Copernicus Global Land Operations
"Cryosphere and Water"
"CGLOPS-2"

Framework Service Contract N° 199496 (JRC)

PRODUCT USER MANUAL

LAKE WATERS

300M MONTHLY PRODUCTS

PRODUCT VERSION 1.3.1

Issue I1.08

Organization name of lead contractor for this deliverable:

Book Captain: Kerstin Stelzer, BC

Contributing Authors: Stefan Simis, Nick Selmes PML

Dagmar Müller, BC

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document Release Sheet

Book captain:	Kerstin Stelzer (BC)	Sign	Date
Approval:		Sign	Date
Endorsement:		Sign	Date
Distribution:	Public		

Change Record

Issue/Rev	Date	Page(s)	Description of Change	Release
1.00	28.04.2017	23	First Version for PUM Lake Water Demonstration products Version 1.1.0	
1.01	11.05.2017	24	Adding illustrative examples, data policy	
1.02	16.06.2017		Answering RIDs from Reviewer 1	
1.03	30.10.2017		Updating for OLCI NRT processing	
1.04	10.01.2018	26	Updating OLCI – MERIS comparison	
1.05	18.06.2018	26	Integration of reviewers' comments	
1.06	15.11.2018	26	Consolidation of version numbers	
I1.07	09.12.2019	28	Description of LWQ Products corresponding to products Version 1.3.0	
I1.08	06.03.2020	26	Description of monthly LWQ Products, specially produced for UNEP	

Table Of Contents

List of Figures

List of Tables

List of Acronyms

ATBD	Algorithm Theoretical Basis Document
BC	Brockmann Consult
CCI	Climate Change Initiative
C-GLOPS	Copernicus Global Land Operations
FTP	File Transfer Protocol
GLWD	Global Lakes and Wetlands Database
GPT	Graph Processing Tool
LSR	Lake Surface Reflectances
NERC	National Environment Research Council (UK)
obs	Observation
OC	Ocean Colour
OWT	Optical Water Type
PML	Plymouth Marine Laboratory
PUM	Product User Manual
QAA	Quasi-Analytical Approach
QAR	Quality Assessment Report
rep	representative
Rw	Water-leaving reflectance
TS	Trophic State
TSM	Total Suspended Matter
TUR	Turbidity
WGS84	World Geodetic System 1984

1 BACKGROUND OF THE DOCUMENT

1.1 EXECUTIVE SUMMARY

This Product User Manual describes a special release of the Lake Water products provided via the Copernicus Global Land Service. This version of the products comprises monthly aggregates of the Turbidity and Trophic State Index Lake Water parameters.

Turbidity is derived from suspended solids concentration estimates and the Trophic State Index is derived from phytoplankton biomass by proxy of chlorophyll-a. This document describes the products derived from 4265 inland waterbodies using version 1.3 of the processing chain. Aggregation of the products include monthly intervals (starting the 1st, ending on last day of each month) as well as multi-annual per-month averages for two periods: 2006-2010 and 2017-2019. The products are mapped to a common global spatial grid at nominally 300m (~0.0022°) resolution. The algorithms used to derive the input for the optical lake water products are implemented in the *Calimnos* processing chain and were tuned and validated against 13 predefined optical water types in the NERC (UK) GloboLakes project. The Algorithm Theoretical Basis Document (ATBD) describes these algorithms and their placement in the *Calimnos* processing chain in detail. The product described here differs from the standard products in the temporal aggregation and a reduced number of parameters, and it is the first release which contains > 4000 re-defined waterbodies. All other processing steps are identical to the NRT service.

1.2 RELATED DOCUMENTS

1.2.1 Applicable documents

AD1: Annex I – Technical Specifications JRC/IPR/2015/H.5/0026/OC to Contract Notice 2015/S 151-277962 of 7th August 2015

AD2: Appendix 1 – Copernicus Global land Component Product and Service Detailed Technical requirements to Technical Annex to Contract Notice 2015/S 151-277962 of 7th August 2015

1.2.2 Input

Document ID	Descriptor
CGLOPS2_SSD	Service Specifications of the Global Component of the Copernicus Land Service.
CGLOPS2_ATBD_LWQ300_1km_v1.3.0_I1.09	Algorithm Theoretical Basis Document of the Lake Water Quality Products, 300m, 10-days, NRT and Archive

CGLOPS2_QAR_LWQ300_1km_v1.3.0_I1.08	Report describing the results of the scientific quality assessment of the Lake Water Quality Products, 300m, 10-days, NRT and Archive

1.2.3 External documents (if any)

N/A

2 USER REQUIREMENTS

The products are following the user requirements by UNEP which have been defined as:

- **Definition**:

The Lake Water Products are composed by Lake Turbidity (TUR) and an estimate of Trophic State Index (TSI). The products shall be provided as monthly averages of the respective parameters as well as multi-annual per-monthly averages for the periods 2006-2010 and 2017-2019. Turbidity is a key indicator of water clarity, quantifying the haziness of the water and acting as an indicator of underwater light availability. Trophic State Index refers to the degree at which organic matter accumulates in the water body and is most commonly used in relation to monitoring eutrophication.

- **Geometric properties**:

The baseline datasets pixel size shall be provided at nominal resolutions of 300m. The target baseline location accuracy shall be 1/3 of the at-nadir instantaneous field of view. Pixel co-ordinates shall be given for centre of pixel.

- **Geographical coverage**:

Global window

The initial window definition is aligned to the global datasets produced during the GIO phase for the most widely used output data:

- geographic projection: lat long,
- geodetical datum: WGS84
- pixel size: 1/112° (for 1 km)
- global window coordinates: UL: 180W-75N, BR: 180E, 56S (40320 col, 14673 lines)

The following output specifications are further optimised with respect to the requirements:

- pixel size at 300m: 0.25/112°
- global window coordinates: UL: 180°W-90°N, BR: 180°E, 90°S
- global grid size at 300m: 161280 columns, 80640 lines

- **Temporal Definition**

Products in the period 2006 – 2010 will be based on observations with the MERIS sensor, whereas the product 2017-2019 will be derived from OLCI sensors.

The products shall provide monthly averages per year as well as multi-year per-month averages.

- **Format**

The products shall be provided in global raster data sets in netCDF format. A recommended open-water mask is provided in each file, which removes most shoreline effects.

1 ALGORITHM

2.1 OVERVIEW

CGLOPS Lake Water processing inherits the processing chain that was developed for the UK-based GloboLakes project. In turn, GloboLakes based the processing chain on work carried out in ESA Diversity-2. The chain was built to process archived ENVISAT-MERIS data at full resolution (300m) and has been further adapted to handle Sentinel-3 OLCI and Sentinel-2 MSI for operational processing. This document refers to 300m products based on MERIS and OLCI generated using *Calimnos* v1.3, the latest version of this processing chain.

Calimnos combines data discovery, subsetting by target area (individual water bodies), radiometric and atmospheric corrections, pixel identification (land/cloud/water/ice), optical water type classification, individual algorithms (per parameter and water type), algorithm blending, conversion and aggregation into a single processing chain (see Figure 1).

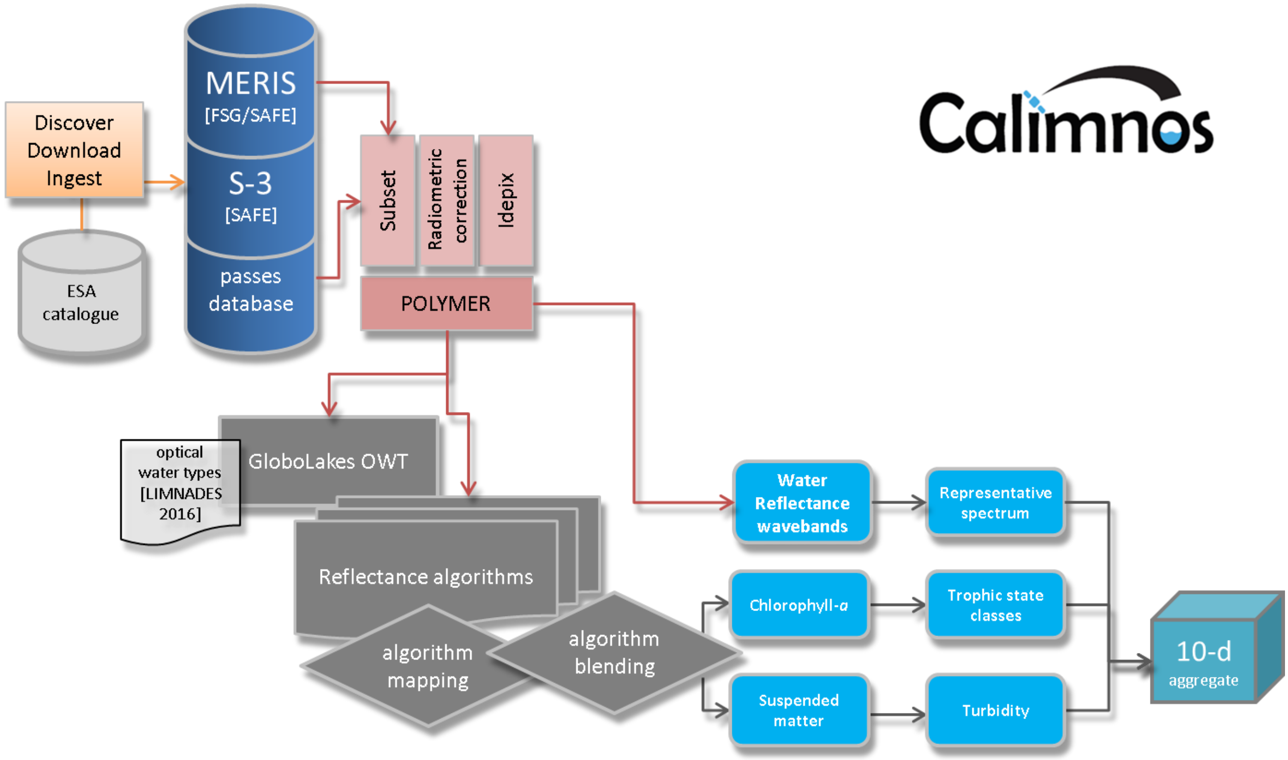


Figure 1: Schematic overview of the Calimnos processing chain

2.2 RETRIEVAL METHODOLOGY

2.2.1 Processing chain and software dependencies

A schematic overview of *Calimnos* is given in Figure 1. The main processing stages and related software / processors / algorithms include:

- Data discovery
    - Following download of new satellite passes at L1B these are entered into a geospatial database. Target regions are similarly specified in a geospatial database and satellite products which overlap any of the target regions are queued for processing. In the context of re-processing, any duplicate passes are removed. The procedure relies on in-house python scripts and postgres database functionality.
- Subsetting
    - Software and dependencies: SNAP Subset operator
    - For best processing performance, satellite passes are subsetted to bounding boxes around each target area, in turn defined by the maximum water extent observed in ESA Land Cover cci v4. The subsetting routine is part of the SNAP toolbox, called through the Graph Processing Tool (GPT).
- Radiometric corrections
    - Software and dependencies:
        - MERIS L1b Radiometric Correction v5.0.3, comprising optional smile correction following the MERIS ATBD and a radiometric equalisation following Bouvet M. & Ramoino F. (2010)
        - OLCI: Gain corrections are part of the atmospheric correction step (see below)
    - Any radiometric corrections defined following the release of the data are applied to the L1B imagery before submitting the data to atmospheric correction. For MERIS reprocessing the 3rd reprocessing and subsequently published radiometric corrections are used as part of the SNAP toolboxes using GPT. The 4th reprocessing of MERIS will be used once it becomes available (expected during 2020). System-vicarious calibrations for OLCI-A are also implemented (identical to those used in the ESA Ocean Colour CCI project. OLCI-B corrections are still pending results of the OLCI–A/B tandem orbits and therefore not used.
- Pixel identification
    - Software and dependencies:
        - MERIS: SNAP Idepix-Water v3.0.
        - OLCI: SNAP Idepix-Sentinel3.Olci v3.0
    - The *Idepix* neural network routine is applied for initial pixel identification as water, land, cloud/haze, cloud shadow or snow/ice. *Idepix* is called through SNAP using the GPT. Pixel identification masks are stored for later masking of invalid (non-water) pixels.

    - External ice information provided by NOAA via ftp.star.nesdis.noaa.gov/pub/smcd/emb/snow/binary/multisensor/global/ has been included for additional masking of misclassified ice. The daily NOAA products have been aggregated into monthly lake-ice masks.
- Atmospheric correction
    - Software and dependencies:
        - MERIS and OLCI: POLYMER v4.12
    - POLYMER according to Steinmetz et al. (2011), updated in Steinmetz (2016 and 2018), parameterized to use the Park and Ruddick (2005) bidirectional reflectance distribution function, and operating only on pixels identified as water by the Idepix module. POLYMER is called using a function wrapper in Python.
- Optical water type classification
    - Software and dependencies: Python implementation
    - Algorithm: the OWT classification is based on the work of Moore et al. (2001) and equivalent software developed for ESA-CCI. The algorithm uses spectral means defined in the GloboLakes project by the University of Stirling (Spyrakos et al. 2018). In contrast to OWT mapping used in other projects we apply the spectral angle (Kruse et al. 1993) rather than Mahalonobis distance as metric for similarity between spectra, which emphasizes difference in spectral shape rather than reflectance amplitude.
    - The optical water type (OWT) classification is applied to each pixel to determine the similarity of the observed water-leaving reflectance spectrum to thirteen known types.
- Water constituent retrieval
    - Software and dependencies: Python implementation
    - Algorithms: Water constituent retrieval algorithms tuned to each OWT in the GloboLakes project (Spyrakos et al. 2018, Neil et al. 2019) are mapped to each individual pixel according to the OWT with the three highest classification scores for that pixel. The algorithm results corresponding to those three OWTs are averaged using the membership score as weighting. The weighting factors are scaled between 0 and 1, where 1 is the highest OWT membership score and 0 is the first OWT score that is not included in averaging (i.e. the fourth). This procedure is used to derive maps of total suspended matter (TSM) and chlorophyll-a (Chla). The underlying algorithms are listed in Section 4.2.3 and 4.2.4, respectively.
    - The chlorophyll-a concentration is converted into the TSI scale as described in Table 1. In the operational processing chain this is further classified into 11 discrete TSI classes, whereas in the monthly aggregates the full scale is provided to support more precise trend analysis.
- Algorithm mapping and blending
    - Software and dependencies: Python implementation
    - For each OWT a best-performing algorithm has been tuned against the global in situ reference LIMNADES data set, as part of the GloboLakes project. For CGLOPS the best performing algorithm corresponding to the OWT of a given pixel is mapped for

both chlorophyll-*a* and suspended matter, which are precursors for Trophic State and Turbidity products.

- <u>Aggregation</u>
    - Software and dependencies: SNAP LakeAggregate operator V1.0.
    - LakeAggregate performs spatial and temporal aggregation of pixel values into cells ('bins') of a planetary grid over a lake. During the Lake Aggregation, invalid pixels are eliminated before averaging. Both standard deviation ('sigma') and mean values are derived for the remaining observations over a pixel. Invalid pixels are recognized based on L1 product flags (L1.INVALID), the Idepix cloud, ice, haze, and land identification flags, and value limits for individual products (water-leaving reflectance non-negative and not exceeding 0.4, Turbidity and TSI non-negative)
    - Not included in this product – but for information to users of the corresponding 10-day aggregated v1.3 products: Most representative spectrum selection. Algorithm developed by PML and BC for use in the Copernicus Global Land Service. For each pixel, water-leaving reflectance spectra are compared to the median spectrum using the root-mean-square difference across all wavebands. The spectrum with the lowest RMS difference is selected as most representative for the observation periodThe reflectance products of the POLYMER atmospheric correction are inspected over the 10 day period and for each pixel the most representative spectrum is chosen. An Algorithm has been developed for the selection by the CGLOPS-2 LWQ team. For each pixel, water-leaving reflectance spectra are compared to the median spectrum using the root-mean-square difference across all wavebands. The spectrum with the lowest RMS difference is selected as most representative for the observation period.
    - Monthly aggregation is done on a per-lake basis after applying masks to select data for water pixels. The aggregated products which contain Trophic State Index and Turbidity are then mapped to a global grid at 0.0022° (nominally 300m) resolution. The global extent is UL: 180°W-90°N, BR: 180°E, 90°S
    - Multi-year per-month aggregation is performed in the same manner as the single year monthly averages, but includes products from all years in the respective period (2006-2010 and 2017-2019), separated by month.
- <u>Static masks</u>
    - A buffered land-water mask is provided in addition to the above-mentioned water pixel identification. The buffered mask should be applied for statistical analyses as it conservatively removes pixels that are expected to be near the shoreline where mixed land and bottom influences increase product uncertainty. The static shoreline mask is generated using the land-water-mask module in SNAP which is based on the SRTM water mask for areas <60°N geographic latitude and GlobeCover world map for regions >60°N geographic latitude in 150m resolution. The buffered water mask is generated by sampling the SRTM water mask to the same resolution as the Water Quality Products with a supersampling of 3x3 pixels. This procedure provides transitional pixels between land and water, which were regarded as pure land pixels to avoid shoreline pixels to influence the water bodies. In addition to this, the water

bodies were shrunk by one pixel to even reduce the risk for the statistical analysis to include shoreline pixel or near-shore pixels influenced by bottom reflection.

- Because the data are taken from a static dataset, lake extent dynamics cannot always be captured by this mask.
- A region-ID variable is included in each aggregated product. This is another static map which describes the area being considered for each lake. The raster map is based on a set of 4265 manually validated and corrected polygons derived from the maximum water extent map of ESA CCI Landcover v4.0 (150m resolution). This mask can be used to identify individual lakes, relating them to other hydrological data sets. The identifiers link the waterbody to existing databases. The range 0-99999999 carries ID information from the Global Lakes and Wetlands Database; 100000000-199999999 correspond to a small set of waterbodies defined in the GloboLakes project; 200000000-299999999 are defined within the Copernicus Land Monitoring Service; 300000000-399999999 correspond to the HydroLakes database waterbody identifiers. A list of all lake IDs and additional information (location, name – where known, area) is available through the service helpdesk.

Table 1: Trophic state index and related chlorophyll-a concentration classes (according to Carlson (1977))

Trophic classification	**Trophic State Index, CGLOPS TSI values**	**Chlorophyll-a (µg/l) (upper limit)**
Oligotrophic	0	0.04
	10	0.12
	20	0.34
	30	0.94
Mesotrophic	40	2.6
	50	6.4
Eutrophic	60	20
	70	56
Hypereutrophic	80	154
	90	427
	100	1183

2.2.2 Basic underlying assumptions

The processing chain is based on a number of assumptions:

- *Idepix* can differentiate adequately between pixels containing water and any of the following conditions: mixed land/water, cloud, cloud shadow, ice, snow, and haze.
- *POLYMER* successfully retrieves the shape and amplitude of water-leaving reflectance.
- The 13 optical water types defined in UK-GloboLakes sufficiently capture the natural optical diversity of inland waterbodies.
- Tuning of reflectance algorithms for chlorophyll-*a* and suspended matter is adequate for each water type.
- The water-leaving reflectance spectra can be assigned a membership score for at least one known optical water type.
- The tuned reflectance algorithms for chlorophyll-*a* and suspended matter yield valid results over the range of reflectances observed over water types to which they have been assigned.
- The translation of chlorophyll-*a* to trophic state is adequate and consistent between water types.
- The translation of suspended matter to turbidity is adequate and consistent between water types.
- The most crucial assumption in versions 1.3.0 and 1.3.1 of the *Calimnos* processing chain is that optical water types which have been defined from a large set of *in situ* data from optically complex waters (lakes, reservoirs, lagoons, estuaries, and coastal areas) can be assigned successfully to each satellite observation (pixel) containing open water. In practise, the assignment to an optical water type can fail due to any of a number of reasons, the most prominent being: failure to identify the pixel as water (or as influenced by cloud or ice) by Idepix, or failure in the atmospheric correction yielding a reflectance spectrum that is incompatible with any of the algorithms used downstream. Misclassification of a given image pixel will normally be associated with a low classification score giving rise to caution in using the resulting products for that pixel. Solutions for misclassification and improvement of atmospheric correction are continuously being explored. A per-pixel uncertainty estimate derived from the optical water type specific algorithm mapping is under development and expected to be included in the next major reprocessing.

2.3 LIMITATIONS OF THE PRODUCT

The most crucial assumption in the *Calimnos* processing chain is that optical water types which have been defined from a large set of *in situ* data from optically complex waters (lakes, reservoirs, lagoons, estuaries, and coastal areas) can be assigned successfully to each satellite observation (pixel) containing open water. In practise, atmospheric correction may have systematic errors for some water types, leading to low membership scores for these water types. This, in turn, implies that suboptimal reflectance algorithms for chlorophyll-a and suspended matter may be selected.

If the pixel identification and thus the flagging of erroneous pixels does not work properly, e.g. at cloud borders, thin clouds or lake ice coverage either covering a whole pixel (misclassification error) or part of the area under a pixel (classification ambiguity), the water-leaving reflectance and subsequent Turbidity and Trophic State Index retrieval may fail. Users interested in lake averages rather than maps are advised to mask a single pixel buffer from shorelines, where such effects are most difficult to control and flag by using the buffered land-water mask provided. However, it is noted that this mask is based on a static definition of lake extent, and during dry periods the coastline may shift further inwards.

In v1.3.1 it was found that ice pixels, particularly thin ice, could be misclassified as water, leading to spuriously high Turbidity values. All variables in the monthly product (except the land-water mask and ID map) have therefore been masked using an external ice mask, derived from monthly aggregated ice cover in 2019. In addition, any pixel with a Turbidity > 500 has been masked in all product variables. The resulting monthly products are released as product version 1.3.1.

The spatial blending of different algorithms and/or the averaging of different, very inhomogeneous days under partial cloud cover can lead to visually inconsistent maps, showing patchy patterns where coverage on different days of observation was incomplete, and if optical conditions in the lake changed over this period. This is considered normal behaviour for the decadal product but is likely to be less visible in monthly or multi-year per-month averages.

The radiometric correction of OLCI on Sentinel 3A is implemented based on system vicarious calibration results. OLCI-B currently follows pre-flight calibrations while results from the tandem flights are pending. The effect of not including system vicarious calibration on OLCI-B is limited to observations from December 2018 onward, and expected to be small.

Per-pixel uncertainty information is not yet provided with the products. A preliminary per-pixel uncertainty estimate has been developed as part of the ESA Lakes_cci project and will be included in the next processing version. This procedure exploits all available matchup data across optical water types, thus overcoming some of the limitations of limited availability of in situ data. These procedures will be included in the next major version update.

<u>Differences with the previous version</u>

The current version of the Calimnos processing chain is 1.3 and has been used to produce 10-day aggregates (product version 1.3.0) and monthly and multi-annual per-month averages (product version 1.3.1).

The first release for the Copernicus Global Land service used *Calimnos* v1.1.0 for reprocessing of the MERIS archive. *Calimnos* v1.0.4 was used to produce the first global adaptive water quality data set in the UK-GloboLakes project to relate water quality changes to environmental change in 1000 lakes globally. Compared to GloboLakes processing, the binning procedure has been changed, to retrieve Lake Surface Reflectance (fully normalized water-leaving reflectances) of the most representative spectrum, and to aggregate the Trophic State Index from the chlorophyll-*a* concentration. The aggregation period for TSI and Turbidity is set to 10 days (being flexible in *Calimnos* processing).

The products have undergone several improvements from initial CGLOPS version 1.1.0. The C*alimnos* processing chain has been extended for the production of OLCI-A and OLCI-B as well as for Sentinel-2 MSI. Vicarious gains are included for OLCI production. The pixel identification has been improved (e.g. introduction of cloud shadow) and additional quality flags are introduced as post-processing step for better identification of mixed pixels at the shorelines. The atmospheric correction evolved from Polymer version 3.4 to version 4.12 (see changes listed above).

The selection of lakes is additionally based on different criteria (large and strategic water bodies). Earlier product versions including the initial set of 1000 lakes, covered an estimated > 50 % of the global surface area of inland water bodies (1,409,030 km^2, not counting the Caspian Sea which is also included in the service). In version 1.3 of the processing chain, the set of lakes has been extended to 4265 waterbodies, an expansion of 27% in terms of surface area.

The monthly products discussed here differ in the temporal aggregation period as well as in the selection of variables compared to the standard Copernicus Global Land Lake products. Further, static masks (region-ID and shoreline masks) are provided with the products, as described above.

External ice maps were used to improve misclassification of ice pixels over lakes, which had become particularly pronounced with the inclusion of a large number of high-latitude lakes in this dataset.

3 PRODUCT DESCRIPTION

3.1 FILE NAMING

For the Lake Water Products, the follow a naming convention is followed:

c_gls_LWQ300m_<YYYYMMDDHHmm>_GLOBE_<SENSOR>_<Version>.<EXTENSION>

where

- <YYYYMMDDHHmm> gives the temporal location of the file. YYYY, MM, DD denote the year, the month, the day of the product (always first day of the month). Because time is not relevant, HHmm is always set to 0000.
- GLOBE indicates the global coverage of the product (Table 2).

Table 2: Naming convention and bounding box for continental subsets

Short name Continent	Continent	Bounding Box
GLOBE	global	180°W – 180°E, 90°N – 90°S

- <SENSOR> gives the name of the sensor used to retrieve the product, either MERIS or OLCI.
- The <Version> is **1.3.1** for MERIS and **1.3.1** for OLCI
- <EXTENSION> is indicating the file format, which is **.nc** for netCDF4 files.

Examples:

c_gls_LWQ300_200704010000_GLOBE_MERIS_V1.3.1.nc

c_gls_LWQ300_201804010000_GLOBE_OLCI_V1.3.1.nc

3.2 FILE FORMAT

The file format is netCDF CF1.7. The format of each parameter (band) is provided in Table 3.

3.3 PRODUCT CONTENT

3.3.1 Data File

The variables included in the products are listed in Table 3.

Table 3: specification of the variables included in Lake Water Products

band name	data type	description
num_obs	int	Number of observations (including non-water observations)
stats_valid_obs_tsi_sum	int	Number of valid observations used to produce TSI averages
stats_valid_obs_turbidity_sum	int	Number of valid observations used to produce Turbidity averages
trophic_state_mean	float	Trophic state index (TSI) obtained from chlorophyll-a observations averaged over the observation period. The TSI product is normally classified into bins (0, 10, 20, 30, 40, 50, 0, 70, 80, 90, 100) corresponding to chlorophyll classes (following categorisation provided in Table 1), but the full scale is provided in the monthly products. .
trophic_state_sigma	float	Pixel-specific standard deviation of Trophic State Index over the observation period.
turbidity_mean	float	Mean turbidity observed over the observation period
turbidity_sigma	float	Pixel-specific standard deviation of Turbidity values over the observation period
lat	float	Latitude in decimal degrees provided as a 1-D netcdf dimension variable
lon	float	Longitude in decimal degrees provided as a 1-D netcdf dimension variable
region_id	int	ID for each lake (pixelwise). The range 0-99999999 links to IDs in the Global Lakes and Wetlands Database; 100000000-199999999 correspond to a small set of waterbodies defined in the GloboLakes project; 200000000-299999999 a small set defined within the Copernicus Land Monitoring Service; 300000000-399999999 correspond to the HydroLakes database waterbody identifiers.
water_mask	int	buffered land-water mask for masking shoreline pixels.
time	float	Time in days since 1-1-1970
crs	string	Geographical projection string

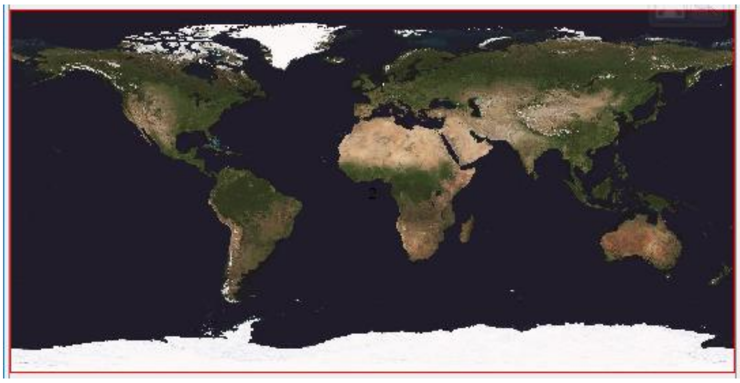
3.4 PRODUCT CHARACTERISTICS

3.4.1 Projection and Grid Information

Global files in NetCDF4 format, mapped to a global 0.0026° grid and including dimensions latitude, longitude (WGS84 projection), and time (days since 1 January 1970).

3.4.2 Spatial Information

The spatial extension of the global product covers the full globe, shown in the red rectangle in Figure 2.



Upper left latitude	89°59'45" N
Upper left longitude	179°59'45" W
Upper right latitude	89°59'45" N
Upper right longitude	179°59'45" E
Lower left latitude	89°59'45" S
Lower left longitude	179°59'45" W
Lower right latitude	89°59'45" S
Lower right longitude	179°59'45" E

Figure 2: Coverage of the global product (red rectangle) and bounding box coordinates.

3.4.3 Temporal Information

The LWQ V1.3 products are monthly composites. The temporal information "YYYYMMDDHHmm" in the filename corresponds to the start date monthand contains all days within the respective month (28, 30 or 31 days).

3.4.4 Data Policies

Any use of the Lake Water Quality products implies the obligation to include in any publication or communication using these products the following citation:

"The products were extracted from the land service of Copernicus, the Earth Observation program of the European Commission. The research leading to the current version of the products has also received funding from ESA (Diversity-II) and the UK NERC (Globolakes)."

3.4.5 Contacts

Accountable contact: European Commission Directorate – General Joint Research Centre,

Email address: copernicuslandproducts@jrc.ec.europa.eu

General email address: lwq_info@brockmann-consult.de

Lead contractor contact: Kerstin Stelzer, BC, kerstin.stelzer@brockmann-consult.de

Lead scientist: Stefan Simis, PML, stsi@pml.ac.uk

Lead engineer: Nick Selmes, PML, nse@pml.ac.uk

3.4.6 Sample products

The following figure provides examples of LWQ products for Lake Huron. They show the Trophic State Index 10D average (Figure 3 upper left), the turbidity 10D average (Figure 3 upper right) and an RGB derived from the representative spectrum within the 10D period (lower row).

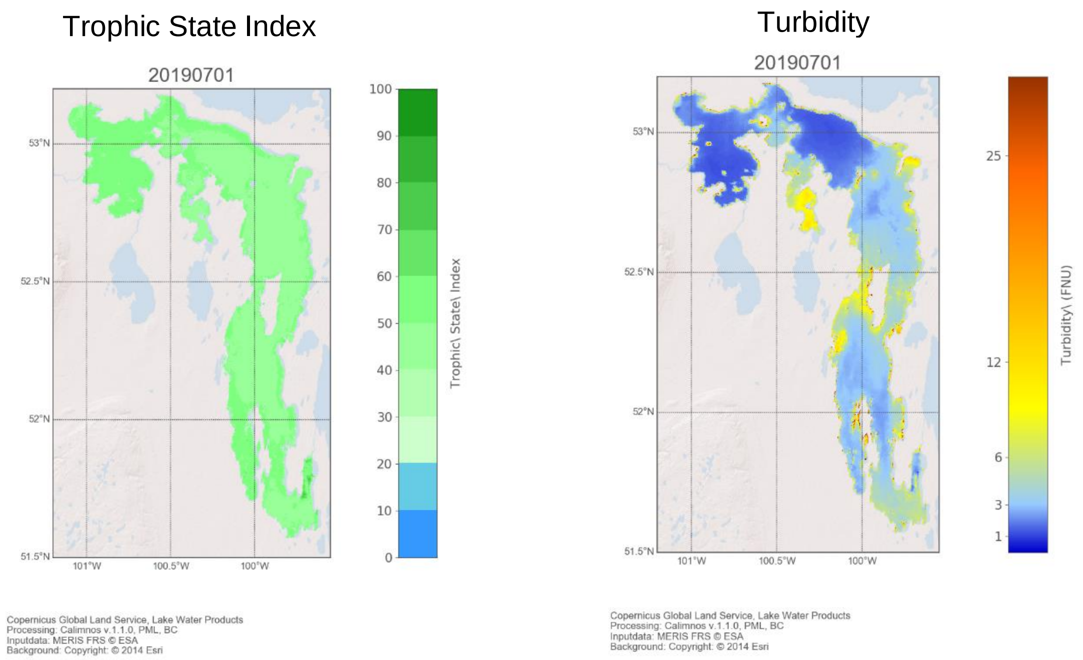


Figure 3: Lake Winnipegosis - Trophic State Index (left) and turbidity (right monthly product July 2019

The monthly products provide a good overview on the seasonal evolution of parameters by mapping them in sequenced maps. Figure 4 shows the multi-year monthly products for the Turbidity for Lake Garda. A clear seasonal trend is observed with increasing Turbidity towards the late spring and summer months. After August the Turbidity decreases again.

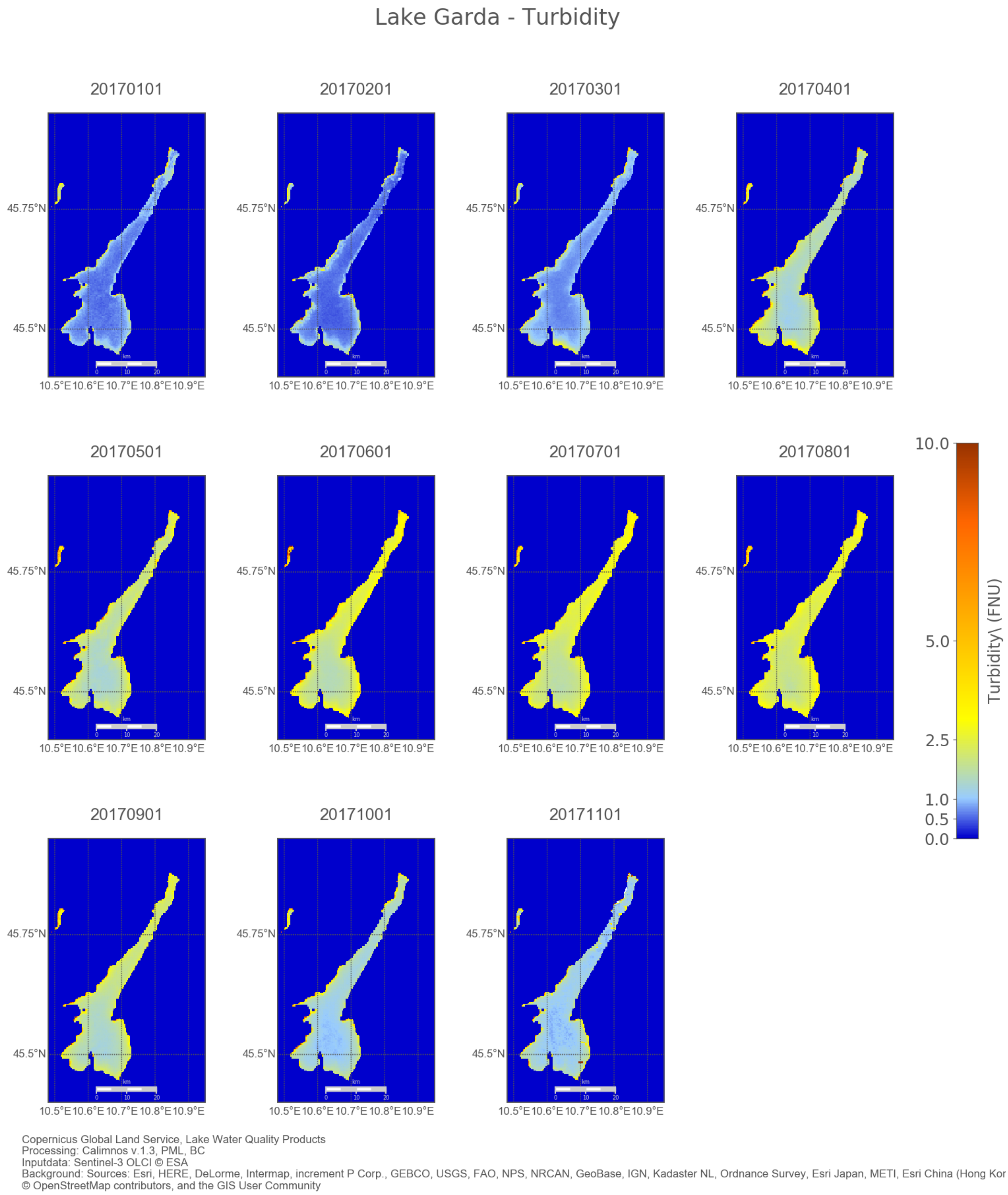


Figure 4. Turbidity in Lake Garda (2018).

4 VALIDATION

A detailed description of the validation and quality assessment is provided with the QAR. The products were tested against consistency (time series) and against in situ data, both for a selected set of lakes.

POLYMER v3.5 was validated against in situ reflectance data contained in LIMNADES within the GloboLakes project (MERIS). POLYMER gave the best performance (unbiased error) in each waveband, although a consistent underestimation is apparent. This systematic error is cancelled out in the whole-chain calibration of TSM and chlorophyll-a retrieval. A correction is not attempted for the LSR because there are not enough in situ validation available to inspect the performance per Optical Water Type. Further improvement of the POLYMER atmospheric correction will be based on results of ongoing investigations, which have thus far shown that the mineral absorption model should not be universally applied, as was previously considered a solution. It should be noted that underestimation of reflectance has a minimal effect on water constituent retrieval algorithms that operate primarily on the shape of the reflectance spectrum. This is the case for turbid water chlorophyll-*a* algorithms and some TSM algorithms.

Time series comparison between in-situ data and EO derived parameters enable to assess the behaviour of both measurement techniques over time. The focus is on the consistency of the time series on the one hand and on the comparability of the data sets on the other hand. The order of magnitude and seasonal patterns are investigated. The assessment of sample lakes shows that the products are consistent in time and mainly also in space. Seasonal patterns are as expected for the known and investigated lakes. The turbidity is sometimes showing spatial patterns that are caused by temporal averaging of patchy (partly cloudy) products. The comparison between the products and in-situ data show same magnitude, but only a few analyses could be performed here.

Manual inspection of all products for more than 4000 water bodies is impossible and, in most cases requires local knowledge. The validation of the products is, and always will be, based on a small sample of well-studied areas. Users of these products are therefore advised to inspect the results for their area of interest before generating derivative products. This inspection could include, for example, histograms to identify outliers. Users are also advised to take into account the number of observations underlying the results. Where observations are sparse, having a small number of satellite passes to cover a large water body can lead to visual inconsistencies that do not reflect the state of the water body at any particular time – this is merely the nature of creating aggregate products.

Expert users are encouraged to take part in the calibration and validation of these products that is increasingly taking place at the global scale. The spatiotemporal coverage and quality of the global lake water products can only be improved if the algorithms underlying these products can be accurately adjusted to waters of each optical type (and in some cases, new water types may need to be defined). We point interested users to the LIMNADES initiative (www.limnades.org), from where many of the presented validation results are derived

5 REFERENCES

Bouvet M., Ramoino F. (2010): Equalization of MERIS L1b products from the 2nd reprocessing. ESA TN TEC-EEP/2009.521/MB

Diversity-II (2015): ESA DUE DIVERSITY II - Algorithm Theoretic Baseline Document (ATBD), Version 2.4. http://www.diversity2.info/products/documents/DEL5/DIV2_Algorithm_Theoretical_Basis_Document_v2.4.pdfhttp://www.diversity2.info/products/documents/DEL5/DIV2_Algorithm_20Theoretical_Basis_Document_v2.4.pdf

Moore, TS., JW. Campbell and Hui Feng. (2001): A fuzzy logic classification scheme for selecting and blending satellite ocean color algorithms. IEEE Transactions on Geoscience and Remote Sensing 39(8) 1764-1776

Neil, C., Spyrakos, E., Hunter, PD, Tyler, AN (exp. 2018): Evaluation of algorithms for chlorophyll retrieval in optically-complex inland waters: establishing a framework for a global approach based on optical water types. Submitted to Remote Sensing of Environment

Spyrakos E, O'Donnell R, Hunter PD, Miller C, Scott M, Simis S, et al. (2017): Optical types of inland and coastal waters. Limnol Oceanogr. Volumne 63, Issue2. doi: doi: 10.1002/lno.10674.

Steinmetz F, Deschamps P-Y, Ramon D. Atmospheric correction in presence of sun glint: application to MERIS. Optics Express. 2011;19(10):9783-800. doi: 10.1364/oe.19.009783

Steinmetz, F. Ramon, D., Deschamps, P-Y (2016): ATBD v1 – Polymer atmospheric correction algorithm, D2.3 OC-CCI project http://www.esa-oceancolour-cci.org/?q=webfm_send/658

Steinmetz, F. (2018): ATBD v1 – Evolution of Polymer Atmospheric correction within Copernicus Global Land Service – Inland Water products. On request