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→ 3rd SENTINEL-2 VALIDATION TEAM MEETING

12–14 March 2019

ABSTRACT BOOK

INP ENSEEIHT

3rd Sentnel-2 Validation Team Meeting

12-14 March 2019

Toulouse

France

Last Updated: 11 March 2019

Contents

1. Committee

Organising Committee

- Valentina Boccia (ESA)
- Ferran Gascon (ESA)
- Rosario Q. Iannone (ESA)
- Vincent Lonjou (CNES)
- Angelique Gaudel-Vacaresse (CNES)
- Thomas Oberlin (ENSEEIHT)

2. Programme

3rd Sentinel-2 Validation Team Meeting Agenda

12–14 March 2019, Toulouse, France

Tuesday 12/03/2019

Time	Title	Speaker
09:00 – 10:30	**Registration**	
10:30 – 11:00	Welcome	H. Laur (ESA)/P. Kubik (CNES)
11:00 – 11:45	Copernicus Sentinel-2 Mission Status and Meeting Objectives	F. Gascon (ESA)
11:45 – 12:30	Copernicus Sentinel-2 Data Quality Overview	V. Boccia (ESA)
	Lunch Break (12:30 – 14:00)	
Session #1: Level-1 Radiometry Validation		Ch: B. Alhammoud/J. Barsi
14:00 – 14:20	Radiometric Calibration and Validation Status from the Copernicus Sentinel-2 Mission Performance Centre	C. Bouzinac (MPC/CS)
14:20 – 14:40	Sentinel-2 radiometric validation at CNES	V. Lonjou (CNES)
14:40 – 15:00	Monitoring of Sentinel-2/MSI-L1C radiometric calibration using Deep Convective Clouds and Sunglint Methods	B. Alhammoud (MPC/ARGANS)
15:00 – 15:20	Estimating Leaf Chlorophyll from Sentinel-2 Data in a Temperate Forest	R. Darvishzadeh (University of Twente)*
	Coffee break (15:20 – 15:40)	
15:40 – 16:00	Monitoring Sentinel-2 MSI Radiometric Stability and Calibration with Landsat-8 OLI	J. Barsi (NASA)
16:00 – 16:20	Vicarious calibration and inter-comparison results for Sentinel-2 MSI, Landsat-8 OLI, and GOES ABI using Radiometric Calibration Test Site (RadCaTS) at Railroad Valley, NV and Salar de Uyuni, Bolivia	J. McCorkel (NASA)
16:20 – 16:40	VENµS Mission and Products: Cross-Calibration and Complementarity With Sentinel2	P. Gamet (CNES)
16:40 – 17:00	Harmonization of multi-sensor high resolution time series: the BELHARMONY approach	S. Sterckx (VITO)
17:00 – 17:20	Verification Of MSI Low Radiance Calibration Over Coastal Waters, Using AERONET-OC Network	V. Leroy (RAYFERENCE)
17:20 – 17:30	**Discussion and Conclusion**	
17:30 – 19:00	POSTERS and DRINK	

Wednesday 13/03/2019

Time	Title	Speaker
Session#2: Level-1 Geometry Validation		Ch: A. Gaudel/S. Clerc
08:30 – 08:50	Copernicus Sentinel-2 Geometric Calibration And Validation Status	A. Gaudel (CNES)
08:50 – 09:10	Copernicus Sentinel-2 Global Reference Image Status	S. Massera (IGN)
09:10 – 09:30	Using pseudo-invariant features to validate the geometric and radiometric stability of Copernicus Sentinel-2 products	S. Clerc (ACRI)
Session#3: Level-2 Validation		Ch: J. Louis/O. Hagolle
09:40 – 10:10	Copernicus Sentinel-2 Level-2 Processing Sen2Cor Status and Outlook	J. Louis (TELESPAZIO)
10:10 – 10:40	Radiometric Performance Assessment of Sen2Cor Version 2.8	B. Pflug (DLR)
	Coffee break (10:40 – 11:00)	
11:00 – 11:20	Validation of Sen2Cor 2.5 cloud masking and classification	M. Main-Knorn (DLR)
11:20 – 11:40	Validation of the L2A and L3A surface reflectance products for Sentinel-2 delivered by Theia	O. Hagolle (CNES)

11:40 – 12:00	Feedback from the Copernicus Sentinel-2 Global Mosaic Service on S2 Level 2A products C. Brockmann (Brockmann Consult)
12:00 – 12:20	CMIX and ACIX: Cloud Masking and Atmospheric Correction Inter-comparison Exercises G. Doxani (SERCO)
12:20 – 12:40	Multi-algorithm atmospheric correction for the Sentinels-2 A&B: an opportunity to optimize the Level 2 products for end users B. Saulquin (ACRI)
Lunch Break (12:40 – 14:00)	
Session#3: Level-2 Validation	**Ch: B. Pflug/R. Van De Kerchove**
14:00 – 14:20	Enhancing Compatibility of Sentinel 2 and Landsat products for improved monitoring of the Earth System E. Vermote (NASA/GSFC)
14:20 – 14:40	Field-based Validation of the Digital Earth Australia Sentinel-2 Surface Reflectance Product A. Siqueira (GeoScience Australia)
14:40 – 15:00	Products validation plan in the AFRICULTURES project G. Laneve (University of Rome, La Sapienza)
15:00 – 15:20	Experiences with Sentinel-2 data in the Belgium Collaborative Ground Segment Terrascope R. Van De Kerchove (VITO)
15:20 – 15:40	Sentinel-2 Surface Reflectance Validation Over Vegetation for the FRM4Veg project N. Origo (NPL)
15:40 – 16:00	Validation of Sentinel-2 LAI and fAPAR products derived from SNAP Toolbox over forests and crops sites using fiducial reference measurements collected under the FRM4VEG project F. Camacho (EOLAB)
Coffee break (16:00 – 16:30)	
16:30 – 16:50	Sentinel-2 support in Karstic fresh water detection on SPM & CHL maps a matter of MSI sensors' sensitivity and L2a processing F. Coulibaly (ARGANS)
16:50 – 17:10	First Results From WATERHYPERNET - a Network of Hyperspectral Radiometers for Multi-satellite Water Reflectance Validation adapted to Sentinel-2ABCD K. Ruddick (RBINS)
17:10 – 17:30	Validation of Radiometric Products Over Optically Complex Waters A. Ansper (TARTU)
17:30 – 18:40	**Discussion and Conclusion**
17:40 – 19:00	**POSTERS and DRINK**

Thursday 14/03/2019

Time	Title / Speaker
Session#4: Downstream Products Validation	**Ch: P. Nima/ K. Ruddik**
09:00 – 09:20	The Copernicus Ground Based Observations for Validation (GBOV) dataset: opportunities for validating Sentinel-2 L2B downstream products L. Brown (University of Southampton)
09:20 – 09:40	Advanced surface/atmosphere characterization with GRASP algorithm: application to space-borne measurements with fine spatial resolution P. Lytvynov (GRASP)
09:40 – 10:00	Radon-augmentation of Sentinel-II imagery to enhance resolution and visibility of (nearshore) ocean-wave patterns E. Bergsma (CNES)
10:00 – 10:20	Sentinel 2 Water Quality Products Generation and Validation D. Müller (Brockmann Consult)
Coffee break (10:20 – 11:00)	
11:00 – 11:20	Towards Seamless Sentinel-2/Landsat Aquatic Science Products N. Pahlevan (NASA)
11:20 – 11:40	Retrieving Marine Litter from Space: An innovative approach to identifying and validating Marine Litter using Sentinel 2 data M. Hennen (ARGANS)
11:40 – 12:00	The Sentinel-2 coastal charting project: An exercise in the calculation of cartographic uncertainties J. Laporte (ARGANS)
12:00 – 12:30	**Discussion and Conclusion**

***Presentation originally included in "Session 3: Level-2 Validation" and inserted here for logistic reasons under request of the Presenter.**

3. Abstracts

Session #1: Level-1 Radiometry Validation

Radiometric Calibration and Validation Status from the Copernicus Sentinel-2 Mission Performance Centre

Bouzinac C[1], Lafrance B[1], Neveu Van Malle M[2], Alhammoud B[3], Clerc S[3], Jackson J[3], Iannone R[4], Boccia V[4]

[1]CSSI, [2]Thales Alenia Space, [3]ACRI-ARGANS, [4]ESA-ESRIN

The radiometric consistency of the image time series is ensured by some specific performance requirements such as radiometric stability, routinely monitored by the Sentinel-2 Mission Performance Centre (S2MPC). This presentation provides a description of the radiometric calibration and validation activities, performed by the S2MPC including several Expert Support Laboratories (ESL). Last measured performances and last analysed results show the good quality of the mission products in terms of radiometry. The current performances for Sentinel-2A and Sentinel-2B are compared to mission product quality requirements.

The Multispectral Instrument (MSI) measures the Earth's reflected radiance in 13 spectral bands from VNIR to SWIR. It has been built by the requirements for large swath high geometrical and spectral performance of the measurements.

The on-board sun diffuser is a full-field/full-pupil diffuser, called the Calibration and Shutter Mechanism (CSM), which is integrated with MSI for radiometric calibration in order to guarantee high quality radiometric performance. This On-Board Calibration Device (OBCD) collects the sun light after reflection by the diffuser to prevent the instrument from viewing the sun directly in orbit.

Calibration and Validation under S2MPC responsibility are critical processes in the quality control of generated products, and ensure that the processed data are meaningful to scientific users.

The radiometric calibration is based on the exploitation of the on-board sun diffuser images (for relative gains calibration and absolute radiometric calibration) and images acquired over ocean at night (for dark signal calibration).

The temporal evolution of the equalisation coefficients is monitored with the monthly sun-diffuser acquisitions. After each sun-diffuser acquisition, a new set of relative gains calibration parameters is generated. The time variation of relative gains is weak for VNIR bands: typically maximal variations do not exceed 0.2 to 0.4% between two monthly assessments. Variations are larger for SWIR bands with a change of gain coefficients up to 3% for some pixels and with an inter-pixel variation more pronounced for SWIR bands than for VNIR bands.

For VNIR bands, the absolute calibration coefficients are very stable, while for SWIR bands (especially for Band 10), the trend of decrease is up to −3% in six months. This is properly compensated with monthly update of the coefficients and the MSI sensitivity is back to nominal after each decontamination operation every six months.

Radiometric validation activities assess all radiometric performances related to image quality requirements.

The instrument response non-uniformity is assessed 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.

For all the VNIR bands, the maximal value of FPN is clearly below the specified limit (0.2% for all bands) typically by an order of magnitude. For SWIR bands, it is not the case: for Bands 10 and 11, the maximal value of FPN can be higher than the specified limit (0.35% for Band 10, 0.2% for Band 11), but the FPN values exceed the limit only for a few pixels as the values of FPN for the 98% quantile are significantly below the specified limit, even for these bands which are more affected by artefacts on the sun-diffuser BRDF characterization than the VNIR bands. The monthly update of equalization coefficients resets the FPN to zero, and ensures that the requirements are met until the next calibration.

The vicarious validation of the radiometric measurements is performed using DIMITRI toolbox and the Radiometric Calibration Test Site (RadCaTS) dataset. Fourteen desert, ocean and snow CEOS PICS are used to achieve this activity. The validation results are consistent over all test sites and over the different methods.

The multi-temporal relative radiometric uncertainty validation results show a good stability of MSI, and the measurements are compliant with the mission requirements of less than 5% error, except for Band 05 due to DIMITRI limitation in Top-Of-Atmosphere (TOA) simulation of spectral bands with significant absorption from water vapour and dioxygen.

The ground reflectance-based approach is used over the RadCaTS to perform the absolute radiometric vicarious calibration over the whole spectral range of MSI. The results indicate a very good agreement with DIMITRI toolbox results for the VNIR bands. The RadCaTS data are provided by the NASA Landsat Cal/Val Team as part of the ESA expert users effort.

The radiometric validation suggests that MSI-A measured reflectances are slightly brighter that MSI-B ones by about 1% (except for Band 12). This small discrepancy could be due to uncertainties in the ground characterization of the sun-diffusers albedo. However, this is not a concern as this difference is within the method's uncertainty magnitude.

The Signal-to-Noise Ratio (SNR) is well inside the requirement (with more than 20% margin) for all bands and appears to be very stable.

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Sentinel-2 radiometric validation at CNES

Lonjou V[1], Lenot X[2], Desjardins C[1], Dick A[1], Marcq S[1], Lourme E[1], Coppolani C[3], Soleilhavoup I[1], Miquel C[4], Guilleminot N[3]

[1]Cnes, [2]CS, [3]Thales Services, [4]Akka

The presentation is focused on Sentinel-2 radiometric validation activities that are conducted at CNES. The absolute calibration monitoring is based on four independent methods that use natural targets acquisitions. They each provide different levels of information.

Deserts are used for cross-calibration with past and operational missions. The cross-calibration between Sentinel-2 and Sentinel-3 will be particularly detailed since they are part of the same Copernicus program. Molecular scattering over oceanic oligotrophic areas is well modelled. These observations are used to derive absolute calibration coefficients for the spectral bands in the visible range. The relative spectral reflectance of deep convective clouds is predictable below 900 nm when they are appropriately selected. Such targets allow to derive inter-bands calibration results. The verification scheme, exploiting photometer in-situ measurements over La Crau plain and Gobabeb, is also described.

A synthesis, including spectral coherence, inter-methods agreement and temporal evolution, concludes the paper.

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Monitoring of Sentinel-2/MSI-L1C radiometric calibration using Deep Convective Clouds and Sunglint Methods.

Alhammoud B[1], Lamquin N[2], Bruniquel V[2]

[1]Argans Ltd, [2]Acri-ST

In the frame of the European Space Agency (ESA) Scientific Exploitation of Operational Missions (SEOM) program a validation approach based on deep convective clouds (DCC) has been developed to validate the Sentinel-2 level 1C (L1C) product radiometry. Due to their physical properties DCCs can indeed be used to monitor the radiometric response degradation of the reflective solar bands of optical sensors. Their observation allows interband radiometry validation from the visible (VIS) to the near-infrared (NIR). Results of the DCC methodology prove the very good radiometric performance of Sentinel-2 with interband gains better than 2% for both A and B instruments.

The Database of Imaging Multispectral Instrument and Tool for Radiometric Intercomparison (DIMITRI) package contains a suite of methodologies for the comparison of Top Of Atmosphere (TOA) reflectance from Earth Observation sensors either between sensors or to radiative transfer simulations. DIMITRI Version-3 is developed and maintained by ESA/ESTEC and ARGANS. It contains four calibration validation methods: sensor-to-sensor inter-calibration, Rayleigh scattering, Desert Pseudo-Invariant Calibration Sites (PICS) and Sun-glint. The first three methods are being used by the Sentinel-2 Mission Performance Centre (S2MPC) to perform the vicarious validation of the L1C products delivered to users.

Although the Sentinel-2 mission is designed to avoid the specular sunglint contamination, one still observes a clear glint contamination over some products. In this presentation we apply the sunglint calibration method over open ocean test sites (e.g. SPG and SIO) used by the S2MPC L1-Val-Rad team. The results show a good interband gain performance better than 2% over the NIR-SWIR1 spectral range, in good agreement with the results from the DCC method where both methods intersect.

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

***Barsi J[1]**, McCorkel J[1], Haque O.[2]*

[1]NASA Goddard Space Flight Center

[2]Stinger Ghaffarian Technologies Inc

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 1.5% 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. There have been 20 near-simultaneous cloud-free acquisitions of Libya-4 and Algeria-3 with Landsat-8 and Sentinel-2A and 13 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).

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 CA (B01) and Blue (B02) analysis has been updated to use the Sentinel-2B relative spectral responses for the SBAF calculation. This has improved the comparison to OLI in both bands, though some systematic differences between the sites remain. 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 0.5-1.7%.

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Vicarious calibration and intercomparison results for Sentinel-2 MSI, Landsat-8 OLI, and GOES ABI using Radiometric Calibration Test Site (RadCaTS) at Railroad Valley, NV and Salar de Uyuni, Bolivia

McCorkel J[1], Czapla-Myers J[2], Anderson N[2], Efremova B[1]
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This work will present vicarious calibration results based on in situ data collected from two test sites: Radiometric Calibration Test Site (RadCaTS) at Railroad Valley, NV and Salar de Uyuni in Bolivia. RadCaTS is an automated facility developed and operated by the Remote Sensing Group (RSG) at the College of Optical Sciences at the University of Arizona. RadCaTS is composed of instruments used to make surface reflectance and atmospheric measurements in order to determine the top-of-atmosphere quantities (e.g. spectral radiance and reflectance). The primary motivation for RadCaTS is the ability to make near-continuous measurements throughout the day during clear-sky conditions while retaining a level of uncertainty on par with the more traditional reflectance-based approach to vicarious calibration. RadCaTS is one of the four instrumented sites that make up the CEOS WGCV Radiometric Calibration Network (RadCalNet), which strives to coordinate the efforts of space agencies to harmonize the uncertainty and traceability of satellite sensors.

In contrast to the persistent measurements acquired by the RadCaTS system, a dedicated field campaign was held 6-12 September 2018 for validation of Geostationary Operational Environmental Satellite-17 (GOES-17) Advanced Baseline Imager (ABI). Surface reflectance and atmospheric measurements were acquired each day of the campaign. Two field spectrometers were used to make the measurements for surface reflectance calculations and the view geometry for each of these spectrometers was assigned depending on the overpass time of various sensors. Nominally, the spectrometers were set for view geometry to match the GOES-16 and GOES-17 point of view, though one spectrometer turned to nadir during the time of a Sentinel-2 or Landsat overpass. Similar to RadCaTS, these surface reflectance and atmospheric measurements are used to calculate top-of-atmosphere reflectance for comparison with on-orbit sensors. We will present a summary of Sentinel-2 results and intercomparisons based on RadCaTS products and field measurements from Salar de Uyuni.

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VENµS Mission and Products: Cross-Calibration and Complementarity With Sentinel-2

Gamet P[1], Dick A[1], Marcq S[1], Hagolle O[2], Dedieu G[2]
[1]CNES, [2]CESBIO

VENµS is a joint space system venture of Israeli and French governments for Earth observation (EO). The scientific mission focuses on vegetation and land surface monitoring. VENµS was launched on August 1st, 2017. It provides 5 and 10 m resolution images in 12 shortwave spectral bands every two days over a set of scientific sites, with constant viewing angle and overpass time. This article presents the objectives of the mission, its main characteristics and products. A special focus is made on the in-orbit absolute calibration, based on vicarious techniques, including specific capabilities such as calibration using Moon images. The process of inter-calibration with Sentinel-2 through simultaneous nadir observation will be explained, and the results detailed.

The data acquired by the Sentinel-2 mission already proved their value for regional and country scales applications, such as detailed land-cover mapping, agri-environment policies, water management, vegetation primary productivity, and yield estimates. All these applications are crucial for defining global change mitigation or adaptation policies. Sentinel-2 is clearly a game changer in the field of EO applications, and therefore the European Commission and the European Space Agency have already started the work for defining the next generation that would launch from the mid-2020s. One of the questions raised by the users regarding Sentinel-2 is the possibility of increasing the revisit period in order to limit the impact of cloud-coverage on the applications and to capture rapid phenomena.

In this context, the main objective of VENµS is to explore the benefit of increasing the time rate of acquisition of high resolution (5 to 10 m) images in the solar spectrum. Towards this end, VENµS acquires images every two days over a set of 110 scientific sites. The main feature of VENµS products is the high frequency of the observations that is also the main driver of VENµS product definition. Since the objectives of the VENµS mission emphasize the potential of data time series, the basic Level 1 products incorporate geometric registration and radiometric calibration. The VENµS Level 1 will thus provide geolocated top of the atmosphere reflectance values with a subpixel multi-date registration, and cloud and cloud shadow masks at 200 m resolution.

The VENµS Level 2 product provides surface reflectances after cloud masking and atmospheric correction for all spectral bands. Surface reflectances are systematically produced in two versions. The first assumes flat terrain, while the second uses a digital elevation model to correct illumination variations due to slope exposures. The algorithms used for Level 2 processing take advantage of the 2-day revisit period with constant observation angles: most short-term variations of top-of-atmosphere (TOA) reflectance are due to atmosphere variations.

VENµS data are freely available to everybody for peaceful and non-commercial uses on the French Theia land data center: http://www.theia-land.fr. Continuous observations will be performed all along the scientific mission duration, until mid-2020.

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Harmonization of multi-sensor high resolution time series : the BELHARMONY approach.

Sterckx S[1], Wolters E[1], Swinnen E[1], Piccard I[1], Bassani C[2], Wirion C[3], Verbeiren b[3]
[1]VITO (Vlaamse Instelling voor Technologisch Onderzoek), [2]Institute of Atmospheric Pollution Research of National Research Council of Italy (CNR-IIA) , [3]Vrije Universiteit Brussel (VUB)

High spatial resolution missions as Sentinel-2 open opportunities to set-up operational Earth Observation (EO) services at local scale. However, due the frequent cloud coverage in Western Europe, combined with the lower revisit time of high spatial resolution sensors, operational services have often to combine data from different missions in order to have sufficiently frequent observations. A seamless combination of EO products coming from different missions is however not straightforward. Radiometric biases at TOA (Top-of-Atmosphere) level might exist. Even for a perfectly cross-calibrated constellation of instruments, intrinsic differences in the Relative Spectral Response Functions (RSRFs) of comparable bands might cause discrepancies in the final products. Furthermore biases in the products can also be introduced through the use of different processors and algorithms (e.g. for the atmospheric correction).

Within the BELHARMONY project, a bottom-up approach is used in order to assess and to improve multi-mission high resolution time series consistency.

First, vicarious radiometric calibration methods are used to assess the consistency at the L1 TOA level. This is done for the following sensors: Sentinel-2A/B MSI, Landsat-8 OLI, PROBA-V, and Deimos-1. The bias assessment is performed over targets with low as well as targets with medium radiance. The consistency evaluation over medium to high radiances is performed over 1) Land Equipped Sites (LES) through the use of the RadCalNet portal and 2) over the Libya-4 Pseudo-Invariant Calibration Site (PICS) site. The use of two different approaches allows for independent validation in order to reduce the uncertainty in the final results. The inter-calibration for low radiances targets is carried out over AERONET OC stations.

Next, to adjust the spectral response of one sensor to another, we model the difference that is related to the difference in the RSRFs , allowing to derive band- and/or index-dependent spectral adjustment functions. For this, we use simulated vegetation spectra derived from physically-based radiation transfer models that consider the leaf optical properties, the canopy structure, and the background reflectance. These simulations are completed by adding spectral libraries of non-vegetated surfaces.

Finally a common processing chain for the processing of the L1 data up to L2 reflectance and L3 higher level products is used. In the common processing environment the iCOR atmospheric correction code is applied to the data of all the considered sensors.

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Verification Of MSI Low Radiance Calibration Over Coastal Waters, Using AERONET-OC Network

Leroy V[1], Govaerts Y[1]
[1]Rayference

In the framework of the Sentinel-2 Radiometric Validation (S2RadVal) ESA project, inter-comparison algorithms were developed to validate Sentinel-2 Level-1C products. One of the algorithms involved in the study used coastal water as a target to validate calibration at low radiance values. The AERONET-Ocean Color (OC) network supplies sea conditions and optical properties in several bands matching some of the Sentinel-2/MSI bands, and its stations' locations were therefore used as targets. AERONET-OC stations are located in coastal areas, where water surface reflectance is higher to that of open ocean water due to higher suspended particle concentration. The shape, size and concentration of aerosols significantly influence the signal received by the satellite. The work performed in the framework of the S2RadVal project consisted in simulating Sentinel-2/MSI observations acquired over AERONET-OC stations using the 6SV radiative transfer model and comparing the resulting top-of-atmosphere BRF values with Sentinel-2/MSI observations, accounting for their respective uncertainties.

This work extends the results obtained at that time with additional data covering 12 AERONET-OC stations and the time range 2015-2018. A complete modular Python processing chain has been developed for that purpose. Independent databases for AERONET-OC and Sentinel-2 L1C products are linked by a matchup database, which consists in a single object able to fully coordinate processing.

Pre-processing starts with matching AERONET-OC observations and Sentinel-2 L1C products, resulting in the creation of matchups. Sentinel products are downloaded only for valid pairs, which minimises the requested bandwidth, and appropriate tiles are then repacked into netCDF files. Matchups can then be filtered based on criteria depending on the features of the radiative transfer model, e.g. to ignore observations where wind speed is too high to get an accurate estimate of water surface reflectance. For every matchup passing all the tests, the top-of-atmosphere BRF is simulated using a version of the 6SV radiative transfer model modified to leverage AERONET-OC data, in particular spectrally-resolved leaving radiance aerosol optical thickness. The computed TOA BRF is then used to compute an absolute bias estimating the discrepancy between the simulated value and the one obtained by Sentinel-2/MSI.

Bias values are then aggregated for different series, filtered by time period and locations. The uncertainty on simulation results is significantly contributed by the aerosol model selection and meteorological conditions. Aggregated values are compared to absolute radiometric requirements, better-suited for low signal intensity, estimated as 5% of the reference level of a typical TOA BRF acquired over vegetated surfaces. This reference level is simulated using 6SV.

In addition to the application of the calibration method, the developed toolchain can be used to perform in-depth analysis and explore potential correlations and dependencies of bias against the aerosol optical thickness or water-leaving reflectance.

Session #2: Level-1 Geometry Validation

Copernicus Sentinel-2 Geometric Calibration And Validation Status

Gaudel A[1], Clerc S[2], Le Berre M[3], Massera S[4], Neveu Van Malle M[5], Bouzinac C[6], Pessiot L[6], Garcia Soto A[7], Iannone R[8], Boccia V[9]
[1]Cnes, [2]ACRI/ARGANS, [3]Airbus Defense and Space, [4]IGN, [5]Thales Alenia Space, [6]C-S, [7]DEIMOS SPACE, [8]Rhea Group, [9]ESA-ESRIN

This paper reports on recent activities on geometric calibration and validation of the Copernicus Sentinel-2, performed jointly by the Sentinel-2 Mission Performance Center (MPC), European Space Agency (ESA) and French Space Agency CNES (Centre National d'Etudes Spatiales).

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. The process is as follows:

- Continuous monitoring of the performance by the MPC geometric validation team at Thales Alenia Space;
- In case of degrading performance, new calibration processed by the MPC geometric calibration team at Airbus DS;
- Independent assessment performed at regular intervals by the CNES geometry team.

Since the launch of Sentinel-2A in 2015, some lessons have been learnt from this process. During one year after launch, the viewing frame of Sentinel-2A evolved slowly until it reached a stable situation. The evolution spanned several tens of meters on ground, which required relatively frequent corrections. For Sentinel-2B, the stabilization period seems to be even longer, as significant changes are still observed more than one year after launch. In addition to this post-launch evolution, some oscillations can be observed with different time periods:

- Seasonal oscillations visible on Sentinel-2A (not yet on Sentinel-2B due to the shorter time series): approximately 2 meters on ground;
- Orbital oscillations: approximately 10 meters from North to South, correlated with the local Sun declination;
- Middle term oscillations (around 2mHz) discovered more recently in the average of 1 to 1.5 meters.

An analysis of a transient event on S2B which degraded the geolocation performance on orbit 8366 will be also presented.

This paper reports on all the geometric performances measured by the CNES and MPC teams during the last year for both satellites, and shows how the calibration approach and this close monitoring have maintained a good performance level, either for absolute geolocation better than 12,5m CE95 or multi-spectral registration better than 0.3SSD CE95.

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Copernicus Sentinel-2 Global Reference Image Status

Gaudel A[1], Massera S[2], Neveu Van Malla M[3], Le Berre M[4], Clerc S[5], Bouzinac C[6], Pessiot L[6], Garcia Soto A[7], Iannone R[8], Boccia V[9]

[1]Cnes, [2]IGN, [3]Thales Alenia Space, [4]Airbus Defense and Space, [5]ACRI/ARGANS, [6]C-S, [7]Deimos Space, [8]Rhea Group, [9]ESA-ESRIN

In the near future, a new calibration approach will be introduced, using the Sentinel-2 Global Reference Image (GRI). In this approach, all images are co-registered on-ground to the reference image.

This reference image is constructed by the Mission Performance Center (MPC) geometric calibration team at IGN (Institut national de l'information Géographique et forestière). GRI is independently validated by CNES (Centre National d'Etudes Spatiales), the MPC validation team at Thales Alenia Space for performance aspects, and by the MPC operation team regarding format aspects. During the last year, progress on the elaboration of the GRI concerned:

- Extension of the area to Northern latitudes and isolated islands;
- Adding products in cloudy areas if possible;
- Re-computation of tie points between continental GRI blocks for coherence (global spatio-triangulation);
- Refinement by datastrips for more flexibility in the spatio-triangulation, continuity ensured using tie points between both datastrips;
- Correction of minor format errors;
- Completion of the performance validation (movements deeper analysis, relative coherence, validation through an increased density of validation points BDAmer (IGN), or BDPHR (CNES), or by superimpositions (MPC-Thales Alenia Space)).

Thanks to the quality of the Global Reference Image, significant improvements are expected both for the absolute geolocation performance and the relative (multi-temporal) performance.

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Using pseudo-invariant features to validate the geometric and radiometric stability of Sentinel-2 products

Clerc S[1]

[1]Acri-st

In this presentation we report about recent improvements implemented in the "S2check" tool for semi-automatic Quality Control of Sentinel-2 products (see Clerc et al, European Journal of Remote Sensing, 2018). A new processing chain has been developed to provide a rapid identification of degradation of the geometric or radiometric performance.

The methodology relies on the generation of a large database of pseudo-invariant features. These features are extracted automatically from cloud-free reference images, and selected according to a texture criteria (Harris corners). A first loop over 100 products is used to remove features with a low temporal correlation.

Once the database is generated, it is possible to monitor the relative evolution of the radiometry and the geometry of the features. Due to the large number of features, one can construct robust indicators by binning the measurements over small temporal periods.

We will present recent results on Sentinel-2 products obtained with this method.

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Session #3: Level-2 Validation

Sentinel-2 Level-2 Processing Sen2Cor Status and Outlook

Louis J[1], Debaecker V[1], Pflug B[2], Main-Knorn M[2], Mueller-Wilm U[3], Quirino Iannone R[4], Gascon F[5], Boccia V[5]
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The 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 generated by Sentinel-2 PDGS since March 2018, in terms of Cloud Screening and Atmospheric Correction.

In addition the presentation will give an outlook on the upcoming improvements available in the Sen2Cor development branch: preliminary results obtained for cloud screening over bright surfaces, cirrus detection in mountainous areas are presented. Concerning atmospheric correction, the novel method using meteorological information from the Copernicus Atmosphere Monitoring Service will be introduced.

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Radiometric Performance Assessment of Sen2Cor Version 2.8

Pflug B[1], Louis J[2], Main-Knorn M[1], Debaecker V[2], Mueller-Wilm U[3], Gascon F[4], Boccia V[4]
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Sen2Cor is a Level-2A processor which main purpose is to correct monotemporal Sentinel-2 Level 1C products from the effects of the atmosphere in order to deliver radiometrically correct surface reflectance (SR) images. By-products are Aerosol Optical Thickness (AOT), Water Vapour (WV) and Scene Classification (SCL) maps. Sen2Cor can be downloaded from ESA website for individual processing by the users. In parallel, Sen2Cor is used for systematic L2A-processing of Sentinel-2 acquisitions over Europe since June 2017. Operational global L2A-processing with the integration of Sen2Cor in Sentinel-2 ground segment (PDGS) started in December 2018.

The presentation provides validation results for AOT and WV maps and performance assessment of the SR retrieval of Sen2Cor version 2.8 which is scheduled for release in January 2019. AOT and WV retrieval is validated by direct comparison of Sen2Cor outputs with reference data provided by AERONET sunphotometers. Quality assessment of SR output of Sen2Cor is based on a reference obtained by running the atmospheric correction with the AOT provided by the AERONET as input. The analysis is performed within 9 km x 9 km area around the location of sunphotometer for more than 20 AERONET sites around the globe, covering different land cover types, latitudes, climate zones and atmospheric conditions.

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Validation of Sen2Cor 2.5 cloud masking and classification

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Sen2Cor is a Level-2A processor for Copernicus Sentinel-2 data, used by ESA for systematic global L2A-processing since December 2018. Main purpose of Sen2Cor is to correct Sentinel-2 Level-1C data from the effects of the atmosphere and to deliver a Level-2A surface reflectance product. Additional products are an Aerosol Optical Thickness (AOT) map, a Water Vapour (WV) map and a Scene Classification (SCL) map with Quality Indicators for cloud and snow probabilities.

The basic framework of the Sen2Cor processor consists of two main modules: the Scene Classification (SCL) and the Atmospheric Correction (AC). The SCL algorithm allows to generate a classification map encompassing 11 classes including clouds, their shadows and snow. This map is used internally in the Sen2Cor AC module to distinguish between cloudy, clear and water pixels, but it is used by the scientific community also for further applications. Therefore systematic accuracy assessment of the SCL products is indispensable and their improvement should be endeavored.

The presentation provides an overview of the validation procedure and validation results for Sen2Cor 2.5 in terms of cloudy pixels, clear water pixels, and clear land pixels recognition. Additionally, current limitations of the algorithm and improvements are presented.

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Validation of the L2A and L3A surface reflectance products for Sentinel-2 delivered by Theia

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Thanks to its open access policy, its systematic and frequent revisit, and its data quality, the Copernicus Sentinel-2 mission revolutionizes the optical earth observation at a high resolution. Before the Sentinel era, most users only had access to a very limited number of images per year on their sites, and used to process the data manually or at least in a very supervised manner. The amount of data provided by Sentinel pushes the users to automatize their processing, or reciprocally, a manual approach would prevent an efficient use of the data provided by Sentinel-2. To allow a robust and automatic exploitation of Sentinel-2 data, Analysis Ready Data products are therefore requested by most users. These ARD products take care of the common burdens necessary for most applications, that include the cloud detection and atmospheric correction steps.

Indeed, the main sources of noise in Sentinel-2 reflectance time series over a given site are the presence of clouds or cloud shadows, and the atmospheric effects due to the variations of atmospheric composition, with a particular sensitivity to the variations of aerosol optical properties. Thanks to the Sentinel-2 feature which allows to observe a given site with constant viewing angles, the anisotropy of earth reflectances only cause issues (directional effects) when trying to build time series issued from different orbits or when trying to stitch data from adjacent paths. To allow a robust exploitation of the information provided by Sentinel-2 satellites, users must have access to high quality time series of surface reflectance, which includes an accurate and robust cloud detection, and corrects data from atmospheric effects to reduce the noise. This is the role of the Level 2A product. The French Land Data center, Theia, produces and distributes Level 2A products (L2A) thanks to the Maja processor, developed by the French and German space agencies, CNES and DLR, and the Centre d'Etudes Spatiales de la BIOsphère (CESBIO). Compared to classical processors based on multi-spectral relations to detect clouds and estimate aerosol content, Maja also involves multi-temporal criteria, based on the fact that land surface reflectance tends to change slowly compared to the atmospheric contribution, including clouds and aerosols.

A large scale validation effort has been done to measure the accuracy of the L2A products generated with MAJA, including the development of a method to build reference cloud masks interactively and efficiently, the use of atmospheric aerosol measurements from the Aeronet Network, or the verification of surface reflectance using automated ground stations in three sites. These validation results against ground truth data are complemented with statistical tools to measure the noise on time series. All these tools indicate that the noise on time series is around 0.01 in reflectance units. But even with accurate surface reflectance and cloud masks, Sentinel-2 data are still complicated to use for a lot of users. The presence of clouds causes spatial and temporal data gaps in the time series that have to be handled by automatic processing, and the swath of Sentinel-2 satellites is limited. It is therefore impossible to observe a large region in one overpass, and users have to rely on data acquired on different dates, which can cause apparition of artifacts at the limits of swaths or around the data gaps due to clouds. Overcoming this difficulty is the role of the Level 3A product (L3A), which provides a monthly synthesis of cloud free surface reflectance. Theia has started distributing L3A products to users based on the Weighted Average Synthesis Processor (WASP), which simply makes a weighted average of surface reflectances after a directional correction to normalize data acquired from different swaths. The WASP processor has been designed by minimize the artifacts, and does it quite well as it may be seen on the joined image. The low level of visible artifacts mainly results from the quality of the L2A products generated by MAJA.

Our presentation details the methods behind MAJA and WASP processors and provides validation results concerning the quality of cloud detection and atmospheric correction, as well as the quality of L3A syntheses.

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Feedback from the Copernicus Sentinel 2 Global Mosaic Service on S2 Level 2A products

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The Sentinel-2 Global Mosaic (S2GM) is a service within the Copernicus Global Land Monitoring service that has been tailored to fulfill the requirements of REDD+ monitoring and other users. It provides convenient and free access to scientifically sound, analysis-ready surface reflectance data from Sentinel-2A and B, which are offered as temporal composites with different compositing periods from one day to one year. The S2GM products are based on the ground segment L2A product as inputs. Before mosaicking and compositing, the input data undergoes a rigorous quality control and different strategies are applied to obtain an optimal cloud screening based on the L2A scene classification and radiometric consistency.

The S2GM algorithm selects an original observation per pixel, which optimally represents the time-series of observed spectra in the given compositing period. Depending on the number of valid observations in the compositing period, either a multi-dimensional median, the MEDOID algorithm, or a Short-Term composite algorithm, which has been adapted from Landat's WELD algorithm, is used to select the optimal observation. It is worth noting here, that no further processing is applied on the data to manipulate the spatial variability of the S2GM products.

The quality of the mosaiked and temporally composed product critically depends on the quality of the L2A input product, in terms of geometric quality, radiometric quality and consistency, and the scene classification. The robustness of the production chain also depends on the formal quality of the L2A input products on ESA's distribution services, i.e. naming convention, meta data and product management. The service has been operated in a ramp-up phase since July 2018, and in full operations since October 2018. We encounter only minor problems with formal aspects, and also the radiometric accuracies as well as the radiometric consistency between Sentinel 2-A and B is of good quality. The geometric quality is still under investigation. The scene classificaiton has improved within 2018 but still is the major source affecting the final product quality. In this presentation we will summarise our finding after 8 months of operations

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CMIX and ACIX: Cloud Masking and Atmospheric Correction Inter-comparison Exercises

Doxani G[1], Vermote E[3], Roger J[3,4], Gascon F[2], Skakun S[3,4], Brockmann C[5], Pahlevan N[3], Mangin A[6]
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Free and open remote sensing data policy allows access to a big volume of remote sensing data, which together with the advanced cloud computing services, facilitate significantly the analysis of long time series. The consistent study of land surface though implies the correction of the atmospheric impacts when optical observations are involved. Many users request nowadays surface reflectance Analysis Ready Data (ARD), meaning data already geometrically, radiometrically and atmospherically corrected for downstream analyses with a minimum user effort. Consequently, several entities have already started to generate, or they plan to generate in the short term, surface reflectance ARD at a global scale for Landsat-8 (L-8) and Sentinel-2 (S-2) missions using suitable atmospheric correction (AC) approaches.

In this context, European Space Agency (ESA) and National Aeronautics and Space Administration (NASA) initiated the Atmospheric Correction Inter-comparison eXercise (ACIX) in the frame of CEOS WGCV (Committee on Earth Observation Satellites, Working Group on Calibration and Validation). The first ACIX was completed in February 2018 allowing a first comparison of AC processors for L-8 and S-2. The input data were L-8 and S-2 products over various sites of different land cover types around the world, i.e. agricultural, deserts, urban, snow and coastal areas. The description and inter-comparison results of this first experiment can be found in the dedicated to ACIX web page (http://calvalportal.ceos.org/projects/acix).

The subsequent improvement of the participating processors and the increasing interest of AC developers to be part of the experiment, stimulated the continuation of ACIX and its second implementation (ACIX II). An additional inter-comparison of cloud masking processors was decided to be performed (CMIX) in parallel with ACIX . Cloud masking is a crucial step of the radiometric pre-processing of optical remotely sensed data and an important contributor to the retrieval of accurate surface reflectance within an AC process. Therefore, it was considered essential to analyse these two processing chains together. In this second experiment particular attention will be given also to aquatic sites, i.e. coastal and inland waters, which they will be analysed as a separate sub-category (ACIX II-Aqua). All the exercises, i.e. CMIX, ACIX II-Land (focused on land) and -Aqua (focused on water) will run in parallel and follow the same timeline. The protocols of their implementation will be presented in this talk, indicating the various study sites, inter-comparison metrics, validation datasets, products, etc. Up to date 35 developer teams from nine countries participate in both ACIX II and CMIX exercises. In continuation of the first ACIX achievements, the outcomes of this second experiment are expected to provide a complete and enhanced standardised approach to inter-compare CM and AC processing products, i.e. Cloud Masks, Aerosol Optical Thickness, Water Vapour, Surface Reflectance and Water Leaving Radiance, and to quantitatively assess their quality when in situ measurements are available.

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Multi-algorithm atmospheric correction for the Sentinels 2 A&B: an opportunity to optimize the Level 2 products for end users

Saulquin B[1], Martin-Lauzer F[2], Alhammoud B[2]
[1]Acri-ST, [2]Argans

Today, level 2 products are processed daily using the Sen2cor algorithm over lands and waters. Nevertheless, Saulquin et al. 2019 (1) show that the Sen2cor surface reflectances are perfectible over waters. In the same time, multiple and innovative algorithms have been developed using the Sentinel 2 L1A observations for atmospheric corrections over waters. The ongoing ESA ACIX II inter-comparison exercise aims currently at assessing the different proposed solutions.

From an operational point of view, it is clear that the delivery of multiple L2 products involves many issues in terms of data storage, versioning, and end user understanding. These latest, who are for the most of them non-specialist of atmospheric corrections, are often confused by the availability of numerous level 2 products that should address the same products. These issues has been raised and addressed by Saulquin et al. 2018 (2) in the scope of the Copernicus Marine Environment Service.

In the first part of the presentation, and following the objective of this third S2VT to gather feedback and exchange on mission Level-1 and Level-2A products radiometric, we show validation results (>250 matchups) of the estimated surface reflectances using the official Sentinel-2 Sen2cor products over land and waters, including the Aeronet networks, the Moby and the Boussole in-situ datasets. We show also the preliminary validation results of the LAC (3) and the MeetC2 (4&5) atmospheric correction processors for the ongoing ESA ACIX II exercise over waters. These results clearly underlie the need to use both algorithms dedicated for the waters and the lands.

Adapting the methodology developed in Saulquin et al. 2018 (2) we show how to merge different algorithms using a membership probability to a type of observed targets, typically from lands to coastal and/or open waters. The membership probability is obtained using a spectral angle and the level 1 observations. Beyond the proposed particular application we show how this approach paves the way to generic methodologies to optimally merge multiple-algorithm retrievals; the underlying idea being to use the ‘best’ dedicated algorithm for the detected target and including smooth transitions.

As a show case and in the second part of the presentation, we show the results of the merged surface reflectances compared with the Aeronet-OC for both land and waters. We show i/ the enhancements compared with the in-situ data; ii/ the spatial continuity of the merged product provided by the continuous membership probability and the two algorithm retrievals. Finally, we also show how to merge and validate the merged uncertainties provided by each algorithm and each pixel.

(1) Saulquin B. et al. multi-scale and multi-algorithm atmospheric corrections for the Sentinels 2, In writing process.

(2) Saulquin, B., Gohin, F., & Fanton d’Andon, O. (2018). Interpolated fields of satellite-derived multi-algorithm chlorophyll-a estimates at global and European scales in the frame of the European Copernicus-Marine Environment Monitoring Service. Journal of Operational Oceanography, 1-11.

(3) LAC: L2 processor from the SEOM project for an operational atmospheric correction for Sentinel-2 above coastal and inland waters team.

(4) Saulquin, B., Fablet, R., Bourg, L., Mercier, G., & d'Andon, O. F. (2016). MEETC2: Ocean color atmospheric corrections in coastal complex waters

using a Bayesian latent class model and potential for the incoming sentinel 3—OLCI mission. Remote Sensing of Environment, 172, 39-49. MeetC2 is freely available for users in the ESA coastal TEP ; go to the "Processors" Tab select "Other" and "MeetC2"
(5) Bertrand Saulquin, François-Régis Martin-Lauzer, Bajhat Alhammoud: Level 2 validation of the Sentinels 2 A&B over waters: state of the art and opportunities.

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Enhancing Compatibility of Sentinel-2 and Landsat products for improved monitoring of the Earth System

Vermote E[1]
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This work describes the steps to ensure validation of the Sentinel 2 reflectance products. We are focusing on calibration/atmospheric correction/cloud, cloud shadow screening. Accurate radiometric calibration is a prerequisite to creating a science quality, time series of surface reflectance and consequently, higher order downstream products. Calibration errors propagate directly into the surface reflectance and create artificial variations that can be misinterpreted as trends, especially if these variations are due to decay in the calibration mechanism. Vicarious calibration provides an additional source of calibration information, to verify and evaluate on-board calibration. We have successfully developed and applied a variety of approaches for several sensors that we are applying to sentinel 2. The atmospheric correction approach, LaSRC (Land Surface Reflectance Code) that we adapted for Sentinel 2, has been developed originally for MODIS but applied to a variety of sensors including Landsat 8 and VIIRS. A theoretical error budget has been developed for LaSRC that relies on rigorous traceable radiative transfer (6SV) and its validation relies on a protocol approved by consensus by a group of international atmospheric correction experts (ACIX). We will present the assessment of performance of the LaSRC sentinel 2 surface reflectance product and its comparison to the Landsat 8 reflectance product. Finally, we will show some results of the LaSRC cloud/Cloud shadow mask for Sentinel 2 using a newly developed cloud validation dataset based on ground based image of the sky.

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Field-based Validation of the Digital Earth Australia Sentinel-2 Surface Reflectance Product

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The effective utilisation and uptake of long-term records of environmental Earth observations, by both government and private sectors, requires Analysis Ready Data (ARD), processed to a minimum set of requirements and organised into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets. Geoscience Australia's Digital Earth Australia (DEA) initiative, funded by the Australian Government, is a unique digital infrastructure and analysis platform that supports the effective utilisation of a range of Earth observation (EO) data collections that span multiple decades.
The DEA Sentinel-2 Surface Reflectance (SR) dataset is a foundational ARD product that enables dense time-series analyses and rapid generation of other downstream information products. Validation of the satellite derived surface reflectance by conventional ground-based observations is critical to characterise uncertainties that determine its fitness for purpose and also important for downstream product development. During 2018, a continental scale validation of the DEA Sentinel-2 SR product was undertaken by coordinated field teams from multiple organisations across Australia.
Around 30 Sentinel-2 overpasses were validated using near synchronous field-based measurements at multiple field sites across Australia. The validation exercise applied best practice field measurement protocols, including field instrument calibration, sampling strategy and approach for post-collection processing and management of field spectral data. This paper reports on the methodology and results of field validation of the DEA surface reflectance product from Sentinel-2 acquisitions over Australia during 2018-19. The collaborative national field data collection campaign in Australia including the identification of permanent field sites, to support the validation effort within the international EO community is expected to serve as a model for coordinated ongoing validation of SR derived from a range of EO platforms at continental to global scales.

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Products validation plan in the AFRICULTURES project

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FAO estimation (State of Food Insecurity in the World 2015) on the number of undernourished people in 2016 was around 795 million. In sub-Saharan Africa, one in every four people, or 23.2% percent of the population, are hungry. According to FAO, "food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (1996 World Food Summit)". From this definition four main components of food security have been defined:

[FAO-FS.1] the physical availability of food, which is related to the production of food itself;

[FAO-FS.2] the economic and physical access to food;

[FAO-FS.3] food utilization by individuals, that determines the nutritional condition of the people; and

[FAO-FS.4] the stability of the three precedent factors over time. Food security is achieved when all the components introduced above are convergent in a given area along time.

Earth Observation (EO) alone is capable to make NRT observations, however lacks the capability to accurately predict food production in a given area. To cope with the complexity of terrestrial systems adequately, a wide variety of data must be recorded. Such data may vary in:

[1] spatial scale, ranging from in-situ collected point information to satellite imagery providing spatially continuous information about the area of study; and

[2] in temporal scale, ranging from past observations to future scenarios analysis and forecasts.

Therefore, tackling food security requires a holistic approach based in the collaborative integration of complementary earth and atmosphere sciences to pave the way forward to accurately map and forecast food production.

Joint exploitation of time series of past and present climate information and EO data coupled, through predictive analytics, with crop models, allow better understanding about the earth surface dynamics affecting food production, hence decision makers can be provided with accurate information to analyse key questions related to food production.

Aligned with the principles exposed above, AfriCultuReS is a 4 years project funded by EC in the framework of the H2020 initiative, which will provide decision makers on food security in Africa with the information and tools required to enrich and improve multi-level decision making. AfriCultuReS will design, implement and demonstrate a holistic Food Security Spatial Decision Support System (FS-SDSS) that will integrate EO data, in situ and crowd-sensed information, crop models, weather forecasts, climate seasonal predictions and climate projections and socio-economic parameters to support science backed decision making on food security. AfriCultuReS will apply geospatial science and enabling technologies to sustainable agricultural development, natural resource management, biodiversity conservation, and poverty alleviation in Africa.

The project will involve all key players of AfriGEOSS, GEOGLAM, SIGMA, ARTEMIS, African Drought Observatory and other initiatives as well as local partners and stakeholders representing the diversity of African agricultural systems, in an effort to push forward the services provided by current monitoring and early warning systems, with innovative fusion of data from multiple sources (EO, in-situ monitoring networks, citizen-based crowdsourcing) in a vertical manner.

Even if the project will integrate EO data and products coming from different satellite imagery preference will be given at exploiting Sentinel-2 and Copernicus data and products.

Eight (8) test area have been selected, one for each of the countries where the African partners of AfriCultuReS are based. In this manner, the validation and test phases will be developed in: Tunisia, Niger, Ghana, South Africa, Mozambique, Kenya, Rwanda, and Ethiopia.

For this reason, a detailed survey on available instruments and sensors for data monitoring and recording, by the partners has been carried out. Based on this survey the validation strategy will be planned in the next few weeks.

AfriCultuReS project foresees two validation phases:

- A validation phase devoted at assessing the accuracy of some of the products on which the project services portfolio is based.
- A validation phase devoted at testing project products and services delivery chain. This activity will be performed by the respective developer in their own facilities.

Crowdsourcing via smart phones is an emerging trend in agricultural monitoring projects, where the "citizen-as-a-sensor" concept ensures that crucial information from the field reaches decision makers. AfriCultuReS will promote this concept, aiming to enrich the data sets upon which the products and services validation activity will be based.

The paper aims at presenting the plan for the Sentinel-2 products validation activity, which will be carried out in the next few months.

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Experiences with Sentinel-2 data in the Belgium Collaborative Ground Segment Terrascope

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[1]Vito

Terrascope, ESA's Collaborative Ground Segment in Belgium, provides the Belgian user community access to Sentinel-1, Sentinel-2 and Sentinel-3 data, as well as the full SPOT-VEGETATION and PROBA-V archive. Currently, Sentinel-2A and Sentinel-2B L2A-data as well as four vegetation indices (LAI, NDVI, fAPAR, fCOVER) over the Belgian territory are accessible on www.vito-eodata.be and via https://viewer.terrascope.be

These images are geometrically and atmospherically corrected using VITO's Sentinel-2 processing workflow which incorporates sen2cor for masking and iCOR for atmospherical correction. New value added products will become available, driven mainly by the Belgian user needs, both in the public and private sector.

In this presentation we will demonstrate the experiences, issues, and validation activities in the framework of Terrascope. Focus will be on i) the geometric quality of the Sentinel-2 L1 products, ii) comparison between the sen2cor scene classification layer and other existing tools; iii) L2A- iCOR validation activities and comparison with the output of Sen2cor/MAJA as well as iv) validation activities of the different L3 products.

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Sentinel-2 Surface Reflectance Validation Over Vegetation for the FRM4Veg project

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The Fiducial Reference Measurements (FRM) programme implemented through ESA is designed to develop reliable and transparent measurement and validation standards and processes for satellite data products. This includes tracing information back to its source and accounting for uncertainties in the data as well as conducting independent validation assessments of land surface products following best practice guidelines. The Sentinel-2 L2A surface reflectance product was identified as one of the key products to assess as part of FRM4Veg. The aim is to create and test a validation protocol which facilitates the production of FRM ready validation data. This includes the collection and processing of in-situ data as well as the satellite product processing.

Surface reflectance is the base product from which several other Level 2 products such as albedo, LAI, and fAPAR are derived. This means it is vital that surface reflectance quality is demonstrated over a range of land covers. Validation over vegetated areas is particularly challenging because of its unique spectral and structural characteristics. However, confidence in the surface reflectance information for vegetated land covers is crucial due to the requirement for analysis ready data in forestry and agricultural applications. Similarly, Sentinel-2 products (particularly surface reflectance) are often used to validate coarser resolution satellite products since they have a spatial resolution that can be more readily approximated by in situ sensors. Therefore, understanding their quality is also important for downstream validation activities.

The FRM4VEG project focused on two field sites: an agricultural field site (Barrax, Spain) and a deciduous forest (Wytham Woods, UK). The measurement campaign and ancillary data collection considers subtle differences between the measurement configuration employed by the satellite and that attainable in the field. We also discuss the sampling trade-offs that were made in order to conduct the measurements within an acceptable time period around the satellite overpass. This trade-off is mitigated by potential solutions using unmanned aerial vehicle (UAV) technology, which we evaluate at the Wytham Woods field site.

The validation procedure considers all the main uncertainty sources such as sampling design, instrument calibration, product definitions, and instrument configuration. The uncertainty derived during the instrument and panel calibrations are propagated through to the calibrated reflectance values and combined with ancillary data streams (e.g. diffuse fraction) along the way, accounting for the correlation between the data inputs. This leads to measured values which correspond directly with the satellite product, and are SI traceable.

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Validation of Sentinel-2 LAI and fAPAR products derived from SNAP Toolbox over forests and crops sites using fiducial reference measurements collected under the FRM4VEG project

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Land biophysical variables (i.e., LAI and fAPAR) are recognized as an Essential Climate Variable by the Global Climate Observing System, since they are useful for a wide range of thematic fields such as the global crop monitoring or the food security applications. Sentinel-2 satellites offer the chance of retrieving such biophysical variables with an outstanding spatial resolution of 10 m, every 5 days combining temporal revisit of Sentinel-2 platforms A and B. In this context, has become crucial to ensure high quality data from such EO missions, and to achieve this goal, data quality controls through calibration and validation activities are mandatory to satisfy potential user demands.

The Fiducial Reference Measurements (FRM) for Vegetation (FRM4VEG) project is focused on establishing the protocols required for traceable in-situ measurements of vegetation-related parameters to support the validation of Copernicus products from Sentinel-2, Sentinel-3 and Proba-V. In the context of the FRM4VEG project, two field campaigns were performed during 2018 in the cropland area of Barrax (Spain) and in a woody forest close to Wytham (UK) where LAI and fAPAR data were collected using LAI-2200 and Digital Hemispherical Photograph over around 50 Elementary Sampling Units (ESUs) in each site. Ground uncertainties were assessed and the quality of field data was checked certifying that it is suitable for satellite validation. Furthermore, the ground data was upscaled using Sentinel-2 data and Orthogonal Distance Regression (ODR) to account for uncertainties in both ground and satellite data. The ground-based Sentinel-2 LAI and fAPAR maps are derived with uncertainty and quality flag information.

In this study Sentinel-2/MSI LAI and fAPAR products estimated using the Biophysical Processor (BP) toolbox of SNAP are validated using the FRM collected in both FRM4VEG campaigns. The validation is performed in two steps: first, direct comparison with FRM collected over ESUs in Barrax and Wytham; secondly, inter-comparison with the ground-based LAI and fAPAR maps over the study area. Validation results for Sentinel-2 BP LAI and fAPAR products using FRM data will be analyzed and main conclusions will be presented

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Sentinel-2 support in Karstic fresh water detection on SPM & CHL maps a matter of MSI sensors' sensitivity and L2a processing

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Detection of fresh water, whether from underwater springs (with a conduit or underwater riverines in rocky conduits) or Submarine Ground water Discharge (SGD) from water tables in soft/unconsolidated sediments is difficult to perform, because the mixing of water from the outlet to the sea-surface blurs the signature, e.g. a remaining few ° of temperature to be spotted with TIR sensors on-board satellites (ASTER, Landsat-8), and too large spatial resolution (40 km) with EO missions like SMOS and SMAP. Remains the detection of sea-surface roughness, but with a few pixels of SAR data such as Sentinel_1's affected by the resurgence (diameter equivalent to the depth), and the detection of modified sea-bottom habitats, changes in SPM due to the vertical currents and as well as phytoplankton and zooplankton concentration in the water column. To detect the latter in Sentinel-2/MSI data sets, one needs the sensor to be very sensitive and the atmospheric correction to be relatively accurate, i.e. spatially. We demonstrate hereby that it is feasible, allowing us to get a proper assessment of the relative accuracy of the S2 MSI L2a measurements.

Figure 1: Groundwater exchange between the land and the sea

–the conduits of water (underground riverines) in Karsts are not represented as we show generic aquifers that have porewater exchanges (SPE), or groundwater discharges (SGD); same for river discharge, the traditional pathway for discharge from land to the ocean in the global water cycle (not only are rivers highly visible open channels that discharge water from great distances inland, but their contributions to the oceans are easily quantifiable); yet SGD per unit length of coastline is a very significant discharge process, because the length of coastline where SGD occurs is very great, and will occur whether or not rivers are present…

 submarine springs, which are found in many parts of the world represent the most glamorous and exotic form of SGD

For the record, karst regions with potential submarine springs represent 7–12% of the Earth's continental area, and about one quarter of the global population is dependent on drinking water from karst aquifers (sources…).

This study is completed in two steps to figure out fresh water positions in sea.

First, analysis in terms of temperature (Sea Surface Temperature) using Landsat_8 thermal bands 10 and 11. In this step, huge spots are highlighted to be fresh water signature.

Second, turbidity and chlorophyll are analyzed using Sentinel-2 images.

This step is important along with thermal analysis. It indicates the level of agitation (turbulence) in the sea, e.g. due to wave agitation, and is a good passive tracer for plume and flux detection. A specific processing chain developed by ARGANS is performed. It includes atmospheric correction to access physical information contains on images.

For BOA Reflectance images, pixel value is encoded on 16 useful bits and is directly proportional to Bottom-Of-Atmosphere reflectance values. Pixel values can go from 0 to 65536. This allows having a huge sensitivity and accuracy.

Turbidly and Chlorophyll values are derived from reflectance values of specific bands of SENTINEL_2. For CHL bands are B2 (490 nm, blue color) and B3 (560 nm, green color) and for SPM the red band (B8, 842 nm) is used.

This method detected 175 fresh water signatures in first step and is validated in a karstic area of 20. 104ha.

Figure 3: SPM map, standard deviation about 2. 103

Figure 2: CHL map, standard deviation about 2. 103

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First Results From WATERHYPERNET - a Network of Hyperspectral Radiometers for Multi-satellite Water Reflectance Validation adapted to Sentinel-2ABCD

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A network of hyperspectral radiometers is being developed for radiometric validation of satellite missions. 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 consists of one radiance and one irradiance sensor on a pointing robot, controlled by a microprocessor and supplemented with GPS, inclinometer and video camera data feeds. The measurement protocol is based on the abovewater method of [Mobley, 1999 and 2015], but includes additional scenarios for different viewing zenith and azimuth configurations. The system is being deployed initially in Belgian coastal and inland waters, then at sites in Argentina and France before full international expansion. The network will provide water reflectance data for the radiometric validation of all visible and near infrared bands of all optical missions, including Sentinel-2A&B, Sentinel-3A&B, PROBA-V, MODIS-AQUA&TERRA, VIIRS, Landsat-8, Pléiades, CHRIS-PROBA, MSG-SEVIRI, PlanetDove … PRISMA, ENMAP, PACE, MTG and ... any future optical missions, including nanosatellites. This presentation will provide results from prototype testing on Aqua Alta Oceanographic Tower in July 2018, including a comparison with a conventional manually-operated TRIOS/RAMSES system and the automated AERONET-OC data from this site. The specific application to validation of the wide and asymmetric bands of Sentinel-2A and -2B will be described. Research in progress on the abovewater measurement protocol and the operational plan for characterisation of all radiometers will also be outlined.

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Validation of Radiometric Products Over Optically Complex Waters

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Sentinel-2 MSI has suitable 10, 20, 60 meters spatial resolution for monitoring small inland waters, however it is originally meant for monitoring land cover. High revisiting with two satellites Sentinel-2A and Sentinel-2B, gives opportunity to estimate water quality more frequently than traditional monitoring methods (water samples collection and further analysis in the laboratory). However, suitable atmospheric correction is essential procedure for removing influence caused by atmosphere for deriving water quality parameters (e.g. chlorophyll a (chl a), total suspended matter (TSM), colored dissolved organic matter (CDOM)) from the satellite images. Estonian lakes represent optically complex waters, with high CDOM and chl a concentration. In situ radiometric data is measured simultaneously with Sentinel-2 overpass and is compared with water-leaving reflectances derived from atmospheric correction processors ACOLITE, C2RCC, Sen2Cor and POLYMER. Results indicate that adjacency effect and high absorption by CDOM produce inaccuracies in derived water-leaving reflectance products and blue and NIR bands are associated with higher uncertainties.

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Estimating Leaf Chlorophyll from Sentinel-2 Data in a Temperate Forest

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Leaf chlorophyll has a vital role in physiological activities and forest health. The performance of Sentinel-2 data and INFORM radiative transfer model for retrieval of leaf chlorophyll content in the spruce stands of a temperate forest is evaluated. Leaf properties, as well as stand structural characteristics, were collected in the Bavarian Forest National Park (BFNP), Germany, concurrent with the timing of the Sentinel-2 image. Leaf chlorophyll was measured both destructively and undestructively. The INFORM radiative transfer model (RTM) was used in the forward mode to generate a lookup table (LUT) using information obtained from the field campaign. The root mean square errors (RMSE), and the coefficient of determination (R^2) between the measured and retrieved leaf chlorophyll were then used to evaluate the obtained results. The use of multiple solutions and spectral subsets in the inversion process were further investigated to enhance the retrieval accuracy of foliar chlorophyll. In general, an agreement between the simulated and measured reflectance spectra of Sentinel-2 was observed, particularly in the visible and red-edge regions. However, examining the average absolute error between the measured and simulated reflectance revealed a large discrepancy in spectral bands around the near-infrared shoulder. A reasonable relationship between the measured and retrieved leaf chlorophyll content using the Sentinel-2 data was observed (RMSE=8.6 ug/cm², R^2=0.45). Using the mean of the ten best solutions improved the retrieval error (RMSE=8.1) When the three red edge bands of Sentinel-2 were used as the spectral subset, the retrieval error of leaf chlorophyll decreased Our findings emphasise the importance of multispectral satellites which benefits from red edge spectral bands for regional mapping of vegetation foliar properties.

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Session #4: Downstream Products Validation

The Copernicus Ground Based Observations for Validation (GBOV) dataset: opportunities for validating Sentinel-2 L2B downstream products

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Recognising the need for quality assurance of bio-geophysical products derived from earth observation data, the European Commission's Joint Research Centre (JRC) recently initiated the 'Ground Based Observations for Validation (GBOV)' service, which aims to develop and distribute robust in-situ datasets for the purposes of direct validation. In the first component of the project, 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, surface reflectance, 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 vegetation variables considered in the project, namely leaf area index (LAI), the fraction of absorbed photosynthetically active radiation (FAPAR), and the fraction of vegetation cover (FCOVER). In the case of all three 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 RMs produced during the first year of the project cover 20 sites between 2013 and 2017, representing a wide range of vegetation types (including cropland, deciduous forest, evergreen forest, grassland, and shrubland). Using these RMs, we evaluate the performance of the L2B retrieval algorithm made available to users in the Sentinel Application Platform (SNAP), in addition to alternative methods including statistical retrieval using vegetation indices and the JRC FAPAR algorithm. Finally, potential improvements to the investigated retrieval algorithms and the GBOV dataset are discussed.

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Advanced surface/atmosphere characterization with GRASP algorithm: application to space-borne measurements with fine spatial resolution

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Nowadays simultaneous treatment of aerosol and surface properties retrieval is considered as powerful tool for advanced surface/atmosphere characterization and monitoring. This approach can be applied for the instrument with different spatial resolution.

New possibilities for accurate extended aerosol and surface properties retrieval are opened recently in the enhanced retrieval algorithm like GRASP (Generalized Retrieval of Aerosol and Surface Properties). It was already demonstrated that simultaneous aerosol/surface retrieval with GRASP algorithm from the space-born instruments of moderate and coarse spatial resolution (PARASOL, MERIS, GOCI etc.) can provide accurate and extended characterization of both aerosol and surface.

GRASP development for simultaneous aerosol/surface properties retrieval in fine spatial resolution will be presented. The results of GRASP/Sentinel-2 retrievals and validation will be discussed.

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Radon-augmentation of Sentinel-II imagery to enhance resolution and visibility of (nearshore) ocean-wave patterns

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Earth observation from space enables the scientific community to investigate, learn about and understand large-scale, global, processes such as climatological changes. Nearshore ocean wave patterns are important to derive large-scale environmental forcing and relate those to (coastal) societal risks (e.g. flooding). Through earth observation programs such as ESA' Sentinel constellations, revisiting times are reduced to at best a few days and deliver imagery at 10 m to 60 m resolution. Here, a technique is presented based on a local Radon-Transformation to enhance the visibility of wave patterns and augment their resolution. The latter aims to unify different detector bands of Sentinel-II (10, 20 or 60 m) to 10 m resolution. This results in 9 high-resolution (10 m) wave patterns reconstructions per Sentinel acquisition instead of 4 (RGB+NIR). A further application to other satellite constellation such as NASA' Landsat or CNES' SPOT creates coherency between wave-patterns and allows to join forces, e.g. reducing the revisiting times to near-daily and enlarging the probability of usable optical satellite data.

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Sentinel 2 Water Quality Products Generation and Validation

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Monitoring water quality in lakes and reservoirs is key in maintaining safe water for drinking, bathing, fishing and agriculture and aquaculture activities. Long-term trends and short-term changes are indicators of environmental health and changes in the water catchment area. Directives such as the EU's Water Framework Directive or the US EPA Clean Water Act request information about the ecological status of all lakes larger than 50 ha. Satellite monitoring helps to systematically cover a large number of lakes and reservoirs, reducing needs for monitoring infrastructure (e.g. vessels) and efforts.

The Copernicus "Global Land Service – Lake Water", CGLOPS, provides an optical characterization of important inland water bodies which are of specific environmental interest. The products contain four (sets) of parameters: lake water surface temperature, lake water reflectance (all wavebands that are available after atmospheric correction), turbidity (derived from suspended solids concentration estimates) and a trophic state index (derived from phytoplankton biomass by proxy of chlorophyll-a). Production and delivery of the parameters are over 10-day intervals on a set grid (starting the 1st, 11th and 21st day of each month) and mapped to a common global grid at 300m spatial resolution with Sentinel-3 OLCI data as input, and will start in 2019 operational production of 100m products based on Sentinel 2. The algorithms used to derive the input for the optical lake water products are implemented in the Calimnos processing chain and were tuned and validated against predefined optical water types.

The multisensor water quality processor C2RCC is a neural network based method for atmospheric correction and water quality processing of optical satellite sensors, including Sentinel 2, OLCI and other sensors. It is used in the Sentinel 3 ground segment for operational production and is available for Sentinel 2 (and all other sensors) through the SNAP toolbox.

The authors of this presentation are responsible for the Copernicus Water Quality Service and develop the C2RCC processor. In this presention we summarize the validation activities and results obtained recently with these different processing options.

Various complementary validation methods were applied to assess the quality of the lake water products. Time series of selected lakes were extracted and plotted for selected variables in to assess seasonal trends, outliers and any unexpected patterns. Visual inspection has been performed in order to assess spatial behaviour of different variables and the the distribution of values (histograms) and to assess the quality of the pixel identification (idepix flagging). Validation against in situ data was carried out to assess (a) time series (Level 2 products) at selected measurement stations and (b) match-ups. For the match-up analysis, the time difference between an in situ measurement and the day of acquisition is set to max. +/-3 hours which is considered an upper limit for inland waters. For most of the comparison exercises with in situ data, a window of 3 x 3 pixels (macropixel) around the location of the measurement stations has been extracted from the satellite products and filtered for invalid pixels before averaging. Consistency tests have been performed that compare the outcome of different sensors (MERIS, OLCI, MSI). Here, time series have been plotted and in case of not-matching temporal overlap, the seasonal trends are compared inner annually.

The assessment of the Sentinel-2 derived surface reflectances and water quality products with C2RCC and CGLOPS products will be presented. Issues are identified, such as negative values in some clear waters for CGLOPs. Some developed processing steps still need to be included in next versions of the products, in particular a cloud shadow masking developed recently. The relative comparisons show slight overestimation of the water leaving reflectances in the blue bands in S-2 compared to MERIS or OLCI.

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Towards Seamless Sentinel-2/Landsat Aquatic Science Products

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Sentinel-2 and Landsat missions are (and will be) the primary source of moderate-resolution, optical images for aquatic applications within the next decade. The remarkable data quality and quantity offered by this virtual constellation have made possible new scientific avenues and operational applications, such as early warning systems for harmful algal bloom detection. As the scientific community strives to develop new algorithms for the retrievals of near-surface water constituents, such as the concentration of total suspended solids (TSS), it is vital to ensure up/downstream products are consistent to a great extent for scientific applications and to a reasonable extent for operational exercises. In this presentation, we will present our evaluations on how Sentinel-2A/B (S2A/B) and Landsat-8 (L8) products compare over bodies of water at three different product levels, i.e., L1B/C, L2, and L3. More specifically, we will provide intercomparisons carried out at near simultaneous nadir overpasses of L8/S2A and L8/S2B since mid 2015. We show that following the vicarious calibration using a heritage ocean color approach, L8-S2A/B L2 products (i.e., aquatic reflectance) agree to within +/- 8% across the four common visible bands. L8 and S2A/B's L1B/C were also found very consistent (< 0.2%) in the 865-nm channel. The residual differences in L1B/C and L2 products, however, were also propagated to time-series of TSS products (L3) derived from an algorithm supplied solely with aquatic reflectances (L2) in the red channel. Given the desire for high consistency in products for scientific studies, it is feasible to further account for the remaining differences in L1B/C observations to allow for creating seamless products.

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Retrieving Marine Litter from Space: An innovative approach to identifying and validating Marine Litter using Sentinel 2 data

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To-date attempts to identify Marine Litter with Earth Observation (EO) data have been largely unsuccessful, due predominately to the relatively coarse spatial resolution of existing datasets and the vast scale of coastal regions. This investigation aims to examine the capabilities of the Sentinel-2 in detection and monitoring of Marine Litter (ML) in coastal regions, where impacts of ML poses a significant threat to marine ecosystems.

As part of the EU Copernicus programme, the European Space Agency (ESA) operates the Sentinel-2 missions that yields optical imagery of high spatial resolution (up to 10 m) and frequent revisit (5 days or less). The Sentinel-2 A and B Multispectral Instruments (MSI) share the same orbit, separated by 180 degrees. The Sentinel-2 mission has been designed to cover large swaths (290 km on ground) with high geometrical and spectral performances in 13 spectral bands from Visible to SWIR.

This investigation has successfully utilised the high temporal and spatial resolution of Sentinel-2 MSI products to identify multiple rafts of ML in coastal regions around the globe. These analyses have enabled the isolation of a unique radiometric signature, yielding the information required to develop an EO processor. Development and validation of such a processor will be of high scientific value, eventually providing the capability to routinely detect ML from Sentinel 2 global data-sets, producing significant environmental and economic benefits.

Accordingly, as part of this project, a validation campaign will commence in the Summer of 2019, where artificially constructed plastic targets will be launched into the Aegean Sea. These targets will be monitored with both surface based (drone) and Sentinel 2 data. Comparison of these results will aim to validate both the spectral signature of ML and the retrieval algorithm developed as part of this project.

These data will be vital in providing a global service, which when operational, will be capable of directing efficient clean-up operations to tackle this global crisis.

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The Sentinel-2 coastal charting project: An exercise in the calculation of cartographic uncertainties

laporte j[1]

[1]*Mr J. Laporte*

With the exception of privileged countries, the World Chart Series used by International shipping are based on accumulated information collected at great cost for the past 150 years by survey ships operating far from their home ports.

Until recently, chart updating could be extremely slow, sometimes well in excess of a century, and the precision is still an embarrassment, to say the least, in remote and impoverished countries, leaving currently gaps of several hundred metres between the coastline depicted on the official documents and the reality. In certain parts of the world, Mariners are constantly reminded to exert extreme caution due to the quality and obsolescence of the data depicted on their navigational documents which, nonetheless, are the United Nations official instruments required to calculate limits such as Territorial Waters or Exclusive Economic Zones (EEZ).

This sorry state of affair is well known of the International Hydrographic Organisation (IHO) who starts to consider satellites as a possible alternative to fill the world many uncharted gaps, alongside field-proven but expensive sensors such as lidar or echosounders.

Not only Sentinel-2 offers a 12 metres absolute horizontal precision, but thanks to the various techniques of Satellite Derived Bathymetry (SDB), Hydrographers can now calculate depths providing the water is transparent enough to let the bottom be seen from space. And this is not all; better understanding of the physical parameters governing the transmission of light in the atmosphere and the water column provides cartographers with a validation tool consisting of deriving Depth of Penetration (DOP) from satellite observations.

Another obvious advantage of the Sentinel imagery is its free public access, which makes it affordable to developing countries, unlike traditional survey systems and Very High-Resolution images that add an additional € 20 per square kilometre. To prove the point, the ESA Sentinel-2 coastal charting project aims at producing a number of Sentinel demonstrators, compliant with IHO cartographic standards and covering selected areas in environments as diverse as Madagascar, Myanmar, the North African coasts, the Mexican Yucatan, the Canadian Northwest Passage and possibly the South China sea.

Bearing in mind the extreme caution demanded to avoid untoward events such as ship groundings and oil spills, calibration and uncertainties are essential to reach the IHO standards of precision characterised by a most stringent 95% coverage requirement.

This presentation proposes to discuss the ever-increasing potential of SDB ground-breaking techniques, the only limitations of which are imposed by the quality and the rigour of calculation of the bathymetric model uncertainties.

POSTERS

Empirical validation of Sentinel2 burn Severity product: Monte Serra-Tuscany September 2018

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Remote sensing at different scale has been proved to provide valuable information's for the consistent study of biomass burning. However, there are still large uncertainties in satellite-based burned areas characterization in part due to the complexity and diversity of the ecosystems affected and in part due to the sensors characteristics and used spectral channels. In this study we have used an empirical approach to validate Sentinel 2 derived burn severity product.

On 24 September 2018 at 22:00pm the Mount Serra in Tuscany has been affected by a major fire which resulted in 600 hectares of woodland burned and 700 people requested to move.

A pair of Sentinel 2 imageries -, acquired respectively before and after the fire have been used to produce a dNBR map (difference Normalized burn ratio). A threshold technique has been then implemented to derive the fire severity classification The result has been empirically analyzed by moving the threshold values against ground truth consisting in a series of photos taken at ground level at the closest that was allowed and to be representative of different burned severity stages. The geo-location of these areas have been realized with the support of Google Earth. The burn severity classification derived by using literature thresholds from similar phenology types have been compared against the photos of a selected area.

To test the strength of the threshold depending on the affected areas, a local "optimal threshold" has been then derived by considering one of the ground truth pictures as training. Such threshold has been tested on the other areas, by considering the other pics as ground truth. The performance obtained using this threshold have been compared with those obtained with local optimized threshold.

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Cross-calibration of the Sentinel-2A and Sentinel-2B MSI reflective solar bands with Terra MODIS

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The Multi-Spectral Instrument (MSI) observes the Earth via 13 spectral bands covering wavelengths from 0.44 to 2.2 µm and at three different spatial resolutions (10 m, 20 m, and 60 m). Since its launch in June 2015, Sentinel-2A has been operating in a sun-synchronous orbit at a 786 km altitude with a 10:30 am descending node. The second MSI instrument on Sentinel-2B was launched in March 2017 occupying the same orbit as Sentinel-2A, but separated by 180 degrees. When operated together, the two MSI instruments ensure that the revisit time is 5 days. MSI is a filter-based pushbroom imager with a swath width of 295 km. On-orbit, the MSI bands have been calibrated using the a solar diffuser and the results have been validated using vicarious approaches, including deep convective clouds, pseudo-invariant calibration sites (PICS) and comparison with other instruments, such as the Landsat 8 Operational Land Imager (OLI). The MODIS instruments onboard the Terra and Aqua spacecraft have been successfully operating since launch and providing an excellent time-series of continuous Earth observations with an enhanced coverage (temporal and spatial) due to their wider swath (2330 km). Furthermore, a stringent calibration requirement, coupled with a suite of on-board calibrators (solar diffuser, solar diffuser stability monitor, and spectro-radiometric calibration assembly) further justifies the use of MODIS bands as a reference to validate the early performance of other earth observing sensors. In this study, same day scenes from MSI and Terra MODIS over Libya 4 PICS from January 1, 2016 to December 31, 2018 are chosen for a reflectance comparison. The Top-of-Atmosphere (TOA) reflectance over a common region of interest (ROI) from the MSI data, downloaded via the USGS Earth Explorer, is compared with the same-day Terra MODIS scenes. Additional correction for the spectral response function (SRF) mismatch between the two instruments is performed using Earth Observing One (EO-1) Hyperion hyperspectral images and corrections for bi-directional reflectance distribution (BRDF) impacts are accounted using a semi-empirical model. The two instruments agree to within 4% after the corrections. The disagreement observed at short wavelengths for non-nadir scenes is also presented and discussed. Efforts to extend this comparison to Aqua MODIS and Suomi NPP VIIRS are also being considered.

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Qualification of L2 products from S2A/B for turbid lakes: results from the Lake Trasimeno

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In this work we analyse the twin satellites of Sentinel-2 (S2A/B) products over optically complex waters (Lake Trasimeno, Central Italy) to test their suitability for the retrieval of water quality parameters, such as Chlorophyll-a (Chl-a) and total suspended matter (TSM) concentrations.

Lake Trasimeno is very shallow, with maximum depth around 6 m and it is the fourth largest Italian lake (124 km2). The lake is not stratified and thus sediment resuspension phenomena (caused by winds) and phytoplankton blooms (including cyanobacteria blooms) occur very often.

Within the H2020 - EOMORES project we integrate the use of water quality products obtained from Sentinel-2 images with Remote Sensing Reflectance (Rrs) measurements collected from spectroradiometers mounted on platforms that allow continuous measurements. The Rrs measures were taken by the WISPStation in Lake Trasimeno (April-September 2018). The WISPStation (Water Insight) is a fixed position spectrometer system for measuring water quality parameters derived from the state-of-the-art optical measurement system. The instrument takes measures of the radiance and irradiance in the spectral range of 350-900 nm with a spectral resolution of 3 nm every 10 minutes. The set-up is such that the instrument looks at the water surface at optimal azimuth angles for most of the day. In the period of operation of the WISPstation, we downloaded a total of 48 images Sentinel 2A-B images; out of the total 18 images were discarded due to clouds and glint and 30 were retained and processed. Atmospheric correction was carried out using the 6SV (Second Simulation of the Satellite Signal in the Solar Spectrum – Vector) code.

In order to retrieve both Chl-a and TSM concentrations from Rrs images and at the Rrs in situ spectra, both a bio-optical model and semi-empirical algorithms were applied. The bio-optical model BOMBER was specifically parametrized with site specific Inherent Optical Properties gathered for Trasimeno Lake whereas, among the semi-empirical approaches, mainly 2-3 band ration algorithms were selected.

Our findings confirm that Sentinel-2 performance was excellent for retrieving water quality products in a turbid lake. The availability of continuous in situ data offered a unique opportunity for both validation of satellite products and evaluation of daily dynamics of water. The results highlighted the extreme variability of Chl-a and TSM concentrations in Lake Trasimeno. Rrs data showed that since July 18 there was the peak of chlorophyll in the RED-NIR region and chlorophyll concentration showed variations greater than 100% during the day. Results show how the integration of continuous in situ spectral measurements and high spatial resolution images with a high frequency is fundamental for monitoring highly dynamic aquatic environments such as Lake Trasimeno.

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The HYPERNETS Project — A prototype network of hyperspectral automated radiometers for land and water optical missions validation

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Networking of automated instruments on unmanned platforms has proved to be the most effective way to provide validation data for earth observation missions. The re-use of data from each site for many optical missions (S2, S3, PROBA-V, MODIS, VIIRS, L8, Pléiades, ENMAP, PRISMA, SABIAMAR,etc.) gives a huge economy of scale. The existing networks (e.g. AERONET-OC, RADCALNET, ...) are based on multispectral instruments requiring modelling associated uncertainties to cover all spectral bands of all sensors. Therefore, the general objective of the HYPERNETS project is to ensure that high quality in situ measurements are available at all spectral bands and for a wide range of water and land types for the validation of the surface reflectance data issued from all earth observation missions. HYPERNETS is expected to fill the very important gap in the current Sentinel-3&2 Validation plans and the in situ component of the Copernicus program and become the main source of surface reflectance validation data for all spectral bands of all optical missions for at least the next 10 years.

The HYPERNETS instrument design of the new lower cost hyperspectral radiometer for automated measurement of water and land bidirectional reflectance is presented as well as the associated pointing system and embedded calibration device. Sensor and system designs of the instrument complies with requirements gathered from the water and land community. In order to test and demonstrate the performance of the developed system and instrument, about 22 sites have been selected covering a wide range of water and land applications and a variety of environmental (cold/hot, wet/dry, calm/windy, biofouling, etc.) and logistical conditions (accessible/remote, standalone/heavily instrumented site, well protected/vulnerable to humans and/or animals). Figure 1 shows the location of the 24 sites selected for the HYPERNETS prototype network. The prototype network design is presented. Site characteristics, including spatial and temporals specificities, are described and challenges with the system set-up are discussed.

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Belgian water and land HYPERNETS test sites for Sentinel-2 validation activities

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Networking of automated instruments on unmanned platforms has proved to be the most effective way to provide validation data for earth observation missions. The re-use of data from each site for many optical missions (S2, S3, PROBA-V, MODIS, VIIRS, L8, Pléiades, ENMAP, PRISMA, SABIAMAR,etc.) gives a huge economy of scale. The existing water and land networks (e.g. AERONET-OC, RADCALNET, ...) are based on multispectral instruments requiring modelling associated uncertainties to cover all spectral bands of all sensors. To fill this gap in hyperspectral validation data, the HYPERNETS project is working on the development of a new lower cost hyperspectral radiometer with an associated pointing system and embedded calibration device. The final objective of the project is to provide high quality hyperspectral in situ measurements for the validation of the surface reflectance data issued from all earth observation missions. However, the accuracy of the hyperspectral validation data also relies on the quality of the match-ups between the in situ and satellite measurements, which in turn, depends on the temporal and spatial coincidences between field observations and remotely sensed images. Spatial mismatches between the satellite and in situ sensor field-of-views may lead to high inaccuracies over heterogeneous surfaces. Similarly, in highly dynamic environments, the time-lapse between the in situ measurements and satellite overpass need to be considered. In the present study we quantify the suitability of the Belgian water and land sites for the validation of Sentinel-2 data. These sites are part of the prototype network of the HYPERNETS project and include two forest sites in the Belgian Ardennes, an inland water site, 2 water sites along the Belgian coast and one snow covered site nearby the Belgian Polar Station in Antarctica. For each site inaccuracies related to temporal and spatial mismatches are evaluated and quantified. Guidelines are provided to ensure high quality in situ-satellite match-up data for the Sentinel-2 validation activities.

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Sentinel-2 based mapping of the growing season (phenology) in High Arctic Svalbard

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The High Arctic Zone is characterized by a short and intense growing season, where even small changes in the timing of the growing season highly influences the plant production and the population dynamics of most animals, birds, and insects. The study area is the central parts of High Arctic archipelago of Svalbard, located at about 78^{o}N and with a mean temperature of 6.5 ^{o}C in the warmest month (July). Due to the location close to the North Pole and the polar orbit of Sentinel-2, data are obtained daily or even twice a day at the ESA SciHub. The data shows a dense cloud cover in more than 80 % of the time. Due to this frequent cloud cover a reliable cloud-mask has to be developed to remove all the noisy data before the interpolation to daily data. Then, at such northern location the solar elevation angle is low, creating shadows in the topographic complex area. At the end of the season, around 1 September, the solar elevation angel is less than 20^{o} at 11 UTC. In this presentation we show how we deal with these challenges in processing a clear-sky time-series. Then, we use this clear-sky time-series to explore which wavebands best identify different phenophases at different vegetation types (shrubby vs. grass dominated vegetation), as validated from RGB phenology cameras ('phenocams') in field. The preliminary results indicate that NDVI is good enough to map the onset of the growth. At autumn different band combinations (indices) have to be used, according to different vegetation types.

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Laser-based characterization of Landsat OLI-2

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Landsat 9 will extend the Landsat data record into its fifth decade once it is launched in December 2020 to the orbit that is now occupied by Landsat 7. The instruments on board Landsat-9, Thermal Infrared Sensor-2 (TIRS-2) and Operational Land Imager-2 (OLI-2), will be near identical builds of TIRS and OLI that are hosted on Landsat 8 which was launched in February 2013. Both instruments are currently in final stages of test and characterization. This poster will highlight a new test that was performed on OLI-2 for its spectral and radiometric characterization that uses a tunable laser facility from Goddard Space Flight Center called Goddard Laser for Absolute Measurement of Spectral Response (GLAMR). The GLAMR facility is mobile and consists of several tunable lasers systems that in combination covers the 350-2500 nm spectral region. The spectral accuracy is on the order of 0.01 nm and radiometric accuracy is 0.8 to 5% depending on spectral region. The GLAMR lasers are coupled to a large integrating sphere to provide an extended, monochromatic source of light such that a large portion of the OLI-2 focal plane is illuminated. OLI-2 was rotated in 14 incremental steps during each GLAMR spectral set point to facilitate spectral characterization of every OLI-2 detector. The GLAMR spectral set points within the 350-2500 nm were defined by in-band and out-of-band test requirements and are detailed in this poster. OLI-2 spectral performance based on the special GLAMR test will be summarized here.

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Sentinel-2 Level-2 Processing With Sen2Cor: An Approach for Improvement in Terms of Speed

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In June 2017, ESA started systematic Level-2A processing of Sentinel-2 acquisitions over Europe using the Cloud Screening and Atmospheric Correction Processor named Sen2Cor. 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.

Although the embedding of Sen2Cor in the processing chain has been proven quite satisfactory, there is a desire to improve its performance in terms of speed, in order to warrant the availability of Level-2A data with a faster update ability.

The objective of the study presented is, to develop and test several strategies to improve the processing of Sen2Cor using compilation, parallel, distributed and cloud-based processing techniques.

For this purpose, we will utilize ahead-of-time compilation to outsource hotspots of the Sen2Cor processor and compile critical paths. Furthermore, we will establish an interface to C to facilitate the use of external C libraries and especially to leverage the Intel Math Kernel Library (MKL).

urther approaches will include NumPy-aware just-in-time compilation to accelerate isolated parts by tying the computations closer to the underlying hardware architecture. These approaches have already been verified to improve the performance of compute-intensive Python applications in several cases [1].

We also will evaluate parallelization approaches on shared as well as distributed memory systems, such as cloud-based high-performance computers. Computations suitable for massively parallel approaches such as routines relying on an extensive amount of Single Instruction Multiple Data (SIMD) operations are also taken into consideration and GPU-offloading approaches will be investigated.

These approaches are introduced and discussed in a more detail and first results are presented.

The study is part of a master's thesis, carried out at TPZV-D in cooperation with the Darmstadt University of Technology.

Keywords: ahead-of-time compilation, just-in-time compilation, parallel processing, cloud-based processing, Sen2Cor, Sentinel-2.

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Sen2like, a Tool to Generate Sentinel-2 Harmonised Surface Reflectance Products - First Results With Landsat-8

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In the last decade the offer of Earth Observation (EO) data has considerably increased, in particular in case of multi spectral high resolution data. Whilst the interest of merging these various data streams is now prevalent in the community, there is not a common approach to

achieve this objective. Also, several major scientific and technical questions are still pending.
In this context, ESA has proposed the development of an innovative prototype (pre-operational demonstration) service providing Analysis Ready Harmonized Landsat 8 (LS8) and Sentinel2 (S2) data/products to the user. This harmonisation process allows to increase the theoretical number of acquisitions of this virtual constellation (95 products / year) by 30 % with respect to Sentinel-2 (S2A & S2B) only acquisitions (73 products / year). The final objective is to promote the pixel-based analysis with the extraction of fit-for-purpose dense time series, essential for bio-geophysical variables monitoring for instance.
For this purpose, the sen2like tool has been developed. Using the S2 tiling system based on the Military Grid Reference System (MGRS), the sen2like tool processes S2/MSI Level-1 products and LS8/OLI Level-1 products and create a harmonized surface reflectance data stack. Working on the same baseline principles as NASA HLS initiative, geometric, radiometric and image processing algorithms are applied. A significant part of the work has been focused on the validation activities of each algorithm involved and also on the final data stack products.
The scope of this paper is to present a detailed description of the functionalities available in the sen2like tool as well as the trade-off adopted to keep an efficient solution in term of processing time and usage. Furthermore, the results of the processing algorithm validation and the results of the time series quality control will be given. A discussion on the sen2like product format and associated uncertainties will be undertaken. Finally, the sen2like next evolutions and the technical/scientific efforts for integrating a new mission will be addressed.

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Sentinel-2 MSI data applications for cyanobacteria dominance and toxicity risk retrieval in Lithuanian eutrophic waters

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In this study, we are aiming to validate data of Sentinel-2 Multispectral Instrument (S2 MSI) for mapping water quality, cyanobacteria and potential of toxicity in two eutrophic Lithuanian freshwater bodies: the Kaunas Reservoir and the Curonian Lagoon. These two waterbodies are extremely important recreational sites, however strongly impacted by eutrophication resulting in severe blooms of cyanobacteria. The ongoing eutrophication with all the consequences leads to the high demand for full-scale operational monitoring of water quality. S2 MSI data opened a great new potential for monitoring of small and large water bodies by remote sensing with a comprehensive spatial and spectral resolution.
The in situ reflectance (Rrs) measurements concurrent with S2 MSI overpasses were collected with WISP-3 instrument (Water Insight) over the Curonian Lagoon and for a first time over the Kaunas Reservoir during summer 2016-2018. Simultaneously, water quality parameters and cyanobacteria toxins were measured at each water body. The performance of six atmospheric correction algorithms (Sen2Cor, C2RCC, 6SV code, iCOR, Polymer and ACOLITE) was tested. For retrieval of chlorophyll-a (Chl-a) concentration by semi-empirical band-ratio algorithms and Chl-a product of C2RCC processor were tested against in situ measurements.
The comparison between Rrs measured in situ and derived from S2 MSI reviled that EO-based Rrs after application of 6SV code showed a slight overestimation, however the shapes of spectra were in a good agreement for both tested study sites. The performance of Sen2Cor, iCOR and Polymer showed also promising results. The results indicate that S2 MSI data has a great potential for eutrophic inland water remote sensing in Lithuania, as we were able to map Chl-a concentration in the Kaunas Reservoir and the Curonian Lagoon by means of commonly used band-ratio type algorithms. Significantly strong correlation was determined between band-ratio at 705 and 665 nm S2 MSI bands and in situ measured Chl-a concentration: the Kaunas Reservoir ($r = 0.89$) and the Curonian Lagoon ($r = 0.91$). Chl-a concentration retrieved after application of C2RCC underestimated in situ measured values and therefore the further investigation on parameterization to local conditions and water type is needed. We will demonstrate the approach, how S2 MSI data can be used for early warning of cyanobacteria presence and for risk assessment of cyanobacteria toxicity.

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Evaluation of Sentinel-2 Imagery Over Belgian Inland and Coastal Waters

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We present results from the first years of the Sentinel-2A (2015-present) and 2B (2017-present) missions over Belgian coastal and inland waters. The performance of different atmospheric correction methods for water applications is evaluated using AERONET-OC data from the Zeebrugge/MOW1 and Thornton C-Power sites, as well as using in situ radiometry collected in Belgian lakes.

Challenges remaining for water applications of Sentinel-2 are highlighted, focusing on sun glint (e.g. Harmel et al., 2018) and adjacency effects (e.g. De Keukelaere et al. 2018). The impact of these effects on reflectance derived products such as turbidity (Nechad et al., 2009) and chlorophyll a concentration (Gons et al., 1999) is illustrated. A method is proposed to estimate these effects from the satellite imagery itself by using the SWIR band observations after the DSF atmospheric correction (Vanhellemont & Ruddick 2018).

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First Comparison of Simultaneous Sentinel-2 MSI and Airborne Active Fire Observations

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The 20 m spatial resolution shortwave infrared (SWIR) bands of Sentinel-2 MSI are easily capable of detecting the strong thermal emission signals emanating from actively burning landscape fires. Threshold based active fire detection algorithms can be operated off such signals, providing with Sentinel-2 the capability to detect fires far smaller than those able to be identified with coarser spatial resolution sensors such as MODIS and SLSTR. Furthermore, when not affected by sensor saturation, the the spectral radiances measured in the MSI wavebands can be used to infer and map certain important properties of the fire itself, such as its effective temperature, sub-pixel area and fire radiative power (FRP) output. Here we report results from the first known example of an active fire jointly observed by Sentinel-2 MSI and an airborne thermal infrared imager, targeting a 7 ha fire lit as part of the experimental burning programme conducted regularly in Kruger National Park, South Africa. This unique simultaneous data acquisition provides the means to evaluate the information content of the MSI-derived active fire dataset via exploitation of the even higher spatial resolution airborne thermal imagery.