

ABSTRACT BOOK

# 12th Coastal Altimetry Workshop

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### 3 Abstracts

#### Opening Session

##### **Altimetric measurement of sea surface height with increasingly high resolution and its applications to the coastal oceans**

**Fu L<sup>1</sup> (Solicited)**

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The measurement of sea surface height (SSH) by satellite altimetry has evolved from essentially one-dimensional sampling at its beginning to two-dimensional mapping with increasing number of satellites in orbit, forming a constellation in recent years. We have seen transformational studies of the ocean circulation from basin scales to mesoscales with increasing resolution, from detecting El Niños, planetary waves, to tracking individual eddies. This global view of the ocean has motivated the development of computer models of ocean circulation with ever-increasing resolution and sophistication, with their applications to understanding the ocean's coupling to the atmosphere from climate scales to weather scales. Through the development of advanced techniques of data processing as well as new measurement approaches, the utility of altimetry observations in coastal and near-shore regions has been increased with leaps and bounds. The impact of climate change on society is to a large extent delivered to the coastal zones though increasing severity of weather extremes superimposed on the slow trend of sea level change: storm surges, floods, and disturbance to estuaries and upstream river basins. The perspectives of future development of altimetry missions, coupled with advanced ocean-atmosphere models, for improved understanding of the complexity of the coastal oceans will be addressed in the talk.

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#### Session 1: Technical Issues in Coastal Altimetry #1

##### **Improving sea level mapping methodology and high-resolution hydrodynamic model for altimetry calibration/validation in the "Pertuis Charentais" area (La Rochelle, FRANCE)**

**Chupin C<sup>1</sup>, Tranchant Y<sup>1</sup>, Testut L<sup>1,2</sup>, Ballu V<sup>1</sup>**

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Observations from satellite altimetry give invaluable information about global sea level and regional variability at large-scale. However deriving reliable information remains challenging in coastal areas. Our project aims to improve the exploitation and validation of altimetry data in coastal area and prepare the validation of future altimetry missions. To this end, we develop a sea level height mapping methodology, using an Autonomous Surface Vehicle (ASV) equipped with various sensors and GNSS towed blanket. We also develop a high-resolution hydrodynamic model to discriminate the contribution of physical coastal processes (tide, currents, ...) in the sea surface height (SSH). As a first step, we will present the results of a mission conducted in June 2019 in the "Pertuis Charentais".

On the west coast of France, the "Pertuis Charentais" zone is a rich coastal area which includes islands and estuaries. It has multiples advantages to study altimeters coastal performances and could be a good probation site for the future SWOT mission. In fact, the area is highly covered by classical altimetry observations (Topex/Jason, SARAL, Sentinel 3) and includes a large network of in-situ observations with tide gauges and GNSS station network. The permanent observatory of Aix Island provides long time series of sea level with both tide gauge information (radar gauge) and continuous land vertical movements (permanent GNSS station). The LIENSs laboratory has expertise and resources (boat, buoys, pressure sensors,...) to organize in-situ observation campaigns, including cal/val activities. To complement the set of available instruments, a new marine ASV (PAMELi) is being developed to quickly collect a wide range of data near the coast.

The "Pertuis" experiment was carried out from 24th to 28th June 2019. The main goal of this mission was to

estimate sea surface measurements quality of the ASV. With PAMELi, sea level monitoring is achieved by a combination of a GNSS receiver and an acoustic altimeter (“mini-cyclopée” system) to estimate GNSS antenna height above water level. During this campaign, CalNaGeo towed blanket is used as a reference for kinematic measurements and static sessions allow us to compare with tide gauge observations. ASV speed and driving tests will also help us to determine repeatability and consistency of mini-cyclopée measurements.

Cal/val activities require temporal and spatial in-situ measurements of SSH along altimetry tracks. To link in-situ measurements to altimetry observations, we discriminate contribution of different physical processes in the SSH field (geoid, tide, currents, ...) with a local and accurate hydrodynamic model. During this experiment, we measure SSH along Topex/Jason and Sentinel 3a tracks in order to map geoid variations.

This first study is going to be regularly repeated in the area of the “Pertuis” in order to improve our knowledge of this complex coastal area. Thanks to this new observation dataset and modelling effort this site will become of interest for validating current altimetry missions and future SWOT mission.

\*\*\*\*\*

### Revisiting the small-scale variability in coastal areas thanks to altimetry constellation

*Raynal M<sup>1</sup>, Labroue S<sup>2</sup>, Denneulin M<sup>1</sup>, Picard B<sup>2</sup>, Dibarboure G<sup>3</sup>, Picot N<sup>3</sup>*

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Due to the proximity of the coast, its multiple configurations, the shallow waters and their bathymetry gradients, the oceanic circulation in coastal areas is very complex (Wright and Nichols 2018). Such ocean (and atmospheric) processes have shorter spatial and temporal scales, compared to open ocean ones, making their observation more difficult (Cipollini et al. 2017).

The objective of this presentation is to describe how vary the main geographical parameters (sea level, sea state, atmospheric content, ...) from the open ocean to the coastal areas.

Analysis performed are based on a specific altimetry configuration: Exploitation of the collocated geodetic and repetitive ground tracks derived from two Jason missions. These analyses allow accessing the small scales variability in the across-track direction. The study performed at global scales, also allows characterizing different kind of coastal areas (stable or dynamic) providing relevant information for CalVal applications.

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## Session 1: Technical Issues in Coastal Altimetry #2

### Proving that Sentinel-3 Altimetry can be a Shore Success

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The narrow altimeter footprint achieved through SAR processing should make the resultant data less susceptible to land clutter impairing the quality of geophysical returns with respect to those from conventional LRM processing. In this talk we will demonstrate the enhanced performance for estimation of wave height by comparing the accuracy and noise levels of SAR-derived and PLRM-derived records around the southwest of the UK.

The region affords a large network of coastal wave buoys and this part of the British coastline provides a diversity of both morphology and of orientation relative to satellite path and to direction of swell from the North Atlantic. In developing this analysis we have pioneered the incorporation of spatial insight from an operational wave model to define marine areas where the wave height will co-vary with that at the selected buoy. Within these coherent areas we find a strong correlation between our satellite and in-situ observations and can demonstrate improved performance for the SAR estimates approaching the coast, whereas the errors for the PLRM estimates increase.

Our coastal analysis finds r.m.s. errors of 0.46 m, with no dependence upon swell direction or period. This methodology of deriving coherent co-varying regions could be readily replicated for other altimeters and parts of the globe, and may suggest a mechanism for improving the assimilation of coastal altimeter data in wave models.

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## Improving the Validation Technique for Coastal Sea Level Rates from Satellite Altimetry and Tide Gauge Observations

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The validation of coastal altimetry sea level products against in situ tide gauge measurements is an essential part of verifying altimetric sea level observations and characterising their errors. The recent introduction of specialised retracers, such as the Adaptive Leading-Edge SubWaveform (ALES), has raised the possibility of retrieving good-quality altimetry data closer to the coast. One way to assess these new data is via altimetry-tide gauge comparisons, but this is complicated by the fact that altimetry measurements are rarely collocated with tide gauge stations, which gives rise to discrepancies between the two due to spatial separation. These discrepancies will be necessarily smaller in regions where sea level signals vary coherently over long length scales and so tide gauges located in such regions will provide a more reliable assessment of altimeter sea level data performance. Here, as part of a study conducted within the framework of the ESA Sea Level Climate Change Initiative (SL\_cci), we identify regions of long sea level trend length scales using data from both the high-resolution NEMO (1/12 degree) global ocean model and altimetry in order to improve the validation technique for assessing the performance of coastal altimetry sea level rates. To this aim, the tide gauges are sorted into groups according to their decorrelation values. The performance of the coastal altimetry observations is then assessed for each group of tide gauges separately. We report on the methodology and the outcome of these results in selected regions around the globe.

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### CalNaGironde: The Gironde Experiment

Bonnefond P<sup>1</sup>, Ayoub N<sup>2</sup>, Barbot S<sup>2</sup>, Benoit L<sup>4</sup>, Brachet C<sup>3</sup>, Calzas M<sup>3</sup>, Conessa C<sup>4</sup>, Drezen C<sup>3</sup>, Fichen L<sup>3</sup>, Froideval L<sup>4</sup>, Garcia J<sup>8</sup>, Giry C<sup>7</sup>, Guillot A<sup>3</sup>, Jan G<sup>9</sup>, Laurain O<sup>10</sup>, Lyard F<sup>2</sup>, Magot L<sup>7</sup>, Picot N<sup>6</sup>, Poisson J<sup>5</sup>, Ternon P<sup>4</sup>, Valladeau G<sup>5</sup>

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In the framework of SWOT, the approach that holds the building of the campaign is to update and complete the knowledge of the absolute height along the river. To this is added the interest of characterizing some sections perpendicular to the banks to give themselves sections of measurements that will enrich the models of

propagation of the tide in the estuarine environment. A multi-instrument campaign took place on the Gironde in October 2018. The "CalNaGironde" field mission took place from 15 to 18 October 2018 on the Gironde estuary and the Garonne. The DT-INSU contributed with different instruments that were deployed: 2 GPS carpets (CalNaGeo), 2 static GPS buoys, Cyclopée (acoustic altimeter) and 2 GPS base stations. The Hydrones company from CLS supplied a micro lidar which was integrated on a drone of the "Azur Drone" company, the latter having dispatched a pilot to perform the flights. An airborne LIDAR from the University of Caen also measured the area the following week due to adverse weather during measurements of other instruments. Results and comparisons of the outputs of the different instruments will be presented.

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### SAR Altimetry performance and improved retrieval methods in the Coastal Zone. Results and recommendations from the SCOOP project.

Cotton D<sup>1</sup>, Moreau T<sup>2</sup>, Makhoul E<sup>3</sup>, Cancet M<sup>4</sup>, Fenoglio-Marc L<sup>5</sup>, Gommenginger C<sup>6</sup>, Naeije M<sup>7</sup>, Fernandes M<sup>8</sup>, Lazaro C<sup>8</sup>, Shaw A<sup>9</sup>, Restano M<sup>10</sup>, Ambrózio A<sup>11</sup>, Benveniste J<sup>12</sup>

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SCOOP (SAR Altimetry Coastal & Open Ocean Performance) is a project funded under the ESA SEOM (Scientific Exploitation of Operational Missions) Programme Element, started in September 2015, to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products, in the coastal zone and open ocean, and then to develop and evaluate enhancements to the baseline processing scheme in terms of improvements to ocean measurements. Another objective is to develop and evaluate an improved Wet Troposphere correction for Sentinel-3, based on the measurements from the on-board MWR, further enhanced mostly in the coastal and polar regions using third party data, and provide recommendations for use.

Two SAR altimeter data sets were produced, a first data set with processing intended to be equivalent to Sentinel-3 baseline processing, and a second data set with modified processing including application of zero-padding (factor 2) and Hamming windowing.

In this presentation we present results from the SCOOP Coastal Zone study, including:

- Analysis of performance of the two test data sets in the coastal zone, in terms of noise, validation against other products and in-situ data, appropriate

methods for data selection and including an investigation of the effect of the “angle of arrival”.

- Analysis of the performance of two further test data sets produced by isardSAT intended to improve performance at the coast, firstly using the first ocean window delay (when the altimeter ground track crosses from land to ocean) as a tracking reference, (2) using the mean sea surface as tracking reference.

- A study by NOC to investigate SAR data characteristics at the coast with the objective to develop and test potential improvements to coastal zone processing, including stack selection, sub waveform retracking, SAR stack optimal weighting.

Finally we present recommendations from the SCOOP Scientific Roadmap for operational SAR mode altimetry processing and further research.

The SCOOP test data sets and relevant documentation are available to external researchers on application to the project team.

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### Assessment of Sentinel-3 and Jason3 Altimetry Data in The Coastal Zone

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The performance of satellite altimetry in the coastal zone has historically been a challenging issue. In recent years, there have been significant developments of specialised radar echo fitting (‘retracking’) algorithms to improve the quality and quantity of altimeter data closer to the coast. In addition, there have been noticeable developments to improve several geophysical corrections that must be applied to altimeter range data in coastal regions (e.g. wet tropospheric delay). Innovative technological solutions have also been used to deliver better performance near the coast. These include Ka-band altimetry with SARAL/AltiKa and its smaller radar footprint; and Delay Doppler Altimetry (DDA) also known as Synthetic Aperture Radar (SAR) altimetry. SAR mode altimetry uses unfocused along-track synthetic aperture to achieve finer spatial resolution along-track and better precision on retrieved parameters.

The SRAL altimeter currently flying on Sentinel-3A and Sentinel-3B can operate in two modes: 1) conventional Low Resolution Mode (LRM) mode corresponding to the pulse-limited altimeters from the TOPEX/Jason reference series; and 2) SAR mode. The default mode for Sentinel-3 SRAL is to operate in SAR mode globally. However, a SAR reduction technique can be applied to incoherently combine SAR mode individual echoes to recreate LRM-type waveforms, to produce what is known as Pseudo-LRM (PLRM). PLRM waveforms follow the conventional Brown model shape of LRM altimetry and can be retracked in the same manner as LRM

waveforms. However, PLRM waveforms suffer from the same contamination issues close to land as conventional LRM altimetry.

This paper presents a comprehensive assessment of Sentinel-3A and Sentinel-3B data in the coastal zone. The analyses consider performance in terms of retrieved sea level, SWH and wind speed, of the evolution of these parameters as a function of distance to the coast and of the impact of geophysical corrections. Results are presented for PLRM waveforms from the Sentinel-3A and Sentinel-3B satellites retracked with the NOC implementation of the Passaro et al. (2014) Adaptive Leading-Edge Sub-waveform (ALES) coastal algorithm. The NOC-ALES Sentinel-3 PLRM results are compared with those obtained for Jason-3 LRM retracked with classical and NOC-ALES retracking. The NOC-ALES S3A and S3B PLRM data are also compared with operational Sentinel-3 SAR data to gauge the quality of SAR mode altimetry in the coastal zone compared to conventional coastal altimetry.

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### Session 1: Technical Issues in Coastal Altimetry #3

#### Retracker bias characterization in coastal zones

*Niño F<sup>1</sup>, Birol F<sup>1</sup>, Blumstein D<sup>1</sup>, Ngo H<sup>2</sup>, Léger F<sup>1</sup>*

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Using data of over 25 years of altimetry satellite measurements, today it is possible to quantify the long-term changes in sea level and to determine the areas where it is rising. However, if the uncertainties of these measurements for the open sea are relatively well known, this is not the case near the coast, where the variations of sea level have the greatest impact. One of the main causes for this is that altimetry radars observe a surface (water and land) whose properties are far more inhomogeneous than that found offshore. Raw altimetry waveforms are seldom like the ideal Brown model, and are thus more difficult to interpret; as a result, the uncertainty about the estimation of the level of the sea that is made, greater.

We present our work towards the characterization of the behavior of altimetry retrackerers on the coastal zone, particularly the MLE3/4 retracker. The general goal is the quantification of the error of range estimation when the retracker tackles coastal waveforms. To do this, we evaluate the range estimated by the retracker, with ground truth. To obtain the latter, we use an altimetry simulator with a synthetic scene (combining a digital terrain/ocean surface model, a land cover map and

reflectance parameters) to create a database with a large number of simulated altimetry waveforms in different conditions (e.g. significant wave height variations) and then analyze how the coastline and the presence of surrounding topography, or inland waters create a bias in the results of retracking algorithms.

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### **Round Robin Assessment of Radar Altimeter LRM and SAR Retracking Algorithms for Significant Wave Height: A Coastal Point of View**

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In June 2018, the Sea State Climate Change Initiative (SeaState\_cci) project was launched by the European Space Agency (ESA). The main goal of the project is the estimation and exploitation of consistent climate-quality time-series of significant wave height (SWH) across different satellite missions. One of the focus areas of the project is the coastal zone, given the current decrease in performance of standard altimetry products when approaching land and the significant impacts of sea state in this area.

The responsibility of the SeaState\_cci Algorithm Development (AD) team is to improve and develop novel retracking algorithms for estimating the SWH parameters yielding increased signal-to-noise ratio (SNR) and better performance in the coastal zone. Furthermore, the new estimation techniques shall generate consistent results in terms of precision and accuracy during the past 25 years of satellite altimetry data. Two novel retracking algorithms with the best retracking performance shall be selected for production, one for each of the two main operational modes of satellite altimetry, i.e. low resolution mode (LRM) and synthetic aperture radar mode (SARM).

In accordance with other ESA CCI projects, a round robin (RR) exercise for algorithm evaluation and selection open to both internal and external teams is being conducted. This presentation will illustrate the selection procedure and present an overview of the results of the different candidate algorithms.

The RR is focused on input datasets of the two missions Jason-3 (J3) and Sentinel-3A (S3A) covering up to two years of data and spanning different sea state conditions. To evaluate the overall performance of the retracker, a series of criteria have been defined, including criteria for both internal statistics and for a comparison against in-situ (buoys) and model data. In the evaluation process, a

differentiation is made between open-ocean and coastal regions and also for different sea states, in order to identify the general applicability of the individual retracking algorithms.

The results of the RR assessment show that the performances of the retracking algorithms strongly depend upon the distance to coast and the sea state. Defining an overall best performance to select the algorithms for production is a challenging task. For instance, some algorithms show high correlations with model and in-situ data, but significantly deteriorate the large-scale wave spectral variability.

The input waveform data and the validation datasets and code will be made openly available so that other algorithm developers may evaluate their products against the same benchmarks.

The RR exercise of the ESA SeaState\_cci project is an excellent opportunity to harmonise the procedures for retracker's evaluation and can be reused in other projects that involve satellite altimetry. Our results show the strong improvements that most novel algorithms achieve with respect to the current standard in the coastal zone and therefore the analysis is relevant also for future choices of wave products tailored for the coast.

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### **Defining a retracking manifold within a radargram stack to improve satellite altimetric water level over coastal seas: A feasibility study**

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Single-waveform retracking for satellite altimetry applications over coastal zones has reached its limits, obtaining decimeter-level accuracy. The existing retracking methods find a retracker offset in a waveform by analyzing the variation in backscattered power along the bin coordinate. This makes the retracking procedure strongly dependent on noise in backscattered power. Moreover, the success of such methods is only guaranteed for certain waveform types requiring cumbersome pre-processing steps including waveform classification.

With the launch of the operational Sentinel-3 series of the European Copernicus programme, the algorithms to obtain highly precise water level estimates over inland waters and coastal seas need to become more robust, efficient and fit for automated use. Therefore, the main objective of this study is to demonstrate the potential of developing a next-level retracking algorithm and, consequently, improve altimetric water level determination over coastal regions. To this end, neighboring waveforms are collected into a (single-pass) radargram and, then, such radargrams are stacked over time. These so-called (multi-pass) radargram stacks contain, unlike single waveforms, the full information on

spatio-temporal variation of backscattered power over water surfaces.

The radargram stack eases the recognition of patterns like retracking gate, shoreline, tides, etc. Instead of a retracking gate as a point in the 1D waveform, in a 3D radargram stack a surface referred to as retracking manifold is to be determined.

The potential of our new approach will be demonstrated using Sentinel 3B data, pass number 655, over the Cuxhaven tide gauge station at the Wadden Sea.

The idea of waveform retracking by analyzing its spatio-temporal behavior in a 3D data structure opens new pathways for achieving robust and more accurate water level estimates from operational missions, e.g. Sentinel 3, and from future missions, e.g. SWOT, over inland waters and coastal seas.

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### **Assessing the quality of 80 Hz Sentinel-3A SRAL sea level data around Spanish coasts**

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Two and a half years (June 2016 - November 2018) of Sentinel-3A SRAL (S3A-SRAL) altimetry data were validated at selected sites around Spanish coasts. They were obtained from the European Space Agency Grid Processing On Demand (GPOD) SARvatore (SAR versatile altimetric toolkit for ocean research & exploitation) service. In this work, the new product with a sampling rate of 80 Hz (equivalent to an along-track distance between two consecutive measurements of about 85 m) is assessed. Three coastal sites in Spain were selected: Huelva (Gulf of Cadiz), Barcelona (Western Mediterranean Sea) and Bilbao (Bay of Biscay). Two tracks were retrieved at each site, one ascending and one descending. Data were validated using in-situ radar tide gauge data provided by the Spanish Puertos del Estado. The altimeter-derived sea level anomaly time series were obtained using the corrections available in GPOD. The sea state bias correction (SSB) is not available at 80 Hz in GPOD; hence, it was empirically approximated to a fraction of the significant wave height that minimises the sea level anomaly RMSE with respect to the tide gauges, i.e. 5% of SWH. The validation was performed using two statistical parameters, the Pearson correlation coefficient ( $r$ ) and the mean square error (rmse). In the 5-20 km segment with respect to the coastline, the results were 6-8 cm (rmse) and 0.7-0.8 ( $r$ ) for all the tracks. The 0-5 km segment was also analysed in detail to study the land effect on the altimetry data quality. Results showed that the track orientation, the angle of intersection with the coast, and the land topography concur to determine the nearest distance to the coast at

which the data retain a similar level of accuracy than in the 5-20 km segment. This “distance of good quality” to shore reaches a minimum of 3 km for the tracks at Huelva and the descending track at Barcelona. Our results demonstrated that data screening plays a key role in the selection of the altimeter valid data. The comparison against tide gauges spotted anomalous sea level data not removed in the standard screening used in this work. To our knowledge, this is the first time that S3A-SRAL sea level data are validated at the highest posting rate available as a standard product.

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### **SWOT Datasets for the Coastal Areas**

*Hausman J<sup>1</sup>, Gangl M<sup>1</sup>, Gierach M<sup>1</sup>, Oaida C<sup>1</sup>, Vannan S<sup>1</sup>*

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The Surface Water and Ocean Topography (SWOT) is an interferometric SAR satellite mission that will measure ocean surface topography and inland surface water heights at a higher spatial scale than any other current altimetric satellite mission. While the mission does not launch until 2021, the products from the mission are known. SWOT will not produce coastal specific datasets, but there are several oceanic and hydrological datasets will be available for the coastal regions. The contents of the Low Rate (LR) ocean and High Rate (HR) inland water datasets will be discussed, along with differences in spatial resolutions and corrections between them. Plans for data access and services, from PO.DAAC, for the SWOT data and other datasets that will be on the cloud will also be covered.

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### **A Multi-epoch SARIN Retracker Dedicated to Freeboard Measurement**

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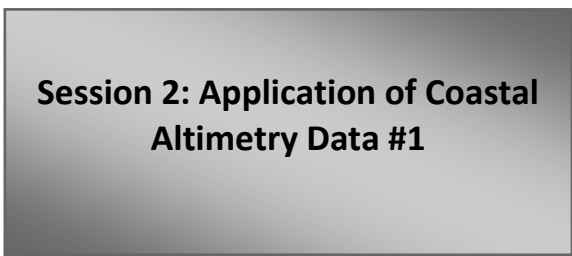
The CryoSat-2 measurements over sea-ice areas make it possible to detect leads and polynyas in order to measure freeboard. Conventional freeboard measurements methods for LRM and SAR modes involve a single class per record assuming that the target of interest is located at NADIR. Adequate filtering and interpolations are performed either on the sea elevations or on the floes elevations. This operation is often performed over multiple tracks and is subject to 2D interpolation over a regular grid. In the case of multiple leads or in the case of lead(s) at far across-track distance the waveforms are often considered as ambiguous and are rejected as they exhibit multiple peaks. In coastal areas where CryoSat-2 often operates in SARIN mode, the phase difference of the complex waveforms make it possible to identify the precise location where the echoes are coming from and even disambiguate which target is located left or right along the ground track.

Multiple peaks retracking is worth in this context where the measurements may be corrected from slant-range geometry to a simulated NADIR geometry at the precise target location.

We have designed a new empirical retracker capable of selecting the major peaks in the waveform in a robust manner. In this communication we are showing the first results and the robustness of the proposed scheme. The retracking scheme is coupled to an improved surface type detection scheme taking into account several stacks derived parameters.

The benefit of such an approach is to be able to densify the number of measurements for each target type with the expectation of improving the interpolation steps that is required for the production of freeboard.

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### **Bathymetry Improvement and Tidal Modelling at Regional Scales**

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Coastal processes (tidal currents, storm surges, waves) are highly dependent on bathymetry and directly impact offshore and coastal activities and studies. Many studies and applications lie on a growing modelling effort of the ocean and the limited accuracy of bathymetry, especially on the continental shelves, contributes to degrade numerical model performance despite significant use of in-situ and satellite measurements assimilation. In particular, the tidal models are very sensitive to the bathymetry accuracy on the shelves, where the ocean tides show the largest amplitudes and are strongly non-linear.

The increase in the grid resolution, combined with local model tuning, is one of the means to improve the tidal model performance in the coastal regions and large improvements have been achieved thanks to this approach. However, increasing the resolution of the model grid implies consistent bathymetry quality and accuracy, which is today the main limiting factor to accurate high-resolution tidal modelling.

In particular this has a direct impact on the quality of the coastal altimetry sea surface heights as the tide correction is one of the largest corrections on the

shelves, ranging from several centimetres to several metres. It is of prime importance for the current and future satellite altimetry missions that already or will enable to retrieve high-resolution coastal observations of the sea surface height, such as Sentinel-3, SWOT and Sentinel-6/Jason-CS.

Various sources of bathymetry data exist but many regions remain poorly known because of too sparse measurements, data access limitation or large temporal variability of the seabed dynamics. In this context, CNES funds a project that aims to improve the bathymetry and the tides in a number of regions, such as the North-East Atlantic Ocean, the Mediterranean Sea and the Arctic Ocean.

The work is divided in several steps: 1) an inventory of the existing bathymetry datasets in the regions of interest; 2) the integration of the collected datasets into a reference global bathymetry dataset; 3) the evaluation of this new bathymetry dataset through hydrodynamic modelling; 4) the assimilation of tidal observations into the hydrodynamic model and the production of high resolution regional tidal atlases.

This paper presents the most recent results obtained within this project.

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### **MSS improvement in the coastal zone - result from the Baltic Sea**

*Andersen O<sup>1</sup>, Abulatitijiang A<sup>1</sup>*

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The Mean sea surface is one of the key geophysical correctoins aplited to derived accurate sea level anomalies in the coastal zone.

In order to create the state of the art Mean sea surface for the coastal zone of the Baltic sea we take full benefit from retracked conventional altimetry using the ALES+ retracker which provides data closer tto the coast compared with conventional altimetry. We investigate the use of the newly processes Exact Repeat Mission data (Jason`etc) in the Baltic focusing on coastal improvement. A novel attempt to use stacked SAR altimetry from Cryosat-2 and Sentinel-3 is also impormented to providing altimetry corrections of higher quality in coastal regions. To this work we use a new correctoin to sea level variability derived by AVISO.

The presentation largely present contribution to the Baltic Seal project.

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## Examining the Performance Sentinel-3A SAR Altimetry Retracker and Hydrodynamic Models using a High-Resolution Geoid Model in the Baltic Sea

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This study examines the performance of Sentinel-3A SAR altimeter data and hydrodynamic models (HDM) in the coastal waters of the Gulf of Finland, Baltic Sea. Validation of satellite altimetry (SA) derived sea surface height (SSH) is often performed with respect to land bounded tide gauges (TG). This method is however limited for satellite points are often located further offshore. As a result, this study not only utilizes TG but also HDM in conjunction with a high-resolution geoid model. The utilization of a high-resolution geoid model allowed all used data sources to be referred to a common reliable reference frame.

The methodology employed encompassed: (i) SSH were computed along three ascending passes nearby tide gauge (TG) sites in the eastern Baltic Sea; (ii) the altimeter computed SSH were compared to a high-resolution marine geoid model in conjunction with a TG corrected hydrodynamic model (HDM) and (iii) an inter-comparison between the SAMOSA2 and SAMOSA+ retracker retrieved SSH values. The quality assessment yielded the root mean square error of 115 and 99 mm for the SAMOSA2 and SAMOSA+ retrieved Sentinel-3A SSH data, respectively. Inter-comparison between the HDM and satellite data with respect to the passes and cycles also allowed identification of key spatial and temporal discrepancies either with the HDM or the satellite retracker. Thus, the methodology employed not only validates the satellite data but also that of the HDM.

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## New CNES-CLS18 Mean Dynamic Topography of the global ocean from altimetry, gravity and in-situ data

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The Mean Dynamic Topography (MDT) is a key reference surface for altimetry. It is needed for the calculation of the ocean absolute dynamic topography, and under the geostrophic approximation, the estimation of surface currents. Those are required for a wide range of applications as the management of fishery resources, the monitoring of potential pollution, maritime security... Also, the MDT is the missing component for the optimal assimilation of altimeter data into operational ocean system as those run under the Copernicus Marine Environment Monitoring Services (CMEMS).

CNES-CLS Mean Dynamic Topography solutions are calculated by merging information from altimeter data, GRACE and GOCE gravity data and oceanographic in-situ measurements from drifting buoy velocities and

hydrological profiles. The objective of this communication is to present the newly updated CNES-CLS18 MDT. The main novelties compared to the previous CNES-CLS13 solution is the use of updated input datasets: the GOCO05S geoid model (instead of DIR4) and the CNES-CLS15 Mean Sea Surface are used together with drifting buoy velocities (SVP-type and Argo floats) and hydrological profiles (CORA database) available from 1993 to 2016 (instead of 1993-2012). The new solution also benefits from improved data processing (in particular, a new Ekman model is used to extract the geostrophic component from the buoy velocities) and methodology (for instance, the way to filter the raw difference between MSS and geoid height has been improved).

An evaluation of this new solution compared to the previous version and to other existing MDT is done through comparison to independent in-situ data. Further validation by "super-users" have also been performed. Compared to the CNES-CLS13 solution, the new CNES-CLS18 MDT shows improved performance everywhere and more significantly in coastal areas.

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## Session 2: Application of Coastal Altimetry Data #2

### Toward Higher resolution Level-3 altimeter product

*Pujol M<sup>1</sup>, Faugère Y<sup>1</sup>, Dupuy S<sup>1</sup>, Vergara O<sup>1</sup>, Dagneaux Q<sup>1</sup>, Dibarboue G<sup>2</sup>*

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In 1998, first Level3 along-track, user friendly altimeter products have been developed with support from CNES and delivered to the users on AVISO+. The Level3 processing includes a homogenization of the SLA for the different altimeters (i.e. reduction of the global and regional biases), allowing the users to directly use the products without any pre-processing. They are widely used for different applications, including assimilation in numerical models. Since 2008, such products are generated and disseminated by the Copernicus Marine Service (CMEMS; previously MyOcean during its demonstration phase).

Since few years, efforts are done in order to improve the altimeter measurement in the coastal area. While the observation of the coastal area remains a challenge for the conventional altimeter measurement, new techniques and processing allow to significantly reduce the measurement errors and noises. Additionally, with the future altimeter missions as the large swath SWOT



mission, the altimeter processing will face a new challenge be able to accurately process the signal at finer spatial scales.

A new generation of along-track products is under development with support from CNES. They are derived from high resolution (20Hz) altimeter measurement and are specifically processed in order to better sample the coastal areas and solve finer scales up to ~30 km. They merge recent developments that enable to optimize the Sentinel3 SAR altimeter processing (Boy 2017, Moreau,2018) and the Jason/Altika noise level (Zaron 2016, Tran 2019) and allow us to better exploit the fine-scale content of the altimetric missions. They also take into account improvements that are also done in geophysical corrections estimation (e.g. internal tide model [Zaron 2018]) and local Mean Sea Surface Estimation (e.g. Dibarboure et Pujol, 2019). Experimental datasets, with a nearly 1km (5Hz) sampling, are already available on AVISO+ (<https://www.aviso.altimetry.fr/duacs>) and can be tested by users. We will present these experimental 5Hz products defined over the Europe region, including part of the North Atlantic, the Baltic, Mediterranean and Black Sea.

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### **The New Generation of High-Resolution X-TRACK/ALES Regional Altimetry Product and the Coastal Applications Associated**

**Léger F<sup>1</sup>, Birol F<sup>1</sup>, Niño F<sup>1</sup>, Passaro M<sup>2</sup>, Cazenave A<sup>1</sup>, Gouzènes Y<sup>1</sup>, Legeais J<sup>3</sup>, Schwatke C<sup>2</sup>, Benveniste J<sup>4</sup>**

<sup>1</sup>LEGOS, Toulouse, France, <sup>2</sup>DGFI-TUM, Munich, Germany, <sup>3</sup>CLS, Ramonville-Saint-Agne, France, <sup>4</sup>ESA-ESRIN, Frascati, Italy

Sea level change is one of the major threats for coastal areas; its observation is essential to better understand and predict the behaviour of the coastal ocean. Altimetry provides a unique long-term and almost global observational dataset to characterize the evolution of sea level variability from the open ocean to the coastal ocean.

More than 10 years ago, the CTOH and LEGOS started to develop the X-TRACK processing chain in order to recover as much as possible coastal sea level observations from the GDR altimetry products. Today, X-TRACK is a mature multi-mission along-track altimetry 1 Hz product and as well an along-track empirical tidal constants product, covering all the coastal ocean, produced by CTOH/LEGOS and distributed by the AVISO+ operational service. In parallel, the ALES retracker has now proven its effectiveness in recovering more coastal sea level observations than other retrackerers. Geophysical corrections, in particular wet tropospheric corrections and tidal corrections, have also been largely improved during past years in the coastal domain. Here we present a new version of the X-TRACK processing chain that includes many of the progress made by the altimetry

community in recent years, both in terms of retracker and geophysical corrections.

In the context of the bridging phase of the ESA's climate change initiative sea-level project (SL\_cci) and acknowledging user needs, we develop a new X-TRACK L3 multi-mission product combining the better spatial resolution provided by high-rate data (20 Hz), the post-processing strategy of X-TRACK and the advantage of the ALES retracker. In this product the number of near-shore sea level data available for the users is significantly increased. For example, for Jason-2, we obtain 80% of valid sea level data at a distance of less than 2 km on average for the Mediterranean Sea, instead of the 7 km for the X-TRACK's previous version. It then provides new information that opens new fields of application. As an illustration, the 20 Hz X-TRACK/ALES SLA data allow to better characterize the signature of the variability of the Northern Current (NW Mediterranean Sea) and to better follow its position very close to the coast, compared to the conventional 1 Hz X-TRACK product.

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### **On The Use of Satellite Altimetry for Validating a Pan-European High Resolution Storm Surge Hindcast (ANYEU-SSL)**

**Fernández-Montblanc T<sup>1</sup>, Ciavola P<sup>1</sup>, Vousdoukas M<sup>2</sup>, Mentaschi L<sup>2</sup>**

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Storm surges are major coastal flooding drivers, causing a great impact at socio-economic level. Surges can persist for several hours and cannot only cause coastal inundation, but also increase the wave driven hazard due to decreased wave energy dissipation at the coastal boundary. To have high quality time series that span several decades is essential for studies concerning the dynamics of extreme sea levels in support of policy making and design of adaptation policies especially in view of climate change.

Accounting for this necessity, a high-resolution Pan-European storm surge (SSL) dataset, ANYEU-SSL was produced using the SCHISM circulation model. The SSL dataset spans a time interval of 40 years (1979-2018), covering the European coastline with a 3-hour temporal resolution. The dataset has been validated extensively for the period spanning from 1979 to 2016, considering the whole time hindcast series, as well as for extreme SSL values. Validation against tidal gauge data shows an average RMSE of 0.10 m, and RMSE below 0.12 m in 75% of the tidal gauges. A limitation was posed by the fact that measuring networks show limitations in temporal and spatial coverage. Consequently, an additional validation took place against a satellite altimetry dataset. The altimeter dataset used was the GLOBAL OCEAN ALONG-TRACK L3 SEA SURFACE HEIGHTS REPROCESSED from CMEMS (Copernicus Marine Environment

Monitoring Service-http://marine.copernicus.eu). The high frequency wind and pressure effects, the so-called Dynamic Atmospheric Correction (DAC), produced by CLS using the Mog2D model from Legos distributed by Aviso+, with support from CNES (<https://www.aviso.altimetry.fr/>) was restored as a linear addition to the SLA in order to include all atmospheric forcing contributions to the sea level variation (SLADAC). SLADAC was compared with the SSL hindcast for the period 1992-2016. Validation with altimetry data show an average RMSE of 0.07 m. The hindcast also shows a good representation of the extreme surge levels (RMSE< 0.12 m) along 73% of the study area. The observed discrepancies can be related with processes omitted in the ocean model contributing to sea surface height, like the steric ocean height driven by the thermo-steric and the halo-steric components. The steric height cycle, with annual development/time scales, is well captured by satellite observation. Further research is required to evaluate its contribution to extreme water levels and assimilate this phenomena in the SSL hindcast dataset. Likewise, future work should be performed using the Adaptive Leading Edge Subwaveform (ALES) derived dataset near the coast.

Finally, SSL trends for the period 1979-2016 are estimated as an example of a potential application case of the dataset. SSLs appear to increase in areas with latitudes >50 °N and to decrease in the lower latitudes. Additionally, a particularly strong seasonal variation of the extreme SSL is observed in the northern areas. The dataset is publicly available and aspires to provide the scientific community with an important data source for the study of storm surge phenomena and consequential impacts, either at large or local scales.

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### **Coastal Altimetry Circulation (CryoSat-2): Comparison with High-Frequency Radar**

**Mulero-Martinez R<sup>1</sup>, Gomez-Enri J<sup>1</sup>, Bruno M<sup>1</sup>**

<sup>1</sup>University of Cadiz, Puerto Real, España

The present work shows the possibility of studying surface circulation in coastal areas using altimetric measurements. With this aim, surface absolute geostrophic current (SAGC) velocities derived from altimetric measurements were compared with surface current velocities obtained from two high-frequency radar stations (HFR) located in the Gulf of Cadiz. SAGC velocities were computed from an edition methodology applied to CryoSat-2 along-track sea level anomalies (SLA) along the Gulf of Cádiz from 4 different tracks between October 2013 and January 2014. The correlation coefficients obtained from the comparison between the geostrophic current derived from altimetric measurements and geostrophic velocities from 72hours averaged high-frequency radar observations show a good fit between both datasets in 3 of the 4 tracks analyzed ( $r = 0.87; 0.79; 0.55$ ).

### **Session 2: Application of Coastal Altimetry Data #3**

#### **Assessment and application of Sentinel-3 fully-focused SAR altimeter range data for enhanced detection of coastal currents along the Northwest Atlantic shelf**

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Fully-focused Synthetic Aperture Radar (FFSAR) processing is a novel approach to Delay Doppler altimeter signal analysis that involves optimal focusing of the complex radar echoes along the satellite ground track (Egido and Smith, 2017). Expected benefits include range measurement noise reduction and improved spatial resolution that may exceed unfocused SAR processing nominally employed with the DDA data. This study seeks to exploit such potential FFSAR improvements to better resolve nearshore and short-scale currents on the Northwest Atlantic (NWA) shelf using satellite data. Coastal areas of interest include the connected Nova Scotian Shelf (NSS), marginal sea Gulf of Maine (GoM), and Mid-Atlantic Bight (MAB) systems. Along this extended coastline there are several persistent and narrow (scales < 10-30 km) coastally-trapped currents that conventional altimetry has usually failed to adequately capture. Regional hydrographic measurements and models have identified the mean characteristics of these currents as well as the importance of resolving monthly-to-seasonal change in their advective transport. The question becomes – can Sentinel-3 DDA data be employed to improve monitoring of nearshore advection along this shelf?

This talk will present a multi-year assessment of FF-SAR processed Sentinel-3A and -3B data on the NWA shelf with a detailed look at range, sea surface height (SSH), significant wave height (SWH) and radar backscatter ( $\sigma_0$ ) measurements as well as SSH-derived cross-track (nearly alongshore in this reference frame) geostrophic currents ( $V_g$ ). Data from this numerically-intensive reprocessing are provided at an 80 Hz along-track posting rate. Comparison benchmarks will include unfocused SAR and pseudo-low resolution mode data. Emphasis is on signal and noise levels at scales inside of 50 km (and even < 2 km), data recovery rates within 1-5 km from the coastline, and possible new identification of short-scale SSHA variation associated with small gyres and internal waves. External validation, with a focus on derived geostrophic currents, comes from a range of

regional ocean surface current datasets, including multi-altimeter GlobCurrent products, in situ ADCP current measurements from the US-IOOS GoM moored buoy and MAB HF Radar (CODAR) networks.

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### **Wave-current interactions in the Agulhas current system**

**Ponce De Leon Alvarez** <sup>S</sup><sup>1</sup>, **Guedes Soares** <sup>C</sup><sup>1</sup>,  
**Johannessen** <sup>J</sup><sup>2</sup>

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The effect that the Agulhas current applies on the wave spectrum. The study was conducted by performing high resolution spectral wave model simulations with and without ocean currents during a winter period (2018). The current field comes from the European Space Agency (ESA) project GLOBCURRENT (Johannessen 2016). The validation of the numerical simulations was performed for the Significant Wave Height (Hs) using all possible satellite altimetry data available for the study period of 2016. Wave spectra and extreme waves parameters were analyzed in deep and shallow water in particular where waves and current are aligned. Sentinel-1 (S1) wave mode Synthetic Aperture Radar (SAR) swell spectra were compared against WAM swell spectra. The comparison of the observed and modeled wave spectra was performed over eddies, rings and meanders (Agulhas Retroreflection current zone) allowing to follow the transformation of the wave spectra due to current refraction.

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### **Toward a New Coastal Altimetry-Based Algorithm for the Detection of Current Intrusions Into the Gulf of Lion**

**Casella** <sup>D</sup><sup>1</sup>, **Meloni** <sup>M</sup><sup>2</sup>, **Doglioli** <sup>A</sup><sup>3</sup>, **Petrenko** <sup>A</sup><sup>3</sup>,  
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Altimetry-derived currents have been largely used in order to monitor large and stable oceanic currents. The use of satellite based data for the monitoring of current events that are relatively small in size and short in time, in regions very near to the coast is a difficult challenge. The return branch of the cyclonic circulation of the northwestern Mediterranean Sea, known as the Northern Current, flows westward along the continental slope of the Gulf of Lion. Occasionally, under particular wind conditions, it can penetrate on the shelf causing an intrusion event. These events strongly impact the local biogeochemistry and consecutively the primary production. By combining coastal altimetric observations (XTRACK) with high-resolution modelling, the relation of intrusion events with the geostrophic currents and

horizontal winds has been analyzed with the objective to develop an algorithm for their detection from satellite altimetry. The algorithm for the detection of these current intrusions uses the random forest approach. It has been trained using 10 years of simulations from the SYMPHONIE model and tested with data from the JULIO bottom-moored Acoustic Doppler Current Profiler. The algorithm correctly identifies more than 90% of the big current intrusions. The results confirmed the well known role of horizontal winds in the dynamic of the intrusion events and the paramount importance of satellite altimetry data even in the proximity of a coast.

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### **The Zone of Influence: Matching along-track coastal altimetry data with high-frequent tide gauge observations for vertical land motion estimation**

**Oelsmann** <sup>J</sup><sup>1</sup>, **Passaro** <sup>M</sup><sup>1</sup>, **Dettmering** <sup>D</sup><sup>1</sup>, **Sanchez** <sup>L</sup><sup>1</sup>,  
**Schwatke** <sup>C</sup><sup>1</sup>, **Seitz** <sup>F</sup><sup>1</sup>

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By enhancing the comparability of coastal satellite altimetry (SAT) and tide gauge (TG) measurements, we improve the determination of vertical land motion (VLM) at the coast, which is a substantial contributor to relative sea level trends.

Coastal GNSS measurements of VLM are accurate, however, the station distribution is not homogeneous worldwide and GNSS data are not available at large areas. An alternative approach is to subtract absolute satellite-based sea level (SL) measurements from relative SL changes recorded by tide-gauges. This application is a promising complement to GNSS VLM-measurements, given the over 20-year long records from altimetry and the larger availability of TGs. In this study, we focus on the improvement of this approach, with respect to the accuracy of resulting trends and the uncertainties of the estimates.

We investigate the impact of innovations in two fundamental components that contribute to the performance of trend estimates by SAT-TG difference: (1) Quality and resolution of the data and (2) the method for SAT-TG combination. First (1), we analyze performance of the gridded altimetry product AVISO against multi-mission along-track altimetry, which features latest improvements of coastal retracking (based on ALES) and geophysical corrections. VLM trends are derived by combining sea level anomalies (SLAs) within a 250km radius around TGs from the monthly PSMSL database. Comparing the RMS of differences of SAT-TG and GPS (ULR6a) trends, application of monthly averaged along-track altimetry instead of gridded products reveals no significant improvements neither by the RMS nor the trend uncertainties.

In a second step (2) we introduce refined selection criteria of SLAs to reduce residuals of the differenced time-series and thus the associated trend uncertainties. Therefore, we match high-frequency TG data from the

“Global Extreme Sea Level Analysis” (GESLA) data set with the along-track data, to determine zones of coherent sea level variability at the highest possible spatial and temporal scale. Using correlation, RMS or the residual annual cycle, we isolate spatial coherent SLA pattern in the coastal regions, representing the best match of SL variability measured at the tide gauge. Such ‘Zones of Influence (ZOI)’ capture predominant dynamics of coastal variability e.g. coastal currents and often project onto bathymetric gradients. High frequent along-track altimetry in combination with GESLA better detects small scale features of those ZOIs than the gridded, monthly-sampled product.

We compute trends from SLAs, which are averaged within the ZOI. Variation of relative thresholds of the aforementioned statistical criteria provides sub-sets of SLAs of different comparability. An optimal relative threshold is identified by minimization of the uncertainties of the estimated trends as well as their deviations from the GPS trends. This novel method of selection reduces the RMS by 20% and uncertainties by 25% with respect to the 250km-radius-selection of along-track data.

We show that the application of advanced along-track multi-mission altimetry data fosters the adjustment to the fine structures of coastal sea level variability, which leads to significant improvements in long-term coastal sea level and VLM trend determination.

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### **Coastal Altimetry using ICESat-2 Photon-Counting Laser Altimeter**

**Wang B<sup>1</sup>, Tourian M<sup>1</sup>, Sneeuw N<sup>1</sup>**

*<sup>1</sup>Institute of Geodesy, University of Stuttgart, Stuttgart, Germany*

Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) operated by NASA was launched in September 2018. The Advanced Topographic Laser Altimeter System (ATLAS) on the mission carries six beam laser transmitter with photon counting detectors, which emits 532-nm laser in 10 kHz repetition rate. ATLAS detects individual photons in a 70 cm separation for each shot on the earth’s surface in the along-track direction with ~17 m diameter footprint. Comparing to radar altimetry, ICESat-2 provides much higher along-track spatial resolution observing global earth surface, including inland water bodies, coasts and open oceans.

For radar altimeters, when the satellite nadir position approaches the coastline, more waveform samples become contaminated by land reflections, which causes poor accuracy of water level comparing to open oceans even some retracking methods may fail. Unlike radar altimetry, small footprint (~17 m) and dense sampling measurements (0.7 m) of ICESat-2 present an opportunity to measure the water surface directly, and to extract the long wave length from the point cloud.

The very dense measurements in a single ground track include reflected noises during the propagation of laser pulses. In this study, we develop an algorithm to monitor the sea surface from the dense point cloud. We employ our method over the coastal area near Los Angeles Harbor with tracks No. 59, 204, 501, 646, 1004, 1049 of ICESat-2 to generate the sea surface height variation time series, and to evaluate the performance on coastal sea measurements with respect to the tide gauge station at the coast of Los Angeles.

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### **The use of Sentinel-1, Sentinel-2, and SWOT-type data for monitoring the topography of coastal intertidal areas**

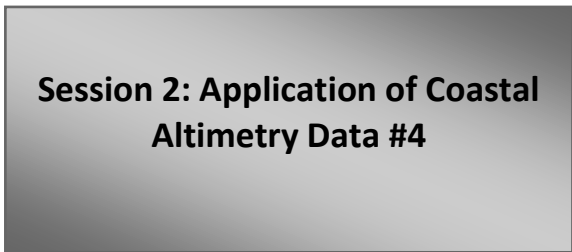
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Intertidal flats in coastal zones lying as a buffer zone between land and sea provide essential services including protection against storm surges and coastal flooding. These environments are characterized by a continuous redistribution of sediments and topographic changes. The continuous monitoring of their topography is fundamental for hydrodynamic and morphodynamic modelling in coastal systems. However, intertidal flats are among the most logistically challenging coastal landforms for ground-based and airborne-based topography monitoring. Spaceborne-based monitoring is sometimes the only viable and cost-effective approach capable of providing up-to-date intertidal topography maps. Various methods exist nowadays for generating intertidal Digital Elevation Models (DEMs) from remote sensing data. The most common technique used is the waterline method introduced by Mason et al. (1995). It consists in extracting the waterlines (shorelines) from a series of remote sensing images acquired at different tidal stages. Then, heights are assigned to the waterlines using sea level information measured by tide gauges or extracted from hydrodynamic models. Finally, the leveled waterlines are assembled and interpolated to produce a gridded-DEM. In this study, an improved approach of the waterline method was developed to derive intertidal Digital Elevation Models (DEMs). The changes include faster, more efficient and quasi-automatic detection and post-processing of waterlines. The edge detection technique consists in combining a k-means based segmentation and an active contouring procedure. This method was designed to generate closed contours in order to enable an automatization of the post-processing of the extracted waterlines. The waterlines were extracted from Sentinel-1 and Sentinel-2 images for two bays located on the French Coast: the Arcachon lagoon and the Bay of Veys. DEMs were generated for the Arcachon Bay between 2015 and 2018,

and for the Bay of Veys between 2016 and 2018 using satellite acquisitions made during summer (low storm activity period). The comparison of the generated DEMs with lidar observations showed an error of about 19 to 25 cm. This study also demonstrated that the waterline method applied to Sentinel images is suitable for monitoring the morpho-sedimentary evolution in intertidal areas. By comparing the DEMs generated between 2016 and 2018, the Arcachon Bay and the Bay of Veys experienced net volume losses of  $1.12 \times 10^6 \text{ m}^3$  and  $0.70 \times 10^6 \text{ m}^3$  respectively. Finally, As the waterline method rely on detecting the water/flats interface and on sea level information, the performance of the forthcoming Surface Water and Ocean Topography (SWOT) mission to generate intertidal DEMs using this method was also investigated. Unlike conventional altimeters, SWOT is a wide-swath interferometric altimeter that will measure the surface water elevation in 2 dimensions, providing surface water elevation together with water extents (water masks). Since SWOT will provide sea height information at high accuracy, height will be associated to waterlines (extracted directly from water masks) without the need of ground-based measurements or modelling of water elevation which will make this method completely independent from in-situ measurements. The performance of SWOT was assessed using intertidal DEMs generated from SWOT-type observables simulated by the SWOT hydrology toolbox developed by the CNES.

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**The assimilation of high frequency altimeters wave data in the model MFHAM : a relevant perspective for wave submersion warning**

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The wave submersion warning in coastal areas is based on outputs from the coastal wave model which are affected by uncertainties related to forcing such as the local winds, bathymetry, surface currents,...etc. To improve the wave forecasting in coastal areas on the french coasts the alternative of using assimilation of high frequency altimetry becomes a relevant priority in the plan managed for the future. This work aims to evaluate the impact of the assimilation of 5-Hz wave data from the CFOSAT and other high frequency altimetry data on the wave forecast. We have investigated the sensitivity of the filtering technique used to prepare the data before

the assimilation. The impact of using a joint high frequency wave heights from available missions such as S3, Saral and Jason-3 has been also examined.

The results of the assimilation runs have been validated with independent altimeter HY-2A and coastal buoys. First results of the validation have showed that the assimilation of 5-Hz CFOSAT data enhances the impact in coastal area in comparison with using 1-Hz data. We also demonstrated the ability of the assimilation of high frequency altimeters to correct significantly integrated wave parameters in storms events. The persistency of the assimilation has been also analysed during such events. Further discussions and conclusions will be summarized in the final paper.

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**CFOSAT Mission: A Proposal for Testing Sites in the North-Western Russia**

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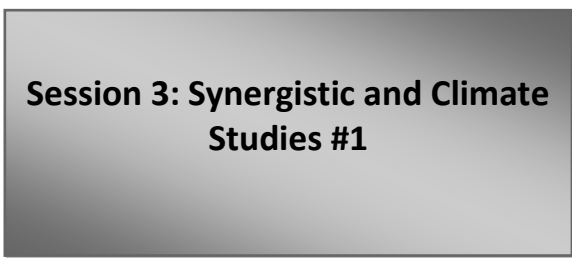
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The team of P.P. Shirshov Institute of Oceanology of Russian Academy of Sciences (SIO RAS) together with North-West Administration for Hydrometeorology and Environmental Monitoring (NWA HEM) proposes experimental facilities available in NWA HEM in the Ladoga Lake (two wave buoys) and in the Gulf of Finland (three buoys) for development new Cal/Val methods and regular in-situ measurements to support CFOSAT mission for the global monitoring of sea waves. The advantage of the proposed testing areas is a possibility to have in-situ data from areas with essentially different wave regimes. It is also very important to calibrate and validate the satellite data based on different data sources and experimental approaches. We will use satellite altimetry data on wind speed and wave height to perform this task, as well as meteo data from the coastal meteo stations located close to the buoy location. This will be done based on our experience on calibration and validation of satellite altimetry data in the coastal zone of the Barents, White, Black, and Caspian Seas. In particular, we will apply a “decomposition” method, we elaborated about 10 years ago during the ALTICORE (ALTimetry for COastal Regions) Project funded by INTAS, which allowed to increase significantly the correlation between wind speed altimetry data and meteo stations.

Another direction of the Cal/Val activities is climate studies based on the Voluntary Observing Ship (VOS) global database for the period of 1888-2016 elaborated and supported in SIO RAS, as well as on new remote

sensing methods and theory of sea waves. In addition to standard meteorological parameters, we have derived the records of visually observed heights, periods, and wind sea and swell directions. The key parameters have been supplemented by independent estimates of steepness, wave age, wavelength derived from alternative approaches (e.g. summer experimental campaigns). Multistage quality control has been applied to correct or eliminate spurious values. Data are presented as individual records for each month and as original monthly mean fields for each parameter. The development of remote sensing methods for sea surface monitoring is based on available novel approaches for altimetry in the near-shore water areas and theoretically based methods of retrieval wave characteristics from satellite altimetry data.

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**Coastal Sea Level rise at Senetosa (Corsica), the calibration site of altimetry missions**

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In the context of the ESA Climate Change Initiative project, we are engaged in a reprocessing of high-resolution (20 Hz) altimetry data of the classical missions along coastal zones of a number of regions worldwide, using the ALES (Adaptative Leading Edge Subwaveform) retracker combined with the XTRACK system dedicated to improve geophysical corrections at the coast. Using the Jason-1&2 satellite data, high-resolution, along-track sea level time series have been generated and sea level trends have been computed over a 15-year time span (as of July 2002). In this presentation, we focus on a particular coastal site where the Jason track crosses land, Senetosa, located south of Corsica in the Mediterranean Sea, for two reasons: (1) Senetosa is the calibration site for the Topex/Poseidon and Jason altimetry missions, equipped for that purpose with in situ instrumentation, in particular tide gauges and GNSS antennas, and (2) the rate of sea level rise estimated in this project increases significantly in the last 3-5 km to the coast compared to the open ocean rate. After careful examination of all sources of potential errors able to explain the increased rate of sea level rise close to the coast (in particular spurious trends in the geophysical corrections), we

conclude that the observed trend possibly reflects real physical processes occurring close to the coast. Trend in coastal waves is explored and discussed.

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**Coastal altimetry at high-latitudes: the Baltic SEAL project observing sea level among jagged coastline and sea ice**

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The use of satellite altimetry at high latitudes and coastal regions is currently limited by: (i) the presence of seasonal sea ice coverage, and (ii) the proximity to the coast. Improvements in technology (such as the advent of Delay-Doppler, or SAR, altimetry), signal processing (retracking), sea-ice classification methods, and advances in geophysical corrections (wet tropospheric correction, sea state bias) have made regional-scale exploitation of satellite altimetry increasingly possible. However, it is now necessary to explore these advances in a region such as the Baltic Sea, which strongly features these limiting conditions. These efforts could improve product quality, and in particular, product applicability to high latitude and coastal regions.

The European Space Agency-funded Baltic SEAL (<http://balticseal.eu/>) activity is framed as a laboratory to explore these factors. Using the Baltic Sea region as a testbed, advanced solutions in the preprocessing and postprocessing of satellite altimetry can be tested, and assessed for integration into global initiatives such as the ESA Sea Level Climate Change Initiative. The project is generating gridded and along-track multi-mission sea level anomalies to estimate sea level trends and map seasonal sea level variability. It is exploiting the full data resources available from the altimetry era, improving our understanding and the utility of altimetry for high latitude and coastal regions.

The dataset will be released within 2020 and includes innovative processing steps such as:

- The homogenous retracking strategy applied for open-ocean, coastal and sea-ice conditions (ALES+),
- The unsupervised classification method based on artificial intelligence developed to detect radar echoes

reflected by open-water gaps within the sea-ice layer, and

-The development of the gridded product based on a triangulated surface mesh, characterised by a spatial resolution higher than 0.25 degree and enhanced utility for coastal areas.

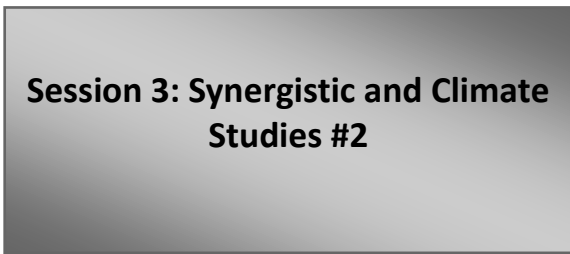
The activity aims at establishing a state-of-the-art altimetry processing chain developed in a region featuring two typical challenges of satellite altimetry. Here we present the methodology and first validation results, as well as preliminary results such as a new regional mean sea surface that benefits from the reprocessed dataset, and insights into the trends of the sea level along the altimetry tracks with the longest records. The developments within this project can be easily exported to other key areas.

nearshore at different time scales (seasonal variation, long-term trend). The differences obtained after comparing outcomes from satellite and tide-gauges are found to be related to some physical and geographical characteristics (e.g. coastal exposure, continental shelf width) . These characteristics are used to define a correcting factor ESF (Extreme Scale Factor), that modifies the return value estimates calculated from satellite data.

The proposed methodology is applied globally along more than 400 coastal units. Results show a coherent seasonal spatial pattern, with a clear zonation between tropical and extratropical cyclone activity regions. Results also show the coastal areas with a higher expected increase in extreme sea levels associated with high return periods.

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### Combining Coastal Altimetry Data With High-Frequency Radar and Drifter Data to Monitor the Dynamics in the South-East Bay of Biscay

*Caballero A<sup>2</sup>, Ayoub N<sup>1</sup>, Rubio A<sup>2</sup>, Mulet S<sup>3</sup>, Manso-Navarte I<sup>2</sup>, Greiner E<sup>3</sup>, Davila X<sup>1</sup>, Mader J<sup>2</sup>*

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### Coastal Extreme Sea Levels From Satellite Altimetry: A Global Study

*Lobeto H<sup>1</sup>, Menendez M<sup>1</sup>*

*<sup>1</sup>Environmental Hydraulics Institute, Universidad de Cantabria, Santander, Spain*

Coastal communities are especially vulnerable to the impact of sea level extreme events. In fact, the population living in low lying areas is expected to grow from 680 million to around 1 billion people by 2050. The development of satellite altimetry since the 90s (more than 25 years of data) and its increasing accuracy nearshore, give the opportunity of using these data to study sea level events with a low probability of occurrence.

In this study we use the new along-track inter-calibrated sea level anomaly database released by CMEMS in 2018 to obtain a non-tidal residual database. Besides, tide-gauge records from a global dataset are also analyzed to calibrate and validate an extreme value analysis method based on satellite data. The non-tidal residual sea level component at each tide-gauge station is obtained after subtracting the astronomical tide from the sea level signal.

The selection of the satellite extreme data sample is based on the spatial correlation between satellite and tide gauge data in the surrounding area of the station. Then, a non-stationary statistical extreme model is applied to non-tidal residual monthly maxima in order to reproduce the behavior of sea level extreme events

The Mean Dynamic Topography (MDT) is a key reference surface needed for estimating the sea level above the geoid from altimeter Sea Level Anomalies (SLA) and monitor the full ocean dynamics. However, in coastal areas, where in-situ measurements are sparse, mainly on the shelf, the global MDT solutions are often less accurate than in the open ocean. Considering the availability of long time-series of high quality HFR velocity measurements in the South-East Bay of Biscay, COMBAT project's (CMEMS Service Evolution 2) main aim is to showcase for this study area the benefit of including HFR data to calculate an improved MDT.

The prerequisites for the computation of this new Mean Dynamic Topography is to remove the non-geostrophic signal from the HF radar measured velocities and to identify the scales resolved by the altimetry in the study area. The latter is characterized by the presence of a narrow shelf in the south and east and a deeper area gently sloping from east to west (the so-called 'Plateau des Landes'). In order to remove the ageostrophic part of the current from the HF radar data, different methods can be applied. To assess their performance in the study area, we have first applied them to two different regional model simulations. This way, we can assess the methodology by comparing the results with the geostrophy computed from the simulated Sea Surface Height. The first simulation is the IBI Reanalysis over the Irish-Biscay-Iberian domain, provided by the CMEMS, with around 8.3 km resolution. The second model is Symphonie in a Bay of Biscay configuration, with variable horizontal resolution (about 800 m in the study area).

Daily surface data from 2011 to 2012 have been analysed.

Then, the processed HF radar can be used in synergy with in-situ data, altimetry and gravimetry to compute a regional MDT. This new regional MDT shows improvement compared with the global MDT, for instance the mean coastal current is better resolved: it flows eastward along the Spanish coast, makes a retroflexion and then flows northward along the French coast. This mean pattern corresponds to what it is observed from in-situ data suggesting that the resulting MDT indeed offers a better solution for resolving the dynamics of the study area. In addition, the method developed in this project for the MDT computation could be reproduced in other coastal areas monitored by HF radars.

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### Case Study of Wind-Driven Waves in the White Sea During the Tandem Phase of Jason-2 and Jason-3 Missions

**Badulin S<sup>1,2</sup>, Grigorieva V<sup>1</sup>, Shabanov P<sup>1</sup>, Sharmar V<sup>1</sup>, Karpov I<sup>1</sup>, Lebedev S<sup>3</sup>, Kostianoy A<sup>1</sup>**

<sup>1</sup>*Shirshov Institute of Oceanology, Moscow, Russian Federation*, <sup>2</sup>*Skolkovo Institute of Science and Technology, Moscow, Russia*, <sup>3</sup>*Geophysical Center, Russian Academy of Sciences, Moscow, Russia*

Altimetry data of missions Jason-2 and Jason-3 are analyzed for the ice-free periods in the White Sea. Special attention is paid to the tandem phase of the year 2016 of the missions. The data in two self-crossover points near the latitude 65.5°N is used for assessment of the variability of wave heights in space and time. The wave steepness is estimated following Badulin (2014), Badulin et al. (2018) from along-track derivatives of significant wave height for non-colinear consecutive paths. The direction of wind-driven waves is calculated based on the assumption of the proximity of the direction with one of the wave field modulations.

The study is accomplished by modeling Sea State Bias (SSB) in the area with the recently proposed parametric model (Badulin et al. 2019). The latter uses the altimetry-derived dimensionless quantities of pseudo-age  $P=gH/U^2$  and wave steepness  $\xi=H_s/(gT^2)$  as arguments. The authentic SGDR data of SSB based on dimensional values of significant wave height  $H$  and the altimeter-derived parameterization of the near-surface wind speed  $U$  is compared with this of the new parametric model. A disagreement of the resulting estimates is explained by features of the local dynamics of the area where relatively young waves generated by strong gusty winds in the nearshore are dominating.

The use of high-resolution data (20Hz and 40Hz) is discussed as a possible perspective of the study.

References:

1. Badulin, S.I., Grigorieva, V.G., Shabanov, P.A., Sharmar V.D., Karpov, I.O. (2020), Sea state bias in altimetry measurements within the theory of similarity for wind-driven seas. - *Advances in Space Research* (to appear)
2. Badulin, S.I. (2014). A physical model of sea wave period from altimeter data. - *J. Geophys. Res. Oceans*, 119. doi:10.1002/2013JC009336.
3. Badulin, S., Grigorieva, V., Gavrikov, A., Geogjaev, V., Krinitskiy, M., Markina, M. (2018). Wave steepness from satellite altimetry for wave dynamics and climate studies. - *Russ. J. Earth. Sci.* 18, ES5005. doi:10.2205/2018ES000638.

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### Understanding Ocean Wave Climate Variability in the Open Ocean and at the Coast

**Gommenginger C<sup>1</sup>, Timmermans B<sup>1</sup>**

<sup>1</sup>*National Oceanography Centre, Southampton, United Kingdom*

Accurate knowledge and understanding of the sea state and its variability is crucial to numerous oceanic and coastal applications, as well as climate change and its impacts including coastal inundation threats from storm surge and energetic waves resulting from extreme weather. But the contribution by ocean waves to the large coastal sea level changes reported in the CCI+ Sea Level project is still unclear. The increasing duration of the altimeter data record motivates global, regional and coastal analyses. For ocean surface waves in particular, the recent development and release of consistent inter-calibrated satellite sea state products make long term analyses of ocean wave climate changes more accessible. In this paper, we present analyses of trends in averages and extremes of significant wave height obtained with products from the ESA CCI+ project for Sea State. Results are compared with state of knowledge from multi-mission altimeter products by Ribal & Young (2019), in situ observations, hindcasts and reanalyses. The paper highlights the current lack of consensus about global wave climate variability and the added challenges faced to characterise wave climate in coastal regions.

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## Session 3: Synergistic and Climate Studies #3

### Freshwater-induced coastal water level variability from SAR altimetry

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River plumes or 'regions of freshwater influence (ROFI)' are important but poorly understood areas where land and ocean processes meet. The highly dynamic nature of these processes makes it notoriously difficult i) to model the river plume hydrodynamics and ii) to observe its spatio-temporal variability. This applies in particular to the Rhine ROFI, which extends maximally a few tens of kilometres from the river mouth. Its dynamics have been studied using satellite-based sea surface temperature and ocean colour data. The associated water level variability remains, however, unknown. The three major reasons for that are: i) satellite radar altimetry (the designated technique to quantify this variability) has difficulties in coastal waters due to waveform contamination by land reflections and poor knowledge of the wet tropospheric delay; ii) LRM altimetry lacks the required along-track resolution; iii) to isolate the signal, very accurate high-resolution background models are needed (i.e., geoid model and hydrodynamic model to remove other contributions to water level variability). SAR altimetry processing, the release of the sub-centimetre accurate NLGEO2018 quasi-geoid model, and the development of the 3D-DCSM-FM hydrodynamic model, allow for the first time to isolate the signal. Based on our in-house developed processing scheme, we will show the freshwater-induced coastal water level variability in the Rhine ROFI from Sentinel-3 SAR data.

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### Continuum of Waters and Estuaries

**Fenoglio L<sup>1</sup>**, Dinardo S<sup>2</sup>, Uebbing B<sup>1</sup>, Kusche J<sup>1</sup>, Benveniste J<sup>3</sup>, Scharroo R<sup>4</sup>, Staneva J<sup>5</sup>

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Coastal areas and estuaries are among the environments most affected by anthropogenic impact and climate change and are defined as multi-risk, due to coastline retreat, flooding by storms and river floods, and pollution. Estuaries, which connect ocean and land, salt and fresh water, have a complex hydrodynamics, with a strong variability of the water level at various temporal and spatial scales, due to the interaction of water bodies and phenomena.

The main goal of this paper is to investigate the coastal and estuarine processes by multi-sensors observations and models. More specifically, we consider in the estuary the interactions of tides with discharge in the channel, the water exchange between the channel and the connected zone in different hydrodynamic conditions, e.g. intertidal and flooded zones, and the role of climate change in the estuary water extremes. The multi-sensors approach is based on the combination of in-situ tide gauge data and multi-satellite data from SAR altimetry, SAR imagery, in preparation to wide-swath SWOT analysis.

The in-situ validation indicates for SAR altimetry water level an accuracy of 2-4 cm in open ocean and of 15-20 cm in rivers of 200-300 km width. These values are reached with dedicated processing with the STAR and SAMOSA+ retracking procedures, while results deteriorate in estuaries and coasts with high tidal regimes. A toolbox OverVirtual performs a careful combination of altimetry and in-situ data in estuaries showing RMS differences of 40 cm for Sentinel-3. Coastal sea level trends are small and long-term variability agrees with variability of the longer datasets.

Further on the analysis shows that the remote sensing information provides critical information on the spatial and temporal variability of water surface elevation under different hydrodynamic conditions. This allows combination and synergy with in-situ and models for a better understanding of the interactions before the different hydrodynamic processes and their impact on the evolution of the environment.

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**SMASH: a mission concept to better monitor inland waters and estuaries**

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The monitoring of water resources at the global scale is already a major challenge whose importance will increase in the next years. Continental waters are essential components of the water, energy and carbon cycles. The river and lake water levels are identified as essential climate variables by the GCOS which recommends daily measurements of these variables. Traditionally, this information was provided by gage data. However, the availability of these in situ measurements is very heterogeneous and is declining (GDRC). The understanding of fluxes in estuaries, the area where river and ocean meet, where a large fraction of the exchanges of water, sediments and nutrients occur, is also a major challenge to which the SMASH mission could contribute.

For the last twenty years, numerous research teams have demonstrated that measurements from space altimeters could be used to mitigate this lack of in situ measurements even if these instruments were mainly designed for measurements over the oceans. However, all the historic and current altimetry missions, based on repeat track orbits with cycle durations of 10 days (T/P, Jason), 27 days (Sentinel3), 35 days (ERS2, ENVISAT, AltiKa) and more (CryoSat) cannot provide these daily measurements.

As the performance of altimetry missions applied to inland water surfaces improves constantly, the next frontier is to increase the frequency of temporal revisit. A “flash” study was performed by CNES to propose altimetry missions which could provide this daily revisit. The constellation of Small Altimetry Satellites for Hydrology (SMASH) is the result of this study.

This is a constellation of ten nanosatellites of class 16 U put on a Sun Synchronous Orbit. Each satellite carries a nadir altimeter and a precise orbit determination subsystem which provide the targeted end to end altimetric performance of 10 centimeters. The altimeter functions have been carefully optimized for waveforms that are most often observed over rivers, lakes and estuaries. The payload will allow us to monitor rivers as narrow as 50 meters wide and lakes as small as 100 meters x 100 meters and the orbit provides a latitude coverage that is largely sufficient to monitor inland waters. The constellation provides a daily revisit for each point on the earth overflight by a satellite. The altimetry products should be provided with a short time latency in order to make full use of the high temporal frequency of the measurements.

There would be a strong synergy between SMASH constellation with Wide Swath altimetry missions like SWOT (launch planned in 2021) and WiSA (ongoing

phase A) which provide almost complete spatial coverage at a lower temporal frequency.

The presentation will provide more details on the SMASH study and its continuation in CNES.

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**Inland radar altimetry for intermediate scale water bodies with nadir specular echoes and a constellation of small satellites.**

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We previously reported (COASTALT Workshop 8, Lake Konstanz, 2017; 25-years..., Ponta Delgada, 2018) on the prevalence of quasi-specular echoes from intermediate scale (50m to 250 m) inland water bodies. Specularity is a boon and bane for Inland radar altimetry. The boon is that specular echoes allow very precise range measurements with coherent ‘zero-Doppler’ summing of a few individual echoes (IEs). (Accuracy of <1 cm was shown with Envisat IEs.) Also, land interference is virtually eliminated. The bane is that such water echoes can only be detected when the satellite nadir is directly over the water surface. The echoes SNR fall perceptibly squinting off nadir. The implication is that with current large spacecraft altimeters only a very small fraction of water bodies are encountered. Also, water level slope (discharge) cannot be measured. Radar altimetry cannot fulfill the hydrologists’ data requirements.

Inland altimetry requires a paradigm shift away from large spacecraft. A wide range of Earth observations and other LEO uses are already migrating to swarms of small satellites (ESA APIES, NASA RainCube, and SpaceX Starlink). The same idea is appropriate for inland altimetry where specular echoes reduce the required radar power 20-40 dB and so much smaller satellites can be used. A constellation of 1000 can provide 100% geographical coverage, water levels and discharge, at 10-day repeat cycles.

we used several Sentinel 3A/B data sets to evaluate water level measurements with specular echoes and extrapolate to smaller satellites. First set is of the Arno River which is 100 m wide, just wide enough to have one full S3 burst over water. Water levels over three years (45 revisits) are compared with river gauges maintained by Centre for Meteorological and Hydrological

Monitoring, Tuscany Region, Italy. A second data set is multiple passes over Salar de Uyuni compared with surface topography measured by Borsa et al 2008. And a third data set of passes over 800 m wide Silsersee Lake (Switzerland) were there is no ground truth but multiple bursts provide inter-data accuracy and further insight on application to larger water bodies.

We degrade SNR on these data sets to extrapolate performance with small sat radars. Details on the algorithms used in this analysis will be provided and illustrated in a companion poster presentation.

[At time of writing this abstract we learned that CNES recently started a small-sat concept study on their own. The authors intent to meet and discuss this paper with the CNES team before presentation in COASTALT 12.]

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**Improving Conventional Altimetry in coastal area:  
Review of the performances derived from innovative  
LRM retracers**

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Thibaut P<sup>1</sup>, Piras F<sup>1</sup>, Picot N<sup>3</sup>**

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<sup>3</sup>CNES, TOULOUSE, France

Since many years, altimetry constellation is delivering relevant measurements to monitor the ocean large scale surface topography. More recently, with our understanding of the oceanic structures, these needs have evolved toward a better characterization of the oceanic mesoscale and sub mesoscales dynamic, over open and coastal areas.

To answer this problematic, many progresses were made in the instrumental design domain. Thanks to the new generation of Delay Doppler altimeters (first time onboard on Cryosat-2 mission), the instrumental noise and spectral bump error were significantly reduced. On the other hand, to continue exploiting the recent and past LRM datasets, a lot of work has been dedicated to improve the retracking methods.

Today, for coastal application, two main algorithms, approaches could be distinguished:

- The ALES (Adaptive Leading Edge Subwaveform) retracker (Passaro et al. Year)
- The adaptive retracker (Thibault et al., OSTST 2018)

This presentation aims at reviewing and comparing their retrieval performances (SSH, wave height, backscatter coefficient) in the coastal areas with respect to the classic MLE4 retracker today used in most of the ground segments. The assessment will be performed using high rate dataset and will address different wavelength ranges in order to distinguish the potential noise reductions from the quality of the sub-mesoscale and mesoscale signals retrieved.

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**SAR single and multi looks water level over small inland water bodies**

**Roohi S<sup>1</sup>, Dinardo S<sup>2</sup>, Scharroo R<sup>3</sup>**

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Inland water bodies need to be monitored precisely, because they are good indicators for climate change studies. Moreover, they play an important role in the ecosystem and support surface water resources.

Monitoring these water bodies at local scale can be performed with local in situ gauge networks. But in global scale, this major needs to use space born techniques, e.g. satellite radar altimetry mission.

The radar altimetry as an irreplaceable and matured technique has been used for a few decades to monitor inland waters. However, these objects are still big challenges in terms of spatial and temporal resolutions as well as the accuracy of water level determination. A better spatial/temporal resolution mainly depends on the satellite orbit and the radar configuration system. The accuracy can be improved based on the measurement modes and data processing methodologies.

New generations of satellite altimetry missions, e.g. CryoSat-2 and Sentinel-3 A, with a new measurement mode, i.e. SAR mode, provide this possibility to overcome partially the challenges in monitoring inland waters. In the SAR measurement mode, a given object is sensed as long as it is in insight of the radar. More measurements are recorded and the delay Doppler processing helps to have single/multi looks analysis, which leads to a better understanding of water level variations even for a small object.

In this study, we analysed L1 A product of Sentinel-3 A and CryoSat-2 (SAR mode) missions from June 2016 to Oct 2019 to study water level variations over small lakes, e.g. Derg lake (in Ireland). We estimated water level variations based on the single look and multi looks measurements of both missions. To this end, L1 A data were processed by GPOD. The results have been validated against in situ gauge measurements.

For the small Derg lake with a surface area of less than 100 km<sup>2</sup>, we arrived the same RMS of 13 cm and 15 cm for single and multi looks of CryoSat-2 and Sentinel-3 A respectively. The study is continued and more samples will be analysed to provide a reliable interpretation of the single look and multi looks water level analysis.

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## The algorithm for processing specular echoes.

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The poster will be a companion to the Inland radar altimetry for intermediate scale water bodies paper to provide extra time and setting to explain the processing ('retracking') specular echoes. The processing flow will be described and illustrated step-by-step in the poster and with live in-the-cloud processing. [For live demo we'll need Wifi and a small stand for a laptop.]

The processing is little changed since the 2017 paper. Steps in processing IEs into range measurements are (1A) a water map from EO images (such as Google Earth), (1B) identify a string of consecutive echoes over water. (2) Verifying that there is actually water with Doppler (expected to be zero), echo power (exceeding a threshold), and coherence (~1). (3) Verifying surface roughness below threshold. (4) Coherently sum IEs into a waveform profile. (5) A parametric fit to two or three range gates to derive sub-gate range accuracy.

For the intermediate water bodies (50-250 m) processing is based on one or two S3 bursts.

There are special considerations for very narrow (<50 m), and wide (>250 m) rivers or lakes. For <50 there is a fair chance the water body will fall in the gaps between S3 bursts so there are no nadir water IEs. The algorithm can be nudged a bit to handle those cases. For >250 there will be several bursts to combine optimally and some probability that the water surface will have variable roughness scales.

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## Regional In Situ CalVal of Sentinel-3 Altimeter Range

**Cancel M<sup>1</sup>, Bonnefond P<sup>2</sup>, Watson C<sup>3</sup>, Haines B<sup>4</sup>, Lyard F<sup>5</sup>, Laurain O<sup>6</sup>, Féménias P<sup>7</sup>**

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In situ calibration ensures regular and long-term control of the altimeter sea surface height (SSH) time series through comparisons with independent records. Usually, in situ calibration of altimeter SSH is undertaken at specific CalVal sites through the direct comparison of the altimeter data with in situ data.

NOVELTIS has developed a regional CalVal technique, which aims at increasing the number and the repeatability of the altimeter bias assessments by determining the altimeter bias both on overflying passes and on satellite passes located far away from the calibration site. In principle this extends the single site approach to a wider regional scale, thus reinforcing the

link between the local and the global CalVal analyses. It also provides a means to maintain a calibration time series through periods of data-outage at a specific dedicated calibration site.

Corsican calibration sites of Senetosa and Ajaccio. It was then successfully implemented at the Californian site of Harvest and at the Australian site of Bass Strait, in close collaboration with JPL and the University of Tasmania, respectively. The method was used to compute the altimeter biases of Jason-1, Jason-2, Envisat and SARAL/AltiKa at all these sites.

These studies gave the first Envisat and SARAL/AltiKa absolute bias estimates at non-dedicated sites using the same method, and showed high consistency with the analyses of the global CalVal teams and the work of the in situ CalVal teams. The method is now used to monitor the Sentinel-3A&B missions and shows high potential for the monitoring of any future altimetry missions.

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## A Regional Evaluation of Sentinel-3 SRAL Derived Geophysical Parameters in Open Ocean and Coastal Areas in The North Sea

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With Sentinel-3 SRAL altimetry, high resolution coastal altimetry data have become available on a global scale. In this work, a detailed evaluation of the performance of the L2 product from EUMETSAT will be presented, covering not only sea surface heights, but also SWH and wind speeds. The L2 product is based on the SAMOSA retracker, which has proven very useful in open ocean altimetry.

Determination of geophysical parameters is more prone to errors in coastal areas, due to waveform contamination caused by the presence of land within the altimeter footprint, making it difficult to fit physical models to the waveform and determine the exact epoch.

In order to evaluate the performance of the L2 product, the three geophysical parameters have been compared to in situ heights and SWH, as well as modelled wind speeds from ECMWF within the North Sea.

The results show, that while the Sentinel-3 product performs very well in open ocean areas with correlation coefficients approaching 1, the physical retracker is challenged in coastal areas, where the discrepancies are larger and correlation coefficients are as low as 0.1 for SWH when compared to in situ data.

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## Validation of Multi-Satellite Altimetry Data Utilizing a High-Resolution Marine Geoid for the Baltic Sea

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Most satellite altimetry products often reflect the Sea Surface height (SSH) with respect to a reference ellipsoid. Alternatively, Sea Surface Height Anomaly can also be referenced to the Mean Sea Level (MSL). This reference MSL is often calculated from SSH measurements that are averaged over a selected time period. Hence the MSL estimates may vary due to different time spans used. Referring to the MSL also indicates that the mean dynamics have been averaged out. In practicality, computations of the Dynamic Topography (DT) that is referenced to the geoid allows for a more stable reference frame and it also represents the mean and time varying ocean dynamics.

In this study we calculate and validate DT from several satellite altimetry (SA) missions (Sentinel-3, CryoSat-2 and Jason-3) by utilizing a regional high-resolution geoid model for the Baltic Sea and in-situ tide gauges (TG). For the years 2016–2018 a comparison is made between the DT calculated from the satellite data sets and tide gauges. The methodology employed firstly required (i) satellite SSH data that are referenced to the ellipsoid to now be referenced to the geoid and (ii) TG measurements to be referred to the zero level of the national vertical datum that is represented by a precise geoid model. Tide gauge data records over several stations are utilized in this study. Spatial and temporal resolution issues between the different sources of data are improved by statistical and interpolation techniques. Results are accessed by calculation of root mean square (RMS) error and standard deviation. The methodology allows not only a validation of the satellite mission with tide gauge data but in addition a comparison of different satellite mission using different retracers and an assessment between differences reference datum utilized. Although this study shows great potential of using SA data for coastal area, results suggests that development of a local retracker considering, sensitive conditions of the complex Baltic Sea and the Gulf of Finland could enhance the measurements quality and thus the usability of the satellite data.

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## Monitoring marine litter with ocean current products in the North Atlantic Ocean

*Lux M<sup>1</sup>, Sahuc E<sup>1</sup>, Cancet M<sup>1</sup>*

<sup>1</sup>*Noveltis, Labège, France*

With an increasing rate of production, plastic management has become a global concern. As a majority of plastic items are single-use products, mismanagement of waste leads to a lot of items ending up at sea. Monitoring plastic litter has become of great importance for the protection of the ocean and water quality. The IFADO (Innovation in the Framework of the Atlantic Deep Ocean) project aims to create new marine services to support the Marine Strategy Framework Directive implementation with the North Atlantic Ocean as a study case. One of the objectives of this project is to use Earth Observation products in order to characterize marine litter convergence zones, pathways and main sources in the North Atlantic Ocean. This information is essential in the perspective of preventive and cleaning actions.

We used the Lagrangian particle modelling tool Opdrift, developed at the Norwegian Meteorological Institute, to evidence convergence areas in the North Atlantic Ocean. The Opdrift tool was fed with global ocean current maps derived from satellite observations (GlobCurrent products) or computed by an ocean circulation model (CMEMS analyses). Different scenarios of marine litter release were considered in order to understand the fate of plastic particles released from land (80% of marine litter ending up in the ocean) and the trajectories of particles floating offshore (shipping and fishing litter). Indicators were developed to highlight the preferential residence zones and pathways for plastic particles.

This presentation highlights the capabilities of ocean current products derived from satellite observations and models to simulate plastic particles trajectories at a basin scale. Comparison of the results shows a good consistency between both products.

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## A new high-resolution coastal model in Kerguelen Island for CAL/VAL operations.

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The sea surface height (SSH) measured by satellite altimeters contains the contribution of geoid, dynamic topography and ocean's response to tides and atmospheric forcing. Calibrating and validating past and future altimetry missions - such as SWOT- requires to significantly increase the resolution and accuracy of local geoids.

In the frame of FOAM project (From Ocean to inland waters Altimetry Monitoring), a GNSS system mounted on a towed blanket - called CalNaGeo - was developed to map the sea surface height. Two campaigns were carried out in 2016 and 2018 in Kerguelen Island, near historical tide gauges and Jason-2&3, Sentinel-3A and SARAL/AltiKa altimetry tracks. In order to recover the geoid contribution to the total SSH obtained from a precise GNSS processing, the contribution of tides, dynamic topography and atmospheric surge have to be evaluated along the survey tracks.

To meet this objective, we developed a high-resolution barotropic model in Kerguelen Island with the modeling system SCHISM (Zhang et al., 2016). The semi-implicit finite element and Eulerian-Lagrangian (ELM) methods used by SCHISM guarantees high stability, efficiency and permissive inclusion of underlying bathymetry (no smooth needed). This study is based on an unstructured grid of 20701 nodes with a resolution ranging from 10km in the deeper ocean to 100m near the coastline, providing a coastal/open ocean continuum. The model is forced by tides from the global tide model FES2014, winds and atmospheric pressure from the ERA5 reanalysis dataset.

After harmonic analysis, the comparison with reprocessed coastal altimetry products (XTRACK/ALES) shows that errors on tide constituents are of the same order for our simulation and a reference data-assimilated model, FES2014. In the nearshore region, the validation against 14 tide gauges exhibits a combined RMS error of ~2.7cm for the 8 major tide constituents.

The simulated atmospheric surge is compared to the difference between co-located radar and bottom pressure gauge observations in Port-aux-Français. Due to a low winds regime during the CalNaGeo mission, the atmospheric surge fits the observed and theoretical inverse barometer contribution, with a RMS error of ~3cm.

Our first results are promising and we are able to model, at first order, the non-stationary contribution of sea surface height and then retrieve geoid patterns in the CalNaGeo residuals.

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**Sentinel 3A approaching the coast: effects of track orientation and coastal topography**

**Gomez-Enri J<sup>1</sup>, Aldarias A<sup>1</sup>, Vignudelli S<sup>2</sup>, Cipollini P<sup>3</sup>**

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In a complementary submission to this workshop we have assessed the quality of high-rate (80-Hz) SAR altimeter data from Sentinel-3 SRAL (S3A-SRAL) by validating them against tide gauge data at three coastal sites around Spain, and found a “distance of good quality” to shore to reach 3 km for some particular

tracks. In this work we examine the effects of track orientation and coastal topography in determining how close to the coast the altimeter can go in each particular case, and we extend the analysis to the whole set of tracks surrounding the Iberian Peninsula. The objective is to see whether a “common distance (from coast) of same quality” might be determined, at least for subsets of cases. This type of analysis was carried out by the SCOOP project for CryoSat-2 SIRAL data and presented at previous CAWs – but to our knowledge – this is the first time that it is done for the 80-Hz S3A-SRAL data.

The data are, as per the other contribution, obtained from the European Space Agency Grid Processing On Demand (GPOD) SARvatore (SAR versatile altimetric toolkit for ocean research & exploitation) service, and are validated against in-situ radar tide gauge data provided by the Spanish Puertos del Estado.

Three specific aspects are considered: track orientation respect to the coastline (land-to-ocean and ocean-to-land transitions), the angle of intersection with the coast, and the land topography affecting the radar beam-limited footprint across track. The metric to evaluate “good quality” is the root mean square error (rmse) between sea level anomaly and tide gauge when a tide gauge is available close to the track – but we also look at the median of the absolute difference of adjacent sea level data as a local estimate of measurement noise, as proposed in Passaro et al., Rem Sens. Env, 2014.

Our preliminary analysis showed accurate sea level data up to 3 km to land (rmse = 6-8 cm with more that 95% of valid data) at Huelva (ascending track #114 and descending #322) and Barcelona (descending track #008), The same level of accuracy was obtained at Barcelona (ascending track #356) and Bilbao (descending track #051 and ascending #071) up to 7 km to the shore. These results indicated that a common distance to the coast with a similar level of accuracy in the SLA from S3A-SRAL cannot be achieved in the three locations. The above mentioned aspects (track orientation, the angle of intersection with the coast, and the land topography) are used to explain these results.

The analysis is being extended to the whole coast of Spain considering the tracks around about 16 tide gauges.

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**Recalculation plan for altimetry measurements of Russian GEO-IK satellites No 1-9 ((1985–1995))**

**Lebedev S<sup>1</sup>**

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The Russian satellite altimetry program GEO-IK (GEOdesic – Inter Kosmos) was developed from June 1985 to July 1995. It included 9 satellites. All satellites worked on a geodetic program.

When processing these data, only the “dry” correction and the tidal correction calculated according to the Shvedersky model were taken into account.

Currently, it is planned to take into account all corrections: a “dry” correction calculated according to the ERA Interium reanalysis data, a wet correction calculated according to the ERA Interium data and microwave SSM/I radiometer data, tidal corrections calculated according to several models, a pole tide correction, and ionospheric correction calculated according to the model IRI2012, sea state bias correction,

It is supposed to carry out verification of the obtained results according to altimetry measurements of the GEOSAT, ERS–1/2 and TOPEX/Poseidon satellites in the crossover points.

The study was funded by the RFBR research project No 18-05-01053\_a «Investigation of hydrometeorological and hydrodynamic regime of the White Sea based on satellite altimetry» and No 19-55-80021\_BRICS «Joint Validation of Multi-Source Remote Sensing Information and sharing in BRICS Countries».

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**Systematic Differences Between Tide Gauges and Altimetry Related to Coastal Tidal Dynamics**

**Esselborn S<sup>1</sup>, Illigner J<sup>1</sup>, Schöne T<sup>1</sup>**

<sup>1</sup>*GFZ Helmholtz Centre Potsdam , Potsdam, Germany*

Tide gauge data are frequently used for satellite altimeter bias estimation and stability monitoring as well as for accuracy assessment. However, only very few tide gauge stations are actually collocated with the altimeter measurements within less than 15 km. Especially in coastal regions, the sea level variability driven by ocean dynamics is strongly related to the water depth and is not necessarily uniform on scales of tens of km. This may add noise to comparisons between tide gauge and altimetry data. Our study is based on tide gauge data sampled every minute from the German Bight (North Sea) and nearby altimeter measurements from the Saral/Altika, Sentinel-3, Jason-2 and Jason-3 missions. The focus is on the assessment of the errors arising from the spatial inhomogeneity of the tidal dynamics. Techniques to cope with this problem are further discussed.

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**The TUDaBo Processor for SAR and RDSAR Mode**

**Fenoglio L<sup>1</sup>, Buchhaupt C<sup>2</sup>**

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TUDaBo SAR-RDSAR is a software processor prototype developed at TU Darmstadt and at University Bonn to experiment with SAR mode data from L1A (FBR) to L2 level data. Reduced SAR, unfocused SAR and Low resolution Range Cell Migration Correction (LRMC) mode data are generated for both CryoSat-2 and Sentinel-3A. The user can experiment with different configurations using various signal processing options and retrackerers. All L1B/L2 products have the same geolocations and time tags, which make possible direct comparison without interpolation.

The processing methodologies are RDSAR (Reduces SAR mode), SAR unfocused and LRMC (Low resolution mode with Range Migration Correction). Further planned is the LRMC-F, which is the LRMC mode with 0,05 integration time.

One first novelty in the methodology is to account for the vertical motion of wave particles (VVWP) by introducing the vertical velocity OV in the waveform model (SINCS-OV).

One second novelty consists in transforming the samples in the stack to get a distribution close to the normal distribution (zero skewness Weibull, ZSK), which improves the SNR.

To evaluate the results, the RDSAR product is used as reference and cross-compared to SAR, LRMC and LRMC-F with SINCS-OV and ZSK. The worst results are shown by the unfocused SAR mode. SAR unfocused with SINCS-OV and ZSK performs better than SAR without these last two options, shows however large difference at SWH smaller than 2 metres. The best results are obtained by LRMC-F, with shows large differences respect to RDSAR only at SWH smaller than 15 cm. ECMWF model data confirm the better quality of LRMC-F compared to unfocused SAR, both retracked with SINCS-OV and using the ZSK transformation.

The TUDaBo processor is part of the ESA's G-POD service and is enabled to registered users. The various options are chosen online. The service allows online access to S3 and CS-2 archive without need to download the input. The GPOD team supports with successive integration of versions, user authorisation and generic user support.

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## **Fully Focused SAR Altimeter Processor for Assessing the Full Capabilities of SAR-mode Altimeter Missions**

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*<sup>1</sup>CLS, France, <sup>2</sup>ESA, Netherlands, <sup>3</sup>CNES, France*

SAR-mode altimeters are currently exploited in operational missions, such as Cryosat-2 and Sentinel-3A and -3B, and the benefits brought by this technique are unanimously acknowledged and valued by the scientific community for most radar altimetry applications. Improvements are clearly being made in monitoring sea ice, ice sheet and inland water but also for estimating the sea surface height over open ocean and coastal zones when comparing to conventional altimetry. There is now a trend toward more use of SAR-mode altimeter in the future (as is the case for the upcoming Sentinel-3C/D and Sentinel-6 missions of the Copernicus programme), contributing thus increasingly to the time series of ocean topography measurements.

The SAR-mode processing as it is currently operated in ground segments does not exploit the full capabilities of the SAR system in terms of spatial resolution. The so-called unfocused SAR altimeter (UFSAR) processing performs the coherent summation of pulses over a limited number of successive pulses (64-pulses bursts of a few milliseconds in length) reducing the along-track resolution down to 300 m only. Since recently [Egido and Smith, 2017], the concept of coherent summation has been extended to the whole illumination time of the surface (typically more than 2 seconds) allowing to increase the along-track resolution up to the theoretical limit (approximately 0.5 m) and thus improving the SAR-mode capability for imaging reflective surfaces of small size. The so-called Fully Focused SAR (FFSAR) processing furtherly improves the effective number of looks with respect to UFSAR processing.

The FFSAR processing method has already been addressed through different NOAA, ESA and CNES projects, but no data was made available to external users. In this respect, and in preparation for the forthcoming SAR-mode altimeter missions, ESA and CNES agencies have taken the initiative to develop an open-source software (called FIXU, which stands for FFSAR Implementation for eXperienced Users) allowing users of an enlarged community to process radar altimeter data in FFSAR mode. In this way, users would be able to assess on their own the performances of this new very-high-resolution mode, and make resulting recommendations to Agencies, if any. FIXU, developed by CLS, consists of one stand-alone processor enabling first to generate FFSAR waveforms from level-1A Sentinel-3 products, then to retrack them to derive range and amplitude estimates. The software reads a configuration file that users can modify to set the processing parameters (such as posting/multi-looking, zero-padding) that are most appropriate for their application. The software also includes the capacity to read input Shapefiles provided by the user, restricting the processing to geographical zones of interest (thus reducing processing times).

FIXU has been tested and validated over transponder and a large range of inland water targets, demonstrating the high-reliability and robustness of the software, and its capability to be used as a suitable point of comparisons with operational processing.

This poster describes the objectives of this project, the different units of the FIXU software and its major characteristics. Validation results demonstrating the potential of this software are also provided.

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## **GEO-IK Space Geodetic System**

*Kosenko V<sup>1</sup>, Zvonar V<sup>1</sup>, Karnaukhov V<sup>1</sup>, Shapovalov D<sup>1</sup>, Eremenko N<sup>1</sup>*

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Space geodesy allows to obtain solutions for scientific, research and development tasks within tighter timelines and more accurately than conventional methods do. The poster contains the information on the development of the Space Geodetic System in the Russian Federation, starting from the Sphera system to the current GEO-IK2 system. It also covers the information on on-board equipment of space geodetic system satellites designed by the ISS-Reshetnev Company, and describes objectives, tasks, methods and the outcomes of each generation of the system.

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## **Waveform retracking analyses of satellite altimetry data on shallow Natuna waters and its surrounding, Indonesia**

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Shallow Natuna waters containing many small islands may lead to a number of non-Brownish waveforms of satellite altimetry data. These will lead to a less accurate of sea surface height (SSH) estimation from satellite altimetry data. The purposes of this research were to identify and retract waveforms of Jason-2 and Jason-3 satellite altimetry data in 2017 and then estimated sea surface height (SSH). To increase the accuracy of SSH estimate, we conducted a fuzzy logic analyses. The study used data of the Sensor Geophysical Data Record type D (SGDR-D) of Jason-2 and Jason-3 in the year of 2017. Waveform retracking analyses were conducted using several retracers such as Offset Center of Gravity, Ice, Threshold, and Improved Threshold. The retracking waveforms were examined using a world reference undulation geoid of EGM08 and Oceanic retracker. Result showed that shape and pattern of waveforms were varied in all passes, seasons, and locations specifically along the coastal regions and around shallow small island waters. In general, non-Brownish and complex waveforms were identified along coastal region and around small island waters. In some cases, however,



Brownish waveform can also be found within coastal region and non-Brownish waveforms within offshore region. The results were also showed that retracking waveform analyses improved the accuracy of SSH estimate. However, there were no dominant algorithm to produce better SSH estimation. Fuzzy logic analyses produced better improvement of SSH estimate than other retrackers. After conducting fuzzy logic analyses, the SSH estimations were strongly match with SSH from tide gauge data with the value of  $R^2=0.91$ .

Keywords: sea surface height, altimetry, validation, retracker, Brownish, Natuna waters

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### Identification Sea Ice Edge Position based on Satellite Altimetry

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Traditional monitoring of the Arctic sea ice cover and ice edge location is based on radar (SAR), optical, infrared and microwave radiometric data. Optical and infrared methods require cloudy free conditions which are rare in the Arctic. During polar night optical method does not work as well. Microwave radiometric data have spatial resolution of about 25 km. Satellite altimetry data can be also used to estimate ice cover extent or position of an ice edge.

The report proposes a method for identifying the position of the ice edge based on the analysis of the reflected pulse shape and the analysis of the slope of the logarithm of the trailing edge calculated by the Ice-2 retracking algorithm. As well as data on radio brightness temperatures measured by a microwave radiometer.

The results of the method were tested in the Barents and White Seas.

The study was funded by the RFBR research project No 18-05-01053\_a «Investigation of hydrometeorological and hydrodynamic regime of the White Sea based on satellite altimetry» and No 18-05-80065 «Analysis and forecasting of dangerous hydrometeorological phenomena in the coastal areas of the Arctic zone of the Russian Federation».

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### CoastalSWH : Supporting Future Operational Ina-WAVES Products using Sentinel 3B and HF RADAR Data Assimilation

**Pratama K<sup>1</sup>, Siadari E<sup>2</sup>, Pratama B<sup>3</sup>**

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Improving the quality operations of Coastal-Significant Waves Height (CoastalSWH) prediction in shallow water areas is needed as a way to improve the forecasting techniques of significant waves and swell in numerical waves prediction in the field of ocean surface. Improvements of the initial input data are needed for the development of better predictions by combining the Sentinel 3B altimetry and High Frequency (HF RADAR) observations data into the ROMS-SWAN model in Indonesia to support the safety needs for sea transportation and marine sector. The assimilation of the Sentinel 3B altimetry is carried out using the Boussinesq approximation for surface waves and adopts the track as a reference in the wave height measurement points in around the bay area.

Whereas the CoastalSWH model integrates OASIS3-MCT to combine the ROMS-SWAN model with the 4D-VAR assimilation technique for getting a wave propagation approach in real-time. Coastal waves prediction involves the shallow water waves and swell components from the boundary points (BOOM2, BOOM4, BOOM6, BOOM8, BOOM10) from HF RADAR observations. The assimilation scheme uses the option with and without assimilation techniques with a temporal time during 3-hours operational. The correction approach of combined assimilation results done by calculating the value of error observation, autoregression and spatial correlation with and without assimilation.

The assimilation of Sentinel 3B altimetry affects the prediction results of models with high background error in shallow waters and bias error level by measuring radar altimeters that cross land lines. The development option modifies the spectral waves data into the ROMS-SWAN model to improve the predictions of coastal waves. Spectral waves data takes the scanning of wave height measurements using the correlation approach of the most accurate HF RADAR observation point and the smallest bias error. Validation of coastal waves operational prediction results is expected to be a reference in future operations for monitoring significant waves in shallow water areas covering all Indonesian seas.

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## Lake Monitoring Using Multi-Mission Satellite Radar Altimetry

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Lakes are one of the sources of fresh water in the world. Lake monitoring is crucial in managing sustainable water demand where lake levels are temporally variable. Satellite radar altimetry is an advanced method for monitoring water level changes over oceans and inland waterbodies. More extended observations are required to study water level variations, which are many times not available, especially in a scarce data country like Pakistan. In Pakistan, the availability of gauge network is rare and insufficient. A technique like radar altimetry is an adequate approach to fill the data gaps. Some scholars question the efficiency of this method for inland water- bodies, but on the other hand, altimetry is extensively being employed worldwide by the researchers for monitoring of lakes, rivers, and reservoirs. This study has derived and compared water levels from Sentinel-3A data and multi-mission altimetric database of GRLM (Global Reservoir and Lake Monitor). GRLM is freely available and managed by the Foreign Agricultural Service of the United States Department of Agriculture (USDA) which provides water level time series of rivers, lakes, and reservoirs. In this study, TOPEX/POSEIDON (T/P) and Jason series are included from GRLM database along with Sentinel-3A. The tracks of these satellites crossing over the Manchar Lake of Pakistan are used for comparison. Manchar Lake is selected as a case study due to its importance in the water supply system of Pakistan. The two datasets showed similar temporal trends in monitoring water heights of the Manchar Lake during 2016-2019. This work will aid the water managers in analyzing the water level variation and transparent monitoring of the Manchar Lake.

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## Altimeter Wave Data Used to Compare with the Data from the Offshore Wave Glider System

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The offshore wave data are very important for model verification as well as boundary conditions of the coastal wave model, but it is not an easy task to perform offshore wave measurement using a buoy system or ocean tower station. Satellite altimeters provide wave information regularly and spatially but limited to wave heights and periods. As an alternative to buoy or tower measurement, a wave glider system was chosen and operated from October 16, 2015, to October 21, 2016, and from January 2, 2017, to March 31, 2017, centered on the East Sea, 130.9 ° E and 36.48 ° N., and wave heights, periods and directions were measured with 30 minute intervals. We examine the quality of wave data measured by wave glider and investigate the feasibility of using it in the East Sea in the future. Significant wave

heights from available satellite altimeter data are compared with wave glider data and wave directional spectrum is studied during high wave conditions. The wave glider data are a good candidate to validate altimeter wave data offshore.

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## Observed sea level changes at different coastal sites from retracked altimetry over 2002-present

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We present results of contemporary coastal sea level changes along the coasts of different regions (northern Europe, Mediterranean Sea, western Africa and southeast Asia), obtained from a dedicated reprocessing of satellite altimetry data done in the context of the ESA 'Climate Change Initiative' sea level project. High-frequency (20 Hz) sea level data from the Jason-1, Jason-2 and Jason-3 missions are considered. The data were first retracked using the ALES adaptive leading edge subwaveform retracker and further combined with the X-TRACK processing system developed to optimize the accuracy of the sea level time series in coastal oceans. Rates of sea level change have been estimated over the period 2002-present along the Jason-tracks, from the open ocean to the coast. After thorough analysis of the results along all tracks and elimination of noisy cases, we have selected a number coastal sites for which the rate of sea level change can be precisely estimated, up to very close to the coast (sometimes less than 1-2 km). Different coastal sea level trend behaviors are observed over the study period: constant trends from the open ocean to the coast, sometimes decreasing trends, or more often, increasing trends within the last ~5 km to the coast. We further discuss the various small-scale processes able to explain departure of the coastal sea level rate from the offshore (open ocean) rate and, when possible (depending on the availability of data or model outputs), try to attribute the observed coastal trends to a given coastal process.

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## Synergy of Coastal Altimetry and Tide Gauge Data in Monitoring Sea Level. A Case Study in the Aegean Sea.

Flokos N<sup>1</sup>

<sup>1</sup>National Technical University of Athens/Survey Engineering, Athens, Ελλάδα

I would like to participate to 12th Coastal Altimetry Workshop, presenting my work in a poster. I am working my thesis on Satellite Altimetry and Tide Gauge data synergy in order to measure sea level in the Aegean Sea. At this moment my work is in research phase. If I have any results by February, I will update the poster including

them. My participation in the workshop would be an opportunity to broaden my knowledge about Coastal Altimetry, and I will be more prepared for my upcoming PhD period.

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**Sea surface height variations in the slick-rich Sulawesi Sea determined by a new coastal retracking algorithm eliminating inhomogeneous smooth sea surfaces within footprints.**

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A new coastal retracking algorithm is applied to 20Hz Jason-2 data along four tracks in the slick-rich Sulawesi Sea in Indonesia, which alters effective footprint sizes by referring along-track series of waveforms in order to eliminate inhomogeneous microwave reflectance within the footprint. The method successfully reduce occurrence of abnormal sea surface height (SSH) measurements possibly caused by slicks, which could remain even after temporal and/or spatial smoothing procedures. Significant SSH variations in the Sulawesi Sea are revealed strongly correlated with ENSO events; positive (or negative) SSH anomaly is found along all tracks in El Nino (or La Nina) periods. In the 2009/10 El Nino period, significant negative SSHA signals were located in the eastern half of the Sulawesi Sea, suggesting presence of the Indonesian through flow from the Pacific to the Indian Ocean. Meanwhile, in the 20014/15 El Nino period, it was the western side of the Sulawesi Sea where significant negative SSHAs were found, which would suggest effect of the South China Sea through flow into the Sulawesi Sea through Makassar Strait in this period.

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**Potential Applications of the SWOT Mission to the Coastal Oceans**

*Fu L<sup>1</sup>*

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The limit of spatial resolution of the present constellation of radar altimeters in mapping two-dimensional sea surface height (SSH) variability is approaching 100 km (in wavelength) with 3 or more simultaneous altimetric satellites in orbit. At scales shorter than 100 km, the circulation contains substantial amount of kinetic energy in currents, eddies and fronts that are responsible for the stirring and mixing of the ocean, especially important in the various coastal processes. Currently under development, the Surface Water and Ocean Topography (SWOT) mission will use the technique of radar interferometry for making high-resolution measurement of the height of water over the ocean as well as on land.

It is a joint mission of US NASA and French CNES, with contributions from Canada and UK. SWOT will carry a pair of interferometry radars and make 2-dimensional SSH measurements over a swath of 120 km with a nadir gap of 20 km in a 21-day repeat orbit. The synthetic aperture radar of SWOT will make SSH measurement at extremely high resolution of 10-70 m, although with relatively large instrument noise. Upon spatial averaging, the SWOT SSH data can achieve 10 cm precision at 250 m<sup>2</sup> pixel and 2.5 cm at 1 km<sup>2</sup> pixel. SWOT will also carry a nadir looking conventional altimeter and make 1-dimensional SSH measurements along the nadir gap. The water-vapor radiometer of SWOT has two beams focusing on off-nadir swaths to addressing cross-track variability of water-vapor induced errors.

The temporal sampling varies from 2 repeats per 21 days at the equator to more than 4 repeats at mid latitudes and more than 6 at high latitudes. This new mission will allow a continuum of fine-scale observations from the open ocean to the coasts, estuaries and rivers, allowing us to investigate a number of scientific and technical questions in the coastal and estuarine domain to assess the coastal impacts of regional circulation and sea level change, such as the interaction of sea level with river flow, estuary inundation, storm surge, coastal wetlands, salt water intrusion, etc. The SWOT Mission, scheduled for launch in late 2021-early 2022, will provide fundamental data to map the spatial variability of water surface elevations under different hydrodynamic conditions and at different scales (local, regional and global) to improve our knowledge of the complex physical processes in the coastal and estuarine systems in response to global climate changes.

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**Performance of Recent Global Tide Models at The Entrance of The Gulf of California With Application to Altimeter Data**

*Valle J<sup>1</sup>, Gómez J<sup>2</sup>, Trasviña A<sup>3</sup>*

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The entrance to the Gulf of California (EGC) is in direct communication with the Eastern Pacific Ocean. It has a marked seasonal variability of sea level and sea surface temperature. The tidal regime is mixed with semidiurnal predominance. There are no local tidal models for this region, so tidal corrections for altimetry data are made using global tidal models (GTM). In order to validate the best global tidal model for our region, we evaluate the amplitudes and phases of 8 common tidal components of 4 GTM (DTU10, HAMTIDE, TPX09, FES2014b). To validate we compare them with the same components obtained from tide gauges located at Cabo San Lucas and Mazatlán. Our results indicate that the TPX09 and FES2014b models attain the best performance in our study area, obtaining a Root sum square (Rss) value of around 2.2 cm. The global tidal model TPX09 solves 13

tidal constituents while the FES2014b model solves up to 34 constituents. Due to the greater number of solved components, we use the tidal corrections from the FES2014b model in order to estimate sea level anomalies (Sla) from the CryoSat-2 mission. Subsequently we validate the Sla from Cryosat-2 with tide gauge data.

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### **X-TRACK Regional Altimeter Products for Coastal Applications: 2020 Release**

*Léger F<sup>1</sup>, Birol F<sup>1</sup>, Niño F<sup>1</sup>, Allain D<sup>1</sup>*

<sup>1</sup>CTOH/LEGOS, Toulouse, France

X-TRACK, has been developed by CTOH (Center of Topography of the Ocean and Hydrosphere) and LEGOS (Laboratoire d'Etudes en Géophysique et Hydrologie Spatiale) in order to optimize the completeness and the accuracy of the sea surface height information derived from satellite altimetry in coastal ocean areas. It is tailored for extending the use of altimetry data to coastal ocean applications. Now, X-TRACK is a multi-mission product covering all the coastal ocean, freely distributed by the operational AVISO+ service. Both Sea Level Anomaly time series and empirical tidal constants are available on 23 coastal region every 6-7 km along the satellite ground tracks for different altimetric missions. Today X-TRACK is mature 1 Hz products used all around the world by more than 700 users since 2007 for more than 60 articles concerning a wide range of coastal application as coastal ocean circulation, mesoscale dynamics, model validation, tides. We present here the different X-TRACK products available for the coastal community and the future development.

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### **Wave Model Confidence Index: A metocean decision support tool**

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<sup>1</sup>Noveltis, Labège, France

How to know and ensure the quality of sea state forecasts, then make decisions to plan operations at sea, reduce technical, human, material and environmental risks? To answer this question, most marine operators use either forecasting models or measurements from different centers around the world. The lack of an online solution that brings all this data together and their use in this way takes time and makes it difficult to use the information to evaluate the situation. To remedy this, the NOVELTIS WMCI service provides operational support to all stakeholders in the maritime sector for the planning and optimization of their activities at sea. This service is born from the many exchanges and reflections carried out between operators at sea and NOVELTIS. This service offers a unique and expertized integration of all measured sea state data (in situ and satellite), facilitating their mutual exploitation and comparison with the most widely used wave forecast models.

The use of such a service may be useful, for example, in the following cases:

-Towing of fragile large structures from one port to another that does not exceed a certain threshold of wave height.

-Planning the navigation route.

-Business planning on offshore platforms.

The service is a decision support tool for marine activity and navigation, based on an ergonomic interface integrating all types of data (observation, models) from various weather-oceanic centers. In particular, it makes it possible to perform multi-model inter-comparisons with observations in situ or along altimetric traces and using state-of-the-art technologies. It provides wave, wind and current forecasts at global and regional scale.

The service is used for customizing reports for metocean services for neashore and offshore activities.

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### **River Water Level Monitoring from Satellite Radar Altimetry Multi Missions: A Case Study of the Amazon and Danube Rivers**

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This study examines results of Envisat and SARAL Satellite Altimetry (SA) standard waveform retracking procedures to monitor the water level of Amazon and Danube rivers between 2002 to 2012 for. In addition, the Jason-2 data has been used to study water level variation of Danube river from 2008 to 2014. Validation of the SA data was performed by water level records of the tide gauge (TG) stations located near the satellite tracks. TG time series of stations were provided by Agencia Nacional de Aguas (ANA) over Amazon River and Országos Vizjelző Szolgálat (HHFS) over Danube River in Hungary. These data cover the span time from 1968 to 2017 that overlaps of about 14 years with SA measurements to assess the derived water level precision.

The methodology entailed that for each satellite's overpass using different possible scenarios with the on-board retracking method. Careful spatial selection and outlier detection was performed, to screen out low-quality data. To correct the altimeter ranges, external models were applied. This holds especially for the atmospheric corrections including dry/wet troposphere delay as well as ionosphere delay and the geophysical (solid Earth tides and pole tide). Water level time series of SA data defined after data selection over the rivers closed to TG stations. Non-qualified data excluded. A

long time series were created by merging all single passes and all tracks then a model has been fitted on it to eliminate the outliers. To find the most robust water level scenario combined time series have been compared with TG data by calculating the RMS errors. Finally, the water levels ascertained from SA data over each station plotted, to give an overall comparison of different scenarios.

Results of the comparisons within the test regions show that the RMS are between 37 and 72cm and the formal error are about 55 cm on average for Amazon and 56 cm for Danube river basin. A good agreement was obtained at Jatuarana station in the Amazon river using MEDIAN value for H-Ocean retracker of SARAL data. Due to the different temporal resolutions, TG data were interpolated at the altimeter epochs. Keeping this in mind, an accuracy of 37cm is good considering SA ground tracks geometry limitation over inland water bodies. The results show that SA time series are consistent and there is not unusual change in terms of bias and systematic error and there is a fine match between them and TG levels behaviour. The annual periodic term also can be seen from the altimetry time series especially for MEDIAN values. In another hand this study is limited to three SA on-board retracking data so, the use of additional missions or sub-waveform tracking could improve data coverage quality.

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#### **Determination of Sea Level Trends of the Marmara Sea from Satellite Altimetry and Tide Gauges Data (2010-2019)**

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Sea level is one of the most used indicators in regional and global climate change studies as it is affected by climate events. It also affected by tectonic motion, earthquake and local effects.

In order to determine sea level, two main methods are used. The first one is tide gauge that is measure sea level relative to a ground benchmark as a datum. It can be also affected by vertical ground movements. The other is satellite altimetry that measures sea level relative to a geocentric reference and not affected by vertical land motions.

The purpose of this study, to determine sea level changes from tide gauges and various satellite altimetry missions in the Marmara Sea. For this aim, relative sea level trends and tidal parameters have been estimated over period 2010-2019 by main tidal frequencies using least-squares harmonic estimation method from two tide gauge stations distributed in the Marmara sea operated by TUDES (Turkish National Sea Level Monitoring System). The Satellite altimetry mission data also have been used to estimate absolute sea level. The data have been obtained by AVISO, ESA-EO, Copernicus Open Access Hub data archive in the period of 2010-2019.

Sea level trend and tidal parameters have been determined and compared with two method both the tide gauge station and satellite altimetry. And tidal parameter also compared to global models such as FES2004, FES2014, DTU10 and Tpxo 7.2.

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#### **Coastal HF Radars and Remote Sensing Altimetry: Complementary Process for Wave Height Observations**

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The west coast of the Iberian Peninsula is strongly influenced by the presence of low-pressure systems in the mid-Atlantic Ocean, as the Azores Anticyclone, and the periodic landfall of storms give rise to severe sea states, mostly during winter. Since its wave climate is one of the most energetic in Europe, its observation and monitoring, at the coast, is very important.

The combination of High Frequency Radar (HFR) and satellite altimetry measurements arises as a promising strategy to improve the continuous monitoring of the coastal area all the way to the shoreline. HFR systems located on the coast can measure surface currents and ocean wave directional spectrum simultaneously from close to the coast to more than 100 km offshore. In Europe, the use of HFR systems is growing, with over 62 HFR sites currently in operation. HFR have been identified as a cost-effective complement to in situ systems, by providing increased spatial coverage with lower maintenance costs. The measurement is typically confined to the coastal zone and can be effective to fill the gaps of other monitoring platforms, such as satellite radar altimeters, but with much higher temporal resolution.

Satellite altimetry measurements are of lower accuracy near the coast due to land contamination; inaccurate removal of atmospheric effects at the surface and incorrect tidal corrections and in some cases the sampling strategy was not designed for near-coast regions. But in open ocean or for offshore areas this could be the only way to measuring operational oceanography parameters, such as surface currents, waves or winds.

HFR are now a well-accepted technology. Wave parameters such as significant wave height, wave periods and mean wave directions can be extracted from the lower amplitude second-order directional spectrum using standard methods. The lower cost of HFR system maintenance, compared with to offshore buoys, ensures more continuous data return. HFR technology, among other applications, could be used for marine safety, tsunami warning, coastal zone management or for numerical model simulation of 3D circulation.

In this study, we have investigated the synergies and differences between coastal HFR and satellite altimeter, two remote-sensing techniques that provide measurements of the ocean wave parameters at different temporal and spatial scales. The study area is located west of the Iberian Peninsula, defined between the parallels 34°N-46°N and meridians 5°W-15°W. A time window for HFR measurements and satellite altimeter products, from 2017 to 2019, were used. Sentinel-3 A/B satellite altimetry data with 1 Hz sampling, which correspond to measurements taken every 7 km along the track were analyzed. The comparison of both data sets in overlapping areas was made and a general agreement between HFR and satellite altimetry was observed in the study area. Data from twelve ODAS buoys were used for calibration purposes. The use of these different remote-sensing techniques could act as a complementary process for wave height observations mostly during the transition between open ocean to nearshore areas, filling the information gaps of in situ systems.

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**Access to Sentinel-3 Marine Center data**

*Lucas B<sup>1</sup>, Scharroo R<sup>1</sup>, Nogueira Loddo C<sup>1</sup>, Martin-Puig C<sup>1</sup>, Dinardo S<sup>2</sup>, Parodi I<sup>3</sup>*

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The Marine data of the Surface Topography Mission of Sentinel3 is produced and distributed by EUMETSAT.

The products made available to the users are SRAL/MWR Level 2 (SR\_2\_WAT\_\_\_) and SRAL Level 1 (SR\_1\_SRA\_A, SR\_1\_SRA\_BS, and SR\_1\_SRA\_\_\_).

User can access the data via EUMETCast, EUMETSAT Data Centre, ODA (Online Data Access) and the pilot service CODA (Copernicus Online Data Access).

This poster will show the different manners to access the available datasets (either operational or the reprocessed).

The focus will be on access via Data Centre and CODA, especially on the automatization of data download.

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**S3 Marine Centre status**

*Lucas B<sup>1</sup>, Scharroo R<sup>1</sup>, Nogueira Loddo C<sup>1</sup>, Martin-Puig C<sup>1</sup>, Dinardo S<sup>2</sup>*

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The poster will show the current status of the S3 Marine Centre. EUMETSAT is responsible for the Ocean and Coastal products of Sentinel-3 mission, on behalf of Copernicus.

Details on the Key Performance Indicators of the data production will be shown, taking into account the completeness and the timelines.

Details on the data production, such as Orbit usage statistics, will also be shown.

The latest events of the spacecraft and also Marine ground segment will be reported.

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**Satellite Altimetry: Coastal Region Research to Applications**

*Srinivasan M<sup>1</sup>*

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More than 27 years of research from satellite altimetry missions has achieved incalculable value to studies in scientific fields and has also contributed valuable information in areas of applied science and applications. Research activities, generally funded by large government agencies—in the case of satellite altimetry, space agencies like NASA and CNES—as well as academic institutions and private research groups, have provided substantial benefits to society stemming directly from the research topics, and also from ancillary analyses and data from the missions.

The literature database for ocean altimetry missions located at <https://sealevel.jpl.nasa.gov/science/litdb/>, has been “mined” for studies which may contribute information in coastal region applications. Altimetry mission applications include weather prediction, coastal impacts (storm surge, coastal currents), fisheries management, ecosystem functioning, marine transport, sea level rise (and related disaster risk management), flooding, and coastal impacts from ocean and surface water changes, among many others. This paper will identify some of the broad topics and specific examples of satellite altimetry research focused in these coastal regions.

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## Highlights of Spatial Altimetry Activities in CNES Related to Coastal Processes

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The Poster presentation will be an overview of several altimetry activities leads by CNES regarding to coastal processes:

- The Short revisit time of 1 day proposed by the SMASH altimeter constellation (phase A project) will improve the understanding of the spatial-temporal dynamics on coastal, oceanographic and hydrological processes.
- A Multi-satellite vision: the increase of satellite sensors to observe water processes (interferometry, SST, SAR imagers, color sensors) requires new methods to integrate them together to better understand water dynamics. The next web platform "Hydroweb NG" will represent one step further to integrate multi-sensor water variables (hydro/coastal) in a single system, gathering altimetry derived products (river discharge, lake volume changes), water color, water surface dynamics, soil moisture, snow coverage, LULC of the surroundings and littoral DEMs
- New water color products based on Sentinel2 will allow a better insight of the continuum between rivers, estuaries and littoral processes
- Contributions on a project for bathymetry inversion algorithms in coastal waters through the measurement of ocean waves velocity field

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## Exploring the Trend of Sea Level Rise and Its Impacts on Coast of Pakistan Using Satellite Radar Altimetry

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Sea level rise (SLR) is serious threat to the coastal regions around the world and a continuous monitoring is imperative to manage this hazard. Pakistan with a coastline of 990 km long is one of those countries, which are most vulnerable to sea level rise. Around 10% population of Pakistan is living near the coastal zones, and over 20% coastal area is developed comprising 40% of industries in Pakistan (M.M Rabbani, 2008). Other infrastructures are also overwhelming after the construction of the Gwadar port and China Pakistan Economic Corridor (CPEC). A SLR of a few millimeter's per year is a dangerous hazard for the coastal areas of Pakistan. This rise can directly and indirectly cause land loss of low-lying areas and destruction of coastal ecosystems, infrastructures, human settlements agriculture lands and other resources. More significantly the sea port of Gwadar, which has an important role strategically and economically in this region may be impacted. By the help of satellite radar altimetry (SRA) variations in wave height can be monitored and it also

measures the topography of sea surface. The measurement of sea surface elevation is possible through altimetry, which gives more precise data than tidal gauge for monitoring SLR. The SRA is used to monitor sea levels along the Pakistan coast using data from 1993 till to date. Which helps in quantifying the rise in sea levels and by the extrapolation the potential of SLR can be predicted for future. For Initial analysis the altimetry data is acquired from Jet Propulsion Lab's Physical Oceanography Distributed Active Archive Center (PODAAC), which shows a rising trend of sea level 4 mm/year. However, the gauge obtained from University of Hawaii Sea Level Center (UHSLC) shows a rising trend of 2.2 mm/year near harbor of Karachi. This study may also lead to an ultimate goal of formulating an integrated coastal zone management plan for adaptation and prevention of adverse effects of SLR.

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## Indus River Level Monitoring using Sentinel 3A data

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In recent years, satellite radar altimetry has emerged as a significant resource of information for monitoring water levels of coastal and inland waters. The effectiveness of these remotely sensed data was evident in both real-time and long-term applications through various studies in the area of discharge modeling, flood mitigation, agriculture water management, and environmental assessment. In addition to the scientific and practical applications, satellite radar altimetry also offers a way of overcoming the transboundary river management issues in cases where hydrological data are considered sensitive information by countries. Therefore, this technique even can fill data gaps with multi-temporal and multi-spatial information pertinent to hydrological studies and modeling approaches. The main focus of this study was to develop a low-cost method for national surface water level monitoring in Pakistan to support sustainable water management. Two sites along the Indus lower reach were selected for validation of altimetry data where in-situ gauges were installed near Sentinel 3A tracks. These sites are the Guddu and Sukkur Barrages in Pakistan. The time-series (June 2016-June 2019) plots of the two datasets have an excellent agreement except for a few records. This technique enabled us to observe river level changes on different segments of the river system where otherwise no measuring devices are installed. As a result, the low gauging frequency along the Indus River can be enhanced by introducing the virtual stations (VSs) of Radar altimetry. In comparison to the limited or restricted availability of gauge data, the present study found the satellite radar altimetry observations advantageous.

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## 2-D Flood Model Validation in the Lower Indus reach Using Satellite Altimetry

**Panhwar V<sup>1</sup>, Zaidi A<sup>1</sup>, Babar N<sup>1</sup>**

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Indus River, the prime water resource of Pakistan, has a limited gauging network, especially at remote locations. The existing system is not sufficient for developing an integrated water resource management plan for the Indus River Basin. The hydraulic models serve to simulate flood waves but are not useful without calibration and validation. For model calibration and validation, ground information is required. If such data are not available, then model calibration and validation is not possible. At places with low gauging frequency, as is the Indus River, satellite radar altimetry water levels may be useful. In this study, altimetry water heights time-series are validated first at locations where in-situ water heights time series are available. After the estimation of water levels from the altimeter and its validation, the water levels from the satellite's virtual stations (VSs) were compared with the results obtained from flood modeling (2D HEC-RAS) of the recent flood event occurred in July 2019 near Nudero city. In this study, four virtual stations (two for calibration and two for validation) were selected in the Lower Indus reach and its adjacent floodplains. The two virtual stations are on the permanent water surface i.e., vs12 (Near Naudero City) and vs13 (Near Pir Jo Goth), while the remaining, vs1 and vs2, are appeared only when the flows are high i.e., during the flood season. The model calibration and validation results are provided in the results section near Pir jo Goth (Khairpur, Sindh).

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## Use of Sentinel3-A satellite altimeter data for Geoid determination over the Western Mediterranean

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Satellite radar altimetry is a powerful tool for studying the sea surface height and physical oceanography, the use of satellite altimetry data to compute marine gravity anomaly and geoid determination provides good results and costs relatively low.

In this study, A method for the computation of the deflections of the vertical from altimetric data of Sentinel3-A satellite altimeter of the year 2018, over the Western Mediterranean, is based on the use of the remove restore technique, the major argument of using DOV rather than geoid heights is the fact that DOV values are less contaminated by long-wavelength errors.

In coastal areas of Algeria, the SSH value which, in addition to standard geophysical corrections, is corrected by local tidal correction using tide gauge records.

By removing a known reference geoid model like earth geopotential model EGM 2008, the mean dynamic topography must also be removed, a residual geoid field is obtained, which is converted to geoidal undulation by means of the inverse Vening Meinesz formula, the last step to get the marine geoid was by restore EGM2008.

Key words: Satellite altimetry, gravity, geoid determination, Sentinel3-A

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## SAR and SARin Altimetry Processing on Demand for Cryosat-2 and Sentinel-3 at ESA G-POD

**Benveniste J<sup>1</sup>, Dinardo S<sup>2</sup>, Sabatino G<sup>3</sup>, Restano M<sup>4</sup>, Ambrózio A<sup>5</sup>**

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The scope of this presentation is to feature the G-POD SARvatore service to users for the exploitation of CryoSat-2 and Sentinel-3 data, which was designed and developed by the Altimetry Team in the R&D division at ESA-ESRIN. The G-POD service coined SARvatore (SAR Versatile Altimetric Toolkit for Ocean Research & Exploitation) is a web platform that allows any scientist to process on-line, on-demand and with user-selectable configuration CryoSat-2 SAR/SARin and Sentinel-3 SAR data, from L1A (FBR) data products up to SAR/SARin Level-2 geophysical data products.

The G-POD graphical interface allows users to select a geographical area of interest within the time-frame related to the Cryosat-2 SAR/SARin FBR and Sentinel-3 L1A data products availability in the service catalogue. The processor prototype is versatile, allowing users to customize and to adapt the processing according to their specific requirements by setting a list of configurable options. Pre-defined processing configurations (Official CryoSat-2, Official Sentinel-3, Open Ocean, Coastal Zone, Inland Water (20Hz & 80Hz), Ice and Sea-Ice) are available. After the task submission, users can follow, in real time, the status of the processing. The output data products are generated in standard NetCDF format, therefore being compatible with the multi-mission "Broadview Radar Altimetry Toolbox" (BRAT, <http://www.altimetry.info>) and typical tools.

Initially, the processing was designed and optimized uniquely for open ocean studies. It was based on the SAMOSA model developed for the Sentinel-3 Ground Segment. However, since June 2015, the SAMOSA+ retracker is available as a dedicated retracker for coastal zone, inland water and sea-ice/ice-sheet. A new retracker (SAMOSA++) has been recently developed and will be made available in the future. The scope is to maximize the exploitation of CryoSat-2 and Sentinel-3 data over all surfaces providing user with specific processing options not available in the default processing chains.

Recent improvements include: 1) A Join & Share Forum to allow users to post questions and report issues



([https://wiki.services.eoportal.org/tiki-custom\\_home.php](https://wiki.services.eoportal.org/tiki-custom_home.php)); 2) A data repository to better support the growing Altimetry Community avoiding the redundant reprocessing of already processed data (<https://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository&highlight=repository>); 3) The extension of the radar receiving window size, up to a factor 4, in the Sentinel-3 service, which is beneficial for inland water analyses over very steep topographic regions; 4) The CREODIAS cluster element to speed up the data processing.

To respond to the request of hydrologists, and simulate data that a river gauge would provide, SARvatore will soon include a post-processing service to convert water level estimates in L2 data to virtual station water level values, which are typically required by hydrologists.

The service is open, free of charge (supported by the ESA SEOM Programme Element) for worldwide scientific applications and available at [https://gpod.eo.esa.int/services/CRYOSAT\\_SAR/](https://gpod.eo.esa.int/services/CRYOSAT_SAR/), [https://gpod.eo.esa.int/services/CRYOSAT\\_SARIN/](https://gpod.eo.esa.int/services/CRYOSAT_SARIN/), [https://gpod.eo.esa.int/services/SENTINEL3\\_SAR/](https://gpod.eo.esa.int/services/SENTINEL3_SAR/)

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### The BRAT and GUT Couple: Broadview Radar Altimetry and GOCE User Toolboxes

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The scope of this work is to showcase the BRAT (Broadview Radar Altimetry Toolbox) and GUT (GOCE User Toolbox) toolboxes.

The Broadview Radar Altimetry Toolbox (BRAT) is a collection of tools designed to facilitate the processing of radar altimetry data from all previous and current altimetry missions, including Sentinel-3A L1 and L2 products. A tutorial is included providing plenty of use cases on Geodesy & Geophysics, Oceanography, Coastal Zone, Atmosphere, Wind & Waves, Hydrology, Land, Ice and Climate, which can also be consulted in <http://www.altimetry.info/radar-altimetry-tutorial/>.

BRAT's last version (4.2.1) was released in June 2018. Based on the community feedback, the front-end has been further improved and simplified whereas the capability to use BRAT in conjunction with MATLAB/IDL or C/C++/Python/Fortran, allowing users to obtain desired data bypassing the data-formatting hassle, remains unchanged. Several kinds of computations can be done within BRAT involving the combination of data fields, that can be saved for future uses, either by using embedded formulas including those from oceanographic altimetry, or by implementing ad-hoc Python modules created by users to meet their needs. BRAT can also be used to quickly visualise data, or to translate data into other formats, e.g. from NetCDF to raster images.

The GOCE User Toolbox (GUT) is a compilation of tools for the use and the analysis of GOCE gravity field models.

It facilitates using, viewing and post-processing GOCE L2 data and allows gravity field data, in conjunction and consistently with any other auxiliary data set, to be pre-processed by beginners in gravity field processing, for oceanographic and hydrologic as well as for solid earth applications at both regional and global scales. Hence, GUT facilitates the extensive use of data acquired during GRACE and GOCE missions.

In the current version (3.2), GUT has been outfitted with a graphical user interface allowing users to visually program data processing workflows. Further enhancements aiming at facilitating the use of gradients, the anisotropic diffusive filtering, and the computation of Bouguer and isostatic gravity anomalies have been introduced. Packaged with GUT is also GUT's Variance/Covariance Matrix (VCM) tool, which enables non-experts to compute and study, with relative ease, the formal errors of quantities – such as geoid height, gravity anomaly/disturbance, radial gravity gradient, vertical deflections – that may be derived from the GOCE gravity models.

BRAT and GUT toolboxes can be freely downloaded, along with ancillary material, at <https://earth.esa.int/brat> and <https://earth.esa.int/gut>.

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### Validation of Sentinel-3 Coastal Altimetry Data on the Baltic Sea and Estonian Lakes

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Multimission satellite altimetry (e.g. ERS, Envisat, TOPEX/Poseidon, Jason, etc.) data have been used for many purposes (i.e. determination of sea-level rise, significant wave height, etc.) for a long time. Since 2016, Sentinel-3 mission has been providing better spatial and temporal sampling compared to its predecessors.

The Baltic Sea coastal area is very shallow and full of small islands. Additionally, there is a dense in situ water level network on the coast. Therefore, the Baltic Sea is well suited for altimetry validation in the coastal area. In this study Sentinel-3A and Sentinel-3B Level-2 product validation results are presented on four altimetry tracks: two on the coast of the Baltic Sea (Sentinel-3A pass 93 and Sentinel-3B pass 312), one on Lake Peipsi (Sentinel-3B pass 321) and one on Võrtsjärv lake (Sentinel-3B pass 264). Four expeditions of GNSS measurements on the boats were carried out along altimetry tracks in the same day with the altimetry passes. Sea surface height (SSH) from altimetry was compared with the SSH from the GNSS measurements. In addition, SSH results from altimetry were compared with the national geoid model EST-GEOID2017 and in situ sea-level measurements. Results show that the accuracy of the Sentinel-3 Level-2 altimetry products is below decimetre level on the Estonian coast (1 km from the coast) and bigger lakes.

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## Satellite Altimetry and In Situ Observations: Estimating Relative and Absolute Sea Level Rise at the Adriatic Sea coast (Venice and Trieste)

*De Biasio F<sup>1</sup>, Baldin G<sup>2</sup>, Papa A<sup>3</sup>, Vignudelli S<sup>4</sup>*

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Considerable efforts are made by space agencies and scientists to develop consistent and long-term satellite-based datasets: the European Space Agency (ESA) Climate Change Initiative (CCI) initiative Sea Level Project (SLCCI) is being producing climate-oriented altimeter sea level products optimized for the coastal zone, a monthly-mean gridded product covering the global ocean at 0.25x0.25 degrees (1993-2015). Based on this heritage, the operational production of climate-oriented altimeter sea level products has been taken over by the European Copernicus Climate Change Service (C3S) with a daily-mean product gridded at 0.125x0.125 degrees covering the global ocean 1993-present. In parallel, refined products are expected in the second phase of the SLCCI project.

We made a comparison of the SLCCI satellite altimetry dataset with sea level time series at selected tide gauges in the Mediterranean Sea, focusing on Venice and Trieste. There the coast is densely covered by civil settlements and industrial areas with a strongly rooted seaside tourism, and tides and storm-related surges reach higher levels than in most of the Mediterranean Sea, causing damages and casualties as in the recent storm of November 12th, 2019: the second higher water registered in Venice since 1872. Moreover, in the Venice area the ground displacements exhibit clear negative trends which deepen the effects of the absolute sea level rise.

Several authors have pointed out the synergy between satellite altimetry and tide gauges to corroborate evidences of ground displacements. Here we exploit the long satellite-altimetry dataset duration and the high quality of sea-level time series at selected tide gauges of the Mediterranean Sea, to estimate the ground displacement rates.

While in Venice, in the period 1993-2015, a relative sea level rise trend of about  $+6.17 \pm 1.51$  mm  $y^{-1}$  has been determined from tide gauge at Acqua Alta Platform, 14 km offshore, in Trieste the tide gauge registered a trend of  $+4.10 \pm 1.38$  mm  $y^{-1}$ .

Similarly, the altimetry product reports at the closest grid points absolute sea level rise rates of  $+4.02 \pm 1.27$  mm  $y^{-1}$  (Venice) and  $+1.15 \pm 1.35$  mm  $y^{-1}$  (Trieste). The estimated vertical land displacement rates, following the direct approach [Cazenave et al. 2009], resulted  $-1.79 \pm 0.72$  mm  $y^{-1}$  (Venice), and  $-2.95 \pm 0.75$  mm  $y^{-1}$  (Trieste). The estimated fitting slopes [Vignudelli et al., 2019] are the object of our investigation using the generalized least mean square procedure with constraints [Menke, 1989].

A partial validation of the resulting estimates has been made against Global Positioning System-derived (GPS) time series at selected stations.

This work will contribute to identify problems and challenges to extend the sea level climate record to the coastal zone with quality comparable to open ocean, and also to assess the suitability of altimeter-derived absolute sea levels as a tool to estimate subsidence where permanent GPS receivers are not available. The Northern Adriatic is a laboratory to assess this tool, in particular considering the prospect of coming refined global products that are being generated within the ESA SLCCI extension (CCI+) project.

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## The Impact of the Large-Scale Atmospheric Patterns in the North Atlantic on the Northern European Sea Level

*Mangini F<sup>1</sup>, Chafik L<sup>2</sup>, Madonna E<sup>3</sup>, Li C<sup>3</sup>, Bertino L<sup>1</sup>*

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In this project, we focus on the wind component of sea level variability over the Northern European continental shelf, the region of the coastal ocean that includes the North Sea, the Norwegian shelf and the Baltic Sea. More precisely, we study how the winter-time large-scale atmospheric patterns in the North Atlantic affect the Northern European sea level at a monthly time scale (we have decided to limit the analysis to the winter months because, in winter, winds are more intense and have a stronger impact on the sea level).

In the past, numerous authors dealing with a similar problem (e.g. Wakelin et al., 2003) looked for the relationship between the Northern European sea level anomaly (SLA) and North Atlantic Oscillation (NAO) index, being the NAO the leading mode of the atmospheric variability in the North Atlantic. However, they found a non-stationary relationship between the two.

Several recent studies showed that the NAO alone is not able to describe the entire winter-time atmospheric variability in the North Atlantic and that other empirical orthogonal functions (EOFs) should also be considered. In particular, Moore et al. (2014) showed that the interplay between the NAO and either the second or the third leading modes of the large-scale atmospheric variability in the North Atlantic, namely the East Atlantic Pattern (EAP) and the Scandinavian Pattern (SCAN), affect the location of the centres of action of the NAO. Following this study, Chafik et al. (2017) showed that the Northern European sea level does not only respond to the NAO, but also to the EAP and SCAN. In particular, they noted that high SLA values in the North Sea are mainly affected by the same positive phase of the NAO

and SCAN, whereas, over the Norwegian shelf, by the same positive phase of the NAO and of the EAP.

In this project, we still focus on the relationship between the large-scale atmospheric circulation patterns in the North Atlantic and the wind component of the Northern European sea level. However, with respect to the previous studies, we follow a different approach. We do not describe the large-scale atmospheric circulation in the North Atlantic in terms of the leading EOFs. Instead, we describe it in terms of the jet clusters. The jet clusters are four recurrent and persistent atmospheric circulation patterns over the North Atlantic. With respect to the EOFs, they have the advantage of being more closely related to the 2D structure of the jet stream and more easily associated to the wind pattern over the North Atlantic. Using gridded SLA data from altimetry, we attempt to understand how each jet cluster individually affects the sea level variability over the Northern European continental shelf at a monthly time scale.

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### **Exploring the Synergy between Optical Imaging Radiometry and Radar Altimetry for Inland Waters: an Experience on the Nasser Lake**

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Lake Nasser, the biggest and most important lake in Egypt, located in the southern part of the Nile River in Upper Egypt, is experiencing significant and rapid water level variations and sedimentation processes, which might influence its storage capacity. In addition, the expected impact of the Grand Ethiopian Renaissance Dam (GERD) on the future availability of the Nile water, make the Nasser Lake one of the most challenging hot spots to be monitored at a global level.

This work describes a preliminary study on the possible usage of the imaging radiometer SLSTR (Sea and Land Surface Temperature Radiometer) onboard Sentinel-3 for estimating water coverage extent in inland water contexts, in synergy with radar altimetry measurements as provided by the SRAL (Synthetic aperture Radar Altimeter) instrument.

Today, various works in the literature propose a combination of optical imagery and radar altimetry to estimate water storage variations in inland water targets. This work wants to exploit the simultaneous acquisition offered by SRAL and SLSTR instruments hosted by the Sentinel-3A/B platform.

The fundamental idea is to experiment an alternative technique to calculating the whole water extent by using high-resolution imagery, starting from the assumption

that a much-reduced subset of pixels may carry enough information for assessing the status of the observed water body. In this particular case, it is possible to estimate the water coverage percent within each single pixel by exploiting the radiometric performance (first of all, the repeatability) of the SLSTR instrument and limit the estimation to a selected subset of pixels.

In our approach, the first N pixels exhibiting the highest variability of the collected radiance are used. As expected, the identified pixels are generally crossed by the coastlines of the target, as a consequence of its morphological characteristics. The obtained timeseries is compared with the timeseries of water levels obtained by processing SRAL data. For this purpose, we used the 20 Hz product generated by running SARvatore on the GPOD platform.

Preliminary results show a promising relationship between the timeseries generated by the two independent instruments, in terms of both general trend and seasonal dependence. Under the hypothesis of a time-invariant system (i.e., no significant morphological changes), once an area-level-volume relationship is identified, volume estimations can be inferred by either altimetric or radiometric measurements per se. Thus, the simultaneous measurements by the two instruments constitute an excellent opportunity for cross-validating the acquired data. Finally, by using the approximation proposed in this paper, a very light computational process can infer an estimation of water storage, when the natural system is fully identified on the basis of ground-truth data.

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### **On the Synergy Between Altimetric data and a WebGis Platform to Understand Coastal Hydrodynamic Processes: The ODYSSEA Project.**

**Gana S<sup>1</sup>**

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The ODYSSEA\* consortium is currently building an innovative platform and network of Mediterranean marine and coastal observatories that will deliver ocean observing data and model outputs to fulfil tailored end-user needs and policy-maker requirement. By setting up this network of integrated marine observing systems, ODYSSEA is increasing the spatial and temporal coverage of oceanographic and ecological monitoring across the Mediterranean region, with a particular focus on data-poor areas.

Gliders and static observing stations started to collect and transmit in near real time in-situ data: Temperature, Salinity, Dissolved Oxygen, Chlorophyll, Microplastics, wave, currents and sea-surface level in 9 areas across the Mediterranean. Simultaneously, operational models, with assimilation capabilities, are being implemented to cover the coastal waters of the 9 areas of interest.

On top of that, the Odyssea platform (see attached figure), which is currently in pre-operational test phase,

integrates all the existing data platforms (Mercator, Seadatanet, Emodnet, NCEP, ESA, ...), so that the user will only have to deal with a unique data server to access to hindcasts, historical maps and timeseries, to metocean conditions of the day and to forecasts.

The interfacing between the data platform and the numerical model is performed using the Delft-FEWS system, which is a powerful tool for managing forecasting processes and/or handling time series data. Delft-FEWS incorporates a wide range of general data handling utilities, while providing an open interface to any external (forecasting model). The modular and highly configurable nature of Delft-FEWS allows it to be used effectively for data storage and retrieval tasks, simple forecasting systems and in highly complex systems utilising a full range of modelling techniques.

Therefore, thanks to the ODYSSEA system, it will be possible to compare the outputs of the models with satellite data covering the coastal zone, especially regarding sea level variation, in order to validate either model outputs or altimetry data, based on what is already known about the observatories areas. As part of a synergistic approach, tests will be done with and without altimetric data assimilation and we will compare quantities as SSH and SLA over a relevant period of time. Besides the comparison with model output, glider data along Sentinel 3 track will be also compared with altimetric data, in order to shed light on the relation between sea surface signature of structures and what is occurring at depth.

Progressively, this synergistic approach will yield to a reliable assimilation of Sentinel-3 altimetric data into the FEWS-DELFT system, along with in-situ data collected by the observatories, in order to better understand the hydrodynamic features occurring in the coastal areas.

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### **Quantification of the Signature of the Northern Current in Sea Level Variations or How Can We Optimally Use Altimetry Observations in Coastal Circulation Studies.**

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Satellite altimetry enables to obtain the Sea Surface Height (SSH) variations along the satellite tracks. More and more accurate observations are available near the coasts thanks to advances in the data processing and to technological innovations. As a consequence, fine-scale coastal structures (eg down to 30-50 km, depending on their signature in SSH) can be regularly monitored. However, in terms of geostrophic current derived from the SSH altimetry gradients, intercomparisons with in situ observations show regularly that their amplitude is

underestimated. This is due to the signal-over-noise ratio associated to altimetry measurements, which results in a loss of information. If we want to optimize the use of altimetry in coastal studies, it is important to quantify what current component can/can't be observed. This is the objective of this work.

The North-Western Mediterranean Sea (NWMed) has become a pilot area for coastal altimetry studies. It is a particularly interesting area in terms of coastal ocean dynamics, associated to a large number of fine scale structures. It also benefits from a large number of in situ current observations (ADCP, gliders, HF radars).

In this study, the objectives are to quantify the SSH signature of dedicated coastal processes in the NWMed and to analyse the spatio-temporal scales associated. We focus on the Northern Current (or NC, less than 60 km wide) which flows cyclonally along the Italian, French and Spanish coasts. We use a high resolution numerical model (Symphonie) which is first validated against independant in situ datasets. Then it is used to quantify the SSH signature of the NC at two distinct locations along the French coast. We then compared the results obtained with the spatio-temporal variations observed in satellite altimetry data and quantify and study the differences. We also analyze the origin of the differences observed between different types of in situ current observations and altimetry data : their respective spatial/temporal resolution, track orientation, differences in location, geostrophic vs total current component,... Finally, this study also allows us to understand the intrinsic differences obtained from different types of ocean current observations.

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### **Extreme Sea Level in the Coastal Zone – Pathway to Improved High-Temporal-Resolution Gridded Sea Level Product over the Baltic Sea**

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Storm surges are a major threat to coastal societies. To use satellite observations to observe storm surges directly, satellite tracks have to coincide with these events. Such coincidences have occurred, for example Cryosat passed over Denmark during the Bodil/Xaver/Sven storm in December 2013, capturing the storm surge event. Hence, we know that the potential for improving modeling and forecast exist, but the current ability to study extreme sea level events using satellite altimetry relies on the random chance that these events coincide with a satellite passing by. To get around this, satellite altimetry data have previously been blended with tide gauge data, using least squares regression with stationary statistical patterns, and assimilated into a sea level model of the Baltic Sea. This improved the overall sea level, but exposed the challenges with extreme sea level events. Extreme sea

level events, or storm surges in cases of high sea level, are short-term events occurring irregularly, and were not well captured by the stationary statistical patterns. To use satellite observations to improve storm surge modeling and forecast, satellite tracks have to coincide with these events. Such coincidences have occurred, for example did Cryosat pass over Denmark during the Bodil/Xaver/Sven storm in December 2013, capturing the storm surge event in Denmark. Hence, the current ability to study extreme sea level events using satellite altimetry relies on the random chance that these events coincide with a satellite passing by. This we aim at improving in the Baltic SEAL project, by developing a high-temporal-resolution (1-3 days) gridded product of the Baltic Sea, combining altimetry observations with tide gauge data using optimal interpolation, with focus on extreme sea level events. Here we will present the current status and preliminary work on this high-resolution product.

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**The first four years of Sentinel-3 Altimetry – The latest Reprocessing**

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Sentinel-3 is part of a series of Sentinel satellites responsible for taking care of a continuous ‘health check’ of the Earth planet under the umbrella of the Copernicus program. The Copernicus program will launch four Sentinel-3 satellites (from A to D) to achieve this goal from 2016 to 2035. EUMETSAT’s Marine Centre is responsible for the processing of the Sentinel-3 science data in the marine environment.

Since Spring 2016 Sentinel-3A’s SRAL Synthetic Aperture Radar Altimeter has been successfully contributing to the continuity of the sea level climate data record

This presentation will provide an overview of the latest evolutions of the Sentinel-3 SRAL processing, the relations between Sentinel-3A and -3B processing, and the strategy that EUMETSAT has adopted to provide the consistent long-term data set while continuing to evolve and improve the processing algorithms and standards.

The latest reprocessing is the baseline for a quality analysis of the Sentinel-3A Marine Centre data in a multi-mission setting. The latter shall allow for revisiting the status of the Jason-3 and Jason-2, in comparison with Sentinel-3A. To this goal this presentation aims at: providing multi-mission time series of the main climate records (sea level, significant wave height and wind speed); quantifying cross-overs (mono- and multi-mission); as well as provide over 4 years of global assessment of SAR mode versus Pseudo-LRM.

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**The Sea-level Budget on the Northwestern European Shelf in the Satellite Era**

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The observed sea-level change (SLC) is a response of different processes acting on different temporal and spatial scales. SLC on multi-decadal to century timescales is mainly the product of barystatic and steric variations (Gregory et al., 2019). Sea-level budget (SLB) studies compare the sum of the different components to the total observed SLC. When the sum of the different components is equal to the observed SLC, the budget is considered closed. The high-precision and resolution measurements of the satellite era – from 1993 until present – have allowed to close the global SLB for this period (Cazenave et al., 2018). However, despite the big advances in the field, the regional SLB under investigation. The improved spatial coverage of satellite altimetry missions is vital to investigate the regional SLB closure consistently for the entire world. On the other hand, the quality of the altimetry data in coastal areas is limited due to land contamination of the signal, and subject of the uncertainty of the models used to correct wind and tides variations. More recent altimetry missions (e.g. Cryosat-2, Sentinel-3) have improved the analysis of sea-level trends in coastal regions (Idzanovic et al., 2017).

In our overarching aim to close the SLB regionally on a global scale, we here focus on the Northwestern European Shelf as a case study. Sea-level change in this region has been extensively studied in the last years, especially in the North Sea (e.g. Slangen et al., 2014; Frederikse et al., 2016; Sterlini et al., 2017), but most studies relied on tide gauge network data, which do not provide a complete spatial view. Sterlini et al. (2017) explained the sea-level rise in the North Sea using altimetry data, however they focused only on open ocean to avoid the coastal limitations of the data. We use merged multi-mission altimetry products from AVISO and SL\_cci to characterize sea-level variations in the NWE shelf, focusing on how such products perform in coastal regions. We used the temperature and salinity data from EN4.2.1 (Good et al., 2013) to obtain the steric sea-level change. We complement our analysis investigating how the use of different noise-models (Bos et al., 2013) can influence and the trend and which uncertainties this can bring to the SLB. We find that the observed total and steric SLC have a trend of 2.642 mm/yr and 1.561 mm/yr from January of 1993 to December of 2017. Areas too close to the coast are not covered by the satellite time-series. We believe that by including coastal altimetry products, we can improve the quality of our budget study.

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