

Coastal Monitoring User Manual Chlorophyll-a (CHL)

Technical Document

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- **Data:** CopernicusLAC Chile. (2025). *Chlorophyll (0.01°) for Latin America and the Caribbean: 2024 Monthly Level 4 Gap-Free Product (Version 0.1)* [Dataset]. <https://www.copernicuslac-chile.eu>

1. Executive summary

This manual describes the chlorophyll-a satellite product developed by CopernicusLAC Chile's Coastal Monitoring Service. The level 4 (L4) product integrates multi-source measurements from different optical sensors (MODIS Aqua, VIIRS SNPP, VIIRS NOAA-20, and Sentinel-3 OLCI), covering the Latin America and Caribbean region at a spatial resolution of 0.01° (~1km at the equator) and monthly temporal resolution.

As an L4 product, it corresponds to a spatially continuous, gap-free variable, obtained through optimal interpolation and deep-learning-based reconstruction, which ensures spatial continuity and bio-optical consistency.

Chlorophyll-a is an integrative indicator of ocean primary productivity, with applications in fisheries management, harmful algal bloom detection, monitoring of coastal eutrophication processes, and surveillance of sensitive ecosystems, such as Caribbean coral reefs. This manual describes the product's technical specifications, generation methodology, and quality control.

2. Introduction

The Latin America and Caribbean region is home to some of the most productive and biodiverse marine ecosystems on the planet, giving chlorophyll-a monitoring particular strategic value for regional environmental and fisheries management. The Humboldt Current system, off the coasts of Chile and Peru, sustains one of the most abundant fisheries in the world thanks to intense upwelling processes that fertilize surface waters; this is complemented by the eastern tropical Pacific, the Patagonian shelf, the Gulf of Mexico, and the Caribbean Sea, which together form a mosaic of highly diverse oceanographic regimes.

Across all of these systems, chlorophyll-a acts as an integrative indicator of primary productivity, making it possible to locate high-biomass areas, anticipate the availability of fishery resources, and support management decisions in a region where fishing and aquaculture are key economic and food-security pillars.

Systematic chlorophyll-a monitoring is also key for coastal environmental management, enabling the detection and tracking of harmful algal blooms — recurrent in the fjords of southern Chile, where they affect salmon farming and shellfish harvesting—, the identification of eutrophication processes linked to urban and agricultural discharges, and the monitoring of stress on sensitive ecosystems such as Caribbean coral reefs. These capabilities give remote-sensing-based tools an early-warning role that is essential for protecting public health, productive activity, and the integrity of coastal ecosystems.

Finally, the LAC region is strongly influenced by climate variability, particularly the El Niño-La Niña cycle, which drastically alters ocean productivity off the coast of South America. Chlorophyll-a time series make it possible to characterize these events, assess the ocean's role in the carbon cycle, and detect long-term trends under a changing climate. Since *in situ* sampling in the region is scarce and discontinuous, satellite observation offers broad, systematic, and cross-country comparable coverage, making it an indispensable tool for oceanographic research and regional decision-making.

3. Product specifications

The technical specifications of the Chlorophyll-a (CHL) product from the Coastal Monitoring Service of CopernicusLAC Chile are detailed below, organized into the following aspects: general product information, description of its content and coverage, and distribution format. This documentation is intended to facilitate the correct download, reading, and integration of the product into oceanographic, ecological, and coastal environmental management analysis tools.

3.1 General information

This subsection brings together the technical parameters that define the Chlorophyll-a (CHL) product generated by the Coastal Monitoring Service of CopernicusLAC Chile. This information provides the user with a complete characterization of the product prior to its download and application in studies of primary productivity, marine ecology, or coastal environmental management. Table 1 summarizes the product's general attributes, including name, version, source sensors (MODIS Aqua, VIIRS SNPP, VIIRS NOAA-20, and Sentinel-3 OLCI), spatial resolution (0.01° , ~1km), monthly temporal resolution, distribution format (NetCDF4 and ZARR), processing level (L4, gap-free), metadata conventions (CF-1.7, ACDD-1.3), and the product's spatial domain over the Latin America and Caribbean region (Figure 1).

Table 1. General information on the chlorophyll-a (CHL) product.

Product	2024-L4_CHL-a_monthly_v0.1
Spatial resolution	0.01° (~1 km)
Temporal resolution	Monthly
Variable	CHL
Format (standard)	NetCDF4, ZARR (CF-1.7, ACDD-1.3)
Geographic coverage	Coasts of Latin America and the Caribbean up to 200 nautical miles (nm) offshore

Temporal coverage	2024
Update frequency	Annual

Source: Own elaboration.

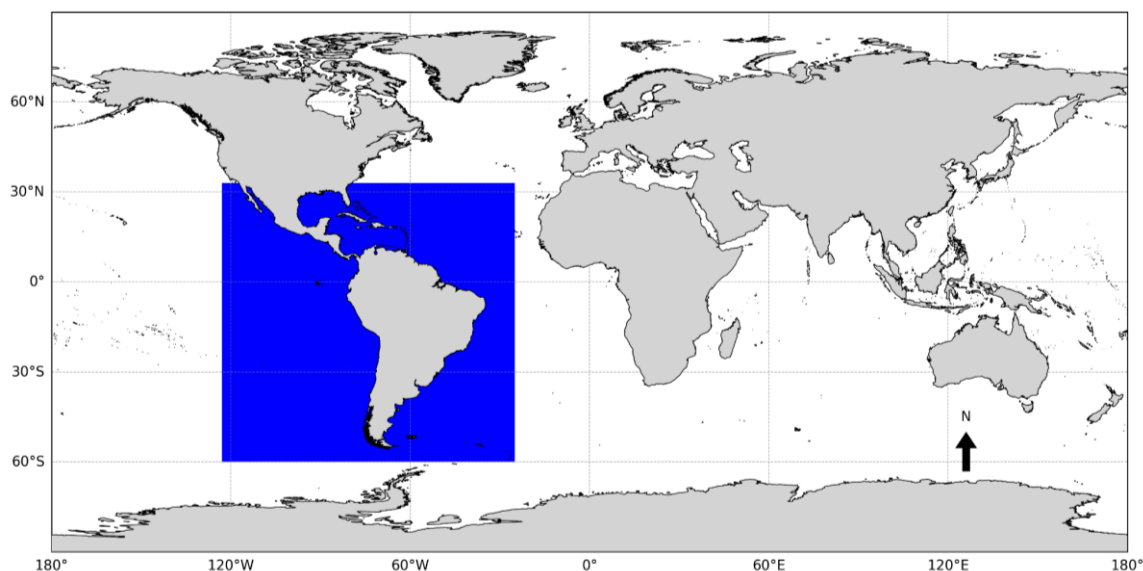


Figure 1. Spatial domain (blue) of the chlorophyll-a product.

Source: Own elaboration.

3.2 Product Description

The Chlorophyll-a (CHL) dataset for Latin America and the Caribbean (LAC) delivers monthly Level 4 (L4) products, generated from Level 2 (L2) satellite observations from the Sentinel-3 OLCI, MODIS Aqua, VIIRS SNPP, and VIIRS NOAA-20 sensors. Each mission contributes remote sensing reflectance (Rrs) and chlorophyll estimates obtained through algorithms of the OCx/CI family (OC3M, OC4v6/OCI, OC4ME) (O'Reilly, 2019), which are mutually consistent and suitable for multisensor integration.

The final product offers continuous monthly CHL fields at a spatial resolution of 0.01° (~ 1 km). This is achieved by combining a multisensor fusion scheme with spatio-

temporal interpolation techniques and neural-network-based reconstruction, yielding a gap-free and bio-optically coherent field. The result is validated against *in situ* measurements and compared with international models and products, generating a robust dataset for ecological studies, productivity analysis, biogeochemical modeling, and operational applications in coastal and oceanic areas.

3.3 Product Format

The CHL product is distributed in NetCDF4 and ZARR format, under the Climate and Forecast Metadata (CF-1.7) and Attribute Convention for Data Discovery (ACDD-1.3) conventions, which allows large volumes of structured data to be stored with easy access for subsequent analysis.

The general structure of the NetCDF files (Table 2), global metadata attributes (Table 3), main variables (Table 4), and flags and fill values (Table 5) are presented below.

Table 2. General structure of the NetCDF file.

Dimension	Description	Type
time	reference time (daily, nighttime average)	double
lat	latitude (degrees north)	double
lon	longitude (degrees east)	double

Source: Own elaboration.

Table 3. Global metadata attributes.

Attribute	Value
institution	CopernicusLAC Chile
source	L3S monthly multi-sensor composites fused into gap-free L4 analysis (SLSTR reference)
id	2024-L4_CHL-a_monthly_v0.1

references	CF-1.7; ACDD-1.3
product_version	v1.0
time_coverage_start	2024-01-01T00:00:00Z
time_coverage_end	2024-12-31T23:59:59Z
geospatial_lat_min	-59.995
geospatial_lat_max	32.995
geospatial_lon_min	-122.995
geospatial_lon_max	-25.005
title	Monthly multi-sensor fused chlorophyll product, LAC 1 km
summary	Monthly multi-sensor fused chlorophyll-a product for LAC at 1 km
history	L3C-to-L3S daily multi-sensor fusion (2025-12-09); Monthly aggregation run (2025-12-17): chlor_a = exp(mean(ln(chl))); chlor_a_median = exp(median(ln(chl))); bitmasks = OR
time_coverage_resolution	P1M
collation_input	List of daily L3S files*
date_created	2026-01-06T11:43:39Z
date_modified	2026-01-06T11:43:39Z
project	CopernicusLAC Chile
processing_level	L4
processing_mode	delayed
license	free and open
geospatial_bounds	POLYGON((-122.995 -59.995 ...))

geospatial_bounds_crs	EPSG:4326
spatial_resolution	0.010° (~1 km)
temporal_resolution	monthly
instrument	multisensor
platform	multisensor
keywords	chlorophyll, ocean color, LAC, multisensor, OLCI, MODIS, VIIRS
publisher_name	CopernicusLAC Chile
publisher_email	info@copernicuslac-chile.eu
publisher_url	https://www.copernicuslac-chile.eu/
metadata_link	https://www.copernicuslac-chile.eu/
Conventions	CF-1.7, ACDD-1.3
_NCProperties	version=2, netcdf=4.9.3, hdf5=1.14.6

Source: Own elaboration.

Table 4. Main variables.

Variable	CF Standard Name	Description	Unit	Type
chlor_a	mass_concentration_of_chlorophyll_a_in_sea_water	mass_concentration_of_chlorophyll_a_in_sea_water	mg m ⁻³	float32
source_of_chl	(not applicable; no CF standard_name exists for bitmask)	Bitmask indicating which sensors contributed to the final CHL value (MODIS,	-	int16 / uint8

		VIIRS-SNPP, VIIRS-N20, OLCI).		
l2_flags	(not applicable; flag variable)	Quality flags from L2 data (cloud, glint, AC failure, invalid geometries). Combined via logical OR across sensors.	-	Int32
nobs_chl	number_of_observations (CF recommended)	Number of valid observations used to generate the monthly field (composite representativeness).	-	int16 / int32
lat	latitude	Latitude of the pixel center.	degrees_north	float64
lon	longitude	Longitude of the pixel center.	degrees_east	float64
time	time	Time of the monthly composite (start of the month).	seconds since 1970/01/01	float64

Source: Own elaboration.

Table 5. Flags and fill values.

l2_flags: Quality masks		
Flag	Name	Description
1	LAND	The pixel corresponds to land
2	CLOUD	Cloud contamination
4	HIGLINT	High uncorrectable sun glint
8	HISATZEN	Saturated solar/sensor angle or invalid geometry

16	HILT	Radiometric saturation in the band
32	CLDICE	Ice/high-reflectance clouds
64	NAVWARN	Potential geolocation error
128	ATMFAIL	Atmospheric correction failure
256	LOWLW	Radiance too low (noise)
512	CHLWARN	Warning in chlorophyll estimation
1024	MAXAERITER	Maximum AC iterations exceeded
2048	SEAICE	Sea ice detected
4096	HWHITE	Extremely bright water
8192	HISOLZEN	High solar angle in polar regions

Source: Own elaboration.

Table 6. Flags and fill values.

source_of_chl: multisensor traceability		
Flag	Name	Description
1	MODIS_Aqua	The pixel includes a valid contribution from the MODIS Aqua sensor.
2	VIIRS_NPP	The pixel includes a valid contribution from the Suomi-NPP VIIRS sensor
4	VIIRS_NOAA20	The pixel includes a valid contribution from the NOAA-20 VIIRS sensor.
8	OLCI	The pixel includes a valid contribution from the Sentinel-3 OLCI sensor
16	model	The final value was filled, corrected, or reconstructed by the L4 analysis module (interpolation + U-Net).

The following figure presents an example of the product visualization, illustrating the spatial representation of the variable, the distribution of its values across the study

area, and the format in which the information is displayed to the user within the service.

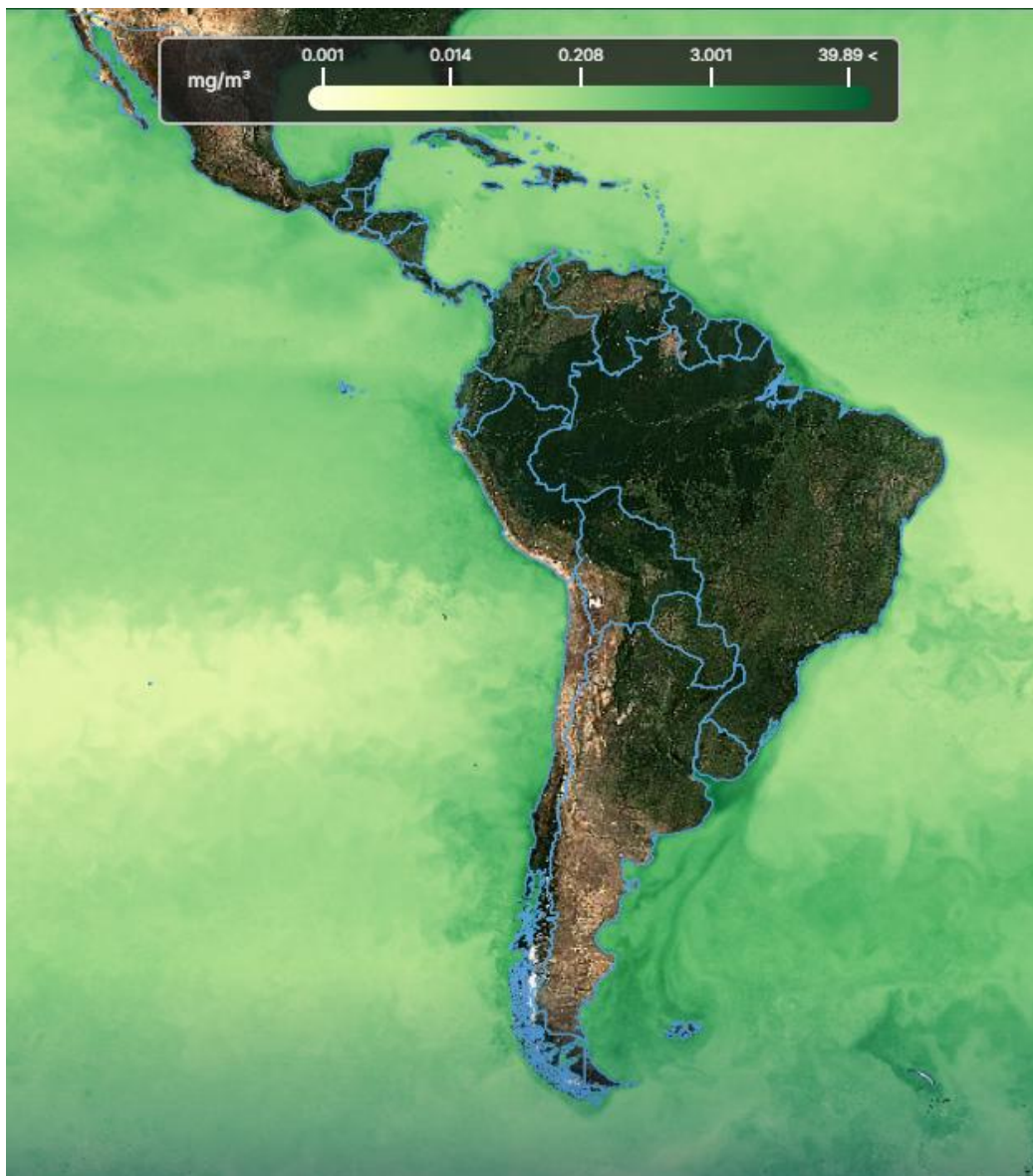


Figure 2. Display of the chlorophyll-a (CHL) product, January 2024.

Source: Own elaboration.

4. Methodological summary

4.1 Production and Processing System

The Chlorophyll production system of Copernicus LAC Chile is based on OC-CCI/GlobColour protocols. It applies Level 2 QC, reprojection to 1km (L3U), daily compositing (L3C), multisensor logarithmic fusion (L3S), and monthly compositing (L3M). Fusion is performed only for CHL; Rrs and NFLH are kept per sensor (CMEMS, 2024; Hernández et al., 2018; IOCCG, 2019; Maritorena et al., 2010; O'Reilly & Werdell, 2019).

Table 7. Satellite data sources.

Dataset	Spatial resolution	Temporal resolution	Reference / Source
OLCI – Sentinel-3A/B (L2)	~300 m (FR), resampled to 1km	Global revisit ~1–2 days; daily delivery	EUMETSAT – Copernicus Data Space: https://data.eumetsat.int
MODIS Aqua (L2)	1km	Daily revisit in polar orbit	NASA Earthdata: https://search.earthdata.nasa.gov
VIIRS – Suomi NPP / NOAA-20 (L2)	750 m – 1 km	Daily revisit (~14–16 orbits/day globally)	NASA Earthdata / NOAA CoastWatch: https://search.earthdata.nasa.gov
Chlorophyll-a (OCx / CI algorithms)	300 m – 1 km (depending on sensor)	Daily	OC3M (MODIS), OC4v6/OCI (VIIRS), OC4ME (OLCI)
Bathymetry	30" (~1 km) / 15" depending on version	Static	GEBCO: https://www.gebco.net

Land-sea mask / observation mask	0.01° (LAC grid)	Static	CopernicusLAC Chile (derived from the regional grid)
Sea Surface Temperature (SST)	0.01° (~1 km)	Monthly / daily	Coastal Monitoring Service – CopernicusLAC Chile
<i>In situ</i> data – chlorophyll and bio-optics	Point-based (stations, campaigns)	Variable depending on platform	NASA SeaBASS: https://seabass.gsfc.nasa.gov
Multi-year historical Chl-a record	4–25 km (depending on product)	Monthly	ESA OC-CCI / GlobColour

Source: Own elaboration.

4.2 Quality Filters and Indicators

Quality control is initially applied at Level 2 (L2), using the official flags provided by each satellite mission. These include CLOUD (cloud presence), LAND (land-signal contamination), HIGLINT (high brightness from specular reflection), HISATZEN (invalid solar and viewing geometries), HILT (saturation), NAVWARN (geolocation errors), and ATMFAIL (atmospheric correction failures). All observations exhibiting one or more of these critical flags are discarded prior to reprocessing. Additionally, strict physical filters are applied to remote sensing reflectance (R_{rs}), removing negative, saturated, or out-of-range bio-optical values ($0-0.15 \text{ sr}^{-1}$), and to estimated chlorophyll, discarding non-physical values ($\text{CHL} < 0$) or values incompatible with regional conditions ($\text{CHL} > 100 \text{ mg m}^{-3}$ in the oceanic LAC domain). These steps ensure that only radiometrically consistent pixels contribute to the product.

During L3U resampling, L3C compositing, and L3S multisensor fusion, quality indicators are incorporated through a cumulative scheme based on the logical OR operation across the valid quality flag variables of all sensors contributing to each cell.

This procedure preserves the traceability of data origin and quality, making it possible to identify complex atmospheric conditions, problematic geometries, or potential radiometric anomalies even after fusion. The systematic application of these masks and filters ensures that the final L4 product is built solely from robust observations, reducing error propagation and improving the bio-optical stability of the reconstructed field.

4.3 Grid Information

All products and levels are interpolated onto a regular 0.01° grid, with coordinates at the center of each cell (lat, lon). The domain extends from -123° W to -25° E and from -60° S to 33° N (Figure 3).

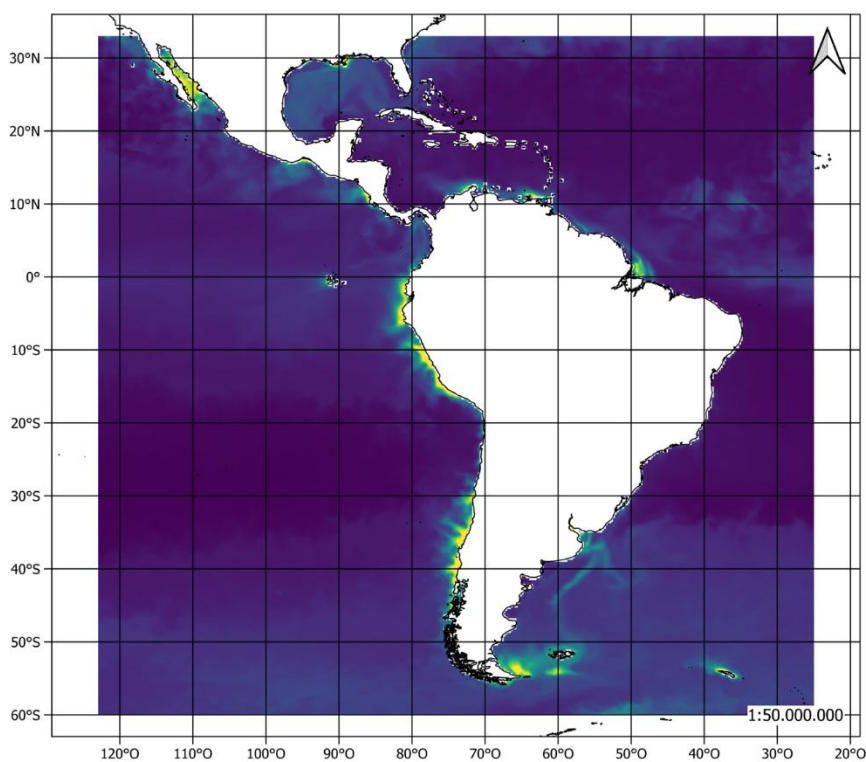


Figure 3. Spatial domain of the chlorophyll-a (CHL) product, January 2024.

Source: Own elaboration.

4.4 Processing Chain

The production system for the Chlorophyll-a (CHL) product follows a hierarchical structure consistent with the operational ocean-color systems of CMEMS, GlobColour, and ESA OC-CCI. The processing chain relies on the Python framework for ocean-color applications. The chain transforms Level 2 (L2) satellite observations into a continuous monthly Level 4 (L4) field, ensuring inter-sensor consistency, radiometric stability, and bio-optical coherence (Figure 4).

The complete workflow consists of the following stages:

1. **Reprojection and quality control (QC):** Level 2 (L2) files from MODIS Aqua, VIIRS SNPP, VIIRS NOAA-20, and Sentinel-3 OLCI undergo uniform quality control based on official flags (CLOUD, LAND, HIGLINT, HISATZEN, HILT, CLDICE, NAVWARN, ATMFAIL) and on bio-optical thresholds that discard non-physical values in remote sensing reflectance (R_{rs}) and chlorophyll (CHL). Valid observations are then projected onto a regular 0.01° (~1 km) grid, generating a single-sensor uncollated (L3U) product for each sensor. For each cell, the mean of valid pixels and the total number of contributing observations (N) are calculated. This step homogenizes the different geometries, spectral resolutions, and sampling densities of each mission.
2. **Daily compositing per sensor:** All L3U products generated on a given day are combined to build a daily mosaic per sensor (L3C). The compositing uses the logarithmic domain ($\log_{10}(\text{CHL})$), which reduces the impact of multiplicative errors between sensors and stabilizes the bio-optical signal, especially in oligotrophic regions. The result is a radiometrically consistent daily field for each mission, accompanied by traceability information (daily N_{obs}) and quality masks accumulated through logical OR.
3. **Multisensor fusion:** The fusion stage follows the principles described in Garnesson et al. (2019) for GlobColour and in Maritorena et al. (2010) for GSM spectral fusion. Fusion is performed exclusively on $\log_{10}(\text{CHL})$, since the OC3M

(MODIS), OC4v6/OCI (VIIRS), and OC4ME (OLCI) algorithms are mutually consistent when compared in the logarithmic domain. For each cell and day, the values contributed by the available sensors are averaged, generating a daily L3S product. In parallel, a sensor_source traceability indicator is built, based on a bitmask identifying which sensors contributed (e.g., MODIS=1, SNPP=2, N20=4, OLCI=8). Flags are combined via logical OR to preserve radiometric and atmospheric warnings throughout the entire chain.

4. **Monthly compositing:** The daily multisensor L3S products are integrated monthly using the median of $\log_{10}(\text{CHL})$, a technique that reduces the influence of outliers and residual anomalies associated with persistent clouds, instrumental errors, or atmospheric contamination. The result is a monthly L3M field, accompanied by aggregated traceability information and monthly quality masks generated via logical OR. This step produces a robust and stable field for ecological and climatic analyses.
5. **Continuous monthly analysis and reconstruction (gap-free field):** The monthly L3M mosaics serve as input to an analysis stage that produces a monthly, gap-free L4 field. This process integrates deterministic methods with advanced deep-learning techniques, following a hybrid approach:
 - Optimal spatio-temporal interpolation: applied to the anomalies and main patterns of chlorophyll, taking into account the spatial and temporal coherence of the bio-optical field. This step reconstructs partially observed regions, preserving coastal gradients and mesoscale ocean structures.
 - Non-linear reconstruction using a U-Net Hann 2D neural network: the model is trained on multi-year historical series, including auxiliary variables such as sea surface temperature (SST), bathymetry, and observation mask. The U-Net architecture with Hann windows reduces edge artifacts and preserves spatial continuity. This phase refines the monthly chlorophyll distribution, fills residual gaps, and improves stability in coastal areas and regions of high bio-optical variability.

The final result is a monthly L4 product, spatially continuous and bio-optically coherent, suitable for climate applications, ocean model validation, productivity analysis, environmental management, and operational monitoring in coastal and oceanic areas of Latin America and the Caribbean.

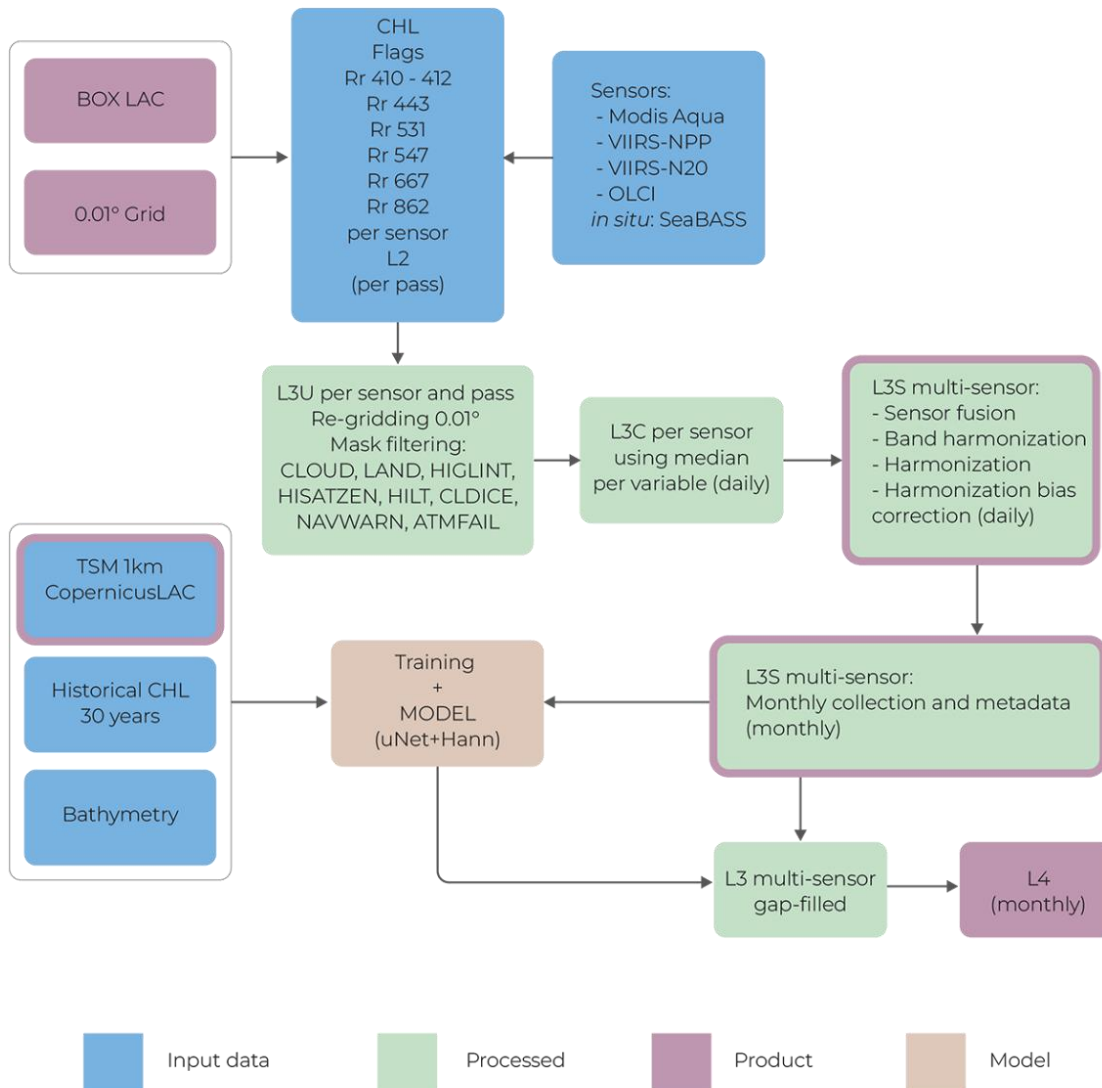


Figure 4. Processing chain of the chlorophyll-a (CHL) product.

Source: Own elaboration.

5. Limitations

The main known limitations of CopernicusLAC Chile's L4 Chlorophyll Concentration (CHL) product are inherent to the technical characteristics of the sensors used, the defined geographic domain, and the spatial reconstruction and gap-filling processes applied to ensure field continuity (gap-free). Awareness of them is essential for correctly interpreting and using the product, especially in applications requiring precision in high-latitude regions, inland-water areas, or periods with persistent cloud cover. The main identified limitations are as follows:

- **Coverage:** The polar area is not included due to satellite limitations and the sensors' orbital geometry.
- **Atmospheric conditions:** Clouds and other atmospheric conditions can affect data quality. However, quality flags make it possible to identify and filter these values.
- **Gap-filling errors:** Although filling based on spatial and temporal interpolation is applied, small inaccuracies may exist in areas without data.
- **Representativeness:** The product is not representative of inland waters or glacial areas.
- **Sensor errors:** VIIRS SNPP exhibits radiometric drift, which is mitigated during fusion.

6. Quality Control and Evaluation

This chapter describes the methodological validation framework and the quality control procedures applied to the CopernicusLAC Chile Chlorophyll-a (CHL) product. It is organized into three components: the general validation framework, including performance metrics and internal quality control, and the coverage and spatial consistency assessment. The set of indicators presented allows the user to assess the product's reliability for their specific applications in the Latin America and Caribbean domain.

6.1 General Validation Framework

Validation of the CopernicusLAC Chile Chlorophyll-a (CHL) product was carried out following the methodological framework of the Ocean Colour Thematic Assembly Center (OC-TAC) described in CMEMS-OC-QUID-009-107to134 (Vittorio, et al., 2024), the recommendations of the International Ocean Colour Coordinating Group (IOCCG) in its 2022 Protocol Series, and taking into account the actual availability of *in situ* data in the LAC domain during the evaluation period. Comparison with *in situ* optical radiometry followed the validation protocols of Zibordi et al. (2019).

Validation was carried out using *in situ* data and external satellite products to ensure product quality. Combining both sources is recommended as a valid complementary tool when *in situ* observations are scarce (CMEMS, 2024). Complementary approaches:

1. **Validation with *in situ* observations (SeaBASS):** Available mainly in the Caribbean for the analyzed time interval. *In situ* CHL measurements (HPLC and fluorometry) were used as an absolute reference to assess:
 - Logarithmic bias,
 - Robust dispersion (RMAD),
 - RMSLE,

- Relative error (MAPE),
- Pearson correlation on the log10 scale.

This procedure follows standard practice given the lognormal distribution of chlorophyll and its regional sensitivity (oligotrophic, mesotrophic, eutrophic).

To ensure methodological compatibility, only *in situ* measurements coincident within the surface layer (≤ 5 m) and subject to individual quality control are used. Comparisons are performed by bilinearly interpolating the product's monthly field (L3M/L4) to the location and date of each SeaBASS measurement.

2. **Validation based on an external operational product (model-model):** For regions where no coincident *in situ* data existed, a consistency-based validation procedure was adopted, using the following product as an external reference:

Global Ocean Colour Plankton MY L4 monthly observations ID:
OCEANCOLOUR_GLO_BGC_L4_MY_009_108

This product is one of the most stable and robust global datasets available, combining:

- Monthly L4 CHL,
- Monthly standard deviation (CHL_error),
- Number of observations (CHL_count), derived from the OC-CCI multi-year fusion.

Using this dataset makes it possible to assess the spatial coherence of the CopernicusLAC Chile product, analyze coastal and oceanic gradients, verify regional stability, and identify systematic anomalies or artifacts in the L4 reconstruction.

The process also incorporates internal quality indicators derived from processing (L2 flags, multisensor bitmask, number of valid observations) and metadata documenting the algorithm version, multisensor fusion, and dataset traceability.

The quality system integrates three components:

1. **Radiometric control:** Direct comparison against *in situ* SeaBASS measurements (HPLC/fluorometry), with analysis of bias, dispersion, and logarithmic relative error. This control assesses the spectral consistency of OLCI, MODIS, and VIIRS after fusion.
2. **Spatial control:** Analysis of bio-optical coherence in key areas: coast and continental shelf, oligotrophic oceanic zones of the South Atlantic and Pacific, and estuarine regions (Plata, Orinoco, Amazon).
3. **Temporal control:** Monitoring of the product's inter-monthly stability, detection of discontinuities, analysis of artificial trends, and consistency with climatological series.

6.2 Performance Metrics

Performance metrics quantify the agreement between the CopernicusLAC Chile Chlorophyll-a (CHL) product and reference observations, both *in situ* (SeaBASS) and from external satellite products (OCEANCOLOUR_GLO_BGC_L4_MY_009_108). Since chlorophyll concentration exhibits a lognormal distribution characteristic of bio-optical variables, the metrics are calculated on a logarithmic ($\log_{10}$) scale to ensure a statistically appropriate evaluation comparable to OC-TAC/IOCCG international standards. Table 8 presents the results for logarithmic bias (BIAS), standard deviation (STD), root mean square logarithmic error (RMSLE), mean absolute percentage error (MAPE), and Pearson correlation coefficient (r) on the $\log_{10}$ scale, obtained during the evaluation period over the LAC domain. These indicators make it possible to identify systematic trends in the estimator, quantify error dispersion, and verify correlation with independent reference measurements.

Table 8. Performance metrics.

Metric	Description	Formula	Unit
Bias (BIAS)	Mean difference between satellite and <i>in situ</i> CHL in log10.	$BIAS = \frac{1}{N} \sum_{i=1}^N (\log_{10}(CHL_{sat,i}) - \log_{10}(CHL_{insitu,i}))$	mg m ⁻³
Standard deviation (STD)	Dispersion of the differences relative to the mean bias.	$STD = \sqrt{\frac{1}{N} \sum_{i=1}^N (D_i - BIAS)^2}$ Where $D_i = \log_{10}(CHL_{sat,i}) - \log_{10}(CHL_{insitu,i})$	mg m ⁻³
RMSLE (Root Mean Square Log Error)	Mean squared error in logarithmic space.	$RMSLE = \sqrt{\frac{1}{N} \sum_{i=1}^N (D_i)^2}$ Where $D_i = \log_{10}(CHL_{sat,i}) - \log_{10}(CHL_{insitu,i})$	mg m ⁻³
MAPE (Mean Absolute Percentage Error)	Magnitude of the relative error.	$MAPE = \frac{100}{N} \sum_{i=1}^N \left \frac{CHL_{sat,i} - CHL_{insitu,i}}{CHL_{insitu,i}} \right $	%
R (Pearson)	Linear correlation on a logarithmic scale.	$r = \frac{S_i(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{S_i(x_i - \bar{x})^2 S_i(y_i - \bar{y})^2}}$ Where $x_i = \log_{10}(CHL_{sat,i})$, $y_i = \log_{10}(CHL_{insitu,i})$	-

Source: Own elaboration.

6.2.1 Internal Quality Control

Each NetCDF file includes metadata documenting the processing workflow (history), source traceability (source, collation_input), dataset creation and modification dates (date_created, date_modified), and the spatial and temporal characterization of the domain (geospatial_* and time_coverage_*). These elements make it possible to verify the product's consistency and ensure the reproducibility of the multisensor procedure used.

During processing, internal controls are applied to ensure the consistency of the monthly product. These controls include:

- **Basic NetCDF file integrity check:** verifying the consistency of its dimensions, variables, and general metadata.
- **Spatial consistency control:** assessed through inspection of bio-optical gradients, detection of anomalous values, and application of the quality masks inherited from L2 data (L2 flags).
- **Physical range control:** applying plausible chlorophyll limits for oceanic and coastal waters ($0.001\text{--}100\text{ mg m}^{-3}$) and discarding non-physical values associated with atmospheric correction failures or invalid observation conditions.
- **Temporal audit:** through assessment of the product's inter-monthly stability and comparison with climatologies and multi-year averages derived from OC-CCI and GlobColour, in order to detect non-physical discontinuities in the series.
- **Post-gap-filling control (L4 only):** comparing the reconstructed field with the original L3M mosaic and verifying the preservation of bio-optical gradients in coastal areas and upwelling regions, as well as the absence of artifacts associated with the reconstruction process.

6.3 Coverage and Consistency Assessment

The monthly product shows improved spatial coverage in regions affected by persistent cloudiness or unfavorable geometries, thanks to the multisensor logarithmic fusion scheme and the reconstruction mechanisms applied in L4.

At the regional scale, the product shows high spatial coherence with known bio-optical structures of the LAC domain, such as subtropical gyres, the upwelling systems of the southeastern Pacific, the Amazon and Orinoco river plumes, as well as highly productive zones in the western Caribbean and the southwestern Atlantic. The resulting spatial distribution is consistent with historical OC-CCI and GlobColour climatologies and with the signal observed in CMEMS L4 products.

In highly dynamic coastal areas, such as central Chile, the Colombian Caribbean, and the southeastern coast of Brazil, the product adequately reproduces gradients and spatial variability patterns, maintaining consistency with available *in situ* observations and with other reference satellite products. These comparisons confirm that multisensor fusion and L4 analysis adequately preserve the spatial structure of the bio-optical field, without significant introduction of artifacts or excessive smoothing in high-variability areas.

7. References

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