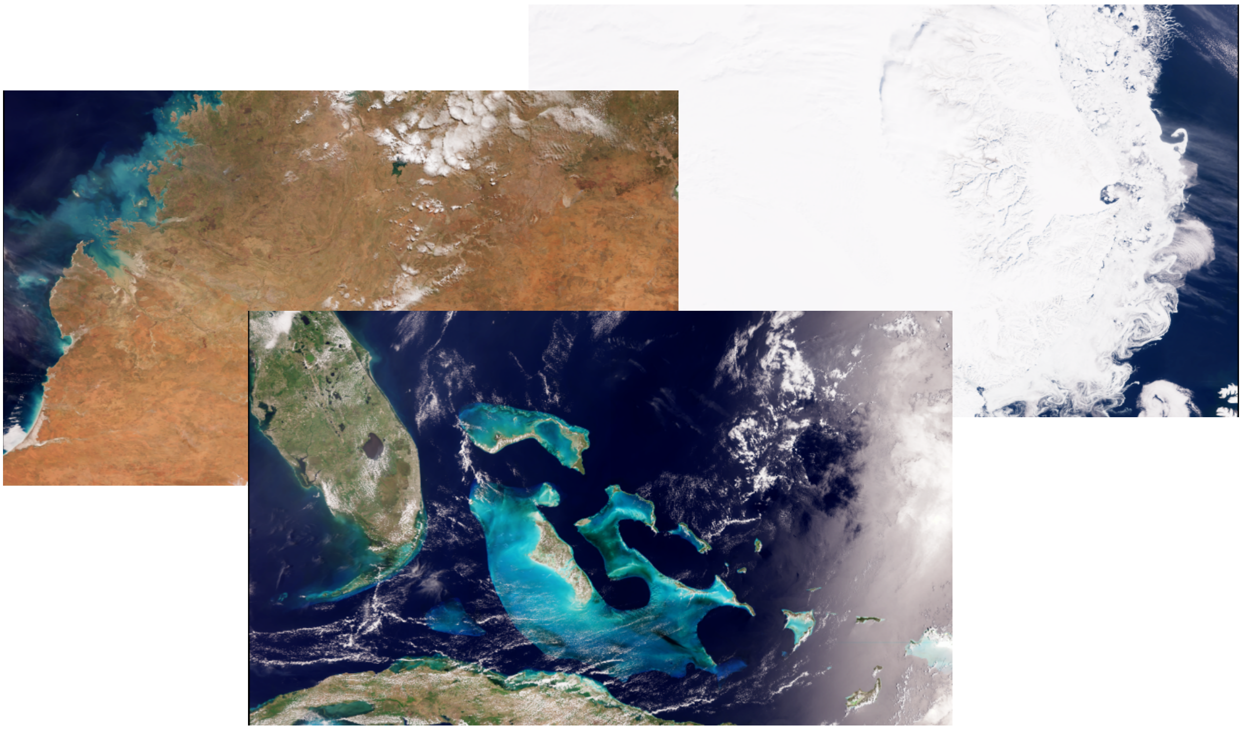
Sentinel-3 OLCI Marine User Handbook

This Document is Public



Doc.No. : EUM/OPS-SEN3/MAN/17/907205
Issue : v1H e-signed
Date : 4 July 2018
WBS/DBS :

EUMETSAT
Eumetsat-Allee 1, D-64295 Darmstadt, Germany
Tel: +49 6151 807-7
Fax: +49 6151 807 555
http://www.eumetsat.int

This page intentionally left blank

Document Change Record

Issue / Revision	*Date*	*DCN. No*	*Changed Pages / Paragraphs*
V1E	1 December 2017		First issue
V1F	5 January 2018		Correction of minor typos
V1H	04 July 2018		Rearranging sections/text for consistency with SLSTR/SRAL handbooks (products and processing sections now separated). New section on history of ocean colour. Updated cross referencing. Addition of coda rep information. L1 processing section updated to latest product notices 14/03/2018. Formatting and minor typological updates. New section on coverage. Updated tense of text concerning S3B.

Table of Contents

Table of Figures

Table of Tables

1 INTRODUCTION

1.1 Purpose

The Sentinel-3 Ocean and Land Colour Instrument (OLCI) Marine Handbook is a user guide that summarises the key information needed to enable an end user (both general and specialist) to get information about the marine Level 1B (L1B) and Level 2 (L2) products. The handbook includes information on the components of the instrument system, the specifics of measurement techniques used, details on applied corrections and processing steps required to derive geophysical variables. The capability of the system is discussed in the context of its complementarity with, and improvements on, other ocean colour missions, with notes on existing limitations. A discussion of file formats, processing tools and data-access routes precedes a presentation of available support resources. Where the detail is not held in the handbook itself, the user is pointed to further (primarily internet based) resources.

1.2 Scope

All current and potential users of the Copernicus Marine Data Stream that are interested in the Sentinel-3 ocean colour products for use in the open-ocean, coastal domain and inland waters.

1.3 Document Structure

Section 1 General information (this section)

Section 2 Background information on EUMETSAT, Copernicus and Sentinel-3 mission requirements.

Section 3 Provides and overview of Copernicus and the SLSTR instrument.

Section 4 Gives an overview of the OLCI instrument, coverage, quality, capability and accuracy

Section 5 Gives a description of OLCI L1 and L2 marine processing.

Section 6 Gives a description of OLCI L1 and L2 marine products.

Section 7 Explains download and visualise OLCI data, and where to find help.

Section 8 Description of the data quality.

Section 9 Frequently Asked Questions, providing information on anomalies and other information not covered elsewhere.

1.4 Applicable Documents

Applicable documents incorporate additional provisions to the source document. A provision may be in the form of requirements, statements, instructions or recommendations.

AD-1	Sentinel-3 Mission Requirements Document, v2.0	EOP-SMO/1151/MD-md
AD-2	Sentinel-3 Mission Requirements Traceability Document, v1.0	EOP-SM/2184/CD-cd

1.5 Reference Documents

Reference documents contain additional information related to this document.

RD-1	IOCCG Report 10 (2010). Atmospheric Correction for Remotely-Sensed Ocean-Colour Products.	ISBN: 978-1-896246-61-1
RD-2	Morel and Gentili. 1996. Diffuse reflectance of oceanic waters.	doi: 10.1364/AO.35.004850
RD-3	Morel et al. 2002. Bidirectional reflectance of oceanic waters: accounting for Raman emission and varying particle scattering phase function.	doi: 10.1364/AO.41.006289
RD-4	Antoine. 2010. OLCI Level 2 Algorithm Theoretical Basis Document: Ocean Colour Products in Case 1 waters	S3-L2-SD-03-C10-LOV-ATBD
RD-5	Siegel et al. 2005. Colored dissolved organic matter and its influence on the satellite-based characterization of the ocean biosphere	doi: 10.1029/2005GL024310
RD-6	IOCCG Report 13. 2012. Mission Requirements for Future Ocean-Colour Sensors.	ISBN: 978-1-896246-64-2
RD-7	Donlon et al. 2012. The Global Monitoring for Environment and Security (GMES) Sentinel-3 mission.	doi: 10.1016/j.rse.2011.07.024
RD-8	Antoine and Morel, 1999. A multiple scattering algorithm for atmospheric correction of remotely sensed ocean color (MERIS instrument): principle and implementation for atmospheres carrying absorbing aerosols.	International Journal of Remote Sensing, Vol. 20
RD-9	Moore et al. 1999. The atmospheric correction of water colour and the quantitative retrieval of suspended particulate matter in Case II waters: application to MERIS.	International Journal of Remote Sensing, Vol. 20

RD-10	Moore, G., C. Mazeran and J.-P. Huot, 2017. Case II. S Bright Pixel Atmospheric Correction. MERIS ATBD 2.6, Issue 5.3. (mesotrophic to high turbidity)	https://www.eumetsat.int/website/home/Data/CopernicusServices/Sentinel3Services/OceanColour/index.html
RD-11	Aiken and Moore. 1997. Photosynthetic Available Radiation, v5	MERIS ATBD 2.18
RD-12	Morel et al. 2007. Examining the consistency of products derived from various ocean color sensors in open ocean (case 1) waters in the perspective of a multi-sensor approach.	doi: 10.1016/j.rse.2007.03.012
RD-13	Doerffer and Schiller. 2007. The MERIS Case 2 water algorithm.	doi: /10.1080/01431160600821127
RD-14	Lindstrot et al. 2012. 1D-Var retrieval of daytime total columnar water vapour from MERIS measurements.	doi: 10.5194/amt-5-631-2012
RD-15	Sentinel-3 Calibration and Validation Plan, v1.0	S3-PL-ESA-SY-0265
RD-16	INSITU-OCR. 2012. International Network for Sensor Inter-comparison and Uncertainty assessment for Ocean Color Radiometry (INSITU-OCR).	http://www.ioccg.org/groups/INSITU-OCR_White-Paper.pdf
RD-17	Mazeran et al. 2017. Requirements for Copernicus Ocean Colour Vicarious Calibration Infrastructure. v2.1	https://www.eumetsat.int/website/home/Data/ScienceActivities/index.html [Commissioned Studies]
RD-18	Bonekamp et al. 2016. Core operational Sentinel-3 marine data product services as part of the Copernicus Space Component.	doi: /10.5194/os-12-787-2016
RD-19	Sentinel 3 PDGS File Naming Convention, v1D	EUM/LEO-SEN3/SPE/10/0070
RD-20	OLCI Level 1 Algorithm Theoretical Basis Document, v4.0	S3-ACR-TN-007
RD-21	Product Data Format Specification – OLCI Level 1 & Level 2 Instrument Products, v1.10	S3IPF.PDS.004
RD-22	O'Reilly et al. 1998. Ocean Color Chlorophyll Algorithms for SeaWiFS.	Journal of Geophysical Research, 103(C11).
RD-23	The Global Observing System for Climate: Implementation Needs (GCOS-200, GOOS-214).	2016

1.6 List of Abbreviations, Acronyms and Symbols

AAC	Alternative Atmospheric Correction
AC	Atmospheric Correction
ADC	Analogue to digital converter
ATBD	Algorithm Theoretical Basis Document
BAC	Baseline Atmospheric Correction
BPAC	Bright Pixel Correction
BRDF	Bidirectional Reflectance Distribution Function
C2RCC	Case 2 Regional / Coast Colour processor
Cal/Val	Calibration and Validation
CCD	Charge-Coupled Device
CDOM	Coloured or Chromophoric Dissolved Organic Matter
CMEMS	Copernicus Marine Environment Monitoring Service
CODA	Copernicus Online Data Access
CZCS	Coastal Zone Color Scanner
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variables
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FOV	Field Of View
FR	Full Resolution
FTP	File Transfer Protocol
FWHM	Full Width at Half Maximum
GCOM-C	Global Change Observation Mission - Climate
GCOS	Global Climate Observation System
H_2O	water
IOCCG	International Ocean Colour Coordinating Group
IOPs	Inherent Optical Properties
IWV	Integrated Water Vapour column
L1	Level 1
L1B	Level 1B
L2	Level 2
L3	Level 3
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MRD	Mission Requirements Document
MRTD	Mission Requirements Traceability Document
MWR	MicroWave Radiometer
NASA	National Aeronautics and Space Administration
netCDF	Network Common Data Format
NIR	Near Infrared

NO_2	nitrogen
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real-Time, delivered to the users less than 3 hours after acquisition of the data by the sensor
NTC	Non-Time Critical products are delivered not later than 1 month (commitment) after acquisition or from long-term archives. Typically, available within 24 or 48 hours.
O_2	oxygen
O_3	ozone
OAA	Observation (viewing) Azimuth Angle
OC4Me	Ocean Colour for MERIS
OCM	Ocean Colour Monitor
OCTS	Ocean Color Temperature Scanner
ODA	Online Data Access
OES	Ocean Ecology Sensor
OLCI	Ocean and Land Colour Instrument
OZA	Observation (viewing) Zenith Angle
PACE	Pre-Aerosols Clouds and ocean Ecosystems
PAR	Photosynthetically Active Radiation
PDGS	Payload Data Ground Segment
POD	Precise Orbit Determination
RR	Reduced Resolution
S3VT	Sentinel-3 Validation Team
SAA	Solar Azimuth Angle
SAFE	Standard Archive Format for Europe
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SLSTR	Sea and Land Surface Temperature Radiometer
SNAP	SeNtinel Application Platform
SNR	Signal-to-Noise Ratio
SRAL	SAR Radar Altimeter
SSH	Sea Surface Height
SST	Sea Surface Temperature
STC	Short-Time Critical, not relevant to OLCI
STEP	Science Toolbox Exploitation Platform
SVC	System Vicarious Calibration
SWH	Significant Wave Height
SZA	Solar Zenith Angle
TOA	Top Of Atmosphere
TSM	Total Suspended Matter concentration
VIIRS	Visible Infrared Imaging Radiometer Suite

2 BACKGROUND

2.1 The Copernicus Programme

Copernicus is the European programme for the establishment of a European capacity for Earth observation and monitoring. The programme aims to deliver information services based on satellite and *in situ* (non-space) components. The Copernicus Programme is coordinated and managed by the European Commission. It is implemented in partnership with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan. The Copernicus programme provides users with free, full and open access to environmental data.

The satellite component of the Copernicus Programme encompasses the Sentinel satellite missions, including Sentinel-3. Sentinel-3 is dedicated to providing high-accuracy optical, radar and altimetry data for marine and land services. EUMETSAT operates the Sentinel-3 satellite series, with ESA support, and is responsible for delivering the Sentinel-3 marine data stream. Looking ahead, EUMETSAT will also will also operate and deliver products from the Sentinel-4, and Sentinel-5 instruments, and the Sentinel-6/Jason-CS satellites.

2.2 European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

Founded in 1986, EUMETSAT is a European-based and globally-focussed intergovernmental operational satellite agency. Its purpose is to gather accurate, reliable and timely satellite data on weather, climate and the environment, and to deliver this to its Member and Cooperating States, international partners, and to users world-wide. With a strategic goal to ensure improvements in, and continuity of, satellite observations, EUMETSAT oversees the development and operation of a range of complex satellite systems that are in constant use in monitoring weather, climate, the oceans and the atmosphere, and supports downstream services such as meteorological forecasting, air-travel safety and shipping.

EUMETSAT operates a fleet of satellites in geostationary and polar orbit from its Mission Control Centre (MCC), based at its headquarters in Darmstadt, Germany. The geostationary Meteosat platforms provide regular imagery over Europe, Africa and the adjacent seas, (Meteosat-9, 10 and 11), and over the Indian Ocean (Meteosat-8). More detailed observations of the global atmosphere, oceans and continents are provided by the polar-orbiting Metop-A and Metop-B satellites. In partnership with NOAA, CNES and NASA, EUMETSAT supports the operational phase of the Jason-2 altimeter and the Jason-3 reference altimeter, providing near real-time ocean topography products to support ocean forecasting and climate analysis.

Under the Copernicus Programme, EUMETSAT provides Earth Observation (EO) data, products and support services to the Copernicus information services and user communities, with a focus on marine, atmosphere and climate. In the marine context, this role encompasses operating the Sentinel-3 and Jason-3 satellites, with future responsibility for Sentinel-6/Jason-CS. The marine capability of the Sentinel-3 OLCI instrument is the sole focus of this document.

2.3 Sentinel-3 objectives

Sentinel-3 is a dedicated Copernicus satellite delivering high-quality ocean measurements. In the marine environment, the primary objective of Sentinel-3 is to determine ocean-surface colour parameters, sea-surface topography, sea-surface temperature; offering EO data with global coverage every two days (with two satellites) in support of marine applications, and with near real-time products delivered in less than three hours.

Sentinel-3A and 3B were launched in February 2016 and April 2018, respectively. Sentinel 3B is currently in the commissioning phase, flying in tandem with Sentinel 3A, 30 seconds apart on the same orbital track. Sentinel 3B will transition to its final orbital track and enter its operational phase in autumn 2018. In the longer term, the Sentinel-3 mission will have further satellites (Sentinel-3C and Sentinel-3D), to extend this global monitoring. Requirements of the Sentinel-3 mission include:

- Visible and Thermal Infrared radiances (‘Ocean Colour’) for oceanic and coastal and inland waters, deter- mined to an equivalent level of accuracy and precision as MERIS data with complete Earth coverage in two to three days, and co-registered with SST measurements.
- Sea surface temperature (SST) determined globally to an equivalent accuracy and precision as that presently achieved by A/ATSR (i.e. <0.3 K), at a spatial resolution of 1 km.
- Sea surface height/topography (SSH) and, significant wave height (SWH) over the global ocean to an accuracy and precision exceeding that of Envisat RA-2.

For more information, users should consult the specific objectives for the Sentinel-3 missions. These are defined in the Mission Requirements Document (MRD) [AD-1], which is adopted in a traceable format through the Mission Requirements Traceability Document (MRTD) [AD-2].

Within the Copernicus framework, the major user of Sentinel-3 marine products is the Copernicus Marine Environment Monitoring Service (CMEMS). CMEMS provides regular and systematic core reference information on the state of the physical and biological oceans and regional seas to support marine applications. The products come from EO data (including Sentinel 3), in situ measurements and numerical modelling, and are made available via the CMEMS website[1].

2.4 Disclaimer

The use of these products is granted to every interested user, free of charge.

EUMETSAT is interested in receiving your feedback, would appreciate your acknowledgment in using and publishing about the data, and like to receive a copy publications about the application of the data. Your feedback helps us in improving product quality and maintaining the resources for the EUMETSAT marine data services.

[1] CMEMS: http://marine.copernicus.eu/

2.5 Useful links

EUMETSAT Copernicus homepage:
www.eumetsat.int/website/home/Satellites/FutureSatellites/CopernicusSatellites/CopernicusResources/

EUMETSAT ocean-colour homepage:
https://www.eumetsat.int/website/home/Data/CopernicusServices/Sentinel3Services/OceanColour/index.html

EUMETSAT training:
https://training.eumetsat.int/

EUMETSAT YouTube home:
https://www.youtube.com/channel/UCiN59j5b1fAGnXVzIYFpaMw

Copernicus YouTube playlist:
https://www.youtube.com/playlist?list=PLOQg9n6Apif1ODObv39j43j8IAvJDOAVY

How to access Copernicus ocean colour data:
https://youtu.be/V3NAuafvlFM

Atlantic Ocean Colour:
https://youtu.be/n2hpWMRWfr0

Sentinel 3 mission status:
https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/mission-status

Sentinel 3 for oceans:
https://www.youtube.com/watch?v=T9WCWnk_qN4

Sentinel 3 playlist:
https://www.youtube.com/playlist?list=PLbyvawxScNbus9n8rmw0GElhPqrCwcsiD

2.6 History of product changes

A history of changes to products can be found in the relevant product notice and specification document via the following link:

https://www.eumetsat.int/website/home/Data/CopernicusServices/Sentinel3Services/OceanColour/index.html

Current and previous Sentinel-3 mission reports can be found via the following link:
https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/mission-status

3 SENTINEL-3 AND OLCI

The Sentinel-3 missions are low earth polar orbiting satellites, operating at an average altitude of 815 km above the Earth's surface with a repeat cycle of 27 days. Sentinel-3B is currently in in a "tandem orbit", occupying the same ground track as Sentinel-3A with a 30 second difference in observations, to enable close inter-calibration of the instruments. In autumn 2018 it will be moved to a position 140° later in its orbit that will mean that the ground tracks of Sentinel-3B and Sentinel-3A are "interleaved", giving a more complete and even sampling of the Earth's surface, so as to better fulfil the monitoring role of the Sentinel missions. They carry three sets of instruments focusing on high-accuracy optical, thermal and altimetry data for marine and land services:

- Optical: OLCI for medium resolution marine and terrestrial optical measurements,
- Thermal: Sea and Land Surface Temperature Radiometer (SLSTR) for marine and terrestrial thermal measurements,
- Altimetry: SAR Radar Altimeter (SRAL) together with the MicroWave Radiometer (MWR) and Precise Orbit Determination (POD) for topography measurements.

It is the former of these, OLCI, which is the subject of this handbook, within a marine context.

3.1 Ocean colour: a brief historical background

The satellite ocean colour era began in the late 1970's with the Coastal Zone Colour Scanner (CZCS). Though experimental, this sensor provided vastly more data than expected and showed the potential of satellite data for observing and understanding the dynamics of marine ecosystems at a global scale. More than ten years passed before new sensors were launched, and the continuous ocean colour record began. The Sea-viewing Wide Field-of-view sensor (SeaWiFS) was launched in 1997 on board the NASA SeaStar satellite, soon followed by the Moderate-resolution Imaging Spectroradiometer (MODIS) on board the Terra and Aqua satellites, launched in 1999 and 2002 respectively, then in 2002 the MEdium Resolution Imaging Spectrometer (MERIS) was launched onboard the European Space Agency (ESA) Envisat satellite. The overlap between these missions has been crucial for developing an understanding of how sensor design affects application, and has facilitated the development of ocean colour data as a time series for climate scale studies. Further sensors were also launched, including the first geostationary sensor (Geostationary Ocean Color Imager (GOCI) from Korea), and the Indian Ocean Colour Monitor (OCM-2) onboard ISRO's Oceansat-2 satellite. Each sensor has offered different advantages in terms of spatial, temporal, and spectral resolution, as well as signal to noise ratios.

The next generation of ocean colour satellites is now being launched, with lessons learned from previous missions improving both sensor design and programme contingency. The NOAA VIIRS sensor and NASA-planned hyperspectral PACE mission, provide a follow-on to NASA's historical ocean colour sensors. Whilst in Europe, the legacy of MERIS formed the basis for the OLCI sensor, on board Sentinel 3A and 3B, as part of the Copernicus programme. OLCI has more spectral bands than MERIS, enhancing both the ability to atmospherically correct the data, as well as to extract a wider range of information about optically significant constituents in ocean waters. OLCI will also provide global coverage at 300m, a further advancement from the MERIS era, when 300m data saw a huge growth in the use of ocean colour data for coastal and inland applications. A further strength of the Copernicus programme is the planned continuity with Sentinel 3B currently in its "tandem" commissioning phase, and with Sentinel-3C and 3D planned, this will not only provide more regular imagery than from a single sensor, but also redundancy, ensuring the ocean colour record continues into the future.

3.2 Complementarities with other ocean colour missions

Sentinel-3 OLCI opens an era of European operational ocean colour observations and represents a significant achievement in the maturity, accessibility, continuity and routine utilization of ocean colour measurements, together with the United States' Visible Infrared Imaging Radiometer Suite (VIIRS).

All these missions, from CZCS to OLCI, tend to follow a set of recommendations provided by the International Ocean-Colour Coordinating Group (IOCCG) working group [RD-6]. IOCCG also provides a more complete list of missions[2], allowing there to be near-continuous global observations of water radiometry and Chl. OLCI is based on its MERIS heritage, in terms of both the sensor design and algorithms that have been used for generating the products.

[2] IOCCG list of missions and instruments: http://ioccg.org/resources/missions-instruments/

4 OLCI: GEOPHYSICAL VARIABLES, INSTRUMENTS AND PRINCIPLE

4.1 Coverage

Sentinel-3A is in a sun-synchronous orbit with a mean altitude of 815 km, completing 385 orbits (i.e. 770 pole-to-pole tracks) in exactly 27 days. Sentinel-3B, launched in April 2018, is currently in "tandem phase" for close calibration with Sentinel-3A, but will subsequently be moved to a set of tracks interleaving those of Sentinel- 3A to give a denser pattern of coverage. This will occur in autumn 2018. Sentinel-3B will retain the orbital characteristics of Sentinel-3A, but ±140^o out of phase. The mean global coverage revisit time for OLCI observations is 1.9 days at the equator (one operational spacecraft) or 0.9 days (in constellation) with these values increasing at higher latitudes, due to orbital convergence.

Note: Throughout this document, we refer to 'ocean colour'. However, the reader should be aware that OLCI provides useful products over all aquatic environments: the open ocean, coastal zones and inland seas. Unless information is specified as only relevant to a given domain (e.g. open ocean only), then it should be considered as relevant to all.

4.2 Ocean colour measurement principles

Ocean colour is the change in the colour of the ocean, and other water bodies such as seas and lakes, due to the substances dissolved and particles suspended within the water. In the middle of the open ocean the water tends to be blue in colour. Close to the coast, the water varies in colour from blue to green, to brown and to white depending on what is present in it. By numerically quantifying this change in colour, concentrations of in-water constituents can be determined. Of major interest are phytoplankton, the microscopic algal plants in the ocean, as well as suspended sediments and coloured dissolved organic matter.

Space sensors retrieve the spectral distribution of upwelling radiance just above the sea surface, which is termed the water-leaving radiance (L_w). From the water-leaving radiance, concentrations of in-water constituents and their inherent optical properties are derived. However, the sensors actually measure the Top Of Atmosphere (TOA) radiance and so the contribution resulting from the atmosphere's scattering and absorption needs to be accounted for through Atmospheric Correction (AC).

Atmospheric correction for ocean colour data is challenging [RD-1] as only about 10% of the radiance measured by a satellite instrument in visible blue and green wavelengths originates from the water surface and significantly less in the red. The sensors thus require very low radiometric and spectral uncertainties and a high signal to noise ratio (SNR), particularly for the 'blue' bands (~ 400 nm). Ocean colour instrument design must therefore incorporate extremely sensitive and stable radiometry, dedicated on-board calibration and spectral channels located at wavelengths of specific interest.

Once corrected, the water-leaving radiance is normalized, L_{wN}, to approximate the Sun at zenith, absence of the atmosphere, and a mean Sun-Earth distance (Morel and Gentili, 1996 [RD-2]):

$$L_{wn}(\lambda_i) = \frac{L_w(\lambda_i)}{t_{down}(\lambda_i)\mu_s C_s} \qquad \text{(Eq. 1)}$$

where t_{down} is the total (i.e. direct plus diffuse, Rayleigh plus aerosol) downward transmittance of the atmosphere, μ_s -the cosine of the solar zenith angle, and C_s -a coefficient accounting for the variation in the Sun-Earth distance. Conversion to remote-sensing reflectance and water-leaving reflectance is expressed in Eqs 2 and 3, where F_0 is the mean extraterrestrial solar spectral irradiance.

$$R_{rs}(\lambda_i) = \frac{L_{wn}(\lambda_i)}{F_0(\lambda_i)} \quad \text{(Eq. 2)}$$

$$\rho_w(\lambda_i) = \frac{\pi L_w(\lambda_i)}{F_0(\lambda_i)} \quad \text{or} \quad \rho_w(\lambda_i) = \frac{\pi L_w(\lambda_i)}{t_{down}(\lambda_i) F_0(\lambda_i) \mu_s C_s} \quad \text{(Eq. 3)}$$

Note that both reflectances in Eq. 2 and 3 are not corrected for the Bidirectional Reflectance Distribution Function (BRDF) (Morel et al., 2002 [RD-3]). These are directional reflectances and are still dependent on their viewing direction, i.e. on the angular distribution of the upwelling underwater radiance and on the transmittance through the sea surface from water to air. Radiance or reflectance products from various missions are often corrected for the BRDF. OLCI standard product is the directional water-leaving reflectance from Eq. 3, the reflectance is not corrected for the BRDF effect.

These radiometric products are then used to estimate geophysical parameters through the application of specific bio-optical algorithms e.g. estimates of phytoplankton biomass through determining the Chlorophyll-a (Chl) concentration. The Ocean Colour for MERIS (OC4Me) Chl algorithm uses the irradiance reflectance (R) as the input [RD-4]:

$$log_{10}\left[Chl\right] = \sum_{x=0}^{4}\left(A_x \log_{10} R_j^i\right)^x \quad \text{(Eq. 4)}$$

A_0	A_1	A_2	A_3	A_4
0.4502748	−3.259491	3.522731	−3.359422	0.949586

$$R_j^i = \max\left(\tfrac{443}{555}R, \tfrac{490}{555}R, \tfrac{510}{555}R\right) \quad \text{(Eq. 5)}$$

$$R(\lambda) = \frac{\rho_w(\lambda) Q}{\pi \Re} \quad \text{(Eq. 6)}$$

where Eq. 6 applies the BRDF correction with the Q factor being Chl-dependant, and $\Re$ is a geometrical factor that encompasses the air-sea interface effects [RD-2].

Chl is more difficult to quantify in complex waters, as opposed to open waters, due to a more compound bio-optical signal. Clear waters in the open ocean, seas and some lakes have the spectral signature dominated by phytoplankton pigments. On the other hand, complex waters are significantly influenced by Coloured Dissolved Organic Matter (CDOM) [RD-5] and/or suspended sediments (Total Suspended Matter, TSM) and phytoplankton and primarily occur in coastal and inland zones. Therefore, OLCI has separate Open Water and Complex Water approaches for deriving its ocean colour products. Open and Complex water classification has been also called Case 1 and Case 2 water, respectively. [Table 4 in section 6.5 explains which approaches are used to derive individual OLCI standard products, e.g. OC4Me being developed for Open Waters and a neural network based approach NN for Complex Waters.]

4.3 OLCI instrument specifics

The key mission driver for the Sentinel-3 OLCI instrument is continuity of the Envisat MERIS instrument capability [RD-7]. As such, it is a push-broom imaging spectrometer with 5 camera modules sharing the Field Of View (FOV):

- The five cameras' FOV are arranged in a fan-shaped configuration in the vertical plane perpendicular to the platform velocity,
- Each camera has an individual FOV of 14.2 degrees with a 0.6 degree overlap with its neighbours,
- Each camera is equipped with a CCD composed of 740 x 520 detectors, where 740 pixels correspond to the spatial extent of the camera FOV and 520 pixels to the decomposition of radiance into spectral components from 390 nm to 1040 nm,
- Five camera FOV is tilted westwards across-track by 12.58 degrees away from the Sun to minimise the Sun glint impact.

OLCI has the following significant improvements when compared to MERIS:

- An increase in the number of spectral bands (from 15 to 21),
- Improved SNR and a 14-bit analogue to digital converter (ADC),
- Improved coverage of global aquatic environments when there are 2 satellites (A & B): ~ 3 days ignoring the effect of clouds.
- A long time-series dataset, made by launching 4 missions (A to D) over 20+ years.
- Improved data delivery timeliness for L1B and L2 products, for NRT products being 3 hours from the time of sensing,
- 100% overlap with SLSTR swath, and simultaneous acquisitions facilitating the use of OLCI and SLSTR in synergy.

The 21 wavelengths used to measure TOA radiance are as shown Table 1, alongside the SNR for a reference radiance (Lref) that approximates the expected signal from an open-ocean water pixel; see [RD-7] for the reference radiance values. The measured spectral response functions, which described the true shape of the wavebands, are available for both Sentinel 3A and 3B. There can be accessed via the link in the footnote of this page[3].

The sampling period of the OLCI detectors (CCD's) runs at 44 ms, which correspond to a mean along-track distance of about 300 m. Therefore, OLCI produces the Full Resolution (FR) product with a spatial resolution of approximately 300 m. In addition, the Reduced Resolution (RR) product is generated with a spatial resolution of approximately 1.2 km with 16 (nominally four by four) FR pixels averaged to create a RR pixel; the number of pixels used is varied in the across track direction, as a function of the across track pointing angle from the RR product pixel centre, so that spatial resolution degradation is minimised at the FOV edges.

4.4 Calibration and validation activities

Sentinel-3 calibration and validation (Cal/Val) activities are essential to the quality of the mission. Calibration determines the quantitative response of a system or measuring instrument, to known and controlled inputs. The calibration of satellite instrument allows it to provide

[3] Link to the OLCI-A and OLCI-B Spectral Response Functions Document: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-olci/olci-instrument/spectral-response-function-data

reliable data to meet the mission requirements (AD-2) and the requirements of applications and services.

In terms of the onboard calibration, OLCI is equipped with a calibration assembly, which includes a motorized wheel with three fixed diffusers, a shutter, and an Earth View port that allows the cameras free access to the Earth in imaging mode. Calibrations happen periodically, mostly at the ecliptic South Pole where the sunlight can reach the exposed diffuser in the calibration assembly [RD-15]. There are 3 Sun diffusers: 2 "white" diffusers dedicated to radiometric calibration, and one doped with erbium dedicated to spectral calibration [RD-15].

In addition to instrument pre-launch and onboard calibrations, a System Vicarious Calibration (SVC) must be applied to achieve the required ocean colour product uncertainties ([AD-2]; [RD-6]; [RD-16]).

SVC uses highly accurate in situ measurements of water-leaving radiances, which are the best quality radiometric Fiducial Reference Measurements for ocean colour. SVC employs these FRMs to reduce residual biases in Level-2 products. Details of the SVC process can be found in [RD-17].

Validation is focused on independently assessing the accuracy and stability of the satellite products. For ocean colour this involves inter-comparisons with high-quality ground-truth in situ measurements (FRMs) of both the radiometry and bio-optical parameters and inter-comparisons with corresponding products from other stable missions and climatologies. In ocean colour, in situ FRMs provide critical knowledge of the ground truth but are sparse due to the complexity of radiometric and bio-optical measurements from ships and instrumented platforms. Mission inter-comparisons allow for large-scale global time-series evaluations.

To support validation, EUMETSAT and ESA have a permanently-open Announcement of Opportunity call[4] "To engage world-class validation expertise and activities to complement Sentinel-3 routine validation activities and ensure the best possible outcomes for the Sentinel-3 Mission". Sentinel-3 Validation Team (S3VT) supports Agency product validation efforts and receives privileged access to the Sentinel-3 OLCI data.

[4] EUMETSAT's Copernicus Marine Cal/Val User Portal: https://www.eumetsat.int/website/home/Data/CopernicusServices/CopernicusMarineCALVALUserPortal/index.html

Table 1: OLCI wavebands; updated from [RD-7]

Band number	Central wavelength [nm]	Spectral width [nm]	SNR @ Lref for each of the 5 cameras*	Function
Oa1	400.000	15	2420 / 2396 / 2324 / 2369 / 2278	AC, improved water constituent retrieval
Oa2	412.500	10	2398 / 2410 / 2341 / 2402 / 2387	CDOM and detrital pigments
Oa3	442.500	10	2161 / 2200 / 2167 / 2186 / 2198	Chl absorption maximum
Oa4	490.000	10	2000 / 2035 / 1995 / 1982 / 1987	High Chl and other photosynthetic pigments
Oa5	510.000	10	1979 / 2013 / 1982 / 1965 / 1984	Chl, TSM, turbidity and red tides
Oa6	560.000	10	1776 / 1802 / 1801 / 1794 / 1818	Chl reference (minimum)
Oa7	620.000	10	1591 / 1610 / 1625 / 1593 / 1615	TSM
Oa8	665.000	10	1547 / 1559 / 1566 / 1533 / 1560	Chl (2nd absorption maximum), TSM and CDOM
Oa9	673.750	7.5	1329 / 1338 / 1350 / 1324 / 1341	Improved fluorescence retrieval
Oa10	681.250	7.5	1320 / 1327 / 1338 / 1314 / 1332	Chl fluorescence peak
Oa11	708.750	10	1420 / 1421 / 1434 / 1413 / 1429	Chl fluorescence baseline
Oa12	753.750	7.5	1127 / 1120 / 1133 / 1124 / 1138	O_2 (oxygen) absorption and clouds
Oa13	761.250	2.5	502 / 498 / 505 / 500 / 507	O_2 absorption band and AC aerosol estimation
Oa14	764.375	3.75	663 / 658 / 667 / 661 / 669	AC
Oa15	767.500	2.5	558 / 554 / 562 / 556 / 564	O_2 A-band absorption band used for cloud top pressure
Oa16	778.750	15	1514 / 1496 / 1523 / 1509 / 1524	AC aerosol estimation
Oa17	865.000	20	1243 / 1213 / 1238 / 1245 / 1250	AC aerosol estimation, clouds and pixel co-registration, in common with SLSTR
Oa18	885.000	10	823 / 801 / 814 / 824 / 831	Water vapour absorption reference band
Oa19	900.000	10	691 / 674 / 683 / 693 / 698	Water vapour absorption
Oa20	940.000	20	535 / 523 / 525 / 539 / 542	Water vapour absorption, linked to AC
Oa21	1020.000	40	346 / 338 / 349 / 346 / 351	AC aerosol estimation

* Data supplied by Donlon (pers. comm.), correct as of June 2017 for Sentinel-3A

4.5 Where to go for further information on the algorithms

The detail of each algorithm is written within an Algorithm Theoretical Basis Document (ATBD), which is publicly accessible[5]. A list of the ATBD documents can be found in Table 2.

Table 2: OLCI ocean colour product primarily ATBDs

Product	ATBD	ATBD Reference
Oa##_reflectance, A865, IWV & T865	Baseline AC: Atmospheric correction over Open Waters with integrated OLCI Bright Pixel Correction (BPAC)	S3-L2-SD-03-C07-LOV-ATBD & S3-L2-SD-03-C08-ARG-ATBD_BWAC
	Alternative AC: Atmospheric corrections over Complex Waters	S3-L2-SD-03-C17-GKSS-ATBD
	Retrieval of IWV column from OLCI Measurements	S3-L2-SD-03-CFUB-ATBD_WaterVapour
PAR	Photosynthetically Active Radiation	S3-L2-SD-03-C12-ARG-ATBD
CHL_OC4ME & KD490_M07	Ocean Colour Products in Open Water	S3-L2-SD-03- C10-LOV-ATBD
ADG443_NN, CHL_NN & TSM_NN	Ocean Colour Complex Water	S3-L2-SD-03-C11-GKSS-ATBD

[5] EUMETSAT's ocean colour webpage:
http://www.eumetsat.int/website/home/Data/CopernicusServices/Sentinel3Services/OceanColour/index.html

5 PROCESSING LEVELS AND SCHEMES

The OLCI operational processor is divided into three major processing levels:

- **Level 0**
  This step processes raw data contained in instrument source packets. Level 0 products are internal products, and are not disseminated to users.

- **Level 1**
  This step processes the Level 0 data to geo-located top of atmosphere radiances for each OLCI channel.

- **Level 2**
  This step processes the Level 1 data to water leaving reflectances and geophysical variables (e.g. chlorophyll).

5.1 Level-1 processing approach

The OLCI L1B processor has 3 modes, each of which produce their own L1B products. The radiometric and spectral calibration modes produce calibration look up tables and wavelength characterisation tables, respectively. The Earth observation mode, produces L1B products related to the raw data for both the full and reduced resolution products. The main data processing steps taken to produce Earth observation L1B products [RD-20] are:

- Data extraction and quality checks
- Radiometric Calibration
  - Primary instrument corrections and radiometric scaling
  - Stray light correction
- Geo-referencing
- Pixel classification
- Spatial re-sampling
- Annotations
- Products formatting

The OLCI Radiometric Model is based on the entire set of in-flight radiometric calibrations. It includes radiometric gain coefficients at a reference date and a long-term evolution model. As of 03/05/18, the set of radiometric gain coefficients used to derive both the Reference Gains and the Evolution Model have been computed using up-to-date geometric and spectral calibration and instrument settings and most of all an upgraded diffuser BRDF model based on in-flight data and diffuser ageing (browning) correction. The Radiometric Model is continuously monitored against new Radiometric Calibration acquisitions. More details can be found in the OLCI product notices[6].

5.2 Level-2 processing approach

As shown in Figure 1, the pre-processing includes an estimation of the Integrated Water Vapour column (IWV) alongside the smile correction and any adjustment for white caps and sun glint. Then, the default operation is that both AC approaches are run in parallel, with the BAC feeding

[6] https://www.eumetsat.int/website/home/Data/CopernicusServices/Sentinel3Services/OceanColour/index.html

all the further ocean colour steps except for the Case 2 Regional / Coast Colour (C2RCC) processor that is fed by the Alternative Atmospheric Correction (AAC).

The Baseline AC (BAC) algorithm is based on the algorithm developed for MERIS (Antoine and Morel, 1999 [RD-8]), to ensure consistency between the two instruments' records. As it was designed for Open Waters, with a spectral signature dominated by phytoplankton pigments, then there is also a Bright Pixel Correction (BPAC) integrated within it (Moore et. al. 1999 [RD-9] and Moore et al., 2017 [RD-10]). The BPAC accounts for situations where the

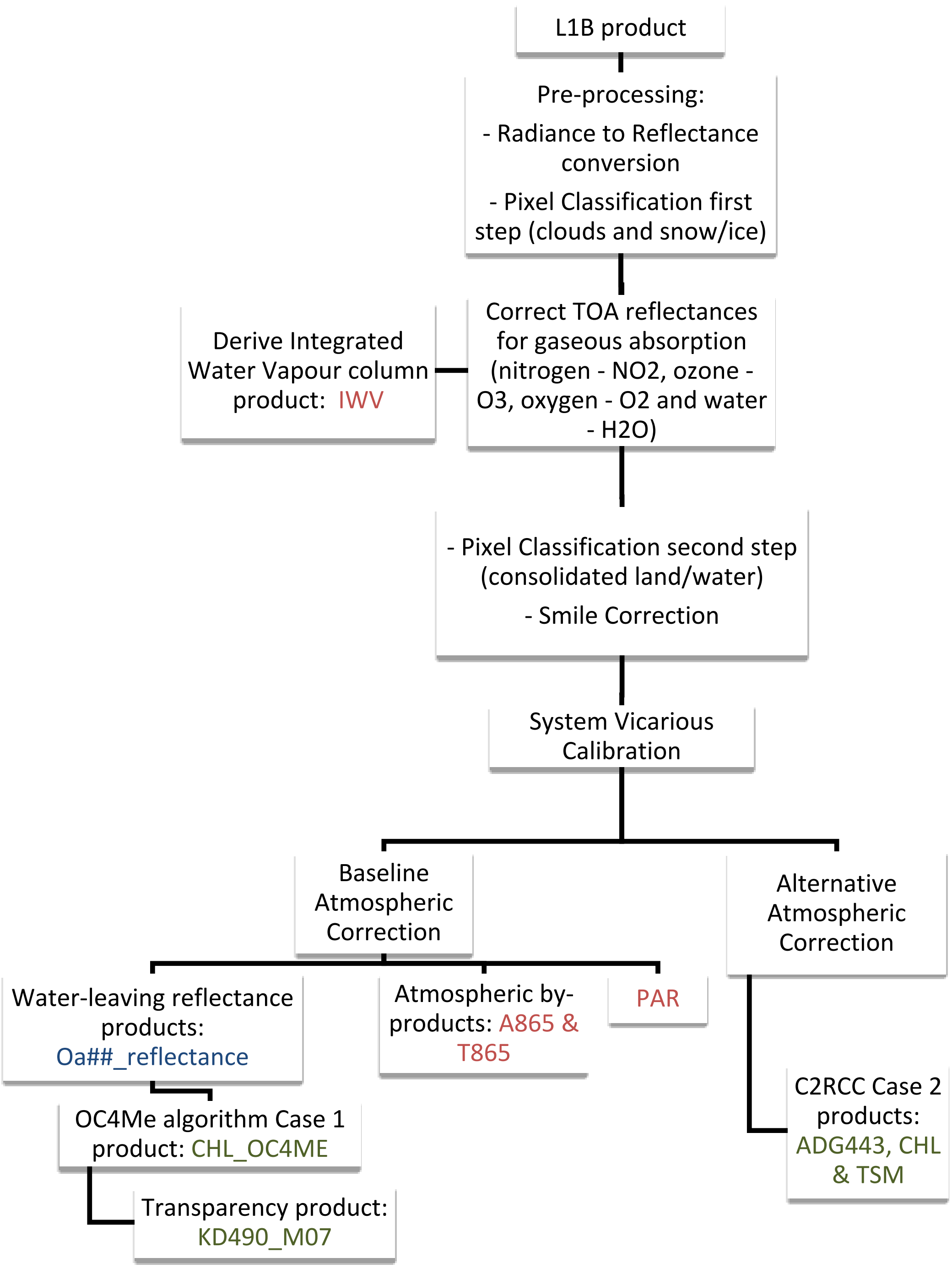


Figure 1: L1 to L2 processing.

Near Infrared (NIR) water-leaving radiance is not negligible i.e., high scattering waters where there's a high Chl and/or TSM concentration. The version implemented in the OLCI processing chain is an update of the Moore et. al. 1999 [RD-9] paper, with improvements to the OLCI ATBD [RD-10] resulting from the 4th reprocessing of the MERIS data. The OLCI algorithm uses a coupled atmosphere-hydrological model where the water contribution is implemented in terms of Inherent Optical Properties (IOPs) rather than TSM. The model is solved using spectral optimization inversion at five NIR bands.

The output of the BAC processing is the water-leaving reflectance (see Eq. 3) alongside the aerosol optical depth (T865) and Ångström exponent (A865) that are calculated as part of the AC process, and indicate the AC's success in subtracting the atmospheric contribution. If the AC is working correctly then the atmospheric by-products shouldn't show contamination from marine features.

The Photosynthetically Active Radiation (PAR) product, inherited from MERIS, is the instantaneous PAR at the water surface. It was originally developed for Sun-stimulated fluorescence calculations (Aiken and Moore, 1997 [RD-11]).

The following ocean colour products, primarily applicable in Open Waters, are then calculated from water-leaving reflectance:

- Algal pigment concentration based on the Ocean Colour for MERIS (OC4Me) algorithm developed by Morel et al. (2007 [RD-12]), following the approach of O'Reilly et al. (1998 [RD-22]), with the product called CHL_OC4ME.

- Diffuse Attenuation coefficient at 490 nm (KD490_M07), as outlined in [RD-12].

For Complex Waters that are significantly influenced by CDOM and/or TSM, there is an Alternative AC (AAC) based on an artificial neural network. AAC was originally developed for MERIS (Doerffer and Schiller, 2007 [RD-13]), and was updated following several ESA funded projects to become the C2RCC processor. The TOA reflectances in 15 bands (400-753 nm, 778, 865 and 1020 nm), corrected for absorbing gases and the smile effect (see Section 8.1.1), are used together with wind speed, salinity, temperature, altitude of the water surface and observation geometry to estimate the water-leaving reflectances and atmospheric parameters. These reflectances and atmospheric parameters are not included within the standard products. The reflectances are firstly used to estimate the total backscattering coefficient (BBP443), total absorption coefficient (ATOT443), phytoplankton absorption coefficient (APH443) and coloured Detrital and Dissolved Material absorption coefficient (ADG443). Then, the following products are generated:

- ADG443 [m^{-1}] as the product ADG443_NN
- Chl [$mg.m^{-3}$] as the product CHL_NN
- TSM [$g.m^{-3}$] as the product TSM_NN

6 OLCI PRODUCTS AND FILE TYPES

There are two OLCI marine product types that are disseminated to users. These are provided at two resolutions, full (FR) and reduced (RR).

- **Level 1 EFR/ERR**
  The Level-1 product provides radiances for each pixel, each view and each OLCI channel, plus annotation data associated to OLCI pixels.

- **Level 2 WFR/WRR**
  The Level-2 water product provides water and atmospheric geophysical parameters.

For the nominal orbit, at sub-satellite point, OLCI Full Resolution is approximately 300 m on ground. For the nominal orbit, at sub-satellite point, OLCI Reduced Resolution is approximately 1.2 km on ground.

OLCI Level-1 EFR/ERR and Level-2 WFR/WRR data products are freely available to the public. OLCI files are collected into a SAFE container containing free-standing NetCDF-4 format files.

6.1 Product timeliness

OLCI data are provided as Near Real-Time (NRT) and Non-Time Critical (NTC) products, with the NTC products being constrained by the timeliness of the input ancillary meteorological information. NRT products use ECMWF meteo forecast data and NTC products use ECMWF analysis data. At Level 1, the difference between OLCI NRT and NTC products is in the ancillary meteo values at tie points and in sun_glint_risk flag that uses the ECMWF wind speed. There is no difference in the radiance products between NRT and NTC at Level 1.

6.2 File naming

The file naming is based on a sequence of fields [RD-19]:

```
MMM_SS_L_TTTTTT_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMS
S_<instance ID>_GGG_<class ID>.<extension>
```

Which for Sentinel-3 OLCI marine data would be, for example:

```
S3A_OL_1_EFR____20160509T103945_20160509T104245_20160509T12490
7_0180_004_051_1979_MAR_O_NR_001.SEN3
```

- **MMM** – Mission id, e.g. S3A
- **SS** - Data source/consumer, e.g. OL is for OLCI
- **L** - Processing level, e.g. 1 for L1 and 2 for L2
- **TTTTTT** - Data Type ID, e.g.
  - "EFR___" = L1B product at FR
  - "ERR___" = L1B product at RR
  - "WFR___" = L2 FR water (marine) product
  - "WRR___" = L2 RR water (marine) product

- **YYYYMMDDTHHMMSS** - 15 character date and time (date plus "T" plus time) for (1) **Data Start** (2) **Data Stop** time, and (3) **Creation Date**
- **<instance id >** - 17 characters e.g. 0180_004_051_1979 is duration (sensing time interval in seconds), cycle number, relative orbit number, and frame along track coordinate (elapsed time in seconds from the ascending node indicating the frame start time)
- **GGG** – Product Generating Centre e.g., MAR = MARINE (EUMETSAT)
- **<class ID>** - 8 characters to indicate the processing system e.g., O_NR_001 is (1) the software platform (O for operational, F for reference, D for development and R for reprocessing), (2) the processing workflow (NR for NRT, ST for STC and NT for NTC) and (3) 3 letters/digits indicating the baseline collection
- **<extension>** - Filename extension, SEN3

6.3 Data format

The data format is a Standard Archive Format for Europe (SAFE) product package containing a collection of files, see Figure 2. The manifest file (xfdumanifest.xml) explains the contents of the package at an overarching level. Each of the measurement and annotation data files are stored in netCDF (version 4) format, with the file names given in Section 5.3.2 and 5.4.2. The product package can exist as a directory in a filesystem, zipped folder or tarball.

OLCI RR data is provided as whole orbits, while the FR data is provided as 3 minute granules as it is much larger in file size than the RR data.

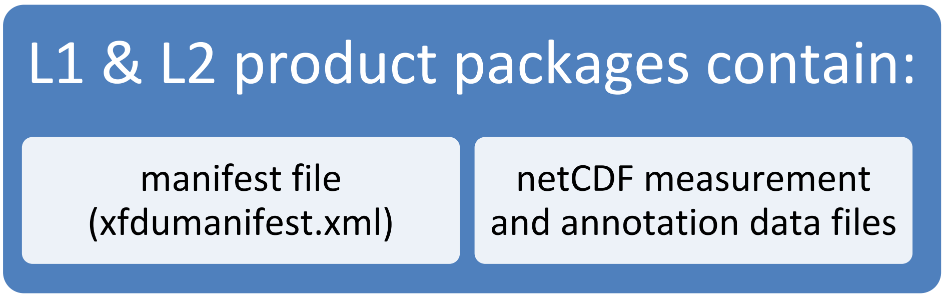


Figure 2: OLCI file format

6.4 Level 1 product contents

The L1B products are TOA (upwelling) radiances [$mW.m^{-2}.sr^{-1}.nm^{-1}$], calibrated to geophysical units and ortho-geolocated onto the Earth's surface. They are spatially resampled onto an evenly spaced cross-track grid, FR or RR, based on the computed pointing angle and according to the surface of the reference ellipsoid. Product pixels are filled with instrument pixels for FR products, and nearest neighbour averages of the surrounding instrument pixels for RR products. The products are then annotated with the illumination and observation geometry, environment data (meteorological data) plus quality and classification flags.

The measurement netCDF data files include [RD-21]:

- "OL_1_ERR___" contains:

    - Oa##_radiance.nc - 21 measurement data files containing the TOA radiances at each band, stored as one band per file, accompanied by the associated error estimates e.g., Oa01_radiance.nc for the band 1 OLCI radiance data.
- "OL_1_EFR___" contains the:
    - Oa##_radiance.nc - the same 21 measurement data files as "OL_1_ERR___",
    - removed_pixels.nc - providing all data related to pixels that have been removed during the re-sampling process.

The accompanied product error estimates Oa##_radiance_err are currently empty.

The annotation netCDF data files [RD-21] include:

- time_coordinates.nc - time_stamp of the each frame of the product
- geo_coordinates.nc - longitude, latitude and altitude
- qualityFlags.nc - quality_flags, as specified in Table 3.

Table 3: L1 Quality flags

Flag	Description
land	land as the underlying surface, whatever the atmosphere conditions i.e., whether cloudy or not
coastline	coastline pixels
fresh_inland_water	pixels within inland water bodies, and so are also flagged as land
tidal_region	pixels enclosed in areas of high tidal activity
bright	any pixel with a TOA reflectance greater than a defined threshold [RD-20] is assumed to be cloud contaminated, thick aerosols or haze, bright land surfaces (such as sand, snow and ice) or bright water surfaces (such as sea ice or sun glint)
straylight_risk	identifies pixels for which an insufficient number of neighbours were available for a good correction of the Ground Imager straylight [RD-7]
invalid	missing data due to a transmission error, resulting in missing packets, or due to out of swath or defects in the CCD cells [RD-20]
cosmetic	if missing data have been cosmetically filled, e.g. because the transmission error gap was between valid frames [RD-20]
duplicated	duplicated pixel during cross-track ground pixel resampling
sun_glint_risk	Sun glint risk flag, estimated from the wind speed and Solar Zenith and Viewing Angles (SZA, VZA) [RD-20]
dubious	pixels within potential contamination by neighbouring saturated pixels
saturated_Oa01 to saturated_Oa21	saturation at the ADC and sensor levels

- Tie-point based data (every 16th cross-track pixel along each row)
  - tie_geo_coordinates.nc – longitude and latitude
  - tie_geometries.nc – solar and observation geometries - SZA, SAA, OZA and OAA
  - tie_meteo.nc – ECMWF modelled atmospheric_temperature_profile, horizontal_wind (vector at 10m altitude), humidity, reference_pressure_level, sea_level_pressure, total_columnar_water_vapour and total_ozone
- instrument_data.nc - OLCI channel central wavelengths and bandwidths (lambda0 and FWHM), equivalent in-band extraterrestrial solar irradiance corrected for the Sun-Earth distance (Solar Flux), instrument detector index representative of product pixel (detector_index), frame_offset and relative_spectral_covariance

6.5 Level 2 product contents

The Level 2 products include the water-leaving reflectance, atmospheric by-products and ocean colour products as shown in Table 4; see Section 5.2 for further details on the processing.

Table 4: OLCI L2 water-leaving reflectance and atmospheric by-products

Product Name	Units	Products	Description	Application
Water-leaving reflectances	dimensionless	Oa##_reflectance → Oa##_reflectance where ## is the band number	Primary output of the Baseline AC (BAC) processing, based on Antoine and Morel (1999 [RD-8]) and Moore et. al. (1999 [RD-9]). In the viewing geometry and so not normalised for the bidirectional reflectance distribution function (BRDF).	Ocean Colour Open Water Products
Algal pigment concentration in open waters	$mg.m^{-3}$	chl_oc4me → CHL_OC4ME	Ocean Colour for MERIS (OC4Me) developed by Morel et al. (2007 [RD-12]).	
Diffuse attenuation coefficient at 490 nm	m^{-1}	trsp → KD490_M07	Developed by Morel et al. (2007 [RD-12]).	
Photosynthetically Active Radiation	$\mu Einstein.m^{-2}$	par → PAR	Instantaneous PAR at the ocean surface (Aiken and Moore, 1997 [RD-11]).	
Aerosol Optical Thickness	dimensionless	w_aer → T865	By-product of the BAC processing.	
Ångström exponent	dimensionless	w_aer → A865	By-product of the BAC processing.	
Algal pigment concentration in complex waters	$mg.m^{-3}$	chl_nn → CHL_NN	Complex water products derived from water-leaving reflectances obtained from the Alternative AC (AAC) processing. AAC is a neural	Ocean Colour Complex Water

Product Name	Units	Products	Description	Application
Coloured Detrital and Dissolved Material absorption coefficient at 443 nm	m^{-1}	iop_nn → ADG443_NN	correction over complex waters. The products are derived from a NN inverse radiative transfer model, originally developed for MERIS by Doerffer and Schiller (2007 [RD-13]), and updated to become the Case 2 Regional / Coast Colour (C2RCC) processor.	Products
Total suspended matter concentration	$g.m^{-3}$	tsm_nn → TSM_NN		
Integrated Water Vapour column	$kg.m^{-2}$	iwv → IWV	Total columnar water vapour based on 1D-Var retrieval originally developed for MERIS by Lindstrot et al. (2012 [RD-14]).	Atmospheric Products

The processing, dissemination and archiving of the near-real time and offline marine products are carried out at the Sentinel-3 Marine Centre located in EUMETSAT [RD-18].

The marine L2 products include:

- Water-leaving reflectance in 16 bands in files named Oa##_reflectance.nc (excludes Oa13, Oa14, Oa15, Oa19 and Oa20 which are dedicated to atmospheric gas absorption measurements)
- Ocean colour products
    - CHL in chl_oc4me.nc and chl_nn.nc from Open and Complex Water approaches
    - ADG443 in iop_nn.nc
    - TSM in tsm_nn.nc
- KD490 in trsp.nc
- Atmospheric by-products
    - PAR in par.nc
    - T865 and A865 in w_aer.nc
    - IWV in iwv.nc

The accompanied product error estimates, e.g. Oa##_reflectance_err, are currently only recommended for qualitative analyses because they do not contain the full uncertainty budget from L1 and L2 processing chains.

There are also annotation netCDF data files that include:

- time_coordinates.nc - Timestamp
- geo_coordinates.nc - Longitude, latitude and altitude
- wqsf.nc – Water quality and science flags, which include Classification and Quality Flags as given in Table 5 and Table 6, respectively

Table 5: L2 Water quality flags

Flag	Description
INVALID	Invalid flag: instrument data missing or invalid
WATER	Water (marine) with clear sky conditions, i.e. no clouds
CLOUD	Cloudy pixel
CLOUD_AMIBUOUS	Possibly a cloudy pixel, the flag removes semi-transparent clouds and other ambiguous cloud signatures
CLOUD_MARGIN	Cloud edge pixel, the flag provides an a-priori margin on the 'CLOUD or CLOUD_AMBIGUOUS' flag of 2 pixels at RR and 4 pixels at FR
SNOW_ICE	Possible sea-ice or snow contamination
INLAND_WATER	Fresh inland waters flag (from L1B); these pixels will also be flagged as LAND rather than WATER.
TIDAL	Pixel is in a tidal zone (from L1B)
COSMETIC	Cosmetic flag (from L1B)
SUSPECT	Suspect flag (from L1B)
HISOLZEN	High solar zenith: SZA > 70°
SATURATED	Saturation flag: saturated within any band from 400 to 754 nm or in bands 779, 865, 885 and 1020 nm
MEGLINT	Flag for pixels corrected for sun glint
HIGHGLINT	Flag for when the sun glint correction is not reliable
WHITECAPS	Flag for when the sea surface is rough enough for there to be whitecaps, which cause a brightening of the water-leaving reflectance
ADJAC	reserved for future use for an adjacency correction, so always set to false
WV_FAIL	IWV retrieval algorithm failed
AC_FAIL	BAC atmospheric correction is suspect
OC4ME_FAIL	OC4Me algorithm failed
OCNN_FAIL	NN algorithm failed
KDM_ FAIL	KD490 algorithm failed

- Tie-point based data (every 16th cross-track pixel along each row)
  - tie_geo_coordinates.nc – longitude and latitude
  - tie_geometries.nc – solar and observation geometries - SZA, SAA, OZA and OAA

    - tie_meteo.nc – ECMWF modelled atmospheric_temperature_profile, horizontal_wind (vector at 10m altitude), humidity, reference_pressure_level, sea_level_pressure, total_columnar_water_vapour and total_ozone
- instrument_data.nc
    - OLCI channel central wavelengths and bandwidths (lambda0 and FWHM)
    - equivalent in-band extraterrestrial solar irradiance (Solar Flux)
    - instrument detector index representative of product pixel (detector_index)
    - frame_offset and relative_spectral_covariance

Table 6: L2 Science flags

Flag	Description
BPAC_ON	Bright Pixel Correction converged and a NIR signal was determined
WHITE_SCATT	"White" scatterer within the water e.g. coccoliths
LOWRW	Water-leaving reflectance at 560 nm is less than a defined threshold or HIINLD_F raised (flag for low pressure water i.e., high altitude inland waters)
HIGHRW	High water-leaving reflectance at 560 nm or the TSM retrieved as part of the BPAC is above a threshold
ANNOT	Annotation flags for the quality of the atmospheric correction, including: • ANGSTROM (Ångström exponent cannot be computed); • AERO_B (blue aerosols); • ABSO_D (desert dust absorbing aerosols); • ACLIM (aerosol model does not match aerosol climatology); • ABSOA (absorbing aerosols); • MIXR1 (aerosol mixing ratio is equal to 0 or 1); • DROUT (minimum absolute value of the reflectance error at 510 nm is greater than a defined threshold); • TAU06 (aerosol optical thickness is greater than a defined threshold)
RWNEG_O01 to RWNEG_O21	Provides a "negative water-leaving reflectance" flag for each band's water-leaving reflectance: the value below which pixels are flagged varies according to the band, with the threshold stored within a Look-Up Table

6.6 Product features and limitations

In OLCI, inland waters have both the INLAND_WATER and LAND flags activated, but not the WATER flag. While marine waters have the WATER flag activated.

The BPAC_ON flag indicates that the spectral optimization inversion in the BAC's Bright Pixel Correction converged and a NIR signal of water was determined.

Product limitations are described in detail in Product Release Notices. Please refer to the Notices for the detailed status of the products.

7 HELPDESK, PRODUCT DISSEMINATION AND TOOLS

7.1 Helpdesk and Training

The EUMETSAT User Helpdesk is available to all users during standard office hours. The service provides support on data access and product usage and application. All user requests on the EUMETSAT OLCI Marine data products should be directed to the EUMETSAT Help Desk at ops@eumetsat.int.

Information on training, including sessions with a focus on the Copernicus Marine Data Stream, is available via https://www.eumetsat.int/website/home/Data/Training/index.html

7.2 Data access routes

EUMETSAT provides data access through a number of routes, depending on your preferred delivery mode and the latency of the data that's needed. The central catalogue in the first tier / row of Figure 3 and Table 7 lists all EUMETSAT missions (Meteosat, Metop, and Jason-2) in addition to the Copernicus Sentinel-3 marine and atmosphere products.

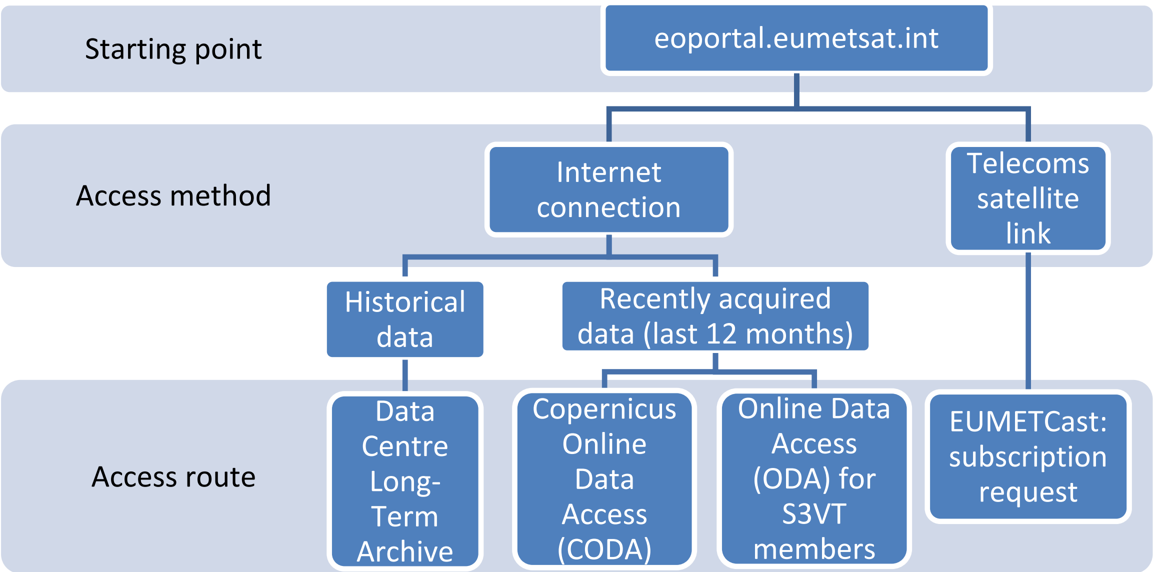


Figure 3: Data access routes

For those downloading data from the internet, there are at least 3 routes. If you are interested in just recently acquired data (up to 1 year) then the best access route is the Copernicus Online Data Access (CODA) that provides an interactive interface. Batch scripting is also possible. In order to discover CODA's functionalities and example scripts to download Sentinel-3 data using CODA APIs, read the User Guide: https://coda.eumetsat.int/manual/CODA-user-manual.pdf

Table 7: Data access locations

	EUMETCast eumetcast.com	Multi service push dissemination system based on multicast technology, which is transported to the user via satellite (EUMETCast Satellite, with coverage over Europe, the Middle-East and Africa).
	CODA coda.eumetsat.int codarep.eumetsat.int	Download service offers all the recently acquired Sentinel-3 marine and atmospheric products through a rolling archive that (at a maximum) will span 12 months. Products from the last year are also available via the EUMETSAT Data Centre Long-Term Archive. Users should note that reprocessed ocean colour data is made available through the parallel **codarep** portal.
	Data Centre Long-Term Archive archive.eumetsat.int	Ordering application that enables users to browse and select products, from EUMETSAT's long-term archive, including the Copernicus Sentinel-3 marine and atmospheric products.
	EUMETView eumetview.eumetsat.int	A visualisation service that allows users to view EUMETSAT's data and Copernicus Sentinel-3 marine data in an interactive way using an online map view.

If you would like to access a historical time-series then the Data Centre is most suitable. Data Centre allows you to access either the global dataset (under the Products tab: enter OLCI as a search term so you see just these products) or large regions of interest such as the North Atlantic and Mediterranean Sea (under the Sentinel 3 Datasets tab); see Figure 4. Then, on subsequent screens you can define a region of interest and time period before ordering the products. Selecting a given dataset or a region of interest will return all products that intercept that region.

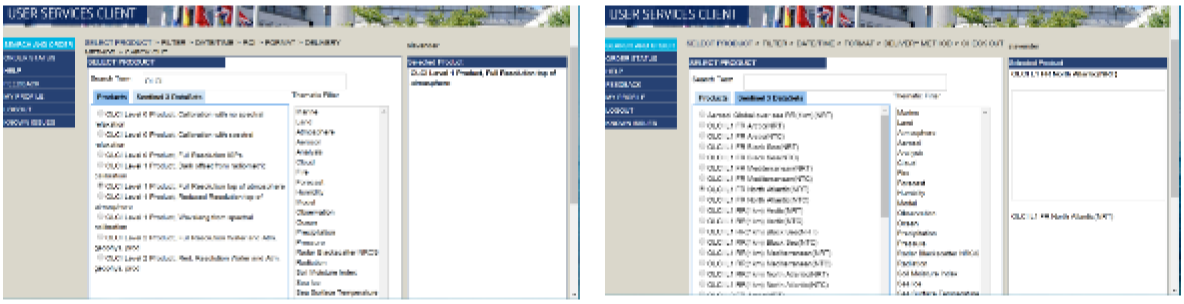


Figure 4: Choosing OLCI datasets within the EUMETSAT Data Centre.

For those who are members of the S3VT, see Section 4.4, there's also FTP access via the ODA that allows you to access both datasets and minifiles. Minifiles are products extracted over small areas of interest and provided in the standard SAFE format.

7.3 Software Tools

7.3.1 Sentinel-3 Toolbox

The Sentinel-3 Toolbox consists of visualisation, analysis and processing tools for the exploitation of OLCI and SLSTR data, and is an extension to the SeNtinel Application Platform (SNAP) that can be downloaded from the Science Toolbox Exploitation Platform (STEP)[7].

Once SNAP has been downloaded and installed it is possible to open L1 and L2 OLCI products. If you need questions answered about the SNAP tool and associated Sentinel toolboxes then there is an on-line forum[8].

7.3.1.1 Installing the toolbox

To install SNAP, click/double-click the installer and follow the on-screen instructions to install SNAP.

7.3.1.2 Opening a Sentinel-3 product

Sentinel-3 products are provided not as single files but as a product package containing a collection of files, the package is a folder. The folder name is the actual product name, ending with ".SEN3". Each folder contains a metadata file named xfdumanifest.xml and at least one netCDF file. Each netCDF file contains a subset of a Sentinel-3 product's content.

To open a Sentinel-3 product you can either:

- Drag and drop the whole folder into the "Products View"
- Drag and drop the xfdumanifest.xml file into the "Products View"
- Choose "File->Open Product", navigate to the xfdumanifest.xml file and click "Open Product"
- Choose "File->Import Raster Data->Multispectral Data->SENTINEL-3", navigate to the xfdumanifest.xml file and click "Open Product"

You can also open single netCDF files. However, keep in mind that this will provide a generic netCDF access without associated information about geocoding, flags and other functionalities.

You can visit the CODA webpage to find information about CODA web-service and video that explain how to download and display Sentinel-3 data:

https://www.eumetsat.int/website/home/Data/DataDelivery/CopernicusOnlineDataAccess/index.html

7.3.1.3 Basic functionality

Once you have opened a product in SNAP there are many different things you can do next. Here are some basic activities:

- Displaying a colour composite: choose "Window->Open RGB Image Window".
- Displaying spectra, choose "Optical->Spectrum View".

[7] STEP download page: http://step.esa.int/main/download/
[8] STEP forum: http://forum.step.esa.int/

- Displaying flags/masking the data: using the Mask Manager, see example in Section 8.2.3.
- Displaying pixel values, geolocation etc...

7.3.2 METIS

The Monitoring & Evaluation of Thematic Information from Space (METIS) tool[9] provides near-real time diagnostics of EUMETSAT's operational L2 and Level 3 (L3) optical products. Ocean Colour functionality is being continuously improved.

[9] METIS: http://metis.eumetsat.int/

8 DATA QUALITY

With Sentinel-3 being an operational mission, three main objectives were defined for the Cal/Val activities [RD-15]:

a) To provide a comprehensive initial assessment of product validity and quality at the end of commissioning activities.
b) To monitor the stability and the quality of the products throughout the operational phase of the mission.
c) To continuously improve the quality of the products in accordance with the evolving user requirements.

In addition, the Global Climate Observation System (GCOS) has identified ocean-colour as an Essential Climate Variable (ECV) with the GCOS Implementation Plan [RD-23] identifying the following set of ocean-colour requirements for climate research; see Table 8.

Table 8: GCOS ocean-colour requirements for accuracy and stability

Requirement category	Ocean-colour requirement
Water-leaving radiance accuracy	5.0 %
Water-leaving radiance stability per decade	0.5 %
Ocean chlorophyll accuracy	30.0 %
Ocean chlorophyll stability per decade	3.0 %

At this stage, the OLCI Cal/Val activities are still at an early stage and so results will be added to this section as they become available.

9 FREQUENTLY ASKED QUESTIONS

Please email any questions to the EUMETSAT User Helpdesk at ops@eumetsat.int.

9.1 OLCI data characteristics

9.1.1 Camera-to-camera discontinuities

Like with MERIS, you may see boundaries between the 5 cameras within the L1 products, and occasionally in L2 data. This is primarily due to the smile effect that causes small variations in the TOA radiances due to slight changes in central wavelengths across the CCDs in the cameras. This effect is visible at L1. At L2, the smile correction is applied which brings all pixels across the cameras' FOV to the nominal instrument centre wavelengths for each band and the effect should be minimized.

As the central wavelength is not constant within a L1 scene, the wavelength is provided as an array for each band in the file instrument_data.nc (lamda0 and FWHM groups); see Figure 5.

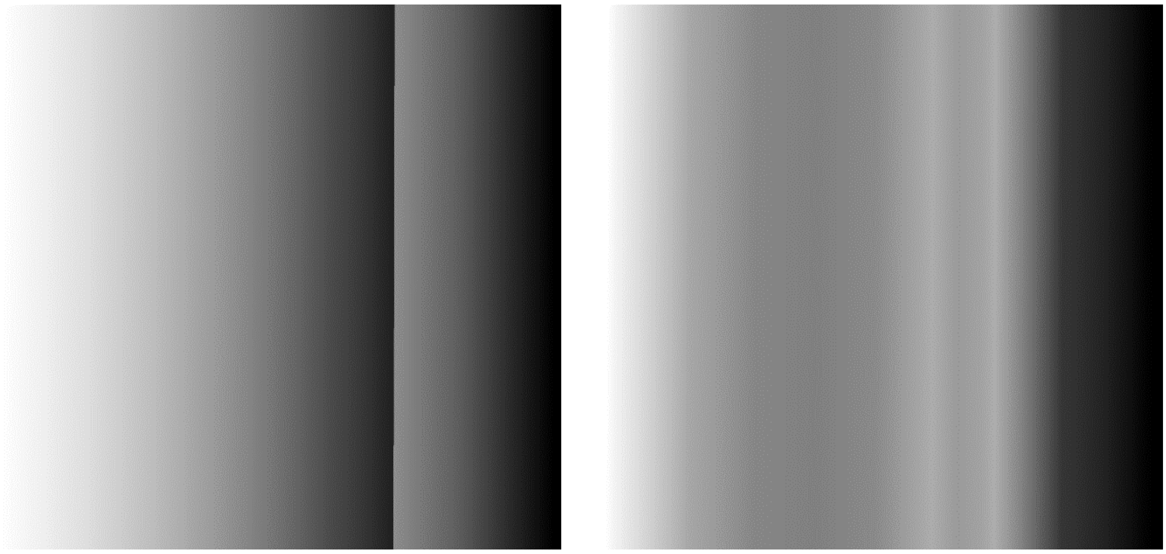


Figure 5: Example arrays of (left) lamda0 and (right) FWHM for band Oa1.

9.1.2 South Atlantic Anomaly

The South Atlantic Anomaly is an area where the Earth's inner Van Allen radiation belt comes close to the Earth's surface, which exposes orbiting satellites to higher-than-usual radiation levels. For OLCI, this is visible in all bands but particularly in the wider bands, like Oa21, where radiation hitting the CCD is visible as noise in an image; see Figure 6 which shows an OLCI scene captured over Argentina.

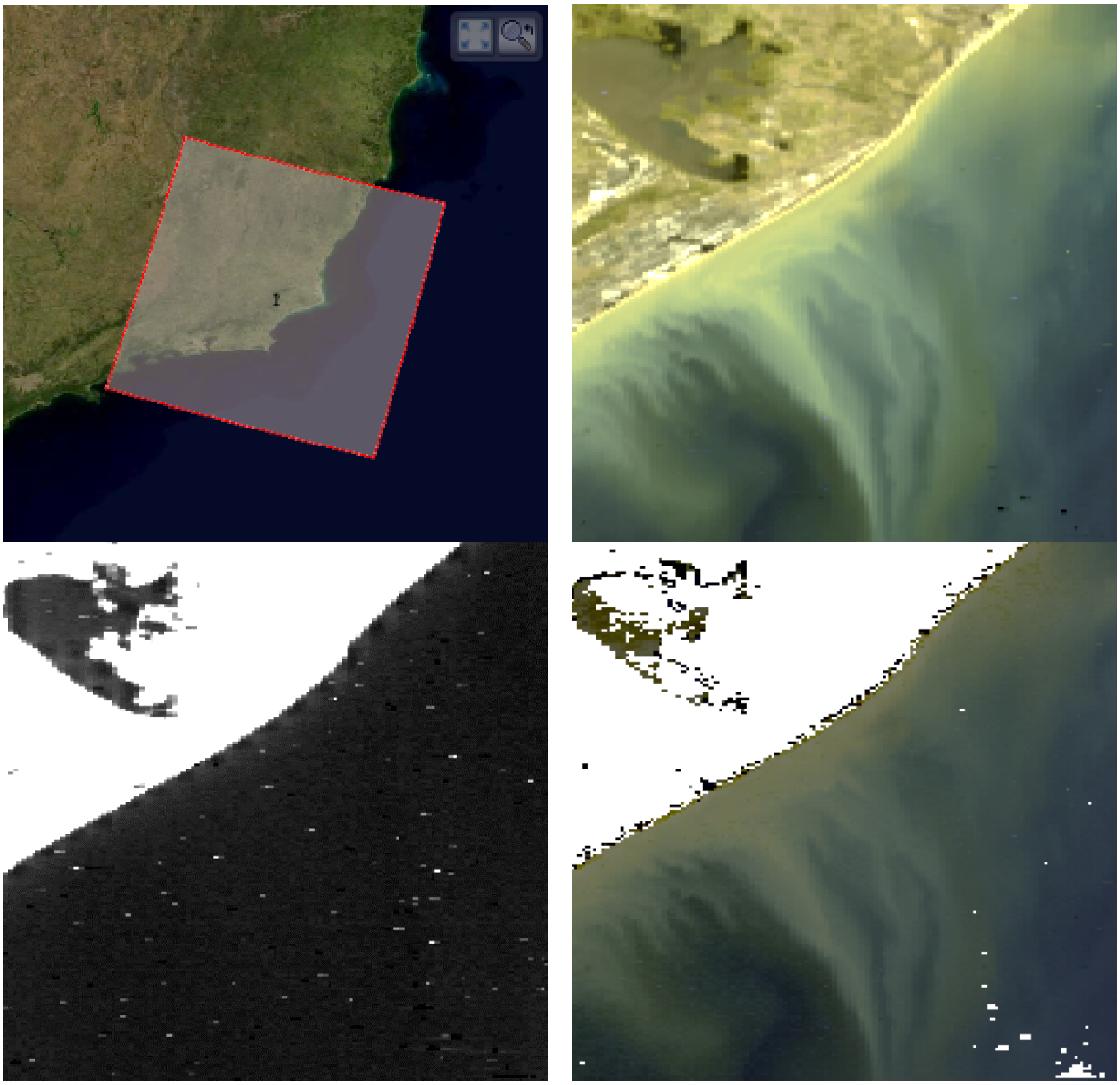


Figure 6: Subset of a Sentinel-3 FR scene with (top left) SNAP's World View and (top right) TOA Tristimulus RGB colour composite with the South Atlantic Anomaly as visible in (bottom right) the TOA band Oa21 radiance and (bottom left) atmospherically corrected data (Tristimulus RGB colour composite).

9.1.3 Sun glint affecting the right-hand side of scenes

OLCI was designed to be tilted to avoid Sun glint, and so has reduced glint contamination compared to MERIS. However, sun glint is not completely avoided. Therefore, you will see it in scenes where there is water; such as in Figure 7.

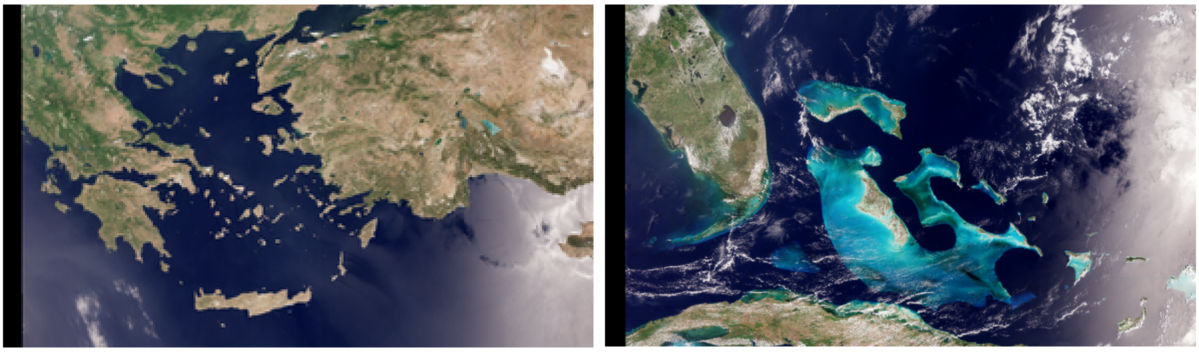


Figure 7: Example L1 scenes showing sun glint down the right-hand side of the scene.

9.2 Handling the data

9.2.1 How to view the contents of a netCDF file?

If you want to browse the detailed contents or metadata of a netCDF file (as opposed to visually looking at and interrogating the array in SNAP) then there are interactive tools such as Panoply [10] alongside Linux commands such ncdump.

9.2.2 How would I calculate the Top of Atmosphere Reflectance from a Level 1 product?

The solar irradiance provided in the L1 products varies throughout the year. It is computed for each product, in order to represent the solar irradiance at the Earth due to the Earth orbit eccentricity around the sun at the current date i.e., the modelling of the seasonal variations is included. Therefore, the OLCI TOA reflectance can be obtained by dividing by the solar irradiance in the L1 product as provided.

9.2.3 Which Level 2 flags should I apply?

The recommended L2 flags for masking unreliable or bad pixels are given in Table 9.

If you're studying inland waters then you'll need to ignore the LAND mask as these waters are also masked as LAND.

Figure 8 shows an example of a scene with this masking applied.

[10] Panoply download: https://www.giss.nasa.gov/tools/panoply/

Table 9: Recommended L2 flags for masking unreliable or bad pixels

<table>
<tr><th>Product names</th><th>Common flags</th><th>Processing chain flags</th><th>Product flags</th></tr>
<tr><td>Water leaving reflectances</td><td rowspan="8">Water Products
(WATER or INLAND_WATER)
and not
(CLOUD CLOUD_AMBIGUOUS CLOUD_MARGIN INVALID COSMETIC SATURATED SUSPECT HISOLZEN HIGHGLINT SNOW_ICE)</td><td rowspan="5">Open Water products
not
(AC_FAIL WHITECAPS ANNOT_ABSO_D ANNOT_MIXR1 ANNOT_DROUT ANNOT_TAU06 RWNEG_O2 RWNEG_O3 RWNEG_O4 RWNEG_O5 RWNEG_O6 RWNEG_O7 RWNEG_O8)</td><td>none</td></tr>
<tr><td>Algal pigment concentration in open waters</td><td>not OC4ME_ FAIL</td></tr>
<tr><td>Diffuse attenuation coefficient</td><td>not KDM_FAIL</td></tr>
<tr><td>Photosynthetically Active Radiation</td><td>not PAR_ FAIL</td></tr>
<tr><td>Aerosol Optical Thickness and Ångström exponent</td><td>none</td></tr>
<tr><td>Algal pigment concentration in complex waters</td><td rowspan="3">Complex Water Products
no specific flags to be applied</td><td>not OCNN_FAIL</td></tr>
<tr><td>Total suspended matter concentration</td><td>not OCNN_FAIL</td></tr>
<tr><td>Coloured Detrital and Dissolved Material absorption</td><td>not OCNN_FAIL</td></tr>
<tr><td>Integrated Water Vapour Column</td><td>Atmospheric Products</td><td>Water Vapour over WATER
not MEGLINT</td><td>not WV_FAIL</td></tr>
</table>

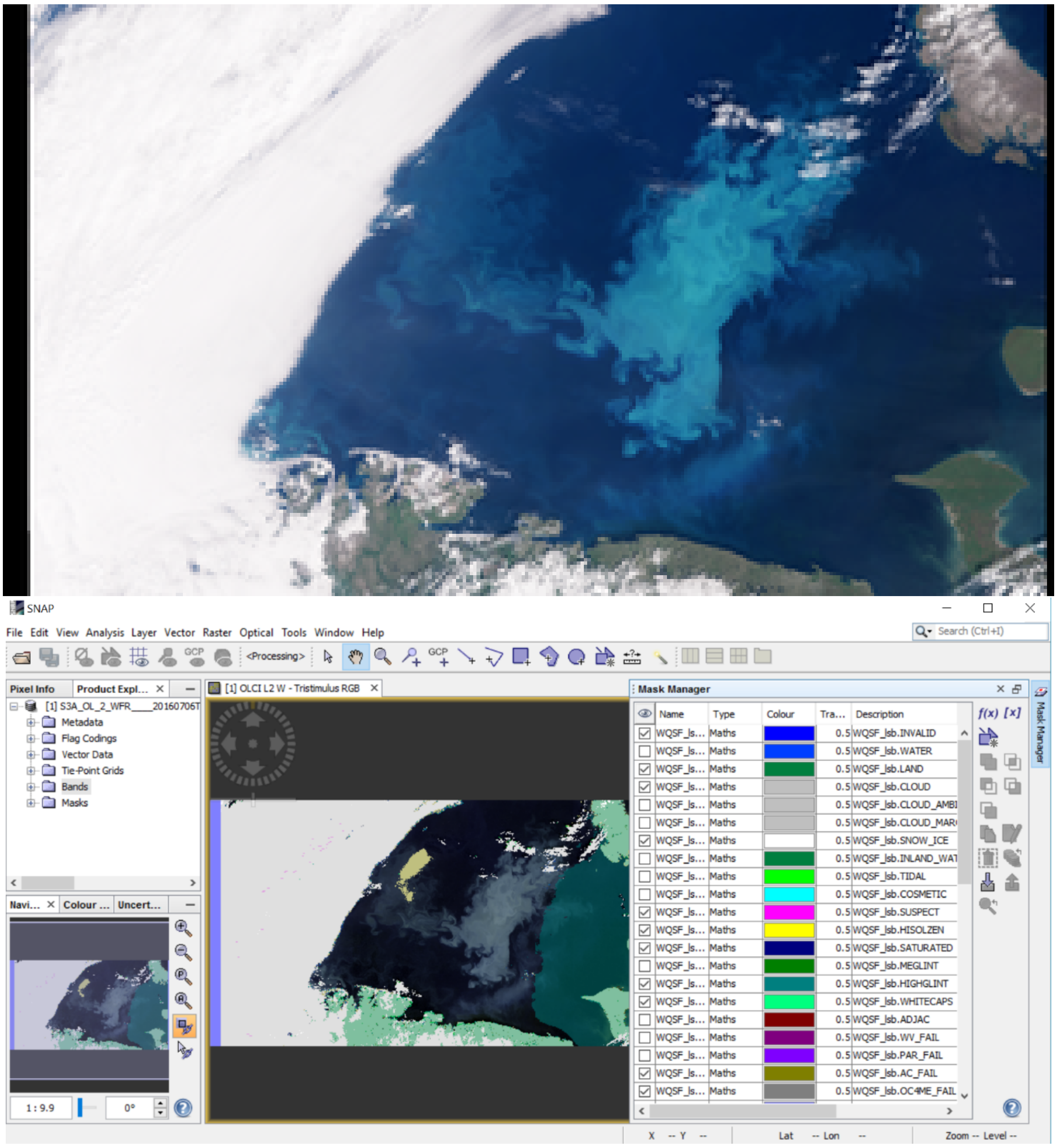


Figure 8: Example (top) L1 scene (bottom) L2 equivalent with the recommended L2 flags applied.