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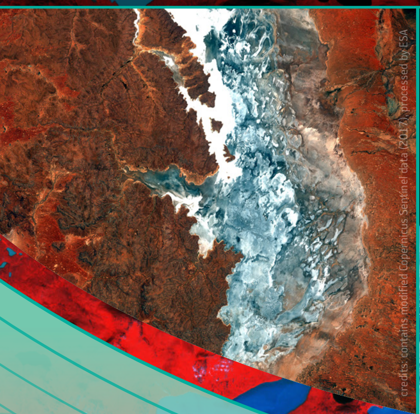
4th SENTINEL-2 VALIDATION TEAM MEETING

15–17 March 2021 | Virtual Event



ABSTRACT BOOK

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Abstract Book

4th Sentinel-2 Validation Team Meeting 2021

15 March-17 March 2021

Virtual Event

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Organising Committee

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Session #1 Level-1 Radiometry Validation

Level-1 Radiometric Calibration and Validation Status from the Copernicus Sentinel-2 Mission Performance Center

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This presentation provides a status of the Sentinel-2 radiometric calibration and validation activities, performed by the Copernicus Sentinel-2 Mission Performance Centre (MPC).

Nominal calibrations are based on the exploitation of the on-board sun diffuser images (for absolute radiometric and relative gain calibration) and images acquired over ocean at night (for dark signal monitoring and calibration). The on-board sun diffuser is a full field/full pupil diffuser, called the Calibration and Shutter Mechanism (CSM), the advantage of which is to provide the instrument with a very uniform and well-known signal, allowing very accurate absolute and relative radiometric calibrations. After each monthly sun-diffuser acquisition, a new set of absolute calibration and relative gains calibration parameters are generated.

The validation activities assess all radiometric performances related to image quality requirements: absolute radiometric uncertainties, multi-temporal and inter-bands relative radiometric uncertainties, instrument response non-uniformity, signal-to-noise ratio (SNR) and modulation transfer function (MTF). Vicarious methods are used for the absolute radiometry validation and the multi-temporal and inter-bands relative radiometry validation. Absolute radiometric performance is assessed as well through cross-missions inter-comparisons. The instrument response non-uniformity is estimated through the Fixed Pattern Noise (FPN) and Maximum Equalisation Noise (MEN) which quantify local non-uniformities in the responses of physical detector pixels across the swath. SNR is assessed at different radiance levels using the on-board sun-diffuser device and dark product acquisitions using a 2-parameters instrument noise model (per pixel). MTF validation relies on MTF assessment using the well-known edge method.

Results obtained show the good radiometric performances of the mission products, thanks to a robust in-flight calibration strategy. Indeed, the radiometry is both accurate (<5% absolute uncertainty) and stable (no detectable trend).

However, monitoring of the calibration coefficients shows seasonal oscillations for both sensors on the absolute and relative gain coefficients. These effects seem to be induced by the sun-diffuser BRDF model. The seasonal oscillations can reach up to 0.3% peak-to-peak over the time series of absolute calibration coefficients of MSI-B. For pixels of the B12 band, the variation of relative gain coefficients for some pixels can reach up to 1% over an annual cycle.

Also, the radiometric validation suggests that MSI-A measured reflectances are slightly brighter that MSI-B ones by about 1% over the VNIR bands.

Possible approaches to remove these oscillations and the bias are currently under consideration..

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Sentinel-2 Radiometric Calibration and Validation Activities Performed by CNES

Rodat D.[1], *Languille F.[1], Nosavan J.[1], Lenot X.[2], Peschoud C.[2], Marcq S.[1], Desjardins C.[1], Lonjou V.[1], Meygret A.[1], Miquel C.[3], Soleilhavoup I.[1], Guilleminot N.[4]*

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After the commissioning phase of the Sentinel-2 satellites, the French space agency (CNES) is also involved in the routine image quality validation of this mission. CNES gives support to the European Space Research Institute (ESRIN) and the Sentinel-2 Mission Performance Centre (S2-MPC) on both the geometric and radiometric aspects.

Regarding the radiometric validation, the calibration is monitored by five vicarious methods: pseudo-invariant calibration sites (desert and Antarctic sites), deep convective clouds, Rayleigh scattering and instrumented sites. The methodology and the associated limitations are presented. Based on these methods, the cross-calibration with other missions (such as Sentinel-3) as well as the cross-calibration

between the two Sentinel-2 satellites are evaluated. These multi-temporal and multi-mission radiometric comparisons are valuable to users namely to leverage several data sources in their studies.

On the geometric aspects, the upcoming geometry refinement based on a Global Reference Image (GRI) will improve the product quality, especially the geolocation consistency between all products. The presentation will focus on the opportunities to use these enhanced products as a reference for other missions studied by CNES.

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Sentinel-2 L1C-Radiometry Validation using RadCalNet dataset and DIMITRI-toolbox

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The Radiometric Calibration Network (RadCalNet) has been established by the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) Infrared and Visible Optical Sensors Subgroup (IVOS) in 2013 and is open to public since July 2018. The RadCalNet consists of four international test sites providing automated in situ measurements and estimates of propagated top-of-atmosphere (TOA) reflectance (Bouvet et al. 2019).

This work uses more than 100 overpasses from RadCalNet over Gobabeb-Namibia (GONA), La Crau-France (LCFR) and Railroad Valley Playa-USA (RVUS) to evaluate the Sentinel-2 radiometry calibration of L1C-products. The Sentinel-2 TOA-reflectance time-series are extracted using DIMITRI-Toolbox.

This analysis confirms the viewing angle effect in the Sentinel-2 data at the RVUS and LCFR sites, which has been observed by Alhammoud et al. (2019) and Jing et al. (2019). The correction of the directional effect following later work improves the results over the ratios of the individual orbits by up to 5% -10%, while the average ratios has been improved by barely about 1%. However a good consistency over the three sites could be observed.

The intercomparison results illustrate the relevance of RadCalNet dataset for the vicarious validation activity.

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Monitoring Sentinel-2 MSI Radiometric Stability and Calibration with Landsat-8 OLI

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The Landsat Calibration and Validation Team, with team members at NASA/GSFC and USGS/EROS, has used the released data products to track and monitor the Sentinel-2 calibration, with an eye towards Landsat users. By regular trending of the pseudo-invariant calibration sites (PICS), the stability of Landsat-8 OLI and Sentinel-2A/B MSI instruments can be monitored to within a few percent for the spectral bands they have in common.

For several of the PICS, the Landsat-8 OLI and Sentinel-2 MSI instruments image the sites within 20 minutes of each other every 80 days. These near-simultaneous overpasses allow for a direct comparison of top-of-atmosphere reflectance. Comparisons have been made between near-simultaneous cloud-free acquisitions of Libya-4 and Algeria-3 with Landsat-8 and Sentinel-2A and near-simultaneous acquisitions of Algeria-5 and Egypt-1 with Landsat-8 and Sentinel-2B. The reflectances of the MSI are corrected to equivalent OLI reflectance based on a Hyperion-derived Spectral Band Adjustment Factor (SBAF).

Historically, the comparison shows that for the bands that OLI and MSI have in common, the Sentinel-2A MSI agrees with OLI to within 1% in all bands. The agreement between Landsat-8 and Sentinel-2B is not as good; the CA and Blue bands differ by 2.5-3% and the other common bands differ by 0.5-1.5%.

Using Landsat OLI as the reference sensor, the two MSI instruments can be compared directly. This comparison indicates that the CA and Blue bands different by 2-3% different and the other bands are different by 0.5-1.7%. The analysis will be updated with data from the last year in the coming weeks.

As part of the Landsat Collection-2 release, the Landsat ground reference was updated using the Sentinel-2 Ground Reference Image (GRI) dataset to improve the co-registration between the Landsat and Sentinel-2 products. Since late 2020, the entire Landsat archive has been reprocessed using the updated Landsat geometric reference. The improved registration between Landsat and Sentinel products will be assessed in the coming weeks.

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Monitoring the Intercalibration of L8/OLI with S2A/MSI over Lybia4 PICS in the frame of PICSCAR CEOS/IVOS initiative

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PICSCAR Initiative covers different activities which the main one focuses on the improvement of Pseudo Invariant Calibration sites (PICS) characterization because PICS are used to evaluate the long-term stability of an instrument and to facilitate inter-comparison of multiple instruments.

A web site is dedicated to the capitalization of the information collected over 6 PICS has been created. It contains radiometric and spectral characteristics on the six sites which are located in Lybia, Mauritania, and Algeria. In a first phase, data were collected over Lybia 4 site from 12 sensors in order to assess the site stability. The site also contains service for users such as a tool for assessing the stability of the reflectances over Libya4.

Following the successful assessment of time series stability, a focus has been done on the intercalibration of L8/OLI with S2A/MSI over Libya 4 Small site in collaboration with CNES and SDSU. The service is operational and updates of radiometric inter calibration results are made each 6 months. The service and the results will be presented.

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FLARE Network Absolute Validation & Performance on Sentinel 2A/2B

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The FLARE Network represents a ground-based calibration and validation system able to deliver spatial, geometric, radiometric, and geodetic information in a single event across multiple Earth Observation platforms and ground sample distances. We present a brief outline of system functions and latest developments in operational status and capabilities. We further detail methods, results and interoperable measurements for our traceable uncertainty performance validation, centered on Landsat 8 and Sentinel 2A/B. Full operational coverage and performance from 350-2400nm will be discussed, as will successful operation with hyperspectral missions including PRISMA and commercial platforms including Planet and MAXAR constellations. Finally, we will provide a roadmap to ongoing projects and research publication efforts coming in calendar year 2021.

Session #2 Level-1 Geometry Validation

Status of the Sentinel-2 Geometric Refining Using the Global Reference Image

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[1]*CS Group, Toulouse, France,* [2]*Acri-ST, Sophia-Antipolis, France,* [3]*IGN, Toulouse, France,* [4]*Thales Alenia Space, Cannes, France,* [5]*Airbus Defence and Space, Toulouse, France,* [6]*Rhea Group, Frascati, Italy,* [7]*European Space Agency, Frascati, Italy*

As part of the Copernicus programme of the European Union (EU), the European Space Agency (ESA) has developed and is currently operating the Sentinel-2 mission that is acquiring high spatial resolution optical imagery. Calibration and validation activities are performed on behalf of ESA by the Mission Performance Center (MPC).

The current geometric calibration strategy relies on the optimization of geometric calibration coefficients used by the geolocation processing on-ground. More precisely, the processing corrects for biases in roll, pitch and yaw between the nominal and real orientation of the instrument reference alignment bias. This calibration approach along with a close monitoring has maintained a good geometric performance level, either for absolute geolocation or multi-spectral registration. However, consistency of the image time-series still needs to be improved. A synthesis of the geometric validation performed by MPC will be presented.

In the near future, a new calibration approach using the Sentinel-2 Global Reference Image (GRI) will be introduced in the operational processing chain. With this approach, as all images will be co-registered on-ground to the same reference image, it is expected to provide a multi-temporal performance between refined products better than 0.5 pixel CE@95%. In this presentation, we will recall the concept of the GRI, its validation and how it will be used in the processing chain.

These last months, testing activities have been performed by the MPC in preparation to the Transfer-To-Operation (TTO) of the Sentinel-2 processor implementing the geometric refinement with the GRI. Outcomes of this validation campaign will be presented.

Connecting S2 satellite time series to Spot World Heritage data

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The Spot world Heritage archive is composed of nearly 30 million images acquired by the SPOT satellite family since 1986. These images are made available at L1C orthorectified radiances level over France and West Africa. They are currently processed by CNES and distributed by the Theia web site.

Access to the CNES archive (www.regards.fr) is possible but the data are provided at Level 1A, i.e. corrected from distortions due to differences in sensitivity of the elementary detectors of the viewing instrument. Users need to perform their own geometric processing to make the images superimposable. While waiting for the processing of the CNES archive to be finished into a level 2A, a service (SWH-CARTO-2A) is opened to project SPOT World Heritage 1A products on Earth from Level 1A to Level 2A Carto. Additional metadata is available for products conversion into TOA reflectances.

The service provides standard terrain corrected product (SWH-2A-Carto products) where the altitude and spatial resolution are set up by the processing in a cartographic projection. With the addition of data georeferencing, the archive could be connected to any sensors with equivalent spatial resolution, in particular S2A and S2B.

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Session #3: Level-2A Validation

Sentinel-2 Level-2 processing: Sen2Cor status and outlook for 2021 Products

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[1]*Telespazio France - A Leonardo / Thales Company, Toulouse, France,* [2]*DLR - German Aerospace Center - Remote Sensing Technology Institute, Berlin, Germany,* [3]*Telespazio Germany - A Leonardo / Thales Company, Darmstadt, Germany,* [4]*CS Group, Toulouse, France,* [5]*RHEA Spa, Frascati, Italy,* [6]*ESA - European Space Agency, ESRIN - European Space Research Institute, Frascati, Italy*

The Copernicus Sentinel-2 mission is fully operating since June 2017 with a constellation of two polar orbiting satellite units. Both Sentinel-2A and Sentinel-2B are equipped with an optical imaging sensor MSI (Multi-Spectral Instrument) which acquires high spatial resolution optical data products. The Sentinel-2 mission is dedicated to land monitoring, emergency management and security. It serves for monitoring of land-cover change and biophysical variables related to agriculture and forestry, monitors coastal and inland waters and is useful for risk and disaster mapping.

Accurate atmospheric correction of satellite observations is a precondition for the development and delivery of high-quality applications. Therefore, the atmospheric correction processor Sen2Cor was developed with the objective of delivering land surface reflectance products. Sen2Cor is designed to process single tile Level-1C products, providing Level-2A surface (Bottom-of-Atmosphere) reflectance product together with Aerosol Optical Thickness (AOT), Water Vapour (WV) estimation maps and a Scene Classification (SCL) map including cloud / cloud shadow classes for further processing.

Sen2Cor processor can be downloaded from ESA website as a stand-alone tool for individual Level-2A processing by the users. It can be run either from command line or as a plug-in of the Sentinel-2 Toolbox (SNAP-S2TBX).

In parallel, ESA started in June 2017 to use Sen2Cor for systematic Level-2A processing of Sentinel-2 acquisitions over Europe. Since March 2018, Level-2A products are generated by the official Sentinel-2 ground segment (PDGS) and are available on the Copernicus Open Access Hub.

The objective of this presentation is to provide users with an overview of the Level-2A product contents and up-to-date information about the data quality of the Level-2A products (processing baseline >= PB.02.12) generated by Sentinel-2 PDGS since May 2019, in terms of Cloud Screening and Atmospheric Correction.

In addition, the presentation will give an outlook on the upcoming updates of Sen2Cor which will improve L2A Data Quality: updated L2A metadata, updated scene classification, updated fall-back method using meteorological information from the Copernicus Atmosphere Monitoring Service, updated Copernicus Digital Elevation Model (DEM).

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Comparison of the Copernicus Sentinel-2 L2A Core Product distributed by ESA and the Sen2Cor Toolbox 'user-generated' product

Pflug B.[1], *Louis J.*[2], *Debaecker V.*[2], *Mueller-Wilm U.*[3], *Quang C.*[4], *Iannone R. Q.*[5], *Gascon F.*[6], *Boccia V.*[6]
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Sen2Cor is a Level-2A (L2A) processor whose main purpose is to correct mono-temporal Copernicus Sentinel-2 (S2) mission Level-1C (L1C) products from the effects of the atmosphere in order to deliver radiometrically corrected Bottom-of-Atmosphere (BOA) data. Byproducts are Aerosol Optical Thickness (AOT), Water Vapour (WV) and Scene Classification (SCL) maps. The Sen2Cor Toolbox can be downloaded from the ESA website for autonomous processing of S2 L1C data by the users, thus generating BOA products here referred as 'user' products. In parallel, Sen2Cor is used for systematic processing of Sentinel-2 L1C data thus generating the S2 L2A products systematically distributed to users. Operational global L2A processing with the integration of Sen2Cor in the Sentinel-2 Ground Segment started in December 2018. These S2 L2A core products can be downloaded from the Copernicus SciHub.

The S2 L2A core products agree with 'user' products as long as both are generated with the same Sen2Cor version and configuration. However, sometimes new versions of Sen2Cor Toolbox are released to public at a different time than their implementation in the S2 Ground Segment processing chain. This may result in a disagreement between 'user' and core products for some time. Additionally, differences between the outcome of the two processing lines can arise due to the DEM used and different minor patches included. Patches are usually included faster in the ESA-L2A core products. Whereas ESA-L2A core products have been using Planet-DEM for a while, the current DEM available to the users is SRTM-DEM. However, the new Copernicus DEM is now available also to users and is going to be used also to generate the S2 L2A core products, this limiting those differences.

Both production lines are compared for what concerns AOT and WV maps, and BOA outputs per band. Both AOT and WV retrievals are validated by comparison with reference data provided by AERONET sunphotometers. Comparison of BOA outputs is performed by statistical metrics for pixel-by-pixel differences between both processing lines over 9 km x 9 km areas. The influence of the different DEMs on resulting BOA will be discussed.

ESA-L2A core products are generated with default configuration values, which are suitable for most situations of this operational mission. 'User' production gives the opportunity to apply individual configuration settings, which may prove favourable in some cases. This will be demonstrated on a few examples.

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Topography processing in Sen2Cor - Impact of horizontal resolution of Digital Surface Model

Louis J.[1], *Debaecker V.*[1], *Pflug B.*[2], *Mueller-Wilm U.*[3], *Quang C.*[4], *Quirino Iannone R.*[5], *Gascon F.*[6], *Boccia V.*[6]
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Since the beginning of the Sentinel-2 mission, the digital surface model “PlanetDEM 90” from Planet Observer is used as source of Earth topography information, within the Sentinel-2 PDGS. It is at 90-meter resolution, based on SRTM data filled and corrected for 40% of Earth surface. However, until now most users had only access to original SRTM data to run with Sen2Cor or had to provide their own DEM following SRTM or DTED formats.

The objective of this presentation is to provide users with an overview of how Sen2Cor makes use of the topography information to improve the quality of the cloud screening and scene classification as well as in the atmospheric correction and terrain correction.

In addition, the presentation gives an outlook on Sen2Cor working with the upcoming Copernicus DEM, a new Digital Surface Model (DSM), which represents the surface of the Earth, including buildings, infrastructure and vegetation. This DEM is derived from an edited DSM named WorldDEM. The presentation shows the different L2A surface reflectance obtained with PlanetDEM 90, global Copernicus DEM at 30 m and at 90 m horizontal resolution, and some of these differences are discussed.

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Atmospheric Correction Inter-Comparison Exercise II

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Free and open data access policy to Landsat-8 and Sentinel-2 satellite imagery has stimulated the development of atmospheric correction (AC) processors for generating Bottom-of-Atmosphere (BOA) products. Several entities have started to generate (or plan to generate in the short term) BOA reflectance products at global scale for Landsat-8 and Sentinel-2 missions. To this end, the European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) have initiated the Atmospheric Correction Inter-Comparison eXercise (ACIX) in the framework of the CEOS Cal/Val Working Group.

ACIX is an international collaborative initiative to inter-compare a set of atmospheric correction (AC) processors for moderate-spatial resolution optical sensors (at 10-30 m). The first ACIX experiment started in June 2016 with the aim to bring together developers of the state-of-the-art atmospheric correction (AC) processors and study the variations amongst the different approaches. The input data were Landsat-8 and Sentinel-2A imagery over various sites of different land cover types around the world, i.e. agricultural, deserts, urban, snow and coastal areas. The description and conclusions of this first experiment are summarized in (Doxani et al., 2018). All the inter-comparison results can be found in the dedicated to ACIX I web site at the CEOS Cal/Val portal.

The enhancements of the participating processors in ACIX I and the increasing interest from additional AC developers to be part of the experiment stimulated the continuation of ACIX and its second implementation (ACIX II). Similarly to the first exercise, ACIX II focuses on Landsat-8 and Sentinel-2 imagery over a set of test areas. Concerning Sentinel-2, the products of both -2A and -2B missions are included in the input datasets. The test sites of ACIX II have been redefined and more representative cases, concerning land cover and aerosol types, are included comparing to the ones of ACIX I. Particular attention is also given to aquatic sites, i.e. coastal and inland waters, which were analyzed as a separate sub-category.

Following the recommendations of ACIX participants and Earth observation data users, an additional inter-comparison of cloud cover assessment was performed in parallel with ACIX, named Cloud Masking Inter-comparison eXercise (CMIX). Cloud screening is a crucial step of the radiometric pre-processing of optical remotely sensed data and an important uncertainty contributor to the retrieval of accurate surface reflectance within an atmospheric correction process. Therefore, it was considered essential to analyze these two processing chains concurrently.

The presentation will describe in details ACIX-II (land) and CMIX and discuss early results and lessons learned.

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CMIX: The Cloud Masking Inter-comparison eXercise

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Cloud screening is a crucial step in the radiometric preprocessing chain of optical remotely sensed data. Besides it is an important contributor to the retrieval of accurate surface reflectance within an atmospheric correction process. In this context, European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) initiated the Cloud Masking Inter-comparison Exercise (CMIX) in the frame of CEOS WGCV (Committee on Earth Observation Satellites, Working Group on Calibration and Validation). The exercise focuses on the comparison of cloud detection algorithms, when applied on Sentinel-2 and Landsat-8 imagery. In particular, 10 cloud masking algorithms participated in the exercise, implementing a variety of approaches, incl. classical mono-temporal spectral tests, machine learning and multi-temporal analysis, for the classification of the clouds. Their performance was assessed with the help of five validation datasets, which were acquired either manually or automatically based on machine learning. The detailed description of the exercise and the estimated performance metrics will be presented together with the next steps for improving CMIX in its next implementation.

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Comparison of Masks of Fmask, ATCOR and Sen2Cor

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Thirty-two Sentinel-2 scenes with a worldwide global coverage were processed by three masking algorithms (Fmask5, Sen2Cor version 2.8.0, and ATCOR version 9.3.0) using the following six classes: clear, semi-transparent cloud, cloud, shadow, water, and snow/ice. The evaluation is performed with the default global settings, i.e. without parameter tuning per scene. All Sentinel-2 bands are resampled to a common 20 m resolution. In case of mountainous terrain the 1 arc-sec (30 m) SRTM Digital Elevation Model (DEM) is used and also resampled to 20 m.

The comparison was performed qualitatively based on visual interpretation. The results show a similar performance of ATCOR and Sen2Cor, with larger differences to Fmask5. The presentation highlights the advantages and limitations of each processor and compares the performance of some critical scenes by selecting areas that are difficult to classify. Although no statistical, quantitative comparison with reference masks is available, all results still show a consistent trend and allow an assessment of the advantages and drawbacks of each processor

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Validation of Sentinel-2 surface reflectances on ROSAS test sites

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Consistent and accurate surface reflectance (SR) products are a prerequisite to quantitative optical remote sensing applications, and require quality assessment of the atmospheric correction processors. The Atmospheric Correction Inter-comparison Exercises, ACIX I and the later ACIX II, jointly organized by ESA and NASA to evaluate the performance of up to 12 processors, mainly relied on a reference SR dataset computed with the 6S radiative transfer code using AERONET measurements. It marginally involved direct validation of surface reflectance with in-situ measurements from two RadCalNet station implemented by CNES (CEOS WGC).

CNES and CESBIO, who continuously develop the MAJA cloud detection and atmospheric correction processor since 2006 (with some contributions from DLR), have devoted a large part of their efforts to the implementation of validation methods and criteria. Since 1997, CNES has set up a Robotic Station for Atmosphere and Surface characterization (ROSAS) on the La Crau site (Southern France). ROSAS is composed of a complete instrumental and post-processing protocol to derive atmospheric and land surface properties, with a particular emphasis on SR and BRDF. Another ROSAS station was then implemented in Gobabeb (Namibia) in 2017, in cooperation between CNES and ESA. Both sites show extremely homogeneous land cover, with pebbles and grass for La Crau, and arid desert sand in Gobabeb.

These sites are perfect for absolute calibration purposes, but correspond to easy cases regarding surface reflectance validation. Early 2021, CESBIO should complete the installation of a new ROSAS station in the Lamasquere experimental site (FR-Lam), a farmland in the South western France. FR-Lam is a class 1 site in the ICOS ERIC which is already heavily equipped with radiation, meteorological and soil sensors. The key objective of this new ROSAS station will be to characterize a vegetated site with a strong inter-seasonal and inter-annual variability of SR and BRDF, combined with adjacency effects from nearby forest plots.

After a discussion on the benefits of existing SR datasets in the evaluation process of the on-going ACIX II analysis, and a focus on MAJA evaluation with regards to ACIX II criteria, a detailed view of the new Lamasquere ROSAS station will be presented together with highlights on studies opportunities.

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The hyperspectral Mission DESIS - Validation of L2A products using Sentinel-2 and RadCalNet data

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The hyperspectral instrument "DLR Earth Sensing Imaging Spectrometer" (DESIS) was integrated into the "Multi-User System for Earth Sensing" (MUSES) platform, on-board of the International Space Station (ISS), on August 2018.

Developed within a collaboration between the US company Teledyne Brown Engineering (TBE) and the German Aerospace Center (DLR), DESIS is in operational phase since October 2019.

This contribution will present a summary of the activities carried out by the DESIS Ground Segment for the validation of the L2A products.

DESIS L2A processor is based on the PACO DLR software package for atmospheric correction, which process also Sentinel-2 data.

The investigations during and after the commissioning phase showed that requirements were met and confirmed the results from laboratory measurements.

The validation results will be focused on the radiometric comparison (TOA and BOA) with Sentinel-2 data and on-ground measurements from the Radiometric Calibration Network (RadCalNet).

Using the aforementioned data sources at TOA and BOA levels, the quality of the DESIS BOA data can be addressed in both relative and absolute ways.

The inter-comparison between DESIS data and Sentinel-2 data has also been used for the vicarious calibration of the DESIS sensor.

The results of this study show a good level of agreement, both at TOA and BOA levels, between Sentinel-2, DESIS, and RadCalNet; demonstrating a consistent radiometric and spectral calibration of the space-borne sensors, as well as a good level of consistency in the atmospheric correction.

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Validation of Sentinel-2 Surface Reflectance Imagery Over Grosseto, Italy Using Hyperspectral Airborne Data From the 2018 FLEX Campaigns

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Surface albedo is a fundamental radiative parameter as it controls the Earth's energy budget and directly affects the Earth's climate. A new method is introduced to upscale surface albedo retrieved from tower albedometer measurements to coarse satellite resolutions using high-resolution Sentinel-2 data. Surface albedos, including both directional hemispherical reflectance (DHR) and bi-hemispherical reflectance (BHR), are retrieved from tower albedometer radiation measurements using the approach described in [1]. The upscaling process uses Sentinel-2 surface reflectance retrievals to fill the spatial gaps between the albedometer's field-of-view (FoV) and coarse satellite scales. Sentinel-2 surface albedo products are generated by combining Sentinel-2 surface reflectance data and MODIS bi-directional reflectance distribution function (BRDF) climatology data. A novel atmospheric correction method, the Sensor Invariant Atmospheric Correction (SIAC) [2], is employed to retrieve surface reflectance from Sentinel-2 top-of-atmosphere (TOA) reflectance measurements. Atmospheric correction of Sentinel-2 data has been demonstrated to be vastly improved using SIAC when compared against sen2cor by using in situ AERONET data. The upscaled albedo products can then be compared with space-based albedo products, including Copernicus Global Land Service (CGLS) based on ProbaV and VEGETATION 2 data, MODIS and multi-angle imaging spectroradiometer (MISR), over both homogeneous and heterogeneous land surfaces. In addition, the existing method allows for large area (10 x 10km) surface albedo maps to be produced at resolutions up to 10m, example of which will be shown at the Hainich and Tumbarumba sites

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Error analyses of the S2 L2 reflectances using in-situ Radcalnet directional reflectances and Irradiance measurements

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Validation processes require in-situ measurements. The qualification of the validation results is often performed using traditional and simple statistical analyses such as e.g. Accuracy, Precision and Uncertainty measurements (A,P,U).

Beyond this traditional result analysis, one may try to define in this presentation a strategy for: i/identify and characterise the errors and ii/ identify some potential improvements for the studied model (here the atmospheric correction model).

In this presentation we firstly validate the Sen2Cor 2.9.0 2018-19 surface reflectances using i/ the Radcalnet Lacrau and Gobabeb sites and ii/ irradiance measurements over Australia. Radcalnet represents currently the best dataset for surface reflectance validation as it gathers the most precise directional radiance measurements over lands. Nevertheless, one must keep in mind that the Radcalnet measurements are performed over arid or semi-arid areas, meaning that it does not represent the whole observed variability in terms of surface coverages, especially concerning the vegetation. Over the vegetation, directional reflectances are not often available, but, many irradiance measurements exist. Such integrated measurements in wavelengths and geometry should also be considered.

In the second part of the presentation, we characterise the errors over the two selected Radcalnet stations. For this, we investigate linear error models as a function of the forcing parameters, namely the geometry of acquisition and the atmospheric conditions:

Error_BXX=c_0+c_1.thetas +c_2.thetav +c_3.dphi +c_4.AOD +c_5.O3 +c_6.WV +c_7.Pressure

Using the Akaike criterion, we keep only the significant forcing parameters from a statistical point of view (pval<0.05). At Lacrau we show that we can correct up to 40% of the errors using the sun angle, the ECMWF aerosol concentration and the relative azimuth. At Gobabeb the analysis shows that the variance of the errors is mainly explained by the atmospheric pressure (Gobabeb is located at 520 m altitude).

These error analyses show some paths to investigate for some potential improvements of the L2 processor: some possible aerosol modelling issues at Lacrau, typically wrong aerosol model selection and possible Rayleigh correction issues (i.e. surf. pressure) at Gobabeb.

In the last part of the presentation we perform some error analyses above the vegetation and using both BRDF and albedo estimations. While the estimated surface albedo (from the S2 L2) fits well the in-situ data, the estimated BRDFs vs the S2 reflectances show some discrepancies in the blue. We try to analyse such differences and give some interpretations for the S2 L2 estimated blue band over this vegetated area.

1. Bozdogan, H. (1987). Model selection and Akaike's information criterion (AIC): The general theory and its analytical extensions. Psychometrika, 52(3), 345-370.

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A Holistic Perspective on the Calibration and Validation of Sentinel-2: Contribution From the CCVS Project

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In this presentation, we report on the preliminary findings of the H2020 project “Copernicus Cal/Val Solution” (CCVS), whose objective is to define a holistic solution to the cal/val of the Copernicus Sentinel missions. We focus more specifically on synergies of the Sentinel-2 mission with other Sentinel or third-party missions, in terms of cal/val requirements as well as reference data sources.

Regarding the first aspect, CCVS will consolidate cal/val requirements for all missions with a unified approach. For instance, we compare validation requirements for Sentinel-2 L2A AOD and Water Vapour products to other optical missions like Sentinel-3 OLCI and SLSTR, as well as atmospheric composition missions. In addition, user-driven inter-operability requirements could lead to specific calibration or validation needs. A first example concerns the radiometric inter-calibration between Sentinel-2A and B, which could be ensured with better accuracy than the absolute calibration of either satellites. Geometric co-registration with other optical missions like Landsat could be also monitored.

In terms of data sources, CCVS will first establish a survey of existing sources, including natural targets and in-situ data acquired in the frame of systematic measurement programs or ad-hoc campaigns. In a second step, we investigate potential data sources needed for calibration and validation, with a specific focus on directional surface reflectance and cloud mask.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the grant agreement No 101004242.

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Sen2Cor - Sentinel-2 Level-2 Optical Processor Applied to Landsat-8 Data

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Sen2Cor is the official ESA Sentinel-2 ground segment processor for the generation of the Sentinel-2 Level 2A core products from the Level 1C top of atmosphere reflectance in fixed cartographic geometry.

Sen2Cor can also be downloaded from the ESA website as a standalone tool for individual Level 2A processing by the users. It can be run either via command line or as a plugin of the Sentinel-2 Toolbox (SNAP-S2TBX).

The Sentinel-2 A/B Level 2A products are bottom of atmosphere reflectance in cartographic geometry, which are widely distributed to the users since March 2018 over Copernicus Open Access Hub and Sentinel Hub.
In this study, we test the capability of the Sen2cor algorithm for scene classification and atmospheric correction to be able to perform Landsat-8 Level 1 input data processing. Both instruments have eight overlapping spectral bands and the measurements are often used complimentarily for studies of vegetation and land parameters. However, there are also distinct differences between the two sensors, such as spectral bands response, calibration and viewing geometries, which are reflected in the differences between the L1 products. In the bands arrangements of Landsat-8, the water vapor band is missing. These have to be taken into account in the modification and upgrade of the Sen2Cor algorithm.
The ability of Sen2Cor to process Landsat-8 scenes in the same manner as the Sentinel-2 ones is of interest for the Sen2Like framework, which is detailed by Telespazio France on a parallel presentation at this workshop. This will allow Sentinel-2 and Landsat-8 TOA reflectance to be converted to surface reflectance using the same atmospheric correction algorithm and a radiative transfer model adapted to the Landsat conditions. We address the necessary algorithmic modifications and the uncertainty due to the Level 1 to Level 2 processing methodology. A qualitative comparison of both Sen2Cor generated products and comparison to the Landsat-8 LaSrc products from USGS is also presented.

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Validation of "Phase 1" Sen2Like Products

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Sen2Like is a processor designed to produce harmonized Level 2 surface reflectance dataset considering as reference Sentinel-2 data. Sen2Like fits with the on-going and growing expectations of the Earth Observation (EO) Community for the merging of an increasing number of input data streams from the various Multi-Spectral (MS) High Resolution (HR) EO mission instruments.
The main objective of Sen2Like is the creation of seamless harmonized spatiotemporal dataset enabling 10-m pixel based analysis at regional scale. From scientific algorithm point of view, the production of Analysis Ready Data (ARD) relies on major critical steps: atmospheric corrections, spectral adjustment, and directional effect correction, radiometric cross calibration and data fusion.
Scientific and technical questions are now raised regarding the data quality of the generated spatiotemporal dataset, uncertainties associated to each processing and the way to ensure the user community that the Sen2Like products are fit for the foreseen application purposes.
This talk is the opportunity to investigate main error sources in the Sen2Like Sentinel-2 (S2)/Landsat 8 (LS8) surface reflectance measurements. The approach to validate data in term of geometric quality, radiometric quality, image quality and time series consistencies will be discussed.
A first validation has been performed by the end of the year 2020. Results confirm that with the proposed harmonization process a very good geometric co-registration accuracy is achieved (within 1/10th of the original image pixel size). In addition, the S2 / LS8 surface reflectance calibration ratio is within 3% comparing with the original top of atmosphere calibration ratio that is within 1-2%. First results regarding LS8 image fusions are promising, and show that the uncertainty is limited within 0.01 (SR). On the other hand, the assessment of temporal consistency demonstrates that the directional effects remain a major source of noise in the time series

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ACIX-Aqua: A global assessment of atmospheric correction methods for Landsat-8 and Sentinel-2 over lakes, rivers, and coastal waters

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The aquatic component of the Atmospheric Correction Intercomparison Exercise (ACIX-Aqua), a joint NASA – ESA activity, was initiated to enable a thorough evaluation of eight state-of-the-art atmospheric correction (AC) processors available for Landsat-8 and Sentinel-2 data processing. Over 1000 radiometric matchups from both freshwaters (rivers, lakes, reservoirs) and coastal waters were utilized to examine the quality of derived aquatic reflectances (ρ̂_w). This dataset originated from two sources: Data gathered from the international scientific community (henceforth called Community Validation Database, CVD), which captured predominantly inland water observations, and the Ocean Color component of AERONET measurements (AERONET-OC), representing primarily coastal ocean environments. The volume of our data permitted the evaluation of the AC processors

individually (using all the matchups) and comparatively (across seven different Optical Water Types, OWTs) using common matchups. We found that the performance of the AC processors differed for CVD and AERONET-OC matchups, likely reflecting inherent variability in aquatic and atmospheric properties between the two datasets. For the former, the median errors in ρ̂_w (560) and ρ̂_w (664) were found to range from 20 to 30% for best-performing processors. Using the AERONET-OC matchups, our performance assessments showed that median errors within the 15 – 30% range in these spectral bands may be achieved. The largest uncertainties were associated with the blue bands (25 to 60%) for best-performing processors considering both CVD and AERONET-OC assessments. We further assessed uncertainty propagation to the downstream products such as near-surface concertation of chlorophyll-a (Chla) and Total Suspended Solids (TSS). Using satellite matchups from the CVD along with in situ Chla and TSS, we found that 20 – 30% uncertainties in ρ̂_w (490≤λ≤743 nm) yielded 25 – 70% uncertainties in derived Chla and TSS products, depending on both the AC processor and the choice of retrieval algorithm. We summarize our results using performance matrices guiding the satellite user community through the OWT-specific relative performance of AC processors. Our analysis stresses the need for better representation of aerosols, especially absorbing ones, and improvements in corrections for sky- (or sun-) glint and adjacency effects, in order to achieve higher quality downstream products in freshwater and coastal ecosystems

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Validation of the CMEMS High Resolution Coastal Products

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As a new production unit within CMEMS, the high-resolution coastal service (HR-OC) will offer ocean colour products based on Sentinel-2/MSI data. The products are generated for the coastal waters (20km strip from the coastline) for all European Seas with a spatial resolution of 100m. The primary variable from which it is possible to derive all the geophysical and transparency products is the spectral Remote Sensing Reflectance (RRS). During the development phase, five atmospheric correction approaches (i.e. C2RCCv1.0, C2RCCv2.0, ACOLITE, POLYMER and iCOR (v2.5) were evaluated using the AERONET-OC network and PANTHYR system for four CMEMS regions (Baltic sea, Mediterranean sea, North West Shelf and Black sea). To achieve high quality RRS spectra for a maximum number of pixels and yet retain the ability to deal with both, unusual water conditions and very challenging atmospheric conditions, a pixel-based selection between two algorithms, C2RCC (version 1.0, normal NN) and ACOLITE/DSF, is used as the baseline L1toL2R approach. These two methods are highly complementary as ACOLITE/DSF makes no assumption about the water reflectance and can therefore achieve good results for turbid waters and even for unexpected water types (e.g., dredging plumes, unusual algae species, etc.), whereas C2RCC constrains the water reflectance to correspond to the training data, always giving a RRS spectrum that looks like water. This extra information/constraint on water reflectance, embedded within the C2RCC approach, provides greater retrieval power in the most difficult circumstances (sunglint, highly absorbing waters) by imposing a solution for RRS.

Additionally, to the RRS product, the HR-OC service will provide the Particulate Backscatter Coefficient spectrum (BBP), Turbidity (TUR), Suspended Particulate Matter (SPM) and Chlorophyll-a Concentration (CHL). These products are generated through the application of automated switching algorithms based on the RRS spectra to adapt to varying water conditions. The products will be introduced in the CMEMS service by May 2021. We will present the products themselves as well as the validation results for the different variables obtained through match-up analysis with in situ data as well as by comparison of the high resolution products with the well established Low Resolution CMEMS Ocean Colour products. Additionally, an overview of known issues when working with Sentinel-2/MSI data for coastal waters will be reported in order to provide a full picture of the new service.

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Session #4: Downstream Products Validation

Validation of S2 A and B Remote Sensing Reflectance in The Eems Estuary using WISPstation observations

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The Eems Estuary is a very dynamic area featuring highly variable turbidity and Chlorophyll-a values. There is an interest to decrease the turbidity and monitoring is being put into place to observe the current status and changes. Remote sensing using Sentinel 2 MSI observations is a candidate monitoring technique but should provide robust and validated results.

Obtaining high quality turbidity estimates starts with validated Bottom of Atmosphere reflectances.

To validate BOA reflectances a WISPstation (Peters et al., 2019) was placed on a fixed structure in open water at 53.4743N and 6.8216W from 13-11-2018 until 05-11-2019. The WISPstation contains 2 sets of sensors (Lup: 40 degrees, Lsky: 40 degrees and Ed): measurements were taken in two directions, N and NE. Some shadowing of the Ed sensors occurred and needed to be filtered out.

The hyperspectral measurements (350-1100 nm; 0.44 nm/pixel or 4.65 nm FWHM) were convoluted to MSI spectral bands using appropriate spectral response functions. Rrs was calculated using a rho retrieved from the Mobley (1999) table in combination with the similarity spectrum approach (Ruddick et al, 2006). Because the WISPstation is measuring all channels with one spectrometer, it is very unsensitive to any uncertainties in the radiometric calibration.

In total 13 cloud free S2 MSI matchup measurements could be taken (S2A/B) , some of which were later flagged out. The S2 matchup data were collected in 3x3 pixel windows and filtered.

Since the WISPstation takes a measurement every 15 minutes we were able to take validation measurements close in time to the overpass, although one of the conclusions remains that -for this area- validation at exact overpass times would be better.

We tested the C2RCC processor together with Polymer v4.10. We will show a detailed analysis of the results of these atmospheric correction processors, in terms of statistical comparison (as e.g. in Warren et al., 2019) and by looking at averaged spectral shape of the MSI Rrs spectra.

For "all datapoints" scatterplots we find R2 values of 0.56 to 0.85 with slopes from 0.54 to 0.90, indicating that the atmospheric corrections mostly underestimate the in-situ measured values with some spread.

For "band averaged" scatterplots we find variable R2 values for all processors (between 0.75 and 0.97) but -again- with slopes deviating from unity: all processors underestimate the reflectance to some extent.

Comparison between Chl-a and TSM derived from S2A/B and WISPstation at the measurement location show promising results.

This research was funded by the Dutch Ministry of Infrastructure and Water Management and the H2020 project MONOCLE (grant agreement No 776480)

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Radiometric Validation of Sentinel-2AB by Prototype WATERHYPERNET Deployments in the North Sea and Adriatic Sea

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The WATERHYPERNET network of hyperspectral radiometers is being developed for radiometric validation of satellite missions. The network will provide water reflectance data for all visible and near infrared bands of all optical imaging missions, including Sentinel-2A&B&C&D, Sentinel-3A&B&C&D, PROBA-V, MODIS-AQUA&TERRA, VIIRS, Landsat-8, Pléiades, CHRIS-PROBA, MSG-SEVIRI, PlanetDove, PRISMA … ENMAP, PACE, CHIME, SBG, MTG and ... any future optical missions, including nanosatellites. This network follows closely the AERONET-OC federation concept [Zibordi et al, 2009] but uses the TRIOS/RAMSES hyperspectral radiometer and a more extensive multi-look pointing scenario. The instrument system, called PANTHYR (Pan-and-tilt hyperspectral radiometer) [Vansteenwegen et al, 2019] consists of one radiance and one irradiance sensor on a pointing robot, controlled by a single-board computer and supplemented with GPS, inclinometer and camera data. The measurement protocol is based on the abovewater method of [Mobley, 1999 and 2015], but allows additional scenarios for different viewing zenith and azimuth configurations. The first two refined prototype systems have been deployed in the Italian Adriatic Sea (September 2019 - present) and the Belgian North Sea (December 2019 - August 2020) providing measurements every 20 mins for validation of all visible and near infrared Sentinel-2 bands (443nm to 865nm inclusive).

This presentation will provide results from these prototype tests, illustrating the usefulness for validation of Sentinel-2A and -2B and outlining the next steps as regards hardware improvements, protocol refinements and quantification of the in situ measurement uncertainties.

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Preparation of Next Generation Hyperspectral Radiometric Validation Networks for Water and Land Surface Reflectance – the HYPERNETS Project

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The HYPERNETS project is preparing the next generation of hyperspectral radiometric validation instruments for validation of water and land surface reflectance derived from satellite missions.

Spaceborne optical imaging missions such as Sentinel-2 are used routinely to provide data for environmental monitoring of water and land surfaces via products such as chlorophyll and suspended particulate matter concentrations in water and Fraction of photosynthetically active radiation absorbed by vegetation (FAPAR) and Land cover over land. These products are derived from the primary radiometric products, the water and land surface reflectance. The quality of the derived products required by end-users obviously depends on the quality of these intermediate radiometric products, which are often significantly affected by problems such as imperfect atmospheric correction. Validation of the water and land surface reflectance products is therefore needed to ensure reliability of the satellite data products that are needed for environmental monitoring and to identify where improvements in accuracy are needed.

For water reflectance, the AERONET-OC network [Zibordi et al, 2009] is currently the main source of radiometric validation data. This network is mature and operational and covers a variety of water sites. The radiometer instrument is multispectral, with the original instrument covering 9 spectral bands in the range 412-1020nm and the most recent upgrade with 3 extra spectral bands. The WATERHYPERNET network is under development to fill spectral gaps and provide full hyperspectral coverage for water reflectance. The first instrumentation integrated within the WATERHYPERNET is the PANTHYR system [Vansteenwegen et al, 2019], based on the mature TRIOS/RAMSES radiometer covering 400-900nm at 10nm spectral resolution – see separate talk for results from the first prototype deployments. A new radiometer, the HYPSTAR®, is being designed and tested within the H2020/HYPERNETS project to provide finer spectral resolution (3nm FWHM for the range 350-1100nm) and higher quality measurements (lower uncertainty) at lower cost.

For land surface reflectance measurements, various radiometer instruments are currently used although there are few automated systems. The importance of measurements in the Short Wave Infrared and the angular variability and spatial heterogeneity are key additional factors for land surface reflectance as compared to water reflectance. RADCALNET is emerging as the most promising network of automated instruments but is currently focussed on providing data for vicarious calibration, based on requirements that are different from the needs for radiometric validation. The new instrumentation being designed and tested within the H2020/HYPERNETS project will provide land surface reflectance measurements at high spectral resolution including spectral coverage extended to 1700nm (with 10nm FWHM resolution) and with angular/spatial variability.

The progress of the H2020/HYPERNETS project will be described here including an overview of: a) the new HYPSTAR® radiometer with computer-controlled pointing system and auxiliary sensors; b) the processing software for the in situ measurements and c) the water and land sites where prototype instruments are being tested.

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Design of the “Fore-Optics Contamination Experiment (FCX)” to Assess Impact of Optical Contamination of Radiometers During Long-Term Automated Deployments.

Ortenzio F.[1], *Beck M.*[1], *Ruddick K.*[1]

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Automated above-water radiometry from AERONET-OC [Zibordi et al, 2009] is the main source of radiometric validation data for Sentinel-2 over water, however the network installations are limited to discrete multi-spectral wavelengths. The new WATERHYPERNET network (https://waterhypernet .org/) is being set up to provide hyperspectral validation covering the full spectral range of all visible and near-infrared Sentinel-2 bands (443nm to 865nm inclusive). While the CIMEL/SeaPRISM instrument used by AERONET-OC measures downwelling irradiance from direct sun radiance and uses collimator tubes to protect the instrument fore-optics, the TRIOS/RAMSES and HYPSTAR (TM) radiometers that are, and will be, integrated within WATERHYPERNET measure downwelling irradiance using a flat “cosine” diffuser and require an unobstructed hemispherical view. The fore-optics therefore cannot be protected by collimator tubes and instead make use of the tilt function of pan-and-tilt units to allow parking in a downward-facing direction when not measuring. Since these instruments are typically deployed for a year at a time with no maintenance for cleaning, it is critical to understand whether the fore-optics remains clean enough for high quality measurements throughout the deployment as well as how to best protect the fore-optics from any contamination.

Various processes may lead to reduced transmissivity of the glass window and of the diffuser materials typically used for radiance and irradiance sensors respectively: deposition of aerosols from diverse sources including urban pollution, occasional dust events, marine salt spray, pollen, etc.; spiders’ webs (particularly for land sites and for concave geometries); bird faeces and snow/ice. Clean rain may also wash these surfaces giving a non-monotonic variation in time. There is a general notion that upward-facing surfaces are more prone to contamination than downward-facing surfaces and therefore parking radiometers downwards is a good idea. To the best of our knowledge, however, there is no scientific data on the subject of fore-optics contamination, despite its importance in acquiring high quality data from long-term, automated deployments.

A “Fore-optics Contamination Experiment (FCX)” is therefore being planned and will be described here to provide scientific data on fore-optics transmissivity over time for long-term deployments as a function of location (hence rainfall, aerosol type) and orientation (downward-, sideways- or upward-facing). The first measurements of a one-year time series will be presented.

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The contribution of PRISMA, DESIS and in situ data for analysing the potential improvement of second generation of Sentinel-2

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It is widely recognized that inland waters play a crucial role in human health and well-being as an increasingly important source of drinking water and food, recreation, and tourism. They provide vital ecosystems services and play a crucial role in the global carbon and nutrient cycles. Many inland waterbodies are under severe anthropogenic pressures including eutrophication and climate change. Water monitoring data are hence needed to support the management of such valuable ecosystems and a variety of programs and projects have been established at regional and national scales (e.g. at the EU level the Water Framework Directive). Some of these programs are based on remote sensing technologies, which have seen major improvements over the last decade to support inland water resources research and applications (e.g. water quality monitoring, Harmful Algal Blooms, aquaculture). In such a framework the Sentinel-2 mission (with the pair of Sentinel-2 A and -B satellites) has been presenting a significant opportunity for monitoring and mapping both water quality constituents and shallow water habitats in environments in which previous sensors could not retrieve any information due to their spatial resolution. Nonetheless, concepts to improve the Sentinel-2 MSI band setting are in place for the Sentinel-2 second generation (S2-SG) for refining the detection of key parameters useful to monitor the status of both terrestrial and aquatic ecosystems. In particular, the possibility of S2- SG to have a new band centred at 620 nm with about 30 nm of bandwidth might support the detection of phycocyanin pigments associated to cyanobacteria, whose blooms are affecting an increasing number of aquatic ecosystems worldwide. Such band might also help to detect chlorophylls c1 and c2 present in diatoms. The possibility to have a band centred at 810 nm could be then a useful indicator of particulate matter in very absorbing (humic-rich) and very turbid (dominate by suspended inorganic matter) waters. By considering the revisit of 5 day and the 10 m pixel size, the S2-SG will offer unique data for a fine-scale monitoring of phytoplankton and turbidity in small to medium size aquatic systems. In this study we are exploring the S2-SG band setting based on hyperspectral measurements gathered both from space (PRISMA-ASI and DESIS-DLR) and from field-based instruments. A simple resampling of hyperspectral data in agreement with a predefined S2-SG spectral setting is presented for a variety of ecosystems (lakes and lagoons) interested by algal blooms. The case studies include waters interested by moderate to high concentration of chlorophyll-a and events characterised by the dominance of different phytoplankton groups, obviously including cyanobacteria. The simulated S2-SG data obtained from PRISMA, DESIS and field measurements will be compared to those acquired by Sentinel-2 A and B satellites for showing the potential improvement that S2-SG might provide to aquatic remote sensing.

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Validation of the Sentinel-2 Level 2 Prototype Processor (SL2P) using Copernicus Ground Based Observations for Validation (GBOV) data

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To meet the need for quality assurance of bio-geophysical products derived from earth observation data, the Ground Based Observations for Validation (GBOV) service aims to develop and distribute robust in situ datasets for product validation. Now in its third year, raw observations from a range of existing networks have been collected and processed to provide datasets suitable for validating albedo, land surface temperature, soil moisture and vegetation products. These consistent and quality-controlled data provide an ideal opportunity for validating a range of bio-geophysical products, including those derived from the Sentinel-2 Multispectral Instrument (MSI). In this contribution, we focus on the three vegetation products considered within the project: leaf area index (LAI), the fraction of absorbed photosynthetically active radiation (FAPAR), and the fraction of vegetation cover (FCOVER). In addition to processing chain improvements, V2 of the GBOV vegetation data set expands the time-series to cover the latest available observations. In the case of the considered vegetation variables, in situ reference measurements (RMs) are derived from raw digital hemispherical photography (DHP), and are provided with associated quality indicators and estimates of uncertainty.

The updated database covers 20 sites between 2013 and 2018, representing a wide range of vegetation types (including cropland, deciduous forest, evergreen forest, grassland, and shrubland). Using these data, we validate LAI, FAPAR and FCOVER retrievals provided by the Sentinel-2 Level 2 Prototype Processor (SL2P) incorporated within the Sentinel Application Platform (SNAP). Good agreement with in situ measurements is demonstrated for effective LAI, FAPAR and FCOVER ($r^2 \geq 0.86$, NRMSD = ≤ 30%), with between 75% and 94% of retrievals meeting the Sentinels for Science (SEN4SCI) uncertainty requirements. When the effects of foliage clumping are considered in the computation of in situ LAI, poorer agreement is observed ($r^2 = 0.84$, NRMSD = 52%), with only 62% of retrievals meeting the SEN4SCI uncertainty requirements. In addition to the baseline processor, we also present results for a modified version of SL2P, which makes use of the Directional Area Scattering Factor (DASF) to constrain retrievals (SL2P-D). Potential improvements to both the L2B products and GBOV dataset are discussed.

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Assessment and refinement of the Simplified Level 2 Prototype Processor for mapping North American forests with S2 MSI

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The Sentinel 2 Mission is required to support the generation of vegetation products, including fraction of absorbed photosynthetically active radiation (fAPAR), fraction canopy cover (fCOVER) and leaf area index (LAI) globally in a free an open manner through collaborative down stream services. The Simplified Level 2 Prototype Processor (SL2P) represents a null-hypothesis algorithm for product generation. A summary of current validation studies indicates that SL2P generally satisfies international threshold user requirements for

uncertainty over crops and for spatial resolution. However, requirements for global product generation, temporal coverage and uncertainty over forests have not been achieved.
A system for global application of SL2P using Google Earth Engine is presented to enable free and open product generation on desktop and mobile devices. Variants of SL2P using tuned algorithms and using a discrete radiaitve transfer model in place of PROSAIL are also implemented. CEOS good practices for product validation are applied to quantify SL2P performance over North American forests in three aspects: 1. temporal coverage of successful retrievals over North America for 2019 and 2020. 2. direct validation over 10 regional sites using in-situ measurements over Canada and USA 3. intercomparison with MODIS and Copernicus Global Land Service products over 35 regional subareas including the BELMANIP2.1 sites.
Results suggest that SL2P has typically less than 50% successful retrievals and offer precise but biased estimates of vegetation parameters over forests; with bias increasing with clumping. Tuning the SL2P calibration database increases successful retrieval but does not decrease bias. Replacing PROSAIL with a discrete radiative transfer model generally reduces bias but decreases precision due to additional model parameters. We hypothesize that constraints from in-situ observation or other sensors (e.g. LIDAR) may reduce bias. To this end an open source Google Earth engine application is provided to allow users to adapted SL2P for local product generation.

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Uncertainties of FAPAR in situ Measurements and Validation of the Sentinel-2 Product- Experiences Across three Forest Ecosystems

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The fraction of absorbed photosynthetic active radiation (FAPAR) is an essential climate variable (ECV) needed for quantifying global carbon balances and monitoring vegetation dynamics and status. To ensure accurate datasets of global FAPAR, the Global Climate Observing System (GCOS) declared an accuracy target of 10% (or 0.05) as acceptable for FAPAR products. Sentinel-2 (S2) imagery is increasingly used for applications in forestry and the Biophysical Processor within SNAP enables the retrieval of a FAPAR product to monitor the productivity of single forest stands. The S2 FAPAR product has been validated against in situ estimates against ground data in different forest ecosystems with good to moderate agreement. Validation strategies differ among current studies, as well as the type of ground measurements applied. In contrast to other ECVs such as LAI, community-agreed validation and sampling protocols are currently under development. From transfer modeling (RTM) it is known that in situ FAPAR measurements may be affected by significant uncertainties depending on the choice of sampling scheme and prevailing environmental conditions. However, uncertainties have remained obscure in field conditions and have therefore not been considered in validation campaigns. We investigated the accuracy of in situ FAPAR estimates based on multi-year, 10-minute PAR measurements with Wireless Sensor Networks at three sites: a mixed spruce forest in Southern Germany, a boreal deciduous forest in Northern Alberta, Canada, and a tropical dry forest in the province of Guanacaste, Costa Rica. The aim of our study was to a) identify main sources of uncertainties of FAPAR estimates due to environmental conditions, b) investigate the minimum number of flux terms necessary, and c) evaluate the Sentinel-2 FAPAR product under uncertainty constraints of ground data.
Main sources of uncertainty of in situ FAPAR measurements were high solar zenith angle (bias up above 0.06 at SZA > 60°), occurrence of colored leaves which confirms previous findings based on RTM. As a new finding, an influence of wind speed was observed, which was particularly evident at the boreal location with a significant bias of FAPAR values at wind speeds above 5 m/s. As for the number of flux terms recommended for FAPAR estimates, the uncertainties of the two-flux FAPAR estimate were found to be acceptable under typical summer conditions when compared to three- and four-flux FAPAR estimates.
As for the validation of the S2 FAPAR product, we found a systematical underestimation at all three study sites. The highest agreement was observed at the boreal site with a mean relative bias of -13% (R^2=0.67). At the temperate and tropical sites, deviations were -20% (R^2=0.68) and -25% (R^2=0.26), respectively. It could be argued that these discrepancies resulted from both the generic nature of the algorithm as well as the higher ecosystem complexity of these forests. Since the uncertainties of FAPAR were quantifiable under field conditions, they should also be considered in future validation studies. Based on our experiments, we can now provide practical recommendations for FAPAR estimates based on direct PAR measurements that could be useful for the development of sampling and validation protocols.

On the use of Sentinel-2 data for mapping of hazelnut crops in Azerbaijan

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Azerbaijan is among the world's top five hazelnut producing countries, while agriculture is Azerbaijan's largest employer, with roughly 40 percent of the working population making some part of their living in agriculture. Hazelnut (Corylus avellana) represents one of the most remunerative cash crops of the country and Azerbaijan's hazelnut orchards predominate in the foothills of the Caucasus Mountains in the northwest and northeast. The end goal of this analysis is to produce a map of hazelnut orchards distribution that represents the current situation in the country necessary to guide further analysis. The methodology is tested in two regions: Shaki- Zagatala and Ganja-Qazakh was selected. The approach has been adjusted for crop mapping using Sentinel 2 and it consists in a time series analysis using the combined temporal information from Sentinel 2 and1. Orchards will be analyzed based on their growing phase (as mature/non mature) considering the remote sensing characteristics: spectral signature, NDVI (and other indexes) trends and temporal information at pixel level.

The suggested approach employs different tools that allows data processing using cloud computing systems (i.e. Google Earth Engine and FAO SEPAL) and multi-temporal images to sequentially classify hazelnut orchards. In addition to the satellite imagery, training data collection is also a necessary (and time-consuming) activity. Point or polygon-based training data of hazelnut and non-hazelnut plantations will be used to train the classifier during the supervised classification. The use of existing land use and land cover maps and reference data (e.g. field data from National Forest Inventory and other (ongoing) projects with geolocations of hazelnuts and other type of tree crops) will be crucial to validate and guide the training data collection (and to differentiate hazelnut from other perennial tree crops). High quality training data guarantees a correct classification of the satellite images, and generally are collected using VHRI, in Google Earth. However, it is important to ensure that features and characteristics can be differentiated also in the Sentinel imagery, considering that these are the data input in the classification in this study.

The final outcome is a hazelnut mask that indicates geospatial locations of hazelnut cultivation zones, at national scale, if possible with a distinction between mature cultivations and non-mature cultivations. These maps will serve to guide further studies on productivity and to support decision makers in the identification of areas for intervention.

Evaluation of Sentinel-2 snow products

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The Copernicus High Resolution Snow and Ice Monitoring service was launched by the European Environmental Agency in 2020. In particular, the service provides fractional snow cover maps at high spatial resolution (20 m x 20 m) derived from Sentinel-2 data at pan-European scale from 01 September onward in near real time. The algorithm was evaluated using multiple datasets including weather station data, very high resolution satellite imagery and crowd-sourced observations in the Alps and Pyrenees mostly. We will summarize these results which are already published. We will also present the results of recent evaluation studies focusing on two specific issues: cloud/snow discrimination and snow detection in forested landscapes. We are also striving to expand the evaluation in northern Europe, where the extensive forest cover and low solar elevation angles can deteriorate the algorithm performance. These studies contribute to a better assessment of the uncertainties associated to these unprecedented snow products.

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A New Copernicus Service Component Based on Sentinel-2: Pan European High Resolution Snow & Ice Monitoring of the Copernicus Land Monitoring Service (CLMS).

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Snow cover and Lake Ice cover have been both specified by the Global Observing System for Climate (GCOS) as part of the 50 essential climate variables (ECVs) to be monitored by satellite remote sensing . They are relevant input parameters for forecasts in the field of weather, hydrology and water management, therefore essential for assessing natural hazards such as floods, avalanches or river ice jams and managing associated risks.

Since July 2020, under European Environment Agency (EEA) delegation, the Copernicus Land Monitoring Service (CLMS) operationally produces and disseminates Pan-European High-Resolution Snow & Ice products (HR-S&I) at high spatial resolution (20 m x 20 m). They are derived from high-resolution optical satellite data, from the Sentinel-2 constellation (Sentinel-2A and Sentinel-2B).

Four types of HR-S&I products are offered:

- The Fractional Snow Cover (FSC) product is generated in near real time (NRT) and provides for each pixel the fraction (0% – 100%) of the surface covered by snow at the top of canopy (FSC-TOC) and on the ground (FSC-OG).
- The Persistent Snow Area (PSA) product is generated on a yearly basis and provides the extent of persistent snow cover, i.e. the area where snow is present throughout the hydrological year.
- The River and Lake Ice Extent (RLIE) product is generated in NRT and provides the river and lake area covered by snow-covered or snow-free ice.
- The Aggregated River and Lake Ice Extent (ARLIE) product is generated quarterly and provides the percent coverage of snow-covered or snow-free ice on lakes and on 10 km river sections.

HR-S&I products are generated over the entire EEA39 (33 member countries and 6 cooperating countries). An archive reprocessing campaign was performed for data from September 1st, 2016 and resulting products are already available to users.

This new Copernicus Service component has been developed and is currently operated by a consortium led by Magellium in partnership with Astri Polska, Cesbio and Météo-France, and contracted by EEA as entrusted entity of DG-DEFIS (European Commission - Directorate General Defense Industry and Space) for this service.

The service is based on preexisting Research & Development (MAJA[1] and LIS[2]) algorithms and products conducted by CESBIO and supported by CNES for Snow products and by Astri Polska developments for Ice products. These algorithms have been turned into operational conditions, based on the WEkEO DIAS European cloud infrastructure.

The ideal user requirement for the turnaround of NRT HR-S&I products after Sentinel-2 data sensing is no later than 6 hours, since the maximum acceptable time lag for time-critical applications such as avalanche bulletins, weather forecasting, etc. is 12 hours. As a result, every effort is made to produce and publish NRT HR-S&I products in less than 3 hours after Sentinel-2 data (L1C products) are available on the ESA Copernicus Service Hub. The publication turnaround by ESA of L1C products on the Copernicus Service Hub also determines the overall time for product availability to end-users.

A complementary component of the HR-S&I service, based on Sentinel-1 data, is currently being developed by EEA and should be operational in 2021.

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End To End Testing And Validation

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The European Space Operations Centre (ESOC) in Darmstadt focuses on End-to-End (E2E) Integration and Testing of the Mission Operations Infrastructure (MOI) products and especially on the automation of Assembly, Integration and Testing (AIT) activities in the End-to-End Ground Segment Reference Facility (E2E GSRF).

During the mission test campaigns or even infrastructure acceptance tests it requires many efforts and time to perform specific tests manually, which leads sometimes to human errors at systems levels. Therefore, the needs of an automatic solution are required to avoid the erroneous. E2EVAL project is a web interface, which is centralised, deployed at ESOC and it connects to different subsystems under test.

This Framework enables the identification, investigation and reproduction of failures at early stages of ground systems developments, during their development lifecycle or use in operations, by performing integration testing in operations representative test assemblies, reducing effort, increasing effectiveness and reproducibility of testing.

The E2EVAL provides the user to test different test assemblies from a standalone ground segment system to a assembly of multiple systems with a given coherent configuration. It gives then the availability to test different versions of an infrastructure ground system with historical results that could be used to compare against at any point of time.

It is beneficial using the tool that allows the definition of generic test cases, which can be used to test the generic infrastructure with different mission configurations, following the same test procedure. This gives the ability to investigate any failure in a safe but still representative environment, increasing the capabilities to support regression-testing, performance of nightly automated testing of new deliveries leading to more robust testing capabilities and results.

In addition, the E2VAL serve the deployment process and the executions of automated test cases, which perform any actions and automatically interact with the system under test, mimicking the actions of the user on the different widgets of the interface. The E2EVAL has been adapted and extended to also allow testing web-based systems.

All reports generated are stored in a large database, which could cover or exceed the mission lifetime. There are different types of reports enabling the tester to perform a thorough analysis of failures only where necessary from test result overview to detailed reports including failure root cause identification features.

The poster presentation will detail the different features of E2EVAL described above, demonstrating the technological breakthrough achieved and the avenues opened by this initiative.

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Sentinel 2 Super Resolution Capabilities: Theoretical Considerations and Usage Limitations

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Super-resolution is a subject which has been studied for decades. As an example, SPOT5 THR sensor has been dimensioned in order to take benefit from this super-resolution concept in the ground segment algorithms [Latry and Rougé 2003].

Moreover, during the last years, "Super-Resolution" using Deep Neural Network has been the subject of several research studies and challenges (for example : https://kelvins.esa.int/proba-v-super-resolution/, [DeepSUM]). Two kinds of algorithms are proposed in the literature: SISR, for Single Image Super Resolution, and MISR, for Multi Image Super-resolution. At first glance, Sentinel 2 mission characteristics (time series with the same acquisition conditions) seem to be well adapted to feed MISR algorithms.

From a practical point of view, generating super-resolved images from Sentinel 2 time series would be of great interest, for example, for the photo-interpretation in the IMINT domain. Using the huge S2 free archive, super-resolution could enable the generation of very high resolution (VHR) reference images everywhere on the Earth at every time in the past, to be compared to current VHR acquisitions for change detection.

In this talk, we recall the concept of MTF, sampling, and aliasing. We will see the physical hypothesis leading to an accurate reconstruction of signal frequencies higher than the Nyquist frequency required by classical methods of super-resolution computation and conclude for the Sentinel 2 case. Sentinel 2 optical Point Spread function of 10m bands is fully adapted to the size of the pixel detector, minimizing the aliasing effect and consequently minimizing the possibility to recover high frequencies (beyond Nyquist) by a super-resolution reconstruction algorithm.

Then, we analyze the super-resolution algorithms using Deep Learning, and emit some recommendations about their use and limitations. As real frequencies corresponding to the super-resolution are not present in the native Sentinel 2 images, the reconstructions of these high frequencies will be only based on statistical information caught by the training. The results are often visually coherent for geotypical simulations. Besides the visual comfort provided generated by highly resolved images, such statistical process can create or modify details which are consistent but absent from the actual scene. Even if these methods are useful for many applications, the obtained images could lead to misinterpretations in the analysis. At these metric resolutions, possible misinterpretation is a strong drawback for IMINT analysts.

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