undisputable reality thanks to the altimeter record. The all-time record for 1 Hz data was set by Jason 2, at 20.1 m, during the 11 February 2011 storm Quirin, in the North Atlantic (Hanafin et al. 2012). But what does this number mean?

At scales smaller than the radar footprint, the sea surface elevation that produces echoes for the satellite altimeters is structured by wind-generated waves. Historically, the analysis of altimeter data has assumed that the surface elevation is horizontally uniform with a Gaussian or slightly skewed distribution. Here we show that this assumption is only valid at large scales, and that wave groups explain most of the small scale variability in retracked wave height and sea level for phenomenal seas and long swells. In fact we can understand the altimeter measurement as a spatial filter of the surface elevation envelope (De Carlo et al. 2023), with a filter shape that depends on details of the retracking procedure (De Carlo and Ardhuin 2024). In terms of LRM waveform, the effect of wave groups is identical to a large and oscillating skewness (Hayne 1980, Srokosz 1986), with both wave groups and skewness producing a significant tracker-induced noise in sea level retrievals. This sea level noise probably explains most of the "bump" in along-track sea level spectra, and can be characterized by combining nadir (altimeter-like) and off nadir (wave spectrometer) beams on the CFOSAT/SWIM instrument. Thinking about the surface elevation field in terms of envelope and wave groups can have interesting applications when resolving smaller and smaller scales. For example it helps detecting the effects of ocean currents on ocean waves (Quilfen and Chapron 2019, De Carlo et al. 2023).

Looking back at our the numbers for phenomenal seas, we can use expected effect of wave groups to estimate uncertainties on wave height measurements and re-define the significant wave height as the average at a scale where wave group effects are reduced. For example the Jason-1 record Quirin storm can be interpreted as a true significant wave height of 18.5 ± 0.3 m, based on a 54~km along-track average. That estimate uses the SeaState CCI-v3 climate record, and a similar analysis of all phenomenal storms is under way to provide reliable properties of historical storms over the past 30 years.

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OPERATIONAL DETECTION AND MONITORING OF RESERVOIRS USING SATELLITE RADAR ALTIMETRY IN A MULTI-MISSION APPROACH

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The number of dams has increased rapidly over the past decades, however important information on their location, size and capacity is often inaccessible to key stakeholders, challenging sustainable management practices and water security. Accurate geolocation and qualification of dams and reservoirs is paramount to monitoring and management and Earth Observations present with a unique opportunity to detect, map and monitor dams and reservoirs in a streamlined and consistent manner. In this study, we present a methodology specifically suited for detecting and monitoring dams and reservoirs at national and regional scale using optical, radar and altimetric information.

Recently, multiple databases have become available combining multi-mission remote sensing data to map lakes and reservoirs. Level is a key variable, often monitored in dam operation and traditionally the focus of near-real-time ground measurements. The typically longer return period of satellite altimetry missions hinder the use for operational observation, as dynamics may change rapidly and faster than a minimum return of 10 days for Sentinel-6. Spatial coverage is also a challenge, as some reservoirs may lie between satellite tracks. Combining multiple altimetry missions (radar and laser) increases the chance of obtaining level information, and by using level-area-volume (LAV) curves in combination with missions such as Sentinel-1 and Sentinel-2 with higher spatio-temporal coverage, near-real time monitoring of reservoir level, area and volume is thus achievable.

The approach uses Sentinel-1 synthetic aperture radar (SAR) and Sentinel-2 optical imagery to detect water bodies. This workflow is data agnostic and can integrate new or commercial imagery as well. Reservoirs are then specifically identified using a multi-criteria analysis based on attributes specific to reservoirs. For the resulting reservoirs, surface water extent time series can be extracted at a dense, near-real time scale. Additionally, we extract water surface elevation (WSE) from radar altimetry (Sentinel-3 and Sentinel-6) as well as laser altimetry. All WSE is merged into a single multi-mission time series for each individual water body.
If the correlation between level and area is sufficiently high, the two datasets can be used to derive LAV curves. Where altimetry is not available, LAV can be derived using more traditional methods including Digital Elevation Models; and for all reservoirs an estimate of maximum capacity can be obtained based on topographic information and water surface frequency maps.

These reservoir attributes constitute an invaluable source of information for national, regional or catchment scale water management, by providing consistent and coherent geolocated information on key water resources. Information on capacity and near-real-time operation state can be combined to inform hydraulic simulations at various levels of detail to screen and prioritize efforts on ground to assess population and infrastructure at risk from dam breach. This use case further highlights the value of satellite radar altimetry at sufficiently high spatio-temporal resolution.

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OPERATIONAL HYDROLOGY AND THE NEED FOR CEOS FRMS

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Satellite radar altimetry over inland waters is now operational and therefore understanding the actual performance is crucial. So far, this has been achieved through application-oriented studies, where satellite products are compared against available in situ data, and through calibration-validation studies, where well-instrumented sites and (almost) simultaneous data collection campaigns allow for the most dependable evaluation. The concept of fiducial reference measurements (FRMs) has recently been established to describe a subset of in situ data, relevant to satellite calibration and validation, and which is underpinned by strong metrological principles of traceability, comparison and uncertainty assessment. The Committee on Earth Observation Satellites (CEOS) has recently defined the concept of a CEOS-FRM that meets the well-defined standards documented on the CEOS calval portal.
Through the St3TART project, we have provided proof of concept for the provision of FRMs in support of validation activities for Sentinel-3 radar altimeters over inland waters (amongst other surfaces). Here, we describe the uncertainty characterisation for FRM-quality measurements over rivers. Uncertainty characterisation of FRMs in St3TART follows the QA4EO (www.qa4eo.org) guidelines. That is that (a) an FRM is identified in direct correspondence to a satellite product and is described as a mathematical measurement function, (2) full traceability to the measurement function is provided through an uncertainty tree diagram, (3) its various sources of uncertainty are characterised through effects tables, (4) its uncertainty is quantified through Law of Propagation of Uncertainties and/or Monte Carlo simulations, and that (5) information associated with the design, implementation and uncertainty characterisation of the FRM is documented for current and future users.
The St3TART project established FRM sites over rivers of different complexities. We would like to showcase the example of a CEOS-FRM for Sentinel-3 derived water level estimates over the Marmande River in France, which was one of the most complex sites considered. The FRM consists of a network of GNSS stations linked to high-resolution lidar rangers (vorteX-io micro-stations), which provide height estimates as time series at the location of suitable bridges on the river. A 'supersite' was established where the bends in the river provide multiple satellite overpasses in close succession. Because of the dynamic nature of the river, with a strong spatial slope and a temporal variation, corrections are needed to account for both the river slope and the time delay between water passing the bridges where the micro-stations are placed, and the position of the satellite overpass. These corrections are made based on drone-board lidar campaigns during different seasons, when the river is in several states of flow. In this analysis, we created a formal, bottom-up uncertainty assessment of the FRM data set at the time and location of the satellite overpass accounting for these corrections.
With this example, we have considered, independently, uncertainties associated with the satellite altimeter measurements of river height, with the in-situ observations, and with the necessary corrections and processing to match the satellite and in situ data. This provides a strong foundation for a metrologically-robust assessment of the comparison between the two.

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PERFORMANCE ASSESSMENT OF SENTINEL-3 HIGH LATITUDE OBSERVATIONS FOR THE FUTURE POLAR OCEAN PRODUCTS

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Sentinel-3A and Sentinel-3B were launched in February 2016 and April 2018, respectively, on the same inclined orbit that allows high latitude observations up to about 82°.

In the context of the EUMETSAT project "Copernicus Altimetry Service for the Sentinel-3 mission" (COPAS) for monitoring the Sentinel-3 marine products, we assessed the performance of Sentinel-3 observations over polar oceans as a prerequisite for the future CMEMS polar ocean products.

Using data reprocessed in baseline BC_005 over the full mission duration, we monitored polar ocean topography with particular focus on a) geographical patterns and large- and low-scale temporal variability; b) the estimation of the sea level anomaly bias between open ocean and ice-covered ocean; c) the assessment of internal consistency between Sentinel-3A et -3B. We also compared Sentinel-3 to measurements from the other available polar altimetry missions, notably SARAL/AltiKa, that uses an adaptive retracker and neural network echo shape classification, and CryoSat-2, that provides polar ocean observations up to 88°N. Finally, despite the scarcity of in-situ data, we provided validation of sea level retrieval in leads in comparison to two in-situ stations, both in the Artic and Antarctic Ocean.

An important aspect of our analysis is also the correct identification of ocean leads over the sea ice. Those are currently identified via a waveform classification analysis, however a preliminary assessment seems to indicate a non-optimal performance of such algorithm based on pulse peakiness and sea-ice concentration when applied to Sentinel-3 observations. Further refinement of the method was studied through synergy between altimetry and synthetic aperture radar (SAR) images, in the framework of collocation with Sentinel-1.

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OCEAN WIND-WAVE PARAMETERS FROM SWIM-CFOSAT FOR DOWNSTREAM APPLICATIONS

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CFOSAT is a satellite mission operated since 2018 whose objective is to measure, in addition to historical nadir parameters, wave spectra on a global scale from space. In this presentation, examples of products from this mission are presented, based on measurements of wind-wave spectra (Stokes drift, waves skewness for example). In principle, CFOSAT can resolve waves down to 30 meters in wavelength, enabling us not only to measure dominant waves, but also to explore the intermediate waves domain, which is a unique capability among ocean satellite missions.

The characteristics of a few products will be presented. An initial validation of these products shows a strong correlation with reference data such as wave models, even stronger than that of the usual integrated wave parameters. Using this information in conjunction with altimeter-derived data (geostrophic currents, for example) could provide an interesting insight into ocean surface dynamics.

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SWOT HR LAKE PRODUCTS AND GLOBAL PERFORMANCE VALIDATION

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SWOT is an innovative altimetry mission launched by NASA and CNES on December 16th 2022. The data acquired by the HR mode of the principal instrument KaRIn enable precise estimation of elevation, area and related parameters for continental water surfaces, globally and repeatedly. In this presentation we will briefly describe the SWOT HR vector products dedicated to lakes, with real-world examples, and we give an overview of the associated Cal/Val activities, in particular related to mission validation of the measured water surface elevation and area. The global performance assessment figures are due for the SWOT Validation Meeting in June 2024.

The single-pass SWOT HR vector product for lakes (L2_HR_LakeSP) consists of polygon shapefiles, delineating the lake boundary and providing the area and average water surface elevation w.r.t. the EGM2008 geoid for each detected lake. There are actually 3 sub-products: The L2_HR_LakeSP_Obs and L2_HR_LakeSP_Prior shapefiles contain detected waterbodies intersecting the polygons of the Prior Lake Database (PLD), whereas the L2_HR_LakeSP_Unassigned shapefile contains detected water bodies that have neither been assigned to PLD lakes, nor to regular river reaches identified in the SWOT Prior River Database (SWORD). There is also a cycle-average lake product (L2_HR_LakeSP) that aggregates the content of L2_HR_LakeSP_Prior shapefiles over one orbit cycle (~21 days in the science phase).

The L2_HR_LakeSP products are required to have a water surface elevation error below 10 cm (1-sigma) for lakes of at least 1 km2, and less than 15% (1-sigma) relative surface area error for lakes down to a size of 250x250 m2.

A huge effort has been made to collect reference data over a large number of sites worldwide, to assess the accuracy of the water surface elevations and areas reported in the L2_HR_LakeSP products, especially during the 6-7 first months of the mission, when SWOT was on a 1-day repeat Cal/Val orbit.

Water surface elevation reference data for lakes mainly stem from existing gauges, but also specifically deployed pressure transducers, citizen science limnimetric scales (OECS, LOCSS) and other equipment. Absolute levelling with an accuracy <<10 cm is required, and has been a challenge to achieve. For a limited number of lakes with known bathymetry, also water storage variations have been assessed. For certain large lakes, height profiles have been measures to study variations in the water surface elevation (geoid variations).

The reference data employed for validation of water surface area are mainly water masks derived from very-high or high resolution optical images (Pleiades, Sentinel-2…) or radar images (RCM, Sentinel-1…), which are split into PLD lakes (and likewise SWORD nodes and reaches for rivers). The acquisitions were mainly carried out during the Cal/Val phase, as same-day SWOT data were then generally available (while acquisition of optical satellite images requires cloud-free conditions).

Both for water surface elevation and area, many examples of lakes where the L2_HR_LakeSP data are within the above-mentioned science requirements have been observed, but also less favorable cases. In the final presentation, the global 1-sigma performances obtained in the framework of the mission validation will be presented.

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COMPLEMENTARITY OF CFOSAT-SWIM, SAR WAVE MODE AND SPECTRAL OCEAN WAVE MODEL FOR SEA-STATE CHARACTERIZATION FROM SPACE

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CFOSAT is an ocean satellite mission operated since 2018 carrying both an altimeter and the first spaceborne wave scatterometer, SWIM. Since 5 years, and after 3 full reprocessings of the mission with ground segment versions improving data performence, it allows to simultaneously measure nadir ocean surface echoes and the sea state in fine detail (ocean waves spectrum), similar to what a wave model like WAM could provide. Few satellite missions aim at providing waves spectra at global scale. They include SAR missions such as Sentinel-1, and they also have their limits of observation (cut off...)

What is the current quality of CFOSAT data ? How does CFOSAT complement SAR and altimetric missions ?

A set of SWIM current production spectra colocalized with S1 and WAM are statistically compared. SWIM enables ocean waves characterization down to a few tens of meters length, with regular global coverage, whereas Sentinel-1 is limited to the largest wave lengths. Although noisy, SWIM observational data complements models such as WAM, and can be used to characterize quantities not accessible via altimetry: wave field directionality, peak parameters and more.

In addition to these now well-established data, we will give an overview of the synergy between CFOSAT and the recently launched SWOT, particularly in the case of long swells. As we shall see, CFOSAT data can be put to many uses, filling the gap between existing observations of sea state.

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COMPARISON BETWEEN VARIATIONS OF MEAN SEA SEVEL TOPOGRAPHY USING SATELLITE ALTIMETRY AND MISSIONS WITH SYNTHETIC APERTURE RADAR TECHNOLOGY IN THE BRAZILIAN COAST.

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With the advent of modern spatial techniques and technological evolutions since the 1980s, it had become clear that there is a discrepancy between the geoid and mean sea level, which is called Mean Dynamic Topography (MDT). The main methodology to obtain it is through a classical and local approach, based on data from tide gauge installed on the ocean coast. However, due to the difficulty of maintaining and recovering long series of tide data, using satellite altimetry and missions with Synthetic Aperture Radar (SAR) technology have been a viable alternative for obtaining oceanic information. Therefore, the present study aims to obtain MDT values generated from satellite altimetry products, through the Sentinel-6A, CryoSat-2 missions and data from a multi-mission solution. MDT variations were estimated for four tide gauge stations belonging to the Permanent Tidal Network for Geodesy, maintained by the Brazilian Institute of Geography and Statistics. These stations are located along the Brazilian coast in Fortaleza-CE, Salvador-BA, Macaé-RJ and Imbituba-SC. The data period used is from April 2022 to August 2023. The BRAT version 4.2.1 software was used to extract the geophysical parameters of Sea Level Anomaly (SLA) and Absolute Dynamic Topography (ADT), and, from this, the MDT was estimated for the four tide stations. However, as the spatial resolution of the missions is not sufficient to punctually cover the tide gauge region, it was carried out the Universal Kriging interpolation of MDT values of satellite tracks for the geographic position of the tide gauge stations. Finally, it was possible to obtain the monthly variations for the Sentinel-6A, CryoSat-2 missions and the multi-mission altimetry. These results were compared with each other by calculating the discrepancy and based on descriptive statistics criteria. The results demonstrate the high potential of the Sentinel-6A altimetric mission, since the discrepancy obtained between the Sentinel-6A and CryoSat-2 missions were smaller when compared to the CryoSat-2 mission and the multimission solution. Thus, resulting in a RMSE of 0.9mm at the Fortaleza-CE station, 3.4 mm at Salvador-BA, 3.3 mm at Macaé-RJ and 7.1 mm at Imbituba-SC. However, the isolated determination of MDT through the multimission solution for the temporal series under analysis was the one that presented a set of noisier data and consequently high amplitudes and deviations, with an average variation of 0.509 m at the tide gauge station in Fortaleza-CE, 0.540 m in Salvador-BA, 0.461 m in Macaé-RJ and 0.530 in Imbituba-SC.

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PORTAGAUGE AND SATELLITE SEA LEVEL MONITORING SYSTEM FOR THE SOUTHWEST INDIAN OCEAN – PASS-SWIO

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Madagascar currently has very limited tidal prediction capability (primarily based on model data) and no national sea level monitoring capability. Working closely with Malagasy partners, the Direction Générale de la Météorologie (DGM), PASS-SWIO aims to help establish a sea level monitoring system for Madagascar based on the deployment of a low-cost relocatable tide gauge (Portagauge).

Financially it is impractical for Madagascar to install tide gauges at all points of interest along their extensive coastlines. It would also take a few decades to collect the data required to derive robust estimates of long-term sea level trends. Yet, tidal information is vital for the safety of communities, infrastructure and commerce, and since short-term hazards can be exacerbated by long-term increases in sea level, knowledge of longer-term change is also essential. Longer-term sea level variability, including trends associated with Climate Change, can be derived from satellite altimetry data. However, for these 'absolute' sea level measurements, calculated relative to an ellipsoidal reference frame, to be meaningful for planning and adaptation purposes they require correction for vertical land motion and 'ground-truthing' to some known fixed point on land. Vertical land motion is traditionally measured by GNSS receivers via the detection of positioning and timing information from a constellation of navigational satellites. The recent GNSS interferometric reflectometry (GNSS-IR) technique exploiting the signal-to-noise ratio, allows sea level to be inferred relative to the same geodetic reference frame as satellite altimetry. Co-location of GNSS receivers with conventional tide gauge sensors (which measure relative to some fixed point on land), allows short-term tide gauge and GNSS-IR measurements to be connected to satellite altimetry, which can substitute for long-term observations from tide gauges.
The Portagauge, which uses GNSS-IR alongside a conventional radar gauge, was deployed at Toamasina port on the NE coast of Madagascar in June 2023. Training has been provided to DGM to maintain and operate the Portagauge, and to process and analyse tide gauge and satellite altimeter sea level data (Jason-2, Jason-3, Sentinel-3A and 3B). Tide gauge data has been validated against satellite data and analyses of tidal and non-tidal sea-level characteristics generated for the Madagascar coastal region, including seasonal signals, inter-annual variability and trends. The PASS-SWIO team has held discussions with agencies and key users in Madagascar to define a road map to establish a long-term, sustainable, national sea-level monitoring system for the country. It is important that the planned capacity development meets key requirements, complements existing capability and is sustainable, considering resource requirements. We believe the project has provided a model sea level monitoring system for developing island states and coastal nations, based on low-cost tide gauges and satellite data.
The presentation will provide an overview of the project, present the results of the cross-validation of the tide gauge and altimeter data, summarise key points from the analysis of characteristics of sea level variability in the Madagascar coastal region, and presents the key points of the road map for future implementation.
PASS-SWIO was funded by ESA under the EO Science for Society Programme – Open Call.

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LAST IMPROVEMENT OF THE L4 WAVE-TAC SIGNIFICANT WAVE HEIGHT NADIR PRODUCTS

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Accurately measuring and mapping of sea surface significant wave height (SWH) is essential for numerous applications spanning maritime safety, marine weather forecasting, and climate research. The Copernicus Marine Service's Thematic Assembly Centre (TAC) serves as a key resource in providing essential products for this purpose. This study focuses on the assessment and enhancement of the quality of SWH mapping within the WAVE-TAC product lines, particularly the Near Real-Time (NRT) Level-3 (L3; along-track) and Level-4 (L4; gridded) products, as well as the Delayed Time/Multi-Year (DT/MY) products.

A key aspect of this investigation is the improvement of SWH mapping quality through the use of new interpolation techniques. By moving from conventional box averaging methods to interpolation, we aim to mitigate inherent limitations such as spatial discontinuities and loss of finer details in sea surface representation.

The quality of the gridded SWH product is assessed through comparisons with independent in-situ measurements and along-track data. Findings suggest that the new NRT and DT products exhibit qualitatively and quantitatively better performances when compared with the established Copernicus L4 WAVE-TAC product. Maps of variance reduction show great improvements especially further from the shore. When comparing the NRT and DT products, it is evident that the NRT product, which has half as many observations as the DT product, performs only half as well, but adding some measurements in the future greatly improves the NRT product performance. Additionally, intercomparison with assimilated model products (e.g., ERA5 or WAVERYS) sheds light on the limitations of the current NRT L4 WAVE-TAC product. Thus, regardless of the approach used (interpolation or box averaging), this product is still inadequate for resolving spatial scales of less than 1000km. Finally, sensitivity studies are carried out for the DT product to identify mapping errors in various altimeters constellation scenarios as the number of nadir altimeters varies with time.

Overall, our study contributes to the refinement of SWH mapping methodologies, thereby enhancing the utility of these products for various scientific and operational purposes.

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IMPROVEMENT OF THE DYNAMIC ATMOSPHERIC CORRECTION FACING THE NEW CHALLENGES OF THE COASTAL REGIONS AND THE HIGH-RESOLUTION ALTIMETER DATA

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Thanks to its current accuracy and maturity, altimetry is considered as a fully operational observing system dedicated to various applications such as climate studies. Altimeter measurements are corrected from several geophysical parameters in order to isolate the oceanic variability.

The Dynamic Atmospheric Correction (DAC) is of significant magnitude, just after the tidal correction one, and long continuing efforts have been deployed for 30 years to reach the best accuracy. However, in shallow seas, storm surges correction errors can now be of the same order or higher than the ones of the tidal corrections and motivated to impulse a renewed effort to minor the overall accuracy gap between both corrections. More specifically, we are investigating the compatibility of storm surges simulations for altimetry data correction requirements in coastal seas. This includes the impact of the improvement of the coastal resolution of global and regional numerical configurations, but also the tides/storm surges interactions. Actually, the dynamic coupling between tides and storm surges is a possible cause for barotropic tides non-stationarity and standalone storm surges inaccuracy. Therefore, we intend to explore fully non-linear, coupled tides/storm surges regional simulations for de-aliasing corrections. We also propose to test the impact of using the recent global mesh of FES2022 model (with a resolution about five time higher than the one of the legacy DAC mesh) on the DAC performances. We aim to present the very first results on our investigations

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ASSEMBLING 30 YEARS OF SATELLITE WAVE MEASUREMENTS FOR CLIMATE SCIENCE : THE SEA STATE CLIMATE CHANGE INITIATIVE

Dodet G[1], *Piollé J*[1], *Sorrieul E*[1], *CCI team C*
[1]*Ifremer*

Robust long-term sea state information are needed for coastal adaptation, offshore engineering, marine energy production, and marine security, but also to constrain modern global wave reanalysis, which often suffer from the assimilation of uneven dataset. In this context, the European Space Agency is playing an active role through the Climate Change Initiative program, which aims at making the most of historical and current Earth Observation missions in order to produce long term records of Essential Climate Variables (ECV). The sea state ECV has been routinely monitored from space with radar altimeters and synthetic aperture radar imagers over more than three decades. Over this period of time, mission designs and technology have evolved alongside climate change, and the production of seamless multi-mission and multi-sensor climate data record has become more and more challenging. For the second phase of the Sea State CCI project,wave measurements from 16 satellite missions, including altimeters (LRM and SAR) and SAR imagers, will be inter-calibrated to minimize the bias between missions and sensor types, and between satellite, ground truth measurements and models. This study presents the satellite missions, the selected in situ and model dataset, and the inter-calibration strategy developped within the project. The impact of the multi-mission/multi-sensor intercalibration on the long-term statistics are finally discussed.

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IMPACT OF SEA STATE VARIABILITY ON THE VALIDATION OF SENTINEL-3A COASTAL SIGNIFICANT WAVE HEIGHTS

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Sea state information is critical for a broad range of human activities (e.g. shipping, marine energy, marine engineering) most of them being concentrated along the coastal zone. Satellite altimeter records of significant wave heights (SWH) represent the largest source of sea state observations available to date. However, the quality of altimeter observations is reduced in the coastal zone due to surface heterogeneity within the radar signal footprint.Major difficulties to assess the performance of coastal altimetry in the coastal zone are the reduced number of valid altimeter records and the increased sea state variability, which have recently fostered the development of new methods to pair and compare nearby altimeter and buoy data. In this study, we use a high-resolution numerical wave model implemented over the European coastal waters in order to characterize the spatial variability of sea states in the proximity of coastal in situ buoys, we explore different model-based data pairing methods to account for coastal sea state variability and we assess their impact on the validation of Sentinel-3A 20Hz SWH measurements. Our results indicate major impacts of data pairing methods on the S3A coastal validation and reveals the contribution of more frequent low SWH conditions, poorly resolved by radar altimeters, in the coastal zone as an additional source of errors in coastal altimetry.

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ENHANCING SAR ALTIMETRY PRODUCTS THROUGH CORRELATION-INFORMED STRATEGIES

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Power spectral analysis is an important tool to characterize various oceanic processes and phenomena. From an oceanographic point of view, the spectra of Sea Level Anomaly (SLA) and Significant Wave Height (SWH) should remain unchanged by the way the measurement was acquired. In practice however, even spectra acquired with the same altimeter show differences based on the applied processing, as is the case for low resolution (LR) and high resolution (HR) modes. Particularly the high-frequency content with wavelengths of 0.3 – 30 km is of interest, since it contains both the information about the random noise and the imprint of small-scale processes on the edge of observability.

It is in this regime where the along-track spectra differ the most (inter-mission, HR vs LR) [5, Fig. 3] and where the spectra of SAR altimeter HR mode variables show different behaviour at 20 Hz posting than at higher posting rates of 80 Hz [1]. Some reasons for this have already been identified:

- First, the spectra may be contaminated by the effects of ocean waves. Certain swell waves are aliased at 20 Hz sampling and increase the energy at the high end of the spectrum [1].
- Second, it was shown using both theoretical analysis and real-world data that the SLA and SWH may generally contain frequencies up to 50 Hz [2]. Therefore, a 20 Hz posting rate implies undersampling.
- Third, the retracked variables SLA and SWH are inevitably correlated with each other [3], so that the high-frequency parts of SLA and SWH spectra are not independent [4], which is currently not accounted for in HR mode (in LR mode there is the “High-Frequency-Adjustment”, see [4]).

This implies that the current 20 Hz SLA and SWH products suffer from undersampling and noise correlations. Using reprocessed UFSAR data at 140 Hz posting rate and the noise covariance model from [2], we attempt to derive revised 20 Hz products by optimal filtering of SLA and SWH. We aim to mitigate high-frequency (swell wave) contamination on one hand and to decrease random noise as far as possible on the other. This requires new, elaborate strategies for filtering and downsampling, which will be presented here.

[1] Rieu, P. et al. “Exploiting the Sentinel-3 Tandem Phase Dataset and Azimuth Oversampling to Better Characterize the Sensitivity of SAR Altimeter Sea Surface Height to Long Ocean Waves.” 2021. https://doi.org/10.1016/j.asr.2020.09.037.

[2] Ehlers, Frithjof, Cornelis Slobbe, Martin Verlaan, and Marcel Kleinherenbrink. “A Noise Autocovariance Model for SAR Altimeter Measurements with Implications for Optimal Sampling.” 2023. https://doi.org/10.1016/j.asr.2023.02.043.

[3] Sandwell, David T., and Walter H. F. Smith. “Retracking ERS-1 Altimeter Waveforms for Optimal Gravity Field Recovery.” 2005. https://doi.org/10.1111/j.1365-246X.2005.02724.x.

[4] Tran, N., D. Vandemark, E. D. Zaron, P. Thibaut, G. Dibarboure, and N. Picot. “Assessing the Effects of Sea-State Related Errors on the Precision of High-Rate Jason-3 Altimeter Sea Level Data.” 2021. https://doi.org/10.1016/j.asr.2019.11.034.

[5] Jiang, Maofei, Ke Xu, and Jiaming Wang. “Evaluation of Sentinel-6 Altimetry Data over Ocean.” 2023. https://doi.org/10.3390/rs15010012.

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GLOBAL REVIEW OF HAIYANG-2 SATELLITES: DATA PERFORMANCES, CONTRIBUTIONS, AND PROSPECTS

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Today, the Hy-2 Chinese satellite constellation is composed of three satellites (Haiyang-2D/C/B). In a near future it will be extended with the launch of Haiyang-2E is scheduled for mid-2025, followed by Haiyang-2F one year later by the China National Space Administration (CNSA). The National Satellite Ocean Application Service (NSOAS) oversees the ground segment processing system and the distribution of collected data of HY-2 Level 2 products. The French contribution to this project, led by the Centre National d’Etudes Spatiales (CNES), primarily involves providing orbit data computed from DORIS and GPS measurements.

The high quality of data from Haiyang-2 satellites has been demonstrated on several occasions [1][2][3][4][5]. They undoubtedly represent a major resource of high-quality data. Some of them already contribute to CMEMS Sea Level and Wind and Waves products. We propose here a comprehensive review of the performances of all Haiyang-2 satellites, their current contributions in multi-mission products, and their potential future contributions. In this study, among other things, we will present performance metrics for single and multi-mission crossing points, stability statistics, and noise indicators of the Haiyang-2 missions by comparing them to other satellites. We will discuss the current contributions of the Haiyang-2 missions to various projects, and then demonstrate the added value of including these missions in CMEMS productions.

[1] Philip et al. "Feed-back and contribution after several years of Haiyang-2B data availability" OSTST conference 2022
[2] Philip et al. "Haiyang-2C data assessment, performance and contribution to DUACS Sea Level "Anomaly products" OSTST conference 2022
[3] Faugère et al. "The 2022 Honga Tonga Tsunami monitored by satellite altimetry and SAR" OSTST conference 2022
[4] Philip et al. "Hy-2B in DUACS : feedback on performances and contribution to multi-mission products" OSTST conference 2020
[5] Philip et al. "Haiyang-2D data assessment and performance for potential assimilation into DUACS and CMEMS products" OSTST conference 2023

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WAVE-TAC COPERNICUS MARINE SERVICE : INTEGRATING SPACE OBSERVATIONS AND IMPROVING SYNERGY SINCE 2017

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Since 2017, the waves observations are integrated in the Copernicus Marine Service, thanks to the WAVE Thematic Assembly Centre (TAC), this project aggregates and deliver to end users the best products of ESA, CNES, CNSA and EUMETSAT missions.

In 7 years, the catalogue has been largely enriched and the product quality, following the wave community R&D upstream activities, keep on improving.

Starting from a nadir altimetry constellation and Sentinel-1 wave mode, more recent altimeters (including HY2, CFOSAT nadir, S6, SWOT nadir...) were taken onboard. More recently, CFOSAT, mission dedicated to the wave characterisation, enabled to enrich the understanding of different sea states thanks to its full spectra. Soon SWOT and its 2D capacities will also hopefully soon be onboarded.

This presentation will propose an overview of the existing products, distributed in Near Real Time, for wave forcasting, as well as Multiyear for climate application.

It will also show how various projects (Sea state CCI projects, SALP-CNES, EUMETSAT...) jointly contribute to the upstream validation and R&D studies.

It will also show the complementarity of the L3 along tracks products (altimeter, diffusiometer, SAR, interferometer...) and how, once the missions merged, they provide the best integrated synergetic characterisation of waves in L4 gridded products.

In memory of Elodie.

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VALIDATION AND UNCERTAINTIES OF A MULTI FREQUENCY ALTIMETRY SNOW DEPTH PRODUCT OVER THE ARCTIC OCEAN

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Since 2010, ESA's CryoSat-2 (CS2) has been monitoring the Polar Oceans, providing unprecedented spatial and temporal coverage. Satellite altimetry enables to measure sea ice freeboard—the height of the ice above the sea surface—and to infer ice thickness. Knowledge of sea ice thickness and its variations are essential to understand the underlying dynamic and thermodynamic processes of the ice and the resulting impact on ocean circulation and global climate. Assimilation of sea ice thickness estimates in late spring and summer has also been shown to greatly improve the forecast of sea ice concentration at the start of the freezing season. Numerous sea ice products developed by the scientific community showed the skills of CS2 to retrieve sea ice thickness. Nevertheless, altimetry-based sea ice thickness estimates are still characterized by relatively large uncertainties. One of the largest sources of this uncertainty is the lack of knowledge of the snow depth covering the sea ice and its dielectric properties.

In 2018, the NASA's ICESat-2 (IS2) mission was launched carrying a photon-counting LIDAR altimeter in space for the first time. We took advantage of the difference of penetration in the snow layer of laser and Ku-band altimetry to compute a snow depth product covering the IS2 period. This "LaKu LEGOS" product is validated and compared to in situ datasets, reanalysis, models and other snow depth products from satellite missions such as SARAL. Comparison to in situ datasets provides encouraging results with correlation of 0.90 with BGEP moorings, and correlation of 0.63 with airborne OIB measurements. The snow depth uncertainties of the LaKu LEGOS product are estimated to be ~6 cm on average.

In July 2020, the orbit of CS2 was raised, as part of the CRYO2ICE campaign, to coincide in space and time with IS2 tracks over the Arctic ocean. This provided a unique opportunity to benefit from along-track colocalised data from the two missions. We present here a methodology to compute IS2-CS2 snow depth along coincident tracks and compare the results with snow depth from available gridded products. We find that the lack of in situ measurements is one of the main limiting factors preventing a proper quantification of the benefits of an along-track snow depth product over a gridded one. Finally, we show how combining laser and Ku-band altimetry reduces the sea ice thickness uncertainties compared to using data from a single sensor (reduction from 30 cm to 50 cm on average). The findings of this ESA-supported study will help prepare for the upcoming Copernicus CRISTAL mission, which will fly a Ka-/Ku-band dual-frequency altimeter for the first time.

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CO-LOCATED OLCI OPTICAL IMAGERY AND SAR ALTIMETRY FROM SENTINEL-3 FOR ENHANCED SURFACE CLASSIFICATION IN SEA ICE

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In our research, we leverage the capabilities of the Sentinel-3A and Sentinel-3B satellites, launched in February 2016 and April 2018, respectively, to deepen our understanding of the polar regions. These satellites offer a unique blend of high-resolution Ku-band radar altimetry data, synthetic aperture radar (SAR) mode altimetry, and the Ocean and Land Colour Instrument (OLCI) imaging spectrometer. This combination enables the acquisition of both optical imagery and SAR radar altimetry data, extending up to 81 degrees North. Central to our study is the application of deep learning techniques, specifically the Vision Transformers (ViT), which adapt the Transformer algorithm for surface classification in polar environments. This approach is instrumental in distinguishing between sea ice and leads, demonstrating robust performance across various metrics, including accuracy and model roll-out on comprehensive OLCI image datasets. We produce our first lead classification maps at the original OLCI swath level resolution of 300m and a lead fraction prototype mosaic spring pan-Arctic product at gridded level of 1km, 5km and 10km resolution and on daily, weekly and monthly timescales. The use of binned statistics in conjunction with our deep learning classifications provides valuable insights into the spatial distribution and changes of leads within the polar ice. We compare our prototype product with other existing lead products and with auxiliary datasets on thin ice (roughness, thickness). Our work combining different satellite products at pan-Arctic intermediate resolution enhances our capacity to estimate sea ice thickness and aids in forecasting future changes in the Arctic and Antarctic regions, thereby contributing to the field of polar remote sensing with direct applications to the future polar missions CRISTAL and CMIR.

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ROBUSTNESS OF ALTIMETRY-DERIVED TIDAL AMPLITUDE TRENDS TO ALTERNATIVE MESOSCALE CORRECTION

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Changes in ocean tides on decadal timescales have been documented at many tide gauges. Recently, data from the TOPEX/Poseidon/Jason altimetry time series has been used to map global trends in the amplitudes of selected tidal constituents. However, the resulting estimates were very sensitive to non-tidal sea level variability. In order to suppress this variability, the multi-mission gridded sea level anomalies from DUACS were removed from the time series prior to harmonic analysis. The presence of (tidal) errors in the DUACS product raises concerns regarding the reliability of the estimated amplitude trends when the DUACS product is subtracted from the altimetry data. We propose an alternative way to handle non-tidal ocean variability. Our strategy is to transform the tidal harmonic analysis problem into a state space formulation, which allows for the inclusion of autoregressive and moving-average terms to the model. These terms have the potential to absorb the low-frequency energy associated with mesoscale sea level variability, which otherwise contaminates estimates of tidal amplitude trends. We will first study the effectiveness of this approach on synthetic data, after which the model will be applied to 30 years of TOPEX/Poseidon/Jason altimetry.

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ENHANCING OFFSHORE WIND FARM MET-OCEAN DATA ACCESSIBILITY: A MACHINE LEARNING APPROACH WITH SATELLITE-DERIVED WAVE MEASUREMENTS IN THE CELTIC SEA

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The MaLCOM (Machine Learning for Low-Cost Offshore Modelling) framework, developed in collaboration with two of the authors present, proposes a new method for characterising waves for marine renewable energy applications. Despite the current limited use of satellite-derived wave data in the offshore renewable energy industry, numerous possibilities to employ this data for much-needed cost reductions in the sector have been identified. As offshore wind energy projects are developed in deeper waters, further from shore, and occupying larger areas, understanding the spatial variation of the wave conditions across a site becomes more important. Deploying more wave buoys in the area can be expensive, and is not always feasible, and perhaps not necessary with the abundance and accuracy of wave data measured by satellite radar altimeters that is now available.

The MaLCOM approach investigated in this work uses a random forest algorithm to train a surrogate model on the relationships between wave conditions at defined locations, to wave conditions across the entire domain of the model, derived from a traditional physics-based, numerical wave model hindcast. In implementation, the surrogate model can then predict wave conditions across the area using only simultaneous data at the point locations. The output predictions were found to be as accurate as traditional nowcasts and forecasts. As the surrogate wave model does not have the high computational demands of the numerical wave model, it can be run on any computer, more frequently, and can quickly update based on real-time measured conditions within the domain. This results in the improved accessibility of met-ocean data for making decisions in the marine environment.

The current MaLCOM arrangement utilises wave buoy data to inform the model of the measured conditions at the point locations. Whilst wave buoys provide continuous data, the single point location limits the geographical spread of measurements available to input to the MaLCOM framework. Radar altimeter wave data acquired by satellites presents another potentially useful and complimentary source of measurements to input into the framework and would enable immediate application of the method globally.

The two key initial considerations of utilising satellite-derived wave data in a MaLCOM style setup are; how to optimise the benefits from the varying locations and times at which the data reports and; how much impact receiving only wave height information will have on the machine learning model training and operation. This study focuses on the second of those challenges, using the South West UK as a case study area. The results demonstrate that running a MaLCOM style surrogate model using only significant wave height, does produce a working model that successfully predicts significant wave height values across the model domain. The reduced accuracy resulting from omitting wave period and direction parameters is small relative to the overall accuracy of the model predictions, and largely constrained to coastal areas.

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CRISTAL - NEXT COPERNICUS CRYOSPHERE ALTIMETRY MISSION

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The primary goal of the Copernicus polaR Ice and Snow Topography ALtimeter (CRISTAL) mission is to provide the understanding of the global cryosphere and its interactions with the planet's atmosphere and hydrosphere. As primary mission objective CRISTAL provides an enhanced retrieval of sea ice thickness and freeboard including retrieval of snow loading, of land ice sheet and glacier elevation. As a secondary objective it supports applications related to coastal and inland waters and to the observation of ocean topography. CRISTAL is strongly benefiting from the Airbus heritage in altimetry missions like CryoSat and Sentinel-6 and is well suited for altimetry platforms on the particular orbit: it copes with pointing three large antenna dishes to the Earth surface, it maintains the power and thermal environment as needed also for the drifting orbit with the sun direction constantly changing and it ensures the storage and downlink of the scientific mission data obtained.

The CRISTAL orbit has an altitude of about 700 km with a high inclination of 92° and a repeat cycle of one year balancing out a good compromise between pole coverage and cross over points for calibration.

The satellite mechanical architecture has large panels towards the nadir direction and body mounted solar arrays that cope with varying sun incident angles. This structure design, together with a propellant tank, which is specifically designed to control the tank Center of Mass (CoM) position during the mission, improves the stringent Center of Gravity (CoG) knowledge needed for an altimetry mission.

The CRISTAL satellite uses the Airbus AstroBus satellite platform and has a nearly identical avionics architecture as its sister satellite LSTM, which is used for an optical mission. Using state of the art platform equipment and a common software and operations concept, the CRISTAL satellite embarks a powerful X-band system able to downlink the altimetry data.

CRISTAL fulfils the requirements for space debris mitigation by performing a direct re-entry at end-of-life in addition to being equipped with interfaces for Active Debris Removal in space.

CRISTAL embarks the IRIS altimeter (Interferometric Radar altimeter for Ice and Snow) measuring in both Ku and Ka bands with 500 MHz bandwidth and allowing for high resolution SAR and interferometry in Ku-band, the Advanced Microwave Radiometer specifically designed for CRistal (AMR-CR) providing tropospheric correction and classification for sea and land ice type, a multi-frequency Global Navigation Satellite System (GNSS) receiver and a Laser Retro Reflector used for Precise Orbit Determination (POD) and frequency monitoring of the IRIS Ultra Stable Oscillator (USO), and three Star Tracker (STR) optical heads mounted on the IRIS antenna subsystem for interferometric calibration.

The System and Instrument Retrieval Simulator (SIRS) allows end-to-end performance monitoring, supports calibration activities and establishes the mission end-to-end data flow. Beyond the common features of a performance simulator, which covers both instrument simulation and Level 1 processing, it also offers geophysical retrieval and capabilities for enhanced performance evaluation.

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ON THE ORIGINS OF THE LOW-FREQUENCY SEA SURFACE HEIGHT VARIABILITY OF THE PATAGONIA SHELF REGION

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In this study, we identify the drivers of the dominant mode of sea surface height interannual variability over the Patagonian shelf using a suite of process-oriented numerical experiments. Consistent with altimetry, the dominant mode of the model sea surface height interannual variability, which accounts for approximately 84% of the total variance, exhibits a robust deterministic low-frequency variability. The weak sea surface height gradients indicate that this mode has a weak dynamical effect, but the contribution of the steric effect is shown to be non-significant. Here we demonstrate that the temporal variability of this mode is not driven by heat or freshwater fluxes but by the propagation of sea surface height perturbations generated in the Pacific. In particular, we show that sea surface height interannual variability over the Patagonian shelf is influenced by wind stress forcing in the offshore region of southern Chile and by the propagation of equatorial sea surface height anomalies.

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30 YEARS OF ALTIMETRY-BASED SEA LEVEL MEASUREMENTS AT GLOBAL, REGIONAL AND LOCAL SCALES : WHAT HAVE WE LEARNED ? WHAT ARE THE REMAINING GAPS ?

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Since the early 1990s, sea level variations are routinely measured by the high-precision altimeter satellites constellation from the global to the local scale. Breakthrough scientific results have been obtained by the international climate community with this unique satellite dataset. In this presentation we summarize the major findings obtained by the community on the sea level evolution over the past 3 decades at global, regional and local scales, as well as on the causes of the observed changes. We highlight the importance of this satellite record for a broad range of applications in climate research and for the adaptation to the impacts of climate change. We also address the remaining gaps in sea level research, with a focus on the still poorly sampled coastal sea level, and finally discuss the highly positive perspectives expected from the novel swath altimetry technology for the monitoring of sea level change in the world coastal zones with a high spatial resolution and global coverage.

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INTRODUCING JASTER (JASON-2/3 ALTIMETRY STAND-ALONE TOOL FOR ENHANCED RESEARCH) FOR MONITORING RESERVOIR WATER ELEVATION CHANGES

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In the absence of in-situ data, satellite radar altimetry, critical for studies that need water surface elevation, faces challenges in outlier removal over inland reservoirs, influenced by surrounding land. We present JASTER (Jason Altimetry Stand-Alone Tool for Enhanced Research), a fully automated tool processing Jason-2 and Jason-3 altimetry data. JASTER generates water elevation time series over a user-defined water body using two outlier removal approaches. The first method employs K-means clustering, interquartile range-based filtering, and the Hampel filter for outlier detection. The second method additionally incorporates a water occurrence threshold and a Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM)-derived elevation threshold. We validate JASTER's capabilities using 44 Jason altimeter crossings over 37 water bodies in the US and Canada, achieving the best Root Mean Square Error (RMSE) and coefficient of determination (R2) of 0.07 m and 0.99, respectively. We assess the significance of applying water occurrence and elevation thresholds and establish the accuracy dependence on these thresholds, Hampel filter parameters, and satellite crossing lengths. JASTER empowers users to obtain the altimetry-derived water elevation changes for diverse applications, even with limited remote sensing expertise. The source codes for JASTER can be accessed from our GitHub repository at https://github.com/satellitehydrology/JASTER .

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SIGNIFICANT WAVE HEIGHT AND WIND CALIBRATION OF SENTINEL-6 MF WITH SEA-STATE OPTICAL TECHNIQUES AND GNSS INTERFEROMETRIC REFLECTOMETRY AT THE ESA PERMANENT FACILITY FOR ALTIMETRY CALIBRATION IN CRETE.

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This work presents the first results on the calibration of significant wave height and wind of Sentinel-6 MF using Sea State Optical (SSO) techniques and GNSS Interferometric Reflectometry (GNSS-IR). A network of a couple of optical cameras has been set up on the mountains of south Crete overlooking the stretch of

ocean between Gavdos and Crete to determine significant wave height and wind remotely while the Sentinel-6A, Sentinel-3A and Sentinel-3B are flying over. Another couple of coastal GNSS stations have also been set up on Gavdos island to estimate the significant wave height, by monitoring south and east of Gavdos ocean waters during altimetry calibration. This SSO and GNSS-IR set up is building up the capacity of the ESA Permanent Facility for Altimetry Calibration in Crete. Every ground reference Cal/Val infrastructure on the ESA PFAC is ensured for the reliability and trustworthiness of its observations as it complies with the strategy of ESA for Fiducial Reference Measurements. The FRM strategy is to employ different, redundant, independent and at times tied to metrology standards techniques to determine the same geophysical quantity used as a reference for altimetry calibration.

The optical imaging system (Sea State Optical) has been designed to (a) monitor sea-state variability by measuring the mean square slope from the Sun glitter intensity or employing the stereo photo reconstruction technique, and (b) measure the sub-mesoscale processes by analyzing the wave dispersion relation estimated from video recording of the Sun glitter. Validation campaigns employing uncrewed aerial vehicles were carried out in Q2 2023. Following the promising results from these campaigns, two optical cameras were installed in Q4 2023 in south Crete to cover an area-of-interest of ocean water which includes both ascending and descending passes of Sentinel-6 but also a Sentinel-3 pass.

The GNSS-IR is a relatively new technique because the oscillation frequency of multipath in signal-to-noise ratio can be analyzed to determine the height of the receiving antenna above the reflecting ocean surface. Thus, the sea-surface and the significant wave height at the open ocean and at the time of satellite altimetry mission overpass are determined. Reconnaissance surveys and short campaigns for the selection of the optimal location in Gavdos island for the establishment of a permanent GNSS-IR site were carried out. The site is operational as of Q2 2024.

Preliminary results indicate that both GNSS-IR and SSO can be used to complement and advance standard PFAC operations and Cal/Val services.

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PRELIMINARY ANALYSIS OF MEAN SEA SURFACE MODELS ALONG THE BRAZILIAN COAST

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In the context of monitoring the planet's dynamics, a trend of rising sea level has been possible to observe over time, mainly based on the analysis of the evolution of global mean sea level from local observations with gauges or derived from altimetric satellites.

The need to monitor and promote the knowledge of changes is due to the dynamic processes that occur on the planet, such as the redistribution of masses, plate tectonics, the effects due to gravitational attraction, the variations in the speed of Earth's rotation, the tidal effects, among others.

This monitoring is characterized as a major challenge for Brazil as it is a country of continental dimensions and has a coastline 7.637 km long, reaching 8.500 km if considering the bays. With the perspective to comprehend the behavior and adequacy of Mean Sea Surface (MSS) models in the Brazilian coastal zone, this research analyzed the behavior of 6 MSS models in relation to mean sea level data in 7 tide gauge stations along the coast.

The MSS models analyzed were: CLS22, CLS15, SDUST, DTU21, DTU18 e DTU15. The tide gauge station and observation periods were: Imbituba (2001-2020), Arraial do Cabo (2017-2020), Macaé (2001-2015), Salvador (2004-2020), Fortaleza (2008-2019), Belém (2019-2020) and Santana (2005-2020). All stations are a part of the Permanent Tidal Network for Geodesy, implemented and maintained by the Brazilian Institute of Geography and Statistics (IBGE). To compare mean sea levels, data were made compatible for the sabe reference ellipsoid (GRS80) and for the mean tidal system.

The CLS15 and SDUST models did not present available data for the Santana region. Considering the other models, the biggest discrepancies were observed for the Santana and Belém stations, located in the northern region of the country. The biggest discrepancy, of 1.574m was observed at the Santana station with the CLS22 model. This same model presented the smallest discrepancy at the Imbituba station (0.006m). The analysis involving the duration of the temporal series of tide gauge observations and the discrepancies presented in relation to the models indicated a low correlation between these two variables.

The RMSE analysis of the discrepancies of the MSS models and mean levels of tide gauge stations resulted in the values of 0,617 m for CLS22, 0,192 m for CLS15, 0,163 m for SDUST, 0,362 m for DTU21, 0,352 m for DTU18 e 0,354 m for DTU15. Excluding from the analysis the Santana and Belém stations, the RMSE values were of 0,187 m for CLS22, 0,204 m for CLS15, 0,191 m for SDUST, 0,181 m for DTU21, 0,131 m for DTU18 and 0,134 m for DTU15.

The analyzes show that the largest discrepancies occur in the northern region, the lack of data in some models in this region is a factor that may contribute to these results. The inclusion of other tide stations along the coast will be important for a broader analysis, which is a challenge considering that there are few Brazilian tide gauge stations connected to a global reference.

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APPLICATION OF SATELLITE SAR ALTIMETRY OVER THE COAST AND SEBKHA OF ORAN (ALGERIA)

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An important challenge in satellite altimetry is the accurate determination of the water level over coastal, and inland water surfaces ,however sar satellite altimetry allows the researcher to study and describe the water level in these areas with better accuracy.
In the first part of this study, we aim to represent the performance of Cryosat-2 and Sentinel missions using a combination data of over the coast of Oran in Algeria Secondary, we provide an analysis that illustrate the application of several retrackers , based on SAR satellite altimetry data delivered by Sentinel 3A and 3B, the analysis, of the different retrackers are tested to retrack waveforms over the Sebkha of Oran, which is one of important features in Algeria.
The data analysis will process the same ground tracks over the two nearby regions coastal and inland water in order to show the benefits of this processing strategy.

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TOPOLOGICAL LAGRANGIAN ANALYSIS FROM ALTIMETRIC AND ELEPHANT SEAL DATA

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The topological approach called templex (Charó et al., 2022) introduces the use of a cell complex endowed with a directed graph as well as an algebra of cycles to characterize the structure of a flow in phase space. The application of these concepts to Lagrangian analysis leads to interesting results regarding chaotic mixing and pattern detection. Fluid particles sharing the same dynamics have the same topological structure in phase space and move together within coherent sets. The success of the procedure depends, however, on the residence time of the particle in the Lagrangian Coherent Set, since the topology is computed from the dynamical reconstruction of a structure which cannot be studied topologically if it is only partially explored.

To compensate for the short-term stability of real ocean particle behavior, we develop a strategy that replaces time with space. A particle bundle is advected using altimetry data fields, with an initial arrangement in the form of a circle organised around a central point. The time-delay embeddings are satisfactory but are, in general, not closed. A quasi-closure detection criterion is defined when the set of particles is back to the vicinity of the initial state. Building the templex from these reconstructions and computing the templex properties enables identifying eddies, jets and other patterns, with a dynamical approach. Elephant seal behavior can also be interpreted using these results, as well as a correlation between topological properties and quasi-planktonic indices defined by Della Penna et al., 2015. The result is consistent with a hunting strategy being driven by mesoscale structures.

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DYNAMIC RESPONSE OF THE OCEAN SURFACE TO THE PASSAGE OF A TROPICAL CYCLONE

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Atmosphere-Ocean interaction, a very important subject in geophysics, is complicated in character. Extreme conditions such as tropical cyclones render the study even more difficult due to hazardous conditions. Fortunately it is now possible to use satellite monitoring at adequate resolution to assist the study.

The aim of this presentation is to analyse data of sea surface dynamics for different oceans and for different tropical cyclones during the 3 last years. Our comparison is based on tropical cyclone parameters such as pressure and wind velocity. We analyse sea surface wave parameters such as maximum and significant height. We also include sea surface salinity, which has a very important impact in tropical cyclone.

In this presentation the authors use the data of Global Ocean Waves Analysis and Forecast from Marina Copernicus Database online. "The operational global ocean analysis and forecast system of Météo-France with a resolution of 1/12 degree is providing daily analyses and 10 days forecasts for the global ocean sea surface waves.

This product includes 3-hourly instantaneous fields of integrated wave parameters from the total spectrum (significant height, period, direction, Stokes drift,...etc), as well as the following partitions: the wind wave, the primary and secondary swell waves." (https://data.marine.copernicus.eu/product/GLOBAL_ANALYSISFORECAST_WAV_001_027/description).

The main conclusion of this presentation is that the stronger the tropical cyclone the stronger the waves on the underlying sea surface.

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CLIMATE MODES AND INTERBASIN INTERACTION ENHANCE THE HEAT AND HEIGHT EXTREMES NEAR THE EAST COASTS OF SOUTH INDIAN OCEAN IN RECENT DECADES

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Sea surface High EXtreme (HEX) events and marine heatwaves (MHW) have increasing impacts on human society and marine ecosystems under climate change. Here, we explore the HEX and MHW events along the Australian and Indonesian coasts of the Indian Ocean using the 30-year satellite altimeter data, tide gauge observations, sea surface temperature (SST) datasets, and reanalysis products combined with numerical model experiments. We found that the Ningaloo Niño – an intense heat surge (i.e., MHW) along the west Australian coast that lasts for one month or longer - has been strengthening since the 1990s comparing to prior decades, while Subtropical Indian Ocean Dipole in the west has been weakening. Climate model experiments using NCAR's Community Earth System Model version 1 (CESM1) suggested that external forcing (e.g., GHG, solar and volcano) causes negligible changes in the Ningaloo Niño, and it is the internal climate variability that causes the Ningaloo Niño intensification. The El Niño – Southern Oscillation (ENSO) in the Pacific contributes partly to, but cannot fully explain, the observed magnitude of Ningaloo Niño intensification. The interbasin coupling between Southeast Indian Ocean and western tropical Pacific (via both atmosphere & ocean) plays an important role in driving the observed change in Ningaloo Niño. Along the Indonesian coasts, the combined influences of ENSO and Indian Ocean Dipole (IOD) mode cause increased no. of co-occuring HEX and MHW events in the past decade.

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ADVANCING SEA-STATE CHARACTERIZATION WITH FULLY-FOCUSED SAR ALTIMETRY: INSIGHTS AND INNOVATIONS

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This contribution presents advancements in Synthetic Aperture Radar (SAR) altimetry for imaging ocean waves. Recently, it was demonstrated that fully-focused SAR waveform tails reveal modulations induced by long waves. The spectral analysis of the waveform tails showed that SAR altimetry modulation spectra [1] can provide insights into the characterization of swells, comparable to Sentinel-1 and CFOSAT. Furthermore, the analysis of the fully-focused SAR waveform tails led to the extraction of an additional independent parameter, known as azimuth cutoff in SAR imaging [2]. The azimuth cut-off serves as an indicator of the shortest detectable waves, the magnitude of which is highly dependent on the variance of the wave orbital velocities, thus making it a valuable metric for sea-state characterization. However, recognizing that SAR nadir-looking altimeters were not initially designed for imaging purposes, limitations are pointed out.

The study further explores the implications of Range Migration Correction (RMC) versus full-resolution RAW Sentinel-6A data, collected during the commissioning phase, in wave imaging applications. RMC function performs a truncation of the altimeter signal onboard, reducing the data rate by a factor or two, mostly affecting the tails of the waveforms [3]. While this truncation proved not to affect geophysical parameter extraction, it seems to impact the SAR altimetry modulation spectra, with RAW data providing enhanced wave modulations due to the increased cross-track ground resolution at slightly larger incident angles.

This study concludes with a comparative analysis of modulation spectra from different satellite missions, including Sentinel-6A (radar altimeters), Sentinel-1 (radar imager) and CFOSAT (scatterometer). The analysis further leverages in situ data, specifically ocean wave spectra from drifters deployed in the Indian Ocean during the One Ocean Expedition 2021-2023, to evaluate the satellite observations. The findings demonstrate a good agreement between satellites and in situ measurements, thereby underscoring the significance of synergizing data from of all available satellites to enhance swell sampling globally.

References:

[1] Altiparmaki, O., Kleinherenbrink, M., Naeije, M., Slobbe, C., & Visser, P. (2022). SAR altimetry data as a new source for swell monitoring. Geophysical Research Letters, 49, e2021GL096224. https://doi.org/10.1029/2021GL096224

[2] Altiparmaki, O., Amraoui, S., Kleinherenbrink, M., Visser, P. N. A. M., Moreau, T., Maraldi, C., Naeije, M. (2024). Introducing the azimuth cutoff as an independent measure for characterizing sea-state dynamics in SAR altimetry, Remote Sensing (under review)

[3] Craig J. Donlon, Robert Cullen, Luisella Giulicchi, Pierrik Vuilleumier, C. Richard Francis, Mieke Kuschnerus, William Simpson, Abderrazak Bouridah, Mauro Caleno, Roberta Bertoni, Jesus Rancaño, Eric Pourier, Andrew Hyslop, James Mulcahy, Robert Knockaert, Christopher Hunter, Alan Webb, Marco Fornari, Parag Vaze, Shannon Brown, Joshua Willis, Shailen Desai, Jean-Damien Desjonqueres, Remko Scharroo, Cristina Martin-Puig, Eric Leuliette, Alejandro Egido, Walter H.F. Smith, Pascal Bonnefond, Sophie Le Gac, Nicolas Picot, Gilles Tavernier (2021). The

Copernicus Sentinel-6 mission: Enhanced continuity of satellite sea level measurements from space, Remote Sensing of Environment, Volume 258, 2021, 112395, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2021.112395

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HOMOGENEOUS MULTI-MISSION 20HZ SEA LEVEL ANOMALY PRODUCTS ASSESSMENT

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Since the launch of TOPEX/Poseidon in the early 90's, more than 15 other Altimetry missions were launched and operated by different agencies. Our goal is to inter-calibrate all missions and provide as much as possible the same up to date corrections. It allows us to build a precise sea level for level 3 CMEMS (Copernicus Marine Service) products, to have consistent time series in the last 30 years for C3S (Copernicus Climate Change Service) and to build the global mean sea level.

In the frame of the SALP (Service d'Altimétrie et de Localisation Précise) project supported by CNES (Centre National d'Etudes Spatiales) and of the Sentinel Marine Altimetry L2P-L3 Service (in cooperation agreement with EUMETSAT in the frame of the Copernicus Programme funded by the European Union) level 2P data are available to users for all the altimeter missions (TOPEX/Poseidon, Jason-1/2/3, ERS-1/2, Envisat, Saral/AltiKa, Sentinel-3A/B, Sentinel-6A, GFO, Cryosat-2, HY-2A/B) on AVISO+ (https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/along-track-sea-level-anomalies-l2p.html) and L3 on CMEMS catalogue (https://marine.copernicus.eu).

In order to improve the resolution of the L2P and L3 sea level anomaly products and better resolve (sub-)mesoscale structures, the L2P is now produced keeping the full sampling rate (20 Hz). Such products are available since 2021 as level 2P 20 Hz data on AVISO+ for Sentinel-3A, Sentinel-3B, Jason-3, Sentinel-6A (since end 2022) and swot nadir (since end 2023) for near-real-time and short-time-critical timeliness. Hereafter the value-added sea level anomaly L2P products are presented and assessed. They are input to the L3 5Hz (global and regional) sea level anomaly products.

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OCEAN SWELL PARAMETERS RETRIEVAL USING SENTINEL-6 FF-SAR CROSS-SPECTRA.

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Swell, an essential component of wave dynamics, holds significant influence over oceanographic systems. Thus, accurate determination of swell wave parameters is considered of high interest. While SAR techniques have long been employed for swell retrieval, radar altimetry presents challenges due to its unique geometry and limited spatial resolution. Traditionally, operational satellite radar altimeter missions processed data with spatial resolutions around 300 metres, which were insufficient for estimating short-period swell parameters. However, recent advancements, such as the Fully-Focused SAR (FF-SAR) backprojection algorithm and the 2D frequency algorithm, have substantially improved processing techniques, increasing along-track resolution to the meter-scale.

In 2022, Ourania et al. demonstrated the feasibility of retrieving swell wave parameters through the analysis of intensity modulations in the waveform tail, paving the way for the development of altimeter-based swell products. However, interpreting swell retrieval in radar altimetry differs substantially from conventional SAR due to differing geometries, ushering in new perspectives. In this context, monitoring swells plays a critical role in discerning the influence of wind waves and swell within the sea-state bias. Additionally, the process of swell-flagging is vital for identifying potential biases of SSH in retracker.

Moreover, swell observations derived from altimetry facilitate their cross-calibration originating from various platforms, contributing to a more comprehensive understanding of swell dynamics. Ongoing projects, such as SARWAVE, funded by the European Space Agency (ESA), are actively involved in researching efforts to provide a detailed understanding of changes in swell intensity. This includes cross-spectra analysis, aimed at enhancing the accuracy of retrieving swell-wave parameters.

In line with these efforts, the authors introduce a methodology for extracting swell parameters from Sentinel-6 radar altimeter data. They employed a sublooking technique to process FF-SAR radar altimeter data, generating a cross-spectra image to extract valuable swell parameters. An Ordinary Least-Squares (OLS) model was trained using swell data from buoys and the ERA5 database as validation data. This training process aimed to refine the model's performance, ensuring its effectiveness in predicting and characterising swell features. In the current presentation, we summarise the main methods employed, from data collection, filtering, and processing, as well as the main results obtained so far.

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IMPACT OF POE-G ORBITS ON SENTINEL-6 MF AND JASON-3 ALTIMETRIC PERFORMANCES

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With an ever growing constellation of altimetric satellites (11 currently in flight, with Sentinel-3C and Sentinel-6B scheduled to launch next year) and a push for more and more accurate sea level measurements, the need for Precision Orbite Ephemerides (POE) has never been higher. In 2024, the new CNES POE-G orbital solutions have started to replace the current POE-F orbits, beginning with the reference mission in altimetry Sentinel-6 MF, and its predecessor, Jason-3.

This presentation discusses the impact of the new POE-G standard on the altimetric performances of Sentinel-6 MF and Jason-3, compared to CNES POE-F and JPL orbits on currently available reprocessed periods. Key performance indicators are assessed, such as direct orbit comparisons and stability of sea surface height at crossovers. A particular focus is given to the tandem phase, during which Sentinel-6 MF was flying on the same ground track 30 seconds behind its predecessor, as well as the impact on the GMSL trend and stability.

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KEY FACTORS FOR IMPROVING THE RESOLUTION OF MAPPED SEA SURFACE HEIGHT FROM MULTI-SATELLITE ALTIMETERS IN THE SOUTH CHINA SEA

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A satellite altimeter measures sea surface height (SSH) along the nadir track. Multiple satellite al-timeters have been in orbit, and the measurements been merged for mapping mesoscale eddies of ~100 km in size in the oceans. The capability of the mapped SSH for resolving mesoscale eddies depends on mapping algorithms. A two-dimensional variational (2DVAR) algorithm was imple-mented to generate mapped SSH at a grid size of 1/12° in the South China Sea. A range of com-parisons were performed between the mapped SSH and the commonly used AVISO (Archiving, Validation, and Interpretation of Satellite Oceanographic satellite data) mapped SSH data product at a grid size of 1/8° and 1/4°. The effective resolution, which represents the spatial scale that the data can resolve, was examined. The effective resolution of the mapped SSH using the 2DVAR algorithm is approximately 100 km, while it is 250 km with the 1/8° and 1/4° AVISO data products. The difference in the effective resolution results from the difference in the background state and thus the background error. The result suggests that the effective resolution of the mapped data could be increased by choosing a background state so that the associated errors could have a smaller decorrelation length scale.

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UPGRADED COPERNICUS IBI WAVE REANALYSIS THANKS TO ALTIMETRY WAVE DATA

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The availability of 30 years of altimetry data opens up the perspective of implementing regional wave reanalysis from model dedicated to the analysis and climate variability of key parameters in coastal sea state forecasting. A new version of the regional wave reanalysis for the Iberian-Biscay-Ireland of the Copernicus Marine Service has been developed in 2023, with improvements in spatial resolution to 2 km and more recent altimetry wave data from the Sentinel-3, CFOSAT and Sentinel-6 missions. The reanalysis is performed by the wave model MFWAM driven by hourly wind forcing from the atmospheric reanalysis ERA5 and hourly surface currents provided by the IBI ocean reanalysis. This new reanalysis includes the assimilation of directional wave spectra from the satellites CFOSAT (2019-2023) and Envisat (2002-2012). The time period of the IBI wave reanalysis is from 1993 to 2023.
The validation of significant wave height from the IBI wave reanalysis with independent HY2 wave data shows an improvement in the scatter index over the last 10 years. We will further discuss these results in comparison with coastal mooring buoys and assess validation metrics on a regional scale. We can highlight the good performance of the model reanalysis for the English Channel and the Golf of Biscay in terms of bias and root mean square errors of SWH. The variability of integrated near-shore sea-state parameters is analyzed, with a particular focus on wave-submersion hazards in the IBI domain. The dataset from IBI wave reanalysis will be very useful for improving the sea-state bias used for altimetry sea-level retrieval.

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REFINING THE ACCURACY AND STABILITY OF TROPOSPHERIC CORRECTIONS FOR SATELLITE ALTIMETRY OVER COASTAL ZONES AND CONTINENTAL SURFACES

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In the last 30 years, major advances have been achieved in satellite altimetry, due to improvements in measurement techniques, orbit ephemeris, retrieval

algorithms and environmental and geophysical corrections. The dry tropospheric correction (DTC) and the wet tropospheric correction (WTC) are important components of the satellite altimetry measurement system.
Considering the relevance of altimeter data for climate applications, in addition to the accuracy, stability and consistency of all corrections applied to the various altimeter missions are important issues. Besides their space-time variability, the height dependence of the tropospheric corrections induces extra difficulties to the retrieval of these quantities over coastal zones and continental surfaces.
This study addresses various problems associated with the retrieval of the dry and wet tropospheric corrections over non-ocean surfaces, where often the best solutions available over open ocean fail, and proposes approaches to tackle them.
Regarding the WTC, over transition zones such as coastal and inland water regions, often the best approach is a combined solution from available datasets, e.g., Global Navigation Satellite Systems (GNSS) and radiometer measurements, and atmospheric models. One of these solutions is GPD+ (GNSS-derived Path Delay Plus), that is being provided operationally in Sentinel-3 and CryoSat-2 and will be included in the next generation of the FDR4ALT products of ERS-1, ERS-2 and Envisat. In this context, the successful combination of the various datasets involves the following main steps: intercalibration of all datasets, including model-derived quantities to ensure continuity and long-term stability of the corrections; reduction of all datasets to the height level of the estimation point. The intercalibration of all datasets against the SSM/I and SSM/IS radiometers ensure the long-term stability of the corrections for all altimeter missions and allow their use for climate studies. Regarding the second point, the dynamic modelling of the height dependence of the WTC by means of ERA5 vertical profiles, when compared with previous approaches, conducts to error reduction of 1-8 cm, depending on point altitude, with main impacts in steep coastal regions.
Over zones where WTC observations are not available, ERA5 is the best compromise between model accuracy and stability. The use of the ECMWF operational model instead of ERA5, induces trends in the mean sea level, over periods of 7-8 years, by about 0.4-0.6 mm/yr globally and over 1 mm/yr in many coastal and inland water regions.
Concerning the DTC, it can be retrieved with an accuracy better than 1 cm e.g., from ERA5 3D pressure fields or from single layer surface pressure fields, followed by appropriate reduction to point altitude. Compared to the use of single layer sea level pressure fields, an improvement up to 1 cm root mean square (RMS) error is obtained for heights above 2000 m.
In conclusion, although individually some of these steps may constitute a small improvement, altogether they ensure the desired consistency, continuity and accuracy of the altimetric tropospheric corrections, over critical and important surfaces such as coastal zones and continental regions, in particular over rivers and lakes. Currently, major benefits occur for Sentinel-3, CryoSat-2, ERS and Envisat.

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RETRIEVAL OF SEA ICE CONCENTRATION FROM SENTINEL-3 A/B MWR BRIGHTNESS TEMPERATURES

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Sea ice concentration (SIC) or sea ice fraction describes the relative area covered by ice compared to a reference area. Good knowledge of SIC is essential to determine the sea ice extent in a region as well as to estimate sea ice freeboard and thickness from altimeter measurements. Currently, in Sentinel-3 Topography Mission processing, SIC information is provided to users in the Level 2 altimeter product. This information is interpolated to the time and location of the altimeter measurement from external models (OSI SAF in the latest Sentinel-3 Thematic Land processing). Sentinel-3 satellites each embark a dual-band Microwave Radiometer (MWR) mainly to provide the wet tropospheric correction for radar altimeter measurements. Radiometer data could be used to estimate SIC collocated with altimeter measurements in order to provide more precise information in space and time without the need for interpolation or external data and models.
In this context, an analysis of sensitivity of S3A/B MWR brightness temperatures to Sea Ice Concentration was carried out at CLS on behalf of ESA and in collaboration with CNES. Based on the state of the art (ESA Sea Ice Climate Change Initiative report, 2013, Ivanova et al. 2015), two algorithms were identified as being applicable to S3A/B MWR channels, characterized by two microwave frequencies (23.8 GHz and 36.5 GHz) and a near-nadir incidence angle. These algorithms are the One-channel algorithm (Pedersen, 1991) and the Bootstrap algorithm (two-channel) in frequency mode (Comiso, 1986 and 1995). We adapted and implemented these two algorithms using one year (2017) of S3A MWR brightness temperatures at the North and South Poles. The OSI SAF Sea Ice Concentration product was used as a reference to validate, evaluate performance, and compare algorithms. To assess the impact of brightness temperature variability due to variable emissivity, atmospheric conditions, and emitting layer temperature, a global SIC retrieval was compared to a local (North/South Poles) and seasonal (Summer/Winter) SIC retrieval. Finally, a specific analysis of SIC retrieval based on the sea ice type (first-year ice, multi-year ice, or wet ice) was performed using a Sea Ice Classification Flag from Sentinel-3 Level 2 products (Tran et al., 2009).
The resulting average root mean square error between the retrieved S3A MWR SIC for both algorithms and OSI SAF SIC, is in the range of 5 % in Winter and 6-8 % in Summer with a very low average bias, most time less

than 1%. These results are very promising as they show performances similar to those of other state-of-the-art algorithms applied to radiometric missions such as AMSR-E, SSM/I or SMMR (ESA Sea Ice Climate Change Initiative report, 2013). Further improvements are even possible. The altimeter Sigma0 in C and Ku bands could provide useful information in addition to brightness temperatures. Corrections such as weather filters to remove spurious ice concentration over the ocean, land-to-ocean spillover correction or atmospheric correction could further improve this performance.

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PROGRESS TOWARDS SATELLITE AND MODEL REQUIREMENTS TO CAPTURE WATER PROPAGATION IN EARTH'S RIVERS

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The water in Earth's rivers propagates through space and time as pulses across global hydrographic networks. A detailed understanding of these pulses is paramount to providing the accurate knowledge of surface water stores and fluxes that is needed to support decision making for water resources management and water-related disaster mitigation for rivers around the world. The in situ data needed to support such an investigation are notoriously limited or even unavailable in many global locations, and much hope is being placed on remote sensing datasets as potential saviors. Yet, it remains unclear what temporal revisit, distance between tracks, footprint size, spatial resolution, and variable of interest from satellites are best suited to capture the space-time propagation of discharge and storage in rivers and other surface water bodies. Additionally, the relative ability of numerical models to make up for data sparsity through model-data fusion also remains elusive.

Here we provide a summary of numerous recent and ongoing efforts designed to shed light on the type of observations and modeling capabilities that could lead to an accurate understanding and representation of daily water movement through Earth's arteries, including a forecast component, and propose additional paths forward towards this goal.

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ASSESSING SPATIOTEMPORAL MISCLOSURE OF THE SEA LEVEL BUDGET THROUGH A COMPREHENSIVE ANALYSIS OF ALTIMETRY, TIME-VARIABLE GRAVITY, AND OCEAN SALINITY MEASUREMENTS

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The now 30-year timeseries of global mean sea level change from satellite radar altimetry has become a paramount climate record. For over a decade, many groups have compared that record to the sum of ocean mass change from GRACE(-FO) time variable gravity fields and steric sea level change from Argo temperature and salinity measurements. Such a comparison is critical, as agreement between these two independent estimates of global mean sea level change lends credibility to the 30-year altimetry record. This comparison has been widely called the Sea Level Budget, and recent work shown at the 2023 Ocean Surface Topography Science Team meeting demonstrated that the budget sees good closure globally through around April 2020. After that time, however, increasingly divergent signals have led to misclosure of the budget and it is an open question as to what is causing that divergence. In this work, we conduct a comprehensive study of spatial and temporal agreement and disagreement between the altimetry and mass-plus-steric sea level budget records. Our study will interrogate possible error sources for all three data types while assessing the geophysical, geodetic, and statistical causes of budget misclosure. We consider potential contributing factors such as instrument errors, mismodeling, geocenter motion, and differences in resolution and sampling between datasets.

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JASON-3 IN-FLIGHT PERFORMANCE

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From TOPEX/Poseidon to Sentinel-6 MF, a long record of high-precision ocean altimetry data has been acquired over the same historical ground track. From 2016 to 2022, Jason-3 was the reference mission orbiting this ground track before giving up its role to Sentinel-6 MF. Nowadays, it keeps orbiting and contributing to the better understanding of the ocean, while before then its instrumental stability has allowed the accurate calibration of Sentinel-6 MF during their tandem phase (another one is planned to prepare the future missions).

Thanks to the CNES SALP (Système d'Altimétrie et Localisation Précise) project, CLS has provided the long-term monitoring of the various Jason altimetric missions on the CNES behalf. This activity provides an estimate of the missions' performances for oceanic applications such as climate studies.
As TOPEX/Jason/Sentinel-6 have all been reference missions used in operational applications and in delayed time studies (especially for the Global Mean Sea Level monitoring), focus has been given to the long-term stability of their Global Mean Sea Level (GMSL).
The Jason-3 GDR-F data have been provided to users since cycle 171 (2020, September), and data reprocessing in standard "F" was performed during 2021 over the past. This reprocessing campaign had a twofold objective: improve the quality of the products and share common standards with Sentinel-6/Jason-CS, as Sentinel-6 datasets have followed standard "F" from its launch (in 2020, November) onwards. Moreover, improvements in the ADAPTIVE retracking method and in the wet tropospheric correction have recently been implemented.
To ensure a reliable content to all scientists involved in climate change studies as well as operational oceanography, it is essential to precisely observe Jason-3 data quality and errors. This monitoring of altimeter and radiometer parameters is even more important due to the ageing of the various instruments onboard. After height years in orbit as a precise altimeter mission, this poster will give an update of Jason-3 data coverage and data quality, but also the performance of delayed and real time products (GDR, IGDR, OGDR) at mono-mission crossovers and along-track.

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IMPACT OF ALTIMETRY OBSERVATIONS ON GLOBAL AND REGIONAL OCEAN PREDICTION SYSTEMS FROM OCEANPREDICT

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Ocean prediction systems are nowadays widely used for a large variety of applications. They range from short term real time forecast to longer sub seasonal to seasonal prediction. Their evolution is toward coupling with more components of the earth system, in addition of the biogeochemistry and ecosystem. With the increased resolution and complexity of the systems in response to user needs, constraining all scales of the ocean analysis and forecasts is challenging.
To support those evolutions and produce reliable ocean analysis and forecasts, it is crucial to have well qualified ocean satellite and in situ observations to assimilate into the systems and constrain the different scales and processes as well as understand their impact. The presentation will focus on the role of Sea Level observations.
Dedicated experiments or diagnostics are produced by ocean prediction centers to better understand and improve the use and impact of observations. Some of them consist of data denial experiments of a given set of real (Observing System Experiment - OSE), or simulated observations (Observing System Simulation Experiments - OSSEs) when considering future observing networks. Other approaches are based on diagnostics to estimate the sensitivity of the forecast to observations. Results and outcomes of impact studies of sea level observations on OceanPredict systems will be discussed, including those made in the context of the UN Decade SynObs project looking at the Synergy of Ocean Observations. The impact of the altimetry observations is considered in different contexts, from high resolution, regional ocean short term prediction to large scale global coupled ocean and atmosphere system. The complementarity with the in situ observing systems is also assessed. The use of multiple systems, as done in the SynObs project, for similar experiments will mitigate the dependency of the results to the system design.

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EVALUATING SENTINEL6-MF HIGH- AND LOW-RESOLUTION ALTIMETER SEA STATE RANGE BIAS (SSB) ACROSS DIFFERING NUMERICAL RETRACKERS

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Delay Doppler Altimetry (DDA), also called SAR (Synthetic Aperture Radar or High-resolution) altimetry is a relatively new radar altimetric technique that differs from conventional pulse-limited radar altimetry (Low-resolution), such as Jason 1-3 altimeters. It is in use on the Sentinel-6MF, Sentinel-3 and Cryosat-2 satellites. One advantage of DDA/SAR altimetry is improved along-track resolution achieved by narrowing the antenna footprint along the track from a few ten km in LRM to a couple of hundred meters in SAR mode. Once the measured sea surface footprint is narrowed to a size similar to or smaller than the length scale of surface long waves (a few hundred of meters or longer), SAR mode may measure only a portion of the long-waves period in the along-track direction (azimuth), leading to sea state dependent variations on the sea surface height distribution inside the radar footprint.

Since the beginning of its satellite operations, observations show significant sea state dependent differences are observed between key altimeter sea surface measurements (i.e. significant wave height, range) retrieved from HRM and LRM altimeter measurements. This has been shown to be due to the impact of long ocean surface waves (the vertical wave motion) on SAR-mode data retrievals. Various signal processing approaches have been proposed for SAR-mode data reprocessing to mitigate the observed discrepancies between HRM and LRM. Recently, a new novel retracker for S6MF SAR measurement was developed for this purpose by Buchhaupt et al. (2023).

The results show a significant reduction in HR-LR inconsistencies. The long wave effects on DDA have been mitigated by introducing a new parameter to DDA/SAR stack retracking.

The current proposed study evaluates data from this newly refined DDA retracker dataset with the goal to assess the remaining and expected sea state bias range correction signal and how it may now differ from what is seen in the LRM data (e.g. the baseline F08 datasets or higher). We propose the following investigations. First, we will evaluate the sensitivity of the new SAR SSHA to ocean long-wave impacts using collocated global wave model information (mean wave period T02, wave propagation direction, etc.). We will also assess the sensitivity of HRM SSHA to wave period $SAR\_T02 = (\pi/2)(SWH/\sigma w)$ where σw is the variation of vertical wave particle velocity in the resolved cell, a retrieval from the retracker. Second, we will develop empirical 2D and 3D SSB models for HRM and LRM data, and evaluate and compare their SSB performances using well-established sea level variance reduction measures. Finally, potential benefits or issues associated with use of 20 Hz DDA range data will be investigated.

Buchhaupt, C., Egido, A., Vandemark, D., Smith, W. H. F., Fenoglio, L., and Leuliette, E. (2023): Towards the Mitigation of Discrepancies in Sea Surface Parameters Estimated from Low- and High-Resolution Satellite Altimetry, Remote Sensing, Volume 15, Issue 17, ISSN 2072-4292, https://doi.org/10.3390/rs15174206.

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UTILIZING MULTIPARAMETER MESOSCALE EDDY TRACKING TO MONITOR CORAL REEF RESILIENCY

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Mesoscale eddies play a major role in the global ocean circulation and have a significant impact on biophysical and biogeochemical processes. These eddies transport ocean properties, can serve as feeding grounds for marine species, heavily impact air-sea interactions of pCO2 exchange, and hurricane forecasts. In the Gulf of Mexico, the Loop Current Extension and associated eddies dominate mesoscale processes, and satellite altimetry has revolutionized how these systems are studied and monitored. Using an adapted version of NOAA's MUltiparameter Near-real time System for Tracking Eddies Retroactively (MUNSTER), which uses multimission daily near-real time satellite observations of sea level anomalies (SLA), geostrophic currents, eddy kinetic energy (EKE), sea surface temperatures (SST), sea surface salinity (SSS), and multi-sensor chlorophyll-a (chl-a) DINEOF gap-filled analysis, these eddies can be tracked and characterized, allowing for their monitoring and studies of related processes. In this study, we leverage an extended version of MUNSTER that takes advantage of the available 30-years of satellite altimetry and combine it with Argo float observations in the Gulf of Mexico to analyze the impact mesoscale eddies have on coral reef resilience over the Flower Garden Banks National Marine Sanctuary. This subtropical, shelf-edge mesophotic reef (14-140 m) is considered near-pristine and experiences a wide range of thermal variability annually, potentially making it more resilient to climate change. We find from satellite observations that mesoscale eddies are present over the reef for at least 15 days of each month, and that the presence of eddies over the reef can have a major impact on winter temperature variations at depth. We also find that cyclonic eddy winter SSTs have been increasing in the past ten years of the record, which can impact the reef's health and may reflect winter subsurface warming. This study highlights the synergy between different types of extended satellite and in situ observations and the varied applications of these data records for operational and research oceanography. Disclaimer: the scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect those of NOAA or the Department of Commerce.

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IRIS, AN INTERFEROMETRIC RADAR ALTIMETER FOR CRYOSPHERE MEASUREMENTS

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The CRISTAL (Copernicus polaR Ice and Snow Topography ALtimetry) mission in the frame of the Copernicus program will aim to provide ice and sea topographic measurements by means of radar altimetry. As priority climate factors, the extent and thickness of sea ice will be measured as well as the land ice topographic elevation and its associated volume. The CRISTAL mission, due for launch in 2027, will provide continuity to the in-orbit Cryosat-2 mission with significant performance improvement of the radar altimeter.

The IRIS (Interferometric Radar altimeter for Ice and Snow) radar is the core instrument of the CRISTAL mission and accompanied by the advanced microwave radiometer (AMR-CR) for tropospheric corrections and sea- and land-ice type classification and the GNSS receiver (PODRIX) for Precise Orbit Determination. The IRIS instrument provides Ku-Band for interferometric measurements and also Ka-Band through a single receive channel with the aim to retrieve the snow depth on sea ice surfaces and to take account of the snow loading effect.

Three high SAR resolution modes are provided by the IRIS instrument among which two of them are interferometric modes either for Sea Ice and Iceberg

(SII) areas with continuous transmission/reception of Ku/Ka pulses (SARIn Open-Burst mode) or for Land Ice and Glaciers (LIG) with separate transmission/reception of bursts of Ku/Ka pulses (SARIn Closed-Burst mode). At last, the SAR Closed-Burst mode is targeted for ocean and hydrological targets.
One main feature of IRIS is the use of Ku/Ka chirps with 500-MHz bandwidth (vs. 320 MHz on former programs) providing a 0.3 m range resolution and improving thus the measurement accuracy of sea ice freeboards and the associated sea ice thickness. Another key performance is the low error (<20 arcsec) achieved on the Angle of Arrival (AoA) during interferometric measurements. This performance is obtained by means of the antenna sub-system architecture consisting of two carbon reflectors mounted on a very stable CFRP baseplate and by means of a flexible external calibration scheme which can be carried out without interrupting the mission (no need to roll the satellite) allowing thus more frequent calibrations than Cryosat-2.
The central electronics of the instrument consists of a compact design based on Poseidon-4 altimeter and new highly integrated architectures used for telecommunication satellites. In particular, the former duplexers have been substituted by switch matrixes implemented by means of RF on PCB technology. All the digital and low level Ku/Ka RF functions, including switch matrixes, are grouped in the Central Electronics Unit (CEU) equipment. The Engineering Model (EM) of the CEU is under assembly and test and the first impulse response results are available. The Ku/Ka amplification functions are ensured by pulsed Solid State Power Amplifiers in GaN technology. The SSPA performances, among which the output power, are currently measured on Ku/Ka SSPA Engineering Models.
The presentation will demonstrate that the key performances of the IRIS instrument are validated at this stage either by means of comprehensive analyses (e.g. AoA error) or by the results obtained on the CEU and SSPA Engineering Models.

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AWI-ICENET1: A CONVOLUTIONAL NEURAL NETWORK RETRACKER FOR ICE ALTIMETRY

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The Antarctic Ice Sheet is an important indicator of climate change and a major contributor to sea level rise. Hence, precise, long-term observations of surface elevation change are required to assess changes and their contribution to sea level rise. Satellite altimetry has been used by various missions to measure surface elevation change since 1992. It has been shown that, next to the surface slope and complex topography, one of the most challenging issues is the spatial and temporal variability of radar pulse penetration into the snowpack, especially over the vast East Antarctic plateau. This results in an inaccurate measurement of the true surface elevation and consequently affects surface elevation change (SEC) estimates.
To increase the accuracy and correct the SEC for radar penetration bias, we developed a deep convolutional neural network (ConvNet) architecture following standard architectural design choices. The ConvNet, was trained by a simulated waveform data set containing more than 3.6 million waveforms, considering different surface slopes, topography, and attenuation. The successfully trained network is finally applied as AWI-ICENet1-retracker to the full time series of CryoSat-2 low resolution mode (LRM) waveforms over the Antarctic and Greenlandic ice sheet. We evaluate the accuracy of the new retracker using intra-mission cross point error analysis and compared it to estimates of conventional retrackers like TFMRA, OCOG or ICE2. Furthermore, we show the AWI-ICENet1 retrieved SEC in comparison to the other retrackers and validate against SEC estimates derived from ICESat2. Our results show decreased cross point error, reduced uncertainty and a strongly reduced time variable radar penetration, making backscatter or leading edge corrections typically applied in SEC processing obsolete. This technique provides new opportunities to utilize convolutional neural networks in altimetry, waveform retracking, and the processing of altimetry data, which can be applied to historical, recent, and future altimetry missions.

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HYDROWEB.NEXT: A CENTRALIZED ACCESS TO HYDROLOGY DATA, INCLUDING SWOT-HR

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In the frame of Theia (Data and Services centre for continental surfaces) and SWOT (Surface Water and Ocean Topography satellite) projects, CNES developed a hydrology production center and a distribution thematic hub, hydroweb.next, https://hydroweb.next.theia-land.fr, to promote a wide access to hydrology data derived from satellite observations. These solutions are focusing on the necessity to answer the needs of users from the hydrology community: water agencies, NGOs, startups, industry, research laboratories…etc.

hydroweb.next is a distribution platform focusing on hydrology users. It provides free access to services (advanced product search, vizualisation on a map or timeseries, download, analyses, etc.) and products that may be useful for hydrology studies. The product catalog currently provides free access to SWOT HR Level-2 data and Theia products such as Hydroweb

Nadir altimetry. However, the ambition is to also add other data sources, including in situ and model data, as long as they are of interest for users and publicly available.

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PRELIMINARY ASSESSMENT OF THE RADIOMETER-BASED WET TROPOSPHERIC CORRECTION ON SWOT PRODUCTS

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SWOT (Surface Water and Ocean Topography) is the first wide-swath altimeter, acquiring surface height measurements over a 120 km swath on a non-sun-synchronous 21-day repeat orbit. At an altitude of 890 km and covering latitudes between 78°N and 78°S, it provides high-resolution observations of ocean topography and the elevation of inland waters. To account for water vapor and cloud liquid water content, SWOT carries a 2-beam, 3-frequency cross-track radiometer similar to the Advanced Microwave Radiometer (AMR) on board Jason-3. This instrument employs two independent cross-track beams to measure the wet path delay approximately at the center of each Ka-band Radar Interferometer (KaRIn) 50-km swath. For each KaRIn across-track line, the radiometer-derived wet tropospheric correction (WTC) is therefore obtained from only the two SWOT Advanced Microwave Radiometers (SAMR) measurements, 60 km apart. The recent release of the SWOT Level 2 Geophysical Data Record (GDR) provides the first opportunity to inspect the SAMR WTC applied to the SWOT range measurements, both those performed by KaRIn and Poseidon-3C. The focus of this study is to carry out a first evaluation of the SAMR-based WTC present in these products. An initial qualitative evaluation will be conducted by inspecting the along-track WTC values present in each SWOT radiometer product. This will be followed by a quantitative analysis involving statistical comparisons with independent datasets, including ERA5 and ECMWF operational models, imaging radiometers such as SSM/IS, GPM, MetOp, and GNSS data at coastal stations. Subsequently, WTC from the GNSS-derived Path Delay Plus (GPD+) algorithm, which has been applied to various nadir altimeter missions such as Sentinel-3 and Cryosat-2, will be used. This algorithm's ability to extend the WTC to regions where the SAMR measurements are invalid will allow exploitation of potential enhancements to the SWOT WTC from each SMWR radiometer, particularly in coastal regions. In addition to the "normal" GPD+ solution which also incorporates valid SAMR observations, "à la Cryosat" version, i.e., based only on external measurements and therefore independent from the SMWR-based WTC, will be employed. The WTC values along SWOT's nadir track, which are currently used to correct the sea surface topography provided by the Poseidon-3C nadir altimeter, will also be analyzed using a similar approach. This analysis will help understand how land and ice contamination issues are addressed in the current SWOT Poseidon-3C products. Insights gained from this assessment will then serve as guidance in evaluating the best approach to the WTC estimation for the full extension of the KaRIn swath.

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ON THE UTILITY OF SATELLITE ALTIMETRY IN MEASURING THE FLORIDA CURRENT VOLUME TRANSPORT

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The Florida Current (FC) represents the beginning of and the swiftest part of the Gulf Stream System. It carries about 32 Sv (1 Sv = 106 m3 s-1) of warm and salty tropical waters northward and thus provides the bulk of both the upper limb of the Atlantic Meridional Overturning Circulation (AMOC) and the western boundary component of the subtropical gyre circulation. Long-term, nearly continuous measurements of the FC with a submarine cable and hydrographic surveys between Florida and the Bahamas started in 1982. These measurements have yielded the longest climate record of a boundary current in existence and served as an integral component of the AMOC observing array at 26.5N (RAPID-MOCHA-WBTS array). Although the cable has been the most reliable and cost-effective FC measurement system, there have been efforts to find a suitable backup and/or replacement system that would substitute the cable during inevitable future system failures and/or future cable breaks. Some substantial data gaps in the cable record have already occurred due to instrument failures as well as logistics or operational issues. Due to the geostrophic balance, changes in the FC are related to changes in the cross-stream sea surface height (SSH) gradient. In this presentation, we review the use of SSH measurements from both the nadir and the wide-swath satellite altimetry, as well as from tide and bottom pressure gauges, to infer the FC volume transport. We show that satellite altimetry can capture about 2/3 of the FC transport variance observed in the concurrent cable estimates, with an accuracy of about 2 Sv. Using concurrent bottom pressure and Acoustic Doppler Current Profiler measurements at 27ºN, we demonstrate that the remaining unexplained variance results from the lack of the vertical coherence of the flow. This is mainly because the cross-stream SSH gradients from altimetry yield accurate flow estimates from the surface through the thermocline, but misrepresent the deep flow. Unlike the in-situ instrumentation, satellite altimetry is not at risk from adverse weather conditions (e.g., tropical storms and

hurricanes), and its quality is homogeneous throughout the 30 years of observations. Together with the cable, satellite altimetry measurements are useful for monitoring the long-term change of the FC that could be associated with a potential weakening of the AMOC, suggested by climate models and proxy-based reconstructions. Our results demonstrate that the FC has remained remarkably stable over the four decades of observations. In conclusion, the altimetry-based estimates of the FC volume transport can be used to fill gaps in the existing cable record, and they do represent a potential replacement system for the existing cable-based system should the latter fail. However, satellite altimetry alone is not sufficient for monitoring the FC volume transport with an accuracy similar to the cable, and the cost-effective cable and ship-borne observations should be maintained as long as possible.

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ASSESSING BAROTROPIC TIDES ESTIMATION FROM SWOT MEASUREMENTS

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LEGOS, NOVELTIS and CLS are continuously engaged in the advancement of tidal measurement and modelling, developing barotropic ocean tide models which lately resulted in the release of the FES2022 atlas. Within this activity, altimetry measurements play an essential role for both model validation and assimilation processes. Since SWOT's launch in December 2022, the satellite's two-dimensional high-resolution measurements have significantly enhanced the identification of ocean processes. These new sea level measurements hold particular significance for tides, particularly during the rapid one-day sampling phase when the satellite covered fewer regions but with a higher time resolution. Our focus extends to crossover regions and polar zones, where the time resolution of sea level time series may be sufficiently high to elucidate ocean aliases and enhance the estimation of primary tidal waves. Preliminary analysis suggests that the three-month Cal/Val phase, with its one-day resolution was not long enough to provide accurate estimation of semi diurnal wave M2, both along-track and at crossover locations. Nevertheless, it appears to be more promising for diurnal wave. Combining measurements from the Cal/Val and Science orbits, to potential of SWOT data for tides will be assessed in polar zones.
This study seeks to determine whether SWOT data could be immediately integrated into our tidal models or if a several-year extended period of measurement would be necessary.

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DORIS EVALUATION OF THE FIRST ITRF2020 UPDATE

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For the first time of the history of the realization International Terrestrial Reference Frame (ITRF), an ITRF solution will be updated by a time extension of the DORIS, GNSS, SLR and VLBI input time series. Thus, the first update of the 2020 realization of the ITRF2020 will be estimated with space geodetic data from 1993.0 to 2024.0.
In this study, we start the evaluation of this first ITRF2020 update by comparing the mean positions and velocities, as well as the annual and semi-annual corrections of the DORIS stations from the original and updated versions of the ITRF2020. Then, we make benefit of the almost complete 2024 year to evaluate the first ITRF2020 update solution in terms of prediction of the DORIS station positions. Finally, we evaluate the impact of switching from ITRF2020 to the first ITRF2020 update while computing the DORIS terrestrial reference frame for Precise Orbit Determination (DPOD) solution.

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GLOBAL MEAN AND LOCAL SEA LEVEL BUDGET FROM UPDATED OBSERVATIONS AND RESIDUAL ANALYSIS

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The closure of the sea level budget with the utmost precision remains a fundamental challenge in modern physical oceanography. Firstly, this closure is crucial to assert that all major contributors to sea level variability are accurately identified and quantified. Secondly, it allows cross-validating complex global observation systems, such as the Argo profiling floats, tide gauges, satellite gravimetric missions GRACE/GRACE-FO, and the satellite altimetry constellation, while closely monitoring their performances. Thirdly, this closure is an effective approach to test the consistency of the various observed variables within the climate system, including sea level, ocean temperature and salinity, ocean mass, land ice melt, and changes in land water storage, in accordance with conservation laws of mass and energy.

In this presentation, we will discuss the state of knowledge of global mean and regional sea level budget with up-to-date observations, encompassing 1) an up-to-date assessment of the budget components and residuals, along with their corresponding uncertainties, spanning from 1993 to 2023 in global mean and throughout the GRACE and Argo era for spatial variations; 2) the identification of the periods and areas where the budget is not closed, i.e. where the residuals are significant; 3) advancements in the analysis and understanding of the spatial patterns of the budget residuals. A focus will be made on the North Atlantic Ocean where the residuals are significantly high. We investigate the potential errors causing non-closure in each of the components (e.g., in situ data sampling for the thermosteric component, geocenter correction in the gravimetric data processing) as well as potential inconsistencies in their processing that may impact large-scale patterns (e.g., centre of reference and atmosphere corrections). Errors linked to the system observability (due to different sampling and resolution of the various observations) will be quantified with synthetic data extracted from ocean simulations.

This work is performed within the framework of the Sea Level Budget Closure Climate Change Initiative (SLBC_cci+) programme of the European Space Agency (https://climate.esa.int/en/projects/sea-level-budget-closure/). This project was initiated by the International Space Science Institute Workshop on Integrative Study of Sea Level Budget (https://www.issibern.ch/workshops/sealevelbudget/).

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EARLY SWOT IMAGES ON DIFFERENT SURFACES: THE EXPECTED AND UNEXPECTED

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We present early results from SWOT SAR Interferometry over multiple surfaces. The fundamental advancement of SWOT is with its 2D elevation maps over different surfaces at the resolution of SAR, in addition to collocated SAR images. SWOT has almost an order of magnitude lower noise than was prudently planned for, and an excellent signal above the noise. Resulting 2D maps of ocean SSH at 2 km resolution show unprecedented details of small-scale ocean eddies and fronts, essential to the ocean's heat and carbon uptake and to structuring of ocean biomass. SWOT reveals the 2D structure of ocean tides propagating within regional seas, coasts and estuaries. Ocean SSH and SAR surface roughness maps reveal patterns of internal tides and soliton propagation, and surface traces of biomass such as Sargassum weed. Daily coverage in the Calibration Phase highlights their rapid evolution, and 21-day global coverage to 78° in latitude during the Science Phase highlights their spatial inhomogeneity.

SWOT's "low-resolution" global data at 250m posting/500m resolution has revealed new characteristics of the ocean bathymetry and geoid perturbations, and the structure and variations of ocean swell in complement to the 2D ocean wave estimations. The increased resolution extends the sea level observation to the coast, well delineated by the SAR images, to study near shore and coastal processes.

Over terrestrial land surfaces, the 10-70 m "high resolution" data with low noise reveals the myriad of small lakes and river tributaries, and their interconnectivity. Since hydrology data require complex ground processing, data suitable for science have been released more slowly than over the ocean. However, released data show the high quality of SWOT's observational capability, including an ability to measure river slopes even in very low slope rivers, and to monitor spatial and temporal water level variations in lakes and reservoirs globally. Some error sources are present sometimes, one of the most prevalent being so-called dark water, in which a very smooth water surface leads to specular reflection of the radar signal away from the sensor. Dark water leads to spatial and temporal gaps in the data over both rivers and lakes.

For the cryosphere, SWOT's collocated elevation and SAR images have revealed the rapid evolution of sea-ice and icebergs, with preliminary estimations of sea-ice height and ocean elevation in the polynyas requiring further investigation.

Due to its temporal sampling, SWOT does not always observe extreme events, but it has already sampled and characterized the ocean response before and after a passing cyclone, captured a tsunami propagation, iceberg calving and its related wave propagation, and monitored the river flow before, and flood damage after, the destruction of the Kakhovka Dam in Ukraine.

SWOT data are complex to process including new techniques for surface detection, data editing, and filtering and improved corrections at the higher spatial resolution. Yet the layers of new scientific information are clearly there, we trust this presentation inspires the community to peel them back and explore the new SWOT era of 2D altimetric heights and SAR images.

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OBSERVING UPPER-OCEAN AND SURFACE PROPERTIES, CURRENTS AND THEIR GRADIENTS FROM MESO TO SUBMESOSCALES

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The ocean and atmosphere exchange mass, momentum, and energy, regulating Earth's weather and climate. These exchanges are particularly complex due to the interactions across a broad range of space and time scales, processes that need to be better understood and in turn parameterized to improve coupled air-sea models. In this work, we present unique coincident and collocated high-resolution observations of the ocean surface properties collected from an airborne instrument, the Modular Aerial Sensing System (MASS), off the coast of Southern California. Central to this work is the development of a new sensor, "DoppVis," capable of measuring surface currents, their gradients and near surface vertical shear along the track of an aircraft. Velocity gradients --- such as divergence, which can be used to infer vertical velocity --- are of particular importance for understanding submesoscale dynamics and their interactions with wind, waves, and biological processes. Computing velocity gradients from traditional velocity measurements including from ships and drifters is limited because these measurements alias quickly evolving submesoscale processes and suffer from sampling bias.

The airborne observations we present provide for the first time a snapshot of the spatial structure of ocean currents and their velocity gradient statistics from sub-kilometer to mesoscales, such as the transition between balanced and unbalanced motion, and the flow structure in vorticity-strain space. Such measurements are crucial to develop a better understanding of the underlying physics of submesoscale dynamics, and validate recent advancements made on this topic through numerical studies.

Combined with the additional collocated and coincident observations captured by MASS (surface waves, SST, ocean color and breaking statistics in particular), we also examine how currents at scales ranging from 1 to 100 km modulate surface gravity waves, that is, bulk, directional and spectral properties.

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IRIS: GLOBAL REACH-SCALE RIVER SURFACE SLOPES FROM THE ICESAT-2 SATELLITE

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We present the latest version of the global reach-scale "ICESat-2 River Surface Slope" (IRIS) dataset, which comprises average and extreme water surface slopes (WSS) derived from observations of the ICESat-2 satellite since October 2018 as a supplement to the "SWOT Mission River Database" (SWORD).
To gain full advantage of ICESat-2's accurate and unique measurement geometry with six parallel lidar beams, the WSS is determined across pairs of beams or along individual beams, depending on the intersection angle of spacecraft orbit and river centerline. Combining both approaches maximizes spatial and temporal coverage. IRIS can be used to research river dynamics, estimate river discharge, and correct water level time series from satellite altimetry for shifting ground tracks.
Additionally, we compare IRIS with observations from the recently launched SWOT mission.

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30 YEARS OF SEA LEVEL CHANGE MEASUREMENTS: WHAT HAVE WE LEARNED?

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Satellite altimetry measurements over the last 30 years have provided a critical climate data record of how the oceans are responding to climate change, even though this wasn't initially the goal. We now understand how quickly sea level is changing, how this varies regionally, and what the primary contributors are. We can interpret the rate and acceleration of global mean sea level change as the forced-response to climate change. In addition, we can map the 30-year trajectory forward to understand how this trajectory compares to climate model projections of future sea level change. We can also map the regional variations of sea level change and understand how ocean-atmosphere dynamics distributes heat around the oceans. This climate data record will only become more valuable as the time series lengthens; therefore it is imperative that these series of reference missions be continued in the future.

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SWOT OVER THE ICE-COVERED POLAR OCEANS

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With the launch of the Surface Water and Ocean Topography (SWOT) mission in December 2022, the global open oceans are mapped with unprecedented resolution in 3-D, a significant advancement when compared to traditional profiling altimetry. The SWOT wide-swath interferometer provides measurements of fine-scale sea surface height (<1km) with centimetric level accuracy. In addition to the primary scientific objectives of the mission, SWOT measurements offer opportunities for addressing other science investigations, including sea ice in the polar oceans. With an inclination of 77.6°, the entire Antarctic ice cover and a large fraction of the Arctic marginal ice zone are covered by SWOT. Here, we demonstrate the utility of SWOT interferometry over the polar oceans to improve our understanding of key physical processes driving the variability of the fast-changing sea ice covers. A first examination of SWOT observations from the 1-day repeat orbit, shows the feasibility to separate the ice-returns from those of the sea surface, which is a crucial step for sea ice freeboard calculation. In addition, we present the first estimates of sea ice freeboard and sea ice thickness from SWOT.

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ADDED VALUE OF 20 HZ CORRECTIONS IN SENTINEL-3 SRAL LEVEL 2 PRODUCTS

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The Sentinel-3 mission (S3) aims at measuring, globally and frequently, sea surface topography, sea surface temperature, and ocean surface colour. Sea surface measurements are acquired with a Synthetic Aperture Radar Altimeter (SRAL) instrument. This ensures a global, frequent, and near-real-time monitoring of ocean, ice, sea-ice, and inland water in a long-term and continuous manner and with a consistent quality and a high level of reliability and availability. The mission is currently flying in a constellation of Sentinel-3A (S3A) and Sentinel3-B (S3B) on the same orbit with a 140° in-plane separation. As part of the current generation, they will be replaced with two satellites, S3C and S3D. In the Level-2 products, produced by EUMETSAT (SR_2_WAT___), the sea surface ranges measured by SRAL are subject to a series of geodetic, geophysical, and atmospheric corrections to deliver corrected sea surface height anomalies (SSHA). While these SSHA variables are available at both 1 Hz and 20 Hz, the corrections themselves are all available at 1 Hz with just a few written at 20 Hz in the products.
For the 20 Hz computation of the SSHA, the corrections participate with a replication from their 1 Hz values: filtered ionospheric correction, modelled dry tropospheric correction, wet tropospheric correction, sea state bias, solid earth tide, ocean tide (equilibrium and its non-equilibrium components), internal tide, pole tide, and dynamic atmospheric correction (high frequency fluctuations or inverted barometer height correction). Some components of SSHA at 20 Hz already exist natively in the product, such as altimeter range, satellite altitude and mean sea surface.
Furthermore, there are other variables that are not used when computing sea surface height anomalies, however, they are crucially important in other applications. Most of them are also currently explicitly computed and provided to the user community only at the 1 Hz sampling. Examples are geoid, mean dynamic topography or SSHA quality flag.
As requested by Sentinel-3 users at S3VT and as discussed during the last Ocean Surface Topography Science Team (OSTST) Meeting in 2023, EUMETSAT plans to compute and provide the user community with all these corrections at 20 Hz. This improvement is expected to be part of the upcoming Sentinel-3 Level-2 processor release along with “GDR-G” standards.
This poster will focus on the several ways to do so: Replicate them from their 1 Hz counterparts, explicitly compute them at 20 Hz from the scratch or interpolate neighbouring 1 Hz points to achieve a smooth 20 Hz correction. The first may be more computationally time efficient, whereas the second may be more accurate but might not bring added value. In this poster, we provide a summary of this undertaking and make thorough analysis of the numerical results obtained assessing the differences in SSHA produced with the different methods.

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ASSESSING THE USE OF ON-BOARD CALIBRATION TO UNBIAS THE SIGMA0 ESTIMATED BY JASON-2 AND JASON-3 MISSIONS ON SSB AND GMSL

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The Global Mean Sea Level (GMSL) has been measured with radar altimetry satellites since October 1992. This indicator is a natural integrator of Climate Change with contribution from ocean thermal expansion and ocean mass change from ice melt.

The robust description and correction of all known errors in the nadir satellite altimetry record is mandatory to provide climate users with reliable time series and associated uncertainties. New recommendations for long-term stability have been established by the scientific community on both global and regional scale (Meyssignac, B., Ablain, M., Guérou, A., et al. How accurate is accurate enough for measuring sea-level rise and variability. Nat. Clim. Chang. 13, 796-803 (2023), https://doi.org/10.1038/s41558-023-01735-z). Tackling upcoming climate science questions will require an altimeter record stability to be lower than 0,1 mm/yr (currently ~0,3 mm/yr). To this objective all contributions to the nadir satellite altimetry error budget must be revisited and improved as much as possible.

Sigma0 is a second-order contributor to the GMSL estimation, throw its impact on the Sea State Bias (SSB) correction. The Sigma0 estimation in the L2 processing is based both on the 20Hz amplitude of the tracked waveform by the retracker, and the emitted and received power via the so-called “scale factors”. The computation of the scale factors need the precise knowledge of the on-board analogical gain control (AGC), and the current processing takes first in-orbit validation (IOV) data as reference. In 2022, a study (Bignalet-Cazalet et al.) showed that the use of these IOV reference data was probably not enough to reach the GMSL uncertainties, as a slight drift could be present in the current dataset.

In 2024, a study has been conducted to precisely assess the residual drift in the GMSL resulting of the use of these first IOV data, and to assess the use of regular onboard calibrations to unbias the sigma0. This talk presents the impacts of the instrumental drift at both global and regional scale in Jason-2 and Jason-3 geophysical data as well as the impact on the GMSL parameters (trend and acceleration) and associated uncertainties.

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VALIDATION OF THE SWOT DATA FOR EDDY IDENTIFICATION IN OPEN OCEAN AND MARGINAL ICE ZONE

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The new Surface Water and Ocean Topography (SWOT) mission, featuring unprecedented resolution and precision, represents a new era in satellite altimetry and exploration of ocean eddy dynamics. This paper provides a specific test case for the inter-comparison of eddy fields in the open ocean and the Marginal Ice Zone (MIZ) in the Fram Strait, utilizing Synthetic Aperture Radar (SAR) data and complementary beta Level 2/Level 3 products from the SWOT altimetry mission.

Based on a visual examination we detected and collocated 7 instances of open ocean eddies from both data sources. The most important and obviously expected result is that even at the present CalVal state of the SWOT mission SSHA fields are clearly capable of resolving small (in our case up to 10 km) submesoscale eddies, which is a huge step forward for satellite oceanography and for oceanographic community in general.

During data analysis, it became clear to us that the visual interpretation of the open ocean eddy polarity from the SAR images poses a serious problem for the observer. Eddy manifestation in the open ocean is mostly revealed via wave-current interactions which modulate surface roughness patterns. Such patterns are not always easily interpretable. Even from a very small eddy sample, it is obvious that in certain cases it is impossible to correctly identify the eddy vorticity solely based on the eddy footprint in the SAR image. This is, in our view, a very important result that should be considered by researchers who use SAR data for eddy identification. The visual method for eddy identification from SAR images is widely employed for the exploration of meso-submesoscale eddy variability. Additionally, it is used for data labeling to facilitate automatic eddy identification from SAR images through machine learning. We believe this method can present false results in terms of eddy polarity and should be revised. Given that the revisit time of the SWOT orbit is 21 days, we do not expect that the data from SWOT will completely replace the current approach for eddy identification from SAR in the nearest future but rather both types of data can complement each other, which will greatly improve the accuracy of the final result.

The comparison of the SAR and complimentary sigma0 fields for the MIZ region revealed a general good agreement between both data types. As the coverage of Sentinel-1 and SWOT missions does not always overlap in space and time, these two data sources can complement each other perfectly. Hence, we can conclude that the data from SWOT present a great interest for studying eddies in the MIZ, as well as for other sea-ice applications.

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INNOVATIVE AUTONOMOUS UAV SOLUTION FOR IN-SITU CAL/VAL OF SATELLITE ALTIMETRY OVER INLAND WATERS AND OTHER SURFACES

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For many years now, satellite altimetry is increasingly used to monitor inland waters all over the globe, and even more with the advent of delay doppler radar altimeter embedded on the Copernicus Sentinel-3 and Sentinel6-MF missions, and the SWOT mission based on interferometric radar imagery. For these instruments, new algorithms are currently being developed to support improved data processing over hydrological surfaces in order to achieve significant accuracy improvements. There is therefore an increasing need for new in-situ systems to provide reference data for large-scale Calibration/Validation (Cal/Val) activities over inland water.

In this context, vorteX-io designed a lightweight remote sensing instrument, inherited from the specifications of radar altimeters on board altimetric satellites, capable of providing water height measurements with centimetre-level accuracy and at high frequency. Mounted on a flying drone, the system combines a LiDAR system and a camera in a single payload to provide centimetre-level water surface height measurements, orthophotos, water surface mask and water surface velocity throughout the drone flight. The vorteX-io system is a review of existing in-situ systems used for Cal/Val of satellite altimetry in hydrology or operational monitoring of water heights (used to anticipate river floods or to monitor reservoir volumes). As the lightweight altimeter is inspired from satellite altimetry, water level measurements are directly comparable to satellite altimeter data. Thanks to the UAV capability, water measurements can be performed on long distances along rivers, and at the same location and time as the satellite pass. New hydrological variables are planned to be added in the next future (water surface temperature, river discharge, turbidity, …).

To perform operational calibration and validation activities, the river profiles measured by the drone altimeter must be combined with in-situ measurement performed by fixed sensors. This processing was designed to overcome the problem of measurements not being simultaneous with those from the satellite. In fact, the ideal method to perform reference measurements is to measure the water altitude at the exact location and time as the satellite measurements. In this context, vorteX-io is developing with its partner I-TechDrone a version of the lightweight altimeter embedded on an autonomous drone.
We present here the concept and the development of this autonomous drone dedicated to hydrology measurements and the early results of the first flights performed in an autonomous mode (i.e. without any human pilot controlling the drone on the field).

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TOWARDS THE PROVISION OF OPERATIONAL FRM MEASUREMENTS FOR SENTINEL-3 OVER INLAND WATER: PROCEDURES, PROTOCOLS AND ROADMAP

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Validation, including the determination of measurement uncertainties, is a key component of a satellite mission. Without adequate validation of the geophysical retrieval methods, of the processing algorithms and the corrections , the computed geophysical parameters derived from satellite measurements cannot be used with confidence. In this context, and in anticipation of the operational delivery of dedicated inland water products based on Copernicus Sentinel-3 measurements, the ESA St3TART project (Sentinel-3 Topography mission Assessment through Reference Techniques), prepared a roadmap and provided a preliminary proof of concept for the operational provision of Fiducial Reference Measurements (FRM) in support of the validation activities of the Copernicus Sentinel-3 (S3) radar altimeter over land surfaces of interest (inland water bodies, sea ice and land ice).

In the framework of this project, the activities related to hydrology include a review of existing methodologies and associated ground instrumentation for validating and monitoring the performance and stability of the Sentinel-3 altimeter measurement via FRM. Methodologies and procedures have been defined considering the errors and uncertainties coming from the measurements of in-situ sensors, satellite measurements and the environment of the validation site. Based on these protocols and procedures, a roadmap has been prepared for the operational provision of FRM to support the validation activities and foster exploitation of the Sentinel-3 SAR altimeter Land data products, over inland waters.
Then, field campaign implementation and realization have been performed as demonstrators based on the procedures and protocols defined in the roadmap.

In this project, a comprehensive review of altimeter uncertainties over inland water bodies was carried out on the basis of a literature review, leading to the identification of the different sources of error with their associated uncertainty level. A full review of all in-situ sensors that have been used for many years for Cal/Val activities for inland waters has also been performed, combined with an analysis of innovative sensors that can fulfil the needs and potentially be used in the framework of the St3TART project. Cal/Val “super-sites” have been carefully selected to implement the roadmap for operational FRM provision. Several campaigns have been performed on the different super sites. In addition of the super sites, opportunity sites from existing national hydrological networks have been studied to significantly increase the number of FRM. Finally, comparison with Sentinel-3 data and FRM have been conducted on all the super sites and the opportunity sites. We propose here to present the final results of these hydrology activities.

A Follow-on of this project has been published by ESA. This new project aims to implement the RoadMap defined in the St3TART project. The consortium that worked on St3TART answered to this call. If the project is won, results from the regular production of FRM will be presented.

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CROSS COMPARISON BETWEEN ALTIMETRIC MISSIONS DATA (SWOT, S3, S6) AND MULTIPLE IN-SITU CAMPAIGNS AND MEANS OVER THE GARONNE RIVER NEAR MARMANDE

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The Garonne River is located in the Southwest of France and drains an area of 56,000 km². Its mean annual discharge near its outlet, where the river width is around 200 m, is around 600 m3 s-1. At the global scale, according to the Global Runoff Data Centre (GRDC) discharge database, it is the 120th largest river in the world by its annual discharge. It is therefore a medium river and makes it very representative of medium river cases. The actual water height variation over a typical year is over several metres. The daily variation during floods can be as large as 2 metres. A recent flood was recorded between 10 and 13 January 2022, with a rise in water level of about 7 metres.

The Garonne near Marmande is one of the Cal/Val sites selected by CNES to evaluate SWOT's performances. In this context, the site was fully instrumented with the deployment of several vorteX-io hydrological micro-stations in 2021. This network has been completed by 19 pressure sensors in 2022. Several altimetric LiDAR drone campaigns have been performed every year since 2021. The moving sensors campaigns have been completed by an airborne LiDAR acquisition by University of Rouen in 2022. Taking advantage of the 1-day Cal/Val orbit phase, the performance of SWOT is currently analysed and compared to in-situ measurements on this site.

This site has also been selected as a "super site" for the St3TART project. The project led by ESA aimed to define a RoadMap toward the operational production of FRM (Fiducial Reference Measurement) to validate Sentinel-3 data over inland waters. Indeed, two Sentinel-3A ground tracks cross on this super site. To compute FRM for Sentinel-3, a measurement of the river topography must be accounted for. The data from altimetric LiDAR drone campaigns have been used during this project. A Sentinel-6 ground track along the Garonne River is also present on this site . CNES computed river topography measurement from FFSAR processing of Sentinel-6 measurement. These longitudinal profiles from altimetric measurements helped us to validate the accuracy of the drone campaigns.

This site will also be a test site for the autonomous drone solution currently developed by vorteX-io and its partner I-TechDrone. This solution will be deployed during summer 2024 on this site and will perform a river topography measurement every day for 1 month.

In the framework of SWOT Cal/Val activities, the vorteX-io team performed a complete comparison of all the altimetric and in-situ data acquired on this super site since 2021.We present here the full result of these comparisons:

- VorteX-io Micro-Stations
- Drone profiles
- Pressure sensors
- Airborne LiDAR
- S3A
- S6
- SWOT
- ICESat-2

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ASSESSMENT OF SENTINEL-3A AND SENTINEL-3B RESIDUAL RADIATION PRESSURE MODELING ERRORS

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Successor of the Envisat mission, Sentinel-3 is part of the European Commission's Copernicus Earth observation and monitoring program. Soon, up to 10 satellites will simultaneously fly with this same purpose. The two satellites Sentinel-3A (2016) and Sentinel-3B (2018) have several objectives, including measuring the height of oceans, large lakes and rivers, as well as their phytoplankton concentration; measuring the thickness of ice floes and glaciers; and measuring temperatures at the surface of our planet.

Sentinel-3A (2016) and Sentinel-3B (2018) are twin satellites, that means they have an identical design, and they orbit at the same altitude. The only difference between them is that their orbital cycle is a day apart. In this study, we focus on the solar radiation pressure modeling errors of both Sentinel-3 satellites, based on a previous work made on Sentinel-6 MF and Jason-3 solar radiation pressure models. The idea is to analyze the estimated empirical accelerations of these two satellites as a function of their beta angle. The Solar Radiation Pressure (SRP) depends only on two parameters: the orbital angle with respect to the sub-solar point and the beta angle. We will then propose updates of the SRP models. The effect of the terrestrial radiative perturbations will also be assessed.

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PROGRESS REPORT AND LESSONS LEARNED FROM DEVELOPING A DORIS POD SOFTWARE

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Since 2021, Dionysos Satellite Observatory (DSO) of the National Technical University of Athens (NTUA) has undertaken the initiative to design and develop a free and open-source software product. This software aims to process DORIS data with efficiency and accuracy, catering to both Precise Orbit Determination (POD) and the derivation of parameters of geodetic interest.

This study aims to provide an overview of the software's current progress along with a series of implementation highlights, analysis and design challenges, adopted solutions, engineering strategies, and design patterns to meet the project's purpose and tight quality constraints.

Lessons learned and experience gained through the process are also discussed with the aim of fostering openness and interactivity within the DORIS/IDS community.

A set of intermediate preliminary results, effectively illustrating the specific precision goals and application range of the software will be presented. Additionally, topics such as installation, dependencies, software policy, user-friendliness, and interaction will also be discussed.

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A NEW METHOD OF OCEAN GRAVITY FIELD MODEL FUSION BASED ON WATER DEPTH

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Thanks to the increasingly abundant altimetry satellite data, scholars have constructed a large number of global ocean gravity field models, the most representative of which is the series of ocean gravity field models built by the Scripps Institution of Oceanography (SIO) in the United States and the series of ocean gravity field models built by the Technical University of Denmark (DTU). The SIO series model is inverted by the deflection of vertical method, while the DTU series model is based on the geoid height method. The two kinds of methods are more advantageous in different types of sea areas respectively, and a single method is difficult to provide high-precision Marine gravity field information in complex sea areas around the world.
The ocean gravity field of the integrated gravity field model is mainly derived from these two series models. For example, the widely recognized EGM08 gravity field model uses DNSC07 values, an earlier version of the DTU model, for the ocean within 195 km of the coastline; For all ocean areas beyond 280 km from the coastline, the v18.1 value of the SIO series model was used; A conical transition from DNSC07 to SIO v18.1 was used on the ocean between 195 and 280 km from the coastline. The current model fusion method of Marine gravity field based on the distance from the coastline needs to set the boundary value manually, which does not realize the real fusion of the information of the two models, but more is the model splice.
In order to overcome the shortcomings of existing fusion methods of ocean gravity field models, this paper proposes a new fusion method of global ocean gravity field models based on water depth, which better reflects the physical mechanism and does not need to rely on high-precision ship survey data around the world.

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DSO DORIS ANALYSIS SOFTWARE INTERMEDIATE OUTCOMES

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Over the past few years, Dionysos Satellite Observatory (DSO) at the National Technical University of Athens (NTUA) has dedicated its efforts to developing a cutting-edge software package for precise orbit determination using DORIS data. The product has been designed and implemented from scratch, trying to comply with strict, state-of-the-art standards, in an
ambitious effort to evolve into a modern processing tool for the DORIS and IDS community over time.

This study serves as a progress report for the ongoing effort, showcasing various intermediate results and modeling approaches. It effectively outlines the design and analysis paradigm employed while summarizing the current accuracy and robustness of the new tool.

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THE CRISTALAIR PROCESSOR

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CRISTAL (Copernicus polaR Ice and Snow Topography ALtimeter) will be the first mission to carry a dual-frequency synthetic-aperture radar altimeter as its primary payload. The altimeter will have interferometric capabilities at Ku-band to improve the across-track resolution and a second Ka-band frequency to provide information on snow layer properties. The development of a novel mission like CRISTAL is crucially dependent on dedicated ground campaigns to provide the essential data for the L1 and L2 algorithm development and validation.
CRISTALair succeeds ASIRAS (Airborne SAR/Interferometric Radar System), which operated in both the Arctic and Antarctic from 2004 to 2019. The main advancement in CRISTALair lies in its ability to acquire data simultaneously in Ku- and Ka-band, with interferometric capabilities on both, elevating the Science Readiness Level (SRL) of dual-band algorithms/processings. Beyond the dual-band radar, CRISTALair will integrate an airborne laser scanner, a colour-infrared camera, and ancillary equipment to ensure precise positioning and attitude of the interferometer. Additionally, corner l reflectors deployed on ground will facilitate the performance evaluation and qualification of the instrument.
The core of the processor of the CRISTALair radar altimeter is the L1 processor, which includes a L1A

processor and three L1B processors: a low resolution one (L1B-LROS), a high resolution Delay-Doppler (L1B-HR) and a Fully-Focussed SAR processor (L1B-FF), being the products of all them aligned with CRISTAL. The L1A processor includes an attitude and position processing module that ingest the navigation data provided by the onboard positioning systems (IMU, GNSS), and a calibration module, which is aimed at processing the internal calibration pulses in order to minimise the effects from instrumental delays, differential phase noise, and overall internal signal amplitude fluctuations. As add-on modules, the CRISTALair processor incorporates a Quicklook Analysis Tool (QAT) and a Performance Analysis Tool (PAT). On the one hand, the QAT is a fast-processing tool aimed at executing non-real time fast processing to inspect the captured data and to generate status reports of instrument functionality, ensuring complete monitoring and allowing for quick conclusions and decisions during the campaigns. On the other hand, the PAT main objective is to provide insight on the performance to demonstrate and track requirement compliance status of the instrument. Therefore, the PAT will ingest processed data and analyse it to verify that the requirements are met.
In this contribution we will describe the processor architecture, the overall processing strategy and the tests performed to verify the functionality of the processor.

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APPLYING NEW PROCESSING CAPABILITIES IN THE SPP CHAIN FOR IMPROVING WAVE CHARACTERIZATION FROM SENTINEL-3 AND SENTINEL-6MF MISSION DATA

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In the frame of the exploitation of the Sentinel-6MF (S6MF) and Sentinel-3A/B (S3A/B) altimetry missions, CNES has contracted CLS for the development of the Sentinel Processing Prototype (SPP) [1]. SPP is a multi-chain (LRM, UF-SAR, FF-SAR, Pulse-Pair, Transponder) processor [2] in which the novel algorithms developed in the CNES/CLS R&D activities are implemented and validated in support to the different thematic applications and in view of promoting them for a possible implementation in operational ground segment.
We present here two main applications made possible by recent developments in the SPP chain:

- We recently implemented the option of retracking unfocused SAR two-dimensional delay-Doppler maps (or stacks) [2], following the work described in [3], in order to best characterize the azimuth smearing in SAR altimetry signals caused by the vertical wave velocity at the sea surface. This retracking solution allows us to estimate the standard deviation of the waves vertical velocity [4], which is related to the mean wave period, thus providing valuable new information for the study of the dynamics of the ocean waves. Including this new parameter into the SAR model makes it also possible to successfully correct for the bias in significant wave height (SWH) observed in HR modes. Our estimates of the standard deviation of the vertical velocity and wave height are found to match the ERA5 wave model.

- We also implemented a SAR altimetry modulation spectrum processing in the SPP, which aims to measure swell properties such as period, direction and significant wave height, from S3 and S6MF FF-SAR radargrams. We follow the approach documented for CryoSat-2 [5], which includes a normalization of the radargram intensity, a resampling of the waveforms, a 2D FFT computation and finally the extraction of a first-guess of swell period and direction, within the ambiguities due to the measurement geometry. We were able to determine the wave spectrum on S3/S6MF crossovers from both S3 and S6MF data using the same algorithm, which gives information on the swell conditions as well as on the swell retrieval capability for the different radar altimeter systems.

Those studies performed with the SPP prototype allowed us to evaluate the relevance of new techniques in view of potential implementation in operational ground segment, with promising results for swell characterization.

References:
[1] Dinardo, S. et al. (2023). Advances in Space Research, 73(1), 337-375.
[2] Rodet, L. et al. (2023). 2023 Ocean Surface Topography Science Team Meeting.
[3] Buchhaupt, C. et al. (2021). Advances in Space Research, 68(2), 853-874.
[4] Buchhaupt, C. et al. (2023). Advances in Space Research, 71(5), 2332-2347.
[5] Altiparmaki, O. et al. (2022). Geophysical Research Letters, 49(7), e2021GL096224.

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SWELL CHARACTERIZATION FROM SENTINEL-3 AND SENTINEL-6MF SAR ALTIMETRY DATA

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The marine products of SAR altimetry data are significantly impacted by the swell at small scales (100-500 meters): the latter induces modulations in the observed waveforms, which increases the noise and correlations in the power spectrum density of the sea level anomaly (SLA). While the default 20 Hz Unfocused SAR (UF-SAR) processing is unable to resolve the swell parameters, the recent development of both an increased posting rate in UF-SAR processing and efficient Fully-Focused SAR (FF-SAR) algorithms [1, 2] have opened new applications for swell characterization and for the mitigation of its impact. Thanks to the increased ground resolution along track, we can now estimate proxies of the period and direction (within geometric ambiguities) of long swell systems on open ocean from L1b Sentinel-3 and Sentinel-6MF data. The two missions have distinct limitations associated in particular with their altitude, but also the altimeter range resolution and the operating mode of the instrument (closed or open burst).

In this work, we aim to assess the wave characterization capability provided by altimetry data for Sentinel-3 and Sentinel-6MF, and how it depends on the L1b processing and the sea state condition. Using new features of the Sentinel Processing Prototype (SPP) [3], we processed altimetry data on several patches of open ocean (including S3/S6 crossovers), with both Unfocused-SAR (UF-SAR) and FF-SAR approaches, with a high posting rate. We follow the approach documented for CryoSat-2 [4] to extract swell information from modulations of the backscatter in altimeter radargrams. Our results show how the increased resolution of FF-SAR data improves the determination of the swell properties, but also evidence the different cut-off frequencies associated with the Sentinel 3 and 6MF missions. This cut-off put theoretical limitations to the mitigation of the swell impact, and thus to the gain brought by the increased resolution.

References:
[1] Rodet, L. et al. (2023). New Processing Capabilities in the SPP Chain for Improving the Sentinel-3 and Sentinel-6 Altimetric Parameter Estimates. 2023 Ocean Surface Topography Science Team Meeting, 73(1), 337-375.
[2] Hernandez-Burgos, S. et al. (2024). A Fully-Focused SAR Omega-K Closed-Form Algorithm for the Sentinel-6 Radar Altimeter: Methodology and Applications. IEEE Transactions on Geoscience and Remote Sensing.
[3] Dinardo, S. et al. (2023). Sentinel-6 MF Poseidon-4 Radar Altimeter: Main Scientific Results from S6PP LRM and UF-SAR Chains in the First Year of the Mission. Advances in Space Research.
[4] Altiparmaki, O. et al. (2022). SAR altimetry data as a new source for swell monitoring. Geophysical Research Letters, 49(7), e2021GL096224.

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ASSESSING ATMOSPHERE AND OCEAN DE-ALIASING MODEL UNCERTAINTY FOR PRECISE EARTH OBSERVATION

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The study of Earth's gravity fields is of paramount scientific importance for revealing the dynamic changes within the Earth system. The European Mass Change and Geoscience International Constellation (MAGIC) and the American Next Generation Gravity Mission (NGGM) are pivotal in advancing the precision and resolution of gravity field measurements. Accurate estimation of atmosphere and ocean de-aliasing error (AOerr) is essential for enhancing the accuracy of these mission simulations. However, current AOerr provided by the European Space Agency (ESA) is derived from four different atmosphere and ocean de-aliasing models, which may lead to a serious underestimate of the AOerr. In order to explore the extent to which AOerr is underestimated, we estimated the overlooked error based on the standard deviation of ensemble members from the ERA5 reanalysis dataset. The study found that this underestimated error accounted for 15%-20% of the AOerr, which has significant implications for the next generation of gravity field simulations, especially for the accurate inversion of terrestrial water storage and sea level changes. By improving the accuracy of AOerr estimation, the application effectiveness of the MAGIC and NGGM missions in global environmental monitoring and prediction can be further enhanced and critical changes in the Earth system can be better interpreted.

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RESULTS FROM INDEPENDENT CALIBRATION AND VALIDATION OF THE SENTINEL-6 MICHAEL FREILICH MISSION

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The Sentinel-6 spacecraft has been collecting sea level measurements along the historical Topex reference groundtrack starting 17 December 2020 and took over as the new reference mission in April 2022. We present a summary of calibration and validation results highlighting the continued high value of Sentinel-6's altimetry products for oceanographic applications at the mesoscale level and for climate studies. The analysis is based on the most recent processing baselines F08 and F09. Sentinel-6's performance is analyzed using along-track as well as crossover statistics. The analysis also includes assessment of the performance using JPL's GPS-based precise orbit solutions.

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ALTIMETER CALIBRATIONS IN THE PRELIMINARY FOUR YEARS' OPERATION OF WANSHAN CALIBRATION SITE

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In order to accomplish the calibration and validation (Cal/Val) of altimeters, multiple satellite altimeter calibration sites have been established internationally. The Wanshan calibration site (WSCS) were used as a calibration site for satellite altimeters since its completion in August, 2019. In this study, we introduced the dedicated equipment placed on Zhi'wan, Wai'ling'ding and Dan'gan islands of the WSCS including permanent GNSS reference station (PGS), tide gauges and dedicated GNSS buoy (DGB) etc. The PGS data of Zhi'wan and Wai'ling'ding islands was processed using the GAMIT/GLOBK and Hector software to define the datum for Cal/Val of altimeters in WSCS. The DGB was used to transfer the datum from the PGSs to the tide gauge stations of Zhi'wan, Wai'ling'ding and Dan'gan islands. The global/regional tide models of FES2014, HAMTIDE12, DTU16, NAO99jb, GOT4.10 and EOT20 were evaluated using the three in-situ tide gauge data of WSCS and Hong Kong tide gauge data (No. B329) derived from the Global Sea Level Observing System. The HAMTIDE12 tide model was chosen to be the most accurate one to maintain the tidal difference between the tide gauge locations and the altimeter footprints. To establish the sea surface connections between the tide gauges and the altimeter footprints, a GPS towing-body and a high accurate ship-based SSH measurement system (HASMS) were used to measure the sea surface of this area in 2018 and 2022, respectively. Moreover, the global/regional mean sea surface (MSS) models of DTU 2021, EGM 2008 (mean dynamic topography minus by CLS_MDT_2018) and CLS2015 were accurately evaluated using the in-situ measured data and HY-2A altimeter, and the DTU 2021 MSS model was used for Cal/Val of altimeters in WSCS. The data collected by the equipment of WSCS, related auxiliary models mentioned above and the hydrological station data placed on Dan'gan island were used to accomplish the Cal/Val of HY-2B/C, Jason-3 and Sentinel-3A (S3A) altimeters. Biases and drifts for HY-2B Pass No. 375, HY-2C Pass No. 170 and 185, Jason-3 Pass No. 153 and 12, as well as S3A Pass No. 260 and 309 are given. The calibration results show that the WSCS can commercialize the satellite altimeter calibration. We also discussed the calibration potential for wide swath satellite altimeter of WSCS.

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SEA LEVEL IN THE SALISH SEA: INSIGHTS FROM THE SWOT ERA

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Estuaries provide extensive ecosystem, economic, and human services. At the interface between ocean and land, estuarine processes and estuarine-ocean exchange link the upstream river and terrestrial-derived material to the coastline and open ocean. The Surface Water and Ocean Topography (SWOT) mission provides a novel data set to examine estuarine sea level fluctuations at scales previously unobtainable by space-based platforms. Along the United States west coast, oceanic signals propagate into estuaries and reflect fluctuations in offshore sea levels caused by interannual and decadal variability such as ENSO/PDO, seasonal variability such as upwelling/downwelling, and synoptic variability such as large storm surges. Locally, sea level setup/set down can be due to nearshore winds and quasi-steady gradients that reflect the system's subtidal circulation. The Salish Sea, a fjord-type estuary, is the largest estuary on the US west coast. Sea-level fluctuations within the Salish Sea, due to seasonal upwelling/downwelling and strong downwelling events on shorter time scales, are strong but are an order of magnitude smaller than the temporal and spatial tidal variation. Thus, accurately removing the tides is required to understand the ocean-estuary connection on subtidal time scales. In this study we use a numerical model of the Salish Sea that has been extensively validated and used in previous studies to assess the influence of tides on SWOT retrievals throughout its 2023-2024 science orbit. Subsequently, we examine the expression of offshore sea level signals that have propagated into the estuary, relying on known forcing conditions such as seasonal and event-scale responses to upwelling and downwelling along the California Current System and the 2023-2024 El Niño.

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APPLICATION OF SWOT DATA IN OCEANIC FINE-SCALE DYNAMICS IN THE NORTHWESTERN PACIFIC AND SOUTH CHINA SEA

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High-resolution sea surface height measurements from the Surface Water and Ocean Topography (SWOT) mission provide a great opportunity to detect fine-scale processes in global ocean. However, whether SWOT can resolve these processes effectively is unclear. As a part of the Adopt-A-Crossover consortium to support the SWOT calibration and validation (CalVal), the Ocean University of China initiated the North West Pacific campaign, which deployed four moorings under the SWOT CalVal orbit in the northwestern Pacific Subtropical Countercurrent region. Based on the moored observations, 1-day SWOT data and nadir-looking altimetry data during the CalVal periods, we revealed that SWOT observed many submesoscale eddies riding on the mesosclae eddies, compared to the nadir-looking altimeters. These eddies have spatial and temporal scales shorter than 50 km and 16 days, respectively. Two submesoscale cyclonic eddies were also observed by the mooring array. Their effective radius are of 16.9 km and 13.6 km. The moored observations indicate that the Rossby number at the edge of eddies and their maximum horizontal velocity are of ~0.4 and ~15 cm/s. We found that the geostrophic velocities estimated from 52-km smooth SWOT data agree well with mooring-observed 50-80 m mean subinertial velocities. Also, in the South China Sea, based on the science phase SWOT data, we found that SWOT not only observed submesoscale eddies similar to those in the Subtropical Countercurrent region, but also internal solitary waves. The features and map of these fine-scale signals in the South China Sea were given. These results indicate that SWOT can well detect oceanic fine-scale processes, which will help us further understand the oceanic dynamics.

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PRECISE ORBIT DETERMINATION OF HY-2D SATELLITE USING ONBOARD GNSS DATA

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Haiyang 2D satellite (HY-2D) is the fourth Marine dynamic environment satellite in China.It was successfully launched from Jiuquan on May 19, 2021, carrying five effective payloads including radar altimeter, microwave scatterometer, calibration radiometer, data collection system and automatic ship identification system. In addition, the satellite has high-precision orbit measurement, orbit determination capabilities and all-weather, all-day, global detection capabilities.

The study examines the accuracy of orbit determination using HY-2D satellite onboard GNSS receiver data from January 1 to 15, 2024, based on the reduced-dynamic method. The results indicate that：1)The root mean square (RMS) average value of phase residuals is about 6.9 mm. 2) The 4-hour orbital overlap comparison shows the RMS difference are 0.6 cm and 1.3 cm in the radial and three-dimensional(3D) respectively. 3) When compared to the CNES orbit, the derived orbit has an RMS difference of approximately 1.25 cm in the radial direction and approximately 3.7 cm in the 3D position. 4) Using global satellite laser ranging (SLR) data with an elevation angle greater than 20° to validate the accuracy of the derived orbit, the mean RMS of SLR validation residuals is 2.54 cm. These results demonstrate that the GNSS receiver can meet the satellite's centimeter-level radial orbit determination requirements for altimetry satellites.

Key words：HY2D satellite; precise orbit determination

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DORIS NETWORK 2024 STATUS REPORT

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The DORIS network has been serving Earth observation satellites for over 30 years. It is more than ever at the heart of IDS challenges for the years to come. Following the IDS Retreat in 2018, several recommendations concerning the network were immediately taken on board.
We provide an update on the status of these network objectives: densification, co-location and connection with atomic frequency standards or GNSS clocks.
We review the network's overall performance in meeting the needs of satellite altimetry and geodesy: stations distribution, data availability, stations equipment, monument stability, and compliance with system requirements.
We detail the network’s main recent events and developments over the past two years: new station installations and renovations, alongside the essential day-to-day work of network teams to keep the stations in operation.
Finally, we give an overview of future prospects for continuing to improve the infrastructure in a difficult geopolitical context.

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DORIS STATIONS CO-LOCATION: STATUS AND RESULTS

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Co-locating DORIS with other techniques has been an ongoing objective throughout the network’s development. This effort has focused on two types of co-location: co-location with other space geodesy techniques, and co-location with tide gauges.
The aim of these co-locations is multiple: obtain information on site stability prior to installation, contribute to the ITRF combination, contribute to the sea level monitoring, compare observations, and improve the DORIS system performance (e.g. observe the beacon oscillator error through DORIS-GNSS ground stations coupling).
We draw up an inventory of current co-locations, show the progress made and highlight the benefits of co-location through a few examples of results.
We explain the technical difficulties involved and the requirements to be met in order to take full advantage of these co-locations.
Finally, we present the outlook for co-location regarding the DORIS network in the coming years.

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THE PERFORMANCE OF SWOT NADIR ALTIMETER FOR MONITORING INLAND WATER BODIES: A FIRST ASSESSMENT

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Surface Water and Ocean Topography (SWOT) is a satellite mission that commenced its operations in the planned science orbit in late July 2023, following its launch in December 2022. Before entering the science orbit, the satellite spent three months in a one-day repeat orbit for Calibration and Validation (Cal/Val) purposes. SWOT's primary sensor for the measurement of lakes and rivers is the Ka-band Radar Interferometer (KaRIN). However, due to the presence of a 20-km gap between the right and left swath, certain lakes and river reaches across the globe will remain unmonitored by SWOT KaRIN. SWOT's secondary sensor, the nadir altimeter Poseidon-3C, covers these otherwise unmonitored water bodies. Hence, it becomes important to assess the performance of SWOT nadir altimetry over inland water bodies. The Cal/Val orbit provides a unique opportunity for such an evaluation, as it provides daily water level time series data. Globally, among the 1011 lakes and reservoirs potentially observed underneath the Cal/Val orbit, we acquire meaningful daily time series from IGDR data for 193 of them, enabling a comprehensive assessment of the SWOT nadir altimeter's monitoring capabilities. Our results show that the Offset Centre of Gravity (OCOG) and the Threshold First Maxima Retracker (TFRMRA) outperform other retrackers. Results vary from 5 cm in terms of RMSE (in large lakes e.g. Caspian Sea, Ontario Lake, Vanern Lake) to 50 cm (in small water bodies such as Karasor Lake in Kazakhstan). We expect the results to improve when using GDR data in the next stages of our study. The decimeter-level accuracy offered raises optimism regarding the potential applicability of SWOT nadir observations to achieve a near-full coverage of water bodies on Earth.

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BLENDING 2D TOPOGRAPHY IMAGES FROM SWOT INTO THE ALTIMETER CONSTELLATION WITH THE LEVEL-3 MULTI-MISSION DUACS SYSTEM.

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The Surface Water Ocean Topography (SWOT) mission was launched in December 2023. It is the result of cooperation between CNES, NASA and their partners from the Canadian and UK Space Agencies. SWOT carries a unique altimetric payload, including a Ku-band Jason-class nadir altimeter and a Ka-band SAR-interferometric (KaRIn) wide-swath altimeter providing 2 swaths 50-km wide. It offers new opportunity for the observation of the small mesoscale structures over the oceans, including near coast and high latitude areas. Thanks to these observation capabilities, SWOT could contribute to a better understanding of the physical processes at play at these scales, and to the applications that flow from them.
Few months after its launch, Level-2 product of the KaRIn measurement were made available for the SWOT Science Team. These products are however designed to meet the mission's primary science objectives. They remain complex for many non-expert users who may need the swath measurement consistent with the other altimeter measurements for different applications. To answer these needs, a Level-3 product was developed in the context of the SWOT Science Team Project DESMOS. It is the result of different processing steps including the use of the state of the art of different geophysical corrections (e.g. Mean Sea Surface, ocean tide), aiming to improve the quality of the sea level measurement at small mesoscale; the multi-mission calibration, that makes the SWOT measurements consistent with other altimeters; the data selection, to identify invalid measurements; the sea surface height noise-mitigation, aiming reduce the noise level on SSHA and allowing the estimation of the geostrophic current and vorticity. We present here the SWOT KaRIn Level-3 product and discuss their benefits, relevance, and limitations for various applications.

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IMPROVEMENTS IN THE PRECISE ORBIT DETERMINATION USING DORIS AND LASER DATA FOR CRYOSAT-2

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In this paper we review the precision orbit determination (POD) performance of the CryoSat-2 mission. We have looked at improvements in the time variable gravity field modeling where we use input from GRACE and GRACE-FO, the AOD1B ocean atmosphere model, and the tides set-up for POD. To model time variable gravity (TVG) we distinguish between two components, there is a short term oceanic and atmospheric part for which we use the AOD1B model; for the longer term part we employ GRACE and GRACE-FO monthly potential coefficient solutions. Our experience is that adding TVG information is not necessarily successful during POD, and that attention must be paid to the proper processing of the GRACE and GRACE-FO data. To demonstrate this property we define four runs where we gradually implement TVG information. An evaluation criterion is the level of POD tracking residuals, the level of the empirical accelerations, and a comparison to precision orbit ephemeris provided by the Centre National d'Etudes Spatiales (CNES). Unexplained empirical accelerations found during POD are on the level of 3 nm/s2 for the along-track component and 13 nm/s2 for the cross-track component. The laser residuals converge at approximately 1.02 cm and the Doppler residuals are on

the level of 0.406 mm/s, the radial orbit difference to the CNES POE-F (Precision Orbit Ephemeris version F) orbits narrows to 6.5 mm. Tracking residuals are not evenly distributed for DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) beacons, the South Atlantic Anomaly effect is for instance clearly visible in the first empirical orthogonal function EOF mode of monthly binned DORIS residuals. After consideration of all possible TVG approaches our conclusion is that 3 hourly AOD1B model fields result in a small but visible improvement. The addition of TVG from GRACE and GRACE-FO is implemented in two different ways from which we can select a version that does lead to a reduction in the Doppler tracking residuals and which does reduce the level of solved for empirical accelerations.

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EVOLUTION AND NEW CHALLENGES FOR THE TIDES CORRECTIONS FOR HR ALTIMETRY AND SWOT

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Thanks to its current accuracy and maturity, altimetry is considered as a fully operational observing system dedicated to various applications such as climate studies. Altimeter measurements are corrected from several geophysical parameters in order to isolate the oceanic variability and the tide correction is one of the most critical. The accuracy of the tide models has been much improved for last 30 years leading to centimetric accuracy in the open ocean and also in many coastal areas.

To address the reduction of remaining errors in shelf/coastal seas and at high latitudes and to face the new challenges of the tide correction for HR altimetry, in particular the new SWOT mission, a new global tide model FES2022 has been developed recently.

This new tidal solution uses higher spatial resolution in coastal areas, extending systematically the model mesh to the narrowest coastal systems (fjords, estuaries, …), and the model bathymetry has been upgraded in many places thanks to an international collaboration effort. The use of nearly 30 years of altimeter measurements, including the most recent altimeter standards and some high inclination altimeters like Cryosat-2, Saral/AltiKa and even Sentinel-3, also allowed retrieving tide observations in the highest latitudes to improve the polar tides modelling. Validation results show a great improvement of the new FES2022 model compared to FES2014 and other state-of -the-art global tide models, especially but not only, in shallow seas. The new model will be available on AVISO in the coming month. Perspectives of evolution of FES tidal modelling are presented including work on coastline accuracy and bathymetry. Some comparisons with the SWOT CalVal orbit dataset are proposed also.

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SWOT 2D OBSERVATIONS OF THE INTERNAL TIDE SURFACE SIGNATURE: AN UNPRECEDENTED INSIGHT OF IT DYNAMICS AND IT CORRECTIONS ADEQUACY

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Thanks to its current accuracy and maturity, altimetry is considered as a fully operational observing system dedicated to various applications such as climate studies. Altimeter measurements are corrected from several geophysical parameters in order to isolate the oceanic variability and the tide correction is one of the most critical. Global ocean and loading tide models GOT and FES are used in present altimeter GDRs to remove the barotropic tide component, and the internal tides signatures can be partly corrected with specific models since recently.

Internal tides have a surface signature of several cm with wavelengths about 50-250 km for the first mode and smaller for higher modes. With the new higher resolution missions giving access to ocean small scale variability, the correction of these small-scale signals becomes mandatory for many applications.
Using recent IT models to correct the stationary IT signal allows a significant altimeter variance reduction on ocean regions where internal tides are generating and propagating (Zaron, 2019; Ubelmann, 2021). However non-stationary IT signal due to seasonal variability of the ocean conditions and the interactions with mesoscales and other ocean waves is still not corrected as it is more difficult to estimate.

The new Surface Water and Ocean Topography (SWOT) altimetry mission launched at the end of 2022 is an opportunity to access ocean variability at a scale extending to 15-30 km and to better understand high-frequency dynamic processes such as the internal tide (IT). This study based on SWOT observations during the Calval (1-day orbit, from mid-March to mid-July) period gives insight into the IT characteristic off the Amazon shelf break. An M2 internal tide model was built from SWOT observations and compared to the existing internal tide model by Zaron et al., 2019. Both models have similarities, SWOT observes mode 1, and mode 2 internal tide. An attempt to separate the coherent and incoherent tide is tested and shown results consistent with the prediction of the incoherency rate in the literature. It also makes it possible to distinguish the seasonal cycle of the internal tide and to observe mode 3. Some investigations are also conducted to analyze the relation between internal tide deformation and interaction with circulation, and internal waves generation. Preliminary analysis will be presented here.

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COMPARISON OF JASON-3 AND SENTINEL-6MF OBSERVATIONS IN THE EQUATORIAL BAND: WAS TOPEX RIGHT FROM THE START?

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The tandem phase between Sentinel-6MF and Jason-3 has allowed to highlight a systematic inter-mission bias on the sea level, located in the equatorial band and of 4 to 5 mm of amplitude. A second band, of smaller amplitude (around 1 mm), is also visible around 40°S. Several potential causes have been discarded, such as the geophysical corrections or the orbit.
This behavior was not observed between Jason-1, Jason-2 and Jason-3. An identical signature was however reported between Topex and Jason-1. As the Jason missions are coherent with one another, the responsibility was naturally put on Topex, until the launch of Sentinel-6MF. It is in fact highly unlikely that Sentinel-6MF and Topex, two missions distant of almost 30 years and with different platforms, present the same structure, on the exact same position and of the exact same amplitude. Further analyses using external products and missions confirm that the equatorial band most likely comes from the Jason series. These analyses will be presented in this talk.
To build the long-term climate record, each mission flying on the reference orbit must be properly aligned both globally and regionally. Such operations are performed within the L2P products. In previous L2P versions (DT2021), Jason-3 was the regional reference mission, and Topex pointed as responsible for this equatorial band was corrected from it and the error propagated to other altimeters. In the DT2024 L2P reprocessing, Sentinel-6MF is used as the regional reference mission, instead of Jason-3 in the previous version (DT2021). For so, Jason series has been now corrected from this equatorial anomaly using an empirical correction. This empirical correction and its impact on the global and regional Mean Sea Level will be assessed in this presentation.

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LATEST IMPROVEMENTS IN ASSESSING THE GLOBAL OCEAN HEAT CONTENT AND EARTH ENERGY IMBALANCE FROM SPACE GEODETIC DATA

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Measuring the Earth Energy Imbalance (EEI) at the top of the atmosphere is a challenging task as it is a globally integrated variable whose variations are small (0.5-1 W.m−2) compared to the amount of energy entering the climate system (~ 340 W.m-2). Uncertainties lower than 0.1 W.m−2 (90% confidence level) are needed to evaluate the temporal variations of the EEI over decadal and longer time scales.
The CERES experiment provides EEI time variations with a typical uncertainty of 0.1 W.m−2 (90% confidence level) and shows a trend in EEI of 0.50 +/- 0.47 W.m−2 (90% confidence level) per decade during the period 2005-2019.
By combining space altimetry and space gravimetry measurements, an estimate of the thermosteric sea level can be obtained, allowing for the estimation of the Global Ocean Heat Content (GOHC) change using the Integrated Expansion Efficiency of Heat (IEEH) coefficient. The GOHC change is an accurate proxy for the EEI as approximately 91% of the excess of energy stored in response to EEI is accumulated in the ocean as heat.
Over 1993-2022, the geodetic GOHC shows a significant positive trend of 0.75 W.m−2 [0.61, 1.04] within a 90% confidence interval, indicating a positive mean value for the EEI. Comparisons with GOHC change estimates based on in-situ ocean temperature and salinity measurements show good agreement within a 90% confidence interval from 2005 to 2019 (Marti et al. 2023, in review), although geodetic GOHC estimates are higher by about 0.2 W.m−2
In this presentation, we highlight the improvements made to the GOHC and EEI estimates from previous versions, as described in Marti et al. 2023. These include improvements in the estimation of manometric sea level from Blazquez et al. 2018, as well as enhancements in the effective temporal resolution of the EEI and advances in the estimation of the IEEH in this new version of the product. We also demonstrate the improved estimation of uncertainties in GOHC and EEI. Following the updated comparisons between different estimates of the EEI, we delve into the sources of the remaining disparities.

The latest version (V6.0) of the GOHC-EEI space geodetic dataset, which is based on space gravimetry and altimetry, will soon be accessible on AVISO-ODATIS at https://doi.org/10.24400/527896/a01-2020.003.

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DERIVING AN END-TO-END SEA LEVEL RISE STABILITY UNCERTAINTY BUDGET TO IMPROVE THE ALTIMETRY RECORD AND REACH THE SCIENTIFIC REQUIREMENTS: THE ESA ASELSU PROJECT

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Since 1993, significant efforts have been made to provide an accurate record of global and regional mean sea level data from altimetry measurements, with a thorough characterisation of their uncertainties. The global mean sea level (GMSL) trend over a period of 20 years is now measured with an uncertainty of 0.3 mm/yr (with a 90 % confidence level), satisfying the uncertainty requirements defined by the GCOS in 2011. Recently, new stability uncertainty requirements have been established in order to address scientific questions related to climate change such as closing the sea level budget, detecting and attributing the signal in sea level forced by the greenhouse gas emissions and monitoring the Earth's energy imbalance (Meyssignac et al., 2023). The primary requirements in terms of long-term stability to answer these scientific questions are: an uncertainty of the GMSL trend of 0.1 mm/yr over 10-year and longer periods; an uncertainty of the GMSL acceleration of 0.5 mm/yr/decade over 20-year+ periods; an uncertainty of the regional sea level trends of 0.3 mm/yr over 20-year and longer periods (each with a 90% confidence level). In order to reach these requirements in the coming decades, it is necessary to identify and quantify all sources of uncertainties, from the instrument measurements, from the geophysical corrections and from the processing.
Within the framework of the European Space Agency ASELSU (assessment sea level rise stability uncertainty) study, we derive the end-to-end uncertainty budget of the global mean and regional sea level records following the FIDUCEO (fidelity and uncertainty in climate data records from Earth observation) formalism (Mittaz et al., 2019). This approach improves the uncertainty characterisation and ensures that all uncertainty sources identification, quantification, and propagation are fully documented.
Additionally, the resulting uncertainties are validated using a variety of validation methods such as along-track or crossover analyses, comparisons with tide-gauges and assessment of the sea level budget. A robust validation requires a detailed assessment of the uncertainty linked to the comparison method itself.
The outcomes of the project will be made available on the ASELSU project website.

References:
Meyssignac, B., et al.: How accurate is accurate enough for measuring sea-level rise and variability, Nature Climate Change, 13, 796–803, https://doi.org/10.1038/s41558-023-01735-z, 2023
Mittaz, J., Merchant, C.J. & Woolliams, E.R. (2019). Applying principles of metrology to historical Earth observations from satellites. Metrologia, 56, 32002.

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JASON-3 NEAR-REAL TIME PRODUCTS LATENCY AND AVAILABILITY FROM SEPTEMBER 1, 2023 TO AUGUST 31, 2024

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The latency Jason-3 near-real time Operational Geophysical Data Records (OGDR) over the past year is examined using timeliness statistics against the requirement that product distribution be less than 3 hours from data collection. Major gaps in the ODGR production will be addressed, as well as periods of large latencies.

Latency calculations have been automated using the ProPro-005 algorithm as outlined in "ALGORITHMS ABOUT JASON-3 TM DATA AVAILABILITY AND OGDR DATA LATENCY, TP4-J0- NT-86- CNES", 30-Mar-2011 by C. Juan (CNES) and J. Lillibridge (NOAA).

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THE NORDIC SEAS OVERTURNING CIRCULATION: THREE DECADES OF SATELLITE ALTIMETRY INSIGHTS AND FUTURE PERSPECTIVES

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The overturning circulation of the Nordic Seas plays a crucial role in shaping the climate of the North Atlantic Ocean. It provides insights into the strength of warm water inflows to the Nordic Seas and the Arctic Ocean, as well as the export of cold, dense waters to the North Atlantic Ocean. In this talk, I will review the significant role that satellite altimetry has played in reconstructing these critical components and in elucidating the dynamics that govern their variability. Furthermore, I will discuss the limitations in our current ability to fully reconstruct the Nordic Seas overturning circulation using conventional altimetry and propose how we might address these challenges going forward.

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NOAA'S JASON PRODUCTS AND CURRENT JASON-3 NOAA NEAR REALTIME GROUND PROCESSING SYSTEM

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The interagency Jason-3 Mission measures sea surface height, wind speed, and significant wave height to help track global sea level rise, ocean currents, and upper ocean heat content. Four partner agencies share mission responsibilities: the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), the Centre National d'Etudes Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). NOAA's roles include satellite command and control, operational data processing, operational data distribution, and archive of data and processing software. NOAA's Environmental Satellite Processing Center (ESPC) generates Jason-3 Operational Geophysical Data Record (OGDR) products. ESPC distributes OGDRs in near real time (within 3-5 hours of observation) in NetCDF format via their Data Distribution Server, and in BUFR format via the World Meteorological Organization (WMO) gateway. All Jason-3 mission data are archived by NOAA's National Centers for Environmental Information (NCEI) using its Comprehensive Large Array-data Stewardship System (CLASS). The OGDRs, CNES-derived interim Geophysical Data Records (IGDRs), and the final science-quality Geophysical Data Records (GDRs), all in NetCDF, are made available by traditional FTP as well as through modern interoperable data services (see https://www.ncei.noaa.gov/products/jason-satellite-products for more information). Jason-3 geophysical data record products are used for ocean nowcasting and forecasting, assimilation into global and region models, hazard monitoring, and hurricane intensification forecasts.

This poster paper will also outline the current Jason-3 NOAA Near Realtime Ground Processing System located at Suitland MD.

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CLIMATE AND HUMAN IMPACTS ON HYDROLOGICAL PROCESSES AND FLOOD RISK IN THE GANGES DELTA

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Water resources in the Ganges-Brahmaputra delta (GBD), located mostly within Bangladesh, are gradually shrinking. The region has historically been rich in water resources. However, climate change, intensive rice irrigation, poor sanitation practices, and the presence of naturally occurring Arsenic contamination in groundwater have severely impacted both the water quality and usual abundant water availability in Bangladesh. Besides, current scientific literature defines sea level rise (SLR) as a major factor in increasing global coastal flood risk in recent and future decades, showing that coastal flood risk, particularly over mega deltas, is exacerbated by natural and human-induced subsidence. However, the impacts of climate-induced hydrological change (CHC) on flooding and synergy with human activities are often overlooked.
Here, we develop and evaluate a modeling system for the GBD that accounts for climate and human impacts on hydrology. Based on "what-if" scenarios and state-of-the-art models, we determine relative impacts of SLR, CHC and land subsidence on increased flood risk over the region. Radar altimetry data is used to represent the impact of SLR on coastal floods. We also examine the role of human impacts through groundwater irrigation and polder construction on flood risk over the region. The modeling system is composed of the HyMAP flood model coupled with the Noah-MP land surface model and an irrigation module, with the assimilation of satellite-based leaf area index (LAI). Simulated flood maps from different scenarios are overlapped with population and cropland maps to quantify the socioeconomic impacts from individual factors. Results of this study could support the decision-making process on climate-induced migration and relocation, as well as the optimal spatial distribution of flood control structures and water management practices.

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30 YEARS OF SOCIETAL BENEFITS FROM OCEAN ALTIMETRY MISSION DATA

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What we have learned from over 30 years of continuous global sea level measurements is that, as challenging and costly as these satellite missions can be, the data and information products that they provide has immeasurable value to both research and operational user communities, and either directly or by proxy, to society. Success can be measured in a variety of ways; by the number of research papers published (nearly 6,000 to date), the number of researchers on science teams for these missions (many thousands over the years), the number of operational agencies and private companies that rely on the data for their work, and the significant advances in our understanding of ocean and coastal dynamics.

These missions have been instrumental in advancing our understanding of the ocean and Earth's climate system. For the research community, the data from these satellites has been pivotal in monitoring global sea level rise, uncovering valuable insights of large and mesoscale features of ocean circulation and heat content, observing global ocean tides, supporting coastal impact assessments, and contributing to climate modeling efforts.

For the operational community, the continuous record has contributed to greater understanding of climate change and its consequences. The ocean surface topography missions have provided a comprehensive record allowing scientists, policymakers, operational agencies, and the private sector to analyze trends, track sea-level rise, assess the health of our oceans, and respond to commercial needs and opportunities. The insights gained are crucial for formulating effective strategies that can help mitigate the impacts of climate change on vulnerable coastal regions and island nations, aid in improving weather forecasts, and support management of marine resources. Operational agencies have reaped substantial benefits from these data by availing of the precise and consistent record of measurements collected over the years.

Collectively these missions have significantly advanced our understanding the dynamics of the Earth's ocean and support many critical aspects of life in and around the ocean. With planned future missions extending into the next decade, they will be vital in assessing the impacts of climate change, providing a comprehensive view of sea level change, aiding in the prediction of extreme weather events, and supporting many private commercial and nonprofit enterprises. In short, they will continue to pave the way for future innovations and continued utilization of radar altimetry for the betterment of society.

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GPS-BASED PRECISE ORBIT DETERMINATION OF THE SENTINEL-6 MF AND JASON-3 MISSIONS

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This presentation focuses on results from GPS-based Precise Orbit Determination (POD) for the Sentinel-6 Michael Freilich (MF) and Jason-3 missions. We examine the effect of the transition from IGS14 to IGS20 on the various tracking metrics, geographically correlated orbit differences, and POD performance in terms of orbit overlap differences. We also present results from the evaluation of our GPS-based POD solutions using independent metrics such as withheld satellite laser ranging data residuals and sea surface height residuals at locations where ascending and descending passes cross (i.e., crossover residuals). Finally, we assess relative performance of our GPS-based Sentinel-6 MF and Jason-3 orbit solutions to the precise orbit ephemeris (POE) that is provided in the science data products.

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SWOT NADIR IN ORBIT CAL/VAL AND PERFORMANCES ASSESSMENT

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[1]*Cnes*, [2]*CLS*, [3]*Fluctus*, [4]*Noveltis*, [5]*Alten*

Since January 2023, Poseidon-3C, the nadir instrument on board SWOT, has been tracking both oceanic and terrestrial water surfaces. Poseidon-3C, a Ku/C band nadir altimeter, is the third model of Poseidon-3 altimeter family after Poseidon-3 on board Jason-2 and Poseidon-3B on board Jason-3.

During the first year, of which six months in the CalVal 1-day repetitive orbit, and six months in the science 21-day repetitive orbit, Poseidon-3C instrument and the SWOT nadir products were monitored and analyzed by the Nadir Cal/Val team lead by CNES.

The near real time (OGDR) and short time critical (IGDR) products were publicly distributed on June 2023, only five months after Poseidon-3C switch on. The no time critical (GDR) product was cleared for public distribution in February 2024.

This talk will present the activities carried out during this phase, the monitoring of the instrument and the performance of SWOT Nadir products.

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SENTINEL-6MF PERFORMANCES OVER OCEAN

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Launched in 2020, Sentinel-6MF mission has been the altimetry reference mission since April 2022, continuing the Topex/Poseidon and Jason-1-2-3 missions. Sentinel-6/MF performances are routinely monitored and analyzed by the CNES MPS (Mission Performance Service) project with the support of CLS CalVal team.

The main objective of this activity is to detect any potential anomaly in its measurements, and to provide an estimation of the mission performances for oceanic applications such as mesoscale or long-term stability of the Global Mean Sea Level (GMSL).

In April 2024 a new processing baseline (PB) will be made available to the user community. PB F09 includes several upgrades to the algorithms in charge of processing High Resolution data. The most outstanding evolutions are: range walk at level-1, HR numerical retracking at level-2 and Vertical Wave Motion (VWM) correction also at level-2. The addition of these evolutions has allowed the mission to satisfy the only HR performance requirement not met till present. With PB F09 Sentinel-6 suffices all mission performance requirements.

This talk will present the routine performance of Sentinel-6MF LR and HR products, with a special attention to the improvements brought by the F09 baseline.

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THIRTY-YEAR TRENDS IN OCEAN TIDES: RETRACKED TOPEX TO SENTINEL-6, WITH AN ASSORTMENT OF POTENTIAL SYSTEMATIC ERRORS

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Recent work with colleagues Lana Opel and Michael Schindelegger has shown evidence for thirty-year trends in the M2 barotropic tide across much of the global ocean. Open ocean trends are very small, almost everywhere less than 0.4 mm/year, with a general tendency for decreasing amplitudes. The open-ocean trends are hard to verify; the main support comes from fairly consistent patterns of changes seen by altimetry and by a high-resolution numerical model that adopts a realistically changing ocean stratification. The picture that emerges is of increasing ocean stratification leading to increased barotropic-to-baroclinic conversion, increasing baroclinic tides at the expense of the barotropic tide. The altimeter time series has been now been further lengthened and improved by recently retracked Topex data. Yet the potential for significant systematic errors from a variety of sources is great. For example, the DAC correction has a large, but spurious, trend in M2 caused by a spurious trend in the ECMWF lunar atmospheric tide. In fact, spurious air tides seem to be a feature in all meteorological reanalysis products, for both solar and lunar tides. We also revisit the question of tidally coherent errors in satellite orbits and in inconsistent models used over the years for both dynamical tidal forcing and by tidal geocenter motion. Differences in satellite ephemerides do show not only M2 differences over 30 years, but also trend differences. These are fortunately small for M2, less than 0.1 mm/year, but can be much larger for other constituents. Other possible systematic errors will be examined as well. We can report that the newly retracked Topex data show better S2 consistency with Jason data, although trends in the S2 ocean tide are probably too small to separate from this and a number of other contaminating error sources.

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FOURTEEN YEARS OF SAR ALTIMETRY: A SUMMARY OVERVIEW

Smith W[1]*, Abileah R, Altiparmaki O, Amarouche L, Aublanc J, Benveniste J, Bouffard J, Boy F, Buchhaupt C, Cipollini P, Cotton D, Cullen R, Desjonqueres J, Dinardo S, Drinkwater M, Egido A, Ehlers F, Fenoglio-Marc L, Fornari M, Francis R, García-Mondéjar A, Gibert F, Gómez-Enri J, Gommenginger C, Hernández S, Kleinherenbrink M, Maraldi C, Martin Puig C, Mavrocordatos C, Mertikas S, Moreau T, Nielsen K, Passaro M, Phalippou L, Raney K, Ray C, Restano M, Roca i Aparici M, Scagliola M, Scharroo R, Schlembach F, Shepherd A, Thibaut P, Tran N, Vignudelli S, Wingham D*
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Doppler beam sharpening altimeters orbited Venus before Earth. The ESA Envisat RAIES product delivered some individual complex pulse echoes, allowing early experiments with echo-to-echo coherent processing, enabling measurement of inland water. The European Space Agency's successful launch of CryoSat in 2010 revolutionized radar altimetry, bringing new vocabulary for its new instrument operating modes LRM (Low-Resolution Mode), SAR (Synthetic Aperture Radar mode), and, uniquely on CryoSat, SARIN (SAR Interferometer mode). CryoSat's primary mission is ice altimetry, but it was already clear by the 2011 OSTST that its SAR mode is also excellent for ocean altimetry. SARIN showed the value of interferometric swath processing over continental ice, but it was CryoSat's SAR mode that continued on Sentinel-3 A&B, and, with a revised Interleaved Mode pulse chronogram, on Sentinel-6, missions whose primary objective is the ocean. SWOT combines SAR and interferometry.

From CryoSat on, SAR operational products exploit coherent processing intra-burst, employing so-called delay/Doppler, or unfocused, SAR (D/D-SAR or UF-SAR). This narrows the measurement footprint and allows closer approach to the coast while improving the precision of derived geophysical measurements. Inter-burst coherent processing ultimately results in fully focused SAR (FF-SAR), which gives the best calibration from transponders and corner reflectors, has measured water heights in narrow canals and rivers, and is enabling new investigations of ocean winds and waves. SAR processing mitigates error from along-track slope, and at higher posting rates has imaged megadunes and solitary waves. This presentation will trace the rich history of discovery flowing from coherently processed altimetry.

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SWATH ALTIMETRY: HOW WE GOT HERE AND WHERE MIGHT WE GO?

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Similarly to the evolution from Galileo's primitive telescope to the Webb telescope, technology and science have co-evolved resulting in new generations of altimeters and scientific results. Swath altimeters, capable of mapping in three-dimensions, are a new evolutionary step in this joint march of science and technology. In this talk, I trace the history of swath altimetry, from the Shuttle Radar Topography Mission (SRTM), to the Wide Swath Ocean Altimeter (WSOA) concept, and the recently launched Surface Water and Ocean Topography (SWOT) mission. Over the ocean, SWOT has enabled unprecedented spatial resolution; over land, it has enabled the first global assessment of water storage and discharge over many of the world's rivers and lakes. The SWOT data shows incredible promise, but it has also shown the limitations of this single platform. As the spatial resolution increases over the ocean, the circulation will not be geostrophic and ageostrophic current components must be estimated using something other than topography. While topography can be used for estimating river discharge, as demonstrated by SWOT, persistent biases occur. For both ocean and hydrology applications, a temporal resolution on the order of one week is too long to be able to characterize quickly changing events, such as ocean front formation or flood waves in rivers. In the second part, I examine how new technology might lead to the evolution of the next generation of swath altimeters and new science opportunities. The first steps towards improving temporal coverage are being addressed by the proposed ESA Sentinel-3 Next Generation Topography Mission (S3NG-TOPO) However, this improved temporal sampling will come at the expense of height precision (although the gain in reducing mapping biases may outweigh this). Here, I would like to suggest a different path that would complement the S3NG constellation. Given the excellent SWOT performance, there is margin to extend its swath to improve its temporal revisit time. Furthermore, by adding Doppler or along-track interferometry to a SWOT-like instrument, a variety of baseline and antenna configurations could allow the simultaneous estimation of topography surface currents. These complementary measurements would allow the estimation of fluxes both on land and over the ocean. They would also remove river discharge biases and improve discharges at River Deltas, where slopes are shallow. In the ocean, it would allow the separation of geostrophic and ageostrophic currents. Coupled with S3NG, as a new member of the constellation, a new generation of integrated measurements would be available globally. However, this added capability will come at a cost. The final part will explore what new architectures, capabilities and complementary observations (e.g., ODYSEA) might be around in the next decade to potentially make this a realizable dream.

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STERIC SEA LEVEL VARIATIONS IN THE DEEP WESTERN BOUNDARY CURRENT OF THE NORTHWEST ATLANTIC OCEAN REVEALED USING FULL-DEPTH IN SITU AND SATELLITE OBSERVATIONS

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The non-closure of the global sea level budget detected since 2017 stimulates the need to better understand the limitations of satellite altimetry and gravimetry measurements, and define important caveats in steric sea level estimates from in situ observations. Time series of full-depth temperature and salinity profiles collected from Deep Argo floats in regional pilot arrays provide the opportunity to study physical processes affecting the time variability of local steric sea level at interannual time scales, and to test the local closure of the sea level budget. Here, we will focus on Deep Argo measurements collected in the Northwest Atlantic Basin between 2017 and 2022. In particular, our analysis seeks to relate the variability of deep (> 2000 m) steric sea level to the strength of the deep western boundary current of the Northwest Atlantic Ocean and mesoscale eddies propagating in this region using observations from the RAPID array. We will make comparisons of steric sea level from Deep Argo and BATS station profiles with JPL and CNES/Magellium geodetic products where the ocean steric sea level is calculated from the difference between sea level from altimetry and ocean mass from GRACE/GRACE-FO. This analysis will validate the performance of satellite-derived products (and their limitations) in two different regimes, the deep western boundary current and recirculation to the west, and the deep ocean circulation over abyssal plains located further east.

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CLASSIFYING ARCTIC ICE TYPES USING NADIR-OBSERVING RADIOMETER AND ALTIMETER DATA FROM THE MARINE DYNAMIC ENVIRONMENT SATELLITE HY-2B

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The passive correction microwave radiometer, (CMR) and active radar altimeter (RA) microwave data from

the Chinese marine satellite (HY-2B) were utilized, for the first time, to classify Arctic first-year sea ice (FYI) and multi-year sea ice (MYI) throughout the entire calendar year of 2019. This study introduces a novel approach to classifying Arctic sea ice by combining two sensors (CMR and RA). By combining both active and passive observational sensor data from the satellite's nadir points and employing the weighted K-means algorithm alongside with a method that sets feature significance weights using the random forest algorithm, the overall accuracy of ice type identification has surpassed 85%. This method offers a significant advantage compared to using only a single type of sensor data. Optimal results are achieved by selecting a K value in the K-means method above 20, ensuring more stable classification outcomes. Through the analysis of total precipitation, snowfall, and clear-sky direct solar radiation at the surface from the ERA5 atmospheric reanalysis model dataset, it was observed that total precipitation and snowfall in the polar region have a lesser impact on sea ice during winter and a more significant influence on identifying ice types in the early stages of sea ice growth.

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CHINA'S HY-2 SATELLITE RADAR ALTIMETRY MISSIONS: REVIEW AND PROSPECT

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Radar altimeter is an active microwave remote sensor, which is able to provide global sea surface height (SSH), significant wave height (SWH) and sea surface wind speed (SSWS) measurements. Radar altimetry data can be further used for study of ocean dynamics, sea surface topography, marine gravity anomalies, seafloor topography, global and regional sea level changes, etc. After decades of development, satellite radar altimetry has made great progress, from instrument design, data processing to application. Radar altimetry data can be used not only for oceanographic research, but also widely used for inland water level changes, sea ice thickness changes, glacier mass balance and abnormal climate impacts.

Haiyang-2A (HY-2A), China's first ocean dynamic environmental satellite, was launched on 16 August 2011. HY-2A first flew on a 14-day near-repeat polar sunsynchronous orbit with a mean altitude of 971 km. In March 2016, HY-2A changed to a 168-day-repeat orbit with a mean altitude of 973 km for the geodetic mission. HY-2B (launched on 25 October 2018), together with HY-2C (launched on 21 September 2020) and HY-2D (launched on 19 May 2021), forms China's first ocean dynamic environment satellite constellation and greatly improves the global observation coverage and timeliness of marine dynamic environmental elements. HY-2B is a polar orbit satellite (inclination: 99.3°), while both HY-2C and HY-2D are inclined orbit satellites (inclination: 66°). Similar to the Jason-1/2/3 radar altimeters, the dual-frequency radar altimeters (Ku band: 13.58 GHz and C band: 5.25 GHz) onboard the HY-2A/B/C/D satellites adopt the pulse-limited operation mode to measure the sea surface height, significant wave height, and sea surface wind speed. At present, China's HY-2E and HY-2F are under development. Unlike HY-2A/B/C/D, HY-2E/F will carry SAR altimeters similar to the Sentinel-6A radar altimeter.

We will first demonstrate the performance of the SSH, SWH and SSWS products of the HY-2A/B/C/D radar altimeters over ocean. Then we will present some applications of the HY-2A/B/C/D radar altimetry data in marine gravity anomaly and seafloor topography retrieval, mesoscale eddy detection, Arctic sea ice lead detection, sea ice thickness and snow depth estimation. At last, we will introduce the design and status of the HY-2E/F SAR altimeters under development.

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FROM 30 YEARS OF STABLE SEA LEVEL ALTIMETRY MEASUREMENTS TO ACCURATE ESTIMATES OF THE EARTH ENERGY IMBALANCE

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Altimetry missions have provided nearly 30 years of precise, accurate, and continuous measurements of near-global sea level measurements thanks to the reference missions in the same orbit: TOPEX/Poseidon, Jasons (1,2,3) and more recently Sentinel-6 Michael Freilich. These measurements have played a crucial role in constructing the global mean sea level record, allowing us to estimate its evolution (+3.3 mm/year) and acceleration (+0.12 mm/year²) over 1993-2021 with high precision: ±0.3 mm/year and ±0.07 mm/year² at the [5%,95%] confidence interval, respectively (Guérou et al., 2023).

By combining altimetry measurements with space gravimetry data from the GRACE and GRACE-FO missions, which measure ocean mass variations, as well as temperature and salinity profiles primarily based on Argo data, the ocean heat content can be deduced. Then, the mean of the Earth Energy Imbalance (EEI) (+0.8 W/m²) can be computed with an uncertainty of ±0.16 W/m² ([5%,95%] confidence interval) over the 2002-2022 period (Marti et al., 2023).
In this study, we emphasise the significance of the 30 year sea level altimetric record in accurately estimating the EEI. We highlight the importance of understanding the uncertainties in altimetry observations, our current

modelling capabilities at both global and regional scales, and how we propagate uncertainties from altimetry measurements to the EEI. Additionally, we discuss the current limitations of the altimetry measurement system and their impact on EEI estimates, aiming to provide a roadmap for improving past and future altimetry mission measurements to address key scientific questions and gain a better understanding of the mechanisms driving climate change.

This study is supported by various projects funded by CNES (Génération d'Indicateurs Climatiques sous ODATIS", SALP) and ESA (MOHEACAN, ASELSU).

References:

Guérou, A., Meyssignac, B., Prandi, P., Ablain, M., Ribes, A., and Bignalet-Cazalet, F.: Current observed global mean sea level rise and acceleration estimated from satellite altimetry and the associated measurement uncertainty, Ocean Sci., 19, 431–451, 2023.

Marti, F., Rousseau, V., Ablain, M., Fraudeau, R., Meyssignac, B., and Blazquez, A.: Monitoring the global ocean heat content from space geodetic observations to estimate the Earth energy imbalance, Rev., https://doi.org/10.5194/sp-2023-26, 2023.

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SENTINEL-6B COMMISSIONING CALIBRATION AND VALIDATION IMPLEMENTATION PLAN

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The Mission Performance Working Group (MPWG) is a body composed of experts from EUMETSAT, NASA, ESA, NOAA and CNES. The group meets on a regular basis, and it is aiming at monitoring the Jason-CS mission performance requirements. One of the duties of the MPWG is to define the calibration and validation implementation plan (CVIP) for the Sentinel-6 satellites including commissioning activities. The Sentinel-6B mission currently is targeted to launch in November 2025 with commissioning activities occurring from January to September 2026.

In this presentation the MPWG will describe the calibration and validation activities planned for S6B commissioning, highlighting differences from the S6MF commissioning. Along the presentation the different activities will be linked to the scientific challenges under investigation and the benefits of some of the planned activities for future altimetry missions. Moreover, the mode mask scenarios planned to support the calibration and validation activities will be presented.

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TOWARDS IMPROVED MULTIMISSION SEA LEVEL GRIDDED PRODUCTS

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For over 30 years, altimetric maps have enabled the oceanographic community to study and monitor the evolution of ocean surface dynamics. These maps are constructed from sparse along-track altimetric data, and an algorithm based on the principle of optimal interpolation fills in the missing data between tracks. While these maps are highly valuable for the community, they have limitations, such as the inability to properly resolve spatial scales below 200 km and a temporal scale of 20 days.

Nowadays, new data (e.g. large swath SWOT data) and new mapping tools/algorithms are being developed to better observe/represent rapid and fine scale oceanic structures. We intend here to present recent developments and results obtained with the MIOST mapping tool (Ubelmann et al., 2021). Our goal is to assess the system's ability to reconstruct ocean surface topography using the current nadir constellation, as well as high-resolution wide-swath data provided by SWOT. We will also address challenges faced by the mapping system in effectively capturing fine oceanic scales, as well as exploring emerging alternative data-driven methods that prove to be effective in retrieving non-linear fine-scale dynamics.

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DTRF2020 UPDATE: CHALLENGES AND FIRST RESULTS

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The last realization of the International Terrestrial Reference System (ITRS) was computed by the three ITRS Combination Centers of the International Earth Rotation and Reference Systems Service (IERS) in 2021. The realizations are based on observations of the four space-geodetic observation techniques (i.e., GNSS, VLBI, SLR and DORIS) until the end of 2020. The ITRS realization computed at DGFI-TUM is called the DTRF2020. In 2023, the ITRS Product Center send out a call for participation for an update of the most recent ITRS realizations. In early 2024, the scientific services which coordinate the activities related to the four space-geodetic techniques provided data sets which cover the time period 2021 until 2023.

In this study, we present the current status of the DTRF2020 update with a special focus on the DORIS contribution. We discuss the provided data set (statistics, data quality, etc.) and relate the obtained solutions to the DTRF2020 and to the other submitted updates. A special highlight is put on the consistency of the submitted updates w.r.t. the ITRS 2020 realizations in terms of discontinuities, network deformations, etc.

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EARTH'S ENERGY IMBALANCE: PERSPECTIVE FROM THE GEODETIC SATELLITES AND THE SEA LEVEL BUDGET

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Geodetic satellite observations have a wide range of synergistic applications that are vital for quantifying and understanding the rapidly changing global climate. We provide an update on the combination of total sea level (from altimetry) and ocean mass (from GRACE/GRACE Follow-On) to estimate Earth's Energy Imbalance (EEI) from 2002 through 2024, using the so-called sea level budget approach. Ocean heat uptake (OHU) poses a vital constraint on EEI and its uncertainty, as over 90% of planetary heat uptake occurs in the oceans. Using recent geodetic observations, geophysical corrections, and new estimates of the ocean's expansion efficiency of heat, we translate steric sea-level change, the difference between total sea-level and ocean-mass change, into a global OHU of 0.89+/-0.25 W/m² over the 2005-2023 period, consistent with the EEI observed by Ceres. During his time, the satellite-based OHU/EEI observations consistently show an increasing tendency of OHU of approximately 0.05 - 0.07 W/m²/yr. This trend implies an acceleration of ocean warming, broadly consistent with global surface warming trends seen over the last decade. As has also been noted by others, subtracting the 0-2000m Argo-based OHU estimate from the geodetic OHU implies a residual that is likely too large to be attributed to the deep ocean only. We discuss regional sea level budgets (e.g., in the South Pacific) and compare the geodetic OHU with select deep ocean hydrographic surveys to assess the extent and realism of deep or residual ocean warming, and possible other residual signals that can arise in the data processing of geophysical corrections.

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EXPLOITING THE POTENTIAL OF SENTINEL 3A TO DETECT THE ANTARCTIC ICE SHEET GROUNDING LINE

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The Antarctic grounding line controls ice sheet discharge and consequently the sea level rise due to its transitory position viz. between grounded ice sheet and floating ice shelf. It also acts as an input to the ice sheet models. Thus, it is very important to detect the advance and retreat of the grounding line. Here, we present a modified elastic beam approach to detect the grounding line at the Institute ice stream region, Filchner Ronne Ice Shelf (FRIS)), Antarctica using sentinel 3A altimeter data. We used Sentinel 3A data of one complete year i.e., 2nd January 2019 (cycle 40) to 19th December 2019 (cycle 52). Prior to elastic beam fitting altimeter passes were interpolated on a given referenced track and elevation differences were computed and corrected for slope effect using 200 m Reference Elevation Model of Antarctica Digital Elevation Model. Differential Interferometric Synthetic Aperture Radar (DINSAR) derived grounding points were taken as reference points. The new grounding line estimates were observed to be ranging between -0.59 m to 0.66 m. Currently, we are refining and automatising the method to obtain sentinel 3 derived estimate for the entire Antarctic ice sheet.

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OBSERVATION OF THE SPATIAL-TEMPORAL VARIATION OF ANTARCTIC SEA ICE THICKNESS FROM CRYOSAT-2

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Antarctic sea ice is one of the most essential factors in the climate system, it has a great effect on both the Southern Hemispheric and global climate. Sea ice thickness is one of the most important parameters of sea ice, the knowing of the spatial distribution and variation trend of Antarctic sea ice thickness is quite significative to understand and predict the climate change process. Here, CryoSat-2 altimeter and Operational IceBridge (OIB) airborne measurement data are used to calculate the penetration depth of Ku band in snow layer, we find that the penetration depth has a quite good correlation with snow depth (a correlation coefficient of 0.85), hence a linear regression equation is constructed for penetration depth estimation. Sea ice freeboard is obtained from the radar freeboard data, and then the penetration depth is estimated and corrected. The accuracy validation result shows that the averaged difference between the penetration-depth corrected sea ice freeboard and AADC in-situ sea ice freeboard is about 6 cm, which is smaller than original method (10 cm). In addition, the averaged difference between the penetration-depth corrected snow freeboard (sea ice freeboard + snow depth) and AADC in-situ snow freeboard is about 6 cm, which is smaller than original method (24 cm), this demonstrates the reliability of our method. The comparisons to the AADC in-situ sea ice thickness measurements show that the accuracy of our method is about 0.31 m, which is obviously smaller that original method (1.31 m). Based on the sea ice thickness data during CryoSat-2 period, the spatial-temporal variation of Antarctic sea ice thickness is analyzed.

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IONOSPHERIC CORRECTION MODELLING FOR ALTIMETRY

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Once upon a time, there were no dual-frequency altimeters, and no GPS satellites. Yet, just like today, the altimeter range has always been influenced by a refraction of the altimeter signal which leads to an extension of the altimeter range. While the correction is simply inversely proportional to the square of the altimeter frequency and proportional to the total columnal electron content (TEC) between the surface and the satellite altitude, obtaining a good estimate for this TEC was not trivial.

Early missions like Geosat and ERS-1 then relied on a climatology (Bent, 1972) which used the solar flux value (F10.7), yet the accuracy was very limited, as was the case for earlier versions of the alternative International Reference Ionosphere (IRI) climatology.

Taking advantage of the dispersive nature of the delay as function of frequency, dual-frequency altimeters were designed, the first being TOPEX. This made the ionospheric significantly more accurate, but not necessarily more precise, since the differencing of the Ku-band and C-band ranges introduces a very large noise, much larger than the intrinsic Ku-band range measurement. Over time, several solutions have been proposed, from simple box car filtering (Imal, 1994) to more advanced multi-step filtering in the Sentinel-3 and Sentinel-6 ground segments.

On the other hand, single frequency altimeters, like currently SARAL/AltiKa and CryoSat-2, still rely on external models. Luckily the large GNSS constellation has helped producing 2-hourly maps of TEC, which can then be interpolated in space and time to derive the ionospheric correction. Similarly, with the wealth these maps, a new climatology (NIC09) could be derived, that performed much better than the previous, even before the GPS era.

One tricky issue here though is that the GNSS signals are impacted my (nearly) the entire ionosphere, while even the highest altimeter missions only sense a (large) part of it. How to reduce the TEC to altimeter altitude has been an issue of debate, with Iijima (1999) proposing a reduction based on the IRI95 model (as is used in all altimeter mission products), and Scharroo (2010) and Dettmering (2022) proposing (different) constant scale factors.

This poster offers some insights into the way the ionospheric correction has been dealt with over time, and the remaining issues to still be resolved.

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VALIDATION OF SENTINEL-6 MICHAEL FREILICH OPERATIONAL PRODUCTS IN A MULTI-MISSION CONTEXT

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Launched in 2020, the Copernicus Sentinel-6 Michael Freilich satellite is the latest payload in the Jason series and the new reference altimetry mission. In spring 2024, the latest processing baseline F09 was released to deliver the operational products. For the first time since the start of the mission, both Low Resolution (LR) and High Resolution (HR) data are processed with the Numerical Retracker (NR). These updates allow us to compare the SAMOSA retracker with the NR for both LR and HR modes, and to observe the impact of the retracker and modes on geophysical retrievals for marine applications.

10 cycles were reprocessed during the tandem phase with Jason-3 using the processing baseline F09. This is a very good opportunity to demonstrate the high value of the Sentinel-6 products and to characterise the difference between the two missions with the latest processing baseline available. We will be able to demonstrate that all performance requirements are met for Sentinel-6.

Moreover, Sentinel-6 and Sentinel-3 performance will be compared in a multi mission context. EUMETSAT is working toward the harmonization of the Radar Altimeter processing performed by EUMETSAT for Sentinel-6 and Sentinel-3. This work will allow identifying still existing differences and suggest the way forward to fully harmonize the operational altimetry products delivered by EUMETSAT.

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PROCESSING FULLY-FOCUSSED SAR WITH GPUS

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The Fully-Focussed (FF-SAR) algorithm for nadir radar altimeters [1] allows to achieve along-track resolution close to the theoretical limits, which is about 0.5 m for typical nadir altimeters such as Cryosat-2, Sentinel-3 A/B, and Sentinel-6. Such improvement with respect to the roughly 300 m-scale resolution of classic Delay-Doppler (DDP) algorithms has enabled the development of new applications over a wide variety of scenarios, such as inland water level and water extent retrievals, sea ice, and ocean swell studies. FF-SAR algorithms can be implemented following two approaches: time domain (backprojection, BP) and frequency domain. The back-projection approach is more accurate than the frequency one because it relies on less assumptions, but the computational time associated to its classic implementation is too high for envisaging an operational implementation. To improve the poor run-time performance, the processor code has been rewritten to work on GPU devices, improving this performance by a factor around 100 using commercial, powerful GPUs, when compared with the CPU-based processor.

This new implementation of the FF-SAR BP processor to work with GPUs is a code that mixes C++ and CUDA programming language (an extension of C language specially designed to work with GPU devices), unlike the CPU-based processor, which was totally implemented in C++. The new CUDA code is entirely tailored to follow the needs of the FF-SAR BP for Sentinel-6 MF, and will take care of all big matrix operations (the ones that take most of the time), so they are performed in the GPU in an efficient and optimal way. With this new implementation, we achieve performances relative to the input data sensing time around a factor of 5 - depending on the configuration and taking into account other accelerations of the BP algorithm-, leaving it close to a near-real time performance, which could be then achieved using several GPU devices in parallel. The new GPU processor has been verified to provide the same results as the CPU-based processor, in order to assess differences in the precision of the results.

References

[1] Alejandro Egido and Walter H. F. Smith. Fully focused sar altimetry: Theory and applcations. IEEE Transactions on Geoscience and Remote Sensing, 55(1):392–406, 2017.

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REVISITING THE ANTENNA PATTERN FOR CONVENTIONAL AND SAR ALTIMETRY – IS GAUSSIAN GOOD ENOUGH?

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For about half a century the antenna characteristic of radar altimeter has been approximated to follow a Gaussian distribution. This choice was made for several reasons. One was that the differences with respect to a more realistic antenna pattern was considered to cause little deterioration. Additionally, a Gaussian distribution could be implemented into a waveform model, while for more complex pattern this was not possible. In this study we will revise the antenna pattern and aim to replace the Gaussian distribution approximation with a better representation [1]. Focus shall lie on expected biases in retrieved geophysical sea state parameters from conventional altimetry (CA) and synthetic aperture radar (SAR) altimetry. We will do this by simulating the CA or SAR altimetry signals numerically with an analytical representation of a real radar altimetry antenna characteristic and fitting those signals with signal models using a Gaussian distribution and a better approximation to estimate biases.

We will discuss how different retrackers behave with respect to the antenna pattern in low resolution (LR) and SAR processing and how to mitigate them. The considered parameters will be sea surface height (SSH), significant wave height (SWH), wind-speed, the standard deviation of vertical wave particle velocities (sigmav), and the mean line-of-sight surface velocity ux. We will investigate following retrackers:

1. SINC2 STD: Numerical 3 parameter LRM waveform retracker (WS, SSH and SWH) [2].
2. SINC2 ZSK: Numerical 3 parameter LRM waveform retracker (WS, SSH and SWH) using a zeros skewness power transform to improve retracking performance [2].
3. SINCS STD: Numerical 3 parameter SAR waveform retracker (WS, SSH and SWH) [2].
4. SINCS-OV ZSK: Numerical SAR stack retracker estimating WS, SSH, SWH and the standard deviation of vertical velocities sigmav [2,3].
5. SINCS-OV2 ZSK: As SINCS-OV ZSK, but with additional parameter describing the Doppler frequency scaling caused by mean line-of-sight surface velocities ux [3].

We will perform a global processing campaign for both Sentinel-6MF and Sentinel-3A covering several months. The results will be validated with respect to LR and the ERA5 wave model. This issue is also of high concern for Ka-band altimeter missions like CRISTAL due to their small antenna aperture, which no longer satisfies the Gaussian approximation of the antenna pattern typically considered in waveform models.

[1] Dinardo, S., C. Maraldi, J.A. Daguze, S. Amraoui, F. Boy, T. Moreau, N. Picot "Sentinel-6 MF Poseidon-4 Radar Altimeter In-Flight Calibration and Performances Monitoring," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-16, 2022, Art no. 5119316, doi: 10.1109/TGRS.2022.3216595.

[2] Buchhaupt C., (2019), Model Improvement for SAR Altimetry, Schriftenreihe
Fachrichtung Geodäsie der Technischen Universität Darmstadt, Darmstadt, Dissertation, http://tuprints.ulb.tudarmstadt.de/9015/

[3] Buchhaupt, C., Egido, A., Vandemark, D., Smith, W. H. F., Fenoglio, L., and Leuliette, E. (2023): Towards the Mitigation of Discrepancies in Sea Surface Parameters Estimated from Low- and High-Resolution Satellite Altimetry, Remote Sensing, Volume 15, Issue 17, ISSN 2072-4292, https://doi.org/10.3390/rs15174206.

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ST3TART: FIDUCIAL REFERENCE MEASUREMENTS FOR SENTINEL-3 LAND ALTIMETRY

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The Copernicus Sentinel-3 Surface Topography Mission (S3 STM) provides critical surface elevation information for inland waters, sea ice, and land ice. This valuable data is acquired through its high-resolution radar altimeter and a unique orbit that reaches the polar regions. To ensure reliable measurements and maximize the mission's benefits, adequate validation is essential. This process involves comparing the mission's geophysical retrieval methods, processing algorithms, and corrections against independent observations known as Fiducial Reference Measurements (FRM).

The St3TART project addresses the need for an operational framework for the provision of FRM to support validation activities and foster the exploitation of the Sentinel-3 SAR altimeter Hydro-Cryo Thematic data products. The project tackles the specific challenges associated with three types of surfaces: inland waters, sea ice and land ice.

To achieve this, St3TART sets forth several objectives, including the identification and operation of super and opportunity sites, the acquisition, processing, and delivery of FRM for Calibration / Validation (Cal/Val) activities, and the characterization of uncertainties associated with each FRM data product and measurand. It also involves the exploitation of FRM for Cal/Val activities, and the preparation of a roadmap for future Altimetry missions beyond S3 STM, focusing on the Cryosphere and Hydrology.

These achievements pave the way for the successful implementation of operational FRM provision, ultimately contributing to the Sentinel-3 mission's goal of delivering accurate and reliable Earth observation data. We will present the project's objectives, tools, accomplishments, and future directions.

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UNDERSTANDING DIFFERENCES BETWEEN CONVENTIONAL AND SAR ALTIMETRY – RESOLVING BIASES AND MORE OPPORTUNITIES

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With the launch of CryoSat in April 2010, synthetic aperture radar (SAR) altimetry became a very important tool in observing ocean surfaces due to its lower measurement noise and better spatial along-track resolution of a few hundred meters. This is achieved by sampling the received power additionally with respect to the Doppler frequency compared to low resolution mode (LRM) sampling only with respect to the range. While this enables the aforementioned improvement in the along-track resolution, the SAR altimeter is also sensitive to vertical wave particle velocities. The latter were believed to have a negligible effect, but more recent studies indicated that those have significant effects on sea state parameters retrieved from SAR altimetry signals, which are not present in CA results.

In this presentation we will give an overview about expected biases in significant wave height and sea surface height retrieved from SAR altimetry signals. Additionally, we will present how including additional sea state quantities in the parameter retrieval process can address these biases. One exciting possibility would be the direct estimation of new sea state parameters for the first, which could be used by operational agencies. We will present two approaches:

1. The look-up-table approach using ERA5 parameters to estimate biases in SSH and SWH.
2. The direct estimation of two new parameters
-a. The second order spectral wave moment M2, which can be used to compute the mean zero upcrossing wave period T02.
-b. A mean line-of-sight velocity mostly caused by vertical wave velocity/along-track wave slope correlations. This parameter can be used to estimate wind-wave direction with respect to the satellite track.

We will validate both with respect to CA and the ERA5 wave model.

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DEVELOPMENT OF A NEW UAV-BASED LIDAR ALTIMETRY SOLUTION FOR IN-SITU WAVE SPECTRUM ESTIMATION IN COSTAL AREA

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For four years now, the development of a UAV-based (Unmanned Aerial Vehicle) LiDAR altimetry system (the vorteX.io VTX-1 light altimeter) has demonstrated its capability to perform water surface height measurements with centimeter accuracy on various inland water bodies (lakes, rivers and estuaries). This unique, new type of lightweight altimeter has been developed specifically for measuring water surfaces. It is based on a LiDAR with 8 beams emitted in the near infrared uniformly distributed over an aperture of 16° perpendicular to the along-track direction of the UAV. Thus, depending on the surface roughness, 8 surface height measurements are acquired simultaneously.

The main objective of the study is the development of a new calibration/validation solution for satellite altimetry systems based on the use of LiDAR onboard UAVs to measure wave/swell spectra over the ocean. In this framework we combine LiDAR acquisitions in the open sea and inversion processing on these measurements in order to extract the sea surface state parameters. We take advantage of the UAV's deployment capabilities and the combination of LiDAR and optical measurements from the vorteX-io light altimeter to develop a new, relevant and flexible calibration solution of radar altimeters on coastal areas.

A first study has been conducted in 2022. During this study we first simulate LiDAR measurements of sea surface height based on the CNES simulator RADARSPY. Then, after defining a specific flight plan, we developed an algorithm performing the estimation of the directional wave spectrum through the sea surface height measurements acquired by the lightweight altimeter. Then a field campaign has been realized close to Saint-Jean-de-Luz (South of France) where drone flights were performed over sea above a wave buoy from the French network CANDHIS. After the data processing of the actual drone measurements, the estimated directional wave spectrum was computed and compared to the one estimated from the CANDHIS one. The results of this campaign were very promising. It has enlightened many improvements of the estimation method.

A second study has been conducted in 2023 to implement the ameliorations identified during the first project. We improved the estimation method based on the water surface height measurements and developed a post-processing to reduce the noise in the directional wave spectrum estimation. These improvements have been tested on simulations generated on the simulator RADARSPY as well. A second method based on the surface speed measurement performed by the altimeter's camera has been developed. This method combines water height and surface speed measurement to improve the estimation of the direction of propagation of the swells systems. A second field campaign close to Saint-Jean-de-Luz will be performed to test and compare the 2 methods.
We present here the final results of the two studies, starting by the work on the simulations, the two developed directional wave spectrum estimator and the drone flights over ocean to compare with the CANDHIS buoy.

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THE MEAN DYNAMIC TOPOGRAPHY MODEL DTUUH22MDT FROM SATELLITE AND IN-SITU OBSERVATIONS

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Initially, a new geodetic mean dynamic topography model DTU22MDT is derived using the new DTU21MSS mean sea surface. The DTU21MSS model has been derived by including re-tracked CRYOSAT-2 altimetry also, hence, increasing its resolution. Some issues in the Polar regions have been solved too. The geoid model was XGM2019e complete to d/o 2160.
The processing scheme used for deriving the new geodetic MDT is similar to the one used for the previous geodetic DTU MDT models. However, the filtering was re-evaluated by adjusting the quasi-gaussian filter width to optimize the fit to drifter velocities. Also, optimal filtering was introduced in the coastal areas.
Subsequently, the drifter velocities are integrated to enhance the resolution of the MDT model. Weights and constraints are introduced in the inversion and tuned to obtain a smooth model with enhanced details. A special concern is devoted to the coastal areas to optimize the extrapolation towards the coast line. The presentation will focus on the coastal zone when assessing the methodology, the data, and the final model DTUUH22MDT.

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ARCTIC AND SOUTHERN OCEAN SEA LEVEL MAPS FROM SATELLITE ALTIMETRY FROM 2011 TO 2021

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In the polar regions satellite sea level observations are limited by the sea ice. Thanks to a dedicated processing, sea level can however be estimated within fractures in the ice (sea ice leads) enabling to produce sea level maps including the ice-covered region.
Maps of sea level of the Arctic (Prandi et al., 2021) and Southern (Auger et al., 2022) ocean were produced over 2011-2021 by combining measurements of 3 satellites from 50°N/S to 88°N/S through optimal interpolation. The three satellite missions (Sentinel-3A, SARAL/AltiKa and Cryosat-2) are processed using the same standards and are in great agreement. The products are provided on the Aviso Regional Products portal and serve as demonstration products for the future generation of operational CMEMS-SLTAC products.
The sea level maps are validated against hourly Gloss/Clivar tide gauge and bottom pressure recorders at the north pole and in the Beaufort Sea (BGEP project) showing great correlation at monthly timescale. At longer timescale, polar sea level trends are also estimated over the 10 years period.
Future improvements concerning the products may be done such as discarding the melt ponds observations in the summer periods and the calibration of the polar products with global ones. The products are to be extended backwards using ENVISAT altimeter (prototype for the Southern Ocean of Mosneron Dupin, 2024 EGU24-10622).

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A COMPARISON BETWEEN KARIN AND BUOY SSH ESTIMATES DURING THE SWOT CAL/VAL PHASE

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The SWOT satellite was launched in December 2022 and placed in a 1-day repeat orbit in January 2023. After completing its commissioning phase, it entered a calibration phase which lasted from March 30, 2023 to July 10, 2023. To support the calibration phase, a set of seven GNSS buoys were deployed at a crossover location off the coast of Monterey, California and they continuously took 1-Hz position measurements throughout the period. This configuration allowed for twice-daily comparisons between the sea surface heights from each buoy and SWOT's main instrument, KaRIn.

We present results comparing the sea surface heights estimated by the seven buoys against those estimated by the KaRIn instrument. We consider the effects of buoy sea-state bias, line tension, and multi-GNSS kinematic position estimation as methods for mitigating errors between the different systems.

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TOOLBOX FOR NGGM/MAGIC

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The NGGM/MAGIC missions are envisaged to advance the applications of satellite based gravity field information for tracking changes in the mass distribution and transport in ground water storages, ice sheets and oceans. The GOCE User Toolbox GUT was originally developed for the utilisation and analysis of GOCE products to support applications in Geodesy, Oceanography and Solid Earth Physics. GUT consists of a series of advanced computer routines that carry out the required computations without requiring expert knowledge of geodesy. Hence, with its advanced computer routines for handling the gravity field information rigorously, GUT may support the MAGIC mission in reaching its goals.

Focusing on NGGM/MAGIC mission goals on unprecedented recovery of ocean bottom pressures, a more flexible processing of the gravity field information may become essential. Furthermore, an integration of ocean bottom pressure changes with changes in the geostrophic surface currents may advance the analyses further. GUT facilitates such a flexible processing and, in addition, contains tools for the computation of the dynamic ocean topography and the associated geostrophic surface currents.

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INTEGRATING GNSS-IR INTO THE GREENLAND TIDE GAUGE NETWORK – PERSPECTIVES AND FIRST RESULTS

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During 2020 DTU was granted money for the Greenland Integrated Observing system (GIOS) where DTU space will establish and updating the existing sea level measurement network in Greenland. The establishment of the new sea level recorders is tasked with the renovation of the existing 4 aging tide gauges: Nuuk (NUUK), Qaqortoq (QAQO), Ittoqqortoormiit (SCOR) and Pituffik Space Base (THUL). Logistic considerations and presence of seasonal sea ice puts strong limitation on the sea level network in Greenland.

In 2022 a new separate pipe and pressure sea level recorder (NUK1) and a GNSS-IR station (NUK2) were established to run in parallel with the existing Anderaa pressure recorder in Nuuk. The three systems will operate for at least one year to ensure stability during the transition phase. For the new pressure sensor, we selected the Valeport MIDAS CTD+ and for the GNSS-IR measurements we selected the Tallysman VP6150

VeraPhase Full GNSS Antenna and Septentrio PolaRx5 GNSS receiver. Also, during 2022 the Qaqortoq tide gauge (QAQO) in southern Greenland was updated from the Anderaa to the Velport MIDAS CTD+ pressure and a new GNSS-IR site (QAQO) was installed near the existing sea level pipe with the same type of antenna and receiver used in Nuuk.

In 2023 a new pipe with a Valeport MIDAS CTD+ sensor was established in Upernavik and the existing tide gauge in Ittoqqortoormiit was upgraded to a Valeport MIDAS CTD+. On the east coast where conventional gauges are close to impossible because of the lack of suitable infrastructure, we installed a standard GNSS-IR system at Danmarkshavn. The final steps in the completion of the Greeland sea level network will be carried out in 2024 with one or two additional GNSS-IR station or pressure sea level recorder at Station Nord or Tasillaq. We present the new Greenland sea level network and the first evaluation of the one year comparison of conventional and GNSS-IR tide gauges observations in Nuuk and Qaqortoq.

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LEVERAGING MULTI-SENSOR SYNERGY FOR ENHANCED UNDERSTANDING OF SWOT DATA

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SWOT has been delivering unprecedentedly high-resolution Sea Surface Height (SSH) data since its launch, providing 2D data across the swath. In addition to offering detailed 2D fields of upper ocean dynamics at resolutions as fine as 250 m, SWOT data has unveiled observations of internal tides, long swells, sea ice, and various other intriguing phenomena. Understanding and validating this data necessitates comparisons with high-resolution 2D ocean observations. Thanks to the advent of new satellites and sensors, a plethora of physical variables can now be observed across different scales. For instance, the Sentinel 1-2-3-6 program encompasses various sensors such as Synthetic Aperture Radar (SAR), Ocean Color, Brightness Temperature, Wave scatterometer and altimeter, each with its own long revisit time but rapid revisit frequency from a constellation perspective. Additionally, geostationary sensors like SEVIRI facilitate hourly retrieval of Infra Red Sea Surface Temperature (SST), significantly enhancing coverage in cloudy regions. These variables contain vital information regarding upper ocean dynamics, even if indirectly.
Managing this vast and diverse dataset and comparing observations of different types with SWOT data can be tedious. Within the OVL-NG project, two open source tools have been developed to streamline the collocation and analysis of such datasets: the Ocean Virtual Laboratory online portal (https://ovl.oceandatalab.com) and the standalone version SEAscope (https://seascope.oceandatalab.com), enabling visualization and analysis of heterogeneous satellite, model and in-situ observations collocated both in time and space.
In this study, we will demonstrate the intercomparison of SWOT data with other sensors such asinstrument from the Sentinels using these tools. First, we will showcase the reconstruction of very fine eddies in SWOT Level 3 2 km products and challenge it against the GlobCurrent CMEMS lower resolution mapped SSH and current, alongside the high-resolution fronts and eddies revealed by Sentinel-3 OLCI chlorophyll-a and SLSTR SST Level 2 products. Then, SSH from SWOT 250 m Level 2, filtered to remove large scales, will be compared with Sentinel-3 True Color derived from Level 1 OLCI data to reveal the signature of internal waves, and with SAR Sentinel-1 data to examine swells. Lastly, we will demonstrate SWOT's potential to detect ice floes and micro tsunamis (glaciogenic ocean-wave events) by examining roughness reconstructed from SWOT Level 2 250 m and SAR Sentinel-1 Level 1 data.

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GDR-G ALTIMETRY STANDARDS

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With a constellation of 11 flying altimeters, and 30 years of satellite altimetry data, the operating agencies continue improving data quality through new algorithms and enhanced auxiliary information. There is a clear need in the ocean user community that all operating mission achieve a certain degree of harmony by means of defining common standards. To this goal CNES, ESA and EUMETSAT are working together supported by NASA and NOAA to define a set of common standards. This presentation will present this initiative, and describe the new standards GDR-G improvements to the user community. These standards will be already operational by the end of this year in Sentinel-6 and Sentinel-3, and later in time for Jason-3 and CryoSat-2.

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SEA SURFACE HEIGHT OBSERVATION EXPERIMENT BY UAV SYNCHRONIZED WITH SWOT

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Typical processes such as submesoscale and small-scale dynamic processes, which are prevalent in the upper layer ocean, have a significant impact on marine ecology. To address the fine-scale observation requirements for submesoscale phenomena, we designed an airborne remote sensing system (ARSS) for unmanned aerial vehicle (UAV) platforms, equipped with a Ku/Ka dual-frequency radar altimeter. To evaluate the observational effectiveness of ARSS, we conducted a maritime altitude observation experiment in April 2023 using UAVs in coordination with the Surface Water and Ocean Topography (SWOT) during its calibration/validation phase on a one-day cycle orbit. During the experiment, we proposed an S-shaped regional continuous observation strategy under the SWOT swath to ensure the reliability and representativeness of the observational results. Considering the susceptibility of the UAV observation platform to mechanical and meteorological influences, we introduced an adaptive feature extraction-based deep learning data inversion method for the airborne altimeter. This method decomposes the variability of normal sea surface height signals through multimodal decomposition and extracts data matching the airborne altimeter, achieving precise sea surface height inversion. After eliminating the influences of sea surface tides and UAV platform noise, the sea level anomaly (SLA) data obtained showed a root mean square error (RMSE) of 1.12 cm when compared with SWOT data. This result indicates that ARSS has the capability to capture sea surface changes at submesoscale or smaller scales, laying the foundation for subsequent collaborative observations with multi-source satellites.

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ESTIMATION OF THE LENGTH OF DAY (LOD) FROM DORIS OBSERVATIONS

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We estimated the true Length of Day (LOD) from DORIS observations. The DORIS RINEX data has been processed by the DORIS development version of the Bernese GPS Software 5.2. We performed single satellite and multisatellite (Sentinel-6A, Sentinel-3A, Sentinel-3B, Jason-3, Jason-2, HY-2C, HY-2D, HY-2C, SARAL, and Cryosat-2), and pre-eliminated solutions. The DORIS data has been processed separately for each satellite on a daily arc basis. The troposphere, frequency offset, and orbit parameters were pre-eliminated from the normal equation systems and the finalized matrices were combined weekly. Hence, individual satellite solutions as well as multi-satellite combined solutions were created. The LOD estimates have been obtained from a not-transformed free network solution.

In LOD estimation, we experimented with 4 different solution versions (called L1-L4) for the years 2016-2023. We performed solutions with different settings, in particular with different handling of cross-track once per revolution harmonic parameters (adjusted with different constraints for L2 (5×10^(-9) m/sec^2), L3 (5×10^(-8) m/sec^2), L4 (5×10^(-6) m/sec^2), or not adjusted for L1), since the amplitude of sine term correlates with LOD. For a comparison of our results, we used the IERS 20 C04 model as a reference. With recent data, we have reached a mean difference of 32 µsec with an RMS of 88 µsec for the L1 solution. Our results indicate that only solution with stronger constraints provides accurate LOD estimation.

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SENTINEL-3 MARINE PRODUCTS - STATUS AND EVOLUTIONS

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The Sentinel-3 (S3) mission plays a crucial role as part of the Copernicus space segment, S3 contributes significantly to environmental and climate monitoring. Since its launch in 2016, the S3 mission has been a continuous ‘health check’ for our planet. The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), is responsible, among others activities, for processing the Sentinel-3 science data related to the marine environment, the focus of this work.

This paper aims at presenting the current status of the S3 altimetry marine products, giving a high-level insight of the roadmap for the S3 altimetry marine products. The stability of the dataset has been greatly improved with BC005, allowing for the climate usage of Sentinel-3 marine altimetry data, this was followed by a full mission reprocessing, that provided the users with a consistent dataset since beginning of mission to the operational data being produced now.
We will highlight the next major processing baseline where the Polar Ocean will be improved with evolutions at both level 1 and level 2 and at the same time to harmonize the altimetry standards and processing methods in a multi-mission approach.

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TOWARDS THE NEXT COMBINATION MEAN DYNAMIC TOPOGRAPHY MODEL DTUUH25MDT

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When deriving the DTUUH22MDT combination model it was found that the differences between the combination model and the geodetic model are within 10 cm. Hence, the effects of integrating the drifter

velocities on the MDT are of that order of magnitude. Also, the scales appear to be shorter than a few hundreds of kilometers agreeing well with the resolution of the geodetic model. For comparison the CNES-CLS18 showed larger differences and at longer scales. A recent comparison with the CNES-CLS22 model show the same features as the 18 model. The differences between the DTUUH and the CNES-CLS models may be caused by differences in the choice of reference models, processing of drifter data, methodologies for integrating the data, etc.

To assess the differences between the combination models this presentation focus on clarifying issues with the correction of the buoy data for wind driven flows. Different strategies for deriving empirical correlations are tested and regional averages are compared with velocities derived from the geodetic MDT. Furthermore, experiments of integrating the drifter velocities with the geodetic model are carried out with different weighting schemes to assess how much the combination solution is constrained to the geodetic model and how regional biases in the drifter velocities are affecting the solution.

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CO-LOCATED SPACE GEODETIC TECHNIQUES OBSERVATORY IN INDIA: PROGRESS TOWARD INSTALLATION OF THE IDS SCIENTIFIC STATION

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Space geodetic techniques, i.e., Global Navigation Satellite System (GNSS), Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) enable research across various Earth science domains, including monitoring plate tectonic movements, earth rotation parameters, post-glacial rebounds, snow and ice melting, precise orbit determination, sea level variations etc. These techniques, preferably co-located, are crucial for accurately realising the International Terrestrial Reference Frame (ITRF), which underpins various geospatial applications such as navigation, precision surveying, cartography, and cadastral mapping.
This presentation aims to provide an introduction to the proposed first co-located space geodetic technique observatory in India (Project Saptarshi) to be established at the Indian Institute of Technology Kanpur (IITK), which will be managed by the National Centre for Geodesy (NCG) established by the Department of Science & Technology, Govt. of India. The already established facilities with corresponding data availability and future plans towards completing this co-located site will also be discussed. However, the primary focus will be to present the current status and progress towards establishing the first IDS scientific station in India as approved by the IDS. It is envisaged that the IDS station at NCG-IITK will be installed and commissioned by the end of 2024.

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SENTINEL-3 STM MPC: PERFORMANCE OF THE S3A AND S3B SURFACE TOPOGRAPHY MISSION OVER SEA-ICE

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The main objective of the Sentinel-3 constellation over sea-ice is to provide accurate measurements of the polar sea surface height, the sea-ice radar freeboard, and its thickness. Compared to previous missions embarking conventional pulse limited altimeters, Sentinel-3 A and B are measuring the surface topography with an enhanced spatial resolution, thanks to the on-board SAR Radar ALtimeter (SRAL), exploiting the delay-Doppler capabilities.

To further improve the performances of the Sentinel-3 Altimetry LAND products, ESA has developed dedicated and specialized delay-Doppler and Level-2 processing chains over the different type of surfaces (hydrological surfaces, Land Ice and Sea Ice). Over sea-ice the T-IPF (Instrument Processing Facility) includes dedicated algorithms, in particular the hamming window and the zero-padding processing that allows significant improvement: thanks to the hamming window, the waveforms measured over specular surfaces are cleaned from spurious energy spread by the azimuth impulse response. The zero-padding provides a better sampling of the radar waveforms, notably valuable in case of specular energy returns that are often encountered in sea-ice regions. In 2024, a new sea-ice type variable has been implemented in the IPF, coming from OSI-SAF OSI-403d products.

The full mission reprocessing has been performed in 2023. The objective of this presentation is to show the progress and even the excellent performances of the sea-ice thematic products with respect to the former LAND products, for the Arctic and the Antarctic Sea ice. Performances of the T-IPF over the whole lifespan of the two missions S3A and S3 will be assessed, with a strong focus on the radar freeboard. An exhaustive inter-comparison with CryoSat-2 will also be performed (time series, gridded maps), showing that the two missions provide now similar performances in the estimated freeboard. Comparisons to external in-situ datasets such as moorings will be also presented. Finally, the future developments considered to further improve the quality of this thematic chain will be proposed.

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COHERENT MODES OF GLOBAL COASTAL SEA LEVEL VARIABILITY

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Sea level dynamics in the coastal zone can differ significantly from that in the open ocean. The presence of the continental slope, shallow waters and the coastlines give rise to a variety of processes that mediate the response of coastal sea level to local and remote forcing and can produce coherent spatiotemporal sea level variations in the alongshore direction. Yet where and how coastal sea levels exhibit variations that emerge as persistent and recurrent patterns along the world's coastlines, remains poorly understood. Here, we use a Bayesian Mixture Model to identify large-scale patterns of coherent modes of monthly coastal sea level variations from coastal altimetry and tide gauge data.

We determine nine clusters of coherent sea level variability that explain a majority of the monthly coastal sea level variance measured by tide gauges (1993-2020). The analysis of along track altimetry data enables us to detect several additional clusters in ungauged regions such as the Indian Ocean or around the South Atlantic basin, which have so far been poorly described. While some clusters (e.g., at the eastern boundary of the Pacific, the Western tropical Pacific, and the marginal and semi-enclosed seas) are highly correlated with climate modes such as the El Niño-Southern Oscillation, the North Atlantic Oscillation, or the Arctic Oscillation, other clusters, especially along the western boundaries, share very little variability with the considered climate modes. Therefore, this analysis supports the hypothesis that in many regions coastal sea level variability manifests distinctly from the adjacent deep ocean.

The existence of the coherent modes of coastal sea level variability suggests that much of the variability observed by tide gauges or altimetry can be attributed to a set of common drivers. Knowledge of these coherent regions thus motivates and enables further investigations on the impacts of local and remote forcing, the differences between eastern and western boundaries, marginal and semi-enclosed seas, and the role of coastal dynamics and characteristics.

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EVALUATING WEIGHTING STRATEGIES IN DORIS MEASUREMENT PROCESSING FOR GEODETIC APPLICATIONS

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In the domain of geodetic measurement processing, accurately weighting observations is crucial for deriving precise and dependable geodetic estimates. This study evaluates four distinct weighting strategies for Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) measurements. These strategies include weighting based on the sine squared of elevation, the sine of elevation, the methodology developed by the French Space Geodesy Research Group (Groupe de Recherche en Géodésie Spatiale, GRGS), and the recommendations by the Precise Orbit Determination (POD) group.

Our approach involves analyzing DORIS data collected over the recent three-year span (2021-2023) utilizing the GipsyX software, in alignment with the activities of the IGN-IPGP Analysis Center, recognized as an Associate Analysis Center by the International DORIS Service (IDS). Specifically, the data processed in this study originate from Cryosat-2, Jason-3, Sentinel 3A & 3B, Sentinel 6A, and SARAL. This selection allows for the satellite-based measurement processing to facilitate the development of both mono-satellite and multi-satellite station solutions.

The objective of this research is to identify the most effective weighting strategy by assessing its impact on the residuals of observations, the coordinates of DORIS beacons, Earth Orientation Parameters (EOPs), and the stability of reference frame parameters. Our comparative analysis highlights the critical importance of selecting an appropriate weighting method to significantly enhance the accuracy of geodetic estimates. The performance of each strategy is evaluated based on its ability to minimize observational residuals and improve the precision and stability of station coordinates and reference frame parameters.

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30 YEARS OF SEA ICE THICKNESS AND VOLUME OVER ARCTIC AND ANTARCTIC FROM SATELLITE ALTIMETRY

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Sea ice is both a key witness and driver of climate change. While sea ice extent and area is well described with observations during the last four decades, sea ice thickness and volumes changes remain poorly known. However, ice thickness is a mandatory variable to better understand the past, present and future changes of sea ice, and to better quantify its impacts on oceanic circulations.

Despite improvements in sea ice thickness estimation from altimetry during the past few years thanks to SAR and laser altimetry, former radar altimetry missions such as Envisat and especially ERS-1 and ERS-2 have remained under exploited so far.

One of the main difficulties is that the footprint of these old Low Resolution Mode altimeters is too large in relation to the disparity of the sea-ice. To overcome this difficulty, we developed a machine learning technique to successively calibrate LRM measurements on CryoSat-2 SAR measurements, taking advantage of their common flight period.

A second difficulty arises from the problem of blurring that impacts ERS1 and ERS2. This problem is due to tracker-board instabilities which are exacerbated on sea-ice, producing blurred waveforms. A correction dependent on tracker-board dynamics reduces this effect before calibration.

We are now able to extend the time series from ERS-1 for both Arctic and Antarctic polar oceans, allowing to provide a 30 years-long sea ice thickness and volume time series. Estimates are combined with uncertainties derived from a Monte Carlo methodology.

We will present this methodology and the resulting time series, which will be freely available. We will also show validation results with field measurements, as well as initial comparisons with solutions derived from models.

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FIRST SEA ICE TOPOGRAPHY MEASUREMENTS USING SWOT

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Sea ice plays a major role in climate, these changes are of great concern to scientists, who are seeking to forecast its behavior and understand their causes and effects. The most common techniques employed to monitor sea ice rely on 2D space imagery in a wide range of frequencies and techniques (optical, thermal, radiometric, SAR imagery). However, we now know that the evolution of sea ice over the course of days or seasons is governed more by its thickness than by its extend. Thickness is therefore an essential parameter for determining the condition of the ice and its ability to withstand particular climatic events (wind, heat waves) or oceanic events (waves, swells, upwelling of warm waters, etc.). Thickness also provides access to volume and mass variations, quantifying freshwater inflows and the effects of stratification on ocean circulation.

The main technique for measuring sea ice thickness is based on nadir altimeters. The result is a series of point measurements of the sea ice taken vertically along the satellite track. This loose sampling between tracks means that we have to wait about a month for data to provide a sufficiently dense spatial representation to be exploitable. Relative to the current sparse observations, SWOT's scan width (120km) offers enormous potential for analyzing sea ice conditions and dynamics on much shorter time scales and with much higher coverage and density.

This mission, whose primary objective is continental hydrology, was given little consideration by the sea ice scientific community, as we felt that the viewing angle (+- 2.7°) would not allow us to obtain feedback on water surfaces in highly specular sea ice fractures. Without this water reference, ice freeboard and thickness cannot be measured. But initial tests carried out by CNES on atypical surfaces, including sea ice, have revealed quality measurements not only on ice, but also in leads, albeit less systematically on these watery.

In addition to these initial observations, we have been able to measure the freeboard of the sea-ice using SWOT data, providing the first topography of the sea-ice surface over swaths 120km wide and several hundred kilometers long. The aim of this presentation is to show the first results obtained, together with comparisons with nadir altimetry measurements.

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ESTIMATING OCEAN CURRENTS FROM JOINT RECONSTRUCTION OF ABSOLUTE DYNAMIC TOPOGRAPHY AND SEA SURFACE TEMPERATURE THROUGH PHYSICS INFORMED DEEP LEARNING ALGORITHMS

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Our study focuses on the improvement of Absolute Dynamic Topography (ADT) and Sea Surface Temperature (SST) mapping from satellite observations. Retrieving consistent high resolution ADT and SST information from space is challenging, due to instrument limitations, sampling constraints and degradations introduced by the interpolation algorithms used to obtain gap-free (L4) analyses. To address these issues, we developed and tested different deep learning methodologies, specifically Convolutional Neural Networks (CNNs) that were originally proposed for single-image super-resolution.
Building upon recent findings, we conduct an Observing System Simulation Experiments (OSSE) relying on Copernicus numerical model outputs and we present a strategy for further refinements.
Previous OSSEs combined low-resolution L4 satellite-equivalent ADTs with high-resolution "perfectly known" SSTs to derive high-resolution sea surface dynamical

features. Here, we introduce realistic SST L4 processing errors and modify the network to concurrently predict high-resolution SST and ADT from synthetic, satellite-equivalent L4 products. This modification allows us to evaluate the potential enhancement in the ADT and SST mapping while integrating dynamical constraints through tailored, physics-informed loss functions. The neural networks are thus trained using OSSE data and subsequently applied to the Copernicus Marine Service satellite-derived ADTs and SSTs, with the primary goal of reconstructing super resolved ADTs and geostrophic currents. A ten years long time series of super resolved geostrophic currents (2008-2019) is thus presented and validated against in-situ measured currents from drogued drifting buoys.
The study suggests that CNNs are beneficial for improving standard Altimetry mapping: they generally sharpen the ADT gradients with consequent correction of the surface currents direction and intensities with respect to the altimeter-derived products.
Our investigation is focused on the Mediterranean Sea, a quite challenging region characterized by Rossby deformation radii as small as 10 km.

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CHARACTERISTICS AND IMPACTS OF MEASUREMENT UNCERTAINTY IN THE LONG-TERM SEA STATE RECORD FROM SATELLITE OBSERVATIONS, FROM COASTAL TO GLOBAL SCALES

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The satellite record of sea sate observations provides a growing and ever more important resource for the study of long term variability, at scales ranging from a few kilometres from shore to near-complete coverage of the global oceans. Uncertainty and error in sea state observations are introduced from a range of sources and affect measurements on different spatial and temporal scales. However, in most sea state datasets, whether acquired from in situ, remote sensing or otherwise, detailed uncertainty information is unavailable. Furthermore, effects of diverse uncertainties propagated through downstream analysis, such as the study of long term variability, remain largely unclear.

For altimeter measurements, at the kilometre scale, along-track variability can substantially affect our ability to resolve steep sea state gradients relevant to coastal applications. However, at larger scales, bias may be introduced through calibration methodology or erroneous reference data. For example, heavily-used reference data, such as that from moored buoys, is known to be problematic in some cases. Inter-calibration of multi-mission datasets may also introduce instability into the record. We are therefore well motivated to evaluate these uncertainties in detail, in order to advance our understanding of sea state variability from observations, and associated limitations. Recent innovations in sea state observations from altimeters have attempted to address some of these issues. For example, datasets produced by the ESA Sea State CCI project include a de-noising technique that leads to improved precision for 1 Hz along-track data. Furthermore, the ESA FDR4ALT project applied an adaptive re-tracking method to ERS1/2 and Envisat altimetry, leading to the development of explicit uncertainty measures for wave height for those missions. These advances reveal previously unseen details of uncertainties at all measurement scales.

In this work, we initially review current knowledge and representation of uncertainties in important satellite and in situ sea state datasets. Then, by exploiting recent innovative satellite and in situ data, we go on to show how different types of uncertainties affect evaluation of long term wave height variability and trends at different scales. In particular, near the coast, we show how uncertainty in satellite observations affects the evaluation of sea state gradients, important to coastal applications.

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GOP ANALYSIS CENTER: DORIS DATA ANALYSIS STRATEGY AND INNOVATIONS

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The Geodesy Observatory Pecný (GOP) analysis center is one of the International DORIS Service (IDS) analysis centers. GOP has fully contributed to the IDS ITRF2020 combination and its recent extension. GOP is also involved in IDS operational solutions. All the DORIS/RINEX data from recent satellites (multi-satellite (Sentinel-6A, Sentinel-3A, Sentinel-3B, Jason-3, HY-2C, HY-2D, SARAL and SWOT) are processed using the DORIS development version of Bernese GPS software 5.2. The Precise orbit determination solutions are based on daily arc processing. The geodetic free-network single- and multi-satellites solutions are created on weekly basis in two steps, when daily normal equation single-satellite matrices are combined.
The impact of the SWOT contribution has been analyzed together with the satellite sensitivity to the South Atlantic anomaly. For Sentinel-6A, different satellite macromodels and their impact in the context of Precise orbit determination, WRMS, Earth pole estimation and station positioning were compared. Other experiments have been devoted to the impact of different time-variable gravity field models application.

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EXPLOITING THE SENTINEL-6MF FULLY FOCUSED SAR WAVEFORMS OVER INLAND WATERS: TOWARD A NEW PROCESSING PROTOTYPE FOR RIVERS.

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In the last decades, monitoring inland water resources (rivers, lakes, reservoirs) using space radar altimetry has become a major challenge as pressure on water resource increases in a context of climate change. In particular, many efforts have been made to improve water level retrieval over rivers usually by exploiting conventional and delay/doppler altimetry signals at the intersection of the river and the satellite ground track, called virtual station (VS). Indeed, the retracking of water height becomes quite challenging over inland waters bodies due to their heterogeneous surface characteristics compared to the ocean. With Sentinel-6MF and its unique radar altimeter operating in Open-Burst mode, it is now possible to exploit the full capabilities of the Fully Focused SAR (FFSAR) processing providing very high azimuth resolution in comparison to the conventional pulse-limited radar and delay/Doppler altimetry [1]. This improved resolution appears to be very useful in differentiating small targets along the satellite track with quite good Signal-to-noise ratio, even in the case of off-nadir targets.

By looking at neighboring waveforms and analyzing 2D radar scenes (the so-called radargram), it is feasible to discern river features emerging as bright curves from the darker surroundings and local ponds. Considering image segmentation and registration techniques, this work aims to (i) locate and isolate the signal coming from the river in the radargrams, (ii) to retrack the 1D waveforms based on a priori location obtained in (i) and retrieve water surface elevation (WSE) profile as the satellite flies over the river, up to a certain cross-track distance of the river as the signal-to-noise ratio decreases with this distance. Besides, this can be done by considering an appropriate slant range correction depending on the off-nadir-looking geometry. (iii) Finally, the definition of VS could be reviewed since WSE profile can be used to densify the number of VS, mainly depending on the river geomorphology (slopes, meanders, steps).

Since the surface roughness and the acquisition geometry have important impact on the waveform shape, we also analyzed the echo modelling applied in (ii) by comparing the use of a sinc square function (specular backscattering) to a physically based approach, inspired from current studies overs lakes [2]. Preliminary results and performances assessment will be presented over French rivers for which a contour mask and in-situ observations are available.

[1] A. Egido and W. H. F. Smith, "Fully Focused SAR Altimetry: Theory and Applications," in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 1, pp. 392-406, Jan. 2017, doi: 10.1109/TGRS.2016.2607122.

[2] Boy, F. et al, 2021. Improving Sentinel-3 SAR mode processing over lake using numerical simulations. IEEE Transactions on Geoscience and Remote Sensing, 60, pp.1-18.

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EXTRACTING SURFACE SIGNATURES OF INTERNAL TIDES FROM SWOT KARIN AND JPSS VIIRS OBSERVATIONS OVER THE SULU AND CELEBES SEAS

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SWOT, as the latest altimetry mission, provides traditional nadir sea surface height (SSH) measurements from its Poseidon-3C altimeter and swath SSH measurements from its KaRIn radar interferometer. The 2D swath SSH measurement, available on 2km and 250 m resolution, covering a distance about 60 km from both sides of nadir, provides a unique opportunity for examining small scale ocean processes in a synoptic picture, such as internal tidal soliton waves, fine scale fronts, eddies etc. In this study, we examine the SSH imagery from KaRIn measurements, mainly focusing on Philippine Archipelago region, including the Sulu and Celebes Seas during science orbit phase and the north of Molucca Sea during Cal/Val orbit phase. The Sulu and the Celebes Seas, on the pathway of Indonesia through flow connecting Pacific Ocean and Indian Ocean, are ideal places to study internal tides caused by the surrounding shallow straits connecting the deep interior and outside ocean basins.

KaRIn L2 SSH measurements show clear surface internal tide signatures in this area. The spatial distribution and amplitude of the internal tides are compared with those derived from the High Resolution Empirical Tides (HRET) model. The SSH anomaly (SSHA) errors due to the internal tidal soliton waves are quantified with KaRIn derived SSH fine resolution spatial structure and compared with current error estimation using internal tidal models.

The internal tide induced soliton waves are often spotted from true color imagery captured under clear-sky, Sun glint, or Moon glint condition. The internal tide spatial signatures are extracted from images captured by VIIRS on JPSS satellites and those by KaRIn. The internal tide spatial structure is compared with KaRIn SSH observations and HRET models. Internal tide packet propagation speed is characterized through inter-comparison among VIIRS and KaRIn images. Preliminary results show clear fortnightly variations of internal waves and spatial differences in propagating speed. During the Cal/Val phase, to the north of Molucca Sea, the internal wave packets are clearly seen propagating northward during the spring tide, but are hardly detectable during the neap tide. Coarse resolution (5km) regional ocean modeling results from a previous study over this region show seasonal variations

in internal tide energy flux. The seasonal variation of the spatial structure and propagation speed from the satellite images are checked and compared against the model. Correlations between surface signatures with seasonal stratification are also examined.
Accurately describing the high-resolution spatial structure and the propagation of internal tides on the ocean surface will help to further reduce tidal alias errors to global and regional sea level change measurements. It will facilitate the understanding of internal tide generation and breaking mechanisms and their interactions with mesoscale eddies and ocean circulation, and hence help the understanding of deep ocean mixing processes that contribute to global thermohaline circulation and tidal energy dissipation.
Disclaimer: the scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect those of NOAA or the Department of Commerce.

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CATALINA ISLAND DUAL BAND TRANSPONDER

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In support of the long-term monitoring of the Sentinel-6 mission, JPL has developed a dual band transponder. It operates simultaneously in Ku and C bands. It allows a full calibration of range and power in both altimeter channels as well as the system time-tag bias. The transponder was first operated with the Sentinel-6 and Jason-3 missions. Its support has now been extended to the Sentinel-3 and SWOT missions allowing inter-mission calibrations. We present the transponder instrument and provide calibration results for the Sentinel-6 and SWOT missions.

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SENTINEL-6 HYDROLOGY MEASUREMENTS DEMONSTRATION OVER THE GARONNE

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The Sentinel-6 mission altimeter has already proved to be a very capable for hydrology especially when combined with the Fully Focus SAR technic (FFSAR) 1 processing technique. It makes possible to reach resolutions as narrow as about 2m which can be beneficial to altimetry over hydrological targets.
We present the latest results obtained in collaboration with CNES, using FFSAR waveforms to derive the height over the Garonne River.

1 Fully Focused SAR Altimetry: Theory and Applications. January 2017.IEEE Transactions on Geoscience and Remote Sensing PP(99):1-15
DOI:10.1109/TGRS.2016.2607122

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TRENDS AND ACCELERATION OF SEA-LEVEL CHANGES FROM GGOS OBSERVATIONS WITH PCA/ICA NOISE REDUCTION ALGORITHM

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Sea-level change is a significant consequence of climate change, primarily caused by melting of ice sheets and glaciers, and expansion of seawater. This study quantifies the global sea-level change using 200 tide gauges (TGs), co-located at 123 GNSS and satellite altimetry data from the Global Geodetic Observing System.We obtain at the TGs, linear trends between -10.00±0.46 and 9.26±0.62 mm/yr. The vertical land motion (VLM) estimated from GNSS time series at the TGs ranges from -7.42±0.24 to 9.42±0.02 mm/yr. After correcting the relative sea level for the VLM, we produce absolute sea-level (ASL) rise and obtain values from -1.59 to 6.85 mm/yr, with a mean value of -2.34±1.42 mm/yr, where the uncertainty represents the spread between the trend values. In addition, we demonstrate that the influence of different stochastic noise models on the estimated trend is small (less than 0.05 mm/yr), but that the effect on the uncertainty is larger (up to 0.16 mm/yr). Secondly, we analyze the satellite altimetry derived ASL time series covering the period 1993 to 2020 at the same 200 locations of the TGs. We obtain a mean ASL trend and acceleration of 2.76±0.97 mm/yr, 0.17±0.27 mm/yr2. Finally, we perform a noise reduction analysis with PCA/ICA on the TG and SSH time series. The results show that PCA/ICA preserving the trend of the original TG and SSH time series, while the trends and acceleration uncertainty’s accuracy improve after PCA denoising.

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EVALUATING ALTIMETER PRODUCTS FOR THE COMPUTATION OF CROSS-SHORE GEOSTROPHIC VELOCITIES AGAINST IN-SITU DATA

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Much of the lateral exchange between the near-coastal and open ocean is believed to be mediated by processes that are in geostrophic balance to leading order. Many of these processes, however, are not well resolved by existing altimetric products due to a combination of ageostrophic phenomena, instrument noise and the methodologies used to process and grid the data.

Recent work with shipboard ADCP data has shown that current variability at scales less than 100 km is predominantly divergent and ageostrophic, suggesting that the geostrophic signal attenuates rapidly with wavenumber and is overwhelmed by the signal from internal waves. We seek to determine if it is possible to recover more of the geostrophic signal from altimetry data at scales just below 100-km wavelength and the feasibility of computing lateral fluxes of mass and heat. We evaluate geostrophic velocities calculated from sea surface height (SSH) derived from along-track altimeter products with dedicated coastal retracking and from the recent surface water and ocean topography SWOT mission against a suite of in situ data and measurements from land-based high frequency radar (HFR) systems. Emphasis is placed on ground tracks for conventional and SAR altimeters that are roughly parallel to the coast of central California. Our analysis uses an iterative approach. A Helmholtz and wave-vortex decomposition is applied to HFR data to better isolate the geostrophic component and to map it onto the altimeter tracks. The difference between the HFR-derived geostrophic current from that directly estimated from SSH is assumed to be caused by altimetric measurement noise. Filters are sought that minimize this noise using a number of algorithms from wavelet transform to machine learning techniques, including recurrent neural networks. The statistics of the geostrophic currents obtained from these filter applications are compared with those from a control calculation using a fixed transition scale obtained from past analysis of shipboard ADCP data. All results are then compared against spectra of the vortical component derived from shipboard ADCP data. The statistics and spectral characteristics of the noise of the analysis are also considered and compared against models of internal wave variability, as we expect that it will dominate scales of order 10-km wavelength. A third independent check is made using SWOT 1-day repeat-orbit data and HFR in a combined analysis to isolate and map the vortical and internal wave components to compare with conventional and SAR altimeter results. Finally, the California coast results are contrasted with those from the tropical eastern Pacific, a region dominated by internal waves.

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AUSTRALIA'S REGIONAL SEAS AND HOW WE MONITOR THEM

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Australia is a marine nation: we all live near the sea. We have a vast marine territory that is home to wonders like the Great Barrier Reef. Recognizing the importance of ocean information, Australia created its Integrated Marine Observing System and Bluelink, our global ocean forecasting system. But these systems can not do their jobs without the wealth of information available to us from the Global Ocean Observing System. One of the biggest step changes of the GOOS occurred just recently: SWOT. In this talk we step through how we gained confidence in SWOT by comparing it with other data, then how we went about incorporating it in our analysis and forecasting systems. The excitement of seeing how SWOT estimates of surface currents align beautifully with single-pass SST images recalls the excitement of seeing how combining Topex/Poseidon with ERS gave us the first maps of mesoscale ocean topography. Our first attempt at assimilating SWOT data into an ocean model was much more successful than we had dared to dream. We thank the SWOT project team for making this all possible, and look forward to sharing examples of the benefits to science and society that they have made possible.

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SUBMESOSCALE-TO-MESOSCALE VARIABILITY IN THE CALIFORNIA CURRENT SYSTEM: FINDINGS FROM SWOT ASSIMILATION

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The Surface Water and Ocean Topography (SWOT) satellite provides unprecedented high-resolution measurements of sea surface height (SSH) along satellite swaths, providing a new expansion of altimetric capabilities and a means to assess submesoscale-to-mesoscale SSH variability. To fill the spatiotemporal gaps between SWOT measurements, for the California Current System, we have developed a high-resolution regional model that expands on the assimilation of nadir altimetry, enabling SWOT data assimilation through the 4D-Var (adjoint-based) method. The assimilation machinery has been applied to SWOT data from the calibration/validation period in April--July 2023, which features a one-day repeat time scale. Using the 4D-Var method, initial and boundary conditions and atmospheric state were adjusted to reduce the model-sampled SSH misfit with SWOT data over the assimilation window. The SWOT observing system information leads to small-scale adjustments in SSH, surface winds, and buoyancy forcing. The SWOT information also propagates downward, constraining subsurface temperature and salinity, and bringing the state estimate into better agreement with contemporaneous Calibration/Validation mooring and glider data that were withheld from the assimilation.

Model fields provide key information to diagnose the leading order submesoscale-to-mesoscale dynamics responsible for transferring energy across scales within the study domain. We use a range of diagnostics, based on the Helmholtz decomposition and on structure functions, to probe the model fields in conjunction with available in situ and remotely sensed observations.

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ITRF2020 UPDATES AND THE IDS CONTRIBUTION

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The ITRF2020 marked considerable innovations compared with previous versions of the ITRF, by modeling nonlinear station motions (seasonal signals and Post-Seismic Deformation –PSD– for sites subject to major earthquakes). It also confirmed the stability of the CM-based frame origin, as sensed by SLR, at the level of or better than 5 mm and 0.5 mm/yr. For the first time in the ITRF history, the scale agreement between SLR and VLBI solutions submitted to ITRF2020 is at the level of 0.15 ppb (1 mm at the equator) at epoch 2015.0, with no drift. Motivated by these results, and for a number of reasons that will be exposed in this paper, the ITRS Center decided to regularly (yearly) update the ITRF2020, with a first update expected to be released around mid-2024. Depending on the input data availability that will be submitted by the four technique services, we expect some preliminary results that will be discussed in this presentation. Emphasis will be given to the IDS contribution and how the DORIS time series of station positions compare with the three other techniques, focusing on the frame physical parameters, namely the origin and the scale.

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THE COOPERATIVE GLOBAL IONOSPHERIC MAP USING NEAR-REAL-TIME DORIS DATA

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The monitoring model and data products for the total electron content (TEC) in the ionosphere provide essential support for applications such as ionospheric delay mitigation in Satellite positioning and space weather monitoring. Some occasional situations may lead to the interruption of real-time ionospheric products. In order to ensure the continuity of real-time correction information, e.g., Real-Time Global Ionospheric Map (RT-GIM) provided by the International GNSS Service (IGS), the differential Slant TEC (dSTEC) from external GNSS stations is used to determinate the weight of RT GIMs in combination processing. Aside from the self-consistency validation methods, the external consistency analysis is required because a direct and truly external assessment is needed for weighted combination. Ionospheric VTEC observables from altimetry satellites and dSTEC from Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) are proved as reliable external references in ionospheric model validation, which shows quantitative consistency with GNSS dSTEC information in collocated analysis scenarios. The new cooperative GIM (RT-CASC) based on DORIS-dSTEC-based weight is presented in this work. The rapid GIM released by IGS (IGRG), JASON-3 altimeter Vertical VTEC (VTEC) observables and the STEC retrieved from 20 rover GNSS stations during the 001–270 Day of Year (DOY), 2022, are set as references to check the performance of different RT GIMs and the new combined one. The validations against three references show that the cooperative products have a comparable accuracy with a standard deviation (STD) range from 2.0 to 4.5 TECU, whereas the single GIM, e.g., IGRG, with an STD of 3.0–7.0 TECU compared to GNSS-STEC. Overall, DORIS dSTEC provides an independent reference for the combination of RT GIMs. In the future, it is also envisaged that DORIS data can be directly incorporated into ionosphere modelling.

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ASSESSMENT OF SWOT L2 HR PIXC (PIXEL CLOUD) PRODUCTS FOR RIVERBED RECOGNITION AND CHARACTERIZATION: CASE OF THE OLD RHINE, BETWEEN KEMBS (FRANCE) AND BREISACH (GERMANY).

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From January to July 2023 ie CalVal Orbit phase, the Rhine River was observed daily by the SWOT mission. A particular attention was paid to assessing the ability of SWOT L2 HR PIXC (pixel cloud) products to characterize the topography of the river, more specifically over the longest reach of “Old Rhine” which flows from Kembs to Breisach (50 km) with a width varying from 80 to 150 m. The Rhine is bypassed by the “Grand Canal d'Alsace” (GCA) between the Kembs diversion dam and Breisach (50km). The minimum flow into the bypassed reach (“Old Rhine”) varies from 52 m3·s−1 (winter) to 150 m3·s−1 (summer). Spills happen when the discharge exceeds 1400 m3·s−1 + the minimum flow, which corresponds to the maximal capacity of the GCA.
The aim of the analysis was to assess the SWOT’s ability to reflect the river’s topography based on water level variability and to identify which geomorphological features (e.g., bars, different bank forms, pools, riffles) are recognizable. To this end, daily profiles based on the PIXCs were generated. The results exceeded our expectations. SWOT PIXC allows identifying the hydraulic features of the river that characterize its topography:

- main slope breaks, with the principal one is the Istein cliff, a limestone outcrop that cross the riverbed. The upstream-downstream elevation difference is around 2 to 3 m;
- series of small riffles, less than one meters high, and successive pools;
- different kinds of bars;

- specific hydraulics structures as the Kembs and Ottmarsheim “bouchon” (i.e. confluences between the GCA and the Old Rhine).

Changes in the river profiles over time, as a function of discharge and river level, were also identified using SWOT data. During the CalVal 1-day orbit, data were captured from beginning of May to mid-July 2023, at different flow levels ranging from 90 to 400 m3/s. Depending on the discharge, it was possible to detect the displacement of the water slope break located at the upstream end of the Breisach dam backwater, over a distance of about 3.5 km, with a downstream displacement when the discharge and water level increase.

Furthermore, SWOT’s measurements match very well with those of the two in situ gauging stations located at Rheinwiller (LUBW) and Ottmarsheim (Vortex autonomous station), which reinforce the robustness of our results.

These preliminary analyses show the ability of SWOT measurements to describe the topography and some hydraulic features of a river with a very good accuracy. These results will be consolidated and extended during the SWOT science phase orbit with the comparison with an HR lidar topo-bathymetric DEM, as well as the monitoring of the riverbed geomorphological evolution during SWOT life notably to assess sediment erosion and deposition processes. Given these very promising results, SWOT measurements could be used in the near future as calibration data for large-scale hydraulic modeling on large rivers all over the world.

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AN ACCELERATED PROCESSOR FOR THE FULLY-FOCUSSED SAR BACKPROJECTION ALGORITHM

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The Fully-Focussed (FF-SAR) algorithm for nadir radar altimeters allows to achieve along-track resolution close to the theoretical limits, which is about 0.5 m for typical nadir altimeters such as Cryosat-2, Sentinel-3 A/B and Sentinel-6. Such improvement with respect to the roughly 300 m-scale resolution of classic Delay-Doppler (DDP) algorithms has enabled the development of new applications over a wide variety of scenarios, from inland water level and water extent retrievals, to sea ice, and to ocean swell studies. FF-SAR algorithms can be implemented following two approaches: time domain and frequency domain. The time-domain approach is in principle more accurate than the frequency one because it relies on less assumptions, however the computational time associated to its classic implementation is too high for envisaging an operational implementation. In order to overcome such drawback, an accelerated algorithm has been elaborated and tested, achieving accelerating factors between 20 and 25 with respect to the classic implementation.

The accelerated backprojection algorithm developed speeds up the computational time by not performing the full focussing at every surface of the geometry grid. Instead, it takes the original backprojection algorithm on selected reference surfaces with spacing larger than the single look final spacing. The fine grid focussing is then achieved by refocussing the stack of pulses of the reference surface, prior to its final coherent summation to the nearby, so-called secondary surfaces. This refocussing is essentially based on the knowledge of the phase slope dependence as a function of the along-track distance between each secondary surface and the closest reference surface. The final code that has been implemented is specific for Sentinel-6 MF data, and it is compatible with GPU acceleration, yielding to almost real-time processing depending on GPU performance. Moreover, a specific configuration of the algorithm allows to eventually generate Delay-Doppler waveforms from the intrinsic FFSAR algorithm. The resulting processor has been validated over point targets such as transponder and corner reflector. Performance over natural target scenarios such as inland waters and open ocean has been assessed. In the present contribution we detail the algorithm architecture and provide an overview of the main results.

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EVALUATION OF THE ICESAT-2 INLAND WATER LEVEL PRODUCT ATL13 OVER DAMS IN KHUZESTAN, IRAN

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Monitoring inland water levels is crucial for understanding hydrological processes and an important variable to indicate lake hydrological balance to climate change impact especially in arid and semi-arid region. Accurate and detailed information of on lake/reservoir water levels and temporal changes is required for water resource management and related studies. Also, the inland water bodies such as reservoirs, lakes and rivers are important source of fresh water which is very important resource for the survival. So, the monitoring of these resources also becomes one of the important tasks. Remote sensing altimetry has proved to be an excellent technique and very useful technology to precisely measure water levels of rivers, lakes, sea water and other inland water bodies. The NASA's Ice, Cloud, and land Elevation Satellite (ICESat) mission uses laser altimetry measurements to determine the elevations at point levels of Earth. ICESat-2, which is a successor to the ICESat-1 satellite mission is a continuation of this series and carries a sensor namely Advanced Topographic Laser Altimeter System (ATLAS). ICESat-2 laser satellite has a very high ability to measure the thickness of polar snows, the height level of sea water and land, lakes, the height of forest trees and vegetation as well as opened new possibilities to use remote sensing altimetry for monitoring earth globally. Although the ATLAS onboard the ICESat-2 was primarily designed for glacier and sea-ice measurement, it can also be applied to monitor lake/river surface height by using ATL13. The ATL13 products provide observations of inland water surface heights, which are suitable for water level estimation at a large scale. Here, we report an accuracy evaluation of the ICESat-2 laser altimetry data over two reservoirs in Khozestan located southwest of Iran using gauge data. The main goal of this research is to evaluate the accuracy of measuring the height of the water level of lakes using satellite altimetry ICESat-2 data of ATL13. The water surface heights were derived from ICESat-2's strong beams data were analyzed and evaluated with the reservoir gauge observations of water level of Dez and Karkheh dam's lakes which located in the North of Khuzestan, Iran during 2018 to 2023. Statistical measurements were used to understand the agreement among the datasets. A strong R2 value of 0.99 was observed betweenICESat-2 derived water level and the reservoir gauge observations in both lakes. The results show that the ICESAT-2 satellite measures the water level of the lakes with very high accuracy. These results demonstrate ATL13's high capability for providing hydraulic, dynamic and other quantities useful for typical hydrology and water resources applications including stream discharge, water body heights, storage, and the impact of climatic change. This study shows the potential of the altimetry data source ICESat-2 ATL13 product for monitoring the long-term behavior of inland water reservoirs for sustainable monitoring.

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SATELLITE ALTIMETRY DERIVED DYNAMIC TOPOGRAPHY USING HIGH-RESOLUTION GEOID MODEL WITH SYNERGIZED SEA LEVEL DATA SOURCES

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In satellite altimetry (SA) the derivation of Dynamic Topography (DT) is often overlooked due to lack of high-resolution geoid models, hence the full potential of sea level data sources and our understanding of ocean dynamics are not fully clear. The usefulness of determining DT however has several advantages that allow to: (i) provide continuous sea level data from coastal to offshore in common vertical reference system with other sea level sources, (ii) describe realistic and accurate sea level variations at sub-mesoscale and (iii) validation of other sea level sources. Accordingly, this study demonstrates the usefulness of a synergized method that derives DT by employing both a geodetic approach that utilizes SA data and tide gauges and also from an oceanographic approach that uses hydrodynamic models. The key component being a high-resolution marine geoid that has been developed for the Baltic Sea region through marine gravity measurement campaigns and various modelling techniques. The Baltic Sea area is an ideal site for examining the aforementioned synergized DT derivation method for it consists of numerous archipelagos, small islands and seasonal sea ice, which can be challenging for satellite altimetry, especially on approaching the coastal areas.

For the geodetic-oceanographic approach the synergy of several data sets was utilized that includes along track multi missions SA (obtained from Baltic+SEAL), a recent high-resolution Baltic Sea Chart Datum BSCD2000 geoid model, a dense network of tide gauge stations and hydrodynamic model. Results show that the SAR mode yields better performance than the LRM mode ones and that SA proved to be an essential source in validation with other sea level data sources especially in the offshore areas with discrepancies within the range of ±20 cm. Most useful revelation however was that the inter-comparison with hydrodynamic models and SA showed that along track SA data have the capabilities to produce more realistic variation of DT. This allowed to identify problematic issues/areas with satellite altimetry (e.g. sea ice), hydrodynamic models (quantification of driving forces), tide gauges (possible vertical reference issues) and the geoid model (sparse data collection on eastern Baltic Sea). The SA calculated sea level trends show more stable results in obtaining realistic trend estimates rather than tide gauge records that may be affected by data gaps and coastal processes (e.g. wave setup/setdown). As a result the synergy of data sets to obtain DT shows the potential of satellite altimetry to be a reliable and accurate sea level source that can be used from coastal to offshore areas for various applications such as climate changes and marine management and planning.

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30+ YEARS OF MONITORING ALTIMETERS: A STORY ABOUT CALIBRATIONS, TEMPERATURES AND HOW THEY IMPACT LEVEL-2 GEOPHYSICAL ESTIMATES.

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The main goal of a radar altimeter is to provide an estimate of the distance ("range") between the instrument and the observed surface, which is deduced from the estimated round-trip time of a microwave signal. The altimeter is composed of different complex units affecting the signal, and instrumental components must be monitored and their performances accounted for during ground processing.

Firstly, the Point Target Response (PTR), is monitored via the on-board CAL1 sequence which has been performed differently from one mission to another since ERS-1. The ideal PTR is a perfect sinc² function, but the actual PTR varies in amplitude, symmetry, and time delay. It is mandatory to compensate these variations as they directly impact the range, sigma0 and SWH. For many years, the PTR has been approximated by a Gaussian function within the retracker, allowing an efficient computation of the inversion of the backscattered echo with less complexity. To compensate this approximation, different techniques have been implemented, from the application of a Hamming weighting window on-board ERS-1/2 to the computation of look-up tables that estimate the bias induced by this approximation, via simulations. Today, state-of-the-art retrackers directly introduce the in-flight PTR as inputs to ensure a perfect consideration of the PTR ageing. An alternative to the numerical retrackers, called complex RIR compensation, is currently investigated by S.Dinardo and proposes to directly correct the PTR at I&Q level.
The second instrumental signal to account for is the thermal response of the receiver chain, that is monitored using the CAL2 sequence. Most altimeters include an analog anti-alias low pass filter in the reception chain (LPF) that drives this thermal response, and LPF variations can also directly impact the geophysical parameters if not accounted for. The Sentinel-6 altimeter's architecture is fully numerical and in principle free from this effect, therefore the S6 thermal response is a low random noise that does not need to be compensated on-ground for the first time. In-orbit temperatures are also monitored, using the house-keeping telemetries collected by the platform. They reveal sensitivity that differ from one mission to another, depending on the sun exposure, PRF or radar cycle scheme (closed-burst or open-burst). Sentinel-6 exhibits significant variability with a direct impact on the calibration parameters, therefore new calibrations sequences have been used to take these variations into account.
Beside the critical impact of these parameters on the scientific estimates, the long-term monitoring of the PTR, LPF and HK temperatures is also crucial to follow the instrument's ageing, and cyclic reports have been regularly produced for each mission by the different agencies to monitor the instrument's health.
The purpose of this talk is first to propose an overview of the different instrumental parameters and their long-term variations, from the ERS missions to SWOT. Then this talk will cover the different techniques used by the Level-2 processing to account for the instrumental variations, and how it is critical to precisely monitor the instruments to be able to quantify the associated uncertainties on the long-term indicators computed using altimeter time series.

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IMPROVEMENTS OF OCEAN RETRACKER SOLUTIONS FOR THE REFERENCE MISSIONS: OVERVIEW, RESULTS AND PERSPECTIVES

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An accurate and efficient estimation of the geophysical parameters is a key goal of the retracking analysis of radar altimetry waveform data. This is indeed crucial to build robust records of Essential Climate Variables as the Mean Sea Level for a rigorous assessment of the climate change at regional and global scales. Major efforts have been made in the last decades to continuously improve the retracking solutions towards this goal. These efforts are indeed challenging and more and more critical because of the high demanding requirements in terms of data precision as of the current reference mission Sentinel-6 MF and upcoming missions.

To ensure the robustness, the optimality and the continuity of the parameter estimation between different missions and surfaces, a retracking algorithm should account for a realistic waveform noise characterisation and for the real time evolution of instrumental properties, namely, the Point Target Response (PTR), if not, this could impact the parameter estimation leading to biases that are difficult to correct and sub-optimality (increase of the parameters uncertainties). Yet, how the different existing retracking solutions deal with these key aspects is not always clear. The definition, naming and description of the different retracking algorithms are not always explicit and can be misleading. Also, a consistent validation of all the algorithms is not available. These are issues when coming to interpreting the results and making choices for both operational implementations and scientific analysis.

In this talk, we will give an overview of the different retracking solutions that have been implemented and in development, for the analysis of the LRM waveform data of the Jason-3 and Sentinel-6 MF reference missions: the MLE4, the numerical retracker, the Adaptive and the FastAdaptive solutions. We will detail why an accurate noise characterisation is important, in particular for Sentinel-6 MF as the pulse-to-pulse correlations linked to the S6 PRF configuration leads to a variation of the Effective Number of Looks (ENL), with respect to both the range gate and the Significant Wave Height, which has a significative impact on the parameters estimation if not correctly accounted for. We will then present a novel approach based on the Bayesian analysis of the waveforms showing how it could offer interesting insights to complement and improve current retracking solutions. In particular: 1) to provide with a robust and consistent estimation of the geophysical parameters uncertainties, 2) to characterize the parameter correlations and the comparison between different waveform models, 3) to assess the impact of likelihood approximations on the parameter estimation. We will highlight the need of thoughtful validation tests on realistic simulations of the different solutions and finally we will discuss the perspectives, namely for high resolution S6 SAR data, and for future radar altimetry missions.

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IMPROVEMENTS IN ESTIMATING 30-YEAR MEAN SEA LEVEL TRENDS AND ACCELERATION FROM GLOBAL TO REGIONAL SCALES

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The accurate measurement of the mean sea level (MSL) and the precise estimate of the MSL trend and acceleration, at global and regional scales, are key goals of high precision satellite altimetry. These estimates are crucial to tackle important scientific questions including the closure of the sea level budget and the assessment of the Earth Energy Imbalance (EEI) in the context of climate change. Great efforts have been put in the last decade to better characterise and understand the uncertainties associated to the MSL measurements from radar altimetry, leading to the design of an error variance-covariance matrix describing the temporal correlations of the MSL uncertainty at global (Ablain et al 2009, Ablain et al 2019, Guerou et al 2023) and at local (Prandi et al., 2021) scales. Precisely quantifying the observational sea level uncertainties is important because uncertainties inform on the reliability of sea level observations and prevent from misinterpretations of artifacts arising from the limitations of the observing system. Following these efforts, the 28-year MSL trend and acceleration uncertainties (at 90%CL) are now down to ±0.3mm/yr ([5%-95%] CL) and ±0.05 mm/yr2 ([5%-95%] CL) at global scales (Guerou et al 2023) and, in average, to ±0.83 mm/yr ([5%-95%] CL) and ±0.062 mm/yr2 ([5%-95%] CL), respectively, at local scales (Prandi et al. 2021). Yet, further improvements, at both global and regional scales, are still required to address three main scientific questions 1) the closure of the sea level budget, 2) the detection, and attribution of the signal in sea level that is forced by greenhouse gases emissions (GHG) and 3) the estimate of the current EEI (Meyssignac et al 2023). Meeting such requirements need further improvements on the accuracy and precision of satellite altimetry data and on the error description and analysis. Concerning the statistical analysis, Mangilli et al. (OSTST 2023) showed that a significant improvement in the estimate of the trend and acceleration uncertainties at global scales, of the order of ~15% and ~20%, respectively, can be gained from an optimal General Least Square estimator, or a Bayesian analysis which optimally include the covariance matrix in the likelihood function. In this talk we first present the updated optimal analysis (with the GLS and the Bayesian approach) of the MSL timeseries at global scales from the recently released L2P DT 24 products. The talk will then focus on how these methods can be applied to the MSL analysis at regional scales, quantifying the improvement of the estimation of the MSL trend and acceleration at local scales, highlighting the results obtained within the ESA cci_SL project.

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JASON-2 GDR-F REPROCESSING IMPACT ON MISSION PERFORMANCES OVER OCEAN

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TOPEX/Poseidon, Jason-1/2/3 and then Sentinel-6A-MF have allowed to build a high-precision ocean altimetry data record on historical ground track as the reference mission serie.
Long-term monitoring of the Jason altimetric system is routinely performed at CLS, as part of the CNES SALP (Système d'Altimétrie et Localisation Précise) project. The main objective of this activity is to provide an estimation of these missions' performances for oceanic applications such as mesoscale or climate studies. As TOPEX/Jason/Sentinel-6 are the reference missions used in operational applications or for delayed time studies and especially for monitoring of the Global Mean Sea Level, we pay special attention to the long-term stability of their Global Mean Sea Level (GMSL). Sentinel-6 datasets have followed standard "F" from its launch onwards. The Jason-3 mission reprocessing in standard "F" was performed during 2021, and the reprocessing of Jason-2 data is ongoing. A precise knowledge of Jason-2 data quality and errors is a key activity to ensure a reliable service to scientists involved in climate change studies.
In this presentation, we aim at presenting the overall performance of Jason-2 through different metrics highlighting the high-level accuracy of this mission. We will give an overview of Jason-2 data coverage and data quality concerning altimeter and radiometer parameters, but also the performance of delayed time products (GDR) at mono-mission crossovers and along-track. We will focus on the way the reprocessing impacts Jason-2 dataset and improves the long-term stability of the reference GMSL.

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30-YEAR LAKE ICE THICKNESS TIME SERIES FROM RADAR ALTIMETRY DATA

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Lake ice thickness (LIT) plays a crucial role in local to regional weather and climate, it strongly impacts lake ecosystems at northern high latitudes. Trends and interannual variability in LIT are largely controlled by changes in near-surface air temperature and on-ice snow depth. Therefore, LIT is an important climate indicator recognized as a thematic product of the 'Lakes' Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS). Yet, the monitoring of LIT is very limited in both time and space from conventional field measurements. In this respect, radar altimetry offers a viable means of filling this critical gap since it provides increasingly longer historical records for many northern lakes required for climate monitoring. Although the potential of radar altimetry is now recognized, it has not yet been fully explored.

Building on recent advances in the development of novel analytically based retracking approaches to accurately estimate LIT from Ku-band radar altimetry waveform data, both low-resolution mode (LRM) and high-resolution Synthetic Aperture Radar (SAR) data (Mangilli et al. 2022, Mangilli et al. 2024), in this talk we will present long LIT time series obtained from radar altimetry data for a selection of northern lakes. More specifically, we will provide an overview of the statistical analysis and methods used to estimate the LIT time series generated and their validation for lakes of different bathymetry, snow and ice conditions, highlighting preliminary results of LIT climatologies. We will then report on recent improvements in LIT estimates obtained from current radar altimetry SAR missions, presenting LIT time series obtained with unfocused and fully focused (UFSAR and FFSAR) SAR data. Finally, we will provide perspectives for future missions such as the European Space Agency (ESA) CRISTAL mission.

The LIT time series produced from the analysis of LRM data have been generated and validated within the ESA Climate Change Initiative (CCI) Lakes project and are publicly available according to the project schedule. LIT estimates with UFSAR and FFSAR data have been generated within the ESA S6JTEX project. Finally, the development and assessment of LIT estimates for the CRISTAL mission is being carried out as part of the ESA CLE2VER project.

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SIMULTANEOUS DYNAMICAL RECONSTRUCTIONS OF SEA SURFACE HEIGHT AND TEMPERATURE FROM MULTI-SENSOR SATELLITE OBSERVATIONS.

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For many years, satellite observations of sea surface height (SSH) and sea surface temperature (SST) have provided invaluable information on the dynamics of the upper ocean at many scales. SSH and SST variables are dynamically linked, and are very often used together for many scientific studies (e.g. estimating heat transport in the upper layer by SSH-derived geostrophic currents). As observations are unevenly distributed in space and time (SSH is measured along one-dimensional trajectories and SST measurements are affected by clouds), many scientific and operational applications rely on gridded SSH and SST products. However, these products suffer from two main limitations. Firstly, conventional mapping techniques rely on static optimal interpolation schemes, which limits the estimation of nonlinear dynamics at scales poorly sampled by altimetry or, for SST, in regions densely affected by clouds (e.g. near western boundary currents). Secondly, SSH and SST reconstructions are performed separately, without relying on synergies between the two variables, which has an impact on the consistency of the two reconstructed fields.

We introduce an original dynamical mapping algorithm to simultaneously reconstruct SSH and SST from multi-sensor satellite observations. This innovative method combines a weakly constrained, reduced-order, 4-dimensional variational scheme with simple physical models – quasi-geostrophic for SSH and advection-diffusion for SST. The weak constraint of the models on the inversion procedure ensures that the reconstructed SSH and SST fields closely match the observations while preserving the space-time continuity of the dynamical structures.

The work focuses on the North Atlantic Ocean over the year 2023 and considers the available along-track altimetric SSH, microwave and infrared SST data. The performances of the method are evaluated through Observing System Experiments, utilizing independent altimetric (from conventional and SWOT satellites) and drifter data. Results show a significant improvement of the reconstruction of short energetic structures, both in terms of SSH and SST, compared to operational products. The benefit of using SST observations for reconstructing SSH fields increases as the number of altimeters is reduced. This opens new opportunity to use the method for sea-level related climate applications that rely on a stable two altimeters constellation.

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DYNAMICAL MAPPING OF SWOT: PERFORMANCES FROM REAL OBSERVATIONS

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The Surface Water and Ocean Topography (SWOT) mission offers two-dimensional measurements of Sea Surface Height (SSH), capturing scales of a few tens of kilometers and enabling the study of previously unobserved short mesoscale dynamical structures. However, the mission faces technical challenges in maximizing scientific benefits, particularly during the science phase with its 21-day repeat orbit, which limits observations of small-scale structure evolution over time.

To address the challenge of high spatial and low temporal samplings, we propose an original dynamic interpolation scheme that we call 4Dvar-QG. This innovative method combines a weakly constrained, reduced-order, 4-dimensional variational scheme with a quasi-geostrophic model. The weak constraint of the quasi-geostrophic model on the inversion procedure ensures that the estimated maps closely match the observations while preserving the space-time continuity of the reconstructed structures.

The 4Dvar-QG method is applied in the North Atlantic Ocean on a constellation of real conventional altimeters and SWOT, during both the SWOT's fast sampling and science phases. Performance evaluations are conducted through Observing System Experiments, utilizing independent data (such as altimetric and drifter data) as ground truth and comparing results to operational products like the Multiscale Interpolation Ocean Science Topography product (MIOST). The 4Dvar-QG method significantly improves the mapping of short energetic structures, reducing the root mean square error by up to 50% and increasing the effective resolutions by up to 30% compared to MIOST, while maintaining good reconstruction of large-scale and/or low energetic structures.

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IMPROVEMENT AND HOMOGENIZATION OF THE LONG-TERM SEA-LEVEL ESTIMATIONS SERIES THROUGH THE TOPEX/POSEIDON-1 GDR-F REPROCESSING

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On August 10 1992, the TopEx/Poseidon satellite was successfully launched into orbit by an Ariane 42P rocket from the French Guiana launch site. For the next 13½ years, the two radar altimeters on board the platform, the NASA Altimeter (ALT) and SSALT (or Poseidon-1), successfully collected valuable oceanographic data. Since both altimeters operated at the same frequency and used the same antenna, a sharing plan of the antenna was established which allowed operation of the ALT 90% of the time with the remaining 10% devoted to Poseidon-1 operation.
In November 2023, the release of reprocessed TOPEX/Poseidon data announcement was done to OSTST community. In addition to being useful for the Global Mean Sea Level determination, this reprocessing also offered the possibility to enrich the long-term altimetry records with homogenized data set. The objective of this presentation consists in giving an overview of Poseidon-1 data quality and assessing the performance of products at mono-mission crossovers and along-track. Comparisons to TOPEX GDR-F final dataset are also presented.

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CRISTALAIR: CRISTAL'S AIRBORNE DEMONSTRATOR

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CRISTALair will be the airborne demonstrator of the Interferometric Radar Altimeter for Ice and Snow (IRIS), which is the primary payload of the Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission. CRISTAL is one of the six Copernicus Expansion Missions (CEM), that are being developed to address EU policy and evolving Copernicus user needs, and it will be the first mission to carry a dual-frequency (Ku- and Ka-band) high-Pulse Repetition Frequency (PRF) radar altimeter. The main objective of CRISTALair is to support CRISTAL science by providing dual-frequency band L1B data from dedicated science campaigns which can be used for L2 algorithm development and validation.
CRISTALair will acquire data simultaneously in Ku- and Ka-band and it will be an interferometric radar in both frequency bands. The instrument will operate at a bandwidth of 1 GHz performing correct sampling of the full bandwidth and it will have a 10 kHz Pulse Repetition Frequency. CRISTALair will therefore acquire data simultaneously with 4 channels (2 channels for Ku and 2 channels for Ka) with a sampling rate of 1.28 GHz. CRISTALair's range window will be 300 m after on-board matched filtering.
To improve CRISTALair's interferometric performance, the instrument will be mounted on a stabilized platform. Additionally, CRISTALair will be equipped with a high precision IMU, an airborne laser scanner and a

colour-infrared digital camera to support data validation and interpretation. The main performance drivers of CRISTALair are the elevation uncertainty and the point target response.
CRISTALair's L1 ground processor will generate L1B products with the same format and processing modes as envisaged for CRISTAL, namely low resolution, Delay/Doppler and fully-focused Ku and Ka waveforms. During the CRISTALair activity, a test flight near Milan, Italy and a functional flight campaign in Iceland (Langjökull) and Greenland (Station Nord) are planned in July 2024 and October 2024, respectively. The objective of the functional flight campaign is to acquire data over land and sea ice to validate CRISTALair with representative data for CRISTAL's primary scientific objectives. Two corner reflectors tailored to the needs of CRISTALair will be manufactured and deployed for the flight campaigns. These corner reflectors will be used for external calibration and validation of the instrument performance.
At the Symposium, following a comprehensive presentation of the instrument features, the results of the test campaign will be shown. These will include processed L1B data, assessment of the achievable interferometric performance and analysis of the point target response from the corner reflectors using fully-focussed SAR processing of the acquired data. The functional flight campaign will also be described in detail, and an outlook will be provided on the future campaigns planned with CRISTALair.

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GRIDDING OF SEA LEVEL ANOMALIES USING COLLOCATED CO-VARIABLES

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Gridded maps of Sea Level Anomalies (SLA) are crucial tools for physical oceanographers, enabling detailed descriptions of the spatial characteristics of the ocean surface. Several approaches exist for creating these gridded maps, with increasing focus on improving them and the scales of the processes observed.

Our study investigates the combination of altimetry-based SLA with other variables, such as SST and wind data, to provide an alternative way of producing gridded SLA fields. This study aims to fill the need for more high-frequency content in the gridded altimetry-based SLA data, focusing on the coastal and shelf regions, where this is increasingly important in understanding ocean processes.

Our current strategy uses Kriging and Co-Kriging with collocated Co-variables to assess Co-variables' effectiveness for the gained SLA maps. Kriging is based on the spatial and temporal dependency in time and space, which can be modeled using semi-variogram functions. The Kriging process provides an optimal, unbiased estimate of the variable's value at the unmeasured point, while in Co-Kriging, the spatial-temporal covariance of the auxiliary variable and their cross-correlation is considered.

We use datasets of altimetry-based SLA from the European Union's Earth observation program CMEMS (Copernicus Marine Environment Monitoring Service), providing SLA as along-track (L3) and gridded data (L4). We compare our gridded SLA data against the CMEMS L4 data in daily resolution on a 0.25° x 0.25° grid. For the gridded CMEMS data in use, we highlight the lack of variability in SLA on the Southwestern Atlantic Continental shelf concerning high-frequency processes and their connection to along-shore winds. This is shown when comparing gridded altimetry SLA to model SLA (GLORYS12V1 product of CMEMS). It is particularly important to investigate the high-frequency variability because, while the newly launched SWOT mission shows great improvements in representing spatial scales, it cannot enhance the description of high-frequency sea level variability due to its repetition cycle. We further use daily GESLA-3 tide gauge data to validate the newly produced data set. We will show the potential of a new gridding method using Co-variables and discuss their impact on the mesoscales of daily SLA maps in the continental shelf and coastal regions.

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MICROWAVE EXPERTISE CENTER : A WORK ENVIRONMENT FOR MICROWAVE DATA EXPLORATION

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The MicroWave Expertise center has first been developed to provide a work environment to support the calibration/validations activities and address the high resolution of Surface Water Ocean Topography (SWOT) mission, launched on December 16th, 2022. Onboard, the new instrument 'KaRIn', is a revolution for both oceanography and hydrology communities and gives access to small scale measurements over ocean, worldwide river heights and flows, and lake heights.

With optimized storage and computation methods, the MicroWave Expertise Center is designed to ease the exploration and studies of 16TB/day products. The tools developed for SWOT are generic and can now be applied to any altimetric mission.

Experts are provided simple and scriptable explore numerous data providers such as copernicus dias, ecmwf, hydroweb.next.

Some tutorials are already available along with visualisation tools. And the list will be growing up in close future from users requirements.

The expertise center is operational and ensure SWOT calval activities. Prospects address SWOT ocean and hydrology studies but could be enlarged to hydrological research, multi-sensor comparison

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GLOBAL REVIEW ON THE ASSIMILATION OF ALTIMETRY WAVE DATA IN OPERATIONAL WAVE MODELS

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The availability of more altimetry wave data on a global scale is a major component for improving wave forecasting and wave climate analysis in critical regions such as the polar oceans. This work aims to implement a global review of the assimilation of Significant Wave Heights (SWH) from altimetry into the operational wave model MFWAM of Copernicus Marine Service over the last 5 years. During the analysis period, several altimetry missions were added, including Sentinel-3A & 3B, Sentinel-6 and CFOSAT. Validation of SWH at global scale has been performed by comparison with independent altimetry data provided by HY2 missions and buoy wave data available in the Copernicus Marine Service-In Situ Thematic Assembly Center (In situ TAC). Additional wave data from other buoys networks, such as those provided by the SOFAR and CDIP. Statistical analysis shows that the scatter index of SWH has improved significantly since 2020, with an average value of less than 9%. One can mention also the reduced scatter index of SWH, below roughly 8% and ~7% for mid-latitude and tropical latitudes, respectively.
We analyzed wave variability in the marginal ice zone during the last five years. Comparison with drifting buoys shows that the contribution of S3 altimetry missions is significant in terms of SWH bias and scatter index reduction. Analysis in areas of strong currents, such as western boundary currents, also reveals an improvement in SWH prediction compared with systems that assimilate less wave data, in comparison with ECMWF wave system, during the analysis period.
In other respects, we investigated the assimilation of wide swath SWH retrieved by artificial intelligence on scatterometers missions such as HY2 and CFOSAT. The results indicate a significant impact on integrated wave parameters, particularly in tracking wave propagation from storm event to coastal area. Examples of extreme waves under typhoons conditions have been analysed and emphasize the benefit of wide swath SWH in comparison with altimetry constellation.
Further discussions and conclusions will be presented in the final paper.

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EVALUATION OF THE ZHD TROPOSPHERIC MODELLING WITH VMF1 ON DORIS ORBITS AND STATION COORDINATES

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Due to the correlations between the troposphere zenith delays and the station heights, a sophisticated troposphere model is needed to estimate precise station coordinates using space geodetic data such as GNSS, VLBI and DORIS. A tropospheric model consists of two parts: 1) the tropospheric mapping function to convert the troposphere delay at a certain elevation angle to a zenith delay and 2) an a priori model for the Zenith Hydrostatic Delay (ZHD). Historically, Analysis Centers have preferred the use of the Global Pressure and Temperature (GPT/GPT2) models to model the ZHD due to the ease of use of data, but nowadays, this tendency is shifting towards a more mature, up-to-date VMF1 model. This study tries then to assess the impact of the VMF1 modelling of the ZHD using DORIS data and the reference mission, Sentinel-6, by evaluating the resulting reduced-dynamic orbits and the precise position of the DORIS stations

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RECENT ADVANCEMENTS IN JOINT USE OF DUAL-RADAR OCEAN OBSERVATIONS FROM CFOSAT MISSION

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A growing number of spaceborne radar sensors provide an increasingly abundant collocated ocean measurements, raising new opportunities for synergetic remote sensing techniques. Interpreting this diverse observational dataset requires novel approaches to consistently process different data types and invert geophysical fields. Although radar scatterometers continuously monitor ocean winds, joint estimation of speeds from various platforms remains challenging. New instruments often lack intercalibration algorithms and exhibit varying sampling and resolution characteristics. Thus, joint utilization of such multimodal data is not straightforward.

The China-French CFOSAT mission aims at providing extensive global observations of key sea surface parameters, including wind vectors, through its two specialized Ku-band rotating radar instruments: the near-nadir SWIM wave scatterometer and the moderate incidence, dual-polarization SCAT wind scatterometer. Their aligned sampling enables simultaneous collocated measurements of backscatter, winds, and waves over the global ocean. This novel SCAT/SWIM combination offers opportunities to advance understanding of ocean wind-wave interrelationships.

We present advances in a common wind vector retrieval framework using heterogeneous collocated radar measurements, developed in the context of IFREMER's Wave and Wind Operational Center (IWWOC) activities. Utilizing CFOSAT's SCAT, SWIM, and METOP ASCAT observations, the flexible framework can incorporate diverse instrument types like scatterometers, altimeters, and SAR.

The innovative SCAT and SWIM instruments require additional calibration and validation work compared to well-established platforms like ASCAT, to ensure the required data quality. Their rotating antennas introduce potential variations related to antenna orientation and platform movement. We propose a simplified stabilization methodology based on histogram matching to address these issues for the SCAT Ku-band backscatter.

Furthermore, we introduce a probabilistic geophysical model function (PGMF) framework synergistically combining heterogeneous radar data. PGMFs map observed backscatter to probability distributions of wind speeds/directions, estimated from collocated radar and numerical weather model data. This captures variability due to hidden geophysical and instrumental factors, moving beyond deterministic geophysical models to represent the probabilistic nature of the radar backscatter.

In this work, we demonstrate the key elements of the retrieval approach using CFOSAT's SCAT and SWIM observations. Ongoing work aims to further improve and comprehensively analyze multisensor wind retrieval techniques. The flexible probabilistic framework provides a new technique for improving ocean surface wind vector estimation by exploiting various spaceborne different-type radar missions, like altimeters, SAR and scatterometers. The present developments constitute key steps toward a robust synergistic multi-sensor analysis framework for wind vector inversion with the potential for extension to include additional geophysical variables, such as sea surface currents and wave state parameters.

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EVALUATION OF WATER LEVELS DERIVED FROM PAST AND CURRENT RADAR ALTIMETRY MISSIONS OVER THE PACIFIC SLOPE OF SOUTH AMERICA

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A total of 11 radar altimetry missions, developed by either CNES, ESA or NASA (sometimes in collaboration with other space agencies), have been in operation since the launch of Topex/Poseidon : Topex/Poseidon, ERS-2, Jason-1/2/3, ENVISAT, SARAL, Sentinel-3A and B, Sentinel-6, and SWOT. The goal of this study is to evaluate the evolution of the performances of this long-term data records over a wide range of lakes in the Pacific slope of South America located in Ecuador, Peru, Bolivia, and Chile. The interest of the selected study area is to encompass a large number of lakes of varying areas (from a few to several thousands km²), in a wide range of ecoclimatic (from densely vegetated areas surrounding lakes in equatorial areas to desert environments) and topographic (flat areas along the coast to medium and high topography in the coastal and Andes cordillera) environments. Time-series of water levels are generated using the Altimetry Time Series (Altis) software for LRM and SAR missions. For the SWOT mission, the Pixel Cloud product will be used to obtain the time-series of water levels. Comparisons will be achieved against in-situ data.

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IDS NEWS

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The International DORIS Service (IDS) had its 20th anniversary in 2023 and is now looking forward to new challenges.
On the one hand, the number of satellites in operation in 2024 - 9 - is as large as the cumulative number of missions in flight over the 30-year period between 1990 and 2020.
This represents an unprecedented scale in terms of the distribution, archiving and processing of DORIS data.
On the other hand, new groups have approached IDS in recent years, bringing new processing capabilities, or wishing to become involved in DORIS processing in the medium term. These new strengths are also opening up new applications. The role of IDS is to support them by providing a framework for collaboration and all the information they need for their work. By 2024, NRT DORIS data (RINEX and orbits) will be made available for all current missions. The main objective is to enable a newly established IDS working group to use them to develop ionospheric modeling applications. But other types of applications could also follow.
In addition, IDS is carrying out other actions to meet the objectives of its strategic plan: growth of the community, extensions of DORIS applications, improvement of technology, infrastructure, and processing.
This presentation provides an update on the progress of these actions, the latest news from IDS, and the future projects.

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A PERFORMANCE ANALYSIS OF FULLY FOCUSED SAR PROCESSORS: FROM CLASSIC AND GPU-ACCELERATED BACKPROJECTION TO NUMERICAL AND CLOSED-FORM OMEGA-K ALGORITHMS.

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Fully Focused SAR (FF-SAR) algorithms for nadir radar altimeters have already demonstrated their capability to achieve along-track resolution down to the sub-meter level, enabling the development of many applications that benefit from such resolution improvement with respect to what is currently achieved by Delay-Doppler operational altimeters, which is around 300 m. Some examples of such applications include swell and coastal studies over open ocean, sea ice monitoring, and high precision inland water level measurements.

However, the classic FF-SAR backprojection algorithm (Egido and Smith 2017) faces challenges due to its increased computational requirements, which in practice has impeded so far the deployment of operational processors. In 2018, Pietro Guccione et. al. introduced the FF-SAR 2D Frequency Domain algorithm, presenting a numerical approach of the omega-K (WK) based algorithm, which demonstrated notable improvements in computational efficiency for the case of CryoSat-2. Building upon this progress, in 2024, Sergi Hernández et al. presented a closed-form algorithm based on the omega-K approach specifically for digital receiver systems, introduced firstly in the Sentinel-6 radar altimeter. Their work showcased a more efficient FF-SAR 2D frequency algorithm, delivering focusing results close to the numerical WK and backprojection method.

In this presentation, a detailed comparison of several techniques for Sentinel-6 data processing will be addressed, including the classic backprojection algorithm, a numerical omega-K, the closed-form omega-K, and an accelerated backprojection algorithm using GPU methods. Our analysis encompasses point target analysis, open-ocean retracking, and computational performance, providing insights to the effectiveness of each method. This analysis will present a global benchmark of the different performances in terms of resolution, precision, accuracy and computational run-time performance that can be of interest for the future missions, as for instance CRISTAL, which will be the first mission to offer FF-SAR operational products. Our findings demonstrate that the accelerated backprojection algorithm using GPU methods improve the computational performance by up to 100 times compared to the classic backprojection, with minimal degradation in point target response. Additionally, the closed-form WK algorithm significantly enhances the computational performance of the classic backprojection by a factor of 3000 and improves the numerical WK approach by a factor of 10.

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AN OVERVIEW OF THE FULLY FOCUSED SAR OMEGA-K CLOSED-FORM ALGORITHM

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The classic FF-SAR backprojection algorithm (Egido and Smith 2017) faces challenges due to its increased computational requirements, which has impeded so far the deployment of operational processors for radar altimeter missions such as Sentinel-6. In 2018, Pietro Guccione et. al. introduced the FF-SAR 2D Frequency Domain algorithm, presenting a numerical approach of the omega-K (WK) based algorithm, which demonstrated notable improvements in computational efficiency for the case of CryoSat-2.

Building upon this progress, in 2024, Sergi Hernández et al. [1] presented a closed-form algorithm based on the Omega-K approach, validated with Sentinel-6 radar altimeter data. This algorithm aims to enhance the computational efficiency of the numerical omega-K, while maintaining high-quality performance. Within our poster, we provide a comprehensive explanation of the omega-K closed-form algorithm. We present its methodology and performance results, focusing on point-target response and open-ocean retracking. Furthermore, we discuss its practical applications, including the retrieval of swell parameters and the tracking of sea ice.

[1] S. Hernández-Burgos et al., "A Fully Focused SAR Omega-K Closed-Form Algorithm for the Sentinel-6 Radar Altimeter: Methodology and Applications," in IEEE Transactions on Geoscience and Remote Sensing, vol. 62, pp. 1-16, 2024, Art no. 5206016, doi: 10.1109/TGRS.2024.3367544.

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CIMR AND CRISTAL: SYNERGIES IN THE POLAR DOMAIN

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The Copernicus Imaging Microwave Radiometer (CIMR) is one of the six Copernicus Expansion Missions currently being implemented by the European Space Agency and the European Commission. CIMR provides microwave imaging radiometry measurements at low frequency (L-,C-,X-, K- and Ka-band) with relatively high spatial resolution and high radiometric fidelity. The primary CIMR mission objective is to determine the sea ice concentration (SIC) in the polar regions on sub-daily timescales at a spatial resolution of <5 km (with 'no hole at the pole' in the Arctic) with an uncertainty of ≤5%. A significant number of additional mission objectives are levied on the CIMR mission including: global daily measurements of SST, Sea Surface Salinity (SSS), ocean wind vectors (using polarimetry), sea ice parameters (Arctic and Antarctic) including sea ice type/stage, thin (≤0.5m) sea ice thickness and sea ice drift vectors, snow depth on sea ice, sea ice surface temperature, as well as terrestrial measurements of snow extent and snow water equivalent. In the context of CIMR, the Level-2 Product & Algorithm Development (CIMR L2 PAD) activity is currently ongoing to define the geophysical retrieval algorithms and the ESA CIMR Level-2 data product format.
CIMR and CRISTAL will support together the implementation of the EU Arctic Policy allowing enhanced monitoring of the cryosphere by retrieval of complementary geophysical variables.
Collocated observations in space and, as much as possible, in time from the different instruments on-board of CIMR and CRISTAL will pave the way for synergies at different levels

- By combining the retrieved geophysical variable, e.g. sea ice thickness from CIMR and CRISTAL can be combined in a similar way as is currently done for SMOS and CryoSAT2
- By exploiting a geophysical variable as an auxiliary input in the retrieval, e.g. the sea ice concentration and type from CIMR can be used as input for the ice thickness retrieval from CRISTAL acquisitions
- By compare correlated geophysical variables for cross-validation, e.g. joint campaign as well as Fiducial Reference Measurement equipments can be planned to validate the Level-2 measurements from both the missions

This abstract is aimed at giving a comprehensive overview of the synergies which are expected between CIMR and CRISTAL in the polar regions, highlighting the added value of the collocated acquisitions from the two missions.

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SVALBARD AS A RADAR ALTIMETER FIDUCIAL REFERENCE OBSERVATORY

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Svalbard, situated halfway between the northern tip of Norway and the North pole, is a natural laboratory for cryospheric satellite reference measurements. Due to high latitude of 74 to 82 degrees satellite tracks converge on Svalbard, increasing the number of overpasses. On Svalbard, cryospheric targets, specifically land ice, sea ice and snow are relatively easy to access in a frequent and sustainable manner, whereas campaigns in other regions of the Arctic tend by a "one off" or restricted to certain months of the year.

The Svalbard Sustainable Climate Reference Observatory is an endeavour to utilise more in-situ measurements of cryospheric ECV's for satellite algorithm development as well as cal/val. In cooperation with local research establishments such as UNIS, SIOS and NPI we aim to provide more in-situ measurements that can be used to support satellite retrievals.

Since 2023, we have collected data under satellite altimeter overpasses. In the 2023 season, emphasis was on snow thickness and glacier elevation measurements under ICESat-2 overpasses. In 2024, we are carrying out a field campaign on landfast sea ice in Van Mijenforden and on the Lomonosovfonna ice cap colocated with CryoSat-2 and Sentinel-3 overpasses. If successful, these measurements can be used to address knowledge gaps recognised for the future CRISTAL mission, namely radar penetration into snow and the measurement of snow on sea ice. The Lomonosovfonna measurements will be used for validation of the CryoTempo EOLIS swath product of glacier elevation.

There is scope for expanded satellite cal/val programs on Svalbard and we encourage the European altimeter community to make use of it. Get in touch with your plans or ideas for future field campaigns that can be coordinated with satellite overpasses.

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RASPBERRY PI REFLECTOR DEPLOYMENT ALONG THE RHINE RIVER

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As part of the Collaborative Research Center (SFB 1502) funded by the German Research Foundation (DFG), a project is carried out to analyze surface water levels and discharge using data from the new generation of satellite altimetery. Within this project, a network of eight Raspberry Pi Reflectors (RPR) was strategically installed (with several placed under Sentinel-3 tracks) along the Rhine from Petersau to Sankt Goar in spring and summer 2023. The main objective of this installation was to validate the SWOT (Surface Water and Ocean Topography) observations of surface water levels. RPR is a low-cost water level sensor recently developed by Karegar et al. (2022) based on an innovative environmental measurement technique called GNSS Interferometric Reflectometry (GNSS-IR). Some of these RPRs were installed in the relatively steep and narrow Middle Rhine Valley where the terrain relief around the instrument can influence the effectiveness of the GNSS-IR approach as well as SWOT measurements. In this presentation, we will discuss the results of the deployment of the RPRs and the challenges associated with using these low-cost sensors to validate SWOT and nadir altimeter water levels.

References:
Karegar, M. A., Kusche, J., Geremia-Nievinski, F., & Larson, K. M. (2022). Raspberry Pi Reflector (RPR): A Low-Cost Water-Level Monitoring System Based on GNSS Interferometric Reflectometry. Water Resources Research, 58(12), e2021WR031713.

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IMPACT OF A LINEAR SCALING SCHEME OF GIM IONOPSHERIC CORRECTION ON JASON MISSION PERFORMANCES

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The GIM ionospheric correction currenlty available in GDR products for the Jason series is derived from TEC maps up to GNSS height which are interpolated at the altimeter altitude using the IRI95 model which describes the vertical distribution of electrons. Inaccuracies of the IRI95 model results in differences between the GIM ionospheric correction and the dual-band correction. Dettmering & Schwatke (2022) proposed an alternate scaling scheme based on a linear regression of total ionospheric correction (up to GNSS height) versus dual-frequency correction.

They convincingly established that this new scaling scheme does reduce the long term discrepancies between GIM and dual-frequency ionospheric corrections. However this is only one aspect of mission performance. Here we investigate how a linear scaling scheme impacts mission performance using other metrics (eg crossovers, SSHA variance) in preparation for future processing baselines (GDR-G). The distribution of residuals with respect to the dual-frequency correction is investigated, highlighting dependencies with solar activity and latitude/local time that are not accounted for by a simplified linear regression model.

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LEARNING FROM CFOSAT TO REFINE ALTIMETRY WAVE AND SEA LEVEL UNCERTAINTY

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The CFOSAT satellite mission (launched in 2018) presents the first opportunity to have observed wave spectra along the entire satellite track. Indeed, CFOSAT's SWIM innovative instrument measures both an off-nadir wave spectra and the historical nadir parameters. This nadir/off-nadir synergy was used to refine our uncertainty of wave height and sea level estimation from nadir altimetry.

This study sums up our learnings about altimetric high frequency content below 100km. This high frequency content was known to be affected by correlated noise, so-called spectral bump, observed both in Hs and SLA spectra and described in Dibarboure et al. 2014 as a signature of heterogeneity in the altimeter footprint (mostly rain or sigma blooms). This bump was also found to be intensified for directional swell conditions and more specifically where wave groups are dominant (Ollivier et al. OSTST 2022, Ollivier et al. LPS 2022, De Carlo et al. 2023).

For wave height measurements, we show that the small-scale variability can be split into speckle noise, wave groups effect and mesoscale variability. Therefore, we propose a parameterization of Hs uncertainty depending on the significant wave height and the peakedness parameter of the spectrum which is a proxy for the groupiness of waves (De Carlo et al. 2023, De Carlo & Ardhuin 2024).

These findings have a direct impact on our understanding of SLA pollution by wave effects at small scales below 100 km. Thanks to simulation and theoretical developments we quantify and characterize the SLA uncertainty and pollution by sea states that are not cancelled by SSB and HFA (Tran et al. 2021).

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RESEARCH ON TWO STEPS RETRACKING ALGORITHM FOR CONSTRUCTED WAVEFORMS OF NEARSHORE RADAR ALTIMETER

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To enhance the precision of nearshore data products obtained from radar altimeters, a novel two-step retracking algorithm for nearshore constructed waveforms has been introduced. Leveraging Empirical Mode Decomposition (EMD), this method extracts trend information along the trailing edge of the waveform. Constructed waveforms are then crafted by connecting the leading edge and trailing edge trend information. The retracking process involves two steps: the first step retracking only a segment of the leading edge, obtaining crucial 4-parameter a priori information. Subsequently, in the second step retracking, retracking encompasses both the leading and trailing edges based on the acquired a priori information. The HY-2B radar altimeter waveform was used for testing, the results show that the nearshore constructed waveform two steps retracking algorithm is better than the Maximum Likelihood Estimation (MLE4) retracking algorithm used in the operational operation of the HY-2B radar altimeter and the Adaptive Leading Edge Subwaveform algorithm (ALES) in significant wave height (SWH) and sea level anomalies (SLA). Compared with the MLE4 algorithm, the standard deviation of the difference in SWH is reduced by 14%, and the standard deviation of the difference in SLA is reduced by about 18%. The two steps retracking algorithm for constructed waveform makes full use of the information of the trailing edge of the waveform, effectively reduces the influence of the peak noise on the leading edge of the waveform, and improves the utilization rate and retracking accuracy of the waveform.

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IMPROVING BALTIC & NORTH SEA ALTIMETRY PRODUCTS BY INTEGRATING REGIONALIZED CORRECTIONS

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Safe and efficient satellite-based marine navigation, the expansion of offshore wind energy or the adaptation to climate change - these and many other applications rely on precise geodetic information in the marine sector. In order to fulfil these growing user requirements the Federal Agency for Cartography and Geodesy (BKG) processes observations of satellite altimetry in the German maritime sectors and the adjacent seas to derive regionalized sea level products with a special focus on accuracy and consistency with other national geodetic products.

A regional calibration of the altimetry missions reveals remaining spatial patterns in the calibration biases, which, if not corrected for, would induce steps in the time series. Integrating precise regional geoid models allowed us to directly calculate geoid-related Absolute Dynamic Topography (ADT) from the altimetric observations, mitigating interpolation and smoothing errors when deriving a Mean Dynamic Topography (MDT). A comparison with a corresponding grid from a hydrodynamic ocean model from Leibniz Institute for Baltic Sea Research (IOW) shows that the derived satellite-only MDT provides realistic results for the Baltic Sea. By integrating this hydrodynamic ocean model in the altimetric processing, we furthermore improved the correction of the high frequency oceanographic signal and hence derived more precise products of the temporal variations of the sea level.

Here we present the first results of these activities and our strategy of combining satellite altimetry with several other observation techniques of sea level changes and land uplift to map and monitor elevation and elevation changes in the coastal zone.

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AN OVERVIEW OF THE SWOT TECHNOLOGICAL BREAKTHROUGH: A PERSPECTIVE OF MAIN DIFFERENCES WITH RESPECT TO NADIR ALTIMETRY OVER OCEAN

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Surface topography over Ocean is measured with success from spaceborn altimeters for more than three decades. The current altimeter system has reached a high maturity level, more than half a million of daily records are ingested in operational chains to feed operational models. The whole time series available is regularly reprocessed and improved with up to date algorithms and geophysical correction models to serve the long term analyses and climate studies.

Nevertheless, the nadir altimetry technology also presents some limitations that prevent the full observation of ocean topography small scales features, non-negligible part of the total signal, involved in ocean and ocean-atmosphere energy transfers. To fill this gap, the National Aeronautics and Space Administration (NASA), the Centre National d'Etudes Spatiales (CNES) with contributions from the Canadian Space Agency (CSA) and the United Kingdom Space Agency (UKSA) jointly developed the Surface Water Ocean Topography (SWOT) mission. The SWOT mission presents a technological breakthrough compared with nadir altimetry as it provides measures of the surface topography with an unprecedented precision over two swaths of 50 km each instead of along-track one dimension profiles. For this purpose, the satellite carries an innovative synthetic aperture Ka-band Radar Interferometer (KaRIn) which both antennas are located on each side of a 10m long mast.

SWOT was launched successfully in December 2022. After more than 1 year in operations, it worth presenting a general status about the instrument capabilities and performances over Ocean. How it is consistent, at long spatial wavelengths, with existing nadir altimetry, our reference for 30 years, and how it revolutionizes our observations of the Ocean small scale topography. For this purpose, a high level description of the main changes with respect to nadir altimetry will be presented. To describe this new paradigm, different general aspects will be addressed, from the general use of the data to the description of new signals observed through a general comparison of the performances measured over open Ocean. The results and information that will be presented aim at demonstrating that SWOT is a revolution that will also contribute to pull the nadir altimetry expertise and knowledge up.

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CORNER REFLECTORS FOR RADAR ALTIMETER EXTERNAL CALIBRATION: LESSONS LEARNT FROM THE FIRST THREE YEARS OF MEASUREMENTS AT THE MONTSEC CALIBRATION FACILITY

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External calibration of radar altimeters by means of passive reflectors is a novel technique that has already demonstrated equivalent performance in terms of range and datation precision as that from active transponders (Gibert et al 2023), and in addition to that has also demonstrated its capability to provide both power and range measurements in the same system, while typical transponders are either specific for range or for sigma0 measurements.

The development of Fully-Focussed SAR (Egido and Smith 2017) processors has been essential for the success of corner reflectors as calibration elements for radar altimeters, as FFSAR algorithms allows to combine optimised along-track resolutions and strong background clutter reduction at the reflector location with respect to other algorithms such as Delay-Doppler. Combining such improvement with a careful site selection, preferably at certain off-nadir distance to reduce even more the cross-track ground resolution, Signal-to-Clutter Ratios up close to 40 dB can be achieved, enough for calibration standards including impulse response function characterisation.

The first long-term corner reflector deployed for radar altimeter external calibration was installed early in 2021 on a summit of the Montsec ridge near Barcelona, and has been operative since Summer 2021 with pass success rate above around 98%. Periodic Sentinel-6 passes have been analysed since then, achieving residual range noise close to 1 cm and Radar Cross Section (RCS) measurements compatible with the theoretical value and with standard deviation below 0.4 dBm2. Sentinel-3B and CryoSat-2 SAR/SARin acquisitions have recently been incorporated to the regular monitoring.

In this contribution we will review the lessons learnt after three years of data acquisition with the Montsec corner reflector. The facility will be described, and the main results will be presented, including a first Sentinel-6 analysis of multi-seasonal correlation with geophysical corrections and the results of a comparative analysis between the different methods available to correct the range from tropospheric delays, including the ones from a new permanent GNSS station installed close to the reflector. Finally, future calibration options based on passive elements for current and upcoming altimetry missions will be discussed.

REFERENCES

F. Gibert et al., "A Trihedral Corner Reflector for Radar Altimeter Calibration", in IEEE Transactions on Geoscience and Remote Sensing, vol. 61, pp. 1-8, 2023.

A. Egido and W. H. F. Smith, "Fully Focused SAR Altimetry: Theory and Applications", in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 1, pp. 392-406, Jan. 2017.

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PORTABLE CORNER REFLECTOR CAMPAIGNS: RESULTS AND LESSONS LEARNT

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The development of Fully-Focussed SAR (FF-SAR) processors [1] has facilitated the external calibration of radar sensors utilising passive reflectors, achieving equivalent performance as that from active transponders in terms of range and datation precision. Indeed, isardSAT deployed the first corner reflector for radar altimeter long-term external calibration in early 2021 [2], providing measurements for Sentinel-6, Sentinel-3B and CryoSat-2 SAR/SARin missions since then.

Within this framework, isardSAT designed a corner reflector featuring reduced dimensions and weight, while preserving robustness, orthogonality and radar cross-section high enough to ensure operatibility over a wide set of clutter scenarios, and allowing easy handling and transportability. The introduction of this type of corner reflectors for external calibration and point target analysis opens up a wide range of new possibilities. It enables the possibility to test potential new calibration sites using the portable reflector before installing the permanent corner reflector or, once the site planning is completed, allows for fine-tuning of the final location to minimise surrounding background clutter to optimise the Signal-to-Clutter Ratio. Additionally, it facilitates preliminary measurements during the initial stage of commissioning in those locations where the orbit will not be the definitive one. Furthermore, these corner reflectors can also be utilised for external calibration or scientific research in remote or inaccessible areas, where otherwise it would not be feasible.

This contribution showcases the performance of the new portable corner reflector designed by isardSAT in various locations, under different clutter and external interference scenarios, covering Sentinel-3, Sentinel-6 and CryoSat-2, and outlines the lessons and conclusions obtained from these tests. It also includes the results of a month-long campaign conducted in parallel at the Montsec calibration facility where the permanent corner reflector is located, enabling a direct comparison of the results obtained between both passive reflectors.

[1] A. Egido and W. H. F. Smith, 'Fully Focused SAR Altimetry: Theory and Applications', IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 1, 2017, doi: 10.1109/TGRS.2016.2607122.

[2] F. Gibert et al., "A Trihedral Corner Reflector for Radar Altimeter Calibration," in IEEE Transactions on Geoscience and Remote Sensing, vol. 61, pp. 1-8, 2023, Art no. 5101408.

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IMPACT OF THE SOUTH-ATLANTIC ANOMALY RADIATIONS ON DORIS ULTRA-STABLE OSCILLATOR: RESULTING EFFECTS ON DORIS MEASUREMENTS AND ORBIT DETERMINATION FOR SENTINEL-3A AND SENTINEL-6A

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Most of altimetry missions rely on both DORIS and GNSS for orbit determination purpose. For both techniques, the knowledge of a frequency reference is crucial.

For the DORIS system, this reference comes from an onboard Ultra-Stable Oscillator (USO). The behaviour of this USO is affected by irradiation rates, especially in the vicinity of the South-Atlantic Anomaly (SAA) where the radiations are important. Throughout DORIS processing, the rapid variations of the USO due to radiations are not accounted, as the behaviour of the latter is only modelled by a polynomial. Consequently, high irradiations rates such as in the SAA result in higher DORIS residuals. This effect is strongly visible for stations located in the SAA region.

The configuration of Sentinel-3A and Sentinel-6A where both GPS and DORIS receiver are coupled to the USO allows to mitigate this issue. Indeed, the GNSS clock is determined during the orbit determination processing. This clock can be used in state and place of the third order polynomial.

This integration of the GPS clock as the modelled DORIS USO is hereby presented. The impact of this modification in the orbit determination is discussed regarding DORIS residuals at first. Notable differences are observable, especially for the DORIS stations located in the SAA.

The resulting orbits are compared with the new POE-G standard orbits in order to characterize the impact of such a correction on the DORIS processing for both Sentinel-3A and Sentinel-6A.

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PRECISE ORBIT DETERMINATION OF ALTIMETRY SATELLITES USING DORIS AND SLR OBSERVATIONS IN DIFFERENT REFERENCE FRAME REALISATIONS

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Since 2023, three different solutions for the latest (2020) realization of the International Terrestrial Reference System (ITRS) are publicly available, namely the ITRF2020, the JTRF2020, and the DTRF2020. All solutions are based on the same input data but were derived using different combination approaches and data correction strategies. Since the ITRS realisations are used as a priori reference frames for precise orbit determination (POD) of Earth orbiting satellites, it is important to investigate the impact of the different frames on the POD results.

In this study, we want to show influences of the different xTRF2020 solutions on the POD of altimetry missions with focus on technique-related frames (SLRF and DPOD). We use single-technique (SLR and DORIS), as well as combined orbit solutions and present, which data correction models with respect to either the reference frames (e.g., non-tidal loading) or observations (e.g., biases) should be applied for reliable POD results. We analyse time series of orbit differences and geodetic parameters.

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TOWARDS A RECONCILIATION OF THE LRM AND SAR ALTIMETRY OCEAN MEASUREMENTS IN AN OPERATIONAL CONTEXT FOR SENTINEL-3

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After 15 years of unfocused-SAR altimetry, from the launch of CryoSat-2 in 2010, significant progress has been achieved in understanding the difference between altimetry measurements in unfocused SAR mode and in (P)LRM mode over ocean and link them to geophysical or instrumental effects.
SAMOSA(+) retracking, LR/HR numerical retracking with interface to in-flight instrument impulse response

([1],[2]), range-walk correction by Chirp Zeta-Transform (CZT) [2] or DFT [5], better calibration scheme [4], stack-retracking estimating directly orbital wave velocity standard deviation and line-of-sight surface velocity [3] are all algorithms which helped to reach the "budget closure" of the net difference between SAR and (P)LRM and at the same time reaching a higher measurement stability.
Some of these innovations are already implemented in an operational context or about to be implemented, as SAMOSA(+) retracking, CZT, numerical retracking, in the EUMETSAT marine ground segments for Copernicus Altimetry missions.
Anyhow, some of these recent innovations are difficult to be ported in an operational context since they would require intense ground segment re-engineering in term of computational time and system architecture changes, impacting the timely operational delivery of data. This has stimulated the exploration of other viable alternatives which can be “ready-to-be-implemented” and at the same time accurate.
In this work, after a very brief recapitulation of all the accomplished efforts in the last 15 years about what we have learnt, we are presenting some of these next operational L2 algorithms for Sentinel-3, which aim to solve in post-processing the current remaining discrepancies between LRM and SAR altimetric measurements in the marine products, acting on basic oceanographic relationships between wave-period, significant-wave-height and wind speed, and on a new type of sea-state-bias solution.
This enables to estimate in a very simple manner from SAR altimetry data new wave parameters as orbital wave velocity standard deviation and successively correct for its effect on the SAR data, (using a look-up table [6], built on data simulations) without using any wave parameters from numerical weather prediction models.
Also, recent efforts to estimate from SAR altimetry data the wave skewness parameter will be featured since they could be useful in the assessment of the maturity degree of the sea and the link with the sea-state-bias.
The study will be based on Sentinel-3 marine reprocessed dataset (baseline collection BC005), given the long span of this dataset.

[1] Buchhaupt et al.(2018): A Fast Convolution-Based Waveform Model for Conventional and Unfocused SAR altimetry. https://doi.org/10.1016/j.asr.2017.11.039
[2] Dinardo et al. (2023): Sentinel-6 MF Poseidon-4 radar altimeter: Main scientific results from S6PP LRM and UF-SAR chains in the first year of the mission. 10.1016/j.asr.2023.07.030
[3] Buchhaupt et al.(2023): Towards the Mitigation of Discrepancies in Sea-Surface Parameters Estimated from Low- and High-Resolution Satellite Altimetry, https://doi.org/10.3390/rs15174206
[4] Dinardo et al.(2023): A Fast-Time Amplitude and Phase Correction for the Global-Range-Impulse-Response of Sentinel-3 Altimeter, Presentation at 8th S3VT, https://www.eventsforce.net/eumetsat/frontend/reg/absViewDocumentFE.csp?documentID=1526&eventID=44
[5] Scagliola et al.(2018): Evaluating the impact of range-walk compensation in delay/Doppler processing over open-ocean https://doi.org/10.1016/j.asr.2019.11.032
[6] Egidio e al.(2022): A Significant-Wave-Height Correction to Account for Vertical-Wave-Motion Effects in SAR Altimeter Measurements, https://doi.org/10.24400/527896/a03-2022.3460

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PRECIPITATIONS AS SEEN FROM ALTIMETRY MISSIONS : FROM TOPEX-POSEIDON TO SURFACE WATER AND OCEAN TOPOGRAPHY MISSION, FROM ONE-DIMENSIONAL COARSE FLAGGING TO TWO-DIMENSIONAL DETAILED CHARACTERIZATION.

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Satellite altimetry missions measure the sea surface height (SSH) at a global scale and with increasing accuracy since 1992. The attenuation of microwave radar pulse depends on the moist air refractivity index, characterized by the pressure, the temperature, the water vapor, the cloud liquid water content and the precipitations (rain, snow, graupel, ice).
The altimeter signal is traditionally emitted in the Ku band at around 13.5 GHz as used by Topex (13.6 GHz) and Poseidon (13.65 GHz) altimeters up to the latest Jason-3 (13.6 GHz) and Sentinel-3 (13.575 GHz) series. Atmospheric attenuation ($\Delta\sigma0$) at the Ku band has been specifically characterized since the very beginning of the spatial altimetry era. As the Ku band is mostly affected by precipitations, early papers are dedicated to characterizing the impact of rain on the Topex/Poseidon observations. Rain flag and even rain rate are estimated from the difference between altimeter backscattering coefficients at the main Ku band and the secondary C band.
A first improvement on the characterization of precipitation by radar altimeter occurred with the launch in 2013 of the CNES/ISRO SARAL/AltiKa mission which was the first attempt by an altimetry mission to use a central frequency in the Ka band at 35.75 GHz. Progresses were made both in terms of spatial resolution (from 15 km to 4 km) and spatial sampling (from 7 km to 175 m). Picard et al. (2021) shown how the observations at Ka-band of the radar backscatter coefficient allows to not only provide more representative statistics on rain cells (occurrences, amplitude, size), but also describe the internal structure of the cells.
A new step forward is made with the launch of the Surface Water and Ocean Topography (SWOT) mission end of 2022. Thanks to the technological breakthrough allowed by the Ka-band Radar Interferometer (KaRIn) operating on the principle of a synthetic aperture radar

(SAR), the Ka-band backscattering coefficent is now available on a two-dimensional grid spanning 70 km on either side of the nadir track with two grid cell resolutions available (250 m x 250 m and 2 km x 2 km). The same approach used for AltiKa has been applied to the first year of data of the SWOT mission allowing a two-dimensional characterization of the precipitation cells. As a matter of comparison, the swath of KaRIn is smaller than the Ka-band precipitation radar (KaPR) of the Global Precipitation Measurement (GPM) (250 km), without its range slicing capability (250/500 m for the KaPR) but with a much greater spatial resolution (5 km for the KaPR).
In the context of the "30 years of Progress in Radar Altimetry" Symposium, we will present an historical overview of the impact of the precipitation on the altimetry system, from a simple flagging approach inherited from the historical mission to the fine characterization using the most up-to-date measurement techniques that have the potential to help the atmospheric community to better understand those complex phenomenon.

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MULTIVARIATE DATA ASSIMILATION FOR HYDROLOGICAL FORECASTING IN LARGE RIVER BASINS: A CASE STUDY ON THE NIGER RIVER BASIN USING THE HYFAA MODELING PLATFORM

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The recent launch of new hydrology-dedicated satellite missions, exemplified by the SWOT mission in December 2022, offers unprecedented opportunities for monitoring and forecasting continental water resources. However, harnessing the full potential of these novel satellite products necessitates the development of fully automated hydrological forecasting systems. To address this need, we present the HYdrological Forecasting system with Altimetry Assimilation (HYFAA), an integrated platform that combines the MGB large-scale hydrological model with an Ensemble Kalman Filter (EnKF) module, enabling the correction of model states and parameters based on discharge observations. While discharge is conventionally employed for data assimilation in hydrological models, it has inherent limitations. Firstly, it provides only one-dimensional information regarding the hydrological flow and fails to capture lateral processes crucial in flooded areas. Moreover, deriving discharge from nadir altimetry data via rating curves introduces spatial sampling limitations. Consequently, combining discharge observations with other types of data can enhance the representation of complex hydrological processes in large basins. In the context of a CNES-funded project, our study focuses on implementing and evaluating multivariate data assimilation techniques in the Niger River basin using the HYFAA platform. Three observations are assimilated: water levels and discharge from the Hydroweb database and surface water bodies derived from Sentinel-1 and Sentinel-2 data processing. We begin by evaluating and comparing the performance of the EnKF when assimilating each variable separately. Subsequently, we investigate the benefits of combining multiple assimilated variables within the system. We employ in-situ or independent datasets whenever possible to validate the assimilation results. In their absence, a random sample of the assimilated datasets is used for validation.
Data assimilation performance in large river basins can be hindered by false correlations between independent cells arising from the finite size of the ensemble. Localization algorithms, which assign distance-decreasing weights to correlations, are commonly employed to mitigate this issue. Nevertheless, existing localization methods typically adopt simplistic homogeneous approaches across the entire basin. In this work, we introduce a model-based localization method that assigns an autocorrelation length to each river pixel and compare its performance against an empirical method employing a constant correlation length.
Finally, we discuss the obtained results in the context of assimilating data from future satellite missions, such as the SWOT mission. The outcomes of this study provide valuable insights into the advancements and challenges associated with multivariate data assimilation for hydrological forecasting, facilitating the utilization of emerging satellite products for improved water resource management and flood prediction in large river basins.

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COMPARISON OF HF RADAR MEASUREMENTS WITH AIS-DERIVED SURFACE CURRENTS, GLORYS REANALYSIS, AND GLOBCURRENT ANALYSIS IN THE AGULHAS CURRENT REGION

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[1]*Eodyn*

The Agulhas Current and Agulhas Bank, situated off the southern tip of Africa, represent one of the world's most dynamic marine environments. Characterized by strong currents and significant oceanographic phenomena, they play a crucial role in global climate regulation and local marine ecosystems. Understanding the surface currents in these areas is pivotal for a range of applications, from navigation safety to climate research.

The advent of Automatic Identification System (AIS) technology, primarily used for tracking vessel movements, presents a novel opportunity to study surface currents. AIS data, as a byproduct of maritime traffic, can potentially offer extensive spatial coverage, leveraging the movements of ships to measure total surface currents.

This paper aims to conduct a comprehensive comparison between AIS-derived surface current data and HF radar measurements used as a reference in the Agulhas Current and Agulhas Bank region. The reliability and accuracy of HF radars make them a highly trusted surface current measurement system. Studies have shown that they can provide precise estimates of radial surface current speed with an average error of less than 10 cm/s ([Paduan and Rosenfield, 1996]; [Chapman et al., 1997]).

In addition to the aforementioned comparison between AIS derived and HF radar data, this research seeks to extend the analysis by including two prominent marine current (re)analysis products:

- Glorys (Global Ocean Reanalysis System), developed by Mercator Ocean International and distributed by the Copernicus Marine Service, offers a comprehensive global ocean reanalysis dataset.
- Globcurrent, developed under the European Space Agency's Data User Element (DUE) programme, provides global ocean surface current analyses. Unlike Glorys, it focuses solely on the upper ocean, combining geostrophic currents derived from satellite altimetry data with Ekman currents derived from wind stress fields.

By comparing the AIS derived ocean surface current data, Glorys reanalyses, and Globcurrent analysis to the HF radar measurements used as a reference, we aim to evaluate the relative strengths and limitations of each product.

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REFERENCE OBSERVATIONS IN SUPPORT OF SEA ICE ALTIMETRY MISSIONS – AN OVERVIEW AND FUTURE NEEDS

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Sea ice altimetry is currently the primary method for estimating climate data records (CDR) of sea ice thickness from space. Evaluation of the satellite-derived sea ice freeboards, thicknesses and related snow depth products are a crucial step for better understanding the mechanisms behind the satellite-derived products and to support consistency of the CDRs to avoid e.g., inter-satellite biases. However, reference measurements are sparsely distributed in the Arctic and even sparser in the Antarctic due to the harsh environment and cost-expensive access. Furthermore, they are rarely presented in a format matching the satellite-derived products.

Here we present a data package of available reference observations of freeboards, thicknesses, drafts and snow depths from multiple sources (airborne campaigns, ship and submarine cruises, moored as well as drifting buoys, and in situ measurements) covering the polar radar altimetry era 1993-present. The data package has been prepared to match the spatial scales (25 km for northern hemisphere and 50 km for southern hemisphere) and temporal resolutions (monthly) of satellite altimetry-derived sea ice thickness data products. The data package (known as the sea ice thickness round robin SIT RRDP) is collected as part of the ESA Climate Change Initiative (CCI) Sea Ice project, and assists the evaluation and algorithm development of the dedicated CCI Sea Ice thickness CDR.

The CCI SIT RRDP has been collocated to satellite-derived sea ice thickness products from CryoSat-2, Envisat and ERS-1/2 produced within the ESA CCI and Fundamental Data Records for Altimetry (FDR4ALT) to demonstrate the availability and inter-comparison between the reference observations and satellite-derived products. We present here, the CCI SIT RRDP along with examples of its use as a validation source for satellite altimetry products and elaborate on the averaging, collocation and uncertainty methodology in terms of discussing their advantages and limitations.

In view of the learnings from the CCI project and a thorough literature review and analysis of existing methods made within the EU/ESA Sentinel-3 Topography mission Assessment through Reference Techniques (St3TART) project we discuss the roadmap and steps forward in support of the best strategy for providing a consistent reference observation network to assist current (CryoSat-2, Sentinel-3, AltiKa) and future (CRISTAL) polar radar altimetry missions.

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EFFECT OF THE SECOND ORDER IONOSPHERIC DELAY ON PRECISE ORBIT DETERMINATION OF DORIS SATELLITES AND ON THE CNES/CLS IDS ANALYSIS CENTER SOLUTION

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Currently, for the DORIS data processing with our POD software GINS we only use the ionospheric-free linear combination to eliminate the first-order term, while ignoring the influence of higher-order terms. So, as already done for the GNSS data processing, we implemented the second order ionospheric correction in GINS software for the DORIS data processing. First, we will look at the impact on Precise Orbit Determination by analyzing statistical results such as one per revolution empirical acceleration amplitudes and orbit residuals. We will also give some comparisons to the CNES precise orbit used for altimetry and external validations of our orbits will be done with independent SLR measurements processing. We will also analyze the impact on the CNES/CLS IDS Analysis Center solution in terms of origin and scale factor.

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CONTRIBUTION OF THE OPEN OCEAN TO SEA-LEVEL VARIATIONS OVER THE NORWEGIAN CONTINENTAL SHELF

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At the "30 Years of Progress in Radar Altimetry Symposium", we would like to present the preliminary results of an ongoing project. The project focuses on density fluctuations along the eastern margin of North Atlantic Ocean and their contribution to sea-level variations over the Norwegian continental shelf.

The project has two main objectives: increasing our understanding of ocean dynamics, and offering insights into the reliability of climate models. The presentation would mostly focus on the first objective, as the analysis of climate models is still under development.

To achieve its first goal, the project aims to identify the patterns of density variations in the open ocean that most significantly correlate to sea-level variations over the Norwegian continental shelf. A preliminary result suggests a role for the upper ocean. Specifically, density variations over the upper 200m of the eastern North Atlantic Ocean show a statistically significant correlation with the sea-level variability over the Norwegian shelf both on intra-annual and inter-annual timescales (after the contribution of local winds has been removed).

This result aligns with the existing literature which links density variations over the eastern margin of the North Atlantic Ocean to northern European sea-level variations using a combination of observational and modelling data. Compared to the existing literature, though, the present project provides additional information on the depth range over which density variations most affect the Norwegian sea-level variability. Furthermore, this project's finding is based on more recent observational datasets when compared to previous works. Indeed, the project analyses sea-level variations over the Norwegian shelf using the ALES-reprocessed coastal satellite altimetry dataset and the mass component of sea-level variations from the GRACE and GRACE-FO satellite gravimetry missions.

The project also uses two different products of ocean temperature and salinity to determine whether different spatial resolutions can impact the results. Specifically, the analysis is performed using EN4, which has a spatial resolution of 1°x1°, and ARMOR3D, which has a spatial resolution of 0.25°x0.25°. Both datasets return comparable results.

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CRISTAL SEA ICE & ICEBERG L2 PROCESSING: BASELINE APPROACH AND NEW DEVELOPMENTS

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The Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) is a satellite system developed as part of the European Union's Copernicus Expansion Mission (CEM) activities. The primary objective of the CRISTAL mission is to measure and monitor variability of Arctic and Southern Ocean sea ice thickness and its snow depth.
Built on the heritage of CryoSat, CRISTAL's main instrument is an Interferometric Radar Altimeter for Ice and Snow (IRIS). This technical solution is based on a dual-frequency synthetic-aperture radar altimeter with interferometric capabilities at Ku-band and a second Ka-band frequency. Moreover, CRISTAL will be equipped with a passive microwave radiometer to aid in atmospheric corrections and surface-type classification.
The features of the CRISTAL instrument will enhance our ability to estimate geophysical parameters:
(i) better precision for sea ice freeboard and along-track resolution, exploiting the open-burst chronogram and the FFSAR processing on-ground;
(ii) the capability to detect leads across tracks through interferometric acquisitions and
(iii) retrieval of snow thickness by analysing scattering range at both Ku- and Ka-bands.
Through this presentation, the current plan for the design, development and validation of the ESA CRISTAL Level-2 products is described. The CRISTAL Level-2 products will include different geophysical parameters in the sea ice domain, in the land ice domain, in the hydrology domain and in the ocean domain.
The CRISTAL Level-2 Ground Processor Prototype (GPP) in the Sea Ice & Iceberg domain will implement the geophysical retrieval algorithms for the following variables: sea ice freeboard, sea ice thickness, snow depth over sea ice, ice shelves thickness, iceberg distribution and volume. To achieve the Mission performance objectives, advanced geophysical retrieval algorithms for sea ice and icebergs are needed, so the CLEV2ER activity will carry out R&D studies to support

the definition and implementation of the new retrieval algorithms. Such R&D studies are geared towards addressing current scientific inquiries regarding sea ice retrieval in the context of CRISTAL:
(i) evaluating variations in sea ice thickness derived from Ku-band and Ka-band altimetry, resulting from differing penetration depths in snow cover on sea ice;
(ii) enhancing the quantity of sea surface height measurements in regions covered by ice through the utilization of multi-peak waveform retracking, identification of leads from nearby tracks, and swath processing; and
(iii) expanding the capacity to retrieve geophysical data in challenging sea ice conditions.
As part of the activity, a Transcoding Tool has been developed in order to adapt L1B data from other altimeters into the CRISTAL L1B format so their products can be used by the GPP to emulate CRISTAL L2 products, validate the new algorithms and derive performance metrics.
This presentation will detail the overall project approach, status and the first preliminary outcomes from the research tasks.

(Note to organising committee - this talk could also fit under theme 7 or 11 if you deem that more appropriate than 4)

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LATEST CNES/CLS IDS ANALYSIS CENTER SOLUTION UPDATES

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The satellite SWOT has been added to the DORIS processing chain of the CNES/CLS Analysis Center. First, we will give a Precise Orbit Determination (POD) status for this new DORIS satellite by presenting statistical results such as one per revolution empirical acceleration amplitudes and orbit residuals. We will also give some comparisons to the CNES precise orbit used for altimetry and external validations of our orbits will be done with independent SLR measurements processing. We will also analyze the SWOT single satellite solution and its contribution to the multi-satellite solution. Previous studies showed that from early 2023 there is a degradation on our POD results for the lowest DORIS satellites likeSentinel-3A. This degradation seems to be correlated with the increased of solar activity. So, we define a strategy to mitigate the impact of the increased of solar activity. We will look at the impact of this strategy on POD results and on our IDS solution.

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VALIDATION OF LONG-TERM MICROWAVE RADIOMETER MEASUREMENTS OF DIFFERENT ALTIMETRY MISSIONS FOR WET TROPOSPHERE PATH DELAY RETRIEVALS

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Microwave radiometers onboard altimetry satellites measure the atmosphere for total water vapor to determine wet troposphere path delay correction (WTC). Calibration errors and drift in the radiometer measurements (brightness temperature) can propagate into the WTC retrievals and hence into global and regional sea level products from altimetry missions. Recent update on path delay correction by JPL for Jason-3 AMR reduces the overall global sea level budget errors. With release of the TOPEX/Poseidon GDR-F sea level products and reprocessed S3A/B sea level datasets, the complete time series of radiometer measurements and of the derived WTC from different missions needs to be reevaluated independently for stability and inter-mission consistency. The Advanced Microwave Radiometer (AMR) onboard the latest altimetry satellite SWOT has two antenna beams (sides), with different off-nadir views for KaRIn's swath observation, which can be affected by roll angle differences and separate calibration, thus need to be evaluated for the calibration stabilities. The Jason/Sentinel-6 satellites and other non-reference missions, form a constellation and provide high spatial and temporal global SSH measurements. Calibration and validation of all the radiometers for stability and inter-mission consistency, with existing and new stable calibration references and through inter-mission comparisons, are essential steps to assure consistency and accuracy of the WTC retrievals and hence of the sea level measurements.
In this study, the Radar Altimeter Database System (RADS) at NOAA NESDIS/STAR with latest updates is used to check the microwave radiometer stabilities and inter-mission consistencies of different missions. Stabilities of brightness temperature time series are checked over the Amazon rainforest and the coldest ocean, which contribute to the hot and the cold sides of dynamic range. Inter-mission cross validations for relative bias and drift are also carried out through Simultaneous Nadir Overpass (SNO) among different altimetry missions, current NOAA JPSS missions, and previous NOAA missions with reprocessed water vapor Climate Data Records products. Global mean time series of brightness temperatures, especially for water vapor bands, are generated and the trends are compared with various references and CDR products. In addition, the WTC retrievals are compared with ERA-5 model results from RADS, and with available GPD+ WTC for different missions from AVISO. The WTC time series are validated against the brightness temperature measurements through sensitivity analysis.

Sentinel-6 High Resolution Microwave Radiometer (HRMR) has three high frequency bands for helping reduce WTC retrieval errors over coastal region. With about 4 years measurements, calibration stability of HRMR will be evaluated through comparison with vicarious calibration targets and the JPSS Advanced Technology Microwave Sounder. Understanding the performance of the Sentinel-6 HRMR will facilitate preparation for the Cal/Val activity of similar instrument onboard future CRISTAL mission.
Disclaimer: The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.

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TIDE GAUGE COMPARISONS FOR SENTINEL-3 AND SENTINEL-6

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The CEOS Virtual Altimetry Constellation now includes multiple altimeter missions that are capable of monitoring sea level change at climate scales. Because Sentinel-6 Michael Freilich is designated as the sea level reference mission of the CEOS Virtual Altimetry Constellation, it requires particularly careful evaluation of its stability to ensure the integrity of the sea level climate data record from altimetry. We present an update of how well the 1-mm/year stability goal has been met with the official data products for Jason-3 and Sentinel-6 MF. While the Sentinel-3 missions don't have a stability goal for sea level, they are near-independent measurements of global mean sea level, and therefore estimating their stability is also valuable to monitoring sea level rise and acceleration.

In this presentation, we provide updates of the NOAA Laboratory for Satellite Altimetry's Tide Gauge Comparison System for Jason-3, Sentinel-3, and Sentinel-6. We will compare results from different mission processing and retracking methods (i.e. High-Resolution, Low-Resolution, Pseudo-Low Resolution Mode, adaptive retracker). In addition to results from the baseline processors, we'll also present results from additional geophysical corrections.

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COMPARISON OF SLR BIASES DETERMINED FROM SATELLITE ALTIMETRY AND GEODETIC SPHERES

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Satellite Laser Ranging (SLR) has become an invaluable core technique in numerous geodetic applications. SLR measurements to passive spherical satellites essentially contribute to the determination of geocenter coordinates and global scale in the International Terrestrial Reference Frame (ITRF) realizations. In addition, SLR measurements to active satellites in Low Earth Orbit (LEO) are up to now mostly used for an independent validation of orbit solutions, usually derived by microwave tracking techniques based on Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) or Global Navigation Satellite Systems (GNSS). This allows for the analysis of systematic orbit errors (e.g., originating from poorly known non-gravitational perturbations or sensor offsets) not only in the radial direction (key to satellite altimetry missions), but in three dimensions.

It has recently been shown, in Saquet et al (2023), that the analysis of SLR data to a constellation of active LEO satellites with fixed microwave-derived orbit solutions is a promising approach to exhibit SLR range biases independently from well-known correlation issues and less prone to geographically correlated orbit errors. In this presentation, we continue our study of these biases by updating our analysis to the ITRF2020 standards. A second part of the presentation is dedicated to the comparison of our estimated range biases to the biases calculated weekly by ILRS with different satellites.

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OCEAN MESOSCALE HOT-SPOT AT THE NORDIC HIGH LATITUDES: THE LOFOTEN BASIN

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The Norwegian Atlantic Current contributes fundamentally to the temperate climate of northwestern Europe and maintains an ice-free ocean well into the Barents Sea even in winter. The interaction between the two branches of the Norwegian Atlantic Current is not known in detail but is generally understood to be mediated by mesoscale eddies. In particular, the Lofoten Basin appears as a hot spot of mesoscale activity in several studies in literature, based on conventional altimetry. While satellite altimetry has made a fundamental contribution to our understanding of ocean circulation, the current constellation of nadir altimeters does not allow for resolving the spatial and temporal scales characterizing the intensification and dissipation of the mesoscale features. The Surface Water and Ocean Topography (SWOT) mission, based on Ka-band Radar Interferometry (KaRIn), extends the capability of existing nadir altimeters to two-dimensional mapping of the ocean surface at an unprecedented spatial resolution. The fast-sampling phase (1-day repeat) of the mission also allowed for resolving the temporal evolution of mesoscale eddies. The Lofoten Basin is located in an area where the SWOT tracks cross, which was sampled twice a day over 90 days in 2023. Building on this unique opportunity, the results presented in this work rely on both the fast-sampling and science (21-day repeat) phases of the SWOT mission to show a comparison of KaRIn retrievals with conventional altimeters and characterize the representation of the mesoscale field emerging from the different altimetry concepts. The mesoscale features are then collocated with high-resolution remote-sensing retrievals (e.g. Sentinel missions) to characterize the impact of eddy-driven anomalies on essential ocean variables.

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STATISTICS OF ESTIMATED GEOPHYSICAL PARAMETERS FOR SEA STATES WITH SWELL.

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This is a report of the results of the ESA Open Call SwellStats Project. In the case that there is a distinct swell present on the sea surface, the presumption of a normal distribution of sea surface elevations fails over a small region such as the region imaged by a SAR altimeter. This deviation from a normal distribution of elevations causes the returned backscattered power to deviate from the mean backscattered power expected from a normally distributed sea surface elevation, leading to biases in the estimation of sea surface elevation and significant wave height when swell is present. It has been found that for a given significant wave height the variance in estimated significant wave height is a function of the fraction of the significant wave height that is due to swell. This functional dependence can be inverted so that the swell amplitude can be estimated from the variance of the significant wave height, and providing unbiased estimates for the sea surface height and significant wave height.

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APPROACHING A DECADE OF SENTINEL-3 AND SENTINEL-6 SAR OBSERVATIONS: LESSONS LEARNED AND WAY FORWARD

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The launch of the CryoSat-2 mission on April 2010 opened the era of SAR altimetry. Nowadays, SAR technology has been adopted by operational oceanography missions such as the Sentinel-3 (A, B and soon C) as well as by the topography reference missions such as the Sentinel-6 (A and soon B).

The continuous time series of dedicated SAR ocean topography observations spans now almost a decade: Sentinel-3A was launched on February 2016, followed by Sentinel-3B on April 2018 and last Sentinel-6A on November 2020. Within this time span, SAR altimetry has confirmed all the improvements expected over traditional nadir altimetry. Notably, higher along-track resolution and clearly reduced noise level in all geophysical retrievals. Altimetry performance over coastal and polar ocean regions has improved, and unleashed the possibility to extend the use of SAR observations over land water bodies. Nevertheless, the continuous Cal/Val monitoring of Sentinel-3 and Sentinel-6 evidenced some challenges newly introduced by SAR altrimetry observations; some already addressed and understood, others remaining to be further investigated.

In particular, to satisfy the needs of increasingly accurate global time series required by climate change studies, special attention has been given to long term stability of SAR altimetry data. Numerous studies have evidenced degraded long-term performances, mostly due to instrumental drift. Tackling these issues led to major updates in the missions' ground segments. The most relevant include: the addition of the range walk correction and the numerical retracker implementation.

This presentation will give an overview of those updates and will assess their impacts on the Sentinel-3 and -6 SAR datasets. Furthermore, the remaining standing issues and foreseen solutions will be discussed, within the long-term perspective of an ever-increasing harmonization of ground segments of the existing and future SAR altimetry missions.

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THREE DECADES OF ALTIMETRY ORBITS: CONSISTENT DORIS-BASED ORBIT SERIES AND VALIDATION

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Radar altimetry has been instrumental in advancing our understanding of Earth's oceans over the past thirty years, facilitating crucial insights into sea level variations, ocean dynamics, and many more. As we commemorate three decades of progress in radar altimetry, the need for a comprehensive and consistent orbit series spanning this period has become increasingly apparent. This presentation introduces an orbit series, based on consistent models and using Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) observations for Precise Orbit Determination (POD).
Our approach begins with an explanation of the adapted methodology used to compute satellite orbits for all DORIS-equipped altimetry missions, from TOPEX/Poseidon to the most recently launched SWOT mission. In order to assess the quality of the orbits, an

internal and external quality control is performed. This is followed by an altimetry analysis, with a focus on the analysis of the crossover points and changes in regional sea level variability and trends.
Quality control measures include the internal comparison with post-fit Satellite Laser Ranging (SLR) residuals and orbit comparisons with internally processed consistent reduced dynamic Global Positioning System (GPS) orbits. Subsequently the orbits are also compared with external combined orbit solutions, which are expected to have reduced minimum residual errors. A key aspect of our analysis involves the identification of geographic patterns in the satellite orbits, providing valuable insights into orbit dynamics and how these can be improved on a global scale. This comprehensive validation process serves to enhance confidence in the accuracy and consistency of the generated orbit series.
Finally, we demonstrate the utility of our orbits in global sea level monitoring, showcasing their effectiveness in key quality parameters such as crossover analysis.
In conclusion, this presentation encapsulates an effort to construct a consistent 30-year orbit series for radar altimetry satellites based on DORIS observations only, a unique opportunity for advancing our understanding of Earth's oceans and their dynamic evolution.

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SYNERGY BETWEEN ALTIMETRY, AIS AND SATELLITE TRACER DATA TO RECONSTRUCT SURFACE OCEAN CURRENTS.

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In the framework of Space4SafeSea project, we investigate the synergy between sea surface height (SSH) from Altimetry, ocean surface current derived from Automatic Identification System (AIS) and satellite-derived ocean surface tracers.

First, we develop an observation-driven methodology for exploring the spatio-temporal dependencies between SSH and sea surface temperature (SST), Chlorophyll-A (CL-A), and Sea Surface Salinity (SSS) fields. We define statistical tools, based on correlation and morphological analysis [Le Goff et al 2016], to assess and detect the spatial connections between SSH anomalies and tracer anomalies. This methodology has been applied to a 10-year time series in the highly dynamic Gulf Stream current region. The resulting space–time analysis reveals a seasonal variation in the overall correlations between SST, CL-A, SSS, and SSH fields and emphasizes different relationships and patterns between positive and negative SSH anomalies. During the summer period, the analysis shows a systematically higher correlation between SSS/CL-A and SSH variability than between SST and SSH. During the coldest months of the year (November to March), the correlation with SSS/CL-A is found to be significantly low as the quality of data is deteriorating. We then integrate these findings with ARGO profile measurements to investigate the seasonal impact of the mixed-layer depth.

Second, we investigate the synergy between AIS-derived and Altimetry-based surface currents in the Agulhas region. In this context, we propose to compare three ocean surface current products. The first two products are derived using optimal interpolation schemes from AIS data [Le Goff 2021] and Altimetry (DUACS), respectively. The last one is a merging product obtained by combining AIS and Altimetry data using MIOST algorithm [Ubelman et al 2021]. We aim to discern the strengths and weaknesses of each product using various metrics, including the misalignment of tracer gradients, direct comparison of velocities obtained from drifters, calculation of the Lyapunov exponents, and novel Lagrangian diagnostic methods suggested by Resseguier et al [Resseguier et al 2022].

Future work will further explore the use of the proposed methodology for the reconstruction of sea surface currents from a joint analysis of satellite Altimetry data, AIS and high-resolution tracer data.

[Le Goff et al 2016]: Le Goff, C., Fablet, R., Tandeo, P., Autret, E., & Chapron, B. (2016). Spatio-temporal decomposition of satellite-derived SST–SSH fields: Links between surface data and ocean interior dynamics in the Agulhas region. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(11), 5106-5112.

[Ubelmann et al 2021]: Ubelmann, C., Dibarboure, G., Gaultier, L., Ponte, A., Ardhuin, F., Ballarotta, M., & Faugère, Y. (2021). Reconstructing ocean surface current combining altimetry and future spaceborne Doppler data. Journal of Geophysical Research: Oceans, 126, e2020JC016560.

[Le Goff et al 2021]: Le Goff, C., Boussidi, B., Mironov, A., Guichoux, Y., Zhen, Y., Tandeo, P., et al. (2021). Monitoring the greater Agulhas Current with AIS data information. Journal of Geophysical Research: Oceans, 126, e2021JC017228.
https://doi.org/10.1029/2021JC017228

[Resseguier et al 2022]: Resseguier V, Chapron B, Mémin E (2022) Effects of smooth divergence-free flows on tracer gradients and spectra: Eulerian prognosis description. Journal of Physical Oceanography 52(1)

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INSIGHTS INTO THE SENSITIVITY OF SWOT KARIN MEASUREMENTS TO LAKE ICE AND OVERLYING SNOW PROPERTIES

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Lakes are integral components of the Earth's hydrological system and serve as sensitive indicators of climate change. For this reason, the Global Climate Observing System (GCOS) identifies "Lakes" as an essential climate variable (ECV), with lake ice cover (LIC) and lake ice thickness (LIT) being two of its thematic products. Lakes cover a significant fraction of the physical landscape in many northern high-latitude regions, and the presence/absence of LIC and its thickness have an impact on local/regional weather, climate, hydrological processes, permafrost conditions, transport between northern communities, recreational activities, and tourism.

Despite the need for frequent monitoring of LIC and LIT, there has been a marked decline in field measurements of lake ice and overlying snow properties over the last few decades, highlighting the need for alternative monitoring approaches. In addition, there has been a long-standing need for retrieving snow properties overlying lake ice, namely snow depth and snow mass (the product of snow depth and snow density), to improve the simulation of LIT from lake models used in standalone mode or as lake parameterization schemes in numerical weather forecasting and climate models. Although advances have been made in the retrieval of LIC and LIT from optical and microwave (Ku- to L-band) satellite remote sensing data, including radar altimetry, little is known about the sensitivity of Ka-band observations to snow-covered lake ice.

Our study focuses on assessing the sensitivity of measurements from the Surface Water and Ocean Topography (SWOT) mission's Ka-band Radar Interferometer (KaRIn) to lake ice and overlying snow properties and, in particular, investigating the potential of the instrument for estimating snow depth/mass on lake ice. By exploring KaRIn-derived parameters such as height, backscatter, coherent power, and phase, we aim to investigate spatio-temporal patterns in snow accumulation and melt and underlying surface ice properties across northern lakes, beginning with Teshekpuk Lake located on the North Slope of Alaska (USA). The presentation will report on our initial findings, supported by the analysis of complementary satellite, meteorological station and field campaign data. The outcomes of this study will benefit researchers working on the estimation of lake water level, LIC, and LIT from radar altimetry and numerical lake models.

Keywords: SWOT, lakes, lake ice, snow, wide-swath altimetry

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REVISITING THE GEOCENTER MOTION FOR AND FROM SATELLITE ALTIMETRY

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The ever-changing fluid mass (oceans, continental water, snow, atmosphere, …) redistributions on the Earth's surface give rise to a motion of the deformable terrestrial crust, that is its geometrical center-of-figure (CF), with respect to the center-of-mass (CM) of the Earth, about which satellites naturally orbit. This motion, called "geocenter motion", is the largest scale variability of mass within the Earth system. Yet, non-tidal geocenter motion, which reflects major water and atmosphere mass transports occurring over large regions, is traditionally neglected.

However, new climate-driven precise monitoring of geocenter motion is needed. Indeed, satellite altimetry and gravimetry precise orbits connect sea level and global water budgets to the Earth's center of mass. As such, the geocenter motion is now the leading error term in Regional Mean Sea Level and mass changes over polar ice sheets estimates. Reliable solutions of geocenter motion are thus crucial for assessing the current status of climate change and its future evolution (e.g., for the Earth's Energy Imbalance).

Global Navigation Satellite Systems (GNSS) measurement models and derived products are currently aligned to the International Terrestrial Reference Frame (ITRF) origin (which is referenced to the crust), instead of CM. Looking at sub-daily cross-track perturbations estimated with the GNSS receivers on board the Jason-3 and Sentinel-6 MF altimetry satellites during their tandem phase (December 18, 2020 – April 7, 2022) revealed consistent diurnal oscillations with an impressive temporal resolution. These could only be related to the miscentering effect of the constellation solution around the Earth' CM. In this paper, a parametric model is derived, representing the translation of the GNSS ground station networks with respect to the center of mass of the whole Earth system. This model is estimated with GNSS-based low Earth satellite precise orbits and unambiguously validated with independent altimetry satellite missions (e.g., Sentinel-3A, Sentinel-6 MF, Jason-3). It helps to clearly identify interannual variations in the geocenter motion, as short as a day long.

Finally, the impact of this newly derived geocenter motion model based on a constellation of Low Earth Orbiters is assessed on the reference altimetry mission, Sentinel-6 MF.

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QUALITY ASSESSMENT OF DORIS STATIONS ENVIRONMENT BASED ON POD RESIDUALS AND SIGNAL INTENSITY VARIATIONS

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The quality of DORIS stations environment based on POD residuals and signal power are regularly evaluated in the framework of the CNES SALP project. Time series and mapping projection of such data are analyzed and compared with POD standards evolution, with databases of material modifications, or in-situ photographies. As a result, some anomalies may be explained, and correcting actions can be taken accordingly by CNES and/or IGN (Institut Géographique National). Moreover, on a yearly base, a ranking of the DORIS stations is established, which enables to target the necessary site renovations. All these analyses allow to improve the quality of the DORIS network, and consequently the applications which rely on this high-accuracy observation network. This presentation summarizes the results obtained on the most recent evaluations.

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EVALUATION OF NADIR-ALTIMETRY OVER CHINESE RIVER

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Fully-Focused SAR processing (FFSAR) offers a significantly enhanced resolution, providing great promise for effectively distinguishing smaller water bodies. This study develops an approach to measure the nadir and off-nadir virtual stations using FFSAR products. The waveform from off-nadir and nadir targets are both aligned first and then applied slant range correction using river centerlines from SWORD. Subsequently, the SAMOSA+ retracker is employed to derive water surface elevation (WSE). Utilizing WSE and slope information obtained from altimetry, we estimated river discharge through two distinct approaches: the Bjerklie method, and the Manning methods.

Here, we utilized Sentinel-3A/3B and Sentinel-6 satellite data spanning from 2016 to 2023. We concentrate on evaluating WSE and discharge against gauge station data for various rivers, including the Yellow, Yangtze, and Pearl Rivers, which exhibit diverse geomorphological conditions. The SWOT HR L2 data were considered here for Cross-validation. The results demonstrate comparable accuracies of WSE between nadir and off-nadir virtual stations, with the smallest Standard Deviations of 0.08 m and 0.10 m, respectively.

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RECENT FRESHENING IN THE LOFOTEN BASIN AND THE ROLE OF MESOSCALE EDDIES

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The Atlantic Water (AW) transported to the Arctic Ocean from the northeast Atlantic via the Nordic Seas plays a major role in the local and global climate system. In the Nordic Seas, the AW due to excessive atmosphere heat loss and freshwater input, transforms, and contributes to the formation of deep overflow waters, a main source of the North Atlantic Deep Water. Situated along the advective path of the AW in the Nordic Seas, the Lofoten Basin (LB) is the place where the AW resides for the longest during its poleward route to the Arctic. LB is also a hot spot of high eddy activity in the Nordic Seas. The AW heat and salt from the two branches of the Norwegian Atlantic Current bordering the LB is transported into the basin interior by mesoscale eddies. AW loses large amount of heat during winter, and not surprisingly, LB is categorised as the place where most of the bulk of light to dense water formation takes place in the entire Nordic Seas. Recent studies showed evidence of freshening in the Nordic Seas, associated with the recent Great Salinity Anomaly (GSA) event in the eastern sub polar North Atlantic during 2012 to 2016. This GSA event has been labelled as the most extreme freshening event in the region during the past 120 years. In here, we use a suite of satellite, in-situ, and ocean reanalysis data to investigate the recent freshening in the LB and the role of ocean mesoscale eddies. The 30-year satellite altimeter data is used to detect the anticyclonic and cyclonic eddies in the LB. Initial analysis shows penetration of less saline waters into the deeper layers of the basin aided by the mesoscale eddies. Further we show the impact of this freshening on the dense water formation as well on the biology of the region.

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SEA-LEVEL RECONSTRUCTION AT THE REGIONAL SCALE OVER THE LAST SEVEN DECADES

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The knowledge gaps on the exact origins for the internal oceanic variability forced by climate episodes and

plausibly resulted in contemporary rapid sea-level changes remain arguably elusive.
This is in light of the relatively shorter but continuing, uniform and global 30-year satellite altimetry sea-level climate record. Here, we use an improved empirical sea-level reconstruction method, aided by deep-learning analytics to conflate longer but sparsely located tide gauge and 30 years of altimetry sea-level records to reconstruct global sea-level changes covering the past seven decades, 1952–2022. The objective aims at improved separation of the evolutions of the climate patterns, including but not limited to, El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO), and rapid sea-level rise at regional scales, to study their plausible interactions under an increasingly warmer Earth. Here, we considered various error sources and their possible mitigations including mitigating data gaps of tide gauge records and their selections, separating the effect of vertical motions at tide gauge locations with geophysical or anthropogenic origins, geocenter motion, multi-decadal periodicities, and other error sources.

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30 YEARS OF PROGRESS IN TECHNOLOGY AND ALGORITHMS FOR THE ALTIMETRY WET TROPOSPHERIC PATH DELAY CORRECTION

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Water vapor in the Earth's atmosphere slows the propagation of the radar signal as it travels from the spacecraft to the ground and back again. This delay translates to extra range that varies from 0 to 45cm and is highly variable in space and time. A range correction, termed the wet tropospheric path delay correction, is applied to enable cm-level height estimates from the altimeter. The wet path delay correction is provided with mm-level uncertainty by a dedicated microwave radiometer on the satellite. The very first such radiometer on-board Topex/Poseidon was literally built from spare parts of the Scanning Multi-frequency Microwave Radiometer that flew on Seasat. Subsequent radiometers built for Jason-1, 2 and 3 incorporated new technology to improve precision, spatial resolution and the overall sensor calibration. As the altimetry record grew and the importance of accurate monitoring of the global mean sea level (GMSL) trend became critical, it was apparent that the stability of these radiometers on decadal time scales was insufficient. In fact, the radiometer was generally considered the largest error term in the GMSL error budget. With Sentinel-6, this issue was addressed by an entirely new radiometer design that enables sub-mm level stability on time scales from 30 days to >>10 years. This radiometer secures our ability to track GMSL changes at the 0.1mm level for the next decade.

Coastal altimetry science and applications have grown exponentially over the altimeter record. Early studies suffered from large measurement uncertainties. This is primarily because we were using a measurement system where it was not designed to operate. In particular, the radiometer becomes contaminated by the radiometrically warm land signal, biasing the wet path delay estimate with ~50km of the coast. Improved processing algorithms were first developed to overcome these limitations to the extent possible. However, with Sentinel-6, a new mm-wave radiometer, called the High-Resolution Microwave Radiometer (HRMR) was included specifically to provide accurate wet path delay to within 5km from land. This instrument has now proven successful and is planned for future missions, such as CRISTAL.

We will provide a brief history of the microwave radiometer technology and wet path delay algorithm evolutions over three decades of altimetry and discuss future trends. We will show the benefits of Sentinel-6 radiometer, which is the most advanced radiometer ever flown in the altimetry family of missions. We will discuss future radiometer technology evolutions in development that will allow even more precise wet delay estimates and also allow for cross-track scanning to support future wide swath altimeters (e.g. SWOT like systems).

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PERFORMANCE OF SATELLITE ALTIMETRY OBSERVATIONS OF WATER SURFACE ELEVATION OVER TROPICAL RIVERS IN INDONESIAN BORNEO

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Indonesia lies along the equator, which leads to its tropical climate with almost-equal precipitation rates over every months. Given the tropical climate, rivers in the vast lowlands of Kalimantan (Indonesian Borneo) pose significant water surface level dynamic over short period due to short lag time and very strong current following torrential rain in the headwaters.
Current satellite altimetry missions, i.e. Jason-3, SARAL/AltiKa, SWOT and Sentinel-3 were evaluated to understand this water surface elevation dynamics. Remote sensing imageries and geospatial information were used to mask the water bodies. The multi-mission altimeter range measurements were filtered with machine learning approach based on waveform shapes that conform to inland water signature. Standard waveform retracking were applied to the multi-mission satellite altimetry range measurements. The

corresponding re-tracked range then processed to reveal water surface elevation of the rivers.
This study is part of a research program that provide a way to monitor water surface elevation in Indonesian Borneo. In the later stage of the research program, the satellite altimetry-derived water surface elevation will be assimilated with the hydro-dynamic model forecast to improve the prediction of catastrophic flood based on the precipitation level along with other hydrological factors.

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MONITORING WATER LEVEL AND DISCHARGE OVER A 200 KM REACH OF THE RHINE RIVER

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Over a 200 km long reach of the river Rhine between Speyer and Koblenz, accuracy, precision and spatial resolution of inland water heights of Sentinel-3 and Sentinel-6 SAR nadir altimeters are investigated against conventional and swath-altimetry and in-situ data.

Our multi-sensor database including forty river gauges, four lidar sensors vortex.io under bridges, sporadic GPS measurements on ships and eight Raspberry Pi Reflectors (RPR) allows to compare from space observed water level, width, slope and derived discharge to in-situ and model data. The favourable Sentinel-3A pass 156, parallel to the river centerline for more than 30 km, facilitates the comparison of the same quantities over complete reaches and at several locations. In nadir altimetry, the best accuracy (6 cm) is obtained with fully-focused SAR (FFSAR) processing for Sentinel-6 tracks perpendicular to the centerline and directly overflying the gauge. We find that the posting rate affects the precision and that the precision of the FFSAR products is higher for a selected posting rate.

Nadir altimetry has been designed for open ocean where homogeneous scattering is expected and land clutter is absent. However, the radar scenario over inland waters is more complex than that for the open ocean, as each individual echo contains a mix of water and land reflections. There might be interferences from backscatter originating from reflectors in the vicinity of the target water surface. Moreover, the surface scenario can change from cycle to cycle, as the satellite drifts from its nominal track. Land interference cannot be assumed as stable over time as, e.g., vegetation might be very quickly changing, and reflectivity of the water shifts from specular to a certain degree of scatter. Moreover, multiple water surfaces can exist in the radar footprint.

FFSAR, Unfocused (UFSAR) SAR and single burst processed data (PISA) have a different sensitivity to the signal from nadir and non-nadir targets. In this work, we show that harbours and ponds contaminate differently the radargrams and the time-series built from these three processing methods. We found that FFSAR is more suitable to construct time-series in rivers also from non-nadir observations, while PISA can better separate and build time-series on a pond. The interference among multiple water surfaces in SWOT observations shall also be investigated in the same region.

This work is carried out in the framework of the collaborative research centre DETECT (Regional Climate Change: Disentangling the Role of Land Use and Water Management) in project B0 that estimates water level and discharge from the new generation satellite altimetry.

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ICEBERG DETECTION IN THE SOUTHERN OCEAN BASED ON A MULTI-SENSOR APPROACH.

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For more than 15 years now, CLS has provided an iceberg detection service in the Southern Ocean for the safety of the largest offshore sailing races around the world.
Initially based exclusively on SAR imagery, which remains the most relevant technique, this service has evolved profoundly, gradually integrating a multi-sensor approach. This service is organized around 2 phases: the first phase is routine monitoring based on the use of several observation techniques whose data are freely accessible, such as those from the European Copernicus program: altimetry, multispectral imaging, optical imaging and SAR imagery. The second phase mainly uses commercial SAR imagery according to specific user needs and a drift-model.
After a quick presentation of the service, we will address more specifically the contribution of altimetry, which makes it possible to describe the overall situation of iceberg populations and to follow their evolution over time. We will discuss the interest, for this service, of the multiplication of sensors, the differences between LRM and SAR-Doppler modes, and the detection performance. Finally, we will present first results on the use of SWOT measurements for the detection of icebergs.

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PERFORMANCE OF THE RADIOMETERS ON SENTINEL-6 AND SWOT FOR WET PATH DELAY CORRECTION

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The AMR-C radiometer on-board the Sentinel-6 satellite features two advanced design evolutions that enable sub-mm level stability from 30 days to decades and the ability to accurately measure wet path delay to within 5km from land. The AMR-S radiometer on the SWOT mission includes multiple beams to provide the first ever swath correction for an altimeter mission. We will provide an update to the performance of these two sensors. For AMR-C, we will show an inter-comparison to other radiometer instruments and models demonstrating the long-term stability to 0.1mm over decades. We will show how the High-Resolution Microwave Radiometer is performing near land, enabling cm-level estimates of the path delay to within 5km from the coast. For SWOT, we will describe the calibration and validation technologies that have been developed for this new measurement approach. This includes the cross-swath inter-calibration of the two radiometer systems that make up the AMR-S. Finally, we will briefly discuss future instruments in development, giving perspectives on new applications they will enable for altimetry science.

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IMPROVING THE MESOSCALE EDDY CHARACTERIZATION THROUGH COMBINED APPROACH WITH ALONG-TRACK DATA AND NUMERICAL MODEL

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Long-lived mesoscale ocean eddies, with lifetimes of weeks to months, play a crucial role in the transport of heat, salt, nutrients, and life in the open ocean. Measuring mesoscale eddies, typically ≃100 km in size and constantly in motion, from satellite altimetry is challenging due to limitations in spatial and temporal resolution. While the global mapped product interpolated from various altimetry data allows access to higher resolution, their accuracy at the scales necessary to resolve mesoscale eddies has not been thoroughly investigated. Therefore, a combined approach is proposed, leveraging a long history of the past 30 years of the along-track data alongside insights derived from a nonlinear eddy generated with a numerical model.

In satellite altimetry-based eddy analysis, aggregate statistics of eddies often assume axial symmetry and describe an average eddy shape with a few parameters (i.e. amplitude and radius). The SSH signature of ocean eddies are never symmetric and only appear so as a result of averaging numerous realizations of individual eddies. Eddies are better represented as ellipses. To identify any potential bias that arises from the symmetric eddy shape assumption, various eddy composite methods are explored using an OSSE (Observing System Simulation Experiment) study. The data are sampled from a synthetic eddy generated from a numerical model in the eddy-centered reference frame. The eddy-centric analysis serves as a testbed for exploring various eddy estimation methods, including commonly employed eddy tracking methods, fitting various eddy profiles from a parametric model that accounts for the eccentricity in eddy shape, and incorporating insights from eddy evolution (i.e. rotation and propagation). The result from the OSSE is also compared to the gridded data, with an approximated covariance smoothing added, to evaluate the accuracy of the interpolated mapped data.

A case study is conducted on a selection of isolated eddies from the real-world observations, aiming to address questions surrounding our current understanding of eddy dynamics, including energy transfer and mass transport (e.g. trapping and leakage). The proposed approach has the potential to improve our ability to accurately infer eddy properties from sparse alongtrack data and provide guidance to processing SWOT data.

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SEASONAL TO DECADAL VARIATIONS IN OCEAN CURRENTS OFF CANADA'S PACIFIC AND ATLANTIC COASTS

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Coastal currents off Canada's Pacific and Atlantic feature complicated spatial and temporal patterns. Nevertheless long-term in-situ current observations are scarce. In the past thirty years, we have used along-track satellite altimetry data in conjunction with ocean circulation models to monitor and study seasonal to decadal variations of sea surface currents. Off Canada's Pacific coast, the shelf-edge current west of Vancouver Island reverses its direction from poleward in winter to equatorward in summer, while largely poleward west of Haida Gwaii. Anti-cyclonic eddies form in Queen Charlotte Sound in spring and summer, while a cyclonic partial gyre dominate in fall and winter. There are substantial interannual variations in coastal currents, and El Niño enhances poleward currents. Off Canada's Atlantic coast, the shelf-edge Labrador Current flows equatorward year-round from Labrador to Nova Scotia. On the interannual/decadal scale, however, the shelf-edge current off Labrador is nearly out of phase with that off Nova Scotia. The Labrador Current is positively and negatively correlated with the winter North Atlantic Oscillation Index off Labrador and Nova Scotia respectively. Ocean current indices based on satellite altimetry data have been developed and integrated in the annual state of the ocean reporting by Fisheries and Oceans Canada.

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THE HARVEST EXPERIMENT AFTER THIRTY YEARS: CHALLENGES AND NEW PERSPECTIVES

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The Harvest oil platform, located 10 km of the off the California coast near Point Conception, served for three decades as the NASA prime verification site for radar altimetry missions. In preparation for decommissioning of the platform, the in situ measurement systems were shut down and removed in late 2022. The last observations from the platform were collected by the tide gauges on November 11, 2022, marking the end of a remarkable 30-yr run that began with the first overflight of TOPEX/POSEIDON on October 4, 1992.

The decommissioning of the platform has been anticipated for years, and new observation systems have been deployed, not simply to compensate for the loss but also to enhance the regional altimeter verification program in the Southern California Bight. A vital element of this program is a new tide gauge, collocated with a nearby permanent GNSS station, at Vandenberg Space Force Base boat dock. Installed by University of Hawaii under the auspices of NOAA, the radar gauge is located about 10 km from the platform along the same ground track that passes by the platform. The tide gauge is complemented by an advanced GNSS buoy, moored within 1-2 km of the platform, which is replenished on a yearly basis. The buoy provides open-ocean observations of sea-surface height, significant wave height and zenith wet troposphere. Additional observing assets, most notably a dual-frequency radar transponder, are located on Catalina Island along the adjacent Sentinel-6 ascending repeat track. We provide an update on the Harvest verification effort, focusing on efforts to seamlessly extend the Sentinel-6 calibration record using data from the new tide gauge and GNSS buoy systems. We address new insights from these systems, but also the challenges associated with reconciling the new observations to the location of the platform which anchors the historical record.

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ANALYSIS OF SUBMESOSCALE PROCESSES IN THE SOUTHWESTERN ATLANTIC: STARTING INSIGHTS FOR BIOGEOCHEMICAL ECOREGIONS FROM SWOT ALTIMETRY

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This study embarks on an explorative journey to delineate the role of meso and submesoscale processes in the Southwestern Atlantic (SWA), leveraging the unprecedented resolution of the Surface Water and Ocean Topography (SWOT) satellite. Our research, initiated under the auspices of the SABIO (Studying physical processes in the Southwestern Atlantic to understand BIOlogical productivity & regional ecosystems) project funded by CNES, aims understanding of these dynamic oceanic features and their significant influence on biogeochemical ecoregions critical for economically and ecologically important marine life.

The SWA, characterized by its complex hydrodynamics and significant biological productivity, presents an ideal laboratory for studying the intricate interplay between physical ocean processes and biological communities. Recent hypotheses suggest that meso and submesoscale processes underpin key ecoregions in the SWA, crucial for the sustenance of biological activity with significant economic and ecological importance. Furthermore, variations in submesoscale activity are posited to drive changes in phytoplankton communities over recent decades, highlighting the need for high-resolution observational capabilities.

Our methodology encompasses a multi-faceted approach, integrating SWOT data with high-resolution satellite imagery, in situ measurements, and advanced oceanographic modeling techniques. This holistic strategy aims to accurately characterize the dynamics, variability, and distribution of submesoscale processes in the SWA and assess their impact on the region's biogeochemical signatures and biological productivity.

While our project is in its nascent stages and devoid of conclusive results, preliminary analyses underscore the potential of SWOT data to revolutionize our understanding of submesoscale dynamics. This investigation is poised to contribute vital insights into the mechanisms driving the distribution and abundance of key marine species, thereby informing conservation and management strategies in the face of global ocean changes.

This research not only promises to enrich the scientific discourse on ocean dynamics and marine ecology but also underscores the transformative potential of SWOT in oceanographic research. By unraveling the complexities of meso and submesoscale processes in the SWA, this study aims to illuminate their pivotal role in sustaining marine biodiversity and productivity.

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OBSERVING WATER LEVELS IN COASTAL, ESTUARINE, AND RIVERINE ENVIRONMENTS WITH IN-SITU GAUGES, NADIR ALTIMETRY AND SWATH ALTIMETRY: CHALLENGES AND OPPORTUNITIES

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Coastal, estuarine, and riverine environments are dynamic interfaces of the climate system where land, water, ocean and atmosphere interact and exchange water, carbon, nutrients and pollutants. Water levels in these environments play a crucial role in shaping natural habitats, impacting coastal infrastructure, and influencing human activities. The ability to accurately observe and predict water levels is essential to reduce vulnerability to natural disasters such as flooding and storm surges, and to inform resource management and climate change adaptation policies. Observing water levels in these dynamic environments can pose significant challenges however, notably because of the high variability of water levels on short spatial and temporal scales. This paper discusses the challenges and opportunities associated with observing water levels using in situ water level gauges, nadir altimeters and swath altimeters like SWOT.
The paper focuses on the Bristol Channel and Severn River-Estuary system, one of the world's most extreme land/ocean interfaces, featuring the second largest tidal range in the world (~ 13 metres) and freshwater discharge from the longest river and second largest mean flow in the UK. Facing the Atlantic, the area is subject to frequent battering by storms and high sea states. It follows that the coastline and river are covered by a dense network of water level gauges (WLGs), which has been continuously operational for a period of decades. The site was also the only coastal/estuarine area, globally, that fell under the SWOT 1-day repeat orbit in April-July 2023.
The paper presents comparisons of water levels and surface water slopes along- and across the Bristol Channel from in situ tide gauges, models, CryoSat-2, Sentinel-3 and SWOT during the SWOT 1-day repeat Cal/Val mission phase. Our results illustrate how coastal dynamics, hydrology and morphology affect comparisons of satellite altimetry and TGs, and the challenge of detecting these processes' fingerprints in 2D water level images from SWOT. Lastly, our work provides a first glimpse of the incredibly complex spatial patterns and fast temporal changes in water levels in these dynamic environments of the ocean/land interface.

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EVALUATION OF SWOT SEA LEVEL DATA IN THE COASTAL AREAS OF THE BALTIC SEA

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This study examines the Surface Water and Ocean Topography (SWOT) mission sea level data in the complex coastal areas of the Baltic Sea. This region is quite diverse with archipelagos, numerous islands and seasonal sea ice that has been challenging for previous satellite missions on determining accurate sea level especially on approaching the coastal areas. As a result we explore how accurate SWOT KaRIn low rate sea level data is in the coastal and offshore waters of the Baltic Sea. To accomplish this both an oceanographic/geodetic approach is utilized by means of a synergy of in-situ, satellite and model data.
The methodology firstly derives dynamic topography (DT) by a geodetic approach that uses the SWOT sea surface height data (version C) by utilization of a high-resolution geoid model. This is followed by a comparison of SWOT derived DT with that of eight coastal tide gauge stations whose vertical datum also refer to the geoid. The second approach consists of a geodetic-oceanographic combination of tide gauges and hydrodynamic models - this is especially important for deriving DT in the offshore areas. Focus is on the SWOT DT data with increasing distance ranges up to 40 km from the coast. Results show that the SWOT DT data at the coastal area is mostly within an acceptable range of 5-10 cm.

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HOW FFSAR CHANGED THE WAY WE THINK ABOUT ALTIMETRY

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Fully focused synthetic aperture radar (FF-SAR) altimetry is a novel data processing technique for nadir-looking altimeters based on the coherent processing of the radar echoes. By correcting for the range and phase variations that a specific target on the surface experiences on the radar-echo space, it is possible to focus the radar energy for the time the target is being illuminated by the radar.

The technique is not new as it has been extensively used in side-looking imaging SARs, but we first applied it to a nadir looking altimeter in (Egido & Smith, 2017). We based our FF-SAR algorithm in a classical back-projection approach, as this is the most precise way to focus a SAR; it is also one of the most computationally expensive approaches.

Since then, other processing methods have been proposed that significantly improve the computation time and allow extensive computation of FF-SAR data. The technique was also rapidly adopted by a wide number of research groups, who took FF-SAR to the next level and developed a wide range of applications that we could not foresee when we were producing the first FF-SAR altimeter image over the CryoSat-2 Svalbard transponder.

FF-SAR prompted a paradigm shift within the altimetry community, redefining the altimeter from a nadir looking one-dimensional radar, into an imaging SAR that just happened to be pointing downwards. From this change in perspective, a wide range of applications that make use of the imaging (and non-imaging) capabilities of SAR altimeters have been developed based on the FF-SAR processing method. In this presentation we intend to do a non-exhaustive review of these novel applications, showcasing the capabilities of this technique.

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COMPARING SENTINEL-6 DELAY DOPPLER ALTIMETER AND SWOT INTERFEROMETER OCEAN MEASUREMENT PERFORMANCE UNDER VARIED OCEAN WAVE CONDITIONS

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New SWOT ocean measurements of sea surface height, normalized radar cross section, significant, wave height and associated KaRIn radar performance metrics will be evaluated under specific wind-wave and ocean swell conditions that coincide with Sentinel-6 Michael Freilich altimeter passes. These two radar systems respond differently to the underlying surface wave field and case studies will be performed to examine SWOT along and across track measurements under situations where ocean swell crosses or travels along the SWOT ground track (range or azimuth travelling directions). Similar cases will be identified where the wind-sea dominates in these two directions. The premise is that Sentinel-6 delay doppler altimeter (DDA) measurements of range and sea state have high fidelity and additional DDA-derived wavefield information can provide additional ground truth including vertical velocity variation dynamics within the crossover data frame. Dedicated DDA 2-D stack data processing will be performed that allow S-6 to invert both the ocean geophysical Doppler and mean wave period. Spatial variability and along-track spectral characteristics of sea surface height and sea state from both sensors will be evaluated under these strongly differing conditions to identify and isolate potential wavefield impacts on their collective sea level and surface wind-wave measurement performance.

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THE NEXT GENERATION COPERNICUS ALTIMETRY MISSIONS: ENHANCING CONTINUITY, PERFORMANCE AND OBSERVATIONAL CAPABILITIES

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The European Space Agency (ESA), under directives the EU Council and European Parliament, has the mandate to define “the overall system architecture for the Copernicus space component (CSC) and its evolution on the basis of user requirements, coordinated by the Commission”. Following this rationale ESA, in close interaction with the EC, EUMETSAT and Member States, has identified key components of the CSC Long-Term Scenario (LTS) (ESA, 2020).

A pivotal element of the CSC-LTS is the Next Generation Topography Constellation, comprising the Sentinel-3 Next Generation Topography (S3NG-T) and Sentinel-6 Next Generation (S6NG) missions.

The S3NG-T mission is designed to ensure an enhanced continuity of the Copernicus Sentinel-3 nadir-altimeter measurements in the 2030s-2050s timeframe. Recognizing the current constellation's limitations in temporal and spatial coverage, S3NG-T aims to significantly upgrade global-scale altimeter sampling. Additionally, hydrology has been elevated as a primary mission objective, introducing a new set of stringent requirements to the mission.

To achieve the sampling and revisit time requirements, The S3NG-T mission is designed a constellation of two large spacecraft, embarking a nadir-looking synthetic aperture radar (SAR) altimeter for baseline continuity and an across-track wide swath altimeter. Featuring two continuous swaths of 50 km on each side of the track, the S3NG-T mission is expected to provide an almost complete coverage of the ocean every 5 days. In addition, a specialised high-resolution mode has also been introduced for hydrology and sea ice applications.

For its part, the S6NG mission will guarantee the reference altimetry measurements for the 2035-2055 time frame, providing enhanced continuity of the satellite altimetry geodetic data record for sea surface height, mean sea level, waves and wind speed measurements, created through the reference altimeter missions, starting from TOPEX/Poseidon, Jason-1, Jason-2, Jason-3, and now the current Copernicus Sentinel-6 mission.

The key driver for the S6NG missions is to provide enhanced continuity responding to evolving user requirements for climate research. New scientific requirements for global and regional mean sea level trend uncertainty have recently been substantiated to address key scientific questions related to climate change such as closing the sea level budget, detecting and attributing the signal in sea level forced by the greenhouse gas emissions and monitoring the Earth's energy imbalance.

Furthermore, the extension of reference altimetry mission sampling to the Arctic Ocean is an urgent necessity, given projections of a seasonally sea ice-free Arctic as soon as the mid-2040s. This extension is paramount for monitoring the profound impacts of climate change on Arctic regions and having a more comprehensive view of global mean sea level trend. Although missions like CRISTAL and S3NG-T provide observational capabilities in polar areas, they fall short of the stringent stability requirements needed for accurate and reliable global and regional sea level monitoring.

This presentation covers the essential requirements, design considerations, and strategic perspectives for the future implementation of the S3NG-T and S6NG missions, underlining their significance within the Copernicus Long-Term Scenario.

ESA, 2020 ,"The next phase of Copernicus" Updated Copernicus Space Component (CSC) Long Term Scenario, ESA/PB-EO(2020)41 Paris, 9 September 2020

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DORIS SYSTEM STATUS IN 2024 AND FUTURE PROSPECTS

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From the 1990 years until now, the DORIS System (Doppler Orbitography and Radio positioning Integrated by satellite) has been contributing to the success of 18 Earth observation and altimetry missions and continue – thanks to its current constellation – to provide measurements of its 60 stations to the IDS.
Next launches of DORIS instruments are in sight, ensuring the continuity of measurements until 2035 and beyond, while new challenging missions like GENESIS are also in preparation.
A brand new generation of instrument (DORIS NEO) is being developed and various system and instruments improvements are considered to answer the needs of future missions.
This presentation will be the occasion to come back on the recent and on-going progress made in the DORIS system and to anticipate its future prospects.

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SWOT SATELLITE MODELS FOR ORBIT DETERMINATION

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With more than one year in orbit for the SWOT satellite, it is possible to observe the systematic errors of the models used in the orbit determination process.

The Solar radiation pressure model is the pre launch model and has not been updated until now. This model is a simple box and wings model and it can be improved, as the satellite has a complex configuration (solar arrays positioned along track with various incidences for the sun, possible shadowing, Karin instrument booms...).

The initial model is described, and the orbit results are analyzed to derive possible improvements for the surface forces model.

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NASA'S CDDIS: 2024 STATUS UPDATE

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NASA's Crustal Dynamics Data Information System (CDDIS) continues to maintain and expand archive services for the International DORIS Service (IDS) and the Space Geodesy community. The CDDIS is continually evolving to fulfill new storage, latency requirements, and to meet new standards such as the shift toward FAIR and open science. In 2024 several improvements have been implemented and more are currently in development.

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DEEP-LEARNING AIDED METEOTSUNAMI EVOLUTIONS OVER LAURENTIAN GREAT LAKES

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Meteotsunamis are large waves caused by atmospheric pressure disturbances under extreme weather conditions, and frequently occur over all five of the Laurentian Great Lakes in North America. These atmosphere-Lake driven storm surges often resulted in tragic loss of lives and inflicted severe economic damages. On 4th July 1929, a large meteotsunami swept over Grand Haven pier, Michigan, where an estimated 45,000 people were on the beach, thus resulted in 10 casualties from waves as high as 6 meters. More recently, meteotsunamis were detected in Lake Superior and Lake Erie in 2012 and 2014, respectively. In 2018, Lake Michigan experienced a large meteotsunami induced by atmospheric inertia gravity waves. At present, fast meteotsunami events are primarily detected using assimilative Great Lakes circulation modeling using sparsely located water level data located at the Great Lakes coastal regions. Here, we combined three decades of multi-mission satellite altimetry and water level gauge records, aided by deep-learning data-driven reconstruction analytics, to spatiotemporally downscale Lake-wide water level time series at ~10 km resolution and ~hourly sampling. In this study, we present study cases to quantify the genesis and evolution of Great Lakes meteotsunamis, including the 6-7 to 11-12 December 2021 episodes in Lake Erie.

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FIRST EVALUATION OF REAL SWOT OBSERVATIONS FOR MONITORING WATER STORAGE CHANGES IN LAKES AND RESERVOIRS IN SWEDEN

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Lakes and reservoirs play a crucial role in the water and energy cycle, and they are considered indicators of climate change due to their sensitivity to climatic variations. Monitoring the dynamics of these water bodies is essential for many applications. Satellite remote sensing has been successfully used to monitor water surface elevation (level) using altimeters and surface extents (area) using optical/radar satellite imagery for numerous lakes and reservoirs worldwide. By combining water level and surface area data, changes in water storage can be estimated from satellite observations.

Conventional nadir altimeters can only measure water levels directly beneath satellite with a limited footprint and a large spacing between orbit tracks, thus they miss many reservoirs. This poor spatial coverage is recently addressed by the new SWOT (Surface Water and Ocean Topography) mission launched in December 2022. The unique capability of SWOT lies in the new generation satellite altimeter that uses radar interferometry to make high-resolution measurements over two 50 km-wide swaths of water simultaneously. While previous studies have demonstrated the potential of simulated SWOT data in enhancing lake monitoring, the actual performance of real SWOT data has not been investigated since its launch.

To bridge this research gap, this study aims to evaluate the accuracy of recently released real observations from SWOT and compare with data from other traditional nadir altimeters for monitoring lake levels and surface areas in Sweden for the first time. In-situ measurements will be used as the ground truth for the evaluation. Furthermore, we will evaluate changes in water storage in Swedish lakes and reservoirs using SWOT data. This study will be among the first to investigate the real SWOT data and its applications in monitoring water resources.

The findings of this study will provide valuable insights into the real capabilities of SWOT in enhancing our understanding of lake dynamics and its potential for monitoring water storage changes in lakes and reservoirs. The results will have significant implications for hydrological modelling, water resource management and climate change studies.

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FAST ESTIMATION OF SPATIO-TEMPORAL COVARIANCE MODELS OF SSH FROM SATELLITE TRACK DATA

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Products of global SSH rely on the interpolation of sparse remote sensing data obtained from orbiting satellites. These data are sparse both in spatial and temporal dimensions. In this talk, we discuss two components that play a key role in the interpolation procedure. Firstly, from a modelling perspective, we investigate spatio-temporal covariance kernels that can incorporate some of the main patterns of SSH processes. We also discuss one potential avenue to address non-Gaussianity, which may be relevant for instance in coastal regions. Secondly, from the perspective of estimation, we discuss fast approximate inference methods, and in particular discuss potential extensions of the Spatial Debiased Whittle likelihood to irregular data such as those obtained from satellite track measurements. Finally, we present the results of a simulation experiment. Data are simulated from the models discussed in the first part of the talk. We then estimate back the parameters of such covariance models from sampled data, where the samples are built according to real satellite track patterns. We then use the estimated covariance models to interpolate back the data and obtain interpolation errors.

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EVALUATION OF SWOT WIDE-SWATH PRODUCTS IN THE SOUTH CHESAPEAKE BAY

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The NASA/CNES experimental Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, will provide the first wide-swath measurements of sea surface heights and inland water levels. SWOT's primary instrument, KaRIN, is the first space-borne Ka-band radar interferometer. As an experimental mission, SWOT's performance will need to be evaluated for suitability for end users. Future operational missions, such as Sentinel-3 Next Generation in the mid-2030s, may adopt swath technology such as that demonstrated on SWOT.

We will present a limited evaluation of SWOT swath products in the south Chesapeake Bay, where the swath coverage has a local maximum. The south Chesapeake Bay is particularly vulnerable to clear skies flooding due to climate change and is a highly trafficked marine area. To evaluate the SWOT swath data, we will compare SWOT sea surface heights, significant wave heights, and wind measurements in the south Chesapeake Bay with results from conventional nadir altimeters and our inhouse processor results of Delay/Doppler high-rate altimeters (Sentinel-3/Sentinel-6).

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THE ROLE OF STERIC HEIGHT IN MESOSCALE ACTIVITY IN THE SOUTHWESTERN ATLANTIC OCEAN DERIVED FROM HIGH RESOLUTION IN SITU DATA, SATELLITE ALTIMETRY AND A REANALYSIS MODEL.

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The sea surface Height (SSH) has two main components: one is related to the mass change (e.g. remotion/addition of water) and the other component, known as the Steric Height (SH), originates from fluctuation in water density. The study of the SH in mesoscale processes, that occur on a spatial scale of hundreds of kilometers and on a time scales of days to weeks, is crucial. It provides insights into how density variations impact ocean circulation, which affects the energy distribution, and nutrient transport.
This study investigates the role of SH in the mesoscale processes in the Southwestern Atlantic Ocean using high-resolution in situ data collected by elephant seals, satellite altimetry and an ocean reanalysis model during September to December 2018 and 2019.

The mesoscale eddy trajectory atlas product from AVISO was used for the selection of the anticyclonic and cyclonic eddies that matched with the period of the Elephant Seals trajectories. This study also uses the ocean reanalysis model, Glorys 12, from the European Union's Earth observation program CMEMS (Copernicus Marine Service). We extracted the vertical profiles of in situ and model data inside and outside the eddies to compare both datasets. The basic variables, Temperature (T) and Salinity (S), of the reanalysis data correlated well with in situ data, especially inside eddies. The correlation coefficient was 0.9 for T in anticyclonic and cyclonic eddies and the correlation values were 0.7 for anticyclonic eddies and 0.5 to cyclonic eddies for S. Outside the eddies, in the surrounding ocean, the correlation was 0.8 for T and 0.6 for S. The high correlation between both datasets couraged us to calculate the SH inside eddies using T/S vertical profiles. The SH derived from the model represented adequately the SH derived from in situ data obtaining a significant correlation of 0.78 for anticyclonic eddies and 0.52 for cyclonic eddies. Therefore, the GLORYS 12 reanalysis model resolves the SH in the mesoscale eddies in the Southwestern Atlantic. From here, we will explore the differences of the SH on anticyclonic and cyclonic eddies and how much is its contribution to sea level. A similar analysis will be done incorporating the Argos buoys, other independent in situ data set.

Keywords: Steric Height, mesoscale eddies, elephant seal, ocean reanalysis model.

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APPROXIMATED LIKELIHOOD FOR GLOBAL SSH INTERPOLATION

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Gaussian processes are popular for spatio-temporal modeling due to flexibility in the model and ability to encode physically-motivated covariance functions. Global SSH modeling often uses sparse remote sensing data which are large and irregularly spaced. Exact likelihood methods rely on calculating the inverse and determinant of the covariance matrix, making them intractable for large datasets. The commonly used Whittle's approximation allows us to diagonal our process in the spectral domain but can only be used on regularly spaced data and often require interpolating the original data. Our work aims to parameterise the effect of interpolating on the covariance structure. Furthermore, we address the finite sampling effects using the debiased Whittle methodology. These effects cause a bias in the classic Whittle estimator and produce other auxiliary effects during interpolation. We present results from simulation data and study how well the interpolated field reconstructs the original field. We will compare the results to the Vecchia model which is able to account for large and irregularly spaced data through clustering the data and assuming conditional independence.

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THE CRISTAL MISSION FOR CRYOSPHERIC SCIENCE, OCEANOGRAPHY AND HYDROLOGY: FEATURES, DESIGN AND EXPECTED PERFORMANCE.

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The cryosphere is undergoing dramatic changes in response to global warming. One of the forthcoming Earth Observation missions that will contribute most to the monitoring and understanding of the cryosphere is the Copernicus Expansion CRISTAL, whose first satellite is planned for launch in 2027 in a high inclination orbit, which ensures an almost complete coverage of the polar regions, up to 88° of latitude.

CRISTAL features a dual-band Ka/Ku, SAR-mode radar altimeter, specifically designed for monitoring of sea ice and land ice. The payload also includes a microwave radiometer to provide information on local cloud, snow, and ice conditions. In addition to measuring ice topography and evolution, the dual-band approach allows the estimation of the depth of the snow on top of the ice, which is needed to reduce the uncertainty in estimates of sea ice thickness and in the measurement of changes in glaciers and icecaps. The CRISTAL radar altimeter has interferometry capabilities in the Ku channel, allowing the measurements to be extended a few km across track.

The CRISTAL Critical Design Review, scheduled for June/July 2024, signals the start of the construction and integration of platform and payload. In this presentation, we will illustrate in detail the features of the instrument, and describe its expected performance. We will also present the results of undergoing science support studies that are contributing to the refinement of the level 2 algorithms. Design and consolidation of the algorithms will also benefit from data acquired during dedicated campaigns: we will provide details of the planned campaigns, which will employ a dedicated airborne demonstrator, CRISTALair, currently being built and available from spring 2025.

Finally, we will review the many applications expected from CRISTAL, and discuss how CRISTAL data are expected to contribute to Copernicus user services, alone and/or in the synergy with other Copernicus Expansion missions such as the Microwave Radiometer CIMR and the Synthetic Aperture Radar ROSE-L. The applications extend well beyond cryospheric science, to include open and coastal ocean dynamics and sea state, sea level studies, and monitoring of river and lake levels.

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GLOBAL OCEAN HEAT CONTENT: METHODS AND SOURCES OF UNCERTAINTY

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The ocean is the largest component of the Earth's energy budget, absorbing more than 90% of the excess energy in the Earth's system—a quantity referred to as the Earth's Energy Imbalance (EEI). This uptake of heat by the ocean is measured as a change in the ocean's heat content relative to a baseline, or the ocean heat content anomaly (OHCA). Calculations of the EEI may be made in a variety of ways—from satellite measurements of radiance at the top of the atmosphere, from estimates of OHCA computed from model output (reanalyses), from satellite altimetry, or from collections of in situ ocean temperature profiles, of which Argo floats form the mainstay for the most recent twenty years. One persistent challenge with the latter method is the relative sparsity of in situ profile data.

In this work, we compare a number of time series of global OHCA in order to understand the state of the science in OHCA estimation. We examine how updates in ocean profile quality assessment techniques will affect the magnitude of integrated OHCA made from in situ profile data. Altimetry has become a critical asset to ocean profile quality control in the Argo era (Guinehut et al. 2009); we consider the impact of additional uses of altimetry to identify the presence and scale of mesoscale features as a step to understanding their effects on OHCA integrals, and our ability to quantify these. Through this intercomparison, we seek to better understand the uncertainty of OHCA estimates as well as the uncertainty in estimation of the acceleration of the OHCA in the 21st century, and to discern the impact of various improvements in the methodologies.

This work is in support of the World Climate Research Programme Global Energy and Water Exchange Data Analysis Panel Earth's Energy Imbalance Project, which was established to examine products which measure or calculate the Earth's Energy Imbalance in its entirety or particular components thereof.

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QUANTUM SENSING FOR SATELLITE ALTIMETRY - HYPE OR OPPORTUNITY?

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Quantum sensing, quantum communication and quantum computing have permeated industry and academia with a flurry of quantum strategies developed to advance quantum technology to real-world applications. An overarching issue that still looms is whether advantages of quantum principles are translating into tangible advances? This presentation will focus on quantum technology that could be applicable to satellite altimetry either through direct sensor integration or indirectly through improved geophysical corrections. This includes optical clocks, navigation systems, laser technology and photonics, gravity and orbit determination, and quantum communication. The Earth system is a very complex target which requires the analysis of many geophysical corrections to create accurate altimetry products. Replacing a classical sensor with a quantum sensor, even with higher performance, does not necessarily translate into better products. The uncertainties in correction models and the complexity of the Earth surface often overshadow sensor improvements. In particular, quantum laboratory experiments under controlled conditions cannot effectively estimate satellite altimetry observations. Analyses of potential improvements through quantum technology for both radar and laser altimetry are presented.

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VARIABILITY OF THE FULL-DEPTH SEA LEVEL BUDGET IN THE SOUTHWEST PACIFIC BASIN USING DEEP ARGO

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High-quality altimeter measurements have provided detailed information about the variability of sea level across the globe since 1992. While altimeters collect important data about the magnitude and location of sea level changes, other instrument platforms must be used to investigate the sources of this sea level variability. Sea level changes are driven by many processes, including density (steric) and mass (barystatic) changes in the ocean. To date, many analyses have assessed whether the sea level budget (SLB) "closes" on a variety of scales, i.e., determined whether the sum of the steric (from Core Argo profiles over 0–2000 dbar) and barystatic (from GRACE/GRACE-FO) sea level records matches the independent, altimeter-based sea level anomalies (SLAs). The SLB closure reveals how well our observing systems are measuring these components of sea level change and improves our understanding of the underlying processes causing the observed variability. While most of the steric change occurs in the upper ocean, fluctuations at depth can also play an important role. Here, we build off of previous SLB studies by using data from a regional array of Deep Argo floats in the Southwest Pacific Basin to explicitly calculate the deep (> 2000 dbar) steric sea level and assess its impact on the SLB closure. Previous work estimated this term from decadal hydrographic surveys but found it difficult to close the SLB in this region without the higher temporal and spatial resolution of the deep steric term from Deep Argo. Over the lifetime of the Southwest Pacific Basin Deep Argo array (January 2016–present), we analyze the SLB within 6° × 6° grid cells that are equivalent in size to four GRACE/GRACE-FO mascons and similar in scale to the ~5° × 5° target resolution of the Deep Argo array. We compare the altimeter-based SLA measurements (from the NOAA/EUMETSAT Radar Altimeter Database System) to the anomalies in the independently observed steric (from Core and Deep Argo floats) and barystatic (from GRACE/GRACE-FO) sea level to assess the SLB closure with respect to both the trend and the seasonal cycle within each grid cell. In some parts of the basin, Deep Argo meaningfully reduces the misclosure in the SLB, demonstrating the value of these data for validating other platforms involved in this SLB analysis and for understanding how the processes affecting sea level vary with depth.

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STERIC HEIGHT CONTRIBUTION TO INTRASEASONAL SEA SURFACE HEIGHT IN THE SOUTHWESTERN ATLANTIC

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The sea level has two components that varies at diverse spatial and temporal scales due to several physical processes. The components are the steric effect, changes in the density of sea water, and the mass changes (e.g. melting ice). In the Southwestern Atlantic, the sea level associated with the steric effect, known as steric height, dominates the seasonal variability and the spatial variation of sea level trends on the Confluence Brazil-Malvinas and adjacent area. The interannual variability, instead, is important on the mid-latitude of the South Atlantic and negligible over the Southwestern Atlantic continental shelf. Little, however, is known about the intraseasonal sea level variability. Thus, the objective of this work is the understanding of the physical drivers of the sea level variability in the

Southwestern Atlantic at temporal scales shorter than seasonal using a combination of high resolution in situ data from CTD attached on elephant seals, altimetry data, and a 3D reanalysis oceanic model. First, we did quality control of the in situ data and selected the best trajectories of 19 female elephant seals off-shore the continental shelf during spring and early summer of 2018 and 2019. The result shows that 14 trajectories out of 19 are reliable. We calculated the potential density in each vertical profile of the elephant seals and estimated the anomaly as a function of a referred density. Two approaches were done: 1) density anomaly referred to the mean along each trajectory, and 2) based on a fixed temperature and salinity value. With the model, the steric height (SHm) was estimated and validated with the in situ steric height (SH). The results show that the reanalysis ocean model represents very well the steric height, obtaining 10 cases where the correlation with the SH is higher than 0.5. Finally, we select one trajectory presentative of 2018 and 2019 and discuss the role of the steric height in the altimetry SLA.

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LAGRANGIAN CHARACTERIZATION OF THE SOUTHWESTERN ATLANTIC FROM A DENSE SURFACE DRIFTER DEPLOYMENT

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The Southwestern Atlantic (SWA) is characterized by its large Eddy Kinetic Energy as the result of the confluence of two major western boundary currents, the northward flowing Malvinas Current (MC) and the southward flowing Brazil Current. The SWA study was addressed in the literature based on altimetry data, in situ measurements, regional models and ocean reanalysis. The present study constitutes the first effort to sample a portion of the SWA, with a dense drifter array (N = 62) deployment. The drifters, drogued at 15 m depths, were deployed across the MC and the Argentine Continental Shelf along two zonal transects located at 47°S and 47.25°S, between the 8th and the 9th of September 2021. Drifters were set to deliver their position every 10 and 60 minutes, providing accurate Lagrangian trajectories that provide information on a large range of space and time scales of the surface currents. Three regions are clearly identified based on the analysis of the speed of the drifters, of their trajectories and of the spectral density of their velocities: the continental shelf, the slope and the open ocean. The comparison of the trajectories of the drifters with satellite altimetry images shows that, in general, drifters follow mesoscale features that are detectable in satellite altimetry maps. The analysis of the drifter trajectories also allowed us the study of submesoscale features of the flow (1 to 10 km) that are not observable in satellite altimetry data. Comparison with cloud-free, high-resolution color images, shows that drifter trajectories organized by the mesoscale flow might also locally follow sub-mesoscale features. In frontal regions it was found that drifter velocities double satellite altimetry geostrophic velocities, which suggests that the dynamics at those regions is largely dominated by ageostrophic components. The ageostrophic Ekman component might explain the direction of the drifters when strong winds from a given direction prevail for several days and the drifters are not in a region with large sea surface height (SSH) gradients. The joint analysis of drifters' trajectory and SSH clearly depicts that mesoscale features on the open ocean region control the cross-shelf exchanges between the MC and open ocean regions as well as the strength and width of the MC. Finally, the spatial density distribution of the drifters during the first hours after deployment and within a small eddy also allowed us to characterize the flow in terms of its divergence, vorticity and strain, indicating that the MC is geostrophic and has a jet-like behavior while the eddy is largely ageostrophic and has a dominant vorticity component over strain. We conclude observing that the analysis of a dense array of drifters provides valuable information of the flow that cannot be attained solely based on satellite data.

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TOWARDS CREDIBLE SEA LEVEL PROJECTIONS: CURRENT STATUS OF THE 30+ YEAR SEA SURFACE HEIGHT CLIMATE DATA RECORD

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Several recent altimeter data reprocessing/recalibration analyses have been completed for both the current Sentinel-6 Michael Frielich mission, and the historical TOPEX/Jason time series including TOPEX/Poseidon retracking, and radiometer recalibrations for Jason-2 and Jason-3. The GOT5.2 ocean tide model is underway, and the GSFC orbit standard std2006 has also been revised to include updated time variable gravity forward modeling. In this presentation we re-estimate Global Mean Sea Level (GMSL) and assess the accuracy of the revised 30+ year sea surface height time series via tide gauge comparisons and ocean mass budget analyses and derive global and regional sea level rise projection estimates.

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DETERMINATION OF THE LOWEST ASTRONOMICAL TIDE OVER THE ALGERIAN COAST AND ON THE LARGE OF WESTERN MEDITERRANEAN

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The Lowest Astronomical Tide (LAT) is a standard chart datum used in nautical charts to determine water depths. It represents the lowest possible level based on lunar and solar gravity. Since water levels below LAT can occur due to weather influences, such as high air pressure or a seaward breeze, it is crucial to understand the concept of LAT and its implications for maritime activities.
The tidal zone is define by its geographical limits and the reference where LAT is determined, the LAT is then calculated at each tide gauge station and therefore it is a difference between the LAT from a station to another. For this is a needed to standardize this chart over the coast of one country and eliminate the notion of tidal zones.
The objective of this study is to determine and fix the position of the LAT at any point relative to a reference ellipsoid.
The techniques and data necessary to calculate the LAT are : Tide gauge measurements, which are the principle data of the process currently used to determine this chart; Leveling, to relate the transform the tide benchmarks in the same vertical reference system; GPS , to obtain the position of tide benchmarks over the reference ellipsoid ; Spatial altimetry, for the mean sea level determination.
Knowledge of the components of the tide (tidal models) it is possible to calculate the relationship between mean sea level and the theoretical LAT over the occidental Mediterranean sea.
The results obtained by processing tide gauge observations from the three stations show that the LAT located at 20.6 cm below mean sea level at the port of Algiers, at 25.4 at the port of Oran and at 20.3 cm at port of Jijel.
The surface of the hydrographic datum relative to the reference ellipsoid is calculate by processing spatial altimetry data over the western Mediterranean based on the TPXO9 tidal model.

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ON THE FEASIBILITY OF MONITORING LAKES VOLUME VARIATIONS WITH SATELLITE IMAGERY AND ALTIMETRY

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This communication is about the very first results of an experiment we carried out regarding the synergistic use of High-Resolution Optical Imagery derived water masks together with High Resolution Altimetry over some lakes. The dataset comprises co-dated and collocated Sentinel-2 MSI, Sentinel-3 SRAL and CryoSat-2 SIRAL products.
We describe our experimental protocol including data selection and the constraints that shall be considered to obtain a dataset that is correctly sampling the lowest to highest water stages of a selected waterbody, including seasonality, cloud cover, latitude, repeat passes and more.
The Satellite Images are pre-processed to obtain a time-series of dated, raster and vector, water masks for the lake of interest. The high-resolution time-series of water masks provide acquisition dates {Tk} around which co-dated altimetry is selected.
A standard altimetry chain is then applied to these datasets (each made of 1 mask, several altimetry tracks), passing though geo-selection of the records within the mask, application of standard and inter-track corrections and outlier rejection.
The main outcome of the previous steps is a series of (area, height) pairs for the lake of interest at dates sorted by increasing lake extent and water level : {(Ak, Zk)} for k in [0, K].
The lake variation can therefore be measured through a step-by-step integration starting from the lowest volume situation (Initial condition that can be estimated thanks to alternative solutions or even ignored). At each step the volume variation can be estimated with the assumption of an average linear slope between two consecutive measured pairs of (water area, water level) following a simple formula providing the lake volume variation dVk for the current layer. The total volume variation of the lake from its lowest to highest observed water stage results from the integration of dVk built from all sorted pairs.
Measurements dispersions are derived from the altimetric point cloud and imagery data.
The results are compared with other data sources.
In the end a critical analysis of the method is provided with its weaknesses and strengths.

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THE HISTORY OF NOAA'S NEAR REAL-TIME OCEAN HEAT CONTENT PRODUCTS

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As an operational agency charged with safeguarding life and property in addition to conducting its scientific mission of oceanic and atmospheric research, NOAA has maintained a strong interest in upper ocean heat content, a driver of tropical cyclone intensification, since TOPEX/Poseidon and ERS-2 were first aloft. In collaboration with the US Navy, NASA, and its academic partners, NOAA has produced weekly ocean heat content (OHC) estimates from altimetry and sea surface temperature since at least March 10, 1998, starting with the Gulf of Mexico. Over the years, this effort has been expanded and refined. Using an updated version of the original Shay and Goni algorithm (Shay et al., 2000), NOAA's Atlantic Oceanographic and Meteorological

Laboratory (AOML) produces near-real time OHC information—specifically tropical cyclone heat potential (TCHP)—over the tropical and subtropical oceans globally. Another updated implementation of the Shay and Goni algorithm runs operationally at NESDIS to provide daily estimates of OHC and mixed layer depth over three ocean basins: the North Atlantic and North and South Pacific Oceans. This version is also run at the University of Miami (UM) with an enhancement that incorporates salinity stratification information as well as temperature in a single "equivalent OHC" field. The latest development, originating within NESDIS in 2019, is a newly formulated OHC algorithm ("Next-Generation" OHC) that provides estimates of the temperature and salinity structure from ~2000 dbar to the surface. This algorithm, which is not climatologically based, utilizes machine learning and brings in additional satellite data streams such as sea surface salinity and ocean winds to tune estimates within the mixed layer. We trace the development of NOAA's OHC algorithms and products from the earliest weekly 1-degree OHC fields for the Gulf of Mexico to the present daily ¼-degree resolution products; we highlight how improvements in both the altimeter constellation and in the OHC algorithms have enabled more accurate estimates of OHC and associated ocean properties, with consequently greater potential impact on tropical cyclone prediction. Characterizations and comparisons between the different products are provided along with comparisons to in situ measurements.

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GLOBAL RIVER DISCHARGE ESTIMATION FROM TRADITIONAL ALTIMETRY MISSIONS AND SWOT

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Monitoring a river's discharge is essential for water management, but in-situ gauging stations have limited spatial coverage. Remote sensing observations from altimetry missions can complement this network, with the possibility to estimate river flows globally. By assimilating the remotely sensed water surface elevation (wse), discharge can be computed globally. This study compares the discharge assimilated from traditional in-situ networks, traditional altimetry missions, and Surface Water and Ocean Topography. We also assessed the possibility of combining traditional altimetry sensors with SWOT observations, increasing the temporal frequency of the data.
Along with the observed water surface elevation, the methodology requires the dry bathymetry of the channel, which can be extracted from global Digital Elevation Models, the water slope, and a prior discharge. In the hydraulic simulation, unknown parameters (wet bathymetry and/or roughness) and the flow rate are obtained via direct Bayesian estimation Preliminary results with SWOT simulated data are promising. For one year of data in the Po River (Italy), combining traditional altimetry with SWOT increased the NSE from 0.55 to 0.73 while reducing the RRMSE from 42% to 35%. However, the discharge estimated only with SWOT has better indicators (NSE=0.93 and RRMSE=9%); further studies with actual SWOT observation will be conducted once sufficient SWOT data is available.

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TOWARDS WATER MONITORING FROM SPACE WITH SWOT AND ICESAT-2

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In the past few decades, satellite observations have become crucial for understanding and monitoring water on Earth. Two recent additions to the fleet are enabling groundbreaking new science and applications: the Surface Water and Ocean Topography (SWOT) and Ice, Cloud, and Elevation Satellite (ICESat-2) satellite missions. SWOT, launched in December 2022 through collaboration between NASA, CNES, CSA, and UKSA, represents a groundbreaking effort to conduct a comprehensive survey of Earth's surface water. With its advanced capabilities, SWOT aims to provide detailed measurements of water levels in lakes, rivers, reservoirs, and oceans, revolutionizing our understanding of water dynamics on a global scale. Simultaneously, ICESat-2 is orbiting the Earth with ~91 repeat time, measuring ice, land and ocean elevations with high accuracy and fine spatial resolution. Together, these missions offer
invaluable insights into sea level variations near the coast where conventional nadir altimetry is challenged, as well as water elevations further inland.

Recent events have highlighted the dynamic nature of water bodies and the volatility of the warming climate. For instance, the transformation of the arid Badwater Basin into a temporary lake following unprecedented rainfall events underscores the complex interplay between climate, geography, and water resources. Such occurrences offer unique opportunities to showcase the efficacy of satellite technology in monitoring and understanding ephemeral water bodies, even in the most challenging environments.

Here we demonstrate using high resolution data from SWOT the temporary inundation of Badwater Basin. We find good agreement with optical images from the Sentinel-2 satellite and provided through the OPERA product but additionally use elevation data to infer water depth – not water extent alone – from the SWOT observations. We also showcase SWOT's detection of recent flooding of the California coastline in the SWOT. Finally, we explore synergies and disagreements between ICESat-2, SWOT, and nadir altimetry to better understand coastal sea level propagation from open ocean to the coast.

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ACCELERATING SOCIETAL BENEFIT OF THE SURFACE WATER AND OCEAN TOPOGRAPHY MISSION

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The Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, represents the next generation of satellite altimetry and will advance applications for both research and applied science user communities. With its novel wide swath altimeter instrument, SWOT will enable both innovative scientific discoveries and a broad spectrum of operational and private sector applications. The goal of the SWOT Applications Program is to maximize user readiness for the SWOT Mission, ease access and use of SWOT data products, and accelerate the uptake of SWOT data for societal benefits. To facilitate this, the SWOT Applications Team, supported by NASA and CNES, have engaged a cohort of Early Adopters (EAs) and have been working with these users since 2018 to proactively ensure preparedness, and enable timely uptake and effective use of SWOT data products in their applications. SWOT EAs are users from operational, academic, and private sectors, as well as other communities from around the world. The SWOT EAs include both new and experienced satellite remote sensing data users. EAs have been working with simulated and proxy data sets and have participated in annual workshops and Hackathons in anticipation of the SWOT data products release in March 2024. This user community demonstrates the very high potential for satellite remote sensing to benefit operational and practical applications in a variety of domains, and will provide a key value assessment of the considerable investments made by the international partner space agencies in Earth observing satellite systems and for societal benefit. This presentation will showcase the progress of several EA groups and highlight additional recent SWOT Applications Program activities and resources.

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EXPLORING STRATEGIES FOR AN OPTIMAL COMBINATION OF MONO-SATELLITE DORIS SOLUTIONS

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IDS Analysis Centers regularly process DORIS data from each individual satellite of the DORIS constellation. Contributions of the different satellites are then combined on a weekly basis, using satellite-dependent weight for the normal equations, to obtain weekly solutions for the Earth Orientation Parameters and DORIS station positions.

The GSC IDS Analysis Center uses fixed scale factors that are based on the relative difference in the SLR fits for the different satellite contributions. However, the latest contributions, based on DPOD2020 and the grgs_rl05 gravity model, show SLR fits on a similar level that does not allow to discriminate DORIS satellite contribution quality. A new strategy to determine the contribution weight of each of the satellites should be further investigated.

Focusing on the period from 2016 to 2023, we explore different strategies to optimally combine the individual satellite contributions on a weekly basis. We evaluate the results by comparing WRMS, Earth Orientation Parameters w.r.t. IERS C04, and site tie residuals.

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VALIDATION OF MULTI-MISSION RADAR ALTIMETRY SINCE 2008 AT COASTAL TIDE GAUGES

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Satellite altimetry has continuously monitored global and regional sea level since the early 1990s. Over the past 30 years, there have been constant improvements in measurement and data processing techniques. In particular, recent missions have deployed Synthetic Aperture Radar (SAR) altimeters, which offer higher accuracy and spatial resolution compared to conventional altimeters. However, the new instruments could potentially introduce inconsistencies in the sea level record.
Here, we asses the accuracy and precision of six recent altimeter missions (Saral, Sentinel-3A, Sentinel-3B, Jason-2, Jason-3, Sentinel-6MF) at eight GNSS-controlled coastal tide gauge stations situated in the German Bight (southeastern North Sea) and in the Java Sea. In additon, we monitor potential regional mission sea level drifts based on the tide gauges. Special focus is on the differences between Sentinel-6MF's convential LRM and SAR mode data. In the German Bight sea level corrections from regional storm surge models are applied in order to bridge the gap between altimeter measurements and tide gauge locations and hence to increase the accuracy of the drift estimations.

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POLARIMETRIC RADAR ALTIMETRY OVER THE CRYOSPHERE: SURFACE-BASED DATA AND FUTURE POSSIBILITIES

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Snow depth and sea ice are WMO-designated Essential Climate Variables. Using the KuKa fully polarimetric dual-frequency radar instrument, deployed in multiple field campaigns, it was demonstrated that using dual-polarisation techniques could provide accurate retirevals of snow depth, performing better than dual-frequency Ku- and Ka-band approaches at the surface-based scale. We explore the possibility of scaling to satellite scale and future possibilities for polarimetric altimetry over the cryosphere, using modelling and considerations of upscaling of findings from surface-based campaigns.

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POD STATUS FOR THE REFERENCE MISSIONS AND THE DETERMINATION OF GLOBAL MEAN SEA LEVEL

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Precise Orbit determination for the reference missions (TOPEX/Poseidon, Jasons 1,2,3 and Sentinel-6A) span 32 years. We review the progress and the status of the POD for these satellites, evaluating the current set of orbits available for these satellites: POE-F (from the CNES), the std2006_cs21 series (available from GSFC), the JPL reduced-dynamic orbits, and other publically available orbit time series. We review the systematic errors and model errors that still possibly still appear in the current set of orbits, and discuss prospects for further improvements. We also evaluate the determination of GMSL using different sets of orbit time series, including through the use of three different ITRF2020 realizations: ITRF2020, DTRF2020 and JTRF2020. Finally, we provide an update on the GPS orbit determination with GEODYN for Sentinel-6A.

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GLOBAL LAGOON ALTIMETRY ALLOWS IMPROVED COASTAL SEA LEVEL FROM SPACE

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Satellite remote sensing has become a powerful tool for scientific studies as it permits global analyses over extended periods. Satellites provide something that ground-truth sensors cannot, i.e., coverage with a single-sensor consistency. Satellite radar altimeters showed capability for globally monitoring open oceans, and only recently a major reassessment of years of coastal altimetry data has provided a detailed view of how to get more and better data near the coast. Results show that comparison scenarios with tide gauges vary significantly from one coastal site to the other. The global coastline is spatially highly variable and irregular, having random geometry being formed by various landforms (e.g., sea cliffs, beaches, tidal flats, river deltas, lagoons, estuaries, bays, etc.). The satellite can approach the coast with different angles and at some distance from the tide gauge location. Therefore, the nearest distance to the coast at which the data retain a similar level of accuracy might depend on the site. The lack of a common protocol on how data are processed and validated against tide gauges makes notoriously difficult inter-compare results from the various studies. Abileah and Vignudelli (2021) introduced a new processing approach (coined Precise Inland Water Altimetry, PISA) which is a waveform and retracker model specifically for flat specular or quasi-specular surfaces greater than 100 m. The new algorithm has been tested in many inland water bodies (rivers and lakes). The Marano-Grado Lagoon serves as a validation platform, with a comparative analysis of data in two Sentinel-3 tracks. We will show that lagoon altimetry is more accurate than state-of-the-art coastal altimetry in measuring coastal sea level from space. Coastal lagoons are a typology well defined geographically, possibly protected from wave action and exposed to weaker and less persistent winds, Therefore, patches of calm water that are specular reflectors can be expected.
The motivation for the study is that there are approximately 32,000 lagoons, spanning 13% of the world's coastline (Carter et al., 1996; Barnes, 1980), and such a wealth of coastal sites could be exploited to extend the coastal altimetry paradigm up to the coastline and further inland There is no database of existing lagoons in contrast to rivers and lakes. Optical imagery from satellites can be used to make an inventory of lagoons globally, and for those crossed by the satellite radar altimeter a time series of sea level change can be estimated. In the poster we will outline the methodology and show preliminary results.
References
Abileah and Vignudelli (2021). Remote Sensing of Environment, 264, 112580, doi:10.1016/j.rse.2021.112580.
Carter and Woodroffe (1995). ISBN 0521598907. doi:10.1017/CBO9780511564420.
Barns (1981). Journal of the Marine Biological Association of the United Kingdom, 61, 2, pp. 549, doi:10.1017/S0025315400047135.

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MONITORING THE BALTIC SEA COASTAL ZONE WITH SWOT AND NADIR-ALTIMETERS

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Coastal-to-land sites are mostly affected by climate changes and are at multi-risks due to coastline retreat, flooding storms and river floods. New altimeter processing and new missions open new possibilities to observe fine-scale spatial changes in this region. Our

expectation is that new altimetry remote sensing observations from the Delay Doppler nadir-altimetry and wide swath altimetry can make an unprecedented progress at monitoring the coastal hydrodynamic processes and the river-to-ocean continuum and understanding estuarine and coastal hydrodynamic processes.
Aim of this study is to study the interaction between river discharge and coastal sea level in the Baltic Sea. First, the inflow from Skaggerack is considered an estuarine like system. Region of analysis are the coasts of the Baltic under the two SWOT cal/val tracks. SWOT and nadir altimetry are compared to field campaign data and models to study dynamical phenomena from ocean and nearshore zones to coastal and estuarine.

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VERTICAL RANGING AND SLANT IONOSPHERIC TEC PRECISION EVALUATION FOR GNSS-R SPACEBORNE WIDE SWATH INTERFEROMETRIC ALITMETRY BASED ON SHORE-BASED EXPERIMENTS

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The Passive Reflectometry and Interferometry System (PARIS), leveraging Global Navigation Satellite Systems (GNSS) reflected signals, was proposed as a method for conducting ocean altimetry concurrently along multiple tracks spanning over 1000 km. Given its ability to harness the full power spectral density of transmitted GNSS signals and its minimal sea state requirements, GNSS PARIS is touted as a highly promising GNSS-R altimetry technique. It offers potential for mesoscale altimetry, complementing other radar altimetric methods, and can deliver dense ionospheric TEC measurements for monitoring and modeling over data-scarce marine regions.
This paper presents an offshore GNSS PARIS experiment that was conducted in the Yellow Sea, China, in 2023, utilizing dual-frequency, multi-beam GNSS PARIS equipment.It focus on assessing the GNSS PARIS vertical range precision of real BDS, GPS, and Galileo signals. The study reports on the inter-satellite interference of GNSS PARIS equipment encountered during the experiment. Following quality control measures, the GNSS PARIS vertical range precision was assessed by comparing GNSS PARIS dual-frequency measurements. Furthermore, the analysis extrapolated performance to spaceborne scenarios with varying along-track spatial resolutions. Additionally, the precision of spaceborne GNSS PARIS TEC was estimated.
The findings reveal that GNSS PARIS can achieve a vertical range precision of less than 5 cm. In spaceborne scenarios with a 40 km along-track spatial resolution, a interferometric vertical range precision of under 15 cm can be attained, providing a TECU product with a precision of less than 0.3 TECU.

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EVALUATION OF RADAR AND LIDAR ALTIMETERS FOR RIVER AND LAKE WATER LEVEL, LAKE VOLUME AND RIVER DISCHARGE MONITORING IN PARTS OF INDIA

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Satellite altimetry has revolutionized river and lake monitoring, particularly for hydrologists working on river flow and reservoirs/lake storage monitoring in sparsely or ungauged areas. Despite this, there's a lack of a comprehensive evaluation of radar and lidar altimeters with varying sensor specifications for river and lake water level retrieval, seasonal change characterization, and water surface slope (WSS) using gauged long-term water level and global navigation satellite system (GNSS) data. This study addresses this gap by combined evaluation of radar (ENVISAT to Sentinel-3 and SWOT) and Lidar (ICESat-1, ICESat-2) altimeters along the Ganga River, from Prayagraj to Varanasi and few selected reservoirs and natural lakes of India . We found that, all the radar altimetry missions showed better accuracy for water level retrievals (R2 >=0.8; RMSE 0.11 to 1.16 m) and water level change quantification (RMSE 0.59 m). However, Sentinel-3 with SAR acquisition mode outperformed (RMSE 0.11 to 0.14 cm) all the traditional radar missions working in low resolution mode. Although,Llidar missions have high vertical accuracy, they showed relatively low accuracy compared to radar missions for water level time series generation at various stations. This may be due to the non-repeating characteristics along the track. In contrary, we showed the potential of ICESat-2 to capture the spatial and seasonal variability of WSS by comparing with gauged and GNSS-based WSS. The radar altimeter and Lidar data was also used to monitor the glacier lakes of Himalaya. SWOT level 2 high rate (HR) data from KaRIn sensor showed high capability of generating the daily time series during April 2023 for Ganga River stretch (Prayagraj to Varanasi). SWOT product has revealed that the generated 2D WSE closely matches in-situ (RMSE: 0.59m) and GNSS data (RMSE: 0.23m). The performance of SWOT data aligns with the accuracy of radar altimeters reported in previous literature.

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ON THE PERFORMANCE OF THE OLD AND NEW GENERATION OF SATELLITE ALTIMETRY MISSIONS TO MONITOR INLAND WATER BODIES

Roohi S[1]

Despite all progress in satellite radar altimetry, still monitoring inland water bodies, e.g., small lakes and narrow rivers, is a challenge for satellite altimetry not only in terms of spatial and temporal resolution but also in terms of erroneous measurements due the presence

of non-water objects illuminated inside the footprint of the radar sensor.
While just water response is needed, reflected pulses over lakes with a small surface area or narrow rivers are a combination of response from water and non-water surface. So, a mechanism is needed to separate water reflections from non-water reflections or minimize the effect of unwanted reflections on the water level measurements.

Sub-waveform retracking scenarios are effective ways to fight against this challenge. Implementing these kinds of the retracking waveforms provides us more qualified water level variations in compare with L2 products. This methodology has been tested and validated over lakes in different climate zones, with different shapes and sizes for Envisat, SARAL, Jason-1/2/3, ICESat, CryouSat-2 and Sentinel-3.
The work is in progress, with analyzing Sentinel-6 and SWOT missions over the areas. Water level variation from the Sentinel-6 and water surface variation obtained from the SWOT mission have been estimated. They are in the validation process against ground-based measurements to evaluate their performance.

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CRYOSAT-2 OCEAN PROCESSOR:

PRESENTATION OF THE BASELINE D

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CryoSat-2 was launched in April 2010 primarily to measure the extent and thickness of the Earth's continental ice sheets and sea ice regions. Nevertheless, the Synthetic Aperture Interferometric Radar Altimeter (SIRAL) on board can also provide information over ocean, including sea level, significant wave height, and wind speed. The CryoSat Ocean Processor (COP), developed by CLS and Aeresys for ESA, has been operational since April 2014. It offers Near Real-Time Products (NOP), Interim Ocean Products (IOP), and Geophysical Ocean Products (GOP).

CryoSat-2 SIRAL operates in three different modes, Low Resolution Mode (LRM), Synthetic Aperture Radar (SAR) and Synthetic Aperture Radar Interferometric mode (SARIn). With its long repeat cycle (369 days with a 30-day sub-cycle), CryoSat-2 aims to provide a high number of cross-over points in polar regions. This orbit allows COP products to be utilized for oceanographic purposes to enhance the resolution of multi-mission mesoscale fields in energetic regions.

The current operational processing version is Baseline D, transferred into operation in June 2024. ESA plans a full mission reprocessing for 2025, to uniform the Cryosat data over the entire mission time.

In Baseline D, the SAR/SARin Ocean retracker has been updated to version Samosa 2.5. Additionally, several geophysical models, including Mean State Bias (MSS) solutions and Mean Dynamic Topography (MDT), have been updated. With the new Baseline D of the COP, the slope correction model (POCA - Point Of Closest Approach correction) has been included in the Level-2 COP products to enhance the accuracy of mean sea surface topography models. This correction is most significant above ocean trenches and large seamounts, where higher slopes are present. In extreme cases, the correction to the mean sea surface height is 40 mm. This correction must be taken into account for LRM and PLRM modes.

The presentation aims to introduce the main content of the Baseline D of the Cryosat Ocean Processors and to discuss the content of the next evolutions to be considered in upcoming deliveries.

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REVIEW AND OUTLOOK FOR SURFACE TOPOGRAPHY MISSIONS,

APPLICATIONS AND SERVICES

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The Copernicus Sentinel-6/Jason-CS is the latest in the series of ocean altimetry missions that have established an uninterrupted 30-year record of critical Global Mean Sea Level observations that started with TOPEX/Poseidon and continued with Jason-1, -2 and -3. The two satellites Sentinel-6 Michael Freilich and Sentinel-6 B, plus a recently approved Sentinel-6C, are intended to secure the continuity of high precision observations of ocean surface topography until 2035+ and provide a reference for cross-calibrating other altimetry missions under the CEOS Ocean Surface Topography Virtual constellation, in order to further consolidate the value of altimetry for climate monitoring. In parallel, the ERS, ENVISAT and more recently the Copernicus Sentinel-3 mission, have gradually brought increased resolution and additional coverage, which proved essential in further consolidating the value of altimetry mission products for society by demonstrating its benefits for weather and ocean operational forecasting in an Earth System modelling context. The Sentinel-3 surface topography mission timeline extends into the 2030 decade and has furthermore opened the door to the development of a wide range of specific products in coastal areas, polar oceans, cryosphere and inland water management, which are reaching more and more user communities in the orbit of EUMETSAT, ESA and the Copernicus services. Finally, additional altimetry missions such as CryoSat, AltiKa, HY-2, SWOT and in the future CRISTAL, have demonstrated and are expected to continue providing improved precision, resolution and coverage, allowing therefore to expand the range of applications of surface topography Earth Observation missions. As Sentinel-6, Sentinel-3 and other current and planned altimetry missions develop their full potential through further exploiting their high resolution capabilities with scientists and users around the world, plans are already under way to ensure continuity and increase capabilities beyond 2030 from both the reference and high inclination Low Earth altimetry orbits. This paper will tell the success story of altimetry missions, illustrate the value of this Earth Observation technique to both science and applications and provide an outlook of what is to come in the next generation of surface topography observing capabilities and services.

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SENTINEL-3A/B MICROWAVE RADIOMETERS PERFORMANCE ASSESSMENT AND LONG-TERM MONITORING

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In the context of the Copernicus Programme, Sentinel-3 satellites, developed by the European Space Agency, are equipped each with a dual-band Microwave Radiometer (MWR) to correct for the altimeter's excess path delay due to the presence of water vapor in the troposphere. This correction (wet tropospheric correction or WTC) is estimated using the two-channels of the microwave radiometers (23.8 and 36.5 GHz) combined to the altimeter backscatter coefficient. The WTC is a major source of uncertainty in the altimetry budget error and in the long term mean sea level trend.

To better quantify the wet tropospheric correction trend, it is important to focus on the detection of potential instrumental drifts. The in-flight calibration is monitored using the vicarious calibration which consists of a statistical selection of the of coldest and hottest temperatures over ocean and the Amazon Forest. The long-term monitoring is also performed on the geophysical products: MWR WTC and the other Level 2 geophysical parameters (atmospheric attenuation, water vapor and cloud liquid water) are compared to model values using ECMWF analysis data. The long-term assessment of the MWR's brightness temperatures and geophysical products allow to have a detailed status on the health of the instrument and to foresee potential evolutions within the MWR processors.

A full mission reprocessing of the Sentinel-3 series on the MWR processors in 2023 covered the beginning of S3A and S3B until March 31st 2023. The full mission reprocessing enabled the users to have access to a fully homogenous Sentinel-3 MWR data set over ocean surfaces. The reprocessed Sentinel-3 datasets had been analysed in detail by the MPC experts and are currently being monitored on a cyclic basis for Sentinel-3 in a multi-mission diagnosis context including Sentinel-6A. The work that will be presented here is carried out within the frame of two projects: S3MPC LAND for ESA and COPAS for Eumetsat. We will present the results of the MWR long-term monitoring and the status on stability of the Brightness temperatures and WTC.

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SURFACE WATER AND OCEAN TOPOGRAPHY (SWOT) MISSION FOR FLOOD MAPPING AND HYDROLOGICAL MODEL CALIBRATION IN INDIA

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Although altimetry has greatly improved our understanding of rivers and inland water bodies worldwide. However, the limited frequency of altimeter measurements often poses challenges for various applications. This study examines how the Surface Water and Ocean Topography (SWOT) mission, launched in December 2022, can improve hydrological applications in India. Specifically, we investigate two research questions: a) Can SWOT data help improve flood mapping in India? and b) How effective is SWOT-based discharge data in calibrating hydrological models? To address the first question, we simulate SWOT overpasses based on its orbital configuration and compare them with flood-affected areas identified in the Indian Flood Inventory (IFI) data. Our findings indicate that SWOT's orbital configuration enables the monitoring of different proportions of Indian districts during each cycle. SWOT would have captured 49% of flood events at least once, and it observed 21% of single-day flood events over India. For the second question, we use proxy-SWOT data generated from sampled in-situ data, introducing errors based on SWOT science team recommendations. We present results for the Mahanadi river basin in India as a case study region to evaluate the feasibility of using SWOT discharge data for hydrological model calibration. Additionally, we generated Near Real-Time (NRT) river discharge data for over 200 stations in India to calibrate flow law parameters for estimation of discharge from SWOT measurements.

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AN EVALUATION OF RECENT OCEAN TIDE MODELS

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Over the last 30 years, ocean tide models have been vastly improved, leading to centimeter-level accuracy in the open ocean. Despite these improvements, significant errors remain in various regions, mainly due to errors in bathymetry, tidal mixing, temporal sea ice presence, and lack of data available for assimilation. We examine regions of the world's oceans where tides remain largely unknown or poorly estimated. We perform an accuracy assessment of recently developed ocean tide models based on enhanced empirical or hydrodynamic approaches, using tide gauge data and satellite altimetry missions data that are independent of the model development (e.g., from the Sentinel-6 Michael Freilich satellite). While some of these models have only been evaluated over global scales, our study extends their assessment to offer a closer look at selected underperforming regions. Beyond these conventional model evaluation methods, we also introduce comparative analyses of ocean tide loading estimates derived from the ocean tide models under study, against estimates obtained from GNSS monitoring stations, including over the polar regions. Our study concludes with an exploration into the feasibility of improved identifications of seasonally fluctuating tides over the aforementioned regions.

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DETECTION AND MEASUREMENT OF WET AND DRY CREVASSES IN ICESAT-2 ATLAS DATA AND THEIR ROLE IN UNDERSTANDING THE PROGRESSION OF AN ARCTIC GLACIER SURGE

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With the Advanced Topographic Laser Altimeter System (ATLAS), NASA's ICESat-2 carries the first space-borne multi-beam micro-pulse photon-counting laser altimeter system, operated at 532nm wavelength. ICESat-2 records returns for every single photon in the 532nm range of the sensor in a photon point cloud, at a nominal 0.7m along-track resolution (under clear-sky atmospheric conditions).

The photon point cloud includes information on the complex structure of the surface of a glacier during surge, however, determination of heights of crevassed surfaces is not included in the standard land-ice data product. We developed the Density-Dimension Algorithms for ice surfaces (DDA-ice), a family of algorithms that allow determination of surface heights, crevasse depths, water in crevasses and water in melt ponds and surface streams.

Application of these new observational capabilities pave the way to high-resolution studies of change processes that occur during the surge in an Arctic glacier, including crevassing, hydrological changes, deformation and mass transfer. Here, we investigate the current surge in the Negribreen Glacier System, Svalbard, which has reached maximal velocities of 22m/d during the height of acceleration in 2017.
The evolution of crevassing, primary surface signature of acceleration and surge expansion, is monitored using the DDA-ice-1. With help of the DDA-ice-2, water in crevasses is detected and measured, indicating the transition from an efficient drainage system to an inefficient one during the mature phase of the surge. Surface-height changes provide the basis for mass transfer calculation and indications of changes in the strain system. Complemented by Sentinel-1 SAR data, ICESat-2 data yield a new observational standard for geophysical analysis of complex glaciological processes during a surge.

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MEASURING SIGNIFICANT WAVE HEIGHT FIELDS IN TWO DIMENSIONS AT KILOMETRIC SCALES WITH SWOT

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The Surface Water and Ocean Topography (SWOT) mission is primarily designed to measure Sea Surface Height in two dimensions at an unprecedented resolution thanks to its innovative Ka-band radar interferometer KaRIn. In addition to the topography measurements derived from the phase difference between the images acquired at each of the two antennas separated by 10 meters, KaRIn can also provide information about the sea state, by exploiting the measured power in each of the SAR images and the interferometric correlation between both acquisition channels.

This last quantity, sometimes referred to as interferometric coherence, is directly affected by the presence of surface waves. This provides a fantastic opportunity to measure, for the first time at a global scale, Significant Wave Height at kilometric resolutions (well below the reach of nadir altimeters) and in two dimensions. This, however, requires estimating all other sources of decorrelation of instrumental origin with an exquisite precision to avoid misinterpreting instrumental effects as geophysical signals.

In this talk, I will briefly describe how the interferometric acquisitions by KaRIn are calibrated and processed to obtain SWH maps in 2D at various km-scale resolutions (typically 2x2 km or 5x5 km), and discuss how the accuracy at which we need to estimate all the other sources of decorrelation varies with cross-track distance and actual SWH to highlight the most challenging regimes for the inversion. I will then present comparisons between the KaRIn two-dimensional SWH measurements and several independent sets of validation data, including data from SWOT's nadir altimeter, from the SAR nadir altimeter on-board Sentinel-3, from MASS's lidar, and from in-situ data. I will finish by discussing various physical features that can be observed in the retrieved SWH fields to illustrate that the high resolution and the two-dimensional character of SWOT measurements really open the door to the quantitative study of the processes that contribute to sea-state variations at small scales.

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OPENADB: DGFI-TUM'S OPEN ALTIMETER DATABASE

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For more than three decades, satellite altimetry has provided valuable measurement data for the monitoring and analysis of ocean and inland water surfaces. Since 1992, there have always been at least two simultaneous missions providing continuous measurement data, starting with TOPEX/Poseidon and ERS-1 in the early 1990s and continuing with about 10 satellites active today, including ICESat-2, Sentinel-6A and SWOT. Most mission data are freely available, but in different formats, processing levels and with respect to different references (e.g. ellipsoid or time), making common multi-mission applications difficult. In addition, the derivation of ready-to-use and high-quality scientific products requires expertise that not every user is willing to acquire. Over the years, DGFI-TUM has developed and maintained an Open Altimeter Database (OpenADB) that allows consistent data management and combination. It consists of the internal Multi-Version Altimetry (MVA) data repository and the OpenADB web portal. OpenADB provides user-friendly access to derived along-track products, such as sea surface heights and ocean tides. It also provides general information about the satellite altimetry missions, their observing configurations and about the data provided in the database. All products are freely available on the OpenADB web portal (https://openadb.dgfi.tum.de) after registration.

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LONG-TERM SEA LEVEL RISE AND COASTAL EROSION IN THE GULF OF HAMMAMET ASSESSED BY COASTAL ALTIMETRY.

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The Gulf of Hammamet, situated in Tunisia and renowned for its expansive sandy beaches, has been a focal point for tourism development since the 1960s, marked by the establishment of large resorts along its coastline. However, the region now faces a pressing challenge: the accelerating erosion of its once pristine beaches. In this study, we utilize coastal altimetry techniques to analyze the long-term impacts of sea level rise on coastal erosion dynamics in the Gulf of Hammamet.

Employing satellite altimetry data from missions such as Sentinel-3 and the Jason series, spanning multiple decades, we investigate temporal trends in sea level rise specific to this region. By integrating altimetry observations with detailed assessments of shoreline changes, we aim to elucidate the relationship between sea level rise and the exacerbation of coastal erosion, particularly along the vulnerable sandy beaches of the Gulf of Hammamet.
Preliminary findings underscore a concerning upward trend in sea level over recent decades, coinciding with accelerated rates of beach erosion along the Gulf of Hammamet coastline. Through advanced statistical analysis and modeling techniques, we seek to unravel the complex interplay of natural processes and anthropogenic factors, including climate change and the historical development of tourism infrastructure, driving these coastal dynamics.

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CEOS COAST: TRANSFORMATIONAL ALTIMETRY EARTH OBSERVATION IN COASTAL REGIONS

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The Committee on Earth Observation Satellites Coastal Observations, Applications, Services, and Tools (CEOS COAST) co-designs new and improved coastal products with regional stakeholders. Many COAST products or suites utilise satellite altimetry and other sensors. In late 2023, COAST released the 'alpha version' of the Application Knowledge Hub (AKH) - a global, open-access information and product portal for users. Feedback is requested on how to make the AKH even more useful. Additionally, new products include:

- Global satellite derived bathymetry and sea level rise. The dynamic coastal bathymetry of submerged shoals along the deltaic region of Bay of Bengal was estimated using Sentinel-1 SAR imagery. The gradient in the backscatter coefficient is modeled iteratively with varying bathymetry slopes. The dynamics of the depositional features are assessed with the existing bathymetry charts and model domains are created integrating updated bathymetry derived using SAR images and the hydrographic charts.

- Coastal application of altimetry for flooding/Inundation. The SWOT mission returned valuable coastal Ka band Radar Interferometric (KaRIn) data for Bay of Bengal to understand the sea level variability. Monitoring of coastal flooding storm surge is now enhanced, including extent and inundation level can be estimated in Chesapeake Bay and Bay of Bengal.

- Coastal waves, currents and eddies

- Marsh Mapping - As another direct response to stakeholder needs, commercial, high spatial resolution satellite imagery was leveraged in combination with altimetry measurements from Sentinel-3 to map marsh species along the Mid-Peninsula of the Chesapeake Bay; species differentiation is beneficial for tracking invasive species and for monitoring carbon sequestration in coastal marshlands. Again, a random forest machine learning classifier was successfully applied, this time to data from Planet's PlanetScope satellite constellation.

- Submerged Aquatic Vegetation (SAV) Habitat Suitability Index (HSI) in Chesapeake Bay - Water quality parameters impacting SAV growth (such as chlorophyll-a, turbidity, sea surface temperature, and Kd490) were taken from medium and low resolution satellite ocean color sensors to develop a map for seagrass bed siting. A maximum entropy approach using the Maxent software for machine learning was used to develop the HSI for both Virginia's Middle Peninsula using Landsat-8 imagery, as well as for the entire Chesapeake Bay using VIIRS-SNPP. Performance of the HSI was assessed against known SAV beds provided from regional partners' annual survey datasets.

- Water Clarity - Routine measurements of inland water clarity were developed for nearly 200 inland freshwater ponds on Cape Cod, Massachusetts, USA, directly meeting stakeholder needs for monitoring and managing large-scale water quality. Using a random forest machine learning algorithm, a multi-sensor approach combining Sentinel-2 and the Landsat Legacy was well-suited for estimating water clarity and was then used to assess long- and recent short-term change across the Cape.

Through new research and product development, CEOS COAST improves scientific and technical capabilities and builds user capacity for a more robust, end-to-end value chain supporting coastal stakeholders and global sustainable development. CEOS COAST is the only coastally focused team within CEOS at this time and is an IOC-endorsed contribution to the UN Ocean Decade.

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COMPARING WATER LEVELS OBTAINED FROM SENTINEL-3A ALTIMETRY WITH FIELD MEASUREMENTS CONDUCTED USING UAV LIDAR: A CASE STUDY FROM THE ODRA RIVER (W POLAND)

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Flood management is a very important task in the context of rapid climate changes. Increasing frequency of extreme weather and fluvial phenomena – such as droughts, water shortages or floods – causes that detecting water bodies and water levels is an important and challenging issue. The network of altimetric Sentinel-3A satellite ground tracks is dense so it may fill the gap between in situ water gauges. However, it is necessary to verify the accuracy of altimetric water level measurements. In places where satellite passes over the river (so called virtual stations), it is difficult and expensive to build water gauges. Hence, other methods of water levels measurements need to be used. Low-altitude remote sensing platforms seem to be the best solution to address this issue. UAVs (unmanned aerial vehicles), commonly known as drones, can reach places with limited access (e.g. high vegetated areas) and conduct survey. The platforms in question can be equipped with many types of sensors, such as RGB and multispectral cameras, as well as radar and LiDAR (Light Detection and Ranging) devices.

In our research, we utilized high accuracy LiDAR manufactured by Greenvalley International mounted on multirotor DJI Matrice 300 RTK. The basic product of LiDAR is a dense point cloud, characterized by strong reflection from land and lack or very weak reflection from water. Thanks to this feature, we were able to mark waterline consisted of many points, from which the Z coordinate is water level. In situ data have been acquired at eight sites on the Oder river (western Poland) during 40 terrain campaigns, in the project entitled "Forecasting water levels at ungauged river sections using satellite altimetric data". LiDAR-based water levels were statistically compared with Sentinel-3A measurements. Preliminary studies allow us to claim that discrepancies between LiDAR and altimetric measurements range from several centimeters to several decimeters.

The research is supported by the National Science Centre, Poland, through the project no. 2020/38/E/ST10/00295.

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ASSESSING THE IMPACT OF CLIMATE CHANGE ON LAKE İZNIK: A DECADE OF WATER LEVEL AND SURFACE AREA DYNAMICS

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The aim of this look at is to investigate the modifications in water level and surface area of Lake İznik, placed in Northwest Anatolia, Turkey, among 2015 and 2024. For this purpose, in-situ and satellite altimetry-based water level data between 2015 and 2024, temperature and precipitation facts to decide the primary indicator of drought tahat Standardized Precipitation Index (SPI), and Standardized Precipitation Evapotranspiration Index (SPEI), and satellite images to estimate the lake surface area have been utilized. Water level records have been acquired from Hydroweb and the Turkish State Hydraulic Works, temperature and precipitation data from the Turkish State Meteorological Service, and Sentinel-2 satellite images from the Copernicus Data Browser.
The trend of Lake İznik's water stage between 2014 and 2024 was estimated as 22.9 ± 0.6 cm/yr and 22.6 ± 0.6 cm/yr respectively from each in-situ and satellite altimetry dataset, whilst a decrease of approximately 3 km² turned into determined within the surface area.
The decrease in lake surface area became decided the usage of ESA's SNAP software program and Google Earth Engine tools.
These findings suggest a decrease in each the water degree and surface place of Lake İznik. Additionally, SPI and SPEI derived from precipitation and temperature records obtained from meteorological stations close to the lake had been tested. These signs reveal a decreasing in precipitation and an increase in temperatures in the Lake İznik basin during the last 10 years. This shows that change within the water level and surface of Lake İznik are prompted by way of climate change, emphasizing the importance of taking important measures for the conservation and sustainable use of the lake. This study is supported by YTU-Scientific Research Project Coordination (Project ID: 6190).

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CONTRIBUTION OF DORIS SYSTEM TO GLOBAL IONOSPHERIC SCINTILLATION MAPPING

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Ionospheric scintillations due to ionosphere irregularities may severely degrade GNSS data in equatorial and high latitudes regions, and consequently the applications that rely on such data. It is thus of high importance for many users in a large variety of applications to have access to global maps of scintillation intensity, for both signal phase and amplitude. Typically, networks of ground based GNSS receivers are used to derive those maps, but it inevitably leads to sparse coverage.
In order to mitigate this weakness, the current study proposes to add original data points based on the DORIS system. DORIS (Doppler Orbitography by Radiopositioning Integrated by Satellite) is a French orbitography system, developed primarily for altimetric purposes by the Centre National d'Etudes Spatiales (CNES), the Institut National de l'information géographique et forestière (IGN) and the Groupe de Recherche de Géodésie Spatiale (GRGS). It consists of a network of around sixty ground-based beacons emitting a radio-frequency signal at 400 MHz and 2 GHz. The on-board receivers (on 9 civilian satellites as of May 2024) then performs Doppler shift measurements that allow precise orbit determination.
Despite a lower data rate (0,1 Hz instead of 1 Hz for the GNSS) and a lower number of satellites, DORIS can add valuable information where there is no GNSS receivers, or by taking advantage of its geometry, in particular with polar satellites. In this study, we will explore to what extent it is possible to define scintillation proxies based on DORIS data losses, phase signal degradation, or power signal attenuation, by a comparison to a scintillation data base from GNSS measurements. Eventually, we will discuss whether the challenging near-real time basis delay is achievable.

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ON THE EFFECTS OF OCEAN SURFACE MOTION ON DELAY-DOPPLER ALTIMETRY

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The Poseidon-4 radar altimeter on board the Sentinel-6 "Michael Freilich" (S6-MF) satellite offers unique opportunities to assess the impact of ocean surface motion on delay-Doppler altimetry (DDA).
In this contribution, earlier "frozen-sea" studies of the instrument response to an isolated sea surface facet are extended to include the effect of surface motions in its delay-Doppler Map (DDM) signature.
Integrating this elementary signature over the instrument field of view, an analytical DDA stacked echo waveform model is then derived.
This waveform is validated against the well-established SAMOSA waveform model for the special case of a frozen sea. Model sensitivity to changes in surface significant wave height, vertical velocity standard

deviation, and the geophysical Doppler vector projection along the satellite ground-track velocity are discussed.
These developments provide theoretical and analytical means to
jointly exploit the S6-MF conventional and delay-Doppler radar
waveforms to improve estimates of sea level and significant wave height and to retrieve and map two new observables (the along-track projection of the GD vector and the ocean waves vertical velocity standard deviation).
These new variables, being sensitive to higher order spectral moments of the wave directional spectrum, may help to mitigate sea state range bias impacts on altimeter sea level measurements.

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VARIABILITY OF ARGENTINE CONTINENTAL SHELF CURRENTS IN SOUTHERN PATAGONIA FROM IN-SITU TIMESERIES, SATELLITE ALTIMETRY AND GLORYS REANALYSIS OUTPUTS

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The Atlantic Patagonia continental shelf is a vast region located in the Southwestern Atlantic Ocean mostly studied using numerical models and hydrographic data due to the scarcity of direct observations of currents. Here, we present the analysis of an array of 3 moorings that provided 18 months of hourly velocities in the whole water column, as well as bottom pressure measurements. The three velocity times series were collected along 44.7ºS. The mean observed currents are towards the west-northwest in the inner shelf and towards the north in the outer shelf. A spectral analysis of the timeseries reveals energetic fluctuations at time scales shorter than 22 days, dominated by semi-diurnal tidal frequencies. To disentangle the origin of the remaining variability we used GLORYS12v1 reanalysis fields and satellite altimetry. Results show that the seasonality is due to a steric height anomaly between the highly seasonal inner shelf and the relatively cold Malvinas Current. 12% of the explained velocity variance in the outer shelf is due to the propagation of northward fast-propagating waves that arrive from the SE Pacific continental shelf. These waves are observed propagating at around 400 km/day in intra-seasonal maps of sea level anomaly derived from the reanalysis. Altimetry data does not capture these features due to its temporal resolution. Future work aims to use the SWOT swath that passed along this region during the CAL/VAL period, providing 3 months of daily data, to try to identify and characterize these fast-propagating waves.

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SENTINEL-6 MICHAEL FREILICH AND JASON-3 TANDEM FLIGHT EXPLOITATION (S6-JTEX) STUDY

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The Sentinel-6 Michael Freilich and Jason-3 Tandem Flight Exploitation (S6-JTEX) is an ESA funded project aiming to provide an exhaustive analysis of the S6-MF measurements during the tandem flight opportunity with Jason-3 that would demonstrate the high benefit of this new altimeter reference mission to extend the legacy of sea-surface height measurements, to produce accurate sea-state data record over ocean, and to enable seamless transition for inland water height. Other objectives are to implement a number of scientific studies that fully exploit the capabilities of the mission and develop innovative processing to allow for new potential products and applications. A further objective is to ensure a full and open sharing of all the research outputs from these studies with the science community, provided in the form of peer-reviewed journal but also summarized in project reports which are made available to the public on the web site https://www.s6-jtex.org/.
The consortium involved in this project gathers various experts who addressed different research issues, organised by surfaces and processing. These activities concern the open ocean (uncertainties and GMSL, CalVal ocean, sea state, internal waves detection), the coastal regions, the inland waters, the cryosphere surfaces (lake ice thickness), and also altimeter data processing (optimization and exploitation of the FF-SAR processing, and a statistical analysis of the S6-MF L1 data). In this presentation, an overview of the main findings from this project is given, and possible follow-on activities will be presented, some of which will be based on the second S6-MF/J3 tandem phase.

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STATUS IN THE DEVELOPMENT OF THE CRISTAL MARINE DATA CENTRE

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The Copenicus polaR Ice and Snow Topography ALtimeter (CRISTAL) is one of the high-priority candidate

missions under consideration by the European Commission (EC) to enlarge the constellation of Sentinel satellites and expand the Earth observation capacity of the Copernicus program. The primary objective of CRISTAL is to measure and monitor key climate change indicators related to the cryosphere (sea-ice thickness, snow depth and ice-sheet elevations) using, for the first time, a Ku/Ka band dual-frequency radar altimeter (IRIS), which will significantly improve the data quality compared to its predecessor altimetry missions. One of the mission secondary objective is to contribute to the global measurement of the sea-surface height, wind speed and significant wave height up to the polar oceans. Thanks to CRISTAL the ocean observing system will benefit from operational ocean data at latitudes currently not covered by any operational mission. This will be essential for the long-term climate records and forecasts of oceanographic essential climate variables. Over Ocean, improved measurement performances are expected thanks to the CRISTAL advanced altimeter features: high range resolution/sampling, dual frequency operation and their synergy, interferometric capability, and open-burst acquisition mode in the polar regions, etc. These advanced technological upgrades will enable the production of very high-accurate sea-surface height into the lead, in addition to capturing smaller ocean structures, and getting closer to the coast shore.

In the context of this mission, EUMETSAT is entrusted to operate the marine data center generating operational global ocean products. To this end, a group of experts, led by CLS in the framework of the Copernicus Altimetry Services (COPAS), is currently supporting EUMETSAT through different steps in the specifications of the CRISTAL marine products.

A state-of-the-art review for the CRISTAL marine products was first carried out by the COPAS team, highlighting the challenges of the CRISTAL mission and recommending algorithms ready for the implementation in the CRISTAL marine Ground Segment (GS). This assessment was made based on altimetry literature, considering the relevance, maturity, readiness and timeliness constraints, as a selection criterion in choosing the best possible solutions for the day-1 processing baseline (PB). The analysis and review cover both level-1 and 2 processings, as well as the various surfaces of interest (open ocean, coastal zone and polar ocean), and also respond to the need to ensure the continuity between the different ocean surfaces.

The following activity will consist in defining the CRISTAL marine Level-1 and Level-2 product generation specifications based on outcomes from the state-of-art review (and on the Sentinel-6 PGS heritage), and then, defining the CRISTAL marine Level-1 and Level-2 product formats (PFS).

This presentation aims to inform the community about the achievements made in this project and the work plan for the 2024 and beyond describing the tasks and activities to be performed for the definition and development of the CRISTAL marine data center.

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AN IMPROVEMENT TO SHORT TERM VARIABILITY IN GLOBAL MEAN SEA LEVEL RECONSTRUCTION

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Global Mean Sea level (GMSL) changes are primarily the result of ocean heat uptake and ice mass loss from glaciers and ice sheets. Consequently, they are often used as a proxy for assessing the health of the world's climate. However, GMSL has only been observed directly by satellite altimetry since 1992. Before altimetry, tide gauges measurements were basically the only source to monitor the sea level, but such measurements are spatially sparse and restricted to coastal locations. Substantial efforts in the past two decades have been dedicated to reconstructing GMSL changes for the period before 1992 through statistical analysis of sea level observations. One of the methods commonly used for sea level reconstructions is the reduced space optimal interpolation, which involves inferring empirical orthogonal functions (EOFs) from the altimetry data and then fitting those to the tide gauge observations to estimate the associated temporal amplitudes. Previous studies have shown that, while EOF reconstructions are able to capture the underlying long-term trend in GMSL with reasonable accuracy, they fail to reconstruct the shorter-term variability. Indeed, a comparison between altimetry-derived GMSL and the GMSL from an EOF reconstruction shows that there is no significant correlation between the two after removal of a linear trend for the altimetry period.

Here, we hypothesize that the inability of EOF reconstruction to reconstruct the GMSL variability is due to differences between the tide gauge observations and the corresponding altimetry data. We corroborate this hypothesis by analysing the newly available altimetry coastal sea level data set produced within the ESA Climate Change Initiative (https://doi.org/10.17882/74354). We reach three important conclusions: 1) the differences between tide gauges and altimetry at the coast are significantly correlated along the coast, ruling out observation errors as the cause and suggesting instead that the differences are due to real oceanographic signals that are not adequately captured by altimetry; 2) such differences are highly correlated with local wind; 3) correcting the differences through regression models prior to the reconstruction, reduces the standard deviation of the reconstructed GMSL variability by 26% and significantly increases the correlation with observed GMSL.

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BAYESIAN TRANS-DIMENSIONAL INVERSION FOR ARCTIC ICE AND SNOW RETRIEVALS FROM RADAR (CRYOSAT-2) AND LASER (ICESAT-2) ALTIMETRY.

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Inverse Methods have been widely used in the field of Earth Sciences and especially in Seismology. In an Inverse problem, we aim to retrieve a model, described by a certain numbers of parameters, based on observations. We introduce here a new application of the TransTessellate2D software introduced by Hawkins et al. (2018) which is a Bayesian trans-dimensional approach that allows us to choose between different types of parameterization for the 2D model space (Voronoi or Delaunay). In this type of inversion, the number of model parameters to retrieve is also an unknown. We use this software to retrieve the sea ice thickness and the snow depth over the Arctic Ocean using freeboards from radar and laser altimeters. We show that we can retrieve these two parameters in only one step without any assumptions on the snow depth. The results of the inversion are compared to Snow and Ice validation products and compare favourably with existing snow and ice products. We also show that the software is capable of retrieving a penetration factor for the radar and laser pulses. This work could be extended in the context of the CRYO2ICE campaign that allowed for near-coincident radar and laser altimetry separated by approximately 3 hours. We investigate also the joint inversion from AltiKa (Ka) and CryoSat-2 (Ku) which paves the way for the future dual-frequency mission CRISTAL.

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TEMPORAL AND SPATIAL VARIABILITY OF EDDY KINETIC ENERGY IN THE SOUTHERN OCEAN

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Eddy kinetic energy (EKE) has been a crucial measure of turbulent energy in the Southern Ocean for the past 30 years. Traditional EKE calculations are limited to along-track altimetry crossovers due to the dependence on meridional and zonal velocities. Outside of crossover points, only cross-track kinetic energy can be computed. To address this limitation, gridded altimetry products have been employed for EKE calculations. However, the gridding process introduces smoothing and spatial correlation effects, which impact the calculated EKE. The Surface Water Ocean Topography (SWOT) satellite mission offers a significant advancement by providing sea surface height measurements along a two-dimensional swath, allowing the computation of meridional and zonal velocities at every point. In this study, we assess the spatial and temporal correlation of EKE derived from SWOT data to evaluate how effectively the 30-year altimetry record captures variations in EKE. This assessment aims to enhance our understanding of turbulent energy distribution and improve the accuracy of the long-term altimetry record.

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