



# Target Requirements and Gap Analysis Document

## Land Cover

Issued by: UCLouvain/ Céline Lamarche

Date: 29/01/2024

Ref: C3S2\_WP3-TR-GAD-2023\_LC\_v1.1

Official reference number service contract: 2021/C3S2\_312a\_Lot5\_VITO/SC1



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## History of modifications

Version	Date	Description of modification	Chapters / Sections
V1.0	30/11/2023	First version (based on material in the previous TRGAD covering six climate variable datasets [RD-3])	All
V1.1	29/01/2024	Document amended to account for feedback from independent reviewer and finalized for publication	All document: minor changes in the text.



## Related documents

Reference ID	Document
RD - 1	<a href="#">E.U. Copernicus Climate Change Service, 2021, Product Quality Assurance Document (PQAD) CDR and ICDR LC v2.1.x products v1.1.</a>
RD - 2	E.U. Copernicus Climate Change Service, 2021, Target Requirements and Gap Analysis D1.1.1-2020_Target_Requirements_and_Gap_Analysis_Document_2020_v1.5
RD - 3	E.U. Copernicus Climate Change Service, 2022, Target Requirements and Gap Analysis Document 2023 C3S2_WP3-TR-GAD-2022_v1.1

## Acronyms

Acronym	Definition
(A)ATSR	(Advanced) Along Track Scanning Radiometer
AF	Active Fire
ASAR WSM	Advanced Synthetic Aperture Radar – Wide Swath Mode
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATBD	Algorithm Theoretical Basis Document
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BA	Burned Area
BHR	Bi-Hemispheric Reflectance
BIROS	Bi-spectral InfraRed Optical System
BRDF	Bidirectional Reflectance Distribution Function
C3S	Copernicus Climate Change Service
CAMS	Copernicus Atmosphere Monitoring Service
CCI	Climate Change Initiative
CCI-LC	Climate Change Initiative Land Cover
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
CEOS-WGCV	CEOS Working Group on Calibration and Validation
CGLS	Copernicus Global Land Service
CGLOPS	Copernicus Global Land Operations Service



Acronym	Definition
CWT	Cross-Walking Table
DHR	Directional Hemispheric Reflectance
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
Envisat	Environmental Satellite
EO	Earth Observation
ERS	European Remote Sensing Satellite
EQC	Evaluation and Quality Control
ESA	European Space Agency
ET	Evapotranspiration
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAPAR	Fraction-Absorbed Photosynthetically Active Radiation
FCDR	Fundamental Climate Data Record
FOV	Field of View
FR	Full Resolution
FRP	Fire Radiative Power
FTP	File Transfer Protocol
GAC	Global Area Coverage
GCOS	Global Climate Observing System
GCS	Global Coordinate System
GeoTIFF	Georeferenced Tagged Image File Format
GHG	Greenhouse gasses
GIMMS	Global Inventory Monitoring and Modeling System
GIO GL	GMES Initial Operations Global Land
GOES	Geostationary Operational Environmental Satellites
GOES-E	GOES-East
GOES-W	GOES-West
HR	High Resolution
ICDR	Intermediate Climate Data Record
I-Band	High-resolution Imagery Bands
IPCC	Intergovernmental Panel on Climate Change
JPSS	Joint Polar Satellite System
LAI	Leaf Area Index
Landsat	Land remote sensing Satellite
LSA SAF	Land Surface Analysis Satellite Application Facility
LC	Land Cover
LCCS	Land Cover Classification System
LS	Land Surface
LSM	Land Surface Model
LTDR	Long Term Data Record
LUT	Look-Up Table



Acronym	Definition
LWIR	Long Wave Infrared
M-bands	Moderate-resolution Bands
MERIS	Medium Resolution Imaging Spectrometer
MIR	Mid-Infrared
MISR-HR	Multi-angle Imaging SpectroRadiometer High-Resolution
MODIS	Moderate Resolution Imaging Spectroradiometer
MR	Medium Resolution
MSI	MultiSpectral Instrument
MSG	Meteosat Second Generation
MWIR	Mid-wave infrared
NASA	National Aeronautics and Space Administration
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NPP	Suomi National Polar - orbiting Partnership
NRT	Near Real Time
NWP	Numerical Weather Prediction
OLCI	Ocean and Land Colour Instrument
PAL	Pathfinder AVHRR Land
PFT	Plant Functional Types
POD	Polar Orbiter Data
POES	Polar Orbiting Environmental Satellite
PROBA-V	Project for On-Board Autonomy, with the V standing for Vegetation
PSD	Product Specification Document
PUGS	Product User Guide Specification
QF	Quality Flag
QA	Quality Assessment
ReBeLS	Regularised BRDF inversion for Land Surface reflectance
SA	Surface Albedo
S3	Sentinel-3
S3 SYN	Sentinel-3 Synergy
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SLSTR	Sea and Land Surface Temperature Radiometer
SPOT	Satellite Pour l'Observation de la Terre
SPOT-VGT	SPOT- Vegetation
SR	Surface Reflectance
SWIR	Shortwave Infrared
SYN	Synergy product, as a combination of Sentinel-3 OLCI and SLSTR
TC	Triple Colocation



Acronym	Definition
TET-1	Technology Experiment Carrier-1
TIR	Thermal Infrared
TIP	Two stream Inversion Package
TOC	Top of Canopy
TR	Target Requirements
UAH	University of Alcalá
UCL	University College London
UCLouvain	Université catholique de Louvain
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
URAD	User Requirement Analysis Document
URD	User Requirements Document
URDB	User Requirement Data Base
VIS	VISible
VIIRS	Visible Infrared Imaging Radiometer Suite
VNIR	Visible and Near Infrared
WMO	World Meteorological Organization



## General definitions

### **Breakthrough (B)**

An intermediate level between threshold and goal which, if achieved, would result in a significant improvement for the targeted application. The breakthrough value may also indicate the level at which specified uses within climate monitoring become possible. It may be appropriate to have different breakthrough values for different uses.

### **Brokered**

A brokered product is a product that has been produced in another service and is provided as input to another service.

### **CDR (Climate Data Record)**

Time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. In C3S, CDRs are expected to be multidecadal in order to be able to assess trends.

### **ICDR (Intermediate Climate Data Record)**

The extension of the CDR in time with regular recent updates.

### **Essential Climate Variable (ECV)**

A variable or group of related variables that critically contribute to the characterization of Earth's climate state and forcing.

### **FCDR (Fundamental Climate Data Record)**

A long-term data record of calibrated and quality-controlled sensor data designed to allow the generation of homogeneous products that are accurate and stable enough for climate monitoring. In this case, FCDR are single sensor products.

### **Goal (G)**

An ideal requirement above which further improvements are not necessary.

### **Land cover**

Land cover is defined as the observed (bio)-physical cover on the Earth's surface for regional and global climate applications.

### **Land cover concept**

The *LC* concept refers to the set of LC features remaining stable over time which define the LC independently of any sources of temporary or natural variability



### **Measurement Uncertainty**

The parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (GUM)<sup>1</sup>. It includes all contributions to the uncertainty, expressed in units of 2 standard deviations, unless stated otherwise.

### **Stability**

The change in bias over time. Stability is quoted per decade.

### **Target Requirements (TRs)**

Requirements on the datasets, production system and documentation for this service to meet the needs of the users. The C3S targets a variety of users, ranging from policy makers to scientists, industry sectors and businesses, although policy makers (e.g., DG CLIMA and Climate-ADAPT) and sectoral users (e.g., water, energy, urban, agriculture) are the main focus. The TRs takes the Global Climate Observing System (GCOS) requirements as a starting point and refine them to meet the specific needs of the C3S services ranging from climate monitoring, constraint of models, data assimilation, initialization of simulations, and attribution. For example, C3S might have requirements on latency for constraining climate prediction. The TRs will continuously evolve in time to capture new needs from users.

### **Threshold (T)**

The minimum requirement to be met to ensure that data are useful.

### **Timeliness**

The time expectation for accessibility and availability of data.

### **Traceability**

Traceability to source is required for all climate information provided by C3S to its users. For ECV products derived from observations this means that all input observations must be clearly identified by source, fully described and documented, and that a means of access must be available to all users of C3S products. Open and free access to input observations is strongly preferred.

### **User Requirement Analysis Document (URAD)**

A document capturing the stratification of User Requirements per domain, importance and feasibility. The URAD is maintained by ECMWF and continually updated in coordination with the Evaluation and Quality Control (EQC).

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<sup>1</sup> [https://www.bipm.org/documents/20126/2071204/JCGM\\_100\\_2008\\_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6](https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6)



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**User Requirement Data Base (URDB)**

A database collecting all requirements for the C3S emanating from a wide variety of user fora, surveys, and support panels. The data base is maintained by ECMWF and continually updated in coordination with the EQC.

**Uncertainty (of measurement)**

A parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (JCGM-100, 2008).



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## Scope of the document

This document provides users with the relevant information on requirements, and gaps for Land Cover (LC) climate variable datasets derived from Earth Observation data. Firstly, the product is described, then the target requirements for the product are presented and finally an analysis is presented that provides a past, present, and future gap analysis for the product and covers both gaps in the data availability and scientific gaps that could be addressed by further research activities (outside C3S).

## Executive summary

The Copernicus Climate Change Service (C3S) provides key indicators on climate change drivers, combining observations of the climate system with the latest science to develop authoritative, quality-assured information about the past, current and future states of the climate in Europe and worldwide. The C3S portfolio will include i) consistent estimates of multiple Essential Climate Variables (ECV); ii) global and regional re-analyses covering the Earth-system components like atmosphere, land, ocean, sea-ice and carbon; iii) products based on observations alone; iv) a near-real-time (NRT) climate monitoring facility; v) multi-model seasonal forecasts; vi) climate projections at global and regional scales. The ECVs are provided as series of gridded Climate Data Records (CDRs) derived primarily, but not exclusively, from satellite data on a routine and sustained basis.

This document discusses:

- the target requirements for the LC Climate Data Records (CDR/ICDR) provided in the C3S for climate applications and Numerical Weather Prediction (NWP). The target requirements for climate applications are established according to the recently updated Global Climate Observing System (GCOS) requirements and according to the World Meteorological Organization (WMO) for global NWP.
- the past, current and future Earth Observation (EO) landscape providing relevant Fundamental Climate Data Records (FCDR) for the LC CDR and ICDR. It analyses the various aspects of the retrieval methodologies that limit the fitness-for-purpose of the current CDRs, and identifies the opportunities and research needs for improvement. Therefore, the gap analysis identifies the remaining activities to be carried out to fully satisfy the target requirements. More specifically, the topics addressed in this document include the data availability from existing space-based observing systems, the development of processing algorithms, methods for estimating uncertainties and the scientific research needs.



## 1 Product description

### 1.1 Land Cover

Considering the importance of land cover as an input in climate modelling, the development of a new global LC database was initiated during the 1<sup>st</sup> phase of the ESA Climate Change Initiative Land Cover (CCI LC) project. The specifications of this new database relied on an in-depth user requirement analysis conducted during the 6 first months of the CCI LC Phase I project (ESA\_CCI\_LC\_URD, 2011).

This analysis revealed first the need to consider LC data under 2 aspects: *stable* in the form of land cover map and *dynamic* in the form of time series. In addition, the LC products should provide *flexibility* to serve different scales and purposes in terms of spatial and temporal resolutions. Their quality should also be transparent by using *quality flags* and controls.

From a remote sensing point of view, these requirements – and the first one in particular – led in rethinking the whole LC concept into *Land Cover (LC)* and *Land Surface (LS) seasonality* (ESA\_CCI\_LC\_PSD, 2014). The *LC* concept refers to the set of LC features remaining stable over time which define the LC independently of any sources of temporary or natural variability. It is agreed that the LC state is well described using the United Nations (UN) Land Cover Classification System (LCCS) (Gregorio et al., 2005), which is also quite compatible with the Plant Function Types (PFT) concept of many models (Gregorio et al., 2005). The *LS seasonality* concept relates directly to the temporary or natural variability of LC features that can induce some variation in land surface over time without changing the LC in its essence. This LS seasonality is typically driven by bio-geophysical processes. It encompasses different observable variables such as the green vegetation phenology, snow coverage, open water presence, and burned areas occurrence, etc.

Furthermore, the need to generate successive LC products consistent over time resulted in the development of a new original classification approach. Most often, LC maps were generated from few instantaneous observations of the land. As a result, classification outputs are sensitive to the date(s) of observation and can reflect temporary conditions (e.g., map savannahs as burned scars, boreal forest as snow, croplands as bare soils, etc.). The developed alternative consisted in describing the LC *from multi-year observation dataset*. In this case, assuming that no LC change – even temporary – has occurred over this multi-year period, the LC is expected to be mapped in a consistent way over time. This approach was successfully implemented for the CCI LC and C3S LC products.



## 2 User Requirements

### 2.1 Land Cover

#### 2.1.1 Requirements from the Global Climate Observing System (GCOS)

GCOS requirements are defined in the 2022 GCOS Implementation Plan (GCOS, 2022a), and in the 2022 GCOS ECVs Requirements (GCOS, 2022b). The main novelty over the previous requirements set by GCOS five years previously (GCOS, 2016), is that in this new document different values (goal, breakthrough and threshold) are presented for each requirement criteria. For details, please see the General Definitions. The new requirements for LC are detailed in Table 2-1.

Table 2-1 - GCOS requirements (GCOS, 2022b) for Land Cover, showing with a grey background which requirements are targeted by the products proposed for this project.

Name	Land Cover				
Unit	Primary units are categories (binary variables such as forest or cropland) or continuous variables classifiers (e.g., fraction of tree canopy cover in percent). Secondary outputs include surface area of land cover/use types and land cover/use changes (in ha). UN/FAO Land Cover Classification System (LCCS) + C3/C4 sub-classification should be used with cross-walking tables to other common classifications.				
Requirements					
Item needed	Unit	Metric	Type of value	Value	Derivation; References and Standards
Horizontal Resolution	m	-	G	100-300	Most climate users are satisfied by a horizontal resolution of 300 m if they can be provided for long time spans.
			B	300-1 km	Suitable for regional (climate) modelling.
			T	>1 km	Suitable for global (climate) modelers.
Temporal Resolution	month	time	G	1	Monthly. Allows regrowth, phenology, changes in water extent related to seasonality to be detected.
			B	12	Yearly. Inter-annual changes can be detected.
			T	60	Every five years. Suitable scale for longer-term mapping, related to broader land cover change dynamics.
Vertical Resolution		-	G	-	N/A, since ECV products provide estimates as total over a certain area with further vertical discrimination. There is currently no consideration of the third dimension for land ECV products though some of the



					definitions (such as forests) often use, among others, minimum height criteria.
			B	-	
			T	-	
Timeliness	month	-	G	3	Seasonal. Ideally, land cover data become available soon after the acquisition of the data but quality processing and ECV product derivation and accuracy assessment, as well as long-term consistency is to be ensured to track changes and trends. These frequent changes may be relevant for land managers who can react quickly to changes.
			B	12	Annual and bi-annual reporting applications. Policy makers will be able to develop and assess policies based on regular updates and observed changes.
			T	60	Every five years. Suitable for longer-term mapping, related to broader land cover change dynamics.
Temporal Extent (Time span)	year	-	G	>50	Historic changes which most users are interested in are captured. Only be achieved with modelling approaches using non-earth observation data sources (i.e., historical maps)
			B	10-50	Historic changes can be assessed for the Earth observation era.
			T	0 (one time only)	Only current and potentially future data are available, but this is useful for those who require current status products, for example for modelling, and static assessments.
Required Measurement Uncertainty	% for accuracy and errors of omission and commission and hectares for area estimates incl. 95 % confidence intervals	Primary: overall map accuracy and errors of omission and commission for individual land cover categories and types of change (incl. confidence interval). Secondary: bias for area estimates (incl.	G	5	For reporting purposes, this would allow sufficient accuracy, where all classes have high accuracies. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.
			B	20	For other uses, this would be sufficient – it would be expected that some classes would have higher accuracy -for example confusion between built-up and forest would be lower, but confusion between agriculture and bare might be higher. An independent



		confidence intervals)			accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.	
			T	35	This threshold would be suitable for maximum commission/omission error for individual categories. Overall accuracy might be expected to be higher. An independent accuracy assessment using statistically robust, global or regional reference data of higher quality is required for any ECV land cover product.	
Stability	% incl. 95 % confidence intervals	Primary: errors of omission and commission for individual land cover categories and types of change (incl. confidence interval)	G	5	Stability is important for long-term land cover datasets where multiple sensors are used to generate a time series dataset. High stability is required for assessing long-term trends. The stability can be assessed by multi-date independent accuracy assessment. The stability requirements are tighter than for overall uncertainty since the aim for multi-date ECV data is to provide information on changes and trends.	
				B	15	
				T	25	

### 2.1.2 Synthesis of the ESA CCI LC requirements

The CCI LC project was carried out in two phases. The activities and results of the user requirements analyses during these two phases can be found in the respective User Requirements Documents (URDs), (ESA\_CCI\_LC\_URD, 2011) and (ESA\_CCI\_LC\_URD, 2015).

The requirement was for a global LC product, matching the requirements from GCOS and key climate users, which could be achievable on a regular basis using the current EO systems and building on the UN Land Cover Classification System (LCCS) for consistency and interoperability with other LC products. Users expressed a particular need for both stable LC data, and a dynamic component (time-series and changes). The requirements therefore included:

- The creation of a consistent dataset of LC maps, dating over a long temporal extent (back to the 1990s and 1980s).
- Land cover change products.
- A high temporal resolution, including annual time steps in LC change (at least in the context of the IPCC land categories).
- A minimum of 300 m spatial resolution, to meet climate modelling requirements for most users.
- A higher accuracy than existing datasets, and the inclusion of quality flags.
- Validation information, including checks with *in situ* data for specific areas.



- A clear description of the classification methodology.
- Standard metadata. The preferred format for the CDR was in NetCDF, with data access through File Transfer Protocol (FTP).

A summary of the user requirements in both phases can be found in Table 2-2. The threshold requirement is the limit at which the observation becomes ineffectual and is not of use for the climate-related application. The target requirement is the maximum performance limit for the observation, beyond which no significant improvement would result for climate applications (ESA\_CCI\_LC\_URD, 2015).

Table 2-2 - Threshold (minimum) and target (optimal) requirements identified for LC products in the User Requirements Survey carried out in the CCI LC project Phase I and Phase II. Asterisk points indicate fulfilled requirements (ESA\_CCI\_LC\_URD, 2015).

	<b>Threshold requirement Phase 1</b>	<b>Target requirement Phase 1</b>	<b>Threshold requirement Phase 2</b>	<b>Target requirement Phase 2</b>
	COVERAGE AND SAMPLING			
<b>Geographic Coverage</b>	*Global	Global with regional and local specific products	*Global with regional specific products	Global with regional specific products
<b>Temporal sampling</b>	*Best/stable map and regular updates	Monthly data on vegetation dynamics and change	*5-10 years epoch maps with monthly vegetation dynamics (NDVI)	*1-year epoch maps. Monthly data on vegetation dynamics (NDVI)
<b>Temporal extent</b>	*1-2 years, most recent	*1990 (or earlier)-present	*1990 (or earlier) - present	1980 (or earlier) - present
	RESOLUTION			
<b>Horizontal Resolution</b>	*1000 m	30 m	*300 m with regional 30 m products	30 m
<b>Vertical Resolution</b>	–	–		
	ERROR/UNCERTAINTY			
<b>Precision</b>	*Thematic LC detail sufficient to meet current modelling user needs	*Thematic LC detail sufficient to meet future model needs	*Thematic LC detail (including conversion tables to PFT for climatic regions) sufficient to meet current and future model needs, incl. key land IPCC changes	Thematic LC detail (including conversion tables to PFT for climatic regions and traits) sufficient to meet current and future model needs, incl. LC changes and management
<b>Accuracy</b>	*Higher accuracy than existing datasets	Errors less than 5-10% either per	Higher accuracy than existing datasets	Errors less than 5-10% either per class



		class or as overall accuracy		or as overall accuracy
<b>Stability</b>	*Higher stability than existing datasets	Errors less than 5-10% either per class or as overall accuracy	Higher stability than existing datasets	Errors less than 5-10% either per class or as overall accuracy
<b>Error characteristics</b>	*Independent one-time accuracy assessment	Operational and independent multi-date validation	*Independent multi-date validation	Operational and independent multi-date validation

### 2.1.3 Target Requirements from the Copernicus Climate Change Service (C3S)

Within the C3S project, Target Requirements (TRs) are defined and updated according to the C3S, GCOS and user needs collected. In order to meet the TRs from the C3S, the expertise already gained during the CCI LC project has been exploited. Table 2-3 provides indications about how the C3S LC dataset complies with the project requirements.

Table 2-3 - Target Requirements from the Copernicus Climate Change Service (C3S).

ECV	Horizontal resolution	Temporal Resolution	Timeliness	Time span	Required measurement uncertainty	Stability (per decade)
Land Cover	300 m	12 months	12 months	> 30 years	Error on overall accuracy < 30%	Max 5% for the overall accuracy

The following TRs apply to the LC ECV in C3S:

- Evolving TRs tailored to C3S and GCOS needs will be documented. The LC ICDR is based on the continuation of the LC CCI products and on the processing chains developed in that project. This sustains the production of LC maps, contributing to consistent long term CDRs.
- The 24 LC maps at 300 m resolution (1992 – 2015) were brokered from the CCI LC project.
- Steps towards cross-CDR consistency are made, by harmonisation of the pre-processing, and the implementation of operational tools to monitor their quality and cross-consistency.
- Secured continuation of the LC products by moving towards Sentinel-3 as a primary data source for the maps since 2020 onwards.



### 3 Gap Analysis

#### 3.1 Description of past, current and future satellite coverage

##### 3.1.1 Land Cover

In order to produce LC maps that date back as far as possible in time, contributing to the provision of long-term and consistent CDRs at the global scale for the Essential Climate Variables (ECVs), it is necessary to use images that originate from a number of different satellites. The images from different satellites used to generate the maps at the start of the time series and those used to generate global annual land cover maps close to the current period are documented in Table 3-1.

In order to meet the GCOS requirements regarding the length of the LC time series starting in the 1980's, no satellite observation is available at 1 km that is consistent with the products for change. The attempt to use the AVHRR Long Term Data Record (LTDR) has not yet been found successful.

Since 2020 onwards, data from the Sentinel-3 (S3) mission was used. Sentinel-3A was launched in February 2016, and Sentinel-3B in April 2018. The current S3-based LC maps rely on the seasonal composite time series from OLCI by applying the adapted processing chain for the ENVISAT MERIS data. A further step is the processing of the season composite time series from the OLCI and SLSTR, onboard Sentinel-3, and these time series will be used to contribute to the LC maps from 2021 and beyond.

Table 3-1 - Satellite data that have been / are used to generate the CCI LC SR time series.

Global SR composite time series	Reference period	Satellite data source	Technical specifications of the satellite data source
AVHRR global SR composite time series	1992-1999	AVHRR-2 on NOAA-11 and NOAA-14	1 km spatial resolution 5 spectral bands in visible and infrared Global coverage
SPOT-VGT global SR composites	1999-2013	SPOT 4, 5 Vegetation sensor	1 km spatial resolution 4 spectral bands in visible, near-infrared (NIR) and shortwave infrared (SWIR) Global coverage
MERIS global SR composite time series	2003-2012	Envisat MERIS FR & RR	300 m or 1,000 m resolution full swath 15 spectral bands in visible and NIR Global coverage
PROBA-V global SR composite time series	2013-2019	PROBA-V	300 m spatial resolution 4 spectral bands in visible, near-infrared and SWIR Global coverage
Sentinel-3 OLCI global SR composite time series	2020	S3 OLCI	300 m resolution full swath 15 spectral bands in visible and NIR



			Global coverage
Sentinel-3 global SR composite time series	2021-2022	S3 OLCI & S3 SLSTR	300 m resolution full swath 21 spectral bands in visible and NIR and SWIR Global coverage
Advanced Synthetic Aperture Radar - Wide Swath Mode (ASAR WSM) time series	2005-2012	Envisat ASAR WSM	150 m spatial resolution Microwave band Global coverage

## 3.2 Development of processing algorithms

### 3.2.1 Land Cover

The algorithms developed during the previous CCI LC project are in place for the operational production of the global LC maps.

At the pre-processing level, the pixel identification and the atmospheric correction and the BRDF correction approaches are designed to process data from different satellites in a consistent way, and have been adapted and applied to combined Sentinel3 OLCI and SLSTR data.

The classification algorithm is designed to be globally consistent, while regionally-tuned, and capitalizes on the GlobCover<sup>2</sup> unsupervised classification chain (Bicheron et al., 2008), complemented by more advanced classification algorithms from the ESA CCI LC project (Defourny et al. 2017). Nevertheless, algorithm adaptations were needed to move to operational processing and to include the new S3 sensor in the processing chain.

C3S focuses on the production of the longest possible, consistent and mature CDRs. For LC the existing datasets for the 1980's could be further investigated. Furthermore, the algorithms may be improved to enhance the consistency between the PROBA-V/OLCI era. For example, the classification algorithms should also be adapted to incorporate data from the combined Sentinel3 SLSTR and OLCI sensors.

<sup>2</sup> [http://due.esrin.esa.int/page\\_globcover.php](http://due.esrin.esa.int/page_globcover.php), accessed 19.06.2023



### 3.3 Methods for estimating uncertainties

#### 3.3.1 Land Cover

The 2022 GCOS ECVs Requirements (GCOS, 2022b) state that global LC databases must be accompanied by a description of class-by-class thematic/spatial accuracy. In this context, a CCI LC validation database has already been developed, to which an international network of LC experts has contributed, using datasets that were not used during the production of the LC maps. This provides reliability and confidence in the quality of the maps through validation against independent data. The different components of this validation process (Figure 3-1) are summarised in the product quality assurance document [RD - 1]. While the sampling design is inherited from the CCI LC project, the collection of HR imagery, independent interpretation and reporting, are carried out within C3S. The independent interpretation of very high-resolution imagery aimed at updating the CCI validation database for the most recent years. The final reporting step consists in exploiting the database to assess the map's accuracy.

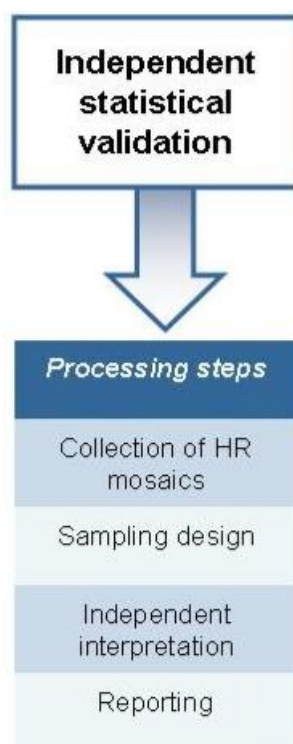


Figure 3-1 - Different components of the independent statistical validation component.

To improve the quantification of uncertainty, this validation database is updated on a yearly basis within the C3S project, allowing the assessment of the accuracy of the 2016 – 2022 LC maps, paying particular attention to the uncertainties of each thematic class.



### 3.4 Opportunities to improve quality and fitness-for-purpose of the CDRs

#### 3.4.1 Land Cover

Cross-CDR consistency is identified as an important aspect in the GCOS 2022 IP (Action C5 activity 6). Various activities will take place to ensure more consistency between ECVs in the second phase of the CCI+ programme such as the investigation of the harmonization of the pre-processing for land ECVs, the set up an operational quality monitoring tool that provides not only information on the quality of the single ECVs, but also their cross-consistency, and the joint-use of various ECVs in climate models. Cross-consistency between all the ECV CDRs is a key for the dependability of the products for users. Harmonizing the pre-processing between the LC CDRs (e.g., pixel status retrieval) will *de facto* increase the LC cross-CDR consistency while documenting the cross-ECV consistency. Moreover, it will increase transparency for users and therefore the LC CDRs interoperability.

In addition, Action C5 activity 1 of the GCOS (2022) highlights the production of annual LC products at 10-30 m resolution for key regions. High-resolution (10 and 20 m) LC continental maps have been produced for Meso-America and Africa in the CCI Medium Resolution (MR) LC project to demonstrate the feasibility of continental land cover mapping at 10 and 20 m. The objective of the CCI High Resolution (HR) LC project is to develop the best algorithms for large-scale land cover mapping and land cover change detection. In this context, regional maps have been produced over Sahel, Siberia and Amazonia at 10 m.

Finally, it would be interesting to update the training reference database with the high-resolution LC datasets recently released publicly to improve the quality of the LC representation of the CCI LC map series. However, this would require the reprocessing of the entire LC map series.



### 3.5 Scientific Research needs

#### 3.5.1 Land Cover

The CCI LC map products can be used for a wide variety of applications, although they are aimed at the climate modelling community. In order to use the LC maps in global land surface models, (LSMs), climate modellers need to translate the LC maps into PFT maps. This is commonly done using a cross-walking table (CWT) based on a set of expert rules reflecting the interpretation of LC class descriptions, which therefore generates some uncertainty (Hartley et al. 2017). The CCI+ Medium Resolution (MR) project<sup>3</sup> moved beyond fine-tuning the cross-walking approach for specific LC classes or regions and, instead, separately quantifies the PFT fractional composition for each 300 m pixel globally (Harper et al., 2022). The result is a dataset representing the cover fractions of 14 PFTs at 300 m for each year within the time range, consistent with the CCI MRLC LC maps for the corresponding year. The PFT v1.0 global dataset has 14 layers, each describing the percentage cover (0-100%) of a plant functional type at a spatial resolution of 300 m: broadleaved evergreen trees, broadleaved deciduous trees, needleleaved evergreen trees, needleleaved deciduous trees, broadleaved evergreen shrubs, broadleaved deciduous shrubs, needleleaved evergreen, needleleaved deciduous shrubs, shrubs natural grasses, herbaceous cropland (i.e., managed grasses), built, water, bare areas, and snow and ice. Further research is necessary to evaluate the impact of such new description on climate models.

Further research on the pre-processing of seamless surface reflectances across sensors and spatial resolutions would greatly contribute to the increase of spatio-temporal consistency of global land cover datasets.

### 3.6 Opportunities from exploiting the Sentinels and any other relevant satellite

#### 3.6.1 Land Cover

The CCI+ phase 1 medium-resolution (MR) and high-resolution (HR) LC projects should allow a multiscale study to be carried out. This would support the quantification of the CWT for different biomes, providing specific and more objective CWTs for land surface parametrization in climate modelling.

The Sentinel-3 mission provides data that is important in the detection of land. In particular, the OLCI instrument provides information about the state of vegetation, aiding land cover mapping, but also the SLSTR instrument is useful in mapping the land surface temperature and providing better detection of clouds. The SYN product is expected to provide more information content than the current PROBA-V time series. Most importantly, the Sentinel-3 mission will ensure regular coverage of the earth's surface in the long term, and continuity and consistency of data that can be used for LC mapping, but this would require some R&D activities to integrate the S3 data in the existing processing chains.

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<sup>3</sup> [https://climate.esa.int/documents/1389/MRLC\\_CCI\\_11thColocation\\_PFT\\_poster\\_Oct2021.pdf](https://climate.esa.int/documents/1389/MRLC_CCI_11thColocation_PFT_poster_Oct2021.pdf), accessed 19.06.2023



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