Copernicus Global Land Operations
"Vegetation and Energy"
"CGLOPS-1"
Framework Service Contract N° 199494 (JRC)

PRODUCT USER MANUAL

MODERATE DYNAMIC LAND COVER
COLLECTION 100M
VERSION 2

Issue I2.20

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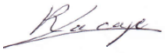
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document Release Sheet

Book captain:	Dr. Marcel Buchhorn	Sign 	Date 10/11/2019
Approval:	Roselyne Lacaze	Sign 	Date 02.12.2019
Endorsement:	Michael Cherlet	Sign	Date
Distribution:	Public		

Change Record

Issue/Rev	Date	Page(s)	Description of Change	Release
	24.06.2017	All	Initial Version	D1.00
	10.10.2017	All	Revision after internal review	I1.20
Draft	29.04.2019	All	Revision for algorithm version 2	D2.00
	10.05.2019	All	Revision for public release with products	I2.10
	10.11.2019	All	Revision after release ATBD and addition of dataset DOI	I2.20

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List of Acronyms

Acronym	Meaning
AD	Applicable Documents
ARD	Analysis Ready Data
ATBD	Algorithm Technical Basis document
BFAST	Break for Additive Season and Trend
CCI	Climate Change Initiative
CF V1.6	Climate & Forecast conventions compliant with version 1.6
CGLS	Copernicus Global Land service
COG	Cloud-Optimized GeoTIFF
CRS	Coordinate Reference System
DDI	Data Density Indicator
DOI	Digital Object Identifier
EO	Earth Observation
EPSG	European Petroleum Survey Group
EU	European Union
FAO	Food and Agriculture Organization of the united nation
GeoTIFF	Geospatial Tagged Image File Format
GSD	Ground Sampling Distance
IIASA	International Institute for Applied Systems Analysis
JRC	Joint Research Center
LC	Land Cover
LC100	Land Cover map at 100 m resolution
LCCS	Land Cover Classification System
MC5	5-daily Median Composite
NDVI	Normalized Difference Vegetation Index
OECD	Organisation for Economic Cooperation and Development
PPSIM	Potential Permanent Snow and Ice Mask
PROBA-V	Vegetation instrument on board of PROBA satellite
PSD	Product Specifications Document
PUM	Product User Manual
PVC	Percentage Vegetation Cover
R&D	Research And Development
REDD+	Reducing Emissions from Deforestation and forest Degradation
RF	Random Forest classifier
RGB	Red Green Blue
SDG	Sustainable Development Goal
SEEA	System of Environmental and Economic Accounting
SM	Status Mask
SSD	Service Specifications Document

SVP	Service Validation Plan
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
URD	Users Requirements Document
UTM	Universal Transverse Mercator
VI's	Vegetation Indices
VITO	Vlaamse Instelling voor Technologisch Onderzoek (Flemish Institute for Technological Research), Belgium
VR	Validation Report
WGS84	World Geodetic System 1984
WUR	Wageningen University and Research

EXECUTIVE SUMMARY

The Copernicus Global Land Service (CGLS) is earmarked as a component of the Land service to operate “a multi-purpose service component” that provides a series of bio-geophysical products (i.e. Essential Variables like the Leaf Area Index, Land Surface Temperature, soil moisture, etc.) on the status and evolution of land surface at global scale. Production and delivery of the parameters take place in a timely manner, at hourly, daily or every 10 days from Earth Observation satellite data, and are complemented by the constitution of long-term time series.

The CGLS delivers a yearly dynamic global Land Cover product at 100 m spatial resolution (CGLS_LC100). Land cover plays a major role in the climate and biogeochemistry of the Earth system. The CGLS Land Cover product provides a primary land cover scheme at three levels, 12 classes at level 1 up to 23 classes at level 3, with classes according to the Land Cover Classification System (LCCS) scheme. Next to these discrete classes, the product also includes continuous field layers or “fraction maps” for all basic land cover classes that provide proportional estimates for vegetation/ground cover for the land cover types. This continuous classification scheme may depict areas of heterogeneous land cover better than the standard classification scheme and, as such, can be tailored for application use (e.g. forest monitoring, rangeland management, crop monitoring, biodiversity and conservation, monitoring environment and security in Africa, climate modelling, etc.)

The first Land Cover map, produced with algorithm V1.0, was provided for the 2015 reference year over the African continent, derived from the PROBA-V 100 m time-series, a database of high quality land cover training sites and several ancillary datasets.

A second version of Land Cover map (V2.0) is provided for the 2015 reference year over the entire globe, reaching an accuracy of 80 % for each continent at Level 1. This Product User Manual describes this global Land Cover V2.0 product. Note that this second version includes for the first time yearly land cover change maps (V2.1) from 2016 to 2018 over the African continent that are described in a specific Product User Manual.

A third version of Land Cover map (V3.0) is in preparation to provide yearly land cover change maps over the entire Globe from 2016 to 2019, derived from the PROBA-V 100m time-series, and from 2020 continued through the use of a Sentinel time-series.

1 BACKGROUND OF THE DOCUMENT

1.1 SCOPE AND OBJECTIVES

This Product User Manual (PUM) is the primary document that users have to read before handling the second version (V2.0) of Collection 100m CGLS Land Cover products.

It gives an overview of the product characteristics, in terms of algorithm, technical characteristics, and main validation results.

1.2 CONTENT OF THE DOCUMENT

This document is structured as follows:

- Chapter 2 summarizes the retrieval methodology,
- Chapter 3 describes the technical properties of the product,
- Chapter 4 summarizes the results of the quality assessment,
- Chapter 5 lists all references to cited literature

The users' requirements are recalled in the Annex.

1.3 RELATED DOCUMENTS

1.3.1 Applicable documents

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

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

AD3: GIO Copernicus Global Land – Technical User Group – Service Specification and Product Requirements Proposal – SPB-GIO-3017-TUG-SS-004 – Issue I1.0 – 26 May 2015.

1.3.2 Input

Document ID	Descriptor
CGLOPS1_SSD	Service Specifications of the Global Component of the Copernicus Land Service.
CGLOPS1_SVP	Service Validation Plan of the Global Component of the Copernicus Land Service
CGLOPS1_URD_LC100m	User Requirements Document for the dynamic

	moderate land cover product
CGLOPS1_PSD_LC100m	Product Specification Document for the Version 2 of dynamic moderate land cover product.
CGLOPS1_TrainingDataReport_LC100m	Report presenting the training dataset used for the Dynamic Moderate Land cover product
CGLOPS1_ATBD_LC100_V2.0	Algorithm Theoretical Basis Document of the Collection 100 m dynamic moderate land cover Version 2 product.
CGLOPS1_VR_LC100_V2.0	Report describing the results of the scientific quality assessment of the Collection 100 m dynamic moderate land cover Version 2.0 product.
CGLOPS1_PUM_LCC100-V2.1	Product User Manual of the Collection 100m land cover change product, version 2.1.

1.3.3 External documents

PROBA-V	http://proba-v.vgt.vito.be/
PROBA-V User Manual	User Guide of the PROBA-V data, available on http://www.vito-eodata.be/PDF/image/PROBAV-Products_User_Manual.pdf

2 ALGORITHM

2.1 RETRIEVAL METHOD

The CGLS Dynamic Land Cover Map at 100 m resolution (CGLS_LC100) product is generated by combining several proven individual methodologies through:

1. Data pre-processing including atmospheric & geometric correction
2. Data cleaning and (temporal) outlier detection techniques,
3. Applying data fusion techniques at multiple levels,
4. Supervised classification, and
5. Including established third party datasets via expert rules.

The workflow, shown in Figure 1, can be divided into the following sections:

1. PROBA-V UTM Analysis Ready Data (ARD) generation,
2. data cleaning & compositing,
3. quality indicator generation from PROBA-V UTM ARD+ input data,
4. data fusion,
5. metrics generation/extraction,
6. ancillary datasets products generation,
7. training data generation,
8. classification / regression,
9. cover fraction layers generation,
10. land cover map generation plus final quality layer assembling.

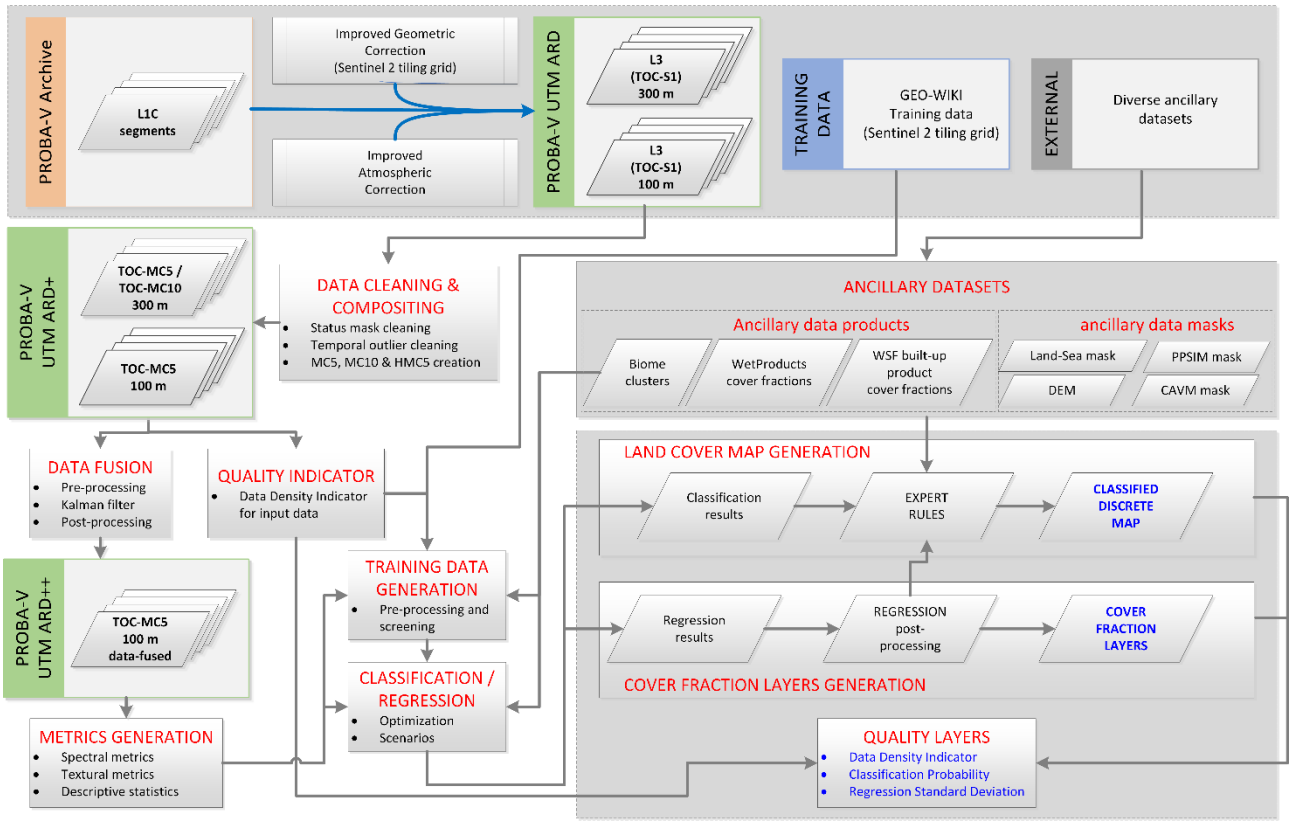

Figure 1: Workflow diagram for the CGLS Dynamic Land Cover 100 m (CGLS-LC100) products

To reduce distortion in the High North, to make our land cover products better usable with other data and to allow continuity of the service, the PROBA-V archive used as current main input data source was reprocessed with a new geometric correction and an improved atmospheric correction. The complete PROBA-V archive was, in this way, translated into the PROBA-V Universal Transverse Mercator (UTM) Analysis Ready Data (ARD) which is fully aligned with the Sentinel-2 tiling grid in tiling naming as well as tile dimensions.

The PROBA-V UTM ARD main product, the 5-daily PROBA-V multi-spectral image data with a Ground Sampling Distance (GSD) of ~0.001 degree (~100 m), is used as primary earth observation (EO) data, and PROBA-V UTM daily multi-spectral image data with a GSD of ~0.003 degree (~300 m) secondarily. Next to a Status Mask (SM) cleaning using the internal quality flags of the PROBA-V EO data, a temporal cloud and outlier filter built on a Fourier transformation is applied to clean the data. From this cleaned and outlier screened data a Data Density Indicator (DDI) is calculated which is used as input quality indicator in the supervised learning process.

Next, to improve the data density in the 5-daily 100 m time series, the 100 m and 300 m EO datasets are fused using a Kalman filtering approach (Kalman, 1960). The Kalman-filled 100 m time series are then automatically checked for consistency. This upgrades the PROBA-V UTM ARD+ archive into the PROBA-V UTM ARD++ archive, which gives temporal cleaned, consistent and dense 5-daily image stacks for all global land masses at 100 m resolution (Note: 300 m data is not existing in the ARD++). Following, several Vegetation Indices (VI's) are generated out of the

PROBA-V UTM ARD++ surface reflectance data for each time step in the archive. Since this data would be too much to be used in a supervised learning, the time dimension in the data stack has to be condensed. Therefore, several metrics explaining the time series are extracted as input for the supervised classification and regression. Thus a harmonic model is fitted through the time steps of each of the reflectance bands of the time series data as well as each of the additional derived vegetation indices. Next to the parameters of the harmonic model which are used as metrics for the overall level and seasonality of the time series, descriptive statistics and textural metrics are generated. Overall, 270 metrics are extracted from the PROBA-V UTM ARD++ archive for the 2015 epoch.

To use external ancillary data in the classification/regression, the datasets have been checked for consistency and if needed re-warped to the UTM coordinate system, resampled to 100 m, retiled into the Sentinel-2 tiling grid, and post-processed to usable ancillary data products. The training data for the supervised learning is collected through manual classification using Google Maps and Bing images at 10 m spatial resolution using the Geo-Wiki Engagement Platform (http://www.geo-wiki.org/). Therefore, the training data not only includes the land cover type, but also the cover fractions of the main land cover classes can be derived for 100 m resolution. In the classification and regression preparation, the metrics of the training points are analysed for inter-specific outliers in the pure endmembers, as well as screened for the best metrics combinations (best band selection) in order to reduce redundant information. The optimized training data together with the quality indicator of the input data (DDI dataset) are input in the training of the supervised classifier/regressor using Random Forest (RF) techniques. The generated models are optimized via a 5-folded cross-validation in order to estimate the optimal classifier/regressor parameters.

Finally, we build upon the success of previous global mapping efforts and/or other ancillary datasets which are included via expert rules in the land cover map generation step. The produced land cover map uses a hierarchical legend based on the United Nations (UN) and Land Cover Classification System (LCCS). Compatibility with existing global land cover products is hereby taken into account. A novelty of this product is the generation of continuous cover fields that allow proportional estimates of cover fractions (also known as Percentage Vegetation Cover (PVC) for vegetation) of all main land cover classes. The input are the cover fractions collected for all training points which are used in a Random Forest regression.

Details of the retrieval method can be found in the ATBD [CGLOPS1_ATBD_LC100_V2.0].

In a final step, metadata attributes compliant with version 1.6 of the Climate & Forecast conventions (CF V1.6) and the colour tables translating the discrete class code into the legend are injected. Moreover, the probability layer indicating the classifier certainty was produced out of the predicted class probabilities of the classification results. This classification quality layer was bundled together with the cover fraction quality layers and the Data Density Indicator layer as quality indicator for the input data as overall product quality layers.

Figure 2 shows an overview of the discrete map with 23 classes on global scale, where Figure 3 shows the legend in more detail. Figure 4 shows the 10 provided CGLS_LC100 cover fraction

layers in a collage. The shown colours for the cover fractions are the ones integrated as RGB colour bars in the metadata of the cover fraction product layers.

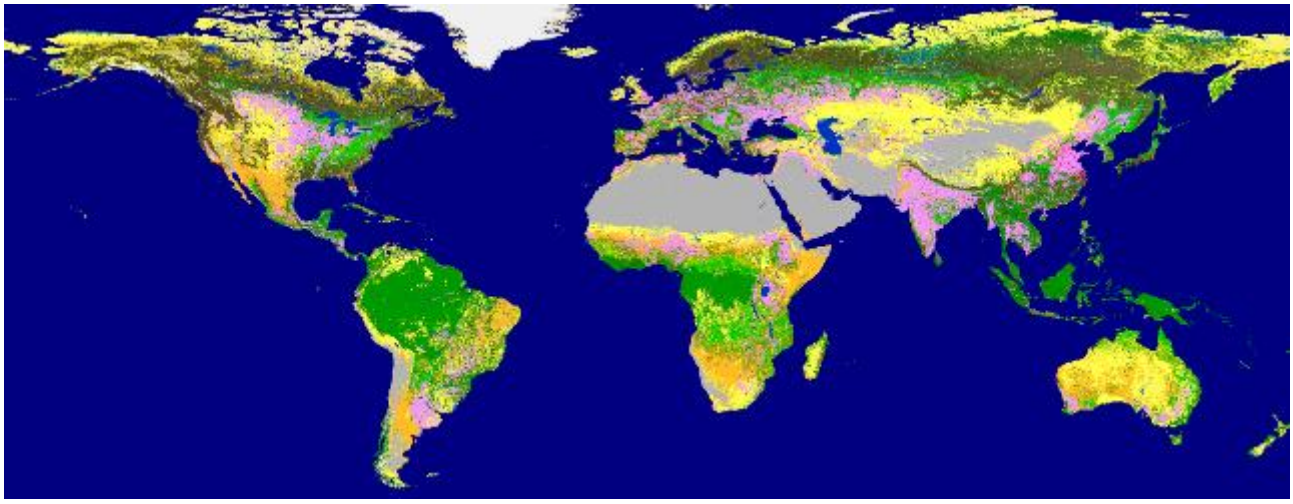

Figure 2: The CGLS Dynamic Land Cover Map at 100 m for epoch 2015 with 23 discrete classes (detailed legend in Figure 3)

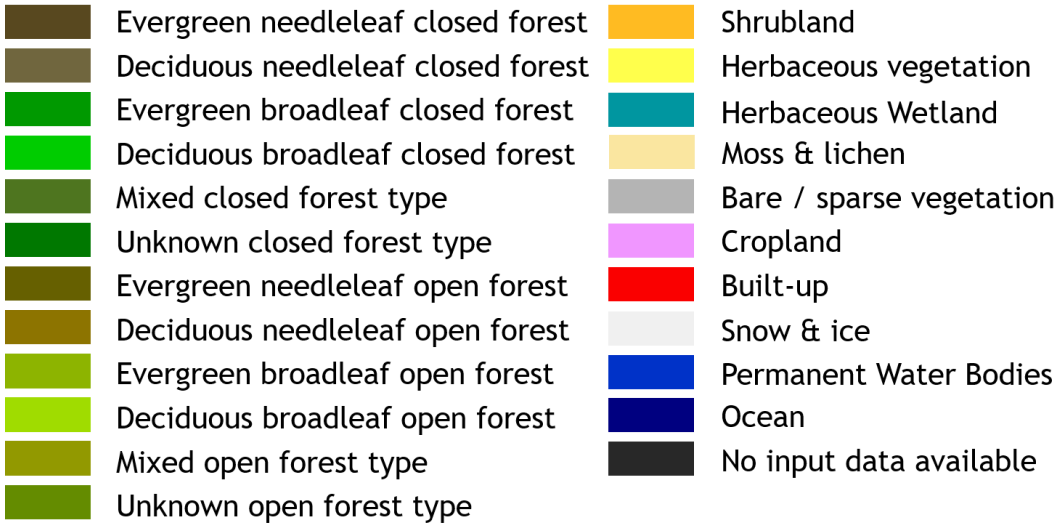

Figure 3: Legend for the 23 discrete classes of the CGLS Dynamic Land Cover Map at 100 m

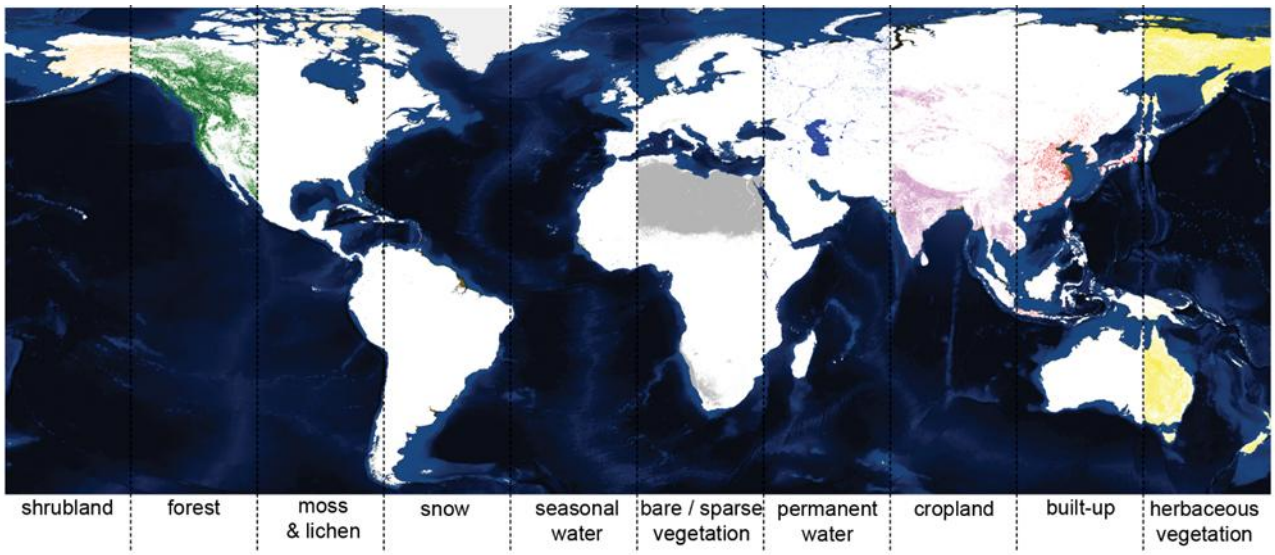

Figure 4: The cover fraction layers for the 9 base land cover classes and the seasonal inland water cover fraction of the CGLS_LC100 product for epoch 2015 (shown as a collage on global scale).

2.2 LIMITATIONS

Although minimization of omission and commission errors is achieved by the usage of ancillary dataset, they are sometimes inevitably. An overview of reasons for omission and commission errors is:

- Due to the used input data the product is limed to a latitudinal extent between 60° South and 78.25° North.
- Due to the usage of optical remote sensing data, classifications in areas with high yearly cloud cover can have lower classification accuracies.
- Artefacts at boundaries of biome clusters can appear due to the used biome cluster vector layer as well as the biome cluster-specific generated hyper-parameter for the Random Forest classifier and regressor.
- Remaining shadowed pixels in the time series not filtered out during the data cleaning process can lead to misclassifications.
- Fires and more specifically burned areas were not yet taken into account yet and therefore could lead to misclassifications.
- Highly fragmented landscapes, in particular mixed areas with very small cropland fields (less < 0.5 ha), are very difficult to map because of the resolution of 100 m (e.g. Nigeria, Ghana). This could lead to an overestimation of croplands.
- Areas with low cropland fragmentation (very sparse cropland fields of a very small size) are difficult to map because of the resolution of 100 m. This could lead to an underestimation of croplands.

- Very small villages or bigger houses are difficult to map, especially when not detected by the World Settlement Footprint layer at 10 m resolution, which could lead to an underestimate of built-up areas.
- Some limitations are due to the legend or class definition, e.g.:
    - In the southern part of Africa, there are huge areas with kind of tundra type of vegetation, NDVI values are very low in these areas and can confuse the classifier to misclassify between grassland or bare land.
    - In Africa, there are a lot of riparian forests, which are evergreen. A lot of pixels where noticed with mixed deciduous trees and riparian evergreen forest which can confuse the classifier to misclassify the forest type.
- Since the water body detection algorithm was adapted from Bertels et al. (2016), the limitations of this algorithm also have to be taken into account. Misclassifications of water bodies can happen in:
    - Dark areas caused by anthropogenic activity, e.g. heavy industry;
    - Dark areas caused by shadow, e.g. high buildings in large cities;
    - Anthropogenic structures with spectral signatures equal to Water Bodies, e.g. some agricultural fields, build-up areas;
    - Natural surfaces with spectral signatures very close to water bodies, e.g. volcanic soils;
    - Areas were the spectral properties of water bodies fall outside the defined thresholds.
- The permanent snow and ice class was limited by the Potential Permanent Snow and Ice Mask (PPSIM) in order to reduce permanent snow&ice misclassifications especially over temporary frozen lakes (mostly in the High Latitudes were high cloud cover is frequent and therefore images of the thawed lakes are rare). This can led to underestimation of newly formed ice&snow areas outside the PPSIM.
- The CGLS-LC100 permanent snow and ice cover fraction layer shows only cover fractions of 0 % or 100 % at the moment. This is due to the fact that not sufficient amounts of training points with a reported permanent snow&ice cover fraction were available. Therefore, we focused on areas with 100 % covered permanent snow&ice. This can lead to an underestimation of permanent snow and ice in partly covered 100 m pixels.
- The usage of PROBA-V multi-spectral data limits the possibilities to successfully distinguish between herbaceous vegetation and shrubland, as well as between open forest and shrubland, especially when the class borders within a pixel are not clear (meaning the cover fraction of the neighboring discrete classes are close and therefore the voting in the classifier is difficult. We implemented an extra rule part in the Expert Rules section to deal with these classification confusions, but still misclassifications between these classes are possible.
- Since the PROBA-V time series is limited at the moment (2014 to 2019), misclassifications can happen especially in temporary ultra-dry and temporary ultra-wet areas. This is due to the fact that some regional effects with a low frequency (e.g. El Nino and La Nina) could not correctly captured with the training data reference base of 2015.

- Due to the pixel-based classification and regression, spatial artefacts can occur. We encourage users to apply cluster/sieving techniques in non-fragmented areas to further improve the regional classification results.
- Due to the low training data density in the High Latitudes, the classification results above 70 degree North can be less accurate.

2.3 DIFFERENCES WITH THE PREVIOUS VERSION

Table 1: Successive versions of Collection 100m Land cover products. The V2.0 described in this PUM is highlighted in bold.

Version	Coverage	Status	Main characteristics
V1.0	Africa 2015	Demonstration	PROBA-V S1 time-series (plate carree) Random Forest for classification
V2.0	**Global 2015**	**Operational**	**PROBA-V L1C time-series (gridded to Sentinel-2 UTM)** **Random Forest for classification**
V2.1	Africa 2015-base, 2016-conso, 2017-conso, 2018-NRT	Demonstration	PROBA-V L1C time-series (gridded to Sentinel-2 UTM) Random Forest for classification BFAST for break detection linear regression
V3.0 (upcoming)	Global 2015-2019	Operational	PROBA-V L1C time-series (gridded to Sentinel-2 UTM) Random Forest for classification Optimized BFAST for break detection

The V2.1 of Collection 100m Land Cover product, which includes yearly land cover changeover the period 2015-2018, is described in its dedicated PUM [CGLOPS1_PUM_LCC100-V2.1].

2.4 ROADMAP

A version 3.0 of Collection 100 m of LC products will be generated from the PROBA-V 100 m and 300 m sensor data and will cover the years 2015-2019 with global coverage.

The Copernicus Global Land service will continue the 100 m production, from 2020, through the combination of Sentinel-1 and Sentinel-2 mission. The adaptation of the retrieval methodology to the Sentinels missions data is currently under test.

3 PRODUCT DESCRIPTION

The Collection 100m global Land Cover version 2.0 products are provided in **ZIP** files, per 20 x 20 degree tile (Figure 5), each containing a set of 20 **GeoTIFF** files corresponding to the following layers:

- One discrete land cover map;
- Fractional cover maps for 10 classes (bare/sparse vegetation, cropland, herbaceous grassland, moss&lichen, shrubland, tree, permanent snow&ice, built-up, permanent water, seasonal water);
- One forest type map
- One discrete classification probability map (quality indicator of the classifier)
- Standard deviation maps for fractional cover of 6 classes (bare/sparse vegetation, cropland, herbaceous grassland, moss&lichen, shrubland, tree) (quality indicator of the regressor)
- Data Density Indicator for PROBA-V UTM 100m input data

3.1 FILE NAMING

The ZIP files, and GeoTIFF files they contain, follow this naming convention:

<TILE>_<SENSOR>_LC100_epoch<YEAR>_global_<VERSION>_<LAYER>_<CRS>.tif

where

- <TILE> the designation of the 20 x 20 degree tile, composed of the 3-digit longitude and 2-digit latitude of the top-left corner (see Figure 5)
  Example: W180N80 for the tile covering the area from 180W to 160W and 80N to 60N.
- <SENSOR> the EO sensor used. Here is “ProbaV”.
- “LC100” indicates this is a 100 m resolution Land Cover product
- epoch< YEAR> indicates the epoch year in four digits.
- “global” indicates that the tile is part of a Land Cover product that covers the global land surface.
- <VERSION> shows the processing line version used to generate this product. The version denoted as vM.m.r (e.g. v2.0.1), with ‘M’ representing the major version (e.g. v2), ‘m’ the minor version (starting from 0) and ‘r’ the production run number (starting from 1) (Table 2).
- <LAYER> gives the name of the data layer (see Table 3)
- <CRS> is the coordinate reference system used. The current tiles are provided in EPSG:4326, geographic latitude/longitude CRS.

Figure 5: Scheme of the 20 x 20 degree tiles

Table 2: Version numbering and recommendations for handling version updates

Versions	Differences	Recommendations
Major	Significant change to the algorithm.	Do not mix various major versions in the same applications, unless it is otherwise stated.
Minor	Minor changes in the algorithm	Can be mixed in the same applications, but require attention or modest modifications
Run	Fixes to bugs and minor issues, updates in input data.	Later run is a drop-in replacement of all former runs.

Table 3: Land Cover layer names in the filename

Layer in filename	Description
discrete-classification	Main discrete classification according to FAO LCCS scheme
discrete-classification-proba	Classification probability, a quality indicator for the discrete classification
forest-type-layer	Forest type for all pixels where tree cover fraction is bigger than 1 %
bare-coverfraction-layer	Fractional cover (%) for the bare and sparse vegetation class
crops-coverfraction-layer	Fractional cover (%) for the cropland class
grass-coverfraction-layer	Fractional cover (%) for the herbaceous vegetation class
moss-coverfraction-layer	Fractional cover (%) for the moss & lichen class
shrub-coverfraction-layer	Fractional cover (%) for the shrubland class

Layer in filename	Description
snow-coverfraction-layer	Fractional cover (%) for the snow & ice class
tree-coverfraction-layer	Fractional cover (%) for the forest class
urban-coverfraction-layer	Fractional cover (%) for the built-up class
water-permanent-coverfraction-layer	Fractional cover (%) for the permanent inland water bodies class
water-seasonal-coverfraction-layer	Fractional cover (%) for the seasonal inland water bodies class
bare-coverfraction-StdDev crops-coverfraction-StdDev grass-coverfraction-StdDev moss-coverfraction-StdDev shrub-coverfraction-StdDev tree-coverfraction-StdDev	Quality indicator (standard deviation) of the percentage vegetation cover regression, for the respective class.
DataDensityIndicator	Data density indicator showing quality of the EO input data between 0 – 100 (0 = bad, 100 = perfect data)

3.2 FILE FORMAT

The 20 Land Cover layers are provided as single-band GeoTIFF files that are internally compressed with standard metadata attributes, and include overview pyramids on levels 2, 4, 8 and 16 for faster loading in GIS.

Note that this format may not be fully compliant with Cloud-Optimized GeoTIFF (COG) requirements. The GeoTIFF format will be further improved towards COG in upcoming Land Cover products.

3.3 PRODUCT CONTENT

All land cover layers are stored as single bytes per pixel, without scaling or offset.

3.3.1 Discrete classification

The discrete classification map provides 23 classes (Table 4) and is defined using the Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO). The UN-LCCS system was designed as a hierarchical classification, which allows adjusting the thematic detail of the legend to the amount of information available:

- The “level 1” legend contains classes with codes that are multiples of ten (10, 20, 30, etc.).
- The “level 2”, also known as regional legend, has class codes of two digits that is not a multiple of ten (i.e. 11, 12 are sub-classes of 10, and so on).
- The “level 3” classes have three digits (i.e. 111 – 116 and 121 – 126) and are used to further distinguish the forest types (sub-classes of 11 – open forest and 12 – closed forest).

The discrete map is coded with special values 200 for sea pixels and 0 signifying missing input data (i.e. not observed by PROBA-V sensor).

Table 4: Discrete classification coding

Map code	UN LCCS level	Land Cover Class	Definition according UN LCCS	Color code (RGB)
0	-	No input data available	-	40, 40, 40
111	A12A3A10B2D2E1	Closed forest, evergreen needle leaf	tree canopy >70 %, almost all needle leaf trees remain green all year. Canopy is never without green foliage.	88, 72, 31
113	A12A3A10B2D2E2	Closed forest, deciduous needle leaf	tree canopy >70 %, consists of seasonal needle leaf tree communities with an annual cycle of leaf-on and leaf-off periods	112, 102, 62
112	A12A3A10B2D1E1	Closed forest, evergreen, broad leaf	tree canopy >70 %, almost all broadleaf trees remain green year round. Canopy is never without green foliage.	0, 153, 0
114	A12A3A10B2D1E2	Closed forest, deciduous broad leaf	tree canopy >70 %, consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.	0, 204, 0
115	A12A3A10	Closed forest, mixed	Closed forest, mix of types	78, 117, 31
116	A12A3A10	Closed forest, unknown	Closed forest, not matching any of the other definitions	0, 120, 0
121	A12A3A11B2D2E1	Open forest, evergreen needle leaf	top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, almost all needle leaf trees remain green all year. Canopy is never without green foliage.	102, 96, 0
123	A12A3A11B2D2E2	Open forest, deciduous needle leaf	top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, consists of seasonal needle leaf tree communities with an annual cycle of leaf-on and leaf-off periods	141, 116, 0
122	A12A3A11B2D1E1	Open forest, evergreen broad leaf	top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, almost all broadleaf trees remain green year round. Canopy is never without green foliage.	141, 180, 0
124	A12A3A11B2D1E2	Open forest, deciduous broad leaf	top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.	160, 220, 0
125	A12A3A12	Open forest, mixed	Open forest, mix of types	146, 153, 0
126	A12A3A12	Open forest, unknown	Open forest, not matching any of the other definitions	100, 140, 0
20	A12A4A20B3(B9)	Shrubs	These are woody perennial plants with persistent and woody stems and without any defined main stem being less than 5 m tall. The shrub foliage can be either evergreen or deciduous.	255, 187, 34
30	A12A2(A6)A20B4	Herbaceous vegetation	Plants without persistent stem or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10 %.	255, 255, 76

Map code	UN LCCS level	Land Cover Class	Definition according UN LCCS	Color code (RGB)
90	A24A2A20	Herbaceous wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.	0, 150, 160
100	A12A7	Moss and lichen	Moss and lichen	250, 230, 160
60	B16A1(A2)	Bare / sparse vegetation	Lands with exposed soil, sand, or rocks and never has more than 10 % vegetated cover during any time of the year	180, 180, 180
40	A11A3	Cultivated and managed vegetation/agriculture (cropland)	Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.	240, 150, 255
50	B15A1	Urban / built up	Land covered by buildings and other man-made structures	250, 0, 0
70	B28A2(A3)	Snow and Ice	Lands under snow or ice cover throughout the year.	240, 240, 240
80	B28A1B1	Permanent water bodies	lakes, reservoirs, and rivers. Can be either fresh or salt-water bodies.	0, 50, 200
200	B28A1B1[1]	Open sea	Oceans, seas. Can be either fresh or salt-water bodies.	0, 0, 128

3.3.2 Fractional Cover layers

The Fractional Cover layers, also referred to as cover fractions, give the percentage of a 100 m pixel that is filled with a specific land cover class (Table 3). As such it provides more detailed information than the dominant class that is shown in the discrete classification.

The Fractional Cover layers are coded as a number between 0 and 100, in steps of 1 %. The sum of all fractional cover layers for a given pixel is 100. Missing values are set to 255.

3.3.3 Forest type layer

The Forest Type layer provides discrete values per type of forest (see Table 5), for all pixels where the tree (forest) cover fraction exceeds 1 %. Value 255 is used for missing values.

[1] Note a distinction is made between Open sea (oceans) = 200 and other permanent water bodies = 80, despite they're mapped to the same UN LCCS layer legend.

Table 5: Forest type coding

Value	Short name	Description
0	Unknown	Doesn't match any of the other types
1	ENF	Evergreen needle leaf forest
2	EBF	Evergreen broad leaf forest
3	DNF	Deciduous needle leaf
4	DBF	Deciduous broad leaf
5	Mixed	Mix of forest types

3.3.4 Quality layers

3.3.4.1 Probability of the discrete classification

The probability of the discrete classification is provided as a number between 0 and 100, in steps of 1 %. Closer to 100 is the probability, higher is the quality of the discrete classification. Value 255 is used for missing values

3.3.4.2 Standard Deviation for the Fractional Cover

The Standard Deviation of the percentage cover regression is provided as a number between 0 and 100, in steps of 1 %. Closer to 100 is the standard deviation, higher is the quality of the associated fractional cover layer. Value 255 is used for missing values.

3.3.4.3 Data Density Indicator (DDI)

The Data Density Indicator indicates the availability of input data from the 5-daily PROBA-V UTM ARD+ composites for 100 m and 300 m resolutions. It is a score between 0 = no input data available and 100 = best data availability. Missing DDI values are coded as 255.

3.3.5 Metadata attributes

The GEOTIFF files provide the metadata attributes as key value pairs, according to the Climate and Forecast Convention (CF, version 1.6):

- on the file-level (Table 6);
- on the band-level, with an example values given for the main discrete classification layer (Table 7).

Table 6: Description of GEOTIFF file attributes

Attribute name	Description	Example(s)
archive_facility	Specifies the name of the institution that archives the product	VITO NV
copyright	Text to be used when referring to this product in publications (copyright notice)	Copernicus Service information 2019
creator	Principal investigator of the algorithm	Dr. Marcel Buchhorn (VITO)
delivered_product_crs	Land Cover product is delivered in this Coordinate Reference System	WGS84 (EPSG:4326)
delivered_product_grid	Land Cover product is delivered in this tile grid	global 20x20 deg tiling grid
doi	Digital Object identifier	10.5281/zenodo.3243509
file_creation	File creation timestamp	Fri Apr 19 11:46:08 2019
history	A global attribute for an audit trail. One line, including date in ISO-8601 format, for each invocation of a program that has modified the dataset.	2019-04-26 Processing line LC100
Info	Additional comment on the processing history.	MasterTile W160N20 for product discrete-classification of CGLOPS LC100 layers for epoch 2015.
institution	The name of the institution that produced the product	VITO NV
long_name	Extended product name	Land Cover
orbit_type	Orbit type of the orbiting platform(s)	LEO
platform	Name(s) of the orbiting platform(s)	Proba-V
processing_level	Product processing level	L3
processing_mode	Processing mode used when generating the product (Near-Real Time, Consolidated or Reprocessing)	offline
production_crs	Coordinate Reference System used for the pre-processed input data and during the different production steps	UTM
production_grid	Grid used for the pre-processed input data and during the different production steps	MGRS (Sentinel-2 tiling grid)
product_version	Version of the product	V2.0.1
references	Published or web references with more product information.	https://land.copernicus.eu/global/products/lc
region_name	Name of the geographic area covered, e.g. name of the 20x20 degree tile	W160N20
sensor	Name(s) of the sensor(s) used	VEGETATION
source	The method of production of the original data	Derived from 100m EO satellite imagery
time_coverage_end	End date and time of the temporal coverage of the input data.	2016-12-31T23:59:59Z
time_coverage_start	Start date and time of the temporal coverage of the input data.	2014-01-01T00:00:00Z
title	A description of the contents of the file	Dynamic Land Cover Map 100m 2015

Table 7: Description of GEOTIFF band attributes.

Attribute	Description	Examples for LCCS layer
CLASS	Dataset type	DATA
band_crs	Coordinate Reference System used for this GeoTIFF band.	WGS84 (EPSG:4326)
flag_meanings	Description for each flag value	unknown, ENF_closed, EBF_closed, DNF_closed, DBF_closed, mixed _closed, unknown_closed, ENF_open, EBF_open, DNF_open, DBF_open, mixed _open, unknown_open, shrubland, herbaceous_vegetation, cropland, built-up, bare_sparse_vegetation, snow_ice, permanent_inland_water, herbaceous_wetland, moss_lichen, sea
flag_values	Provides a list of the specific values used.	0, 111, 112, 113, 114, 115, 116, 121, 122, 123, 124, 125, 126, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200
long_name	A non-standardized, descriptive name that indicates a variable's content.	Land Cover Classification
missing_value	Single value, outside of valid_range, used to represent missing or undefined data, for applications following older versions of the standards.	255
short_name	A shortened, non-standardized name.	discrete-classification
unit	Physical unit. None or omitted when the data is dimensionless.	None
valid_range	Smallest and largest valid values.	0, 254

3.4 PRODUCT CHARACTERISTICS

3.4.1 Projection and Grid Information

The Land Cover V2.0 products are delivered in a regular latitude/longitude grid (EPSG:4326) with the ellipsoid WGS 1984 (Terrestrial radius=6378 km). The resolution of the grid is 1°/1008 or approximately 100 m at equator.

3.4.2 Spatial Information

The Land Cover V2.0 products cover the geographic area from longitude 180°E to 180°W and latitude 78.25°N to 60°S. They are provided in 20 x 20 degree tiles (see Figure 5).

The position of a pixel is by standard, through GeoTIFF format, given by the "upper left corner", as marked with the GDALMD_ARE_OR_POINT[2] geotransform metadata entry.

3.4.3 Temporal Information

The Land Cover V2.0 product represents the land cover for the epoch or reference calendar year (from 01 January to 31 December). The data 1 year prior and past of the reference year is used in its processing. As such, the temporal coverage provides a start date of 01 January Year-1 to 31 December Year+1.

For instance, the temporal coverage of the global 2015 Land cover V2.0 product spans from 1st January 2014 to 31 December 2016.

3.5 DATA POLICIES

EU law[3] grants free and open access to Copernicus Sentinel Data and Service Information, which includes Global Land Service products, for the purpose of the following use in so far as it is lawful:

a) reproduction;
b) distribution;
c) communication to the public;
d) adaptation, modification and combination with other data and information;
e) any combination of points (a) to (d).

EU law allows for specific limitations of access and use in the rare cases of security concerns, protection of third party rights or risk of service disruption.

By using (Sentinel Data or) Service Information the user acknowledges that these conditions are applicable to him/her and that the user renounces to any claims for damages against the European Union and the providers of the said Data and Information. The scope of this waiver encompasses any dispute, including contracts and torts claims that might be filed in court, in arbitration or in any other form of dispute settlement.

Where the user communicates to the public on or distributes the **original** Land Cover products, he/she is obliged to refer to the data source with (at least) the following statement (included as the copyright metadata item):

Copernicus Service information [Year]

With [Year]: year of publication

Where the user has adapted or modified the products, the statement should be:

[2] GDAL identifies GDALMD_AOP_AREA as "geotransform is the position of the upper left corner of the area spanned by the pixel, which center is the upper left point in the dataset if interpreted as DTM".
[3] European Commission, Regulation (EU) No 377/2014 and Commission Delegated Regulation (EU) No 1159/2013.

Contains modified Copernicus Service information [Year]

For complete acknowledgement and credits, the following general statement can be used:

"The product was generated by the Global component of the Land Service of Copernicus, the Earth Observation programme of the European Commission. The research leading to the current version of the product has received funding from various European Commission Research and Technical Development programs. The product is based on PROBA-V data provided by Belgian Science Policy Office (BELSPO) and distributed by VITO."

For citation in scientific publications, the following statement can be used:

Buchhorn, M., Smets, B., Bertels, L., Lesiv, M., Tsendbazar, N.-E., Masiliunas, D., Herold, M., Fritz, S. (2019). Copernicus Global Land Service: Land Cover 100m, Collection 2, epoch 2015 Global (Version V2.0.2) [Data set]. Zenodo. DOI: 10.5281/zenodo.3243509.

The user accepts to inform Copernicus about the outcome of the use of the above-mentioned products and to send a copy of any publications that use these products to the scientific & technical support (help desk) contact specified in the next section.

3.6 ACCESS AND CONTACTS

The Land Cover products are available through the Global Land Cover viewer, available at https://land.copernicus.eu/global/lcviewer (see Figure 6). It displays the various land cover layers (discrete map, cover fractions, false-colour combinations of cover fractions) on a map, allows downloading the data in 20x20 degree tiles and reports on land cover statistics per administrative area.

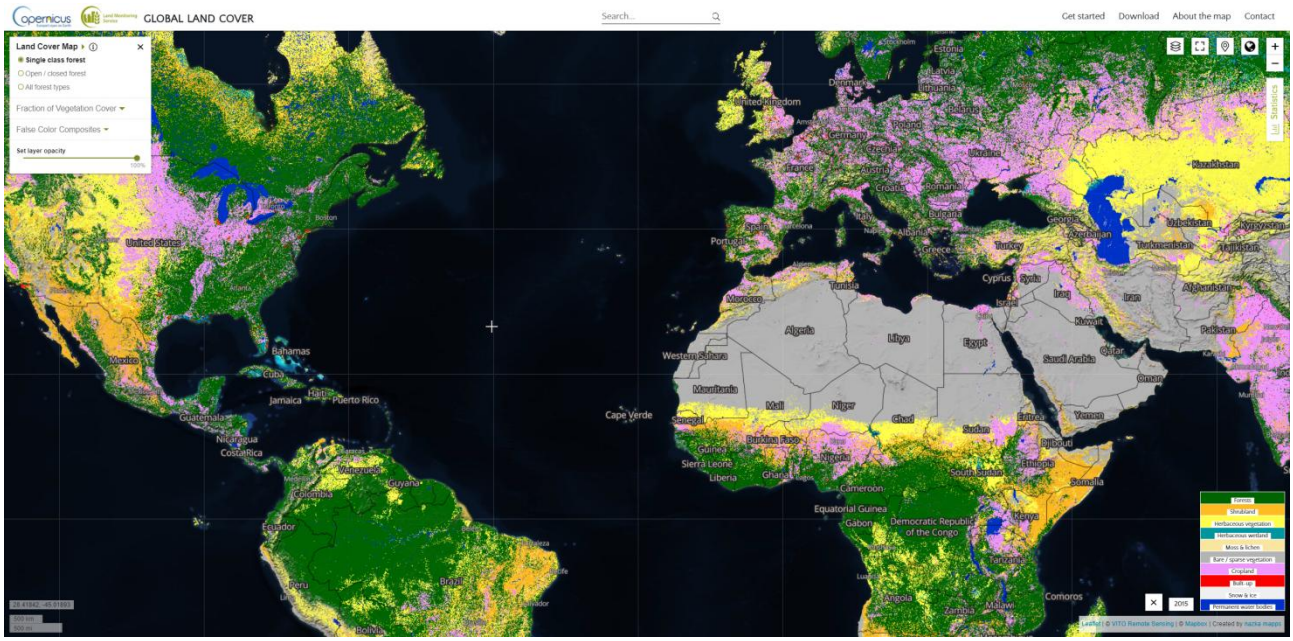

Figure 6: Screenshot of the Global Land Cover viewer

More information and documentation about the product is available from the Copernicus Global Land Service web site at https://land.copernicus.eu/global/products/lc

Accountable Contact: European Commission, Directorate-General Joint Research Centre, Italy Email address: copernicuslandproducts@jrc.ec.europa.eu

Scientific & Technical support contact e-mail address: https://land.copernicus.eu/global/contactpage.

Direct access to the data can also be achieved through the Digital Object Identifier (DOI), following the information as shown in Table 8 below.

Table 8 : Digital Object Identifier information

Attribute	Value
Dataset	Collection 2
Provided epochs	2015
Dataset version	2.0.2
Concept DOI	10.5281/zenodo.3243508
Version DOI	10.5281/zenodo.3243509
Citation	Marcel Buchhorn, Bruno Smets, Luc Bertels, Myroslava Lesiv, Nandin-Erdene Tsendbazar, Martin Herold, & Steffen Fritz. (2019). Copernicus Global Land Service: Land Cover 100m: Collection 2: epoch 2015 (Version V2.0.2) [Data set]. Zenodo. DOI: 10.5281/zenodo.3243509
Direct Access	http://doi.org/10.5281/zenodo.3243509
Data layers per epoch	20
File Size	63.3 GBytes

4 VALIDATION RESULTS

The discrete global land cover V2.0 map and the nine cover fraction layers were validated using an independent validation dataset containing around 21 600 points generated in collaboration with regional experts. In addition, the CGLS_LC100m V2.0 discrete map was qualitatively and quantitatively compared against other existing global land cover maps. The validation procedure and the detailed results are presented into the Validation Report [CGLOPS1_VR_LC100_V2.0]. The main outcomes are summarized below.

Assessments show that the CGLS LC100 discrete map is mapped with 80.2 % +/-0.7 % accuracy. Forest, bare/sparse vegetation, snow/ice and permanent water are mapped with very high accuracies (>85%). The class accuracies of herbaceous vegetation, croplands, urban are moderate, while herbaceous wetland, lichen and moss and shrubs classes have lower accuracies (<65%). For the continents, accuracies are also around 80% for the most of the continents, with exceptions to North America (77.1 ± 1.7) and Asia (83.3± 1.5). At Level 2, when closed and open forests classes are separated, global overall accuracy is 75.1% +/-0.7%, ranging from 71-79.5% for the different continents.

Among the fractional land cover layers, snow & ice, built-up, water and lichen/moss fraction maps show lowest errors, followed by crops and bare/sparse vegetation fraction types. On the other hand, fractional herbaceous vegetation cover layer has the highest error.

The visual comparison of the CGLS LC100m V2.0, the LC-CCI 2015 and the Globeland30 2010 maps shows good agreements between the CGLS LC100m V2.0 and the Globeland30 2010 map for the characterization of natural vegetation classes and croplands. Classes such as wetland and cropland tend to have smaller extent in the CGLS LC100 V2.0 map as compared to the other maps. This can be partially attributed to the differences in the class definitions.

Visual inspection of the CGLS_LC100m V2.0 further reveals some artefacts and misclassifications. For example, there are artefacts in the CGLS_LC100m V2.0 in the open water of Caspian sea while the Level 3 legend of the discrete map depicts considerably large forest areas specified as “unknown” forest type (value 0 in Table 5). They should be addressed for improvements.

Users are encouraged to provide feedback on disagreement areas through the GEO-WIKI platform feedback tool at https://application.geo-wiki.org/Application/index.php or through contacting the helpdesk (see §3.6).

5 REFERENCES

Bertels, L., Smets, B., Wolfs, D. (2016). Dynamic Water Surface Detection Algorithm Applied on PROBA-V Multispectral Data. Remote Sens., 8, 1010.

Kalman, R. E. (1960). A New Approach to Linear Filtering and Prediction Problems. Journal of Basic Engineering. 82: 35. doi:10.1115/1.3662552.

Wagner, J. E., Stehman, S. V. (2015). Optimizing sample size allocation to strata for estimating area and map accuracy. Remote Sensing of Environment 168 (2015) 126-133, doi:10.1016/j.rse.2015.06.027

ANNEX: REVIEW OF USERS REQUIREMENTS

According to the applicable documents [AD2] and [AD3], the user's requirements relevant for Dynamic Moderate Land Cover are:

- **Definition**: Dynamic global land cover products at 300m and/or 100m resolution using UN Land Cover Classification System (LCCS)
- **Geometric properties**:
  - Pixel size of output data shall be defined on a per-product basis so as to facilitate the multi-parameter analysis and exploitation.
  - The baseline datasets pixel size shall be provided, depending on the final product, at resolutions of 100m and/or 300m and/or 1km.
  - The target baseline location accuracy shall be 1/3 of the at-nadir instantaneous field of view.
  - Pixel co-ordinates shall be given for centre of pixel.
- **Geographical coverage**:
  - geographic projection: lat long
  - geodetical datum: World Geodetic System 1984 (WGS84)
  - pixel size: 1/112° - accuracy: min 10 digits
  - global window coordinates:
    - Upper Left: 180°W-75°N
    - Bottom Right: 180°E, 56°S

- **Accuracy requirements**: Overall thematic accuracy of dynamic land cover mapping products shall be >80%. The overall accuracy assessment (including confidence limits) will be based on a stratified random sampling design and the minimum number of sampling points per land cover class relevant to the product shall be calculated as described in Wagner and Stehman, 2015.

Few workshops were held in 2016 to consult different stakeholders to understand users' needs for global land cover maps. A feasibility study was performed to define the guidelines to create the first LC100 map. More details can be found in [CGLOPS1_URD_LC100m]. Larger consultations in 2017 and 2018 allowed collecting the requirements of wide user communities which were translated in product specifications [CGLOPS1_PSD_LC100m].

Table 9 summarizes the usefulness of information on LC and LC change processes for different international actions and programmes. Table 10 includes the LC classes that are required by different JRC units and are marked by ("X"), respectively. The last column provides the following information: either a class is included in the LC100m V2 product's legend, or it can be derived by users from the fraction layers, or additional R&D is needed.

Table 9: Usefulness of information on LC and LC change processes for different international actions and programmes.

	LC types	Related land change processes	UNFCCC	UNCCD	OECD	SEEA/FAO	SDGs
1	Urban/built-up areas	Urbanization	✓	✓	✓	✓	✓
2	Cropland	Crop expansion	✓	✓	✓	✓	✓
3	Cropland and other vegetation	Land abandonment	✓	✓	✓	✓	✓
4	Forest	Deforestation	✓	✓	✓	✓	✓
5	Forest	Reforestation	✓	✓	✓	✓	✓
6	Wetland	Wetland degradation	✓	✓	✓	✓	✓
7	Water body	Expansion of water surface			✓	✓	✓
8	Water body	Reduction of water surface			✓	✓	✓
9	Bare areas	Desertification			✓	✓	✓

Table 10: List of land cover classes requested by users.

Code Level 1	Code Level 2	UN LCCS level	Land cover class	Forest modelling/REDD+	Crop monitoring	Biodiversity	Monitoring Environment and Security in Africa	Climate modelling	Class included in the product
10		A12A3A20B2	Forest/tree cover	X		X	X	X	Yes
	11	A12A3A20B2D2E1	Evergreen Needleleaf forest	X			X	X	Yes
	12	A12A3A20B2D1E1	Evergreen Broadleaf forest	X			X	X	Yes
	13	A12A3A20B2D2E2	Deciduous Needleleaf forest	X			X	X	Yes
	14	A12A3A20B2D1E2	Deciduous Broadleaf forest	X			X	X	Yes
	15	A12A3A20B2D	Mixed forest	X		X			Yes

Code Level 1	Code Level 2	UN LCCS level	Land cover class	Forest modelling/REDD+	Crop monitoring	Biodiversity	Monitoring Environment and Security in Africa	Climate modelling	Class included in the product
		1D2							
	16	A12A3A10B2XXXX (assuming that an intact forest is a very dense forest)	Intact forest	X		X		X	To map these classes, addition R&D is required for methodology. Either we develop an expert rule based on other datasets such as: http://www.intactforests.org/data.ifl.html or new training and validation datasets. These classes could potentially be included in the next product evolutions.
	17	-	Secondary forest	X		X		X	
	18	A11A1	Managed forest	X		X		X	
		A11A1	Plantation forest/tree crops	X	X	X		X	
		A11A1	Oil palm plantation	X	X				
		-	Forest logging	X	X	X			
		A12A3	Dominant tree species, e.g. spruce, pine, birch	X		X			
		A11A1(A2/A3)	Shifting cultivation system	X	X			X	
20		AA12A4A20B3(B9)	Shrub			X	X	X	Yes
	21	A12A4A20B(B9)XXE1	Evergreen shrubs			X			These classes could be potentially included in the next product evolutions. We will have to collect corresponding training and validation data.
	22	A12A4A20B3(B9)XXE2	Deciduous shrubs			X			
30		A12A2(A6)A20B4	Herbaceous vegetation			X	X	X	Yes
		A12A6A10 // A11A1A11B4XXXXXF2F4F7G4-F8	Pasture/managed grassland					X	To map these classes, addition R&D is required for methodology. Also we will have to develop new training and validation datasets. These classes could
		A122(A6)A10	Natural grassland			X		X	
		A12A2	Grass types for Western Africa			X			

Code Level 1	Code Level 2	UN LCCS level	Land cover class	Forest modelling/REDD+	Crop monitoring	Biodiversity	Monitoring Environment and Security in Africa	Climate modelling	Class included in the product
									potentially be included in the next product evolutions.
		A12A3A11B2XXXXXXF2F4F7G4-A12; A12A3A11B2-A13; A12A1A11	Savannas			X			The LC100 V2 product includes such a LC class as open forest, which is a mix of trees (more than 15%), shrubs and grassland. This class only partly corresponds to savannas because a 100m x100m pixel may include less trees but still be considered as savanna. However, users are encouraged to use the fraction layers to produce their own savanna layer by applying specific thresholds for tree, shrub and grass cover.
40		A11A3	Cultivated and managed vegetation/agriculture		X	X	X	X	Yes
	41	A11A3XXXXXXD3(D9)	Irrigated cropland		X			X	To map these classes, addition R&D is required for methodology. Also we will have to develop new training and validation datasets. These classes could
	42	A11A3XXXXXXD1	Rainfed cropland		X			X	
	43	A11A3	Big and small farming/field size		X				
	44	A11A1-W8/A2	Permanent crops		X			X	
	45	A11A3	Row crops		X				

Code Level 1	Code Level 2	UN LCCS level	Land cover class	Forest modelling/REDD+	Crop monitoring	Biodiversity	Monitoring Environment and Security in Africa	Climate modelling	Class included in the product
		A11A2	Crop types: long/short cycle or winter/summer crops		X				potentially be included in the next product evolutions.
		A11A2	Multiple crop cycles		X				
50		B15A1	Urban/built up			X	X	X	Yes
60		B16A1(A2)	Bare/sparse vegetation				X	X	Yes
70		B28A2(A3)	Snow and Ice				X	X	Yes
80		B28A1	Open water				X	X	Yes
90		A24A1(A2/A3/A4)	Wetland			X	X	X	Yes
		A24A3	Mangroves	X		X			To map this class, addition R&D is required for methodology. Also we will have to develop new training and validation datasets. These classes could potentially be included in the next product evolutions.