Product Specification Document (PSD)

ReferenceCCI-LAKES2-0003-PSD

Issue 1.1 –17/01/2023

11 rue Hermès, Parc Technologique du Canal — 31520 Ramonville Saint-Agne, France
Tel +33 (0)5 61 39 47 00 Fax +33(0)5 61 75 10 14
www.cls.fr

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Checked by	Stefan Simis – PML J-F Cretaux - LEGOS	
Approved by	Alice Andral - CLS	
Authorized by	Clément Albergel - ESA	

DISTRIBUTION

Company	Names	Email
ESA	Clément Albergel	clement.albergel@esa.int
BC	Carsten Brockman	carsten.brockmann@brockmann-consult.de
BC	Kerstin Stelzer	kerstin.stelzer@brockmann-consult.de
CLS	Alice Andral	aandral@groupcls.com
CLS	Anna Mangilli	amangilli@groupcls.com
CLS	Beatriz Calmettes	bcalmettes@groupcls.com
CLS	Christophe Fatras	cfatras@groupcls.com
CLS	Pierre Thibault	pthibaut@groupcls.com
CLS	Yann Bernard	ybernard@groupcls.com
CNR	Claudia Giardino	giardino.c@irea.cnr.it
CNR	Giulio Tellina	tellina.g@irea.cnr.it

CNR	Mariano Bresciani	bresciani.m@irea.cnr.it
CNR	Monica Pinardi	pinardi.m@irea.cnr.it
CNR	Marina Amadori	amadori.m@irea.cnr.it
H2O Geo	Claude Duguay	claude.duguay@h2ogeomatics.com
H2O Geo	Yuhao Wu	mark.wu@h2ogeomatics.com
H2O Geo	Jaya Sree Mugunthan	jayasree.mugunthan@h2ogeomatics.com
LEGOS	Jean-François Cretaux	Jean-Francois.Cretaux@legos.obs-mip.fr
PML	Stefan Simis	stsi@pml.ac.uk
PML	Xiaohan Liu	liux@pml.ac.uk
Sertit	Hervé Yésou	Herve.yesou@unistra.fr
Sertit	Jérôme Maxant	maxant@unistra.fr
Sertit	Rémi Braun	remi.braun@unistra.fr
UoR	Chris Merchant	c.j.merchant@reading.ac.uk
UoB	Iestyn Woolway	Iestyn.woolway@bangor.ac.uk
UoR	Laura Carrea	l.carrea@reading.ac.uk
UoS	Dalin Jiang	dalin.jiang@stir.ac.uk
UoS	Evangelos Spyrakos	evangelos.spyrakos@stir.ac.uk
UoS	Ian Jones	ian.jones@stir.ac.uk

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REFERENCE DOCUMENTS

PSD	Product Specification Document of the Lakes_CCI project Phase 1 (CCI-LAKES-016-PSD-V2.0)
URD	User Requirements Document of the Lakes_CCI project Phase 2 (CC-LAKES2-005-URD-V1.0)
ATBD	Algorithm Theoretical Basis Document
E3UB	End to End Uncertainty Budget

1 Introduction

The purpose of this product specification document (PSD) for the Lakes Climate Change Initiative project (Lakes_cci) is to translate a set of product requirements into a specification of the data sets being generated. This document has been updated with respect to the last version of the PSD (V2.2).

A set of product requirements is described in the "User Required Document" (URD). It, contains a synthesis of the information obtained through a review of existing reference documents and scientific literature, and collected from meetings of the Climate Modelling User group (CMUG, including related documents), Climate Research Group (CRG) and the wider lake research community, the latter via three surveys. Table 1 contains those target requirements. Nevertheless, this does not mean that they are achieved.

Table 1. Synthesised observation of the target requirements for the Lake ECV thematic variables. Based on G: GCOS, Q: Questionnaire, P: Project team experience and L: Literature review.

Product	Lake Water Level	Lake Extent (or Lake Area)	Lake Surface Water Temperature	Lake Ice Cover (LIC)	Lake Ice Thickness (LIT)	Lake Water Leaving Reflectance (or Lake Colour)
Measurement uncertainty	1.5 cm for large lakes (G) 5 cm for the reminder (G)	5% (relative) (G) 2.5% (for 70 largest lakes) (G)	0.15°K (P)	10% (G,P)	5 cm (P)	10-30% for peak waveband vs low signal bands (P/L), 0.1 mg m^{-3} chlorophyll-a (L) and 1 g m^{-3} suspended matter.
Stability	0.5 cm/decade (G)	2.5% /decade (G)	0.07°K per decade (P)	1% /decade (G)	1 cm/decade (P)	1% /decade (G,P,L)
Spatial resolution	N/A : per lake (Q)	N/A : per lake (Q)	100 m (P)	100 m (P)	100 m (G)	100 m (P)
Temporal resolution	daily ground-based or satellite observations (G)	daily changes (G)	Daily (P)	daily observations (G,P)	Weekly observations (P)	Daily observations (Q)
Length of record	>10 years (L)	>10 years (L)	>10 years (L)	>10 years (L)	>10 years (L, P)	>10 years (L/P)
Maximum delay before availability of	1 year (P)	1 year (P)	1 year (P)	1 year (P)	1 year (P)	1 year (P)

data (for climate users)						

Table 2 synthesises requirements on products that apply to all the variables. A primary requirement (satisfying most users) and a secondary requirement (an alternative that satisfies other users) are provided where relevant.

Table 2. Synthesised product requirements for the Lakes ECV

Aspect of products	Primary requirement	Secondary requirement
Slicing of data (Q)	Timeseries per lake	
Spatial aggregation (Q)	Per-lake value (LWE, LWL) Spatially resolved (LSWT, LIC, LWLR) Along-track values (LIT)	Per-lake value (LSWT, LIC, LIT, LWLR)
Data format (Q)	NetCDF	GEOTIFF
Access (Q)	FTP	Web mapping service
Availability of uncertainty (Q)	Required	
Projection (Q)	Regular latitude-longitude ("Level 3")	

Lakes_cci dataset is generated in a global grid and scripts are available (https://github.com/cci-lakes/lakes_cci_tools) to download files for a given lake or on a defined zone and period of time.

Lakes_cci has produced three releases of the Lakes climate data record during Phase 1 of the project:

- V1: The lakes products were generated using existing algorithms. This dataset corresponds to the state of the art at the beginning of the project. This release provided the first harmonized set of the five products that comprise the lakes ECV (Level, Extent, Ice Cover, Temperature and Reflectance). It was released in May 2020 (Climate Research Data Package CRDP delivery V1)
- V1.1: Improvements in this intermediate version included new algorithms to estimate Lake Ice Cover and increased coverage for Lake Water Level and Lake Water Extent.
- V2.0.1: The lake products were generated using algorithm and wider product improvements achieved in the first phase of the project. This version, with improved algorithms and geographical coverage, has been released in March 2022.
- V2.0.2: As previous, but with correction applied to a small number of corrupted files.

The anticipated next versions of the data set for Phase 2 of the project are:

- V2.1.0: with various consistency improvement, extended spatiotemporal coverage (including 2021) for the established set of 2000+ lakes, and first results on Lake Ice Thickness
- V3.0.0: including various anticipated algorithm updates, further improved coverage across all thematic variables.

The current version of this PSD accompanies v2.1.0 of the Lakes ECV.

2 Description

The Lakes ECV dataset is composed of the 6 following thematic variables:

- Lake Water Level (LWL)
- Lake Water Extent (LWE)
- Lase Surface Water Temperature (LSWT)
- Lake Ice Cover (LIC)
- Lake Ice Thickness (LIT)
- Lake Water Leaving Reflectance (LWLR)

These thematic variables are offered in a consistent merged format to provide users access to any combination of variables available within each daily aggregation interval.

2.1 Sources of satellite data

Data generated in the Lakes_cci project are derived from a wide range of satellite missions and instruments, as shown in Table 3.

Note that lake water extent product is derived from the lake water level product. Therefore, sensors listed in Table3 are the one used to define an a-priori relationship between water level and surface, i.e. the hypsometric curve.

Table 3. Satellites and instruments used to generate the Lakes ECV

Product	Satellite	Instrument	Temporal Coverage
LWL	TOPEX/Poseidon (T/P)	Poseidon-1	1992-2006
	Jason-1	Poseidon-2	2001-2013
	Jason-2	Poseidon-3	2008-2019
	Jason-3	Poseidon-3B	2016-2022
	Sentinel6A	Poseidon-4	2022-
	ENVISAT	Radar Altimeter (RA-2)	2002-2012
	SARAL	AltiKa	2013-2022
	Sentinel-3A	SAR Altimeter	2016-
	Sentinel-3B	SAR Altimeter	2018-
LWE	Landsat-4	MSS (Multispectral Scanner) TM (Thematic Mapper)	1982-1993
	Landsat-5	MSS (Multispectral Scanner) TM (Thematic Mapper)	1984-2013
	Landsat-7	ETM+	1999-2022
	Landsat-8	OLI	2013-
	Landsat 9	OLI 2	2021-
	Sentinel-2 A&B	MSI (Multi-Spectral Instrument)	2015-
LIC	Terra/Aqua	MODIS	1999/2002-
LIT	ENVISAT	Radar Altimeter (RA-2)	2002-2012
	Jason-1	Poseidon-2	2001-2013
	Jason-2	Poseidon-3	2008-2019

	Jason-3	Poseidon-3B	2016-2022
	Sentinel6A	Poseidon-4	2022-
LSWT	ERS-2	ATSR-2	1991-2003
	Envisat	AATSR	2002-2012
	Metop-A/B	AVHRR	A:2007-2019 B:2012-2019
	Sentinel3A/B	SLSTR	A:2016-2020 B:2020
	Terra	MODIS	2000-2020
LWLR	Envisat	MERIS	2002-2012
	Sentinel-3 A/B	OLCI A/B	016/2018-
	Aqua	MODIS	2002-

A consequence of this diversity of products and instruments is that temporal and spatial resolutions as well as data availability are not identical between the thematic variables (Table 4). The LWL and LWE products, that are produced in grid format, are duplicated in the grid for the area given under the nominal spatial delineation of that lake, derived from its maximum water extent.

Table 4. Spatial and temporal resolution range of the input and intermediary data.

Product	Spatial Resolution*	Temporal Resolution	Temporal Coverage
LWL	N/A	1 to 10 days	1992 – 2022
LWE	N/A	1 to 10 days	1992 – 2022
LIC	250 m	Daily	2000 - 2022
LIT	10 Km	1 to 10 days	2000-2022
LSWT	1 km	Up to daily	1995 - 2022
LWLR	300m – 1100 m	1-3 days	2002 - 2022

*Spatial resolution in meter refers to the nominal resolution at the equator, assuming the longitudinal and latitudinal pixel dimensions are similar), as is conventional in some domains and projections for land products. Resolution in degrees is the native sampling resolution.

2.2 Harmonization

A central issue in the Lakes_cci project is the harmonization of the thematic variables. Each thematic variable relies on specific sensing concepts and therefore sensors and missions, which are not necessarily synchronous nor do these provide consistent spatiotemporal coverage. First-order harmonization of the thematic variables ensures that each NetCDF file contains all information available for each product, identifying missing values as such. The harmonized products have the following characteristics:

- Daily aggregation interval pinned to 12:00:00 UTC. Thematic variables that do not exist for a given date will be set to the netCDF fill value.
- Grid format with spatial resolution of 1/120 degrees (near 1 km at the equator)
- Variables not produced in grid format (LWL and LWE) are duplicated as described in the previous section.
- Datum: WGS84
- Extent: -180 to 180 degrees longitude, -90 to 90 degrees latitude, where positive signs point north and east. The pixel coordinate will be the centre of the pixel.
- The number of grid rows will be 21600, the number of grid columns will be 43200.

Further detail on product dimensions is provided in the sections below.

Uncertainty estimates and quality flags are provided for each product except for LIC (this addition is foreseen in version 3.0.0 of the CRDP). The meaning of the quality flags is specified in the "flag_meaning" attribute in the product tables reported in Section 6. Quality flags and meanings vary between the variables they are associated with and are fully described in the Algorithm Theoretical Basis Document (ATBD) associated with the CRDP corresponding to this PSD. The ATBD corresponding to CRDP V2.0.2 version of the ATBD is available at the project website (ATBD V3.1) and it will be updated to include improvements in CRDP V2.1 Users are advised to adhere to the quality indicators prior to using the data. Procedures used to derive uncertainty estimates are provided in the End-to-End Uncertainty Budget document (E3UB).

3 File naming convention

As recommended in the CCI data standards document, the name of the files in the Lakes_cci are formed as:

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>-<Indicative Date>-fv<version>.nc

Where:

- <CCI Project>: LAKES
- <Processing Level>: L3S. The Lakes_cci product is Super-collated: observations combined from multiple instruments and observation times into a common spatiotemporal grid.
- <Data type>: LK_PRODUCTS
- <Product String>: MERGED. This means data derive from more than one platform and/or sensor
- <Indicative Date>: in YYYYMMDD format
- <Version>: V2.1.0

Thus, an example file name in the last data release is:

ESACCI-LAKES-L3S-LK_PRODUCTS-MERGED-20080808-fv2.1.nc

4 Global Attributes

To ensure consistency where the same global attributes apply to several ECVs, and to avoid ambiguity, relevant terms have been gathered in an ontology, defining the CCI entities and the relationship between those entities, including:

- project
- platform
- sensor

- institution

Table 5 contains the global attributes that are included in the output files following the CCI standards.

Table 5 Global data attributes provided with each file

Attribute	Value
title	ESA Lakes_cci product
institution	LWL: Laboratoire d'Etudes en Geodesie et Oceanographie Spatiales, Collecte Localisation Satellites
	LWE: Laboratoire d'Etudes en Geodesie et Oceanographie Spatiales, Collecte Localisation Satellites and ICUBE SERTIT Université de Strasbourg
	LSWT: University of Reading
	LIC: H2O Geomatics
	LIT: H2O Geomatics, Collecte Localisation Satellites
	LWLR: Plymouth Marine Laboratory
source	LWL: European Space Agency (ESA), National Aeronautics and Space Administration (NASA), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), National Oceanic and Atmospheric Administration (NOAA).
	LWE: European Space Agency (ESA), National Aeronautics and Space Administration (NASA)
	LSWT: European Space Agency (ESA), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), European Centre for Medium-Range Weather Forecasts (ECMWF), National Aeronautics and Space Administration (NASA)
	LIC: National Aeronautics and Space Administration (NASA)
	LIT: European Space Agency (ESA), National Aeronautics and Space Administration (NASA), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), National Oceanic and Atmospheric Administration (NOAA)
	LWLR: European Space Agency (ESA), National Aeronautics and Space Administration (NASA)
history processing history of the dataset	LWL: Generated by Laboratoire d'Etudes en Geodesie et Oceanographie Spatiales, Collecte Localisation Satellites
	LWE: Generated by Laboratoire d'Etudes en Geodesie et Oceanographie Spatiales, Collecte Localisation Satellites and ICUBE SERTIT Université de Strasbourg
	LSWT: University of Reading LSWT processor version v2.6.1-146-gfe50b81_RES120
	LIC: Lake ice cover processor by H2O Geomatics
	LIT Lake ice thickness processor by CLS
	LWLR: Calimnos processor by Plymouth Marine Laboratory, including calls to Idepix (SNAP) and POLYMER (Hygeos) algorithms
references	https://climate.esa.int/en/projects/lakes/

Attribute	Value
tracking_id	Universal Unique IDentifier (UUID)
conventions	CF-1.10
product_version	v2.1.0
Summary	This dataset contains L3S daily ECV Lakes products: Water Level (LWL), Water Extent (LWE), Ice cover (LIC), Ice Thickness (LIT), Surface Water Temperature (LSWT) and Water-Leaving Reflectance (LWLR). L3S data are observations combined from multiple instruments into a common spatiotemporal grid
keywords	Satellite, Lake, Climate Change, Lake Water Level, Lake Water Extent, Lake Surface Water Temperature, Lake Ice Cover, Lake Water Leaving Reflectance; INSPIRE: Orthoimagery; GCMD: WATER-LEAVING RADIANCE, EARTH_SCIENCE-TERRESTRIAL_HYDROSPHERE,WATER_QUALITY_WATER_CHEMISTRY-CHLOROPHYLL, SUSPENDED_SOLIDS, TURBIDITY; GEMET: water, algal bloom, aquatic environment, freshwater, freshwater quality, ice, inland water, lagoon, lake, dam, phytoplankton, turbidity, water monitoring, water quality, water reservoir, climate, seasonal variation, environmental data, environmental monitoring, monitoring, remote sensing" ;
keywords_vocabulary	Infrastructure for Spatial Information (INSPIRE), NASA Global Change Master Directory (GCMD), General Multilingual Environmental Thesaurus (GEMET)
id	*Populated when the data package is generated (filename)*
naming_authority	lakes.esa-cci
cdm_data_type	Grid
comment	These data were produced for the ESA Lakes_cci project
date_created	YYYY-MM-DD *Populated when the data package is generated*
creator_name	ESA Lakes_cci
creator_url	https://climate.esa.int/en/projects/lakes/
creator_email	lakes_cci@groupcls.fr
project	Climate Change Initiative - European Space Agency
geospatial_lat_min	-90.0
geospatial_lat_max	90.0
geospatial_lon_min	-180.0
geospatial_lon_max	180.0
geospatial_vertical_min	NA
geospatial_vertical_max	NA
time_coverage_start	UTC time coverage start in ISO-8601 format (YYYYMMDDTHHMMSSZ)
time_coverage_end	UTC time coverage end in ISO-8601 format (YYYYMMDDTHHMMSSZ)
time_coverage_duration	time coverage duration in ISO8601 format: P1D
time_coverage_resolution	time coverage resolution in ISO8601 format: P1D
standard_name_vocabulary	CF Standard Name Table v78

Attribute	Value
license	ESA CCI Data Policy: free and open access
platform	LWL: TOPEX/Poseidon, Jason-1, Jason-2, Jason-3, Sentinel-6A, Envisat, SARAL, GFO, Sentinel-3A, Sentinel-3B, ERS-1, ERS-2
	LWE: Landsat-<4,5,7,8, 9>, , Sentinel-2, Sentinel-3A, Sentinel-3B + Lake Water Level from altimeters (see line above)
	LSWT: ERS-2, Envisat, Metop-A, Metop-B, Sentinel3A, Sentinel3B, Terra
	LIC: Aqua, Terra
	LIT: Jason-1, Jason-2, Jason-3, Sentinel-6A, Envisat
	LWLR: Aqua, Envisat, Sentinel-3A, Sentinel-3B
sensor	LWL: Poseidon-1, Poseidon-2, Poseidon-3, Poseidon-3B, RA, RA-2, AltiKa, SRAL;
	LWE:, MSI, SRAL, MSS, TM, ETM+, OLI, AMI
	LSWT: ATSR-2, AATSR, AVHRR-3, SLSTR, MODIS
	LIC: MODIS
	LWLR: MERIS, OLCI A/B, MODIS
spatial_resolution	1 km at Equator
key_variables	lake_water_level, lake_ water_extent, lake_ice_cover, lake_surface_water_temperature, chla_mean, turbidity_mean, Rw[xxx] where * where xxx is one of 400, 412, 443, 469, 490, 510, 531, 547, 560, 620, 645, 665, 674, 681, 709, 754, 779, 859, 885, 900, 1020nm
geospatial_lat_units	degrees_north
geospatial_lon_units	degrees_east
geospatial_lat_resolution	0.008333333
geospatial_lon_resolution	0.008333333
doi	*Dataset Digital Object Identifier* *Populated when the data package is generated*

5 Dimensions

Following the CCI data standards, the gridded products have the dimensions time, latitude and longitude (Table 6)

Table 6. Lakes_cci dimensions

Dimension Name	Attribute	Type	Value
time	units	c	seconds since 1970-01-01 00:00:00
time	standard_name	c	time
time	long_name	c	time
time	calendar	c	gregorian
lat	units	c	degrees_north
lat	standard_name	c	latitude
lat	long_name	c	latitude
lat	valid_min	f	-90
lat	valid_max	f	90
lat	axis	c	Y
lat	reference_datum	c	WGS84 datum
lat	bounds	c	lat_bounds
lon	units	c	degrees_east
lon	standard_name	c	longitude
lon	long_name	c	longitude
lon	valid_min	f	-180
lon	valid_max	f	180
lon	axis	c	X
lon	reference_datum	c	WGS84 datum
lon	bounds	c	lon_bounds

6. Products

The attributes of the variables in the NetCDF files follow the CCI data standards guidelines and consequently, the CF recommendations.

6.1 Lake Water Level (LWL) variables

Table 7. Variables included in the thematic ECV Lake Water Level

Variable Name	Attribute	Type	Value
lake_water_level	long_name	c	Lake water level above geoid
lake_water_level	units	c	m
lake_water_level	valid_min	f	-50
lake_water_level	valid_max	f	5000
lake_water_level	_FillValue	f	9.96921e+36
lake_water_level	anciliary_variables	c	Water_surface_height_uncertainty
lake_water_level	grid_mapping	c	crs
lwl_uncertainty	long_name	c	water surface height uncertainty
lwl_uncertainty	units	c	cm
lwl_uncertainty	valid_min	s	0
lwl_uncertainty	valid_max	s	5000
lwl_uncertainty	scale_factor	f	0.01
lwl_uncertainty	_FillValue	s	-32767

Variable Name	Attribute	Type	Value
lwl_uncertainty	grid_mapping	c	crs
lwl_quality_flag	long_name	c	quality of the lake water level estimated
lwl_quality_flag	valid_min	b	0
lwl_quality_flag	valid_max	b	2
lwl_quality_flag	flag_meanings	c	best_quality medium_quality lower_quality
lwl_quality_flag	flag_values	b	0b, 1b, 2b
lwl_quality_flag	_FillValue	b	-127
lwl_quality_flag	comment	c	These are quality indicators, and they are important to properly use the data.
lwl_quality_flag	grid_mapping	cs	crs

6.2 Lake Water Extent (LWE) variables

Table 8. Variables included in the thematic ECV Lake Water Extent

Variable Name	Attribute	Type	Value
lake_water_extent	long_name	c	Lake Water Extent
lake_water_extent	units	c	km2
lake_water_extent	valid_min	f	0
lake_water_extent	valid_max	f	500000
lake_water_extent	_FillValue	f	9.96921e+36
lake_water_extent	anciliary_variables	c	lake_surface_water_extent_uncertainty
lake_water_extent	grid_mapping	c	crs
lwe_uncertainty	long_name	c	Water extent uncertainty
lwe_uncertainty	units	c	percent
lwe_uncertainty	valid_min	s	0
lwe_uncertainty	valid_max	s	5000
lwe_uncertainty	scale_factor	f	0.01
lwe_uncertainty	_FillValue	s	-32767
lwe_uncertainty	grid_mapping	c	crs
lwe_quality_flag	valid_min	b	0
lwe_quality_flag	valid_max	b	2
lwe_quality_flag	flag_meanings	c	best_quality medium_quality lower_quality
lwe_quality_flag	flag_values	b	0b, 1b, 2b

Variable Name	Attribute	Type	Value
lwe_quality_flag	_FillValue	b	-127
lwe_quality_flag	comment	c	These are quality indicators, and they are important to properly use the data
lwe_quality_flag	grid_mapping	c	crs

6.3 Lake Surface Water Temperature (LSWT) variables

Table 9. Variables included in the thematic ECV Lake Surface Water Temperature

Variable Name	Attribute	Type	Value
lake_surface_water_temperature	long_name	c	lake surface skin temperature
lake_surface_water_temperature	units	c	Kelvin
lake_surface_water_temperature	valid_min	s	-200
lake_surface_water_temperature	valid_max	s	5000
lake_surface_water_temperature	scale_factor	f	0.01
lake_surface_water_temperature	add_offset	f	273.15
lake_surface_water_temperature	_FillValue	s	-32767
lake_surface_water_temperature	comment	c	The observations from different instruments have been combined.
lake_surface_water_temperature	ancillary_variables		lswt_uncertainty, lswt_quality_level
lake_surface_water_temperature	grid_mapping	cs	crs
lswt_uncertainty	long_name	c	total uncertainty in lake surface water temperature
lswt_uncertainty	units	c	Kelvin
lswt_uncertainty	valid_min	s	0
lswt_uncertainty	valid_max	s	10000
lswt_uncertainty	scale_factor	f	0.001
lswt_uncertainty	add_offset	f	0.0
lswt_uncertainty	_FillValue	s	-32767

Variable Name	Attribute	Type	Value
lswt_uncertainty	comment	c	Total uncertainty was computed with LSWT uncertainties from the Optimal Estimation and bias correction uncertainty.
lswt_uncertainty	grid_mapping	c	crs
lswt_quality_level	long_name	c	Lake surface water temperature quality level
lswt_quality_level	valid_min	b	0
lswt_quality_level	valid_max	b	5
lswt_quality_level	flag_meanings	c	no_data bad_data worst_quality low_quality acceptable_quality best_quality
lswt_quality_level	flag_values	b	0b, 1b, 2b, 3b, 4b, 5b
lswt_quality_level	_FillValue	b	0b
lswt_quality_level	comment	c	These are quality indicators, and they are important to properly use the data.
lswt_quality_level	grid_mapping	cs	crs

6.4 Lake Ice Cover (LIC) variables

Table 10. Variables included in the thematic ECV Lake Ice Cover

Variable Name	Attribute	Type	Value
lake_ice_cover_flag	long_name	c	Lake ice cover flag
lake_ice_cover_flag	valid_min	b	1b
lake_ice_cover_flag	valid_max	b	2b
lake_ice_cover_flag	_FillValue	b	0b
lake_ice_cover_flag	flag_meanings	c	does_not_form_ice forms_ice
lake_ice_cover_flag	flag_values	b	1b, 2b
lake_ice_cover_flag	grid_mapping	c	crs
lake_ice_cover_class	long_name	c	Lake ice cover
lake_ice_cover_class	valid_min	b	1b
lake_ice_cover_class	valid_max	b	4b
lake_ice_cover_class	_FillValue	b	0b
lake_ice_cover_class	flag_meanings	c	water ice cloud bad
lake_ice_cover_class	flag_values	b	1b, 2b, 3b, 4b
lake_ice_cover_class	ancillary_variables	c	lake_ice_cover_flag lake_ice_cover_uncertainty
lake_ice_cover_class	grid_mapping	c	crs
lic_uncertainty	long_name	c	lake ice cover uncertainty
lic_uncertainty	units	c	percent
lic_uncertainty	valid_min	s	0
lic_uncertainty	valid_max	s	10000
lic_uncertainty	scale_factor	f	0.01
lic_uncertainty	_FillValue	s	-32767

Variable Name	Attribute	Type	Value
lic_uncertainty	grid_mapping	c	crs

6.5 Lake Ice Thickness (LIT) variables

Table 11. Variables included in the thematic ECV Lake Ice Thickness

Variable Name	Attribute/type	Type	Value
lake_ice_thickness	long_name	c	Lake ice thickness
lake_ice_thickness	units	c	m
lake_ice_thickness	valid_min	s	0
lake_ice_thickness	valid_max	s	10
Lake_ice_thickness	scale factor	f	0.001
lake_ice_thickness	_FillValue	s	-32767
lake_ice_thickness	grid_mapping	c	crs
lit_uncertainty	long_name	c	Lake ice thickness uncertainty
lit_uncertainty	units	c	m
lit_uncertainty	valid_min	s	0
lit_uncertainty	valid_max	s	1
lit_uncertainty	scale factor	f	0.0001
lit_uncertainty	_FillValue	s	-32767
lit_uncertainty	grid_mapping	c	crs
lit_quality_flag	long_name	c	Lake ice thickness quality flag
lit_quality_flag	valid_min	b	0
lit_quality_flag	valid_max	b	2
lit_quality_flag	flag_meanings	c	Best_quality no_data degraded_quality

lit_quality_flag	flag_values	b	0b, 1b, 2b
lit_quality_flag	_FillValue	b	-127
lit_quality_flag	comment	c	Degraded measurement (quality flag 2) can be used but the fit quality is degraded (median of the reduced chi2 values in the RoI: 2.5 < red_chi2 <3)
lit_quality_flag	grid_mapping	cs	crs

6.6 Lake Water Leaving Reflectance (LWLR) variables

Table 12. Variables included in the thematic ECV Lake Water Leaving Reflectance

Variable Name	Attribute	Type	Value
Rw[xxx]*	_FillValue	f	9.96921e+36
Rw[xxx]*	coordinates	c	lat lon
Rw[xxx]*	radiation_wavelength	c	[xxx]
Rw[xxx]*	radiation_wavelength_units	c	nm
Rw[xxx]*	long_name	c	Fully normalized water-leaving reflectance at [xxx] nm*
Rw[xxx]*	units	c	1 [dimensionless]
Rw[xxx]*	ancillary_variables	c	Rw[xxx]_uncertainty_relative, Rw[xxx]_uncertainty_relative_unbiased
Rw[xxx]*	valid_min	f	0
Rw[xxx]*	valid_max	f	1
Rw[xxx]*	grid_mapping	c	crs
Rw[xxx]_uncertainty_relative*	_FillValue	f	9.96921e+36
Rw[xxx]_uncertainty_relative*	coordinates	c	lat lon
Rw[xxx]_uncertainty_relative*	radiation_wavelength	c	[xxx]
Rw[xxx]_uncertainty_relative*	radiation_wavelenght_units	c	nm
Rw[xxx]_uncertainty_relative*	long_name	c	Relative uncertainty in fully normalized water-leaving reflectance at [xxx] nm
Rw[xxx]_uncertainty_relative*	units	c	percent
Rw[xxx]_uncertainty_relative*	valid_min	f	-10000
Rw[xxx]_uncertainty_relative*	valid_max	f	10000
Rw[xxx]_uncertainty_relative*	grid_mapping	c	crs
Rw[xxx]_uncertainty_relative_unbiased*	_FillValue	f	9.96921e+36
Rw[xxx]_uncertainty_relative_unbiased*	coordinates	c	lat lon
Rw[xxx]_uncertainty_relative_unbiased*	radiation_wavelength	c	[xxx]

Variable Name	Attribute	Type	Value
Rw[xxx]_uncertainty_relative_unbiased*	radiation_wavelength_units	c	nm
Rw[xxx]_uncertainty_relative_unbiased*	long_name	c	Relative unbiased uncertainty in fully normalized water-leaving reflectance at [xxx] nm
Rw[xxx]_uncertainty_relative_unbiased*	units	c	percent
Rw[xxx]_uncertainty_relative_unbiased*	valid_min	f	-10000
Rw[xxx]_uncertainty_relative_unbiased*	valid_max	f	10000
Rw[xxx]_uncertainty_relative_unbiased*	grid_mapping	c	crs
chla_mean	_FillValue	f	9.96921e+36
chla_mean	coordinates	c	lat lon
chla_mean	units	c	mg m^{-3}
chla_mean	valid_min	f	0
chla_mean	valid_max	f	1000
chla_mean	long_name	c	Concentration of chlorophyll-a
chla_mean	ancillary_variables	c	chla_uncertainty
chla_mean	grid_mapping	c	crs
chla_uncertainty	_FillValue	f	9.96921e+36
chla_uncertainty	coordinates	c	lat lon
chla_uncertainty	units	c	percent
chla_uncertainty	valid_min	f	0
chla_uncertainty	valid_max	f	200
chla_uncertainty	long_name	c	Relative uncertainty in concentration of chlorophyll-a
chla_uncertainty	grid_mapping	c	crs
turbidity_mean	_FillValue	f	9.96921e+36

Variable Name	Attribute	Type	Value
turbidity_mean	coordinates	c	lat lon
turbidity_mean	units	c	1
turbidity_mean	valid_min	s	0
turbidity_mean	valid_max	s	10000
turbidity_mean	long_name	c	Turbidity in Nephelometric Turbidity Units
turbidity_mean	ancillary_variables	c	turbity_uncertainty
turbidity_mean	grid_mapping	c	crs
turbidity_uncertainty	_FillValue	f	9.96921e+36
turbidity_uncertainty	coordinates	c	lat lon
turbidity_uncertainty	units	c	percent
turbidity_uncertainty	valid_min	f	0
turbidity_uncertainty	valid_max	f	200
turbidity_uncertainty	long_name	c	Relative uncertainty in turbidity
turbidity_uncertainty	grid_mapping	c	crs
lwlr_quality_flag	_FillValue	u1	255
lwlr_quality_flag	coordinates	c	lat lon
lwlr_quality_flag	valid_min	u1	0
lwlr_quality_flag	valid_max	u1	128
lwlr_quality_flag	long_name	c	Quality flag of LWLR pixels

Variable Name	Attribute	Type	Value
lwlr_quality_flag	flag_meanings	c	lwlr_cloud lwlr_land lwlr_snow_ice lwlr_bright_pixel: lwlr_land_contaminated: lwlr_atmospheric_correction_failure lwlr_poor_consistency lwlr_low_consistency
lwlr_quality_flag	Flag_values	u1	1, 2, 4, 8, 16, 32, 64, 128
lwlr_quality_flag	comment	c	These quality indicators inform the user on the reasons behind missing observations and on proper use of the data: lwlr_cloud: not processed due to suspected cloud lwlr_land: not processed due to suspected land lwlr_snow_ice: not processed due to suspected snow or ice lwlr_bright_pixel: masked due to extreme reflectance values lwlr_land_contaminated: risk of land influence on water signal lwlr_atmospheric_correction_failure: no atmospheric correction result lwlr_poor_consistency: illegal combination of LWLR, LWST, and/or LIC lwlr_ low_consistency: pixel includes at least some suspect combinations of LWLR, LWST, and/or LIC
lwlr_quality_flag	ancillary_variables	c	Rw[XXX], chla_mean, turbidity_mean
lwlr_quality_flag	grid_mapping	crs	crs

* where xxx is one of 400, 412, 443, 469, 490, 510, 531, 547, 560, 620, 645, 665, 674, 681, 709, 754, 779, 859, 885, 900, 1020nm. Specific source of sensor, potential application and time span for each LWLR variable can be found in

Table 13 and

Table 14.

Table 13 Waveband selection and unified reporting in LWLR sub-variables (variables starting with 'Rw') across the MERIS, MODIS-Aqua and OLCI sensors. Sensor records are not currently merged in the Lakes_cci: MERIS is used over the 2002-2012 period, MODIS-Aqua in the 2012-2016 period, and OLCI in the period 2016-present (see

Table 14). Overlap between MODIS and the other sensors is only used to investigate inter-sensor bias. The OLCI band set is taken as the reference variable name, with MERIS/MODIS bands within 6 nm reported under the same variable. The variable attribute 'radiation_wavelength' specifies the sensor-specific centre wavelength of each band. All visible and near-infrared wavebands that are not exclusively used for cloud identification or atmospheric correction, are included.

	Band centre (width) in nm			*CCI band*	*Potential applications*
	OLCI (Ref.)	*MODIS-A*	*MERIS*		
1	400 (15)			1	Aerosol correction, improved water constituent retrieval (yellow substance, pigment)
2	413 (10)	412 (44.9)	413 (10)	2	Yellow substance and detrital pigments
3	443 (10)	443 (41.9)	443 (10)	3	Chlorophyll-a absorption maximum, vegetation
4		469 (35.3)		4	Chlorophylls and other accessory pigments
5	490 (10)	488 (32.1)	490 (10)	5	Chlorophyll-a and accessory pigments
6	510 (10)		510 (10)	6	Chlorophyll-a, sediment, turbidity, accessory pigment
7		531 (27.9)		7	Accessory pigments, vegetation
8		547 (21)		8	Chlorophyll-a reference
9	560 (10)	555 (29)	560 (10)	9	Chlorophyll-a reference
10	620 (10)		620 (10)	10	Suspended sediment, cyanobacterial pigment
11		645 (21.8)		11	Suspended sediment, cyanobacterial pigment reference
12	665 (10)	667 (9.5)	665 (10)	12	Chlorophyll-a (red chlorophyll-a absorption maximum), sediment, yellow substance/vegetation, turbidity
13	674 (7.5)	678 (8.7)	-	13	Chlorophyll-a absorption/fluorescence, smile correction with OLCI 665 and 681 nm bands
14	681 (7.5)		681 (7.5)	14	Chlorophyll-a fluorescence peak, red edge
15	709 (10)		709 (10)	15	Chlorophyll-a fluorescence baseline, red edge transition
16	754 (7.5)	748 (10.2)	754 (7.5)	16	O_2 absorption/clouds, vegetation
17	761 (2.5)		761 (3.75)	-	O_2 absorption band/aerosol correction.
18	764 (3.75)		-	-	Atmospheric correction

	Band centre (width) in nm			CCI band	Potential applications
	OLCI (Ref.)	*MODIS-A*	*MERIS*		
19	767 (2.5)		-	-	Fluorescence (land), O_2-A band for cloud top pressure
20	779 (15)		779 (15)	17	Suspended sediment, atmospheric correction
21		859 (24.7)		18	Vegetation, suspended sediment, water vapour reference
22	865 (20)	869 (6.2)	865 (20)	-	Atmospheric correction
23	885 (10)		885 (10)	19	Suspended sediment, vegetation, atmospheric correction
24	900 (10)		900 (10)	20	Water vapour absorption/vegetation monitoring
25	940 (20)		-	-	Water vapour absorption, atmospheric correction
26	1020 (40)		-	21	Water detection, atmospheric correction
27		1240 (5.4)		-	Cloud and aerosol
28		1640 (7.3)		-	Cloud and aerosol
29		2130 (1)		-	Cloud and aerosol

Table 14 Time span and sensor source for LWLR and derived variables.
MODIS-Aqua coverage is for a reduced number of lakes following validation of inter-sensor consistency. Seven LWLR bands are provided over the full time-series from 2002 to 2021. These are Chlorophyll-a, Rw412, Rw443, Rw490, Rw560, Rw665, and Rw754.

Variable	MERIS	MODIS-A	OLCI	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Chlorophyll-a	x	x	x																				
Turbidity	x		x																				
Rw400			x																				
Rw412	x	x	x																				
Rw443	x	x	x																				
Rw469		x																					
Rw490	x	x*	x																				
Rw510	x		x																				
Rw531		x																					
Rw547		x																					
Rw560	x	x*	x																				
Rw620	x		x																				
Rw645		x																					
Rw665	x	x*	x																				
Rw674		x	x																				
Rw681	x		x																				
Rw709	x		x																				
Rw754	x	x*	x																				
Rw779	x		x																				
Rw859		x																					
Rw885	x		x																				
Rw900	x		x																				
Rw1020			x																				

For conciseness, MODIS Rw bands with band centres < 6nm from MERIS/OLCI bands with an equivalent purpose are reported under the same name as the equivalent MERIS/OLCI band. This applies to MODIS bands (labelled as x) at 488, 555, 667, and 748 nm.

7. Additional variables

The Coordinate Reference System (CRS) variable is included to explicitly indicate the system used for horizontal spatial coordinate values. This information is required for some GIS programmes and may be useful for some users

Table 15. Attributes of the additional variable with the Coordinate Reference System

Variable Name	Attribute	Type	Value
crs	grid_mapping_name	f	9.96921e+36
crs	longitude_of_prime_meridian	f	0
crs	semi_major_axis	f	6378137
crs	inverse_flattening	f	298.257223563
crs	crs_wkt	c	GEODCRS["WGS 84", DATUM["World Geodetic System 1984", ELLIPSOID["WGS 84",6378137,298.257223563, LENGTHUNIT["metre",1.0]]], PRIMEM["Greenwich",0], CS[ellipsoidal,3], AXIS["(lat)",north,ANGLEUNIT["degree",0.0174532925199433]], AXIS["(lon)",east,ANGLEUNIT["degree",0.0174532925199433]], AXIS["ellipsoidal height (h)",up,LENGTHUNIT["metre",1.0]]]

In addition, to comply with CCI data standards, the grid boundaries (latitude and longitude bounds) are included

6 Mask file

The file containing the lake mask using for the generation of the dataset as well as the distance to land is provided separately. It follows the same latitude and longitude dimensions as the ECV product files. The variables and their attributes are shown in Table 16.

Table 16. Attributes of the variables in the lake mask file

Variable Name	Attribute/type	Type	Value
lakes_cci_id	_FillValue	i	-2147483648
lakes_cci_id	long_name	c	Lake ID
lakes_cci_id	units	c	1
lakes_cci_id	valid_min	s	1
lakes_cci_id	valid_max	s	9999999999
lakes_cci_id	comment	c	First digit for source database: 0=GLWD, 1=GLBL, 2=CGL2, 3=HYLA. Remaining digits: lake id at source
distance_to_land	_FillValue	s	-32678
distance_to_land	units	c	km
distance_to_land	long_name	c	distance_to_land
distance_to_land	valid_min	s	0
distance_to_land	valid_max	s	27183
distance_to_land	scale factor	f	0.01
distance_to_land	add_offset	f	0
distance_to_land	resolution	c	0.1 kilometers

Variable Name	Attribute/type	Type	Value
distance_to_land	comment	c	Distance to nearest land defined in in Carrea L., Embury O., Merchant C.J. (2015): GloboLakes: high-resolution global limnology dataset v1. Centre for Environmental Data Analysis, 21 July 2015. doi:10.5285/6be871bc-9572-4345-bb9a-2c42d9d85ceb.

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Appendix A - Acronyms

This is a generic list containing acronyms commonly used in the project

AATSR	Advanced Along Track Scanning Radiometer
AATSR	Advanced Along Track Scanning Radiometer
AERONET-OC	AErosol RObotic NETwork - Ocean Color
AMI	Active Microwave Instrument
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
APP	Alternating Polarization mode Precision
ASAR	Advanced Synthetic Aperture Radar
ASLO	Association for the Sciences of Limnology and Oceanography
ATBD	Algorithm Theoretical Basis Document
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced very-high-resolution radiometer
BAMS	Bulletin of the American Meteorological Society
BC	Brockman Consult
C3S	Copernicus Climate Change Service
CCI	Climate Change Initiative
CDR	Climate Data Record
CDOM	Coloured Dissolved Organic Matter
CEDA	Centre for Environmental Data Archival
CEMS	Centre for Environmental Monitoring from Space
CEOS	Committee on Earth Observation Satellites
CF	Climate and Forecast
CGLOPS	Copernicus Global Land Operation Service
CIS	Canadian Ice Service
CLS	Collecte Localisation Satellite
CMEMS	Copernicus Marine Environment Monitoring Service
CMUG	Climate Modelling User Group
CNES	Centre national d'études spatiales
CNR	Compagnie Nationale du Rhône
CORALS	Climate Oriented Record of Altimetry and Sea-Level
CPD	Communication Plan Document
CR	Cardinal Requirement
CRG	Climate Research Group
CSWG	Climate Science Working Group
CTOH	Center for Topographic studies of the Ocean and Hydrosphere
DUE	Data User Element
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ELLS-IAGRL	European Large Lakes Symposium-International Association for Great Lakes Research
ENVISAT	Environmental Satellite
EO	Earth Observation
EOMORES	Earth Observation-based Services for Monitoring and Reporting of Ecological Status
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ESRIN	European Space Research Institute
ETM+	Enhanced Thematic Mapper Plus

EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAQ	Frequently Asked Questions
FCDR	Fundamental Climate Data Record
FIDUCEO	Fidelity and Uncertainty in Climate data records from Earth Observations
FP7	Seventh Framework Programme
GAC	Global Area Coverage
GCOS	Global Climate Observing System
GEMS/Water	Global Environment Monitoring System for freshwater
GEO	Group on Earth Observations
GEWEX	Global Energy and Water Exchanges
GloboLakes	Global Observatory of Lake Responses to Environmental Change
GLOPS	Copernicus Global Land Service
GTN-H	Global Terrestrial Network – Hydrology
GTN-L	Global Terrestrial Network – Lakes
H2020	Horizon 2020
HYDROLARE	International Data Centre on Hydrology of Lakes and Reservoirs
ILEC	International Lake Environment Committee
INFORM	Index for Risk Management
IPCC	Intergovernmental Panel on Climate Change
ISC	International Science Council
ISO	International Organization for Standardization
ISRO	Indian Space Research Organisation
JRC	Joint Research Centre
KPI	Key Performance Indicators
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LIC	Lake Ice Cover
LIT	Lake Ice Thickness
LSC	Lake Storage Change
LSWT	Lake Surface Water Temperature
LWE	Lake Water Extent
LWL	Lake Water Level
LWLR	Lake Water Leaving Reflectance
MERIS	MEdium Resolution Imaging Spectrometer
MGDR	Merged Geophysical Data Record
MODIS	Moderate Resolution Imaging Spectroradiometer
MSI	MultiSpectral Instrument
MSS	MultiSpectral Scanner
NASA	National Aeronautics and Space Administration
NERC	Natural Environment Research Council
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NSERC	Natural Sciences and Engineering Research Council
NSIDC	National Snow & Ice Data Center
NTU	Nephelometric Turbidity Unit
NWP	Numerical Weather Prediction
OLCI	Ocean and Land Colour Instrument
OLI	Operational Land Imager
OSTST	Ocean Surface Topography Science Team
PML	Plymouth Marine Laboratory
PP	Payment Plan
PRISMA	PRecursore IperSpettrale della Missione Applicativa
Proba	Project for On-Board Autonomy

QSR	Linear Correlation Coefficient
R	Linear Correlation Coefficient
RA	Radar Altimeter
RMSE	Root Mean Square Error
SAF	Satellite Application Facility
SAR	Synthetic Aperture Radar
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SIL	International Society of Limnology
SLSTR	Sea and Land Surface Temperature Radiometer
SoW	Statement of Work
SPONGE	SPaceborne Observations to Nourish the GEMS
SRD	System Requirements Document
SSD	System Specification Document
SST	Sea Surface Temperature
STSE	Support To Science Element
SWOT	Surface Water and Ocean Topography
TAPAS	Tools for Assessment and Planning of Aquaculture Sustainability
TB	Brightness Temperature
TM	Thematic Mapper
TOA	Top Of Atmosphere
TR	Technical Requirement
UNEP	United Nations Environment Programme
UoR	University of Reading
UoS	University of Stirling
US	United States
VIIRS	Visible Infrared Imaging Radiometer Suite
WCRP	World Climate Research Program
WHYCOS	World Hydrological Cycle Observing Systems
WMO	World Meteorological Organization
WP	Work Package