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Copernicus Climate Change Service

Product User Guide and Specification

Ocean Colour Version 6.0

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History of modifications

Version	Date	Description of modification	Chapters / Sections
1.0	29/04/2022	Creation	All
1.1	22/02/2023	Document updated following independent review and published.	Minor updates to all sections, document finalised for publication

List of datasets covered by this document

This document refers to CDR version 6.0 and the corresponding temporal extensions (ICDR).

Deliverable ID	Product title	Product type (CDR, ICDR)	Version number	Delivery date
WP2-FDDP-OC-v6.0_ C3S2-Lot3_DatasetDelivery-of-v6.0-OC-CDR_v1.0	Ocean Colour ECVs	CDR	6.0	15 June 2022
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WP2-ICDR-OC-v6.0_C3S2-Lot3_DatasetDelivery-of-v6.0-OC-ICDR_v1.0	Ocean Colour ECVs	ICDR	6.0	31 January 2022

Related documents

Reference ID	Document
C3S2_ATBD	Jackson, T., Hockley, K., Calton, B., Chuprin, A. (2022) *C3S Ocean Colour Version 6.0: Algorithm Theoretical Basis Document*. Issue 1.1. E.U. Copernicus Climate Change Service. Document ref. WP2-FDDP-2022-04_C3S2-Lot3_ATBD-of-v6.0-OceanColour-product.
C3S2_PQAD	Jackson, T., et al. (2023) *C3S Ocean Colour Version 6.0: Product Quality Assurance Document*. Issue 1.1. E.U. Copernicus Climate Change Service. Document ref. WP1-PDDP-OC-v6.0_C3S2-Lot3_PQAD-of-v6.0-OceanColour-product.
C3S2_PQAR	Jackson, T., Calton, B., Hockley, K. (2023) *C3S Ocean Colour Version 6.0: Product Quality Assessment Report*. E.U. Copernicus Climate Change Service. Document ref. WP2-FDDP-2022-04_C3S2-Lot3_ PQAR-of-v6.0-OceanColour-product.
OC_CCI-PUG	OC_CCI Product User Guide. Available at https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 5th September 2022].
OC_CCI-URD	OC-CCI User Requirements Document Version 2.0 (2022). Available at https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 5th September 2022].
OC_CCI-PVASR	OC-CCI Product Validation and Algorithm Selection Reports (atmospheric and in water reports all available). Available at https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 5th September 2022].
OC_CCI_POLYMER_ATBD	Steinmetz, F., Ramon, D., Deschamps, P-Y. (2016) *ATBD v1 - Polymer atmospheric correction algorithm*. Issue 2.1. Report submitted under the Ocean Colour Climate Change Initiative Phase 1, ESA/ESRIN contract no. AO-1/6207/09/I-LG. Available at https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 5th September 2022].

Acronyms

Acronym	Definition
ATBD	Algorithm Theoretical Basis Document
C3S	Copernicus Climate Change Service
CDR	Climate Data Record
CDS	Climate Data Store
CF	Climate and Forecast
Chl	Chlorophyll
CMUG	Climate Modelling User Group
EO	Earth Observation
ESA	European Space Agency
GAC	Global Area Coverage
GCOS	Global Climate Observing System
ICDR	Interim Climate Data Record
LAC	Local Area Coverage
MERIS	Medium Resolution Imaging Spectrometer
MODIS	NASA Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Format
nLw	Water-Leaving Radiance
OC	Ocean Colour
OC-CCI	Ocean Colour Climate Change Initiative
OLCI	Ocean and Land Colour Instrument
OPeNDAP	Open-source Project for a Network Data Access Protocol
PQAD	Product Quality Assurance Document
PQAR	Product Quality Assessment Report
Rrs	Remote Sensing Reflectance
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SNAP	Sentinel Application Platform
THREDDS	Thematic Real-time Environmental Distributed Data Services
URD	User Requirements Document
UUID	Universally unique identifier
VIIRS	Visible Infrared Imaging Radiometer Suite

General definitions

Atmospheric Correction

Atmospheric correction is the process of removing the effects of the atmosphere on the satellite images so that we can obtain information about the surface of the Earth. Atmospheric effects in optical remote sensing are significant and complex but can be largely considered as absorbing or scattering factors. Also keep in mind that the light reaching the satellite borne sensor has passed through the atmosphere twice, from the sun to the surface and then back to the sensor. For ocean colour remote sensing, the surface signal from the ocean is typically ≤10% of the total signal received by the satellite (with the other 90+% coming from the atmosphere).

Binning

In the context of this document, binning refers to the process of aggregating data into bins. This is an essential process when it comes to merging data from multiple sensors. Each remote sensing platform used to observe the Earth collects data in a manner that is constrained by the sensor design and satellite orbit. This means that different sensors will collect data at difference spatial resolutions and viewing geometries. Once the data has been processed at its native resolution it can be binned onto a defined grid for easier use.

Chlorophyll-a

Chlorophyll-a is a green pigment and the most prevalent photosynthetic pigment in both terrestrial and marine photosynthetic organisms. As an indicator of phytoplankton abundance, and therefore the base of the marine foodweb, chlorophyll-a concentration (chl-a) is recognised as an Essential Climate Variable. Oceanic chlorophyll-a is usually measured in units of mg m^{-3}, with concentrations ranging over multiple orders of magnitude.

Climate Data Record

The term Climate Data Record has a specific definition developed by the CEOS-CGMS Joint Working Group on Climate in 2020. The CEOS definition scheme defines three types of climate data records: 1) Fundamental Climate Data Records (FCDRs) consist of a consistently processed time series of uncertainty-quantified sensor observations calibrated to physical units, located in time and space, and of sufficient length and quality to be useful for climate science or applications; 2) Climate Data Records (CDRs) consist of a consistently processed time series of uncertainty-quantified retrieved values of a geophysical variable or related indicator, located in time and space, and of sufficient length and quality to be useful for climate science or applications; 3) Interim Climate Data Records (ICDRs) are consistently processed times series of uncertainty-quantified estimates of CDR values produced with better timeliness than, but otherwise minimising differences with, the estimated CDR values.

Essential Climate Variable

An Essential Climate variable (ECV) is a physical, chemical, or biological variable or a group of linked variables that critically contributes to the characterisation of Earth's climate. The Global Observing

Systems Information Center (GOSIC) provides further background, definitions, requirements, network information, and data sources for the ECVs.

In-water algorithms

The term ‘in-water’ is used to describe algorithms that estimate in-water properties of the surface water from the surface reflectance signal. These algorithms often provide estimates of concentrations of substance (such as chlorophyll-a or sediment) but could also provide estimates of Inherent Optical Properties (IOPs) such as absorption or scattering.

Level-[x] remote sensing data

Within remote sensing and ocean colour applications, datasets are often described in terms of levels. The level is representative of the amount of processing that has been performed. **Level-0** is the rawest data format available. It is full resolution data, as it comes from the instrument, with some processing applied to remove artefacts from data communication between the satellite and the ground stations. **Level-1** data is full resolution sensor data with time-referencing, ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, computed and added to the file. **Level-2** refers to derived geophysical variables (such as water-leaving reflectance or ocean colour products) at full resolution. This will have required processing to remove the atmospheric component of the signal. Pixels will also be masked by use of data quality flags. **Level-3** data is a binned version of the level-2 products at a given temporal and spatial resolution.

Masking

Masking is the process of setting pixels to NaN or blank values where a flag has been raised that the data would not be of sufficient quality for the intended purpose (or processing has failed). There are many factors that can lead to remote sensing data being of insufficient quality for a climate data record, so we shall not list them all here, but commonly applied masks in ocean colour remote sensing include cloud, cloud shadow, land, glint, and algorithm failure masks.

Match-ups

In the context of this document a match-up refers to a matched pair of in situ and remote sensing data. These measurements are matched based on their time and location information where some permitted time or space offset is permitted, for example we might match an in situ measurement to the closest pixel on the satellite data grid for the same day of observation. It is also of note that these measurements are also made using information at very different scales; an in situ measurement of chlorophyll-a might be from a litre of filtered seawater while the remote sensing estimate may be derived over a pixel 1km square (or larger).

Ocean Colour

When sunlight passes through the atmosphere and enters the ocean, the different colours in the light spectrum are absorbed and scattered as they encounter different particles and substances on their journey. This absorption and scattering of the visible spectrum confers a spectral signal to the reflected light measured by the sensors as ‘ocean colour’ data.

The Global Climate Observing System (GCOS) define ocean colour as:

> "Ocean colour is the radiance emanating from the ocean normalized by the irradiance illuminating the ocean. Products derived from ocean colour remote sensing (OCRS) contain information on the ocean albedo and information on the constituents of the seawater, in particular, phytoplankton pigments such as chlorophyll-a. OCRS products are used to assess ocean ecosystem health and productivity, and the role of the oceans in the global carbon cycle, to manage living marine resources, and to quantify the impacts of climate variability and change."

Phytoplankton

Phytoplankton are aquatic microscopic photosynthetic organisms. This group includes some bacteria, protists, and single-celled plants. There is a great diversity in appearance and function across phytoplankton, with orders of magnitude in size between the largest and smallest phytoplankton. Given their photosynthetic abilities, phytoplankton form the base of the marine food web. Phytoplankton growth primarily depends on the availability of sunlight and nutrients.

Remote sensing reflectance

Remote Sensing Reflectance, $R_{rs}(\lambda)$, has units of sr^{-1} (per steradian) and is the water-leaving radiance, corrected for bidirectional effects of the air-sea interface and sub-surface light field, normalised by downwelling solar irradiance, $Ed(\lambda)$, just above the sea surface. This is usually measured at multiple wavelengths by a given ocean colour sensor, so R_{rs} is a spectral product. R_{rs} is the primary variable of the Ocean Colour ECV, and the chlorophyll-a products are derived from the Rrs data.

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Scope of the document

This document is intended to support users in being able to make best use of the C3S OC products. It provides a summary of the main details of these products. Given that the C3S OC products are based on a processing chain originally developed by the ESA OC-CCI project, the reader is referred to OC-CCI documentation where applicable.

Executive summary

The Ocean Colour Essential Climate Variable includes **daily** measurements of the **oceanic surface water reflectance** and **chlorophyll-a concentration**. These data can be used to study the distribution of **phytoplankton and other optically active materials** (such as coloured dissolved material, sediments, and other particles). These data are therefore **essential** to global studies of **the ocean biosphere**.

In this context "Ocean colour" products refer to quantities that can be inferred by looking at differences in the proportion of incoming sunlight reflected from the ocean surface at different wavelengths. The variables provided through C3S are:

- Chlorophyll-a
- Remote Sensing Reflectance (Rrs) at 412, 443, 490, 510, 560 and 665 nanometer wavelengths.

This document provides an overview of **the datasets available**, **how to access them,** and examples of **how to use or visualize them.**

Recent improvements of note between the V5.0 and the V6.0 datasets include:

- Inclusion of the MERIS-4th reprocessing. V5.0 used the MERIS 3rd reprocessing.
- Addition of data from the Ocean and Land Colour Instrument (OLCI) aboard Sentinel 3B.
- We have upgraded the Quasi-Analytical algorithm (QAA) used in the band shifting to QAAv6 (the V5.0 data used the QAAv5).
- Minor update to the inter-sensor bias correction.
- MODIS and VIIRS data have been dropped from the record after 2019 due to concerns about the continued quality of data from the ageing sensors.
- Temporal extension of the dataset into 2022.

The OC products released through C3S are produced using a processing chain developed in collaboration with the ESA OC-CCI project. The reader is referred to the associated C3S ATBD and ESA CCI documentation[1] for in-depth detail of particular processing aspects.

When using these products there are a few **things to note**:

[1] https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 11th October 2022]

1. All input sensors are passive, making use of the sun as the illumination source for observation, so data coverage exhibits a strong seasonal signal at high latitudes.
2. Many Ocean Colour variables, such as chlorophyll-a, exhibit a log-normal distribution at the global scale. This means that when you perform statistical analyses, such as calculating mean values or standard deviations, it is often more appropriate to log-transform the values prior to analysis in order to maintain the required underlying statistical assumptions.
3. Great care is taken to create a harmonised record across multiple ocean colour sensors and we perform analysis to ensure that post inter-sensor-bias-correction sensor records are aligned. However, because different combinations of sensors and atmospheric correction schemes have differing capabilities to observe optically complex conditions, we see changes in the coverage of the record at the large scale as sensors add to or drop from the record. For example, there are more coastal observations when MERIS is contributing to the record.

1. General Information

Ocean Colour data

Ocean colour remote sensing analyses ocean surface radiances measured from space to derive information about the optical properties and constituents of the upper ocean. This information plays an essential role in our ability to monitor the health and productivity of marine ecosystems, assess the role of the oceans in the global carbon cycle, and quantify the impacts of climate change. Satellite remote sensing is the only method for regular monitoring of the ocean biology on a global scale. Within C3S the Ocean Colour products consist of Remote-sensing reflectance and Chlorophyll-a.

Remote-sensing reflectance (or Rrs) is defined as the ratio of water-leaving radiance to downwelling irradiance and serves as the main input to algorithms used to derive other ocean colour products. Chlorophyll-a (Chl-a) is the main photosynthetic pigment found in phytoplankton, which form the base of the marine food-web and are responsible for approximately half of global photosynthesis. Chl-a can be estimated from Rrs data using different algorithms. This document describes the fundamentals of the product files the user can download or use. The theory and processing that underpins delivery of these products are described in detail in the ATBD (C3S2_ATBD), which the user is strongly recommended to consult as part of their product appraisal for use.

Product description

As mentioned above the term 'ocean colour data' can cover a range of variables. The fundamental variable is the reflectance of the ocean waters (Rrs) and the most commonly used derived variable is chlorophyll-a concentration (Chl-a). Both of these variables, or products, are available through the C3S Ocean Colour Service. The products (Rrs and Chl-a) are provided in separate files and so are discussed separately in dedicated sections following the description below of the datasets as a whole and common data attributes.

The current C3S Ocean Colour dataset is Version 6.0, being created by the 6th incremental improvement of a climate data production system, that has been developed using over a decade of scientific research and improvement. The details of this system are available in the ATBD and the key difference between the V6.0 and the preceding V5.0 are:

- Inclusion of the MERIS-4th reprocessing. V5.0 used the MERIS 3rd reprocessing.
- Addition of data from the Ocean and Land Colour Instrument (OLCI) aboard Sentinel 3B.
- We have upgraded the Quasi-Analytical algorithm (QAA) used in the band shifting to QAAv6 (the V5.0 data used the QAAv5).
- Minor update to the inter-sensor bias correction.
- MODIS and VIIRS data have been dropped from the record after 2019 due to concerns about the continued quality of data from the ageing sensors.
- Temporal extension of the dataset into 2022.

For both Chl-a and Rrs variables, the outputs of the C3S Ocean Colour processing chain are level-3 mapped daily composites, generated from multiple sensors, with a spatial resolution of 4 km/pixel.

The data are stored as CF-compliant NetCDF files[2]. NetCDF version 4 is used because it allows for transparent internal compression of the data, which would otherwise be approximately 15 times larger using NetCDF 3; hence, users need to ensure that their NetCDF libraries are at least version 4.0.0 (released in 2008) or higher to be able to read these files.

Prior to geographic mapping, cloud and land are masked out, as well as other features (such as significant sun glint) that would reduce the accuracy of the data. A complete list of the masks applied is presented in Table 2 of the ATBD. No interpolation of masked data has been undertaken, therefore all data in the file are observations rather than interpolated or modelled data.

1.1.1 Grid and map projection

The products are available in the plate carrée projected coordinate system, based on the WGS84 convention[3]. The plate carrée projection is an sub-set of the equidistant cylindrical (also known as an equirectangular) projection, with the equator set as the standard parallel. It is simple to use as it is a regular rectangular array, however it does misrepresent the area at the poles unless this is specifically accounted for.

All files contain CF-compliant latitude and longitude (and time) dimensions, allowing each data cell to be specifically associated with a location. All latitudes and longitudes are given in WGS/84 datum.

Note that the primary projection used in the processing chain is a global, sinusoidal equal-area grid (see Figure 1), matching the NASA standard level 3 binned projection. The default number of latitude rows is 4320, which results in a vertical bin cell size of approximately 4 km. The number of longitude columns varies according to the latitude, which permits the equal area property. Unlike the NASA format, where the bin cells that do not contain any data are omitted, the CCI format underpinning the products available through the C3S retains all cells and simply marks empty cells with a NetCDF fill value. The compression built into NetCDF version 4 achieves nearly the same space efficiency as that possible with NASA's omission of these cells while making the CCI/C3S product significantly easier to use. All product processing and calculation is performed with sinusoidally binned data. This is then mapped to the plate carrée projection for ease of user access. Further information on the processing and re-mapping can be found in the ATBD.

[2] https://www.unidata.ucar.edu/software/netcdf/ [last accessed 5th September 2022]

[3] https://support.virtual-surveyor.com/en/support/solutions/articles/1000261351-what-is-wgs84- [last accessed 5th September 2022]

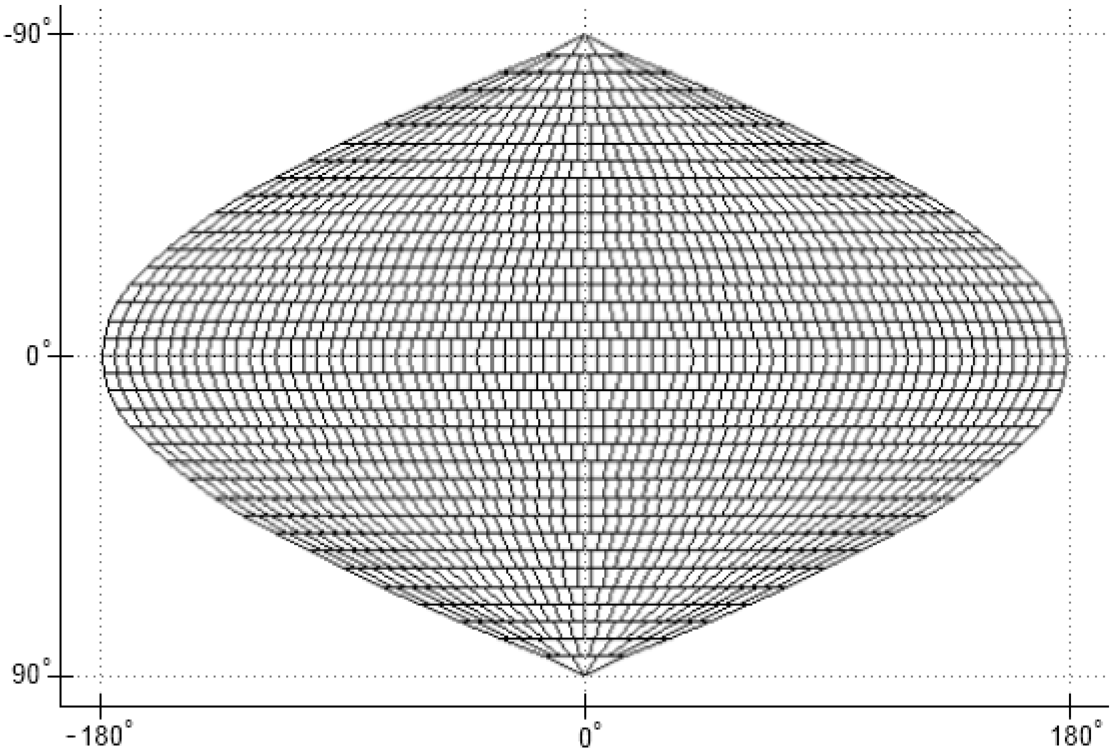

Figure 1: Sinusoidal Grid example

1.1.2 Product dimensions

The final products' dimensions referenced in the following are:

- **lat**, which determines the latitudinal position .
- **lon**, which determines the longitudinal position.
- **time**, which determines the point in time. For all released products, this is a dimension with a length of 1. It is included both for standardisation purposes and to simplify "stacking" of multiple files into a single data cube.

1.1.3 Geophysical variables

NetCDF is a self-documenting format, meaning that the majority of the information needed to correctly use and interpret the data are incorporated into the file metadata. These metadata are compliant with CF[4] standards, as noted in the global attributes (Table 1). The product specific metadata is discussed in the product description sections below and shown in it's entirety in the appendices, but some metadata attributes are common to all files.

The global attributes listed in Table 1 are common to all the Ocean Colour C3S datasets. The global attributes are based on the CF-convention, the Unidata discovery metadata[5] convention, and the CCI

[4] https://cfconventions.org [last accessed 5th September 2022]

[5] https://www.unidata.ucar.edu/software/ldm/basics/data-product.html [last accessed 5th September 2022]

guidelines[6] to data producers document. Table 1 lists the global metadata attributes and the appendices show examples of complete metadata sets.

Table 1. Common Product Metadata

Element name	Description
Metadata_Conventions	The conventions to which these global attributes are compliant
standard_name_vocabulary	The source of the standard name table
title	A short description of the dataset
license	Licensing policy (open)
tracking_id	A UUID allowing this file to be uniquely referenced back against other information in a database, providing complete provenance on request
git_commit_hash	A unique identifier tying the dataset to the codebase that created it.
Keywords	A comma separated list of key words and phrases
id	The file name
history	An audit trail for modifications to the original data
naming authority	Identifies a namespace provider
creation_date	Time of file creation
date_created	
creator_name	The data creator's name, URL, and email. The "institution" attribute will be used if the "creator_name" attribute does not exist.
Creator_url	
creator_email	
institution	
project	The scientific project that produced the data
platform	Satellites used for these data
sensor	Sensors used for these data
grid_mapping	Link to a document describing the grid
time_coverage_start	Describe the temporal coverage of the data as a time range
time_coverage_end	
time_coverage_duration	
time_coverage_resolution	
processing_level	A textual description of the processing level of the data
geospatial_lat_min	Describe a simple latitude, longitude, and vertical bounding box
geospatial_lat_max	
geospatial_lat_resolution	
geospatial_lat_units	
geospatial_lon_min	
geospatial_lon_max	
geospatial_lon_resolution	
geospatial_lon_units	
source	The input level 1 datasets used at the start of the processing chain
product_version	The version of the products
number_of_optical_water_types	The number of optical water types used in the product generation
spatial_resolution	Short description of the grid spacing
summary	A description of the dataset

[6] https://climate.esa.int/en/explore/esa-cci-data-standards/ [last accessed 5th September 2022]

Element name	Description
references	Attributes that are required by CF or unidata conventions. Some of these (such as vertical min and max) are essentially unused (as the data have no depth dimension).
Cdm data type	
comment	
geospatial_vertical_max	
geospatial_vertical_min	
license	
keyword vocabulary	
standard_name_vocabulary	

Note that in addition to some common metadata elements (global attributes), the files also contain descriptive elements relevant to the data cells themselves (variable attributes). The variable attributes encompassing the geophysical measurements are described in Section 3 and are only found in the files containing the relevant product. In addition, all the files share a set of variables that indicate how many observations were made of a specific data cell. These variables can be extracted/visualised/analysed as with the primary ocean colour variables. There are total and per-sensor counts, allowing some flexibility in estimating relative importance of the sensors. It should be noted that the SeaWiFS data used was a mixture of LAC (1km) and GAC (4 km) resolution while the MERIS, MODIS, VIIRS and OLCI data were originally 1km prior to binning. Consequently, the latter two sensors can contribute ~16 times as many observations per 4 km pixel and the number of observations (nobs) counts will reflect this. The number of observations is a float variable (i.e. decimal) because the binning process allows for a partial coverage of a cell (currently in $1/9^{th}$s, due using a super-sampling factor of 9).

The variables containing the number of observations are:

- total_nobs(time, lat, lon): total_nobs:long_name = "Count of the total number of observations contributing to this bin cell" ;
- MODISA_nobs(time, lat, lon): MODISA_nobs:long_name = "Count of the number of observations from the MODIS sensor contributing to this bin cell" ;
- MERIS_nobs(time, lat, lon) : MERIS_nobs:long_name = "Count of the number of observations from the MERIS sensor contributing to this bin cell" ;
- VIIRS_nobs(time, lat, lon) : VIIRS_nobs:long_name = "Count of the number of observations from the VIIRS sensor contributing to this bin cell" ;
- SeaWiFS_nobs(time, lat, lon) : SeaWiFS_nobs:long_name = "Count of the number of observations from the SeaWiFS sensor contributing to this bin cell" ;
- OLCI-A_nobs(time, lat, lon) : OLCI-A_nobs:long_name = "Count of the number of observations from the OLCI-A sensor contributing to this bin cell" ;
- OLCI-B_nobs(time, lat, lon) : OLCI-B_nobs:long_name = "Count of the number of observations from the OLCI-B sensor contributing to this bin cell" ;

Examples of the 'Total' number of observations, 'MODIS Aqua' number of observations, Chl-a and Rrs (at 443nm) are shown in Figure 2 to 5.

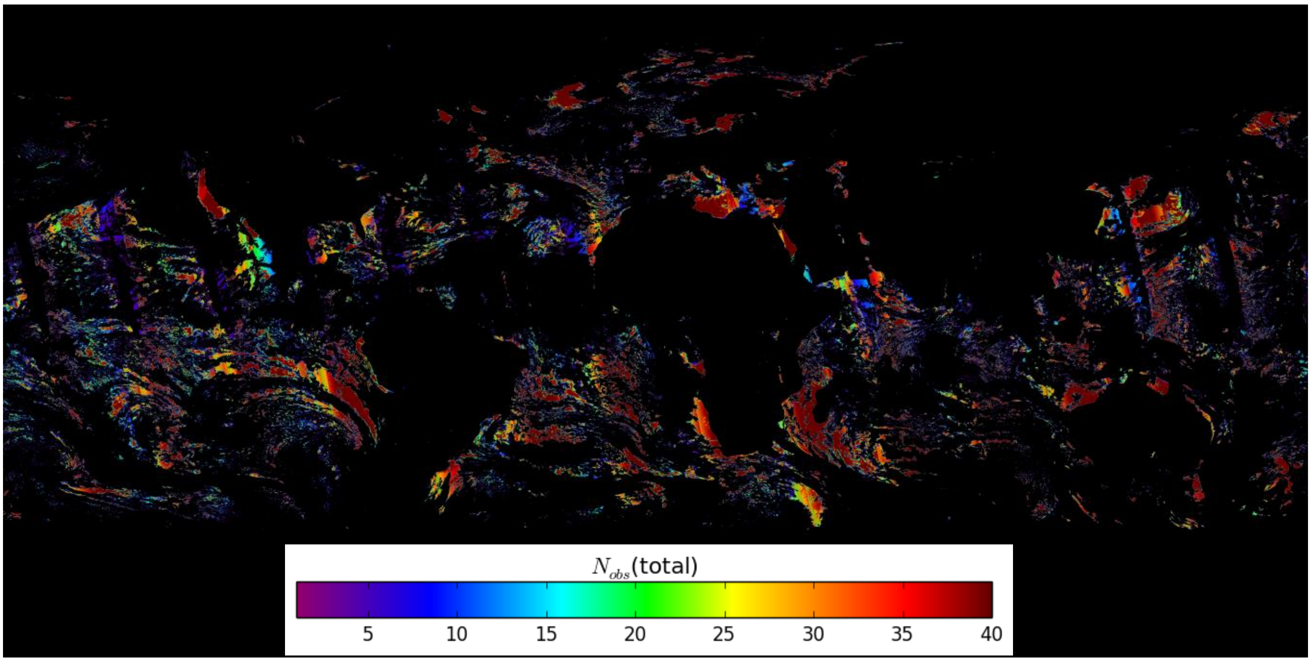

Figure 2: The total number of observations contributing to the products for the 5th May 2012.

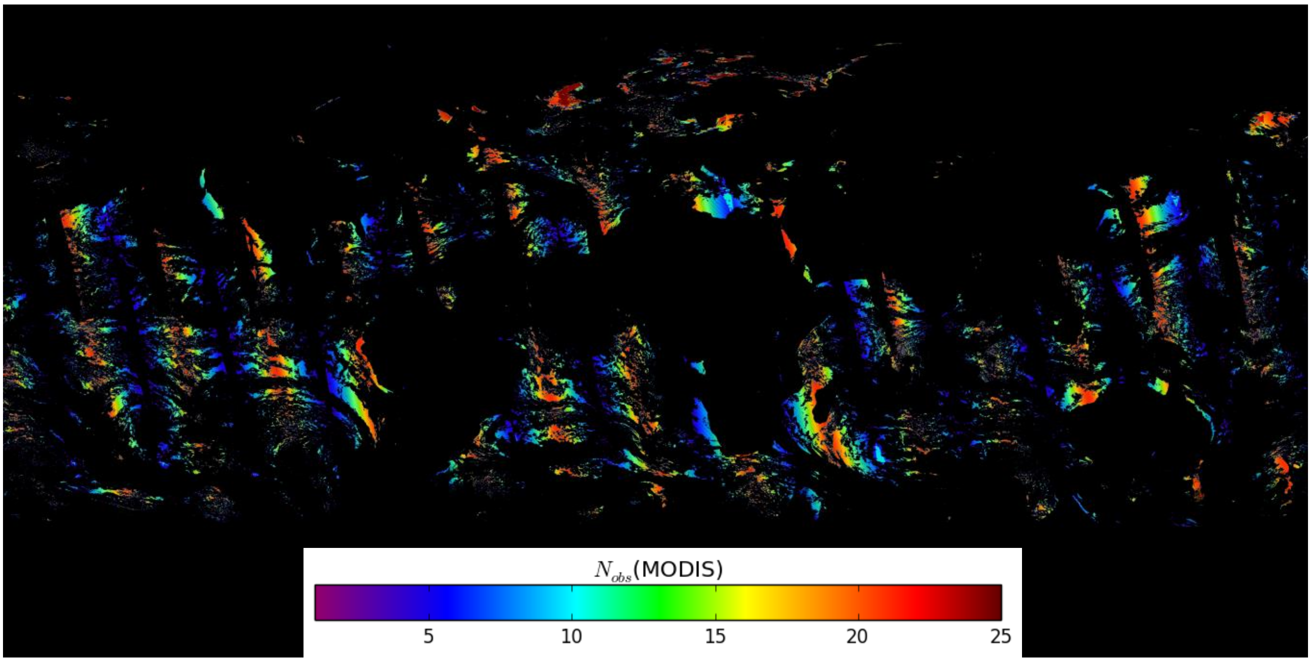

Figure 3: The number of MODIS Aqua observations contributing to the products for the 5th May 2012.

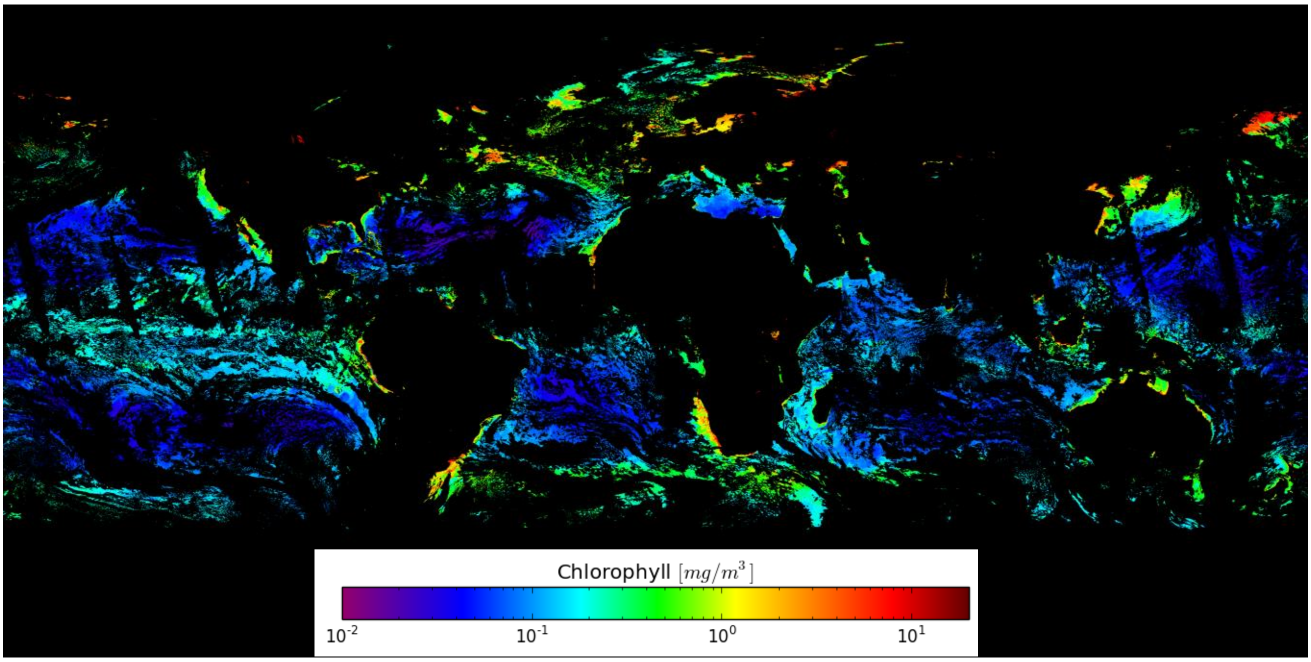

Figure 4: The chlorophyll-a product for the 5th May 2012.

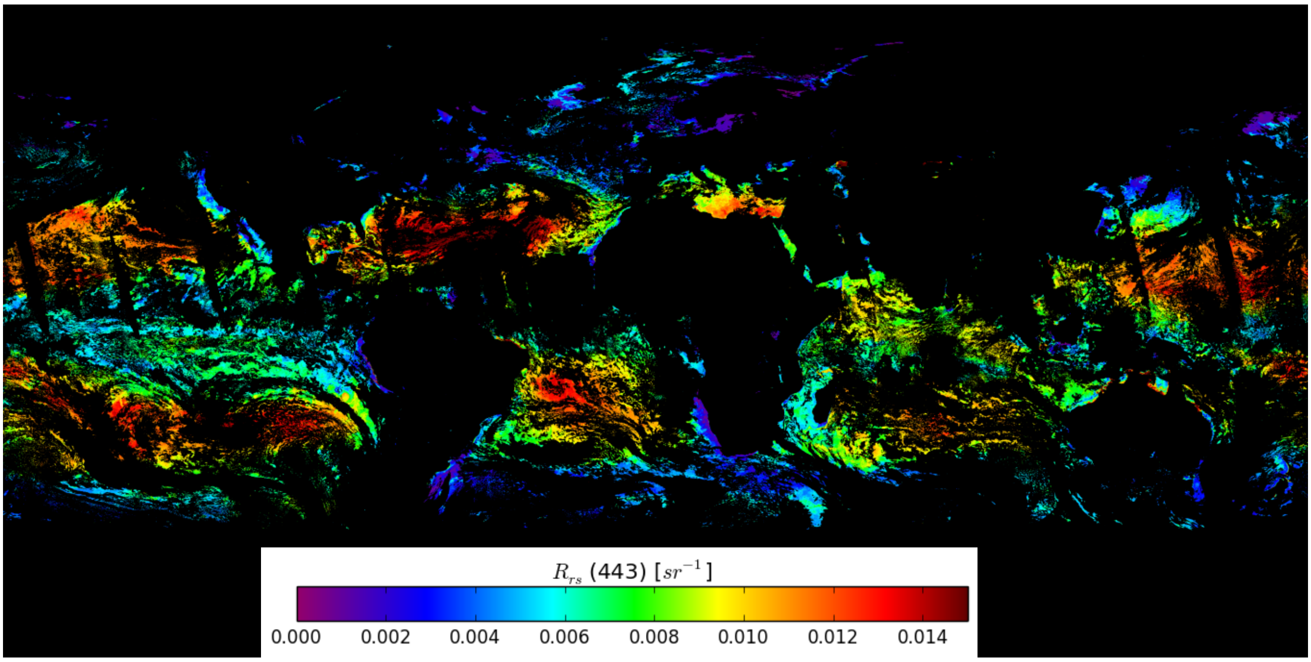

Figure 5: The Rrs(443) product for the 5th may 2012.

2. Chlorophyll

2.1 Product description

The C3S Ocean Colour Chlorophyll-a product is derived from the Rrs data. The details of this variable production are covered in the ATBD but the key details are summarised below and the essential meta-data attributes are shown in Table 3. The chlorophyll-a data has units of mg m^{-3} and is provided as daily products with a horizontal resolution of ~4 km/pixel. Furthermore, the root-mean-square (RMS) uncertainty and the bias in the log10 chlorophyll-a concentration are provided, based on comparison with match-up in-situ data. The chlorophyll-a values are calculated by blending algorithms based on the water-type as documented in the associated Algorithm Theoretical Baseline Document [C3S-ATBD]. For v6.0, this involved the blending of the OCI algorithm (as implemented by NASA, itself a combination of CI and OC4), the OCI2, the OC2 and the OCx algorithms, described comprehensively in [C3S-ATBD].

The C3S chlorophyll product includes data from the sensors shown in Table 2.

Table 2. Input sensors for the Chl-a product and their temporal coverage.

Satellite and Sensor	Temporal coverage
SeaStar SeaWiFS	September 1997 - December 2010
Aqua-MODIS	May 2002 – December 2019
ENVISAT MERIS	March 2002 - April 2010
Suomi-VIIRS	November 2011 – December 2019
SENTINEL-3A OLCI	May 2016 - Present
SENTINEL-3B OLCI	May 2018 - Present

The key attributes of the chlorophyll-a variable as found within the data file is summarised below:

Table 3. Key attributes of the chlorophyll-a variable as found within the data file

Name	chlor_a
Dimensions	(time, lat, lon)
FillValue	9.96921e+36f
Units	mg m^{-3}

An example of the chl-a product is shown in Figure 4.

2.2 Target Requirements

The user requirements for the C3S chlorophyll product are inherited from, and build upon the work of, the OC-CCI project (which conducted ocean colour user surveys in [OC_CCI-URD]) with a strong input from the Global Climate Observing System (GCOS)[7]. Please refer to the Target requirements and Gap Analysis Document (TRGAD) associated with this product (and the OC-CCI URD) for a detailed description of the source of the following target requirements. This TRGAD draws on input from CCI, GCOS and CMUG. A summary is given in Tables 4 and 5 below so that users understand why the products were created in the form and resolution that they are presented in. In these tables the terms "Goal", "Breakthrough" and "Threshold" follow the meaning:

Goal: The ideal requirement, above which further improvements are not necessary. This is likely to evolve as applications and technologies progress.

Breakthrough: Values that enable additional uses within climate monitoring.

Threshold: The minimum requirement: the value that has to be met to ensure that data are useful.

Table 4. User requirements for the C3S chlorophyll product (time and space).

Chlorophyll-a	**Horizontal Resolution**			**Observing Cycle**		
Source of requirement ↓	Goal	Break-through	Threshold	Goal	Break-through	Threshold
Requirement from GCOS	30 km (global)			Weekly averages		
Requirement from the Climate Modelling User Group (CMUG)	4km			1d		
Requirement from CCI – Modellers	0.1-1km	1-10km	1-10km	1 day	7 days	30 days
Requirement from CCI – Earth Observation (EO) scientists	0.1-1km	0.1-1km	1-10km	1 day	7 days	30 days

[7] For the relevant GCOS requirements see https://gcos.wmo.int/en/essential-climate-variables/ocean-colour/ecv-requirements [last accessed 29th August 2022]

Table 5. User requirements for the C3S chlorophyll product (Accuracy, Precision and Stability)

Chlorophyll-a	Accuracy			Precision			Stability		
Source of requirement ↓	Goal	Break-through	Thres-hold	Goal	Break-through	Thres-hold	Goal	Break-through	Thres-hold
Requirement from GCOS	30 % in Case-1 waters in the concentration range 0.01-10 [mg m-3]			Not Given			3 % per year		
Requirement from CMUG	30%			30%			Not Given		
Requirement from CCI – Modellers	<10%	10-25%	<10%	<10%	<10%	10-25%	1%	1%	10%
Requirement from CCI - EO scientists	<10%	10-25%	<10%	<10%	10-25%	10-25%	1%	1-2%	5%

Validation results for comparison are available in the Product Quality Assessment Report [C3S2-PQAR] but a summary is presented below.

The current (v6.0) performance of the OC products is set out in Table 6.

Table 6. Current performance of the V6.0 C3S OC products

Chlorophyll-a	Currently achievable performance
Accuracy	5-50 % in Case-1 waters. 60-70 % for coastal waters and regional seas, which are typically Case-2. In areas of extreme optical-complexity these errors can be as high as 200-300 %. For these areas it is recommended that tailored algorithms be implemented.
Stability	Has not yet been assessed
Spatial resolution	4-9 km horizontal available 1km data available on request through OC-CCI.
Temporal Resolution	Daily observing cycles are available at global scale

2.3 Data usage information

The primary dataset is contained within a variable called "chlor_a", with a number of supporting variables included in the release file (for example, per-sensor number of observations for each pixel). A full sample metadata listing is provided in Appendix A - Full metadata for the Chl-a products.

The data are provided in a geographic (plate carrée) projection. Note that the geographical projection used leads to a latitudinal statistical over-representation of the importance of the areas north/south of the equator, especially at the poles.

It is of note that the files can be large (>1GB) and this has been an issue for some users. The netCDF format allows for rapid slicing and extraction of data but currently C3S only allows whole file downloads. Tools such as OPeNDAP and THREDDS allow the subsetting of data on the fly (pre download) but these are not currently available through C3S.

There are no known significant issues with the dataset.

3. Remote Sensing Reflectance (Rrs)

3.1 Product description

The remote-sensing reflectance at the sea surface (R_{rs}) C3S product has units of sr^{-1} (per steradian) and a resolution of ~4 km/pixel. R_{rs} values are provided for the standard MERIS wavelengths (412, 443, 490, 510, 560, 665nm) with pixel-by-pixel uncertainty estimates for each wavelength. These are merged products based on SeaWiFS, MERIS, Aqua-MODIS, VIIRS and OLCI data. Atmospheric correction was carried out using the POLYMER algorithm for MERIS, MODIS, VIIRS and OLCI (see the Polymer Algorithm Theoretical Baseline Document (Steinmetz, 2016) and SeaDAS v7.3 processor for SeaWiFS[8]. The R_{rs} values from SeaWiFS, MODIS and VIIRS were band-shifted to MERIS wavebands if necessary, and SeaWiFS and MODIS were corrected for inter-sensor bias when compared with MERIS in the 2003-2007 period using the approach developed by Mélin at al (2016). VIIRS and OLCI were also corrected to MERIS levels via a two-stage process comparing against the MODIS-corrected-to-MERIS-levels (2012-2013 for VIIRS and 2016-2019 for OLCI), with correction method the same as for any other sensor pair.

The C3S R_{rs} product includes data from the sensors identified in Table 7.

Table 7. Sensors from which the C3S R_{rs} product includes data

Sensor	Temporal coverage
SeaStar SeaWiFS	September 1997 - December 2010
Aqua-MODIS	May 2002 – December 2019
ENVISAT MERIS	March 2002 - April 2010
Suomi-VIIRS	November 2011 – December 2019
SENTINEL-3A OLCI	May 2016 - Present
SENTINEL-3B OLCI	May 2018 - Present

The data from each sensor are band-shifted to match MERIS bands and bias-corrected to remove inter-sensor systematic biases (as described briefly above and in detail in the ATBD document). Atmospheric correction is carried out using the POLYMER algorithm for MERIS and MODIS, SeaWiFS, VIIRS and OLCI.

The key attributes of the R_{rs} variable(s) as found within the data file are shown in Table 8 (where <wavelength is one of 412, 443, 490, 510, 560 or 665).

[8] https://seadas.gsfc.nasa.gov/history/ [last accessed 5th September 2022]

Table 8. Key attributes of the chlorophyll-a variable as found within the data file.

Name	Rrs_<wavelength>
Dimensions	(time, lat, lon)
FillValue	9.96921e+36f
Units	sr-1
Wavelength	<wavelength>

3.2 Target Requirements

The user requirements for the C3S Rrs product are inherited from, and build upon the work of, the OC-CCI project (which conducted ocean colour user surveys in [OC_CCI-URD]) with a strong input from the Global Climate Observing System (GCOS)[9]. Please refer to the Target requirements and Gap Analysis Document (TRGAD) associated with this product (and the OC-CCI URD) for a detailed description of the source of the following target requirements. This TRGAD draw on input from CCI, GCOS and CMUG. A summary is given in Table 9 below.

Table 9. Water Leaving radiance requirements

	Horizontal Resolution	**Observing Cycle**	**Accuracy**	**Precision**	**Stability**
Source of requirement ↓	Threshold	Threshold	Threshold	Threshold	Threshold
Requirements from GCOS	4 km (global) 1 km or smaller for regional and coastal applications	Daily	5 % Specifically for the blue and green wavelengths in Case-1 Waters	Not Given	0.5 % per year
Requirement from CCI – Modellers	10-100km	30d	10-25%	~25%	2%
Requirement from CCI - EO scientists	0.1-1km	1d	~10%	~10%	1%

Validation results for comparison are available in the Product Quality Assurance Document [C3S2-PQAR] but a summary is presented below.

[9] For the relevant GCOS requirements see https://gcos.wmo.int/en/essential-climate-variables/ocean-colour/ecv-requirements [last accessed 29th August 2022]

The current performance of the OC products is set out in Table 10:

Table 10. Current performance of the OC products

Water leaving radiance	**Currently achievable performance**
Accuracy	5-15 % for water leaving radiances (for the blue and green wavelengths)
Stability	Has not yet been assessed
Spatial resolution	4 km horizontal widely available 1 km and 9km horizontal resolution is available on request
Temporal resolution	Daily, weekly, monthly observing cycles are available globally, dependent on sensor

3.3 Data usage information

The primary datasets are contained within a variable called “Rrs_nnn”, where “nnn” is the band wavelength in nanometres. A number of supporting variables are included in the release file (for example, per-sensor number of observations for each pixel). A full sample metadata listing is provided in Appendix B - Full metadata for the Rrs products.

The data are provided in a geographic (plate carrée). Note that the geographic projection leads to a latitudinal statistical over-representation of the importance of the areas north/south of the equator, especially at the poles.

It is of note that the files can be large (>1GB) and this has been an issue for some users. The netCDF format allows for rapid slicing and extraction of data but currently C3S only allows whole file downloads. Tools such as OPeNDAP and THREDDS allow the subsetting of data on the fly (pre download) but these are not currently available through C3S.

There are no known significant issues with the dataset.

4. Data access information

4.1 Data visualisation tools

As the products are provided in NetCDF format, they can be ingested with all NetCDF compatible software packages. Note that the NetCDF library used must be version 4.0.0 or higher (first released 2008, so default installs on modern systems are likely to be sufficient) to support transparent internal compression and to read the products.

The analysis package currently recommended is the SNAP toolbox, specifically developed by ESA for the exploitation of Earth Observation data products. SNAP is particularly useful as it can cope with the large file sizes typical for the Rrs data for example. These file sizes can lead to challenges initially visualising the data when using more mainstream GIS and image processing softwares. SNAP is open source and freely available from http://step.esa.int/main/toolboxes/snap/. Regarding the OC-CCI products, SNAP could be used for example to:

- view the images and metadata
- create regional subsets
- investigate the products by creating statistics, histograms, and scatter plots
- perform image analysis (e.g. clustering)
- validate ocean colour data by comparison with in-situ or any other kind of reference data
- analyse time series using the time series tool that is part of SNAP (see screenshot below)
- band arithmetic using a fast expression language

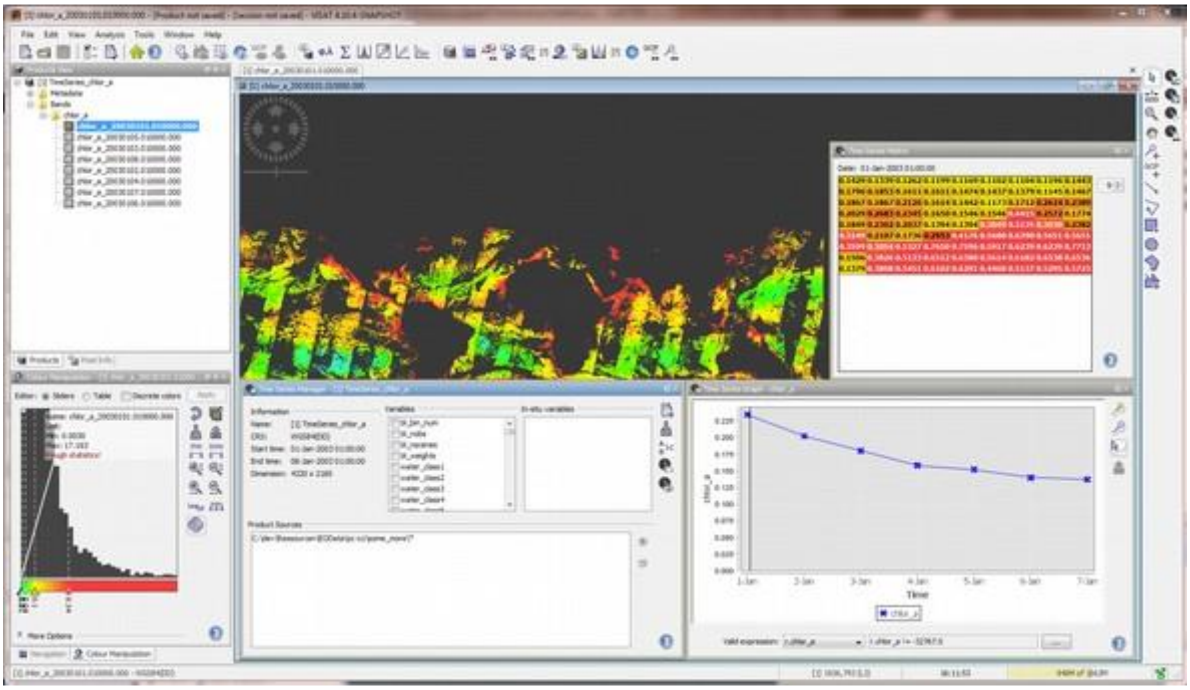

Figure 6: Viewing and manipulating data in SNAP

At the time of writing (April 2022), the current released version of SNAP (9.0, with all updates applied) in its default configuration can read the product projection format (plate carrée) without difficulty. In addition, it can read the processing outputs in sinusoidal format should the user be interested in working with processing-level data.

Additionally:

- The CDS Toolbox is an online C3S service for working with data in the CDS: https://cds.climate.copernicus.eu
- The CCI Toolbox is a desktop application for analysis and visualisation of CCI climate data sets and provides easy access to data from the CCI Open Data Portal: http://climatetoolbox.io/
- The core visualisation package for SeaDAS 7 and above is the result of a collaboration between NASA and Brockmann Consult. It is based on the BEAM/SNAP framework with extensions that provide the functionality of previous versions of SeaDAS, with a focus on the NASA sensors/products. SeaDAS versions 7.3 and above can handle both file projection systems the user may encounter as noted above.

4.2 Data analysis / programming languages

Numerous programming languages exist that can be used for reading and analysing netCDF files. These include both compiled languages such as Java, Fortran and C, and languages that allow interactive analysis and plotting of data. Some examples of the latter are:

- **Python** http://www.python.org/ with add on modules such as:
  - netCDF4 http://unidata.github.io/netcdf4-python/
  - NumPy http://www.numpy.org/
  - xarray http://xarray.pydata.org/en/stable/index.html
  - matplotlib http://matplotlib.org/
  - Iris and Cartopy http://scitools.org.uk/iris/
- **R** https://cran.r-project.org with libraries such as:
  - ncdf4 https://cran.r-project.org/web/packages/ncdf4/index.html
  - maptools https://cran.r-project.org/web/packages/maptools/index.html
- **IDL** http://www.harrisgeospatial.com/SoftwareTechnology/IDL.aspx
- **MATLAB** https://www.mathworks.com/products/matlab.html

Appendix A - Full metadata for the Chl-a products

```
netcdf ESACCI-OC-L3S-CHLOR_A-MERGED-1D_DAILY_4km_GEO_PML_OCx-20120505-fv6.0 {
dimensions:
	time = UNLIMITED ; // (1 currently)
	lat = 4320 ;
	lon = 8640 ;
variables:
	float MERIS_nobs(time, lat, lon) ;
		MERIS_nobs:_FillValue = 0.f ;
		MERIS_nobs:long_name = "Count of the number of observations from the 
MERIS sensor contributing to this bin cell" ;
	float MODISA_nobs(time, lat, lon) ;
		MODISA_nobs:_FillValue = 0.f ;
		MODISA_nobs:long_name = "Count of the number of observations from the 
MODIS (Aqua) sensor contributing to this bin cell" ;
	float OLCI-A_nobs(time, lat, lon) ;
		OLCI-A_nobs:_FillValue = 0.f ;
		OLCI-A_nobs:long_name = "Count of the number of observations from the 
OLCI A sensor contributing to this bin cell" ;
	float OLCI-B_nobs(time, lat, lon) ;
		OLCI-B_nobs:_FillValue = 0.f ;
		OLCI-B_nobs:long_name = "Count of the number of observations from the 
OLCI B sensor contributing to this bin cell" ;
	float SeaWiFS_nobs(time, lat, lon) ;
		SeaWiFS_nobs:_FillValue = 0.f ;
		SeaWiFS_nobs:long_name = "Count of the number of observations from 
the SeaWiFS (GAC and LAC) sensor contributing to this bin cell" ;
	float VIIRS_nobs(time, lat, lon) ;
		VIIRS_nobs:_FillValue = 0.f ;
		VIIRS_nobs:long_name = "Count of the number of observations from the 
VIIRS sensor contributing to this bin cell" ;
	float chlor_a(time, lat, lon) ;
		chlor_a:_FillValue = 9.96921e+36f ;
		chlor_a:long_name = "Chlorophyll-a concentration in seawater (not 
log-transformed), generated by as a blended combination of OCI, OCI2, OC2 and OCx 
algorithms, depending on water class memberships" ;
		chlor_a:parameter_vocab_uri = 
"http://vocab.ndg.nerc.ac.uk/term/P011/current/CHLTVOLU" ;
		chlor_a:standard_name = 
"mass_concentration_of_chlorophyll_a_in_sea_water" ;
		chlor_a:units = "milligram m-3" ;
		chlor_a:units_nonstandard = "mg m^-3" ;
	int crs ;
		crs:grid_mapping_name = "latitude_longitude" ;
	double lat(lat) ;
		lat:units = "degrees_north" ;
		lat:long_name = "latitude" ;
		lat:standard_name = "latitude" ;
		lat:valid_min = -89.9791666666667 ;
		lat:valid_max = 89.9791666666667 ;
		lat:axis = "Y" ;
	double lon(lon) ;
		lon:units = "degrees_east" ;
		lon:long_name = "longitude" ;
		lon:standard_name = "longitude" ;
		lon:valid_min = -179.979166666667 ;
```

```
            lon:valid_max = 179.979166666667 ;
            lon:axis = "X" ;
      int time(time) ;
            time:axis = "T" ;
            time:standard_name = "time" ;
            time:units = "days since 1970-01-01 00:00:00" ;
      float total_nobs(time, lat, lon) ;
            total_nobs:_FillValue = 0.f ;
            total_nobs:long_name = "Count of the total number of observations
contributing to this bin cell" ;

// global attributes:
            :Conventions = "CF-1.7" ;
            :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
            :cdm_data_type = "Grid" ;
            :comment = "See summary attribute" ;
            :creation_date = "20220518T125505Z" ;
            :creator_email = "help@esa-oceancolour-cci.org" ;
            :creator_name = "Plymouth Marine Laboratory" ;
            :creator_url = "http://esa-oceancolour-cci.org" ;
            :date_created = "20220518T125505Z" ;
            :geospatial_lat_max = 90.f ;
            :geospatial_lat_min = -90.f ;
            :geospatial_lat_resolution = ".04166666666666666666" ;
            :geospatial_lat_units = "decimal degrees north" ;
            :geospatial_lon_max = 180.f ;
            :geospatial_lon_min = -180.f ;
            :geospatial_lon_resolution = ".04166666666666666666" ;
            :geospatial_lon_units = "decimal degrees east" ;
            :geospatial_vertical_max = 0.f ;
            :geospatial_vertical_min = 0.f ;
            :git_commit_hash = "b99fc96426cd507fe88877f2862d22078f4108fd" ;
            :history = "Wed May 18 13:56:00 2022: ncks -x -v crs
standardised_geo/ESACCI-OC-L3S-OC_PRODUCTS-MERGED-1D_DAILY_4km_GEO_PML_OCx_QAA-
20120505-fv6.0.nc ESACCI-OC-L3S-OC_PRODUCTS-MERGED-1D_DAILY_4km_GEO_PML_OCx_QAA-
20120505-fv6.0.nc\n",
                  "Source data were: NASA OBPG SeaWiFS level1 R2018.0 LAC and GAC
[A/C via l2gen], NASA OBPG VIIRS L1 R2018.0  [A/C via polymer], NASA OBPG MODIS
Aqua L1 R2018.0 (A/C via polymer), ESA MERIS L1B (3rd reprocessing inc OCL
correction) [Polymer v4.12]  and OLCI L1B [Polymer v4.12]; Derived products were
mainly produced with functions validated from the current NASA SeaDAS release and
some custom implementations.  Uncertainty generation determined by the fuzzy
classifier scheme of Tim Moore (2009) as updated by Jackson et al. (2017) and
Jackson et al. (in prep)." ;
            :institution = "Plymouth Marine Laboratory" ;
            :keywords = "satellite,observation,ocean,ocean colour" ;
            :keywords_vocabulary = "none" ;
            :license = "C3S Data Policy: free and open access.  When referencing,
please use: Ocean Colour Climate Change Initiative dataset, Version <Version
Number>, European Space Agency, available online at http://www.esa-oceancolour-
cci.org.  We would also appreciate being notified of publications so that we can
list them on the project website at http://www.esa-oceancolour-
cci.org/?q=publications" ;
            :naming_authority = "uk.ac.pml" ;
            :number_of_optical_water_types = "14" ;
            :platform = "Orbview-2,Aqua,Envisat,Suomi-NPP, Sentinel-3a, Sentinel-
3b" ;
            :processing_level = "Level-3" ;
```

```
            :product_version = "6.0" ;
            :project = "Copernicus Climate Change Service" ;
            :references = "http://www.esa-oceancolour-cci.org/" ;
            :sensor = "SeaWiFS,MODIS,MERIS,VIIRS,OLCI-A,OLCI-B" ;
            :source = "NASA SeaWiFS  L1A and L2 R2018.0 LAC and GAC, MODIS-Aqua
L1A and L2 R2018.0, MERIS L1B 3rd reprocessing inc OCL corrections, NASA VIIRS
L1A and L2 R2018.0, OLCI A L1B, OLCI B L1B" ;
            :spatial_resolution = "4km nominal at equator" ;
            :standard_name_vocabulary = "NetCDF Climate and Forecast (CF)
Metadata Conventions Version 1.7" ;
            :time_coverage_duration = "P1D" ;
            :time_coverage_end = "201205052359Z" ;
            :time_coverage_resolution = "P1D" ;
            :time_coverage_start = "201205050000Z" ;
            :title = "Copernicus Climate Change Service Ocean Colour Product" ;
            :tracking_id = "2a3e2b88-498c-4c5f-9306-a0eea30fc0f2" ;
            :NCO = "netCDF Operators version 4.7.5 (Homepage = http://nco.sf.net,
Code = http://github.com/nco/nco)" ;
            :id = "ESACCI-OC-L3S-CHLOR_A-MERGED-1D_DAILY_4km_GEO_PML_OCx-
20120505-fv6.0.nc" ;
            :summary = "Data products generated for C3S using the latest
processing configuration from the Ocean Colour component of the European Space
Agency Climate Change Initiative project. These files are daily composites of
merged sensor (MERIS, MODIS Aqua, SeaWiFS LAC & GAC, VIIRS, OLCI) products.
MODIS Aqua and SeaWiFS were band-shifted and bias-corrected to MERIS bands and
values using a temporally and spatially varying scheme based on the overlap years
of 2003-2007.  VIIRS was band-shifted and bias-corrected in a second stage
against the MODIS Rrs that had already been corrected to MERIS levels, for the
overlap period 2012-2013; and at the third stage OLCI was bias corrected against
already corrected MODIS, for overlap period 2016-07-01 to 2019-06-30.  VIIRS,
MODIS, SeaWiFS and MERIS Rrs were derived from a combination of NASA\'s l2gen
(for basic sensor geometry corrections, etc) and HYGEOS Polymer v4.12 (for
atmospheric correction). OLCI Rrs were sourced at L1b (already geometrically
corrected) and processed with polymer.  The Rrs were binned to a sinusoidal 4km
level-3 grid, and later to 4km geographic projection, by Brockmann Consult\'s
SNAP.  Derived products were generally computed with the standard algorithms
through SeaDAS.   The final chlorophyll is a combination of OCI, OCI2, OC2 and
OCx, depending on the water class memberships. " ;
}
```

Appendix B - Full metadata for the Rrs products

```
netcdf ESACCI-OC-L3S-RRS-MERGED-1D_DAILY_4km_GEO_PML_RRS-20120505-fv6.0 {
dimensions:
	time = UNLIMITED ; // (1 currently)
	lat = 4320 ;
	lon = 8640 ;
variables:
	float MERIS_nobs(time, lat, lon) ;
		MERIS_nobs:_FillValue = 0.f ;
		MERIS_nobs:long_name = "Count of the number of observations from the
MERIS sensor contributing to this bin cell" ;
	float MODISA_nobs(time, lat, lon) ;
		MODISA_nobs:_FillValue = 0.f ;
		MODISA_nobs:long_name = "Count of the number of observations from the
MODIS (Aqua) sensor contributing to this bin cell" ;
	float OLCI-A_nobs(time, lat, lon) ;
		OLCI-A_nobs:_FillValue = 0.f ;
		OLCI-A_nobs:long_name = "Count of the number of observations from the
OLCI A sensor contributing to this bin cell" ;
	float OLCI-B_nobs(time, lat, lon) ;
		OLCI-B_nobs:_FillValue = 0.f ;
		OLCI-B_nobs:long_name = "Count of the number of observations from the
OLCI B sensor contributing to this bin cell" ;
	float Rrs_412(time, lat, lon) ;
		Rrs_412:_FillValue = 9.96921e+36f ;
		Rrs_412:long_name = "Sea surface reflectance defined as the ratio of
water-leaving radiance to surface irradiance at 412 nm." ;
		Rrs_412:parameter_vocab_uri =
"http://vocab.ndg.nerc.ac.uk/term/P071/19/CFV13N26" ;
		Rrs_412:standard_name =
"surface_ratio_of_upwelling_radiance_emerging_from_sea_water_to_downwelling_radia
tive_flux_in_air" ;
		Rrs_412:units = "sr-1" ;
		Rrs_412:units_nonstandard = "sr^-1" ;
		Rrs_412:wavelength = 412 ;
	float Rrs_443(time, lat, lon) ;
		Rrs_443:_FillValue = 9.96921e+36f ;
		Rrs_443:long_name = "Sea surface reflectance defined as the ratio of
water-leaving radiance to surface irradiance at 443 nm." ;
		Rrs_443:parameter_vocab_uri =
"http://vocab.ndg.nerc.ac.uk/term/P071/19/CFV13N26" ;
		Rrs_443:standard_name =
"surface_ratio_of_upwelling_radiance_emerging_from_sea_water_to_downwelling_radia
tive_flux_in_air" ;
		Rrs_443:units = "sr-1" ;
		Rrs_443:units_nonstandard = "sr^-1" ;
		Rrs_443:wavelength = 443 ;
	float Rrs_490(time, lat, lon) ;
		Rrs_490:_FillValue = 9.96921e+36f ;
		Rrs_490:long_name = "Sea surface reflectance defined as the ratio of
water-leaving radiance to surface irradiance at 490 nm." ;
		Rrs_490:parameter_vocab_uri =
"http://vocab.ndg.nerc.ac.uk/term/P071/19/CFV13N26" ;
```

```
            Rrs_490:standard_name =
"surface_ratio_of_upwelling_radiance_emerging_from_sea_water_to_downwelling_radia
tive_flux_in_air" ;
            Rrs_490:units = "sr-1" ;
            Rrs_490:units_nonstandard = "sr^-1" ;
            Rrs_490:wavelength = 490 ;
      float Rrs_510(time, lat, lon) ;
            Rrs_510:_FillValue = 9.96921e+36f ;
            Rrs_510:long_name = "Sea surface reflectance defined as the ratio of
water-leaving radiance to surface irradiance at 510 nm." ;
            Rrs_510:parameter_vocab_uri =
"http://vocab.ndg.nerc.ac.uk/term/P071/19/CFV13N26" ;
            Rrs_510:standard_name =
"surface_ratio_of_upwelling_radiance_emerging_from_sea_water_to_downwelling_radia
tive_flux_in_air" ;
            Rrs_510:units = "sr-1" ;
            Rrs_510:units_nonstandard = "sr^-1" ;
            Rrs_510:wavelength = 510 ;
      float Rrs_560(time, lat, lon) ;
            Rrs_560:_FillValue = 9.96921e+36f ;
            Rrs_560:long_name = "Sea surface reflectance defined as the ratio of
water-leaving radiance to surface irradiance at 560 nm." ;
            Rrs_560:parameter_vocab_uri =
"http://vocab.ndg.nerc.ac.uk/term/P071/19/CFV13N26" ;
            Rrs_560:standard_name =
"surface_ratio_of_upwelling_radiance_emerging_from_sea_water_to_downwelling_radia
tive_flux_in_air" ;
            Rrs_560:units = "sr-1" ;
            Rrs_560:units_nonstandard = "sr^-1" ;
            Rrs_560:wavelength = 560 ;
      float Rrs_665(time, lat, lon) ;
            Rrs_665:_FillValue = 9.96921e+36f ;
            Rrs_665:long_name = "Sea surface reflectance defined as the ratio of
water-leaving radiance to surface irradiance at 665 nm." ;
            Rrs_665:parameter_vocab_uri =
"http://vocab.ndg.nerc.ac.uk/term/P071/19/CFV13N26" ;
            Rrs_665:standard_name =
"surface_ratio_of_upwelling_radiance_emerging_from_sea_water_to_downwelling_radia
tive_flux_in_air" ;
            Rrs_665:units = "sr-1" ;
            Rrs_665:units_nonstandard = "sr^-1" ;
            Rrs_665:wavelength = 665 ;
      float SeaWiFS_nobs(time, lat, lon) ;
            SeaWiFS_nobs:_FillValue = 0.f ;
            SeaWiFS_nobs:long_name = "Count of the number of observations from
the SeaWiFS (GAC and LAC) sensor contributing to this bin cell" ;
      float VIIRS_nobs(time, lat, lon) ;
            VIIRS_nobs:_FillValue = 0.f ;
            VIIRS_nobs:long_name = "Count of the number of observations from the
VIIRS sensor contributing to this bin cell" ;
      int crs ;
            crs:grid_mapping_name = "latitude_longitude" ;
      double lat(lat) ;
            lat:units = "degrees_north" ;
            lat:long_name = "latitude" ;
            lat:standard_name = "latitude" ;
            lat:valid_min = -89.9791666666667 ;
            lat:valid_max = 89.9791666666667 ;
```

```
            lat:axis = "Y" ;
      double lon(lon) ;
            lon:units = "degrees_east" ;
            lon:long_name = "longitude" ;
            lon:standard_name = "longitude" ;
            lon:valid_min = -179.979166666667 ;
            lon:valid_max = 179.979166666667 ;
            lon:axis = "X" ;
      int time(time) ;
            time:axis = "T" ;
            time:standard_name = "time" ;
            time:units = "days since 1970-01-01 00:00:00" ;
      float total_nobs(time, lat, lon) ;
            total_nobs:_FillValue = 0.f ;
            total_nobs:long_name = "Count of the total number of observations
contributing to this bin cell" ;

// global attributes:
            :Conventions = "CF-1.7" ;
            :Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
            :cdm_data_type = "Grid" ;
            :comment = "See summary attribute" ;
            :creation_date = "20220518T125505Z" ;
            :creator_email = "help@esa-oceancolour-cci.org" ;
            :creator_name = "Plymouth Marine Laboratory" ;
            :creator_url = "http://esa-oceancolour-cci.org" ;
            :date_created = "20220518T125505Z" ;
            :geospatial_lat_max = 90.f ;
            :geospatial_lat_min = -90.f ;
            :geospatial_lat_resolution = ".041666666666666666" ;
            :geospatial_lat_units = "decimal degrees north" ;
            :geospatial_lon_max = 180.f ;
            :geospatial_lon_min = -180.f ;
            :geospatial_lon_resolution = ".041666666666666666" ;
            :geospatial_lon_units = "decimal degrees east" ;
            :geospatial_vertical_max = 0.f ;
            :geospatial_vertical_min = 0.f ;
            :git_commit_hash = "b99fc96426cd507fe88877f2862d22078f4108fd" ;
            :history = "Wed May 18 13:56:00 2022: ncks -x -v crs
standardised_geo/ESACCI-OC-L3S-OC_PRODUCTS-MERGED-1D_DAILY_4km_GEO_PML_OCx_QAA-
20120505-fv6.0.nc ESACCI-OC-L3S-OC_PRODUCTS-MERGED-1D_DAILY_4km_GEO_PML_OCx_QAA-
20120505-fv6.0.nc\n",
                  "Source data were: NASA OBPG SeaWiFS level1 R2018.0 LAC and GAC
[A/C via l2gen], NASA OBPG VIIRS L1 R2018.0  [A/C via polymer], NASA OBPG MODIS
Aqua L1 R2018.0 (A/C via polymer), ESA MERIS L1B (3rd reprocessing inc OCL
correction) [Polymer v4.12]  and OLCI L1B [Polymer v4.12]; Derived products were
mainly produced with functions validated from the current NASA SeaDAS release and
some custom implementations.  Uncertainty generation determined by the fuzzy
classifier scheme of Tim Moore (2009) as updated by Jackson et al. (2017) and
Jackson et al. (in prep)." ;
            :institution = "Plymouth Marine Laboratory" ;
            :keywords = "satellite,observation,ocean,ocean colour" ;
            :keywords_vocabulary = "none" ;
            :license = "C3S Data Policy: free and open access.  When referencing,
please use: Ocean Colour Climate Change Initiative dataset, Version <Version
Number>, European Space Agency, available online at http://www.esa-oceancolour-
cci.org.  We would also appreciate being notified of publications so that we can
```

```
list them on the project website at http://www.esa-oceancolour-
cci.org/?q=publications" ;
		:naming_authority = "uk.ac.pml" ;
		:number_of_optical_water_types = "14" ;
		:platform = "Orbview-2,Aqua,Envisat,Suomi-NPP, Sentinel-3a, Sentinel-
3b" ;
		:processing_level = "Level-3" ;
		:product_version = "6.0" ;
		:project = "Copernicus Climate Change Service" ;
		:references = "http://www.esa-oceancolour-cci.org/" ;
		:sensor = "SeaWiFS,MODIS,MERIS,VIIRS,OLCI-A,OLCI-B" ;
		:source = "NASA SeaWiFS  L1A and L2 R2018.0 LAC and GAC, MODIS-Aqua
L1A and L2 R2018.0, MERIS L1B 3rd reprocessing inc OCL corrections, NASA VIIRS
L1A and L2 R2018.0, OLCI A L1B, OLCI B L1B" ;
		:spatial_resolution = "4km nominal at equator" ;
		:standard_name_vocabulary = "NetCDF Climate and Forecast (CF)
Metadata Conventions Version 1.7" ;
		:time_coverage_duration = "P1D" ;
		:time_coverage_end = "201205052359Z" ;
		:time_coverage_resolution = "P1D" ;
		:time_coverage_start = "201205050000Z" ;
		:title = "Copernicus Climate Change Service Ocean Colour Product" ;
		:tracking_id = "2a3e2b88-498c-4c5f-9306-a0eea30fc0f2" ;
		:NCO = "netCDF Operators version 4.7.5 (Homepage = http://nco.sf.net,
Code = http://github.com/nco/nco)" ;
		:id = "ESACCI-OC-L3S-RRS-MERGED-1D_DAILY_4km_GEO_PML_RRS-20120505-
fv6.0.nc" ;
		:summary = "Data products generated for C3S using the latest
processing configuration from the Ocean Colour component of the European Space
Agency Climate Change Initiative project. These files are daily composites of
merged sensor (MERIS, MODIS Aqua, SeaWiFS LAC & GAC, VIIRS, OLCI) products.
MODIS Aqua and SeaWiFS were band-shifted and bias-corrected to MERIS bands and
values using a temporally and spatially varying scheme based on the overlap years
of 2003-2007.  VIIRS was band-shifted and bias-corrected in a second stage
against the MODIS Rrs that had already been corrected to MERIS levels, for the
overlap period 2012-2013; and at the third stage OLCI was bias corrected against
already corrected MODIS, for overlap period 2016-07-01 to 2019-06-30.  VIIRS,
MODIS, SeaWiFS and MERIS Rrs were derived from a combination of NASA\'s l2gen
(for basic sensor geometry corrections, etc) and HYGEOS Polymer v4.12 (for
atmospheric correction). OLCI Rrs were sourced at L1b (already geometrically
corrected) and processed with polymer.  The Rrs were binned to a sinusoidal 4km
level-3 grid, and later to 4km geographic projection, by Brockmann Consult\'s
SNAP.  Derived products were generally computed with the standard algorithms
through SeaDAS." ;
}
```

References

Mélin, F., Chuprin, A., Grant, M., Jackson, T., and Sathyendranath, S., (2016) ATBD Ocean Colour Data Bias Correction and Mergin. Issue 3.7. Report submitted under the Ocean Colour Climate Change Initiative Phase 2, ESA/ESRIN contract no. AO-1/6207/09/I-LG. Available at https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 5th September, 2022].

Steinmetz, F., Ramon, D., Deschamps, P-Y. (2016) *ATBD v1 - Polymer atmospheric correction algorithm*. Issue 2.1. Report submitted under the Ocean Colour Climate Change Initiative Phase 1, ESA/ESRIN contract no. AO-1/6207/09/I-LG. Available at https://climate.esa.int/en/projects/ocean-colour/key-documents/ [last accessed 5th September, 2022].

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