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Copernicus Climate Change Service

Product User Guide and Specification

ICDR Land Cover 2016 and 2017

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Version	Date	Description of modification	Chapters / Sections
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V1.1	11/02/2019	Document updated to represent all C3S LC maps	All
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List of datasets covered by this document

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Related Documents

Reference ID	Document
[D1]	ECMWF, 2017: C3S ECMWF Copernicus Procurement: Invitation to Tender Copernicus project: Proposal for Lot 5: Surface albedo, LAI, fAPAR, Land Cover and Fire, 15.06.2017 (not publicly available).

Acronyms

Acronym	Definition
(A)ATSR	(Advanced) Along Track Scanning Radiometer
API	Application Programming Interface
ATBD	Algorithm Theoretical Basis Document
AVHRR	Advanced Very High-Resolution Radiometer
BC	Brockmann Consult GmbH
C3S	Copernicus Climate Change Service
CCI	Climate Change Initiative
CCI-LC	Climate Change Initiative Land Cover
CDR	Climate Data Record
CDS	Climate Data Store
CEOS	Committee on Earth Observation Satellites
CEOS-WGCV	CEOS Working Group on Calibration and Validation
CMC	Climate Modelling Community
CMUG	Climate Modelling User Group
CRS	Coordinate Reference System
ECV	Essential Climate Variable
ERS	European Remote Sensing Satellite
Envisat	Environmental Satellite
EO	Earth Observation
ESA	European Space Agency
ET	Evapotranspiration
fAPAR	Fraction-Absorbed Photosynthetically Active Radiation
FR	Full Resolution
GCOS	Global Climate Observing System
GCS	Global Coordinate System
GDAL	Geospatial Data Abstraction Library
GIS	Geographic Information System
ICDR	Intermediate Climate Data Record
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
Landsat	Land remote sensing Satellite
LC	Land Cover
LCCS	Land Cover Classification System

Acronym	Definition
LS	Land Surface
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NetCDF	Network Common Data Form
NDVI	Normalized Difference Vegetation Index
PFT	Plant Functional Types
PROBA-V	Project for On-Board Autonomy, with the V standing for Vegetation
PUG	Product User Guide
SPOT	Satellite Pour l'Observation de la Terre
SPOT-VGT	SPOT- Vegetation
SR	Surface Reflectance
UCLouvain	Université catholique de Louvain
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WB	Water Body
WGS84	World Geodetic System 84

General definitions

Land cover

Land Cover and land cover change are becoming more and more related to the climate modelling effort. Land cover change as a pressing environmental issue, is acting as both a cause and a consequence of climate change. The importance of these issues requires continuous monitoring systems and data. The Copernicus Climate Change Service provides Intermediate Climate Data Records for many Essential Climate Variables, among which is land cover. The C3S global Land Cover maps 2016 and 2017 are consistent with the existing European Space Agency Climate Change Initiative global annual LC maps from 1992 – 2015 to ensure continuity.

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Scope of the document

The Product User Guide Specification (PUGS) is the reference product description, which describes data format, filenames, metadata and thematic content with the aim to familiarize users with the products.

The Copernicus Climate Change Service (C3S) has generated global Land Cover (LC) maps for 2016 and 2017 consistent with the existing global annual LC maps from 1992 – 2015 produced by the ESA-CCI LC project [ESA, 2017b]. This annual production of consistent global LC maps will be further continued for 2018 – 2019. This document aims at guiding the user on how to use the ICDR LC 2016 and 2017 products. Further PUGS will be produced for the 2018 – 2019 LC products.

The document is divided into 2 sections that are shortly described below:

- Section 1 provides specifications of the C3S Land Cover (C3S LC) product;
- Section 2 explains how to access the C3S-LC products and give their terms of use.

This document contains one appendix (A) with additional detailed information.

Executive summary

The Copernicus Climate Change Service (C3S) provides Intermediate Climate Data Records (ICDRs) for many Essential Climate Variables (ECVs), among which is land cover.

This document describes the consistent global LC maps at 300 m spatial resolution of the years 2016 and 2017 with the aim of familiarizing users with the products. The land cover concept is first presented to justify the methodological choices. Input datasets and algorithms are then briefly documented. After characterizing the global LC maps themselves, validation results and recommendations are finally described.

The annual land cover maps at 300 m spatial resolution for 2016 and 2017 are delivered as ICDR to the C3S.

1 Land Cover maps 2016 and 2017

1.1 Product description

The C3S LC project delivers the global LC maps at 0.002778° (approximately 300 m) spatial resolution for 2016 and 2017 (version 2.1). The Coordinate Reference System used for the global land cover database is a geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid.

The global 300m LC maps for 2016 and 2017 are based on the PROBA-V satellite and are consistent with the existing CCI global annual LC maps from 1992 – 2015 (see table below).

Table 1: Summary of the C3S LC products

Product	Coverage		Resolution		Sensor	Projection	Format
	Spatial	Temporal	Spatial	Temporal			
Annual LC maps	Global	2016 & 2017	0.002778°	1-year	PROBA-V	Plate-Carrée	NetCDF

Figure 1 presents the LC map from the year 2017 at global scale and Figure 2 shows an example of the classification obtained throughout the years over a region of Argentina.

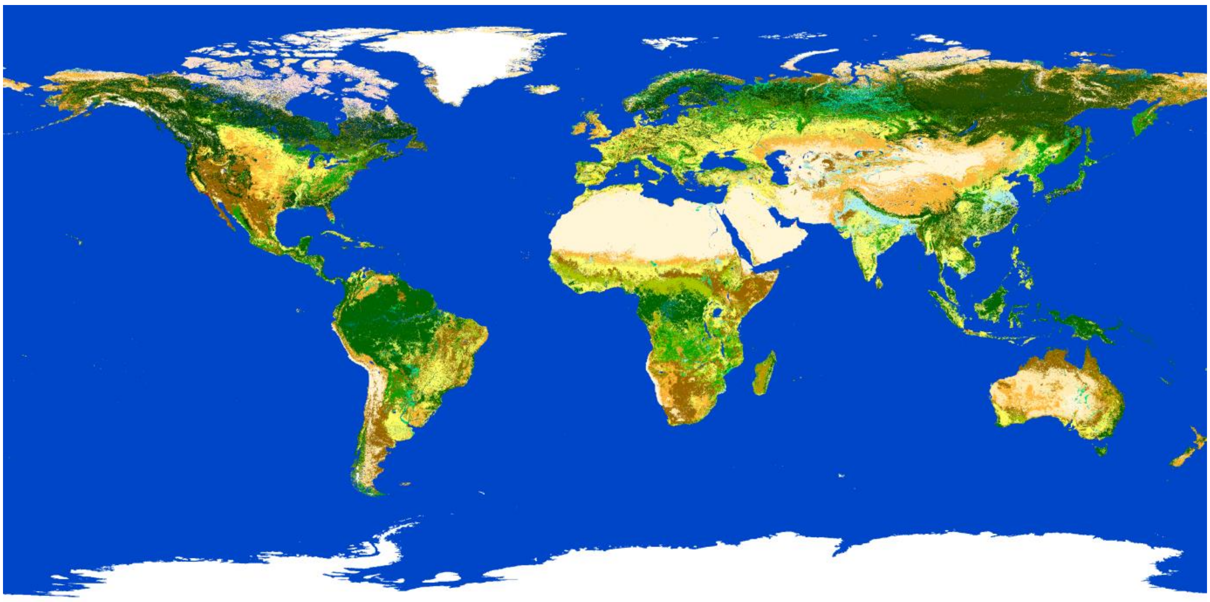

Figure 1: The most recent map from the LC map series from the year 2017, at 300 m spatial resolution.

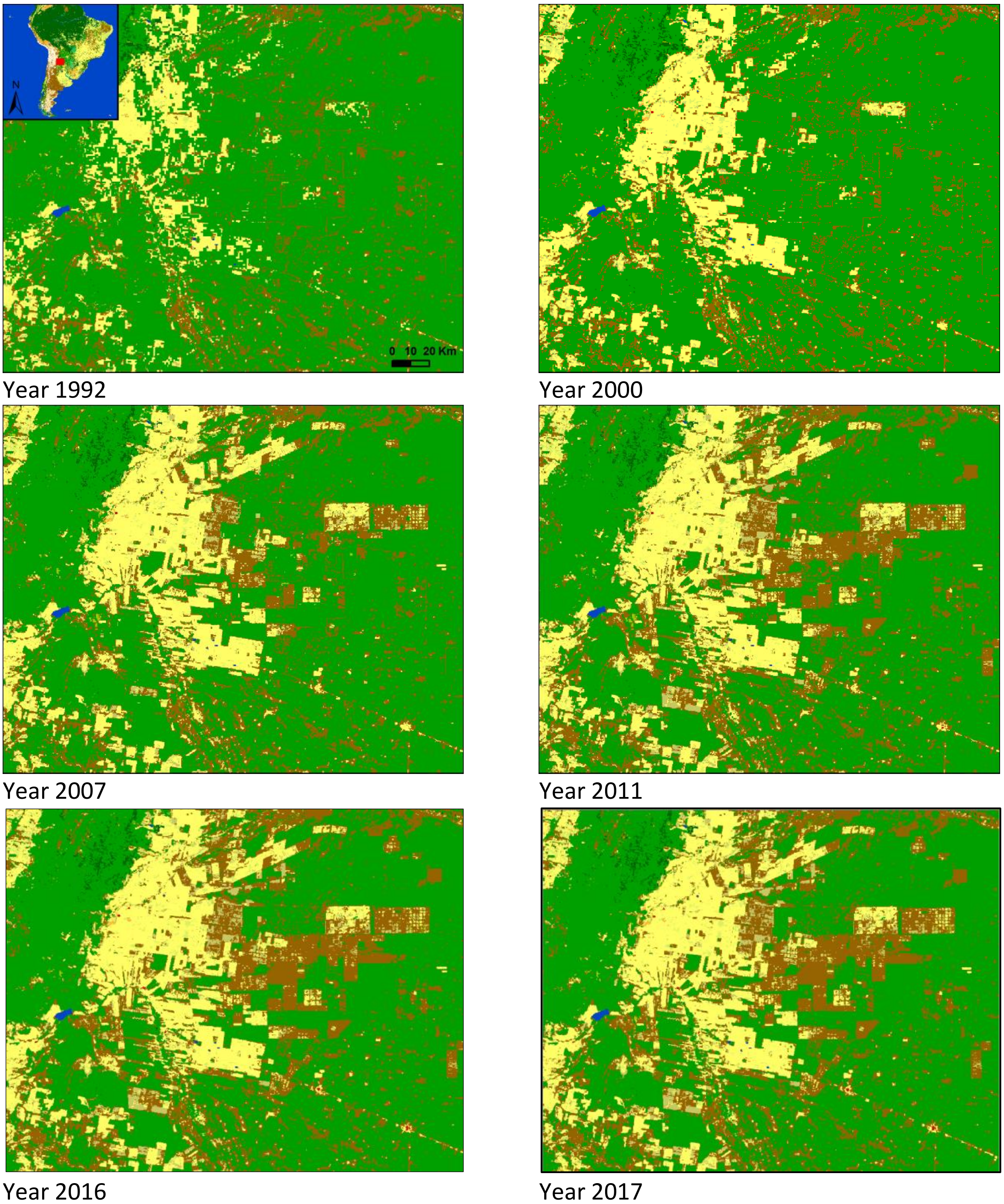

Figure 2: Illustration of a sequence of the global annual land cover maps for years 1992, 2000, 2007, 2011, 2016 and 2017 for an area of the Salta Province in Argentina.

The method used, and characteristics of the 2016 and 2017 LC maps are consistent with the process used to create the CCI-LC maps. The following sections describe the legend of the LC maps, the processing chain including the classification and change detection modules and finally, the format of the maps and their four quality flags, valid for the full-time series.

1.1.1 Legend

The typology was defined using the Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO), with the view to be as much as possible compatible with the GLC2000, GlobCover 2005 and 2009 products. In addition, the UN-LCCS was found quite compatible with the Plant Functional Types (PFTs) used in climate models [ESA, 2011].
The UN-LCCS defines LC classes using a set of classifiers. The system was designed as a hierarchical classification, which allows adjusting the thematic detail of the legend to the amount of information available to describe each LC class, whilst following a standardized classification approach.
As the LC maps are designed to be globally consistent, their legend is determined by the level of information that is available and that makes sense at the scale of the entire world. The "level 1" legend – also called "global" legend – presented in Table 2 meets this requirement. This legend counts 22 classes and each class is associated with a ten values code (i.e. class codes of 10, 20, 30, etc.).
The LC maps are also described by a more detailed legend, called "level 2" or "regional". This level 2 legend makes use of more accurate and regional information – where available – to define more LCCS classifiers and so to reach a higher level of detail in the legend. This regional legend has, therefore, more classes, which are listed in Appendix A. The regional classes are associated with non-ten values (i.e. class codes such as 11, 12, etc.). They are not present all over the world since they were not properly discriminated at the global scale.
The explicit LCCS definition of each LC global and regional class is provided in Appendix A.

Table 2: Level 1 (or global) legend of the LC maps, based on the UN-LCCS.

Value	Label	Color	RGB
0	No Data		0, 0, 0
10	Cropland, rainfed		255, 255, 100
20	Cropland, irrigated or post-flooding		170, 240, 240
30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)		220, 240, 100
40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)		200, 200, 100
50	Tree cover, broadleaved, evergreen, closed to open (>15%)		0, 100, 0
60	Tree cover, broadleaved, deciduous, closed to open (>15%)		0, 160, 0
70	Tree cover, needleleaved, evergreen, closed to open (>15%)		0, 60, 0
80	Tree cover, needleleaved, deciduous, closed to open (>15%)		40, 80, 0
90	Tree cover, mixed leaf type (broadleaved and needleleaved)		120, 130, 0
100	Mosaic tree and shrub (>50%) / herbaceous cover (<50%)		140, 160, 0
110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)		190, 150, 0
120	Shrubland		150, 100, 0
130	Grassland		255, 180, 50
140	Lichens and mosses		255, 220, 210
150	Sparse vegetation (tree, shrub, herbaceous cover) (<15%)		255, 235, 175
160	Tree cover, flooded, fresh or brackish water		0, 120, 90
170	Tree cover, flooded, saline water		0, 150, 120
180	Shrub or herbaceous cover, flooded, fresh/saline/brackish water		0, 220, 130

Value	Label	Color	RGB
190	Urban areas		195, 20, 0
200	Bare areas		255, 245, 215
210	Water bodies		0, 70, 200
220	Permanent snow and ice		255, 255, 255

Among these LC classes, four were largely identified thanks to external datasets: the “tree cover, flooded, saline water” (class value 170) class which is based on the global mangrove atlas [UNEP-WCMC, 2002], the “urban areas” (class value 190) which relies both on the Global Human Settlement Layer [Pesaresi et al., 2016] and on the Global Urban Footprint [Esch et al., 2017], the “water bodies” (class value 210) which have been inherited from the CCI global map of open water bodies and the “permanent snow and ice” (class value 220) which comes from the Randolph Glaciers Inventory [Pfeffer et al., 2014] (to which the CCI-Glaciers project is one of the main contributors).

1.1.2 Processing chain

A key aspect of the LC maps consists in their consistency over time. As a result, the set of annual maps are not produced independently, but they are derived from a unique baseline LC map, which is generated thanks to the entire MERIS FR and RR archive from 2003 to 2012. Independently from this baseline, LC changes are detected at 1 km based on the AVHRR time series between 1992 to 1999, SPOT-VGT time series between 1999 and 2013 and PROBA-V data for years 2013 to 2017. When MERIS FR or PROBA-V time series are available, changes detected at 1 km are re-mapped at 300 m. The last step consists in back and up-dating the 10-year baseline LC map to produce the 26 annual LC maps from 1992 to 2017.
The logical model underlying this processing chain is illustrated in Figure 3 and the EO data used to generate the global LC maps are summarized in Table 3.

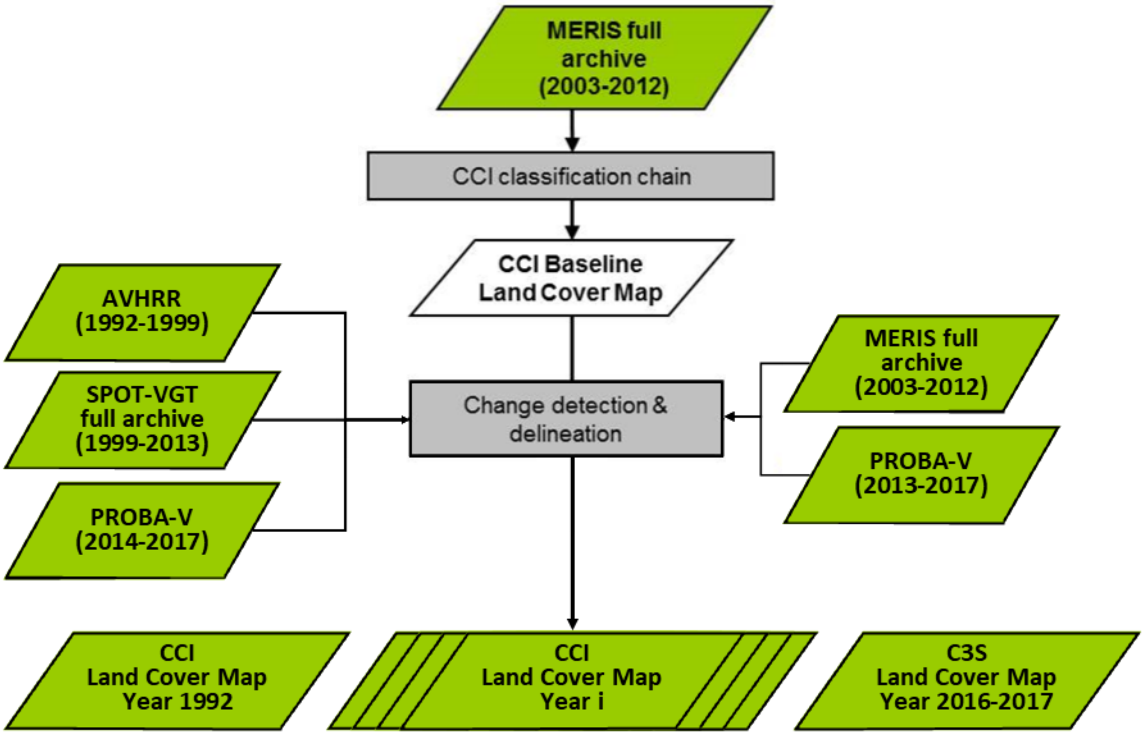

Figure 3: Schematic representation of the LC classification chain that generates global annual LC maps. The chain is made of 2 main processes and makes use of the entire archives of Envisat MERIS (2003 -2012), AVHRR (1992 - 1999), SPOT-VGT (1999 - 2013) and PROBA-V data for 2013 - 2017.

Table 3: Satellite data sources used to generate the global LC maps.

Global LC database	Reference period	Satellite data source
Baseline 10-year global LC map	2003-2012	• MERIS FR/RR global SR composites between 2003 and 2012
Global annual LC maps	1992-1999	• Baseline 10-year global LC map • AVHRR global SR composites between 1992 and 1999 for back-dating the baseline
	1999-2013	• Baseline 10-year global LC map • SPOT-VGT global SR composites between 1999 and 2013 for up and back-dating the baseline • MERIS FR global SR composites between 2003 and 2012 to delineate the identified changes at 300 m spatial resolution • PROBA-V global SR composites at 300 m for year 2013 to delineate the identified changes at 300 m spatial resolution
	2014-2017	• Baseline 10-year global LC map • PROBA-V global SR composites at 1 km for years 2014 to 2017 for up-dating the baseline • PROBA-V time series at 300 m for 2014 to 2017 to delineate the identified changes the LC map spatial resolution

The classification module that generates the baseline map was developed by the Université catholique de Louvain (UCLouvain). It was designed to be globally consistent while regionally-tuned. It capitalized on the GlobCover unsupervised classification chain [Bicheron et al., 2008] while also relying on a machine learning algorithm and on a multiple-year strategy [Bontemps et al., 2012]. In this way, it combined both the spectral and temporal richness of the MERIS FR time series.
The change module works independently from the above-mentioned classification module. It consists of 2 consecutive steps: change detection at 1 km and change delineation at 300 m. The first step of the change module consists in mapping the dynamics of the land surface by analysing, on a per-pixel basis, annual time series of 1-km global classifications from 1992 to 2017 [ESA, 2017a]. These annual classifications are derived from AVHRR time series between 1992 to 1999, SPOT-VGT time series from 1999 to 2013 and PROBA-V time series from 2014 to 2017. With their 1 km resolution, they allow capturing the dominant land cover transitions. Yet, to avoid false change detections due to the inter-annual variability in classifications, each change must be confirmed over more than two successive years in the classification time series.
In the most dynamic regions of the world, more than one land cover change can be detected between 1992 and 2017. Most of the pixels are associated with 0, 1, 2 or 3 land cover changes, knowing that each change needs to last at least two years to be detected. For instance, a forest loss to shrubland for two years followed by a forest recovery is too short to be detected as LC change.
Examples of annual classification time series analyses are given in Figure 4.

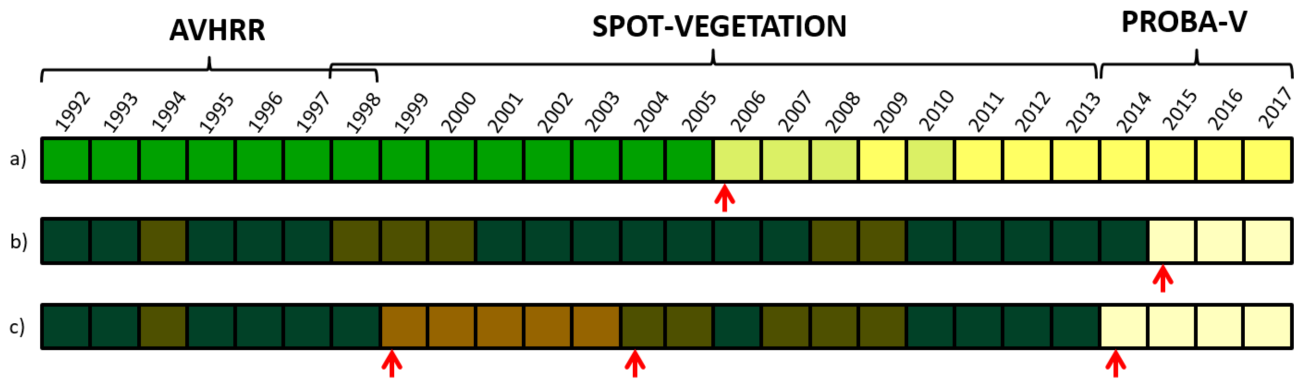

Figure 4: Change detection on a pixel basis from a time series of annual 1-km global classifications (1992 to 2017): AVHRR, SPOT-VGT and PROBA-V). Red arrows indicate years of change detected along the time series.

The change is detected between land cover classes grouped into the six IPCC land categories, i.e. cropland, forest, grassland, wetland, settlement and other land. This latter class is further split into shrubland, sparse vegetation, bare area and water. This grouping was a requirement expressed by the climate users. It also avoids false change detection between LC classes that are semantically close. The correspondence between these IPCC land categories and the LCCS legend used in the LC maps is defined in Table 4.

Table 4: Correspondence between the IPCC land categories used for the change detection and the LCCS legend used in the LC classes.

IPCC Classes considered for the change detection		LCCS legend used in the CCI-LC maps	
1. Agriculture		10, 11, 12	Rainfed cropland
		20	Irrigated cropland
		30	Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)
		40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (< 50%)
2. Forest		50	Tree cover, broadleaved, evergreen, closed to open (>15%)
		60, 61, 62	Tree cover, broadleaved, deciduous, closed to open (> 15%)
		70, 71, 72	Tree cover, needleleaved, evergreen, closed to open (> 15%)
		80, 81, 82	Tree cover, needleleaved, deciduous, closed to open (> 15%)
		90	Tree cover, mixed leaf type (broadleaved and needleleaved)
		100	Mosaic tree and shrub (>50%) / herbaceous cover (< 50%)
		160	Tree cover, flooded, fresh or brackish water
		170	Tree cover, flooded, saline water
3. Grassland		110	Mosaic herbaceous cover (>50%) / tree and shrub (<50%)
		130	Grassland
4. Wetland		180	Shrub or herbaceous cover, flooded, fresh-saline or brackish water
5. Settlement		190	Urban
6. Other	Shrubland	120, 121, 122	Shrubland
	Sparse vegetation	140	Lichens and mosses
		150, 151, 152, 153	Sparse vegetation (tree, shrub, herbaceous cover)
	Bare area	200, 201, 202	Bare areas
	Water	210	Water

The second step of the change module is the detailed delineation of the change detection 1-km hot spots and their surroundings (up to 5 km) at 300 m between 2004 and 2017 thanks to the MERIS and PROBA-V time series available at a spatial resolution of 300 m at this period.

1.2 Target requirements

Considering the importance of LC as an input in climate modelling, the development of a new global LC database was initiated during the 1st phase of the 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, 2011].

This analysis revealed first the need to consider LC data under 2 aspects: stable in the form of LC 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 LC state and LS seasonality [ESA, 2014]. The LC state 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 state products consistent over time resulted in the development of a new original classification approach. Most often, LC maps were generated from a few instantaneous observations of the land cover state. As a result, classification outputs are sensitive to the date(s) of observation and can reflect temporary conditions (e.g. map savannahs as burnt scars, boreal forest as snow, croplands as bare soils, etc.). The developed alternative consisted in describing the LC state 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 in the CCI LC and C3S LC projects.

As a result of the CCI user requirement analysis, a number of product requirements were identified, as outlined in Table 5. These requirements are transferable and applicable in the C3S LC project.

Table 5: Threshold (minimum) and target (optimal) requirements identified for LC products in the User Requirements Survey carried out in the CCI LC project Phases I and II. Check-marks indicate fulfilled requirements [ESA, 2015].

	Threshold req. Phase 1	Target req. Phase 1	Threshold req. Phase 2	Target req. Phase 2
	COVERAGE AND SAMPLING			
Geographic Coverage	Global ✓	Global with regional and local specific products ✗	Global with regional specific products ✓	Global with regional specific products ✗
Temporal sampling	Best/stable map and regular updates ✓	Monthly data on vegetation dynamics and change ✗	5-10 year epoch maps with monthly vegetation dynamics (NDVI) ✓	1-year epoch maps. Monthly data on vegetation dynamics (NDVI) ✓
Temporal extent	1-2 years, most recent ✓	1990 (or earlier)-present ✗	1990 (or earlier) - present ✓	1980 (or earlier) - present ✗
	RESOLUTION			

	Threshold req. Phase 1	Target req. Phase 1	Threshold req. Phase 2	Target req. Phase 2
Horizontal Resolution	1000 m ✓	30 m ✗	300 m ✓ with regional 30 m products ✗	30 m ✗
Vertical Resolution	–	–		
	ERROR/UNCERTAINTY			
Precision	Thematic LC detail sufficient to meet current modelling user needs ✓	Thematic LC detail sufficient to meet future model needs ✗	Thematic LC detail (incl. conversion tables to PFT for climatic regions) sufficient to meet current and future model needs, incl. key land IPCC changes ✓	Thematic LC detail (incl. conversion tables to PFT for climatic regions and traits) sufficient to meet current and future model needs, incl. LC changes and management ✗
Accuracy	Higher accuracy than existing datasets ✓	Errors less than 5-10% either per class or as overall accuracy ✗	Higher accuracy than existing datasets ◆	Errors less than 5-10% either per class or as overall accuracy ◆
Stability	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 ◆
Error Characte-ristics	Independent one-time accuracy assessment ✓	Operational and independent multi-date validation ✗	Independent multi-date validation ✓	Operational and independent multi-date validation ✓

1.3 Data usage information

1.3.1 Naming convention

The filename convention of the global LC maps delivered by the C3S LC project is the following:
Filename = <id>-v<version>.nc

where <id> = <project>-<level>-<var>-<code>-<spatres>-<tempres>-<epoch>-<area>

The dash "-" is the separator between name components. The filename convention obeys NetCDF CF by using the postfix ".nc". The different name components are defined in Table 6.

Table 6. Components that make the name of the LC maps delivered by the CCI-LC project

Field	Signification	Value
project	Project acronym	C3S-LC (constant)
level	Processing level	L4 (constant)
var	Unit of the LC product	LCCS (constant)
code	Product code identifier for C3S-LC products	Map (constant)
spatres	Spatial resolution	300m (constant)
tempres	Temporal resolution	P1Y (constant)
epoch	Year of the product	[2017 -]
version	Incremental that follows the successive revisions of the CCI-LC Processing lines	Version of product revision, preferably major.minor, optionally with processing centre [a-zA-Z0-9._]*

An example filename of the global LC map for year 2017 would be:

C3S-LC-L4-LCCS-Map-300m-P1Y-2017-v2.1.nc.

1.3.2 Processing level

Level 4 (i.e. "variables that are not directly measured by the instruments, but are derived from these measurements" [CEOS, 2008].

1.3.3 Units

Each pixel value corresponds to the label of a land cover class defined using UN-LCCS classifiers (see Table 2 in Section 1.1.1 and in Appendix A – Specifications for Land Cover maps 2016 and 7).

1.3.4 Spatial Extent

All terrestrial zones of the Earth between the parallels 90°N and 90°S.

1.3.5 Spatial Resolution

The spatial resolution of the LC product is approximately 300 m. The products are distributed in a cartographic projection with pixel size of 0.002778 degrees.

1.3.6 Temporal Resolution

The LC maps are generated on an annual basis.

1.3.7 Product Layer

The land cover maps are delivered along with four quality flags, which document the reliability of the classification and change detection (Table 7).

Table 7: Quality flags of the LC maps.

Bandname in product	Data Type	Description
lccs_class	byte	LC classification in LCCS (22 global classes + NoData coded as 0)
processed_flag	byte	Indicates if the pixel has been processed (1) or not (0) 0 - pixel not processed 1 - pixel processed
current_pixel_state	byte	Indicates the pixel status as defined by the pre-processing: 1 - Pixel flagged as "clear land" 2 - Pixel flagged as "clear water" 3 - Pixel flagged as "clear snow and ice" 4 - Pixel flagged as "cloud" 5 - Pixel flagged as "cloud shadow" 6 - Pixel flagged as "filled"
observation_count	byte	Indicates the number of valid observations available to derive the classification
change_count	byte	Provides the number of LC change observed during the period 1992-2017 (ranging from 0 to 5) per pixel

1.3.8 Projection

The projection is a Plate-Carrée with a geographic Lat/Long representation based on the WGS84 ellipsoid (Figure 5). The Coordinate Reference System (CRS) used for the global LC products is a geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid and using a Plate Carrée projection.
The projection makes use of an equatorial radius (also called semi-major axis) of 6378.14 km and of a polar radius (also called semi-minor axis) of 6356.76 km. The inverse flattening parameter is of 298.26 m. The coordinates are specified in decimal degrees. A complete description of the CRS is given in as an ISO 19111 WKT representation.

```
GEOGCS["GCS_WGS_1984",
    DATUM["D_WGS_1984",
        SPHEROID["WGS_1984",6378137.0,298.257223563]],
    PRIMEM["Greenwich",0.0],
    UNIT["Degree",0.0174532925199433],
AUTHORITY["EPSG",4326]]
```

Figure 5: Description of the coordinate reference system defining the global LC products.

1.3.9 File format and size

The LC maps are delivered in NetCDF-4 format. The NetCDF files specification follows the CF conventions [NetCDF, 2010].
The size of one global land cover map product is around 2.5 GB. These estimations take an internal LZW compression into account.

1.3.10 Metadata

The metadata for the LC maps are provided as global attributes in the NetCDF file. It follows the CCI guidelines [Bennett, 2012].

1.4 Qualitative assessment

The following figures present the consistency between the 2016 and 2017 annual LC maps, which are the most recent of the LC map series, and selected LC maps of the 1992 - 2015 series.

The drying up of the Aral Sea is in agreement with recently published research [Pekel et al., 2016].

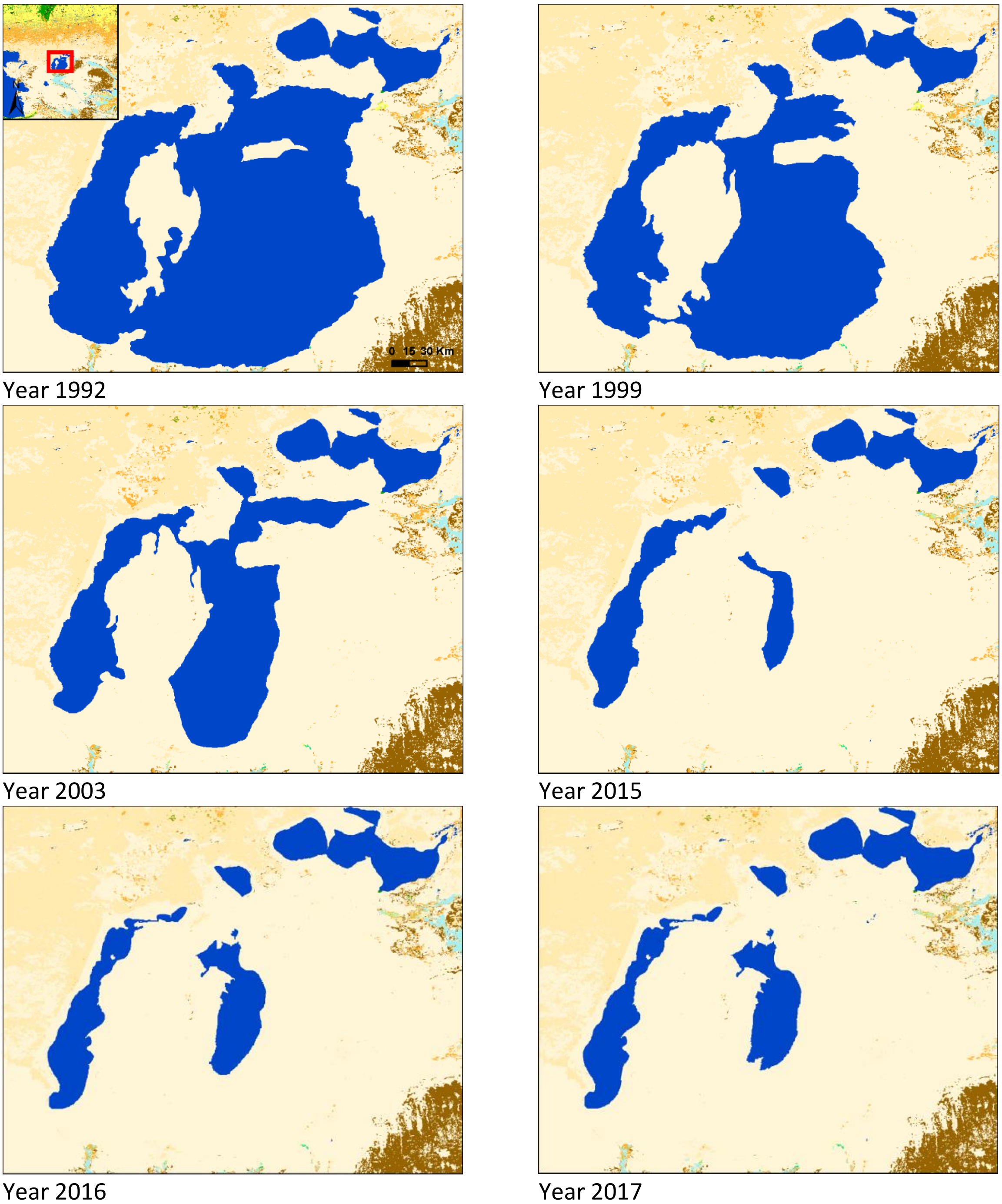

Figure 6: Dynamics of the Aral Sea illustrated by the CCI global annual land cover maps for years 1992, 1999, 2003, 2015, 2016 and 2017.

1.5 Validation

A critical step in the acceptance of the LC maps by the user communities is providing confidence in their quality, through validation against independent data such as ground-based reference measurements, or alternate estimates from other projects and sensors.
The main objective of the validation is to allow a potential user determining the "map's fitness for use" for his / her application. There are several definitions of validation available from various agencies, and it was agreed that the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (CEOS-WGCV) definition would be adopted within the CCI program:

> *"The process of assessing, by independent means, the quality of the data products derived from the system outputs".*

The validation process independence has been ensured (i) using validation datasets that were not used during the production of the LC maps and (ii) being carried out by external parties, i.e. by staff not involved in the production of the LC maps.
The results of the contingency matrices and overall accuracies will be communicated as soon as it is possible to do so.

1.6 Limitations

- **Classification accuracy related to the number of observations in the MERIS archive**

As already mentioned, users have to know that the quality of the map varies according to the region of interest. Looking at the number of valid observations available over a region (information that is provided in the quality flag 3) can give a first indication about the input data quality and the expected classification reliability. Areas affected by a lower MERIS FR coverage are the western part of the Amazon basin, Chili and the southern part of Argentina, the western part of Congo basin as well as the Gulf of Guinea, the eastern part of Russia, the eastern coast of China and Indonesia.

- **Not all possible changes between the 22 LC classes are captured in the dataset**

Given the methodology to detect the change (section 1.1.2), it is of paramount importance to highlight that the LC dataset does not capture all the possible changes between the 22 LCCS land cover classes.
The 22 LCCS land cover classes are indeed grouped into the 6 IPCC land categories, with the consideration of the subcategories shrubland, sparse vegetation, bare area and water (forming the "Other" IPCC main land category), as explained in Table 4.
Consequently, any change occurring between LCCS classes being part of the same IPCC land category is not captured by the LC dataset. More precisely, the LC dataset does not provide information on:

- the conversions between rainfed (class values 10, 11 and 12) and irrigated agriculture (class value 20). As a result, the agriculture intensification through the irrigation will not be detected as a change;
- the conversion between forest classes (e.g. conversion of broadleaved to mixed forests, flooded forest dewatering or salinization of a forest flooded with fresh water);
- the conversion between sparse vegetation (class value 150) and lichens and mosses (class value 140);

- the conversion between a “pure”[1] class and a mosaic class (e.g. forest degradation characterized by the evolution of a pure forest (class values 50 to 90) to a mosaic of natural vegetation (class values 100 and 110); cropland intensification characterized by the conversion of a mosaic of cropland and natural vegetation (class values 30 and 40) to a rainfed or irrigated cropland (class values 10 to 20); forest regeneration characterized a mosaic of natural vegetation (class values 100 and 110) to a pure forest (class values 50 to 90).
- the conversion between “level 2” or “regional” classes (see section 1.1.1), whatever the IPCC land category. This corresponds to any dynamics specific to herbaceous vs woody cropland (class values 11 and 12), to the density of the forests (depicted in the level 2 of the forest classes 61, 62, 71, 72, 81 and 82), to the phenology of the shrubland (class values 121 and 122), to the type of the sparse vegetation (class values 151, 152, 153) or the type of bare area (class values 201 and 202).

- **Abrupt changes better captured than gradual ones**

To allow the detection of a change from a class X to a class Y, the developed method needs to observe the new class Y during at least 2 consecutive years. This was explained in detail in section 1.1.2, Figure 4. Consequently, abrupt changes are better captured than gradual ones.
Abrupt changes are characterized by sudden LC transitions from one IPCC class to another that most often last more than 2 years (e.g. a forest loss to an agriculture class in Figure 2).
Conversely, gradual changes that can be understood as slow transitions between two IPCC classes by going through intermediate mosaic classes are not so well detected. An example of gradual change would be transitions from shrubland (class value 120) to bare area (class value 200) by going through successive land cover states such as mosaics and grasslands classes lasting during maximum 2 years.

- **Change delineated at 300 m based on hot spots of change detected at 1 km**

All annual LC maps are delivered at 300 m spatial resolution, but it is to be reminded that the change detection is performed at 1 km spatial resolution, based on the AVHRR, SPOT-VGT and PROBA-V missions. It means that only land cover changes visible at 1 km are detected. These hot spots of change and their surroundings (up to 5 km) are then further delineated at 300 m starting 2004 onwards thanks to the availability of the 300 m MERIS and PROBA-V time series at this period.
As a result, several cases of change omissions are observed in the annual LC maps. First, changes of low intensity and/or surface below 1 km² are not detected. Second, changes are not delineated at 300 m if it does not occur in the surroundings of a hot spot of change detected at 1 km. In other words, if the change occurs at a distance greater than 5 km away from the 1 km change hot spot. Finally, changes will not be delineated at 300 m if they occur before year 2004 as no MERIS and PROBA-V time series exist at 300 m before 2003.

- **Changes along the coastlines and of permanent snow and ice class not included in the LC products**

Changes along the coastlines are not captured with a change detection algorithm based on 1-km observations. Yet, an exception is made for changes related to the Saudi Arabia manmade islands.

[1] “pure“ is here expressed as opposed to “mosaic“ or “mixed“ class, which have the values 30, 40, 100 and 110

In addition, the permanent snow and ice (class value 220) remains constant over time and relies solely on the Randolph Glaciers Inventory [Pfeffer et al., 2014].

- **Change during the AVHRR 1992 - 1999 period**

The performance of the change detection is highly dependent on the input data quality and availability. The general lower quality of AVHRR surface reflectances and georeferencing implies a less reliable change detection. In addition, the lack of AVHRR data in year 1994 reduces the change detection reliability for this year.

2 Data access information

2.1 Access to the users through the CDS

The C3S LC maps are available through the C3S Climate Data Store (CDS). The CDS provides open, free and unrestricted access to a wide range of quality-assured climate datasets. In addition to this, the CDS includes a set of tools for analysing and predicting the impacts of climate change.

Once the data have been published by the CDS, the data can be accessed using this link: https://cds.climate.copernicus.eu/ and searching for Land Cover. But the data sets are not yet available at the moment of the review of the document in April 2019.

Furthermore, the CDR LC products are also made available through the CCI-LC visualization interface (http://maps.elie.ucl.ac.be/CCI/viewer/index.html).

2.2 Data provider

The C3S Land Cover v2.1 is a dataset produced by UCLouvain. BC is responsible for the required pre-processing and for the distribution of the dataset.

The point of contact is:

- Email: copernicus-support@ecmwf.int
- Website: http://climate.copernicus.eu/contact-us

2.3 Copyright notice: © ESA Climate Change Initiative – Land Cover project 2017 and EC C3S Land cover

Should you write any scientific publication on the results of research activities that use one or several CCI-LC or C3S products as input, you shall acknowledge the ESA CCI Land Cover and the EC C3S Land cover project in the text of the publication and provide the project with an electronic copy of the publication (contact@esa-landcover-cci.org and copernicus-support@ecmwf.int).

If you wish to use one or several LC products in advertising or in any commercial promotion, you shall acknowledge the ESA CCI Land Cover and EC C3S Land cover project and you must submit the layout to the project for approval beforehand (contact@esa-landcover-cci.org and copernicus-support@ecmwf.int).

Appendix A – Specifications for Land Cover maps 2016 and 2017

Appendix A - C3S and CCI Land Cover legend

Hierarchical global and regional legends

Label		Value		Color	RGB
Global	Regional	Global	Regional		
No Data		0			0, 0, 0
Cropland, rainfed		10			255, 255, 100
	Cropland, rainfed, herbaceous cover		11		255, 255, 100
	Cropland, rainfed, tree or shrub cover		12		255, 255, 0
Cropland, irrigated or post-flooding		20			170, 240, 240
Mosaic cropland (>50%) / natural vegetation (tree, shrub, herbaceous cover) (<50%)		30			220, 240, 100
Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%) / cropland (<50%)		40			200, 200, 100
Tree cover, broadleaved, evergreen, closed to open (>15%)		50			0, 100, 0
Tree cover, broadleaved, deciduous, closed to open (>15%)		60			0, 160, 0
	Tree cover, broadleaved, deciduous, closed (>40%)		61		0, 160, 0
	Tree cover, broadleaved, deciduous, open (15-40%)		62		170, 200, 0
Tree cover, needleleaved, evergreen, closed to open (>15%)		70			0, 60, 0
	Tree cover, needleleaved, evergreen, closed (>40%)		71		0, 60, 0
	Tree cover, needleleaved, evergreen, open (15-40%)		72		0, 80, 0
Tree cover, needleleaved, deciduous, closed to open (>15%)		80			40, 80, 0
	Tree cover, needleleaved, deciduous, closed (>40%)		81		40, 80, 0

Label		Value		Color	RGB
Global	Regional	Global	Regional		
	Tree cover, needleleaved, deciduous, open (15-40%)		82		40, 100, 0
Tree cover, mixed leaf type (broadleaved and needleleaved)		90			120, 130, 0
Mosaic tree and shrub (>50%) / herbaceous cover (<50%)		100			140, 160, 0
Mosaic herbaceous cover (>50%) / tree and shrub (<50%)		110			190, 150, 0
Shrubland		120			150, 100, 0
	Evergreen shrubland		121		150, 100, 0
	Deciduous shrubland		122		150, 100, 0
Grassland		130			255, 180, 50
Lichens and mosses		140			255, 220, 210
Sparse vegetation (tree, shrub, herbaceous cover) (<15%)		150			255, 235, 175
	Sparse tree (<15%)		151		255, 200, 100
	Sparse shrub (<15%)		152		255, 210, 120
	Sparse herbaceous cover (<15%)		153		255, 235, 175
Tree cover, flooded, fresh or brackish water		160			0, 120, 90
Tree cover, flooded, saline water		170			0, 150, 120
Shrub or herbaceous cover, flooded, fresh/saline/brackish water		180			0, 220, 130
Urban areas		190			195, 20, 0
Bare areas		200			255, 245, 215
	Consolidated bare areas	201			220, 220, 220
	Unconsolidated bare areas	202			255, 245, 215
Water bodies		210			0, 70, 200
Permanent snow and ice		220			255, 255, 255

LCCS coding of the C3S and CCI-LC legend

Value	LCCS Entry	LCCS Label	LCCCode	LCCLevel
10	A11 Cultivated Terrestrial Areas and Managed Lands	Rainfed shrub crops // Rainfed tree crops // Rainfed herbaceous crops	11494 // 11490 // 11498	A2XXXXXXD1 // A1XXXXXXD1 // A3XXXXXXD1
11		Rainfed herbaceous crops	11498	A3XXXXXXD1
12		Rainfed shrub crops // Rainfed tree crops	11490 // 11494	A1XXXXXXD1 // A2XXXXXXD1
20		Irrigated tree crops // Irrigated shrub crops // Irrigated herbaceous crops // Post- flooding cultivation of herbaceous crops	11491 // 11495 // 11500 // 11499	A1XXXXXXD3 // A2XXXXXXD3 // A3XXXXXXD3 // A3XXXXXXD2
30		Cultivated and managed terrestrial areas / Natural and semi-natural primarily terrestrial vegetation	0003 / 0004	A11 / A12
40		Natural and semi-natural primarily terrestrial vegetation / Cultivated and managed terrestrial areas	0004 / 0003	A12 / A11
50	A12 Natural and Semi-natural Terrestrial Vegetation – Woody / Trees	Broadleaved evergreen closed to open trees // Broadleaved semi-deciduous closed to open trees	21496 // 21497-15048	A3A20B2XXD1E1 // A3A20B2XXD1E2-E4
60		Broadleaved deciduous closed to open trees	21497	A3A20B2XXD1E2
61		Broadleaved deciduous closed (100-40%) trees	21497-121340	A3A20B2XXD1E2-A21
62		Broadleaved deciduous open (40-(20-10)%) trees	20132-3012	A3A11B2XXD1E2-A13
70		Needleleaved evergreen closed to open trees	21499	A3A20B2XXD2E1
71		Needleleaved evergreen closed (100-40%) trees	21499-121340	A3A20B2XXD2E1-A21
72		Needleleaved evergreen open (40-(20-10)%) trees	20134-3012	A3A11B2XXD2E1-A13
80		Needleleaved deciduous closed to open trees	21500	A3A20B2XXD2E2
81		Needleleaved deciduous closed (100-40%) trees	21500-121340	A3A20B2XXD2E2-A21
82		Needleleaved deciduous open (40-(20-10)%) trees	20135-3012	A3A11B2XXD2E2-A13
90		Broadleaved closed to open trees / Needleleaved closed to open trees	21495 / 21498	A3A20B2XXD1 / A3A20B2XXD2

Value	LCCS Entry	LCCS Label	LCCCode	LCCLevel
100	A12 Natural and Semi-natural Terrestrial Vegetation	Closed to open trees / Closed to open shrubland (thicket) // Herbaceous closed to open vegetation	21445 // 21449 / 21453	A3A20 // A4A20 / A2A20
110		Herbaceous closed to open vegetation // Closed to open trees / Closed to open shrubland (thicket)	21453 / 21445 // 21449	A2A20 / A3A20 // A4A20
120	A12 Natural and Semi-natural Terrestrial Vegetation – Shrubs	Broadleaved closed to open shrubland (thicket)	21449	A4A20
121		Broadleaved Evergreen Closed to Open Thicket // Needleleaved Evergreen Closed to Open Thicket	21517 // 21520	A4A20B3XXD1E1 // A4A20B3XXD2E1
122		Broadleaved Deciduous Closed to Open Thicket // Needleleaved Deciduous Closed to Open Thicket	21518 // 21521	A4A20B3XXD1E2 // A4A20B3XXD2E2
130	A12 Natural and Semi-natural Terrestrial Vegetation – Herbaceous	Herbaceous closed to very open vegetation	21453	A2A20
140		Closed to open lichens/mosses	21465	A7A20
150	A12 Natural and Semi-natural Terrestrial Vegetation	Sparse trees // Herbaceous sparse vegetation // Sparse shrubs	20052 // 20055 // 20058	A3A14 // A4A14 // A2A14
151		Sparse Trees	20052	A3A14
152		Sparse Shrubs	20055	A4A14
153		Herbaceous Sparse Vegetation	20058	A2A14
160	A24 Natural and Semi-natural Aquatic Vegetation	Closed to open (100-40%) broadleaved trees on temporarily flooded land, water quality: fresh water // Closed to open (100-40%) broadleaved trees on permanently flooded land, water quality: fresh water	41638-R1 // 41724-R1	A3A20B2C1D1-R1 // A3A20B2C2D1-R1
170		Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) broadleaved trees on permanently flooded land (with daily variations), water quality: brackish water // Closed to open (100-40%) semi-deciduous shrubland on	41638-4891-R2 // 41638-4891-R3	A3A20B2C1D1-C5-R2 // A3A20B2C1D1-C5-R3

Value	LCCS Entry	LCCS Label	LCCCode	LCCLevel
		permanently flooded land (with daily variations), water quality: saline water // Closed to open (100-40%) semi-deciduous shrubland on permanently flooded land (with daily variations), water quality: brackish water		
180		Closed to open shrubs on permanently flooded land // Closed to open herbaceous vegetation on permanently flooded land // Closed to open shrubs on temporarily flooded land // Closed to open herbaceous vegetation on temporarily flooded land // Closed to open shrubs on waterlogged soil // Closed to open herbaceous vegetation on waterlogged soil Water quality: fresh, brackish or saline water	41897 // 41983 // 42069 // 42347 // 42348 // 42349	A4A20B3C1 // A4A20B3C2 // A4A20B3C3 // A2A20B4C1 // A2A20B4C2 // A2A20B4C3
190	B15 Artificial Surfaces	Artificial surfaces and associated areas	0010	B15
200	B16 Bare Areas	Bare areas	0011	B16
201		Consolidated Material(s)	6001	A1
202		Unconsolidated Material(s)	6004	A2
210	B28 Inland Waterbodies, snow and ice	Natural water bodies // Artificial water bodies	7002 // 8002	A1B1 // A1B1
220		Artificial perennial snow // Artificial perennial ice // Perennial snow // Perennial ice	7005 // 7008 // 8006 // 8009	A2B1 // A3B1 // A2B1 // A3B1

Appendix A – NetCDF attributes

The global land cover products description is based on the structure of the NetCDF files. The global attributes of the land cover maps are described in Table 8 and the variables and variables' attributes of the global LC maps NetCDF file are presented in Table 9.

Table 8 : Global attributes of the global LC maps delivered by the C3S and CCI LC projects, according to the structure of the NetCDF files

Attribute Name	Format	Value	Description
title		C3S-LC-L4-LCCS-Map-300m-P1Y-2017-v2.0cds.nc	Product identifier (see "naming convention" above)
summary		This dataset contains a global land cover map obtained from surface reflectance composites, placed onto a regular grid.	
project		Climate Change Initiative - European Space Agency	
references		http://www.esa-landcover-cci.org/	References that describe the data or methods used to produce it.
institution		UCL	Where the map data has been produced
contact		Pierre.Defourny@uclouvain.be	
source		Proba-V	Source of the original data
history		lc-mosaic-1.1 lc-compositing-1.0 lc-stratification-1.0 lc-classification-1.0 lc-labeling-1.0	List of applications that have modified the surface reflectance composites, with time stamp, processor and parameters
comment			Miscellaneous information about the data or method used to produce it
Conventions		CF-1.6	Name of the conventions followed
type		LCMap-300m	Product type
date_created	yyyy-MM-dd'T'HH:mm:ss'Z'	e.g " 20130424T124732Z"	Creation time of product
creator_name		UCL-Geomatics	
creator_url		http://www.uclouvain.be/elie.html	
creator_email		Pierre.Defourny@uclouvain.be	
epoch	YYYY	[YYYY] where the two "YYYY" are the year of the product	Year of the product,
geospatial_lat_min	-90.0 ... 90.0		South border of the bounding box
geospatial_lat_max	-90.0 ... 90.0		North border of the bounding box

Attribute Name	Format	Value	Description
geospatial_lon_min	-180.0 ... 180.0		West border of the bounding box
geospatial_lon_max	-180.0 ... 180.0		East border of the bounding box
geospatial_lat_units		degrees_north	
geospatial_lat_resolution		e.g " 0.002778 "	
geospatial_lon_units		degrees_east	

Table 9: Variables and variables' attributes of the global LC maps delivered by the C3S and CCI LC projects, according to the structure of the NetCDF files

Variable	Attribute	Format	Value	Description
crs		int		Coordinate reference system attribute container
	grid_mapping_name		Plate Carrée	
	semi_major_axis		6378137.0	
	inverse_flattening		298.257223563	
	false_easting		0.0	
	false_northing		0.0	
	longitude_of_central_meridian		0.0	
	scale_factor_at_central_meridian		1.0	
time		double(time)		Start time of the multi-year period
	standard_name		time	
	long_name		multi-year period	
	units		year	
lon		double (lon)	-180.0 .. 180.0	Longitude coordinate of image column
	standard_name		longitude	
	long_name		WGS84 longitude coordinate	
	units		degrees east	
	valid_min		-180.0	
	valid_max		180.0	
lat		double (lat)	-90.0 .. 90.0	Latitude coordinate of image row
	standard_name		latitude	
	long_name		WGS84 latitude coordinate	

Variable	Attribute	Format	Value	Description
	units		degrees north	
	valid_min		-90.0	
	valid_max		90.0	
lcss_class		byte (lat,lon)		LC classification in LCCS
	standard_name		land cover	
	long_name		LC class defined in LCCS	
	vocabulary		UN-LCCS 2005	
	valid_min		1	
	valid_max		240	
	_FillValue		0b	
processed_flag		byte (lat,lon)		LC map quality flag 1: pixel processed or not
	standard_name		land_cover status_flag	
	long_name		LC map processed area flag	
	valid_min		0	
	valid_max		1	
	_FillValue		-1b	
current_pixel_status		byte (lat,lon)		LC map quality flag 2: pixel status
	standard_name		land_cover status_flag	
	long_name		LC map area type mask	
	valid_min		0	
	valid_max		6	
	_FillValue		-1b	
observation_count		short(lat,long)		LC map quality flag 3: number of valid observations
	standard_name		land_cover number_of_observations	
	long_name		number of valid observations	
	valid_min		0	
	valid_max		32767	
	_FillValue		-1s	
	_FillValue		-1b	
	scale_factor		0.01f	
change_count		byte(lat,long)		LC map quality flag 4: change

Variable	Attribute	Format	Value	Description
				confidence level
	standard_name		change confidence_level	
	long_name		Change confidence level based on change detection module	
	valid_min		0	
	valid_max		100	
	_FillValue		-1b	

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