GLOBCOVER

Products Description and Validation Report

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Acronyms

AD : Applicable Document
AOT : Aerosol Optical Thickness
ARVI : Atmospherically Resistant Vegetation Index
ATBD : Algorithm Theoretical Basis Document
BEAM : Basic ERS & Envisat (A)ATSR and Meris Toolbox (http://envisat.esa.int/services/beam/)
AR : Acceptance Review
CCN : Contract Change Notice
CNES : Centre National d'Etudes Spatiales (French space agency)
CYCLOPES : FP5 project (contract n° EVG1-CT-2002-00076), Carbon cYcle and Change in Land Observational Products from an Ensemble of Satellites
DDF : Design Definition File
DJF : Design Justification File
DEM : Digital Elevation Model
ECMWF : European Climate Meteorological Weather Forecast
FAO : Food Agricultural Organisation
DUE : Data User Element
EEA : European Environmental Agency
ENVISAT : ESA Environmental Satellite
ESA : European Space Agency
ESRIN : European Space Research Institute
FRS : Full Resolution Swath
GOFC : Global Observatory Forest Cover
GLC : Global Land Cover
GLOBCOVER : ESA DUE (http://dup.esrin.esa.it/invitations.asp)
GMES : Global Monitoring for the Environment and Security
JRC : Joint Research Center
LCCS : Land Cover Classification System
MERIS : Medium Resolution Imaging Spectrometer Instrument (http://envisat.esa.int)
MODIS : Moderate Resolution Imaging Spectroradiometer (http://modis.gsfc.nasa.gov/MODIS/)
POSTEL : Pôle d'Observation des Surfaces Terrestres aux Echelles Larges (http://medias.obs-mip.fr/postel/)
RMS : Root Mean Square
RR : Reduced Resolution
SMAC : Simplified Method for the Atmospheric Correction of satellite measurements in the solar spectrum
SoW : Statement Of Work document
TS : Technical Specification
TOA : Top Of Atmosphere
TOC : Top Of Canopy
UCL : Université Catholique de Louvain
VEGETATION : CNES Earth's observation sensor onboard SPOT-4
WGS : World Geodetic System

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1. Introduction

1.1. Purpose

The objective of this Globcover report is to describe the Globcover products and their respective validation. The objective of the ESA-Globcover project is the generation of a land cover map of the world using an automated processing chain from the 300m MERIS time series. The Globcover project carried out by an international consortium started in April 2005 and relied on very rich feedback and comments from a larger partnership including end users belonging to international institutions (JRC, FAO, EEA, UNEP, GOFC-GOLD and IGBP) in addition to ESA internal assessment.

The Globcover products presented here and freely available for any non-commercial use are the following:

- Bimonthly MERIS Full Resolution (FR) mosaics (6 products a year, 10 products from December 2004 to June 2006). The bimonthly MERIS FR mosaic is computed every 2 months and provides, for each spectral band, the average surface reflectance calculated from all valid observations of this 2 months period.
- Annual MERIS FR mosaic (1 product a year). The annual MERIS FR mosaic is computed by averaging the surface reflectance values of the bimonthly products generated over one year.
- The Globcover Land Cover map for the period December 2004 - June 2006 (1 product). This global Land Cover map is derived by an automatic and regionally-tuned classification of a MERIS FR time series. Its 22 land cover classes are defined with the UN Land Cover Classification System (LCCS).
- The regional Globcover Land Cover maps for the period December 2004 - June 2006 (11 products). This set of regional land cover maps are also derived by the same automatic and regionally-tuned classification of a MERIS FR time series. However, the land cover typology has been extended to 51 possible land cover classes consistently discriminated only at the continental scale.

1.2. The MERIS instrument

On-board ENVISAT launched in 2002, MERIS is a wide field-of-view pushbroom imaging spectrometer measuring the solar radiation reflected by the Earth in 15 spectral bands from about 412.5nm to 900nm (Rast et al., 1999). Each of these 15 bands is programmable in position and in width (cf Appendix I). MERIS is designed to acquire data over the Earth whenever illumination conditions are suitable. The instrument's 68.5° field of view around nadir covers a swath width of 1150 km at a nominal altitude of 800 km enabling a global coverage of the Earth in 3 days. This wide field of view is shared between five identical optical modules (*Figure 1*) arranged in a fan shape configuration. Linear Charged Couple Device (CCD) arrays provide spatial sampling in the across-track direction, while the satellite's motion provides scanning in the along-track direction. A spatially bi-dimensional image is obtained by the gathering and the processing of subsequent images as ENVISAT moves along.

MERIS is able to deliver Full and Reduced spatial Resolution products (FR and RR mode). These two spatial resolutions are at sub-satellite point 290 m (along track) x 260 m (across track) for the full spatial resolution and 1.2 km x 1.04 km for the reduced resolution. The spatial resolution varies only slightly from the sub-satellite point to the image edge in spite of its large field of view. RR mode is activated on a global basis whereas the FR mode is acquired regionally by direct reception.

The Globcover project has benefited from 19 months of global Fine Resolution Full Swath product (FRS) available from December 2004 until June 2006 processed at level 1B, i.e. calibrated top of atmosphere gridded radiances.

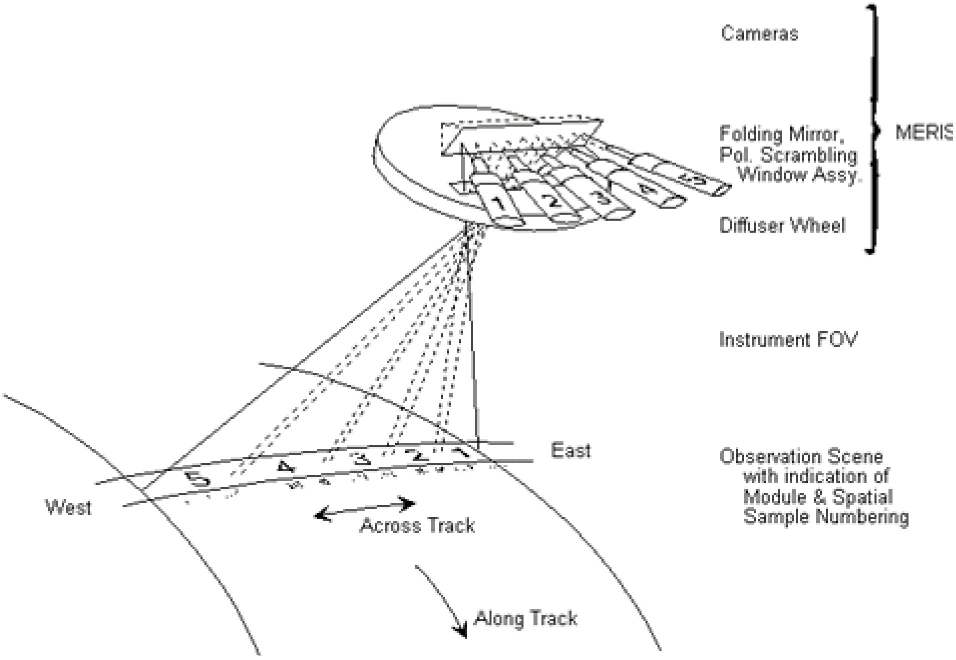

Figure 1. MERIS sensor: FOV, camera tracks, pixel enumeration and swath dimension (source ESA)

2. Principle of Globcover processing chain

The challenge of the Globcover processing chain is to automatically deliver a land cover map from MERIS FRS level 1B data. A processing chain has been developed considering two major modules (*Figure 2*):

- a pre-processing module leading to global mosaics of land surface reflectance at 300 m resolution in 13 spectral bands which is described in more detail in section 2.1;
- a classification module leading to the final land cover map at 300 m resolution which is described in more detail in section 2.2.

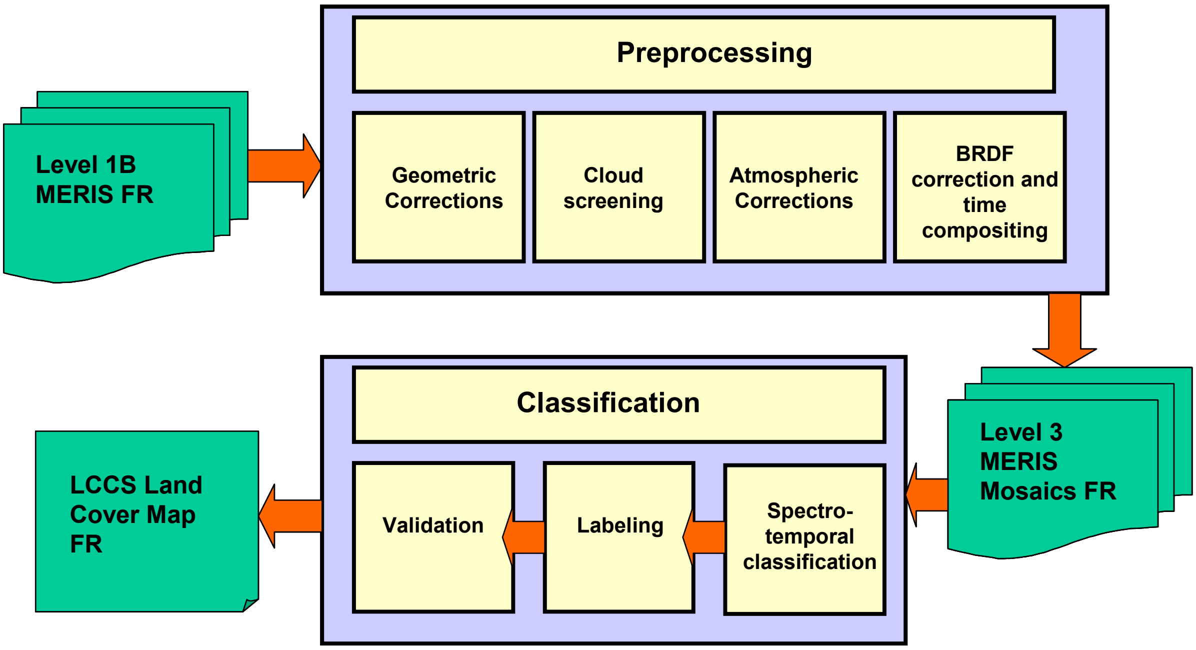

Figure 2. Algorithmic principle of the Globcover chain

2.1. Surface Reflectance mosaics generation

Overall around 30 Terabytes of MERIS FRS level 1B data have been processed to produce the mosaics of land surface reflectance. The surface reflectance mosaics are obtained from the MERIS FRS level 1B images with a series of pre-processing steps, including the following modules:

- geometric correction of the input data to achieve at least a 150 m geo-location accuracy;
- cloud screening and shadow detection;
- land/water reclassification and a correction of the smile effect;
- atmospheric correction, including aerosol correction;
- BRDF correction and temporal compositing;

Geometric corrections

The geometric corrections are done using the AMORGOS tool (Bourg et al., 2007) developed by ACRI. AMORGOS uses as input MERIS FRS products, restituted satellite attitude, orbit ephemeris files, a Digital Terrain Model at 30" resolution, and produces as output corrected latitude, longitude and altitude for each pixel. The projection tool has been developed by the POSTEL/Medias-France team and CNES. The ortho-rectified images in output of AMORGOS and of the Projection tools have demonstrated a relative geo-location accuracy of 52 m RMS and an absolute accuracy of 77 m RMS (*Figure 3*). These performances are seen as satisfactory and permit to use the MERIS images at their full resolution of 300 m.

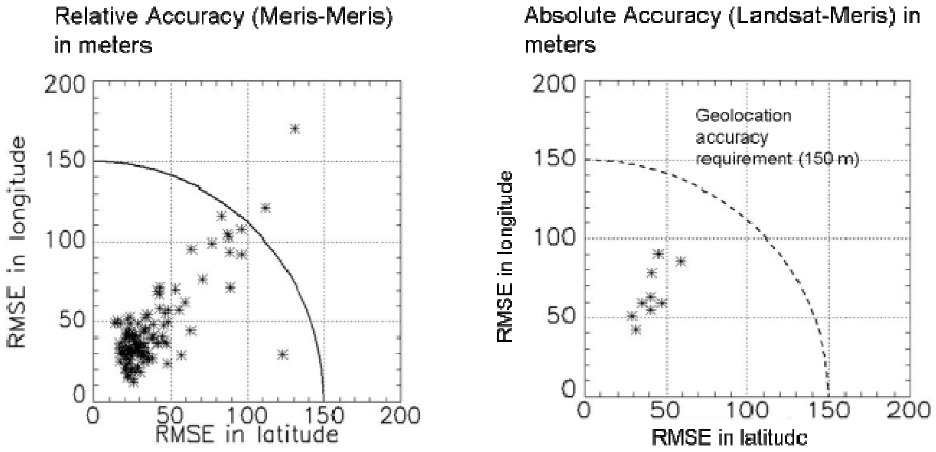

Figure 3. MERIS ortho-rectified images geo-location accuracy

Atmospheric correction

The atmospheric correction permits to transform Top of Atmosphere (TOA) radiances into surface reflectances. The effects of Rayleigh and aerosol scattering and gaseous absorption are taken into account. The algorithm uses a neural network relying on the so-called MOMO method (Fischer and Grassl, 1991) which has been selected because it was validated in the framework of the ESA Albedo Map project (Fisher et al., 2006). The aerosol correction is performed using a monthly aerosol optical depth product at 1 km resolution derived from 2005-2006 MERIS-Reduced Resolution data with an algorithm developed by Brockmann-Consult. This new method significantly decreases an effect called the "blue shade" effect (*Figure 4*) due to an imperfect estimation of the aerosol optical depth. The gaseous absorption correction uses an ozone field from ECMWF, and oxygen and H_2O fields derived from the MERIS data (ratios B11/B10 and B15/B14 for O_2 and H_2O respectively).

Cloud screening

Two methods are combined to screen clouds, the first one using the MOMO method already quoted, and the second one using thresholds of reflectance on the bands at 443, 753, 760 and 865 nm. The results of the cloud screening have been validated using ground truth data from the synoptic network of meteorological stations operated by Meteo-France over Europe and Africa, and a Cloud Toolbox developed by NOVELTIS and CNES. Cloud top height is estimated for a better determination of shadows. The snow reflectance is kept at its TOA level.

Land/Water and Water/Land reclassification

The original MERIS level 1B Land/Ocean mask that covers sea, oceans, and the largest in-land lakes is applied and the reflectances are computed only for the unmasked water bodies. Yet, this mask presents some geo-location inaccuracies and is therefore not absolutely correct. In order to take into account these inaccuracies, a Land/Water and Water/Land reclassification is applied to finally generate status 'Land', 'Water' or 'Flooded' (corresponding to pixels declared wrongly as 'Land' before the reclassification).

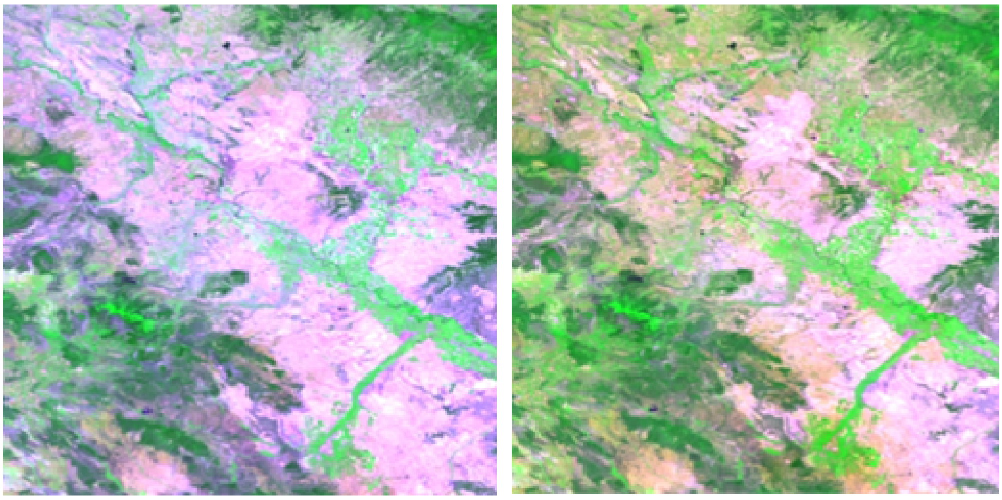

Figure 4. Multispectral bimonthly composite over Spain, May-June 2005 (the blue shade effect at left). The same colorscale is applied on both images

Plate-Carrée projection

The surface reflectance products are projected in a Plate-Carrée projection (WGS84 ellipsoid). The geographic location information is given in Table 1 and is included in the products metadata stored in HDF-EOS2 format. Opened with current visual imaging software, the products geo-referencing requests a simple and manual use of these metadata.

<table>
<tr><th>Field</th><th colspan="2">Description</th></tr>
<tr><td>Projection</td><td colspan="2">Plate-Carrée with a Geographic Lat/Lon representation (GCTP_GEO)</td></tr>
<tr><td>Reference ellipsoïd</td><td colspan="2">WGS 84 (R= Spherical Radius= Equatorial Radius=Re= 6378,14km)</td></tr>
<tr><td>Pixel resolution</td><td colspan="2">1/360°</td></tr>
<tr><td>Tile Upper Left pixel location</td><td colspan="2">Tiles H{h}V{v} with H{h}: h ∈ [0 ; 71] and V{v} v ∈ [0; 35]
Upper Left pixel longitude: -180° + h x 5° E
Upper Left pixel latitude : 90° – v x 5° N</td></tr>
<tr><td>Tile size</td><td>Angular size: 5° x 5°</td><td>Size in pixels: 1800 x 1800</td></tr>
<tr><td>Tile Upper Left corner of Upper Left pixel</td><td colspan="2">Upper Left corner of Upper Left pixel longitude:
-180° + h x 5 -0.5 x Res_{deg} E
Upper Left pixel of Upper Left pixel latitude :
90° – v x 5° N + 0.5 x Res_{deg} ° N
As the projection is Geographic LatLon (GCTP_GEO), the coordinates are specified in degrees/minutes/seconds (DDDMMMSSS.SSS) in the associated HDF-EOS2 metadata</td></tr>
</table>

Table 1. Geographic location information of the surface reflectance products

BRDF Correction and Temporal Compositing

Two methods are combined to remove the directional effects due to variations of sun and view geometry in the successive measurements of surface reflectances. The Mean Composite method (Vancutsem et al., 2007) is processed as a first reference time series of surface spectral reflectance over a compositing period of 60 days. Then the CYCLOPES method of Hagolle et al. (2004) is used to screen this dataset and remove spurious data affected by undetected sources of noise (residual thin clouds, aerosols, shadows...). The temporal compositing is then an average of the time series of surface reflectances corrected for directional effects over various periods depending on the needs: 2 months or one year.

2.2. Land Cover product generation

The classification process transforms the cloud-free reflectance mosaics into a land cover map. It is organized in four main steps (*Figure 5*). Before the classification process, the world is stratified in equal-reasoning areas. The classification process has been designed to run independently for each delineated equal-reasoning area. More details on the stratification and classification can be found below. The land cover product editions that were realized after the classification are also listed.

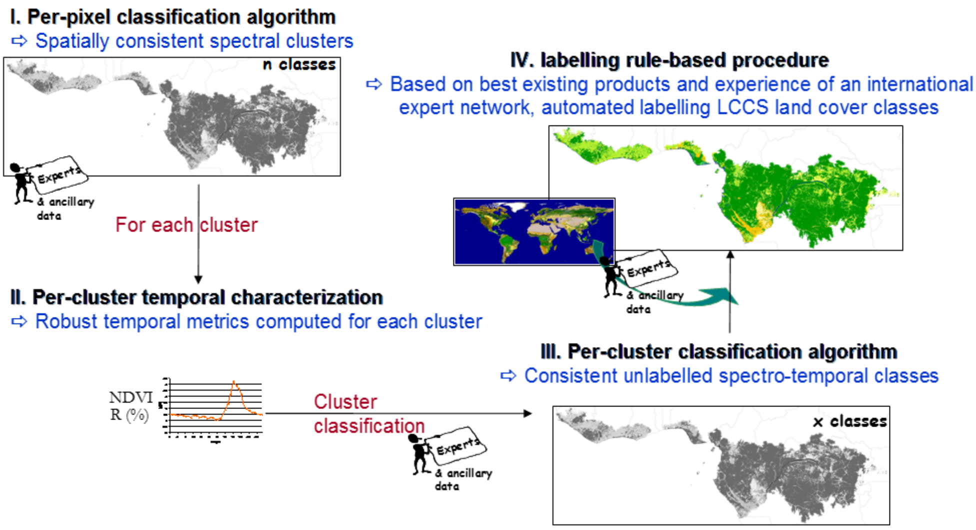

Figure 5. Scheme showing the principle of the classification algorithm starting with biweekly mosaics

Stratification

The stratification splits the world in equal-reasoning areas from an ecological and a remote sensing point of view. The objectives are twofold: (1) reducing the land surface reflectance variability in the dataset in order to improve the classification efficiency and (2) allowing a regional tuning of the classification parameters to take into account the regional characteristics (vegetation seasonality, cloud coverage, etc).

The stratification mainly relies on natural discontinuities (oceans, seas, mountains area, etc) and on sharp interfaces clearly depicted from a remote sensing point of view (e.g. forest-savannah interfaces). *Figure 6* provides an overview of these areas.

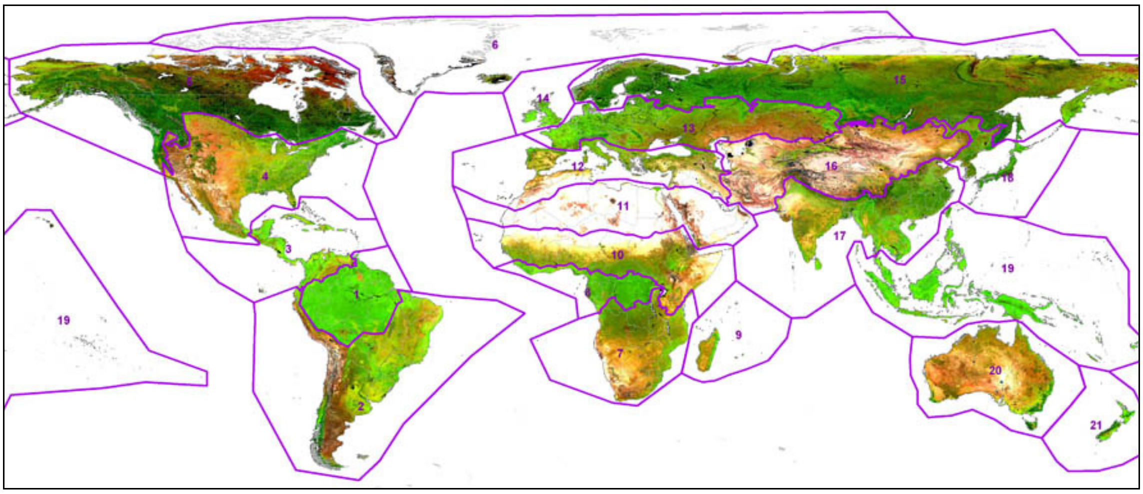

Figure 6: Overview of the stratification coarse limits. The 22 areas are overlaid to the annual composite of SPOT VEGETATION (SWIR, NIR, RED, year 2000)

Step I. Per-pixel classification algorithm

The spectral classification consists of a supervised and an unsupervised classification. The supervised classification aims at identifying land cover classes that are not well represented, i.e. urban and wetland areas. The pixels classified through this process are masked and an unsupervised classification is then applied on the remaining pixels to create clusters of spectrally similar pixels.

Step II. Per-cluster temporal characterization

The second step is the temporal characterization of the spectral clusters produced by the unsupervised classification in the equal-reasoning areas which present a high seasonality. In these strata, two phenological metrics (minimum and maximum of vegetation) are derived from the MERIS time series and spatially averaged for each cluster.

Step III. Per-cluster classification algorithm

From the temporal information that characterizes each cluster, this third step groups the clusters into a manageable number of spectro-temporal classes according to their similarity in the temporal space.

Step IV. Labelling-rule based procedure

The labelling procedure merges and transforms the spectro-temporal classes into land cover classes defined with the UN LCCS. The labelling procedure is automated and based on a global reference land cover database. The global reference land cover database is compiled from GLC2000 and several local reference land cover maps selected as the most accurate map available for a given region, with the highest spatial resolution and with a Globcover-compatible legend.

The Globcover land cover label is decided according to the correspondence between both set of classes, i.e. the spectro-temporal classes and the reference land cover classes. Several decision rules have been defined with the help of international land cover experts to derive unique label for each spectro-temporal class.

Post-classification edition

- *Gap filling*

As shown in *Figure 8* and *Figure 9*, the data coverage of MERIS FR acquisitions is uneven due to programmatic constraints, resulting in gaps in the data and therefore in the land cover product. These gaps are filled out using the reference land cover database.

- *Flooded forest*

The lack of SWIR band in the MERIS sensor has hampered some discrimination. Typically, the classes “Closed broadleaved forest regularly flooded with fresh water” and “Closed broadleaved semi-deciduous and/or evergreen forest regularly flooded with saline water” appeared to be largely under-estimated in the Globcover classification. They are therefore directly imported from the reference land cover database.

- *Water bodies*

As already mentioned, a Land/Water mask is applied for the production of the land surface reflectance products (section 2.1). Yet, this mask is not absolutely correct: it is not exhaustive – especially regarding inland water bodies – and it presents some geo-location inaccuracies. In order to face this problem, it has been decided to use an external dataset, the SRTM Water Body Data (SWBD), to improve the ‘water bodies’ delineation in the Globcover classification.

3. Description of surface reflectance mosaics

3.1. Data coverage

Each MERIS FR mosaic is organised on a 5° by 5° tiling without any overlap (*Figure 7*). The entire Earth is therefore covered by 2592 tiles (72 horizontal tiles x 36 vertical tiles). Each tile of the MERIS FR mosaic (bimonthly and annual) has an approximate size of about 100 Mbytes. Out of 2592 tiles needed to cover the whole world, only 1266 tiles include land cover.

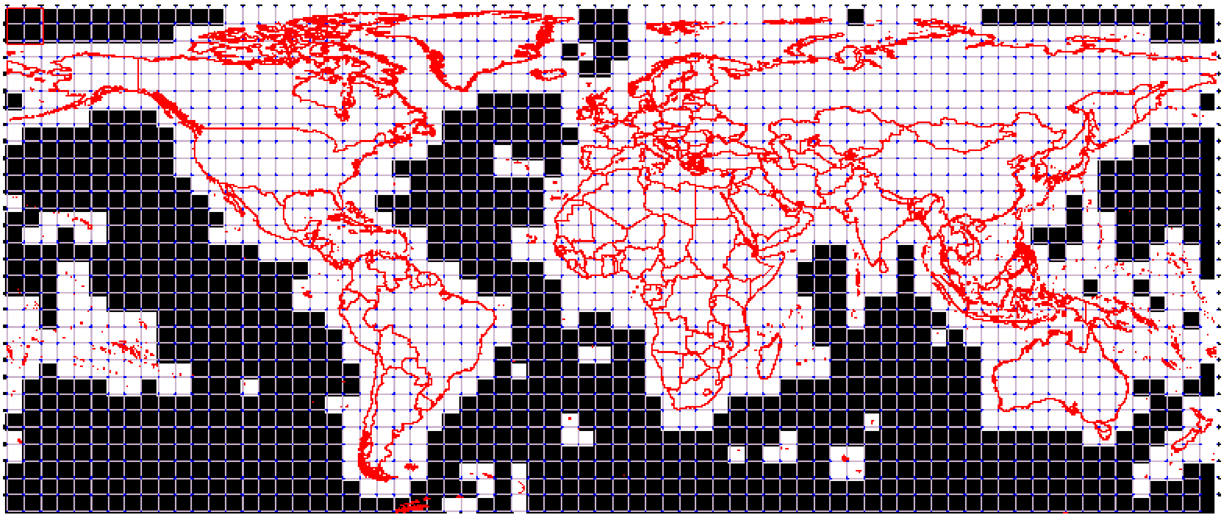

Figure 7 : Scheme of the Globcover tiles location

The very first challenge of Globcover was the global acquisition of a MERIS time series while the instrument was not initially designed to do so. As shown in *Figure 8*, the data coverage is uneven due to programmatic constraints. In areas such as Central and South America, North East of America, Korean peninsula and East Siberia, the data coverage is significantly lower than elsewhere.

As expected, the number of valid observations (cf the parameter “NMOD” in Appendix I) after the pre-processing steps, in particular that of cloud screening, is also rather variable (*Figure 9*). Combining the effect of poor acquisition and persistent clouds coverage, some areas (South America, North East of America, Central Siberia, North East of Asia, Korea, Philippines and Malaysia and Central Africa.) show a very low number of valid observations. These areas are not expected to be accurately classified in the land cover product. In few areas like South America none valid observation has been obtained over the 19 months period.

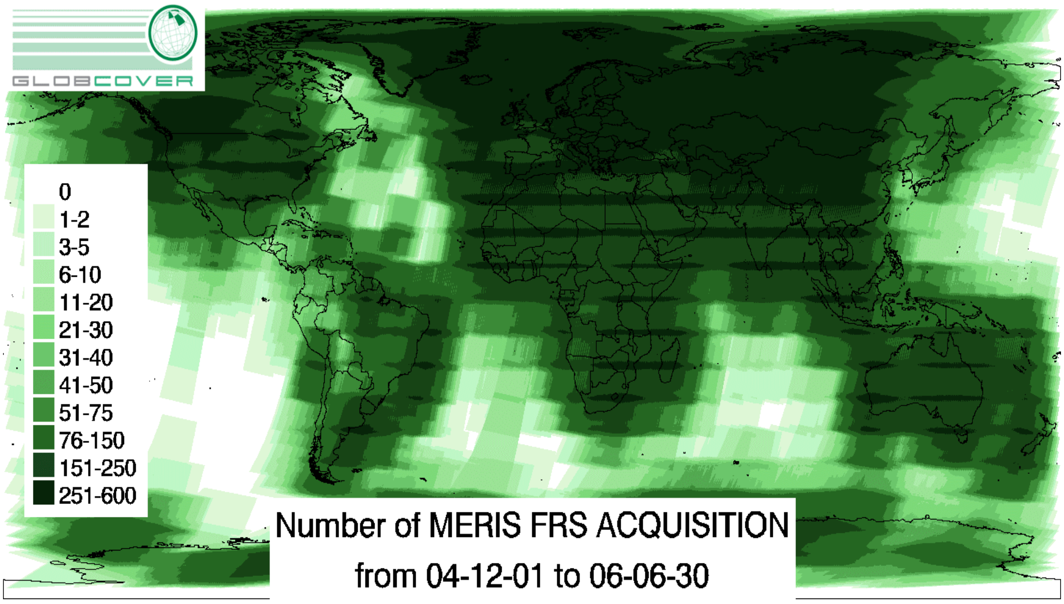

Figure 8. Density of MERIS FRS acquisitions from 1st December 2004 to 30th June 2006.

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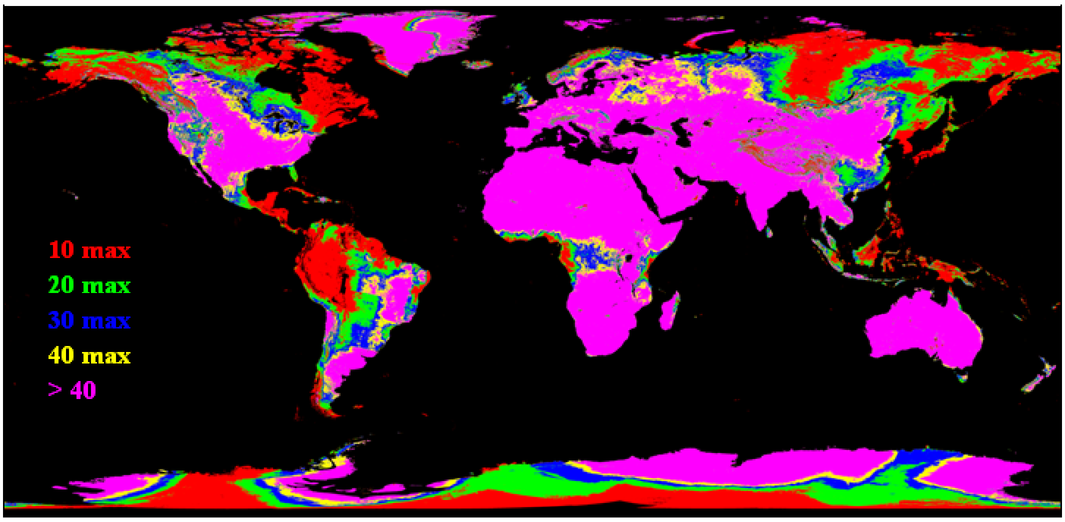

Figure 9. Number of valid observations obtained after 19 months of MERIS FRS acquisitions. Magenta areas are defined as well covered (>40 observations)

3.2. Products description

A complete description of format and content of the Globcover surface reflectance mosaics is given in the Product Description Manual (Bicheron et al., 2008) and is briefly recalled in Appendix I.

The surface reflectance mosaics have both a global and a regional character. It is not possible to illustrate at the same time the fine resolution of the product and its global feature. *Figure 10* illustrates the global aspect and *Figure 11* the regional aspect.

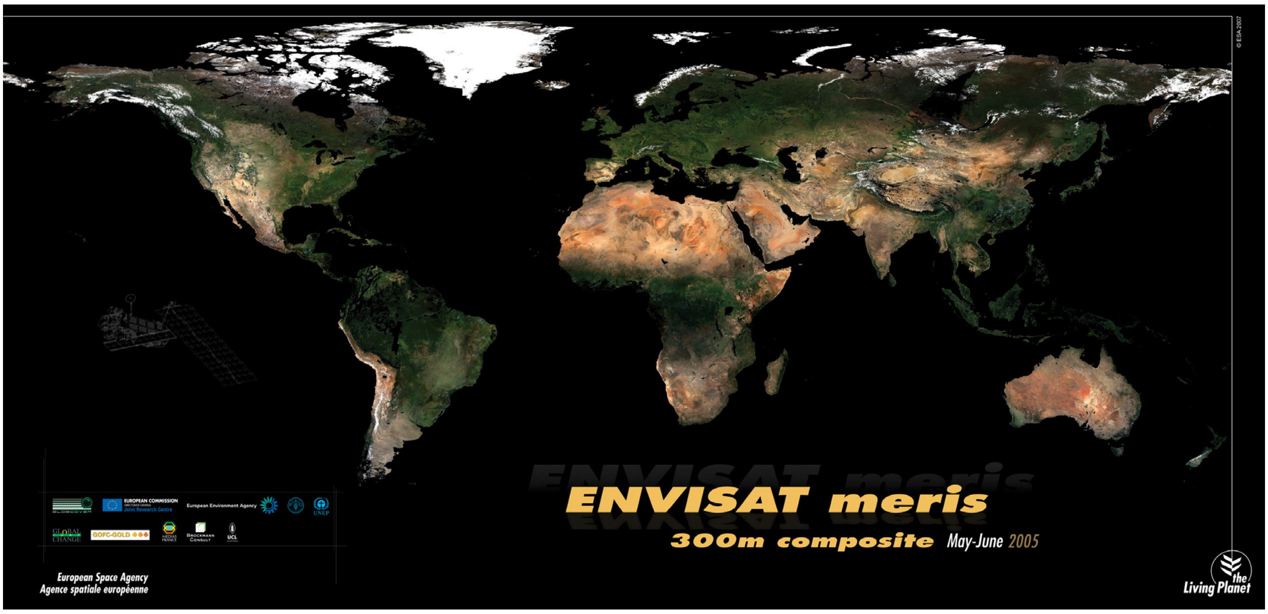

Figure 10. One of the early mosaics, presented at the ESA conference of Montreux in June 2007.

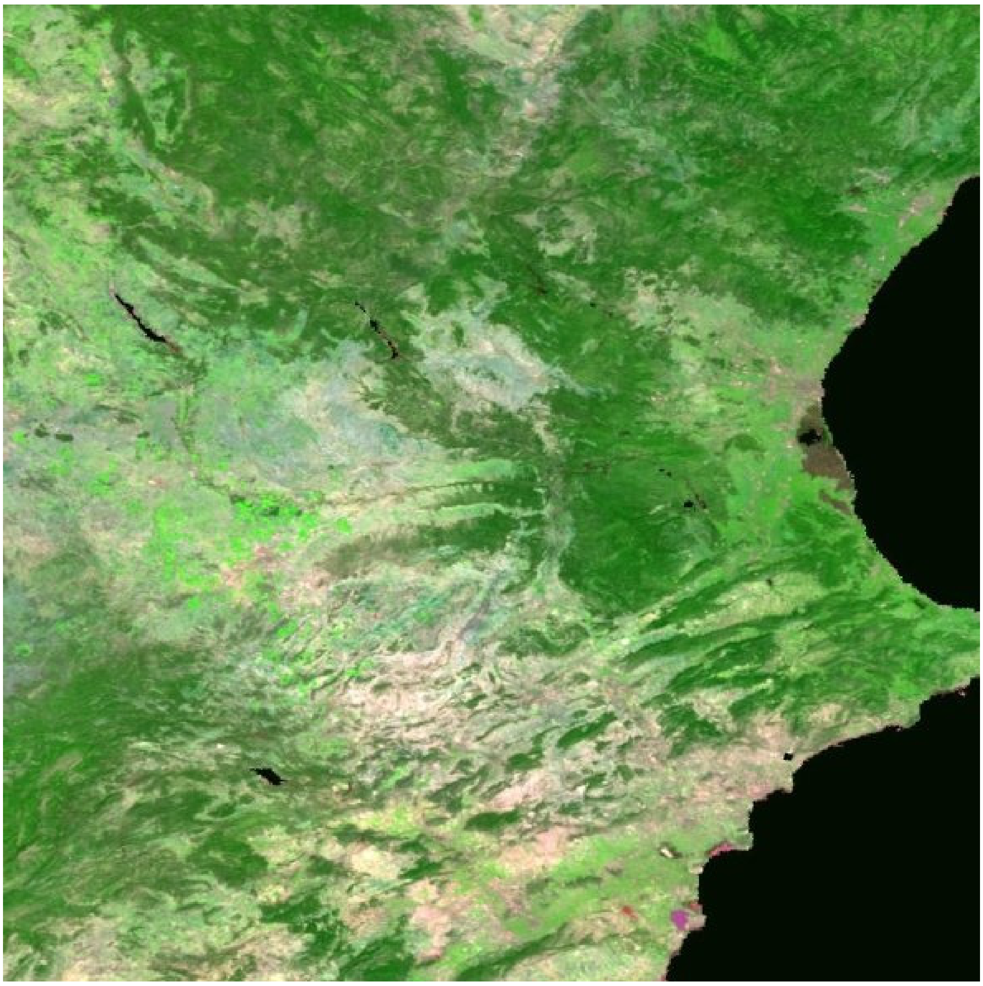

Figure 11. Multispectral color composite on a mosaic in the Valencia region (Spain) (Spring 2005)

3.3. Identified issues

The issues identified in the Globcover surface mosaic products are:

(i) data coverage

Some areas are only partially covered even with an acquisition period of 19 months. MERIS RR products that are systematically acquired represent a valuable source of information to increase the dataset, although the spatial resolution is lower. This improvement can be foreseen for the future. In addition, the number of the receiving stations is planned to be increased in the future (especially in America). As a result, the number of downloaded MERIS FRS products can also be increased especially over areas with a current low coverage.

(ii) aerosol correction

The blue shade effect has been removed but led to the apparition of spurious dark patches at times.

(iii) coastline delineation

The original MERIS level 1B Land/Ocean mask presents too strong inaccuracies (because of geo-location uncertainty, high tide zones and seasonal variations of water level) for a sharp delineation of coastline. The Land/Water and Water/Land reclassification module has been developed to recover pixels misclassified. The module is applied to all pixels with altitude greater than -50 meters but does not solve completely the issue. Land pixels still sometimes appear on sea.

4. Description of land cover products

4.1. Introduction

The classification module of the Globcover processing chain consists in transforming the MERIS FR multispectral mosaics produced by the pre-processing modules into a meaningful global land cover map. As explicitly requested by ESA, the challenge is to produce, in an automatic, repeatable and global way, a global land cover map at 300m resolution with a legend defined and documented using the UN Land Cover Classification System (LCCS). The typology has been defined using UN LCCS with the view to be as much as possible compatible with GLC2000 (Fritz et al., 2003). The classification module has been designed by UCL-Geomatics to combine both the spectral and temporal richness of the MERIS FR time series and to be globally consistent while regionally-tuned.

4.2. Legend description

In LCCS, the land cover classes are defined by a set of classifiers. LCCS has been designed as a hierarchical classification, which allows adjusting the thematic detail of the legend to the amount of information available to describe each land cover class, whilst following a standardised classification approach. The Globcover land cover product has been designed to be a global, consistent land cover map. Therefore, its global 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”, meets this requirement (Table 2).

The global Globcover legend is compatible with the GLC2000 global land cover classification (http://www-tem.jrc.it/glc2000/legend.html).

A Globcover global class corresponding to the “Closed (>40%) needleleaved deciduous forest (>5m)” was initially expected but it doesn’t appear in the final product. On the other hand, the distinction between the post-flooding or irrigated croplands (class 11) and the rainfed croplands (class 14) has been possible, thus making the discrimination of the cultivated and managed areas higher than expected.

The Globcover land cover product is also described by a more detailed legend, called level 2 or regional legend. 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 II.

The regional classes are not present all over the world since they were not properly discriminated at the global scale and the level of detail in the reference land cover database was not available everywhere. As a result, only regional products are delivered with this extended legend.

The explicit LCCS definition of each Globcover global and regional class is provided in Appendix III.

Value	Global Globcover legend (level 1)	
11	Post-flooding or irrigated croplands	
14	Rainfed croplands	
20	Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)	
30	Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)	
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	
50	Closed (>40%) broadleaved deciduous forest (>5m)	

60	Open (15-40%) broadleaved deciduous forest (>5m)	
70	Closed (>40%) needleleaved evergreen forest (>5m)	
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	
110	Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)	
120	Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)	
130	Closed to open (>15%) shrubland (<5m)	
140	Closed to open (>15%) grassland	
150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)	
160	Closed (>40%) broadleaved forest regularly flooded - Fresh water	
170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water	
180	Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water	
190	Artificial surfaces and associated areas (urban areas >50%)	
200	Bare areas	
210	Water bodies	
220	Permanent snow and ice	

Table 2. *22 classes of the global (or level 1) Globcover legend*

4.3. Products description

The Globcover land cover product is the first 300m global land cover map produced for the period December 2004 – June 2006. The map projection is a Plate-Carrée (WGS84 geoid) just like the surface reflectance products (section 2.1).

The Globcover classification has both a global and a regional character. As explained in section 4.2, the global land cover product has the property to be consistent: it is described by a legend counting 22 land cover types that are well documented and comparable all over the world. On the other hand, regional Globcover maps (cf. Appendix IV *Figure 19* for their delineation) may show more detailed legends, depending on the reference land cover maps available to discriminate them. *Figure 12* presents the global Globcover land cover map and *Figure 13* illustrates the additional information provided by the regional legend through a snapshot of the Globcover regional product over North-America.

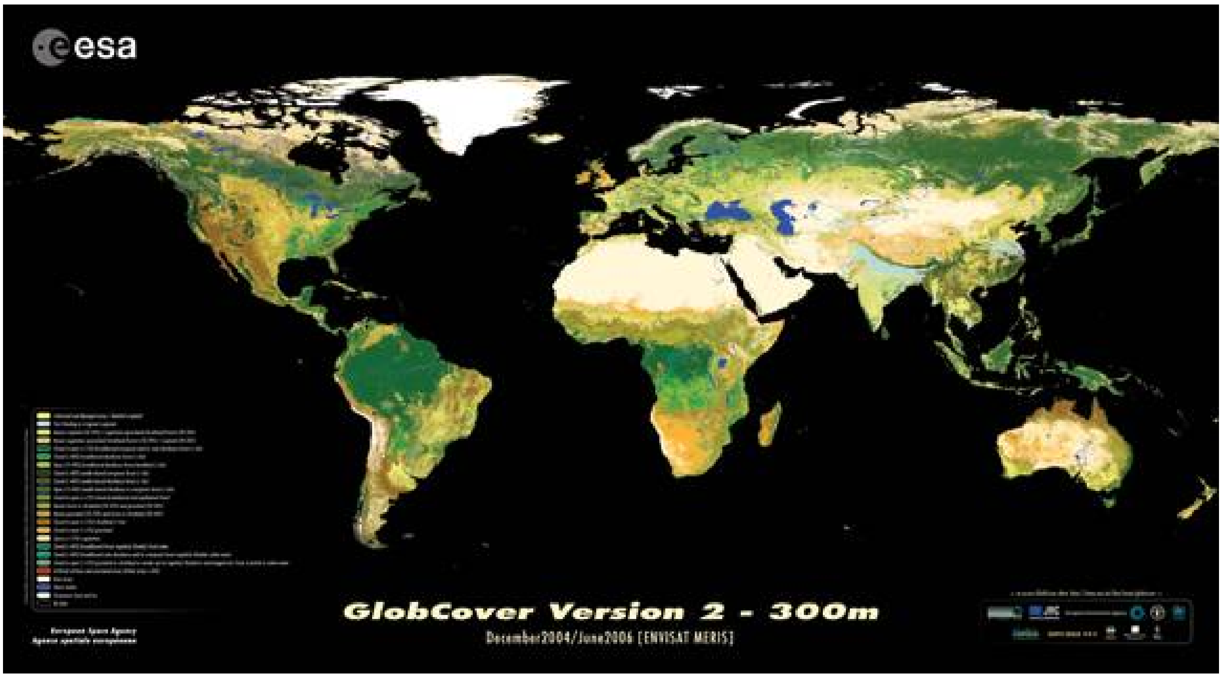

Figure 12: The Globcover product as the first 300m global land cover map for the period December 2004- June 2006

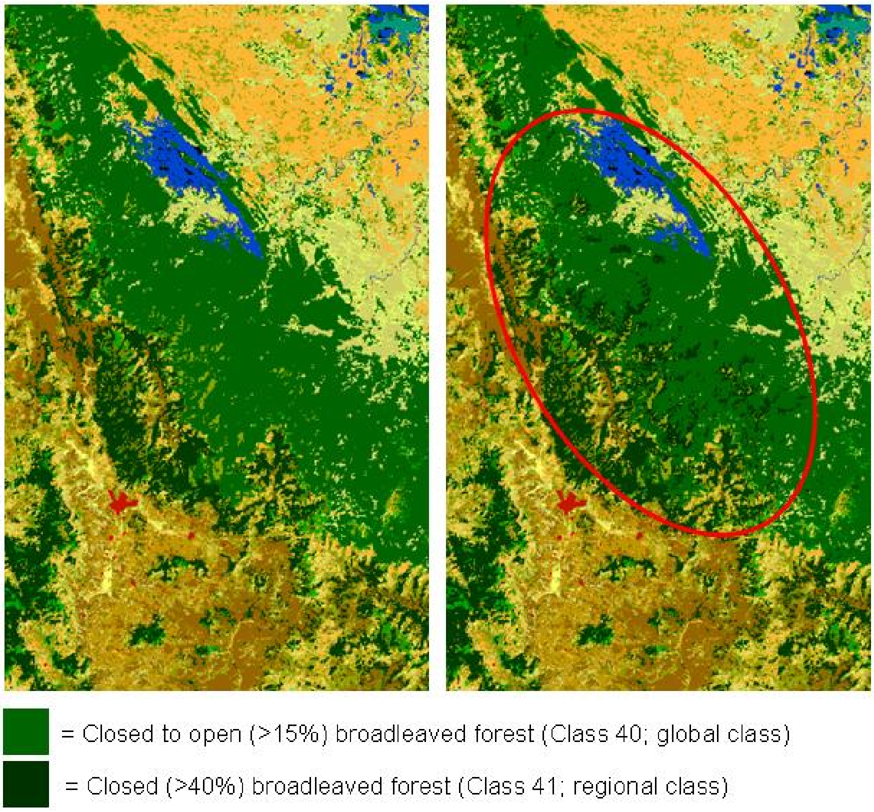

Figure 13: Global product (left) versus regional product (right) in Mexico. In the regional product, pixels that are clearly identified as closed forest (class 41) are labelled as such; in the global product, this distinction is not done (class 40)

Table 3 presents the area covered by the 22 global classes, computed after a projection of the land cover map into a Lambert cylindrical equal area projection and expressed in percentage. Some classes are little represented as expected: class 160 “Closed (>40%) broadleaved forest regularly flooded - Fresh water”, 170 “Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water”, 180 “Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water”, and 190 “Artificial surfaces and associated areas (urban areas >50%)”.

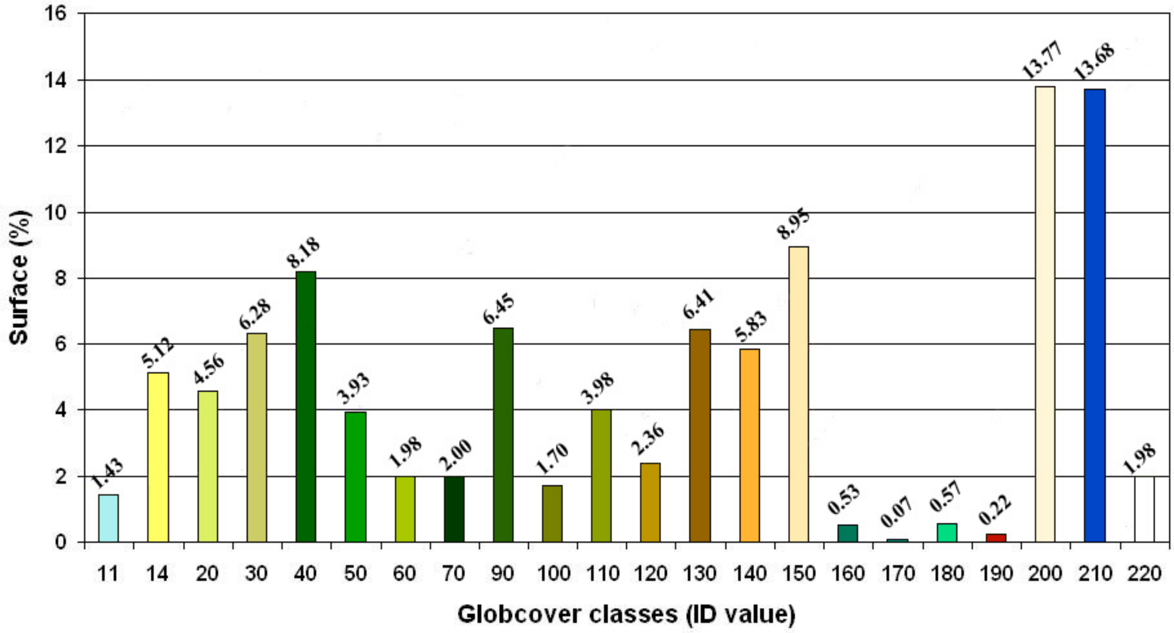

Table 3. Area (%) covered by the 22 global classes

The use of medium resolution data brings a considerable improvement in comparison with other global land cover products at lower spatial resolution. *Figure 14* provides a comparison between GLC2000 (1km spatial resolution) and Globcover (300m spatial resolution) in Amazonia (Brazil), in Saudi Arabia and in Russia.

The quality of the Globcover product is highly dependent on the reference land cover database used for the labelling process and on the number of valid observations available as input. When the reference dataset is of higher spatial resolution with a high thematic detail, the Globcover product also shows a high accuracy. *Figure 15* provides an example in Europe, where the reference dataset is the Corine Land Cover.

On the other hand, the number of valid observations is a restrictive factor. The spatial coverage of the MERIS data clearly determines the quality of the temporal mosaics and therefore, of the land cover map, as shown in *Figure 16*.

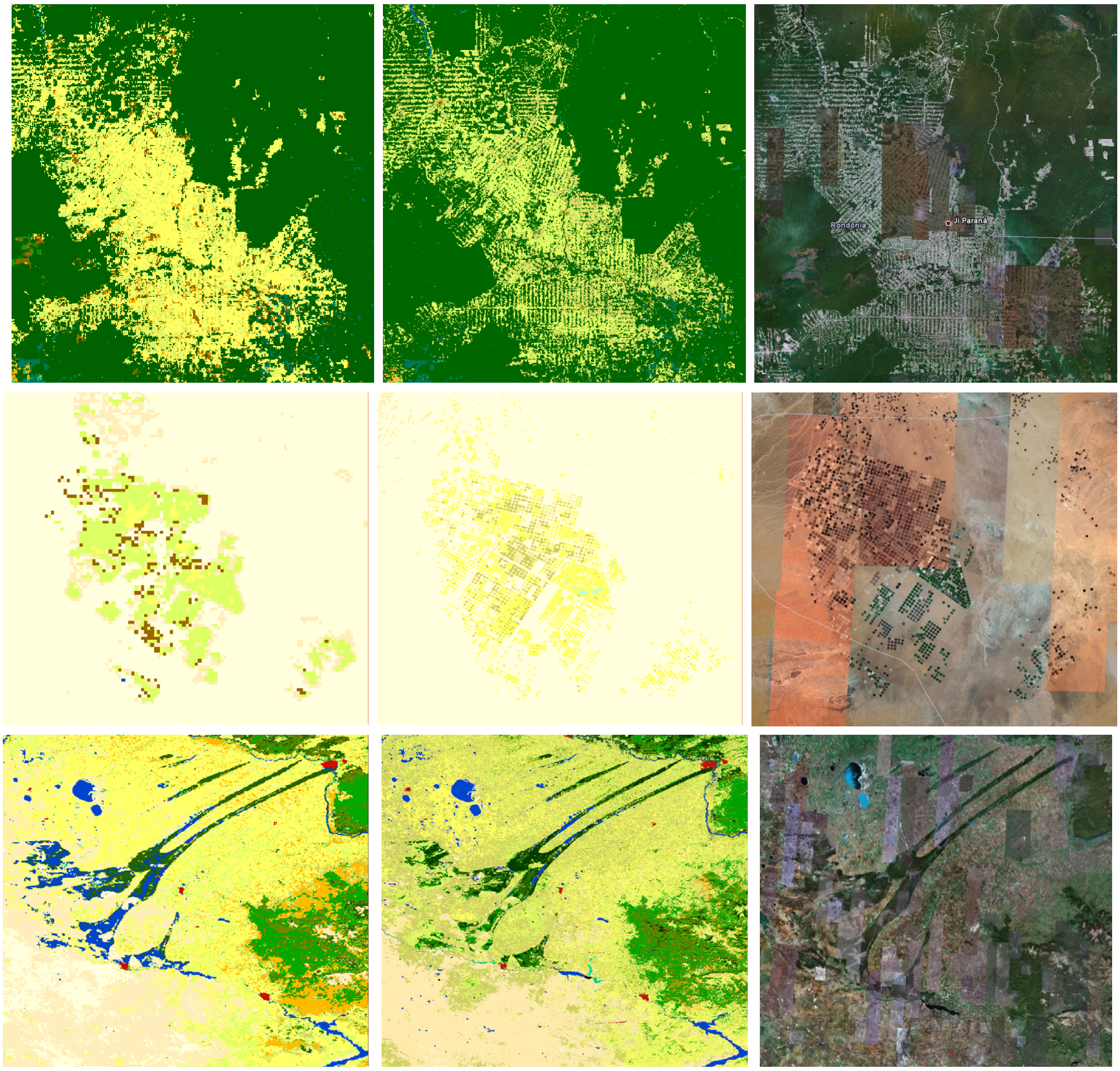

Figure 14 : Improvement of the spatial detail due to the 300m spatial resolution. Deforestation clear cuts in Amazonia (top), irrigated crops in Saudi Arabia's desert (centre) and specific vegetation structure in Russia (bottom). GLC2000 (left), Globcover (centre), GoogleEarth(right)

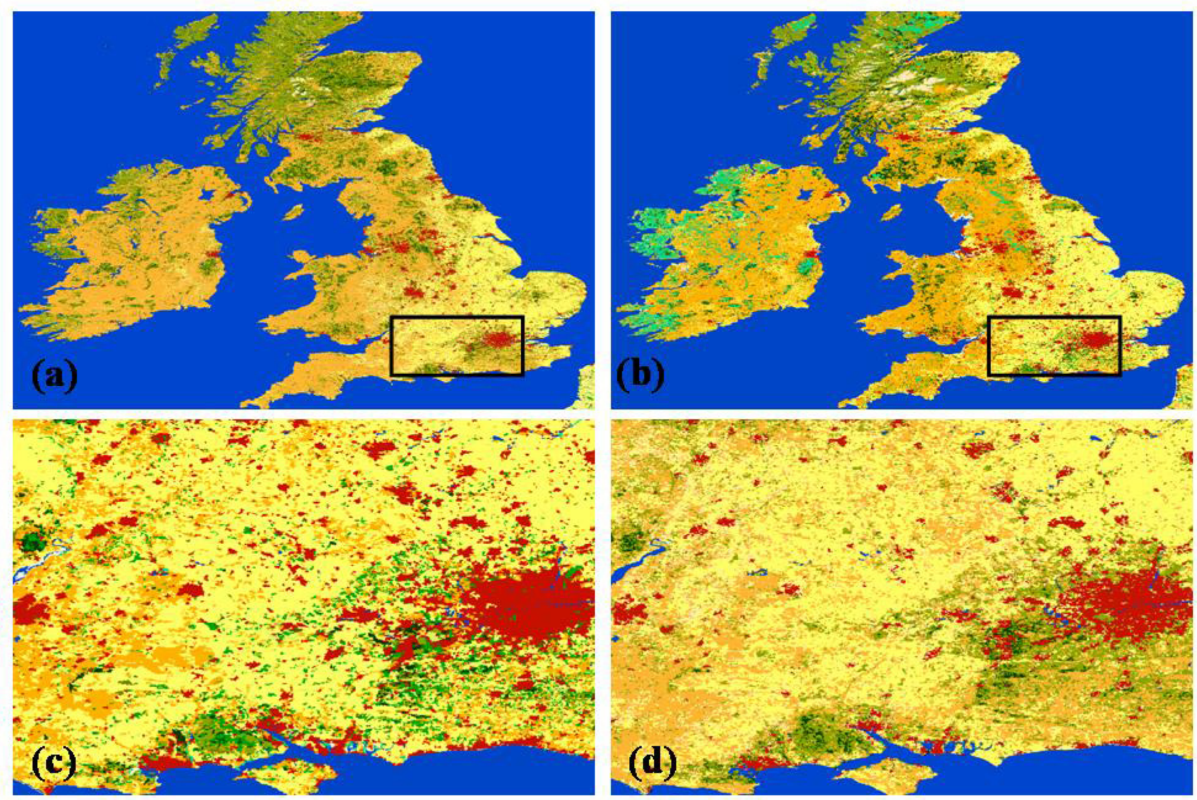

Figure 15 : Globcover product over England and Ireland (b), compared with CLC (a). Spatial patterns and details of CLC (d) are also present in Globcover (c), which illustrates the dependency of the Globcover quality on the reference dataset

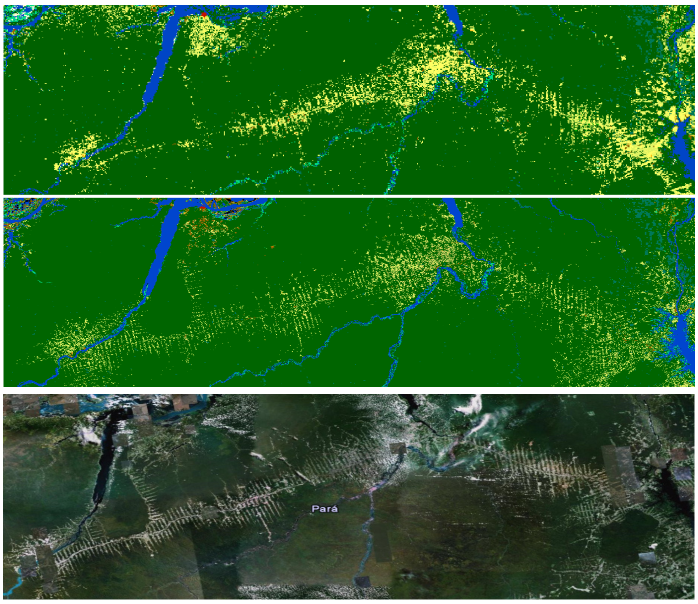

Figure 16 : Comparison between GLC2000 (top), Globcover (centre) and Google Earth (bottom) in an Amazonian area of low data coverage. The deforestation patterns along the trans-Amazonian highway are not well captured by the Globcover product while they are detected in GLC2000.

As mentioned in 2.2, the SWBD was used to improve the water bodies delineation in the Globcover classification. As a result, the water bodies are delineated with a greater spatial accuracy than the MERIS pixel size (*Figure 17*).

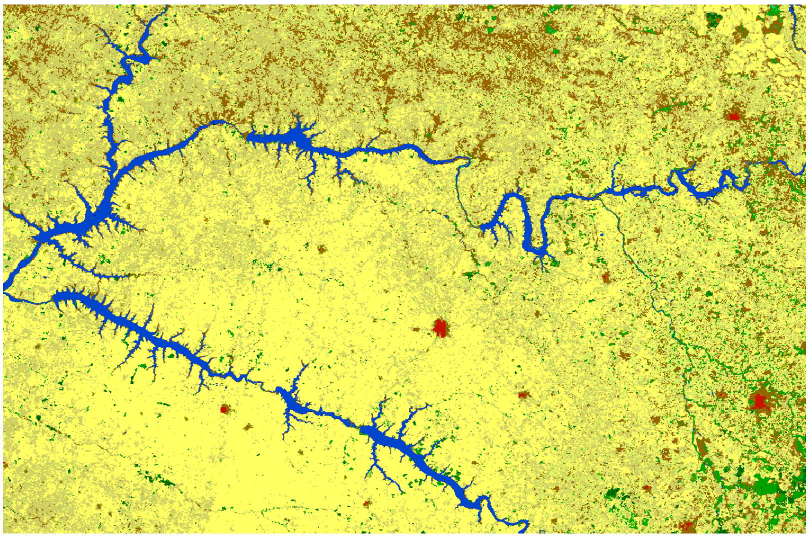

Figure 17. Delineation of the Parana river and of its tributaries in Brazil

4.4. Identified issues

The issues identified in the Globcover land cover product mainly concern:

(i) inconsistencies due the lack of data

There are still some regions of the world (e.g. some areas in Amazonia) where data coverage is limited. The limited number of available data has consequences on the quality of the land surface reflectance mosaics and therefore, it can have several effects on the land cover product.

In areas of very low data coverage (about 2% of the world continental areas) the pixel values where derived from the reference land cover map leading to possible discontinuity in the classification. When the data coverage is poor, there is still a tendency for Globcover to overestimate forest areas.

A flag indicating whether the reference dataset has been used instead of the output of the Globcover classification scheme has been documented in the CLA_QL band (Bicheron et al., 2008), and it is strongly recommended that users consult this information.

(ii) forest estimation

As mentioned above, there is a trend to overestimate forest areas when the data coverage is poor. In addition, the lack of SWIR channel in the MERIS sensor may lead to misclassifications in tropical forests. The case of the flooded forests (classes 160 and 170) is particularly problematic; their identification is thereby mainly resulting from ancillary data.

(iii) limits between 2 strata

In the classification process, the world has been split in 22 equal reasoning regions. Each region (or stratum) is processed independently. The impact of the stratification is, in some cases, visible on the map, in particular over drylands.

(iv) lakes and rivers

It has to be kept in mind that the identification of water bodies is largely based on the SWBD (cf. section 2.2). It should furthermore be noted that the SWBD is based on year 2000 data and is limited on -60° and +60° of latitude.

(v) classes with a limited spatial extent

Sometimes, a lower accuracy for land cover classes with small spatial extent, e.g. ‘urban areas’ or ‘flooded lands’ has been noted. Urban areas are underestimated and the distinction between irrigated and flooded lands is very difficult in several regions (e.g. in Sudan), leading to an underestimation of cultivated areas.

(vi) thematic errors

In very rugged terrain (e.g. Andes or north Laos), it has been noted that mountain shadows may lead to misclassifications. In the Andes areas, they have often been mapped as flooded grasslands.

Bare areas (i.e. limestone formation) in central Laos are classified as “Natural and Semi-natural Terrestrial Vegetation - Woody / Trees”. This type of classification error mainly relates to difficulties with the 15% vegetation threshold of the LCCS.

Finally, it’s noteworthy that, from the end users point of view, the Globcover land cover map contains a significant amount of mosaic classes, which may limit the thematic sharpness of the Globcover product and its relevancy to derive very specific products.

5. Land cover validation

5.1. Introduction

The quantitative validation of the Globcover land cover product aims at assessing the accuracy of the global land cover map (counting the 22 global classes) from an independent reference dataset. The validation results allow a potential user determining the map's "fitness for use" for his or her application. The validation process is designed to be scientifically sound, internationally acceptable and feasible from a cost and time point of view. This is based on the document of the CEOS Land Product Validation subgroup: *"Global Land Cover Validation: Recommendations for Evaluation and Accuracy Assessment and of Global Land Cover Maps"* (Strahler et al., 2006).

The validation process includes three different steps: collecting reference data sources, elaborating the sampling strategy and assessing the product's accuracy. In the framework of the Globcover project, the reference data collection could only rely on already existing expertise distributed all over the world. An independent private company, namely Infram B.V., has developed the data collection tool and completed the data analysis for the accuracy assessment.

5.2. Methodology

The creation of an international expert network is the key element of the validation process. 16 international experts have used a dedicated working environment for on-screen collection of 'ground truth' data. They have been invited for 6 different 5-day workshops held at UCL premises (Louvain-la-Neuve, Belgium). The experts have truly committed themselves to assess the quality of the Globcover product. The experts have been selected according to the following criteria: undisputed expertise on land cover over relative large areas, familiarity with interpreting remote sensing imagery, commitment, complementarity to the other experts and belonging to well-known international network. Table 4 reports the name and current affiliation of all the experts involved in the validation of Globcover product.

Region	Experts	Institution
Africa	André Nonguierma	Centre Agrhymet – Niger/Economic Commission of Africa
	Bruno Gérard	ICRISAT
	Philippe Mayaux	Global Environment Monitoring unit – Joint Research Centre
Europe	Sander Mücher	Alterra - (Pelcom) - Netherlands
	Allard de Wit	Alterra - (Pelcom) - Netherlands
	Gerard Hazeu	Alterra - (Pelcom) - Netherlands
	Gabriel Jaffrain	ETC-LUSI Technical Team
Russia	Sergey Bartalev	Space Research Institute (IKI), Russian Academy of Science
Asia	Huang Lin	Institute of Geographical Sciences and Natural Resources Research – Chinese Academy of Sciences
	Hans-Jürgen Stibig	Global Environment Monitoring unit – Joint Research Centre
	Andreas Heinimann	National Centre of Competence in Research North-South – Centre for Development and Environment (CDE)
North and central America	Rasim Latifovic	Canada Centre for Remote Sensing – Ottawa – Canada

	Chandra Giri	United States Geological Servey – EROS Data Center
South America	Carlos di Bella Valéry Gond	Instituto Nacional de Tecnología Agropecuaria – Argentina CIRAD-Guyane – Université Laval
Australia	Peter Cacetta	Commonwealth Scientific and Industrial Research Organisation – Australia

Table 4. Name and affiliation of the international land cover experts

To enhance the potential use of the Globcover validation dataset it was strongly recommended to gather from the experts most of the LCCS classifiers in order to characterise the land cover of each validation sample. This is the reason why this validation dataset is not specifically related to the current Globcover legend and needs to be translated into the 22 land cover classes of the global Globcover product afterwards.

International experts could report at maximum 3 land cover types for each validation point or observational units. Where they only report one land cover type, this is a relative straightforward process. The set of selected classifier values is transformed by Infram B.V. into a single Globcover class (for instance, from Land Cover 1 of Table 5 into Globcover class describing LC 1 of Table 6). In case the experts described two or three land cover types to describe the area covered by a sample, this translation process becomes less obvious. In addition to the single translation into the respective classes (as for instance, from Table 5 to Table 6), it may be also necessary to consider assigning the sample to a mosaic class. The Globcover legend includes only eight mosaic classes and therefore it is not possible to assign all combinations of land cover types to mixed mapping class. These mosaic classes are thus derived from the combinations of Land Covers 1, 2 and 3 as indicated by the experts. As the combinations of LC 1, LC 2 and LC 3 allow various interpretations, the Infram B.V. team assigned up to 2 different mosaics to some of the samples.

For illustration purpose, Table 5 reports the values of LCCS classifiers selected by the expert to describe a given observational unit covered by three different land cover types. These three sets of classifiers can then be translated to three different Globcover classes, as shown in the Table 6.

Land Cover 1	**Land Cover 2**	**Land Cover 3**
Natural & Semi-natural terrestrial vegetation	Cultivated & managed lands	Natural & Semi-natural terrestrial vegetation
Shrubs	Herbaceous	Trees
Open (70-60 - 20-10%)	Rainfed	Open to very open (40-20 - 10%)
5-0.3 m		>3-30 m (for Trees)
Broadleaved		Broadleaved evergreen

Table 5. Three sets of LCCS classifiers that describe the land cover for an observational unit out of the validation dataset.

Globcover class describing LC 1	**Globcover class describing LC 2**	**Globcover class describing LC 3**
Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) shrubland (<5m)	Rainfed (cultivated and managed lands)	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (> 5m)

Table 6. Globcover classes to which the land cover types from table 5 have been assigned.

The fact that 3 land cover types have been identified for one observational unit gives cause to consider mosaic classes as well. The expert described the most dominant land cover type first, followed by the land cover type that was second in dominance and, in some cases, a third land cover type was described as Land Cover 3. We do not know how much more dominant Land Cover 1 is compared to Land Cover 2 or Land Cover 3. Therefore, in addition to the Globcover classes reported in Table 6, two possible Globcover classes that are in fact mosaic classes can then also describe the land cover within the concerned observational unit:

- Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
- Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)

These different possible translations of the classifier sets provided by the expert to describe a given validation sample must be taken into account to analyse the confusion matrix comparing the Globcover product with the validation dataset.

Furthermore, it is worth mentioning that many combinations of land cover types cannot be transformed to a Globcover mosaic class. Indeed, a legend that would cover for all these potential combinations is not desirable because the mosaic classes are often considered less informative and therefore less useful from an end-user point of view.

5.3. Sampling strategy

In order to ensure that each pixel has an equal chance of being sampled, the Globcover product is projected from the default Plate Carrée projection to the Lambert Azimuthal Equal Area Projection. As there is however no equal area projection that does justice to the entire world, the world is divided into 5 regions (Africa, Australia & Pacific, Eurasia, North America and South America) for which it is possible to apply an equal area projection.

The samples are selected using a stratified random sampling. The experts could base their evaluation of the land cover type(s) of the sample on more than just the sample point itself. Those are automatically overlaid either in Virtual Earth or Google Earth allowing a rapid access to recent remote sensing images with zooming capabilities. In addition the expert could also support his work using any additional sources of information such as detailed maps or so. For a given sample the expert saw not only the sample point but also a box that coincided with the so-called observational unit. This unit corresponds to 5x5 MERIS pixels, which equals a surface area of 225 ha. The effective observational unit is not necessarily a square or a circle around the point. Some land cover classes, notably lakes and wetlands, can be rather elongated and this form should not be discarded because of the shape of the observational unit. The main purpose of the box was to give an idea of the extent of an area of 225 ha, regardless of the zoom level or the resolution of the data that the expert is analysing. As an extra guideline we informed the experts that if a land cover type would cover more than 75% of the observational unit they could consider it to be the sole dominant land cover class. If two or three land cover types cover each between 25 and 75% of the observational unit, these land cover types should be described as well.

For each validation sample, the NDVI profiles were extracted by UCL from the 1 km daily SPOT-Vegetation time series acquired over 9 years from 2000 to 2007. The eight annual profiles and the corresponding average profile were associated and displayed for each validation point complementing the interpretation of the high resolution imagery by its seasonal dynamics.

5.4. Reference dataset

The available Globcover validation dataset contains 4258 points. This number includes, in addition to the expert efforts, 341 points corresponding to river basins ground truth which originate from International Water management Institute (IWMI, Sri Lanka) and which allow partially to fill a gap in the Indian subcontinent. Some areas in the world remain poorly covered by reference points, most noteworthy Central America, including Colombia and the eastern tip of Brazil, parts of the Indian

Subcontinent and its vicinity (notably Pakistan, Afghanistan and Iran) and Japan. Still, the current set of reference dataset represents a unique distribution over the global land surface and the results of the analysis will give a good indication of the product accuracy.

In 3167 cases, the experts were (explicitly) certain that the information they provided was correct, in 797 cases they were reasonably sure and in 294 cases they had some reservations.

The distribution of these 3167 points is shown in *Figure 18*. Finally, to explore the effect of heterogeneous areas the validation set is even further reduced to 2115 points by removing all the points for which the experts needed to define more than one land cover type.

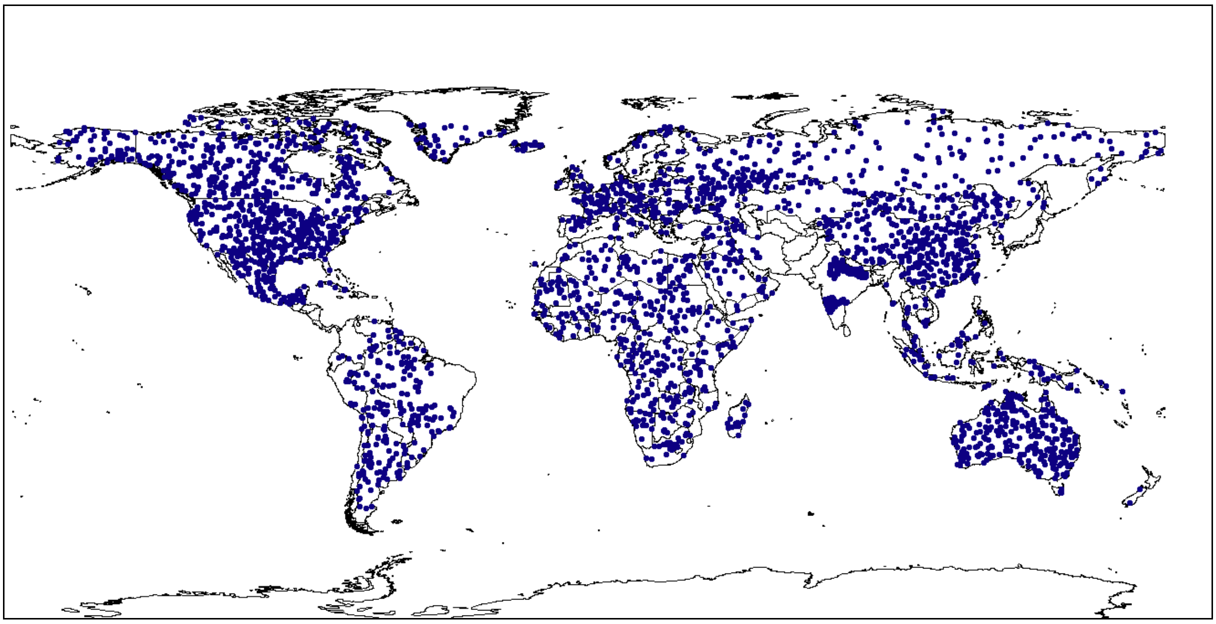

Figure 18. Distribution of the 'certain' points in the validation dataset.

5.5. Validation results

The reference dataset of 3167 points is then matched to the Globcover map codes extracted for all the validation points in order to build a confusion matrix (Table 7). It is important to mention that the dominance between land cover types identified by the expert for a given sample is not taken in account in the validation process.

The results shown in *Table 8* is that the accuracy level is found to be 67.10 %.

The confusion matrix includes 24 items while the global Globcover legend has been reduced to 22 classes. The class 10, namely "cultivated and managed areas", includes pixels for which the information about irrigation practices has not been specified by the experts. For the sake of clarity, these pixels, mainly corresponding to "rainfed croplands", have been relabelled into class 14. The class 80, corresponding to "closed (>40%) needleleaved deciduous forest (>5m)", was initially foreseen in the global Globcover legend but finally, it didn't appear in the product.

Next to the overall accuracy and the user's and producer's accuracies, the Kappa index has been computed. This index is commonly used in classification processes of land cover or land use. It expresses the proportionate reduction in error that a classification process generates compared to a classification process that would completely random assign the pixels to classes. The probability that the agreement is due to chance was computed using all classes in both rows and columns. If the corresponding class in the other direction did not exist the result of the multiplication was always zero.

The previous accuracy results are derived with equal weighting for each of the stratified randomly sampled reference points. Classes that cover only small surfaces are overrepresented in the sample set and classes that cover large surfaces may have been underrepresented in the set. According to CEOS recommendations, the overall accuracy values are weighted by the area proportions of the various land cover classes. The weighting factor corresponding to the area proportion of the given class is derived from the Globcover product that is projected in an equal area projection. Table 8 shows the results.

Globcover validation dataset	**Global accuracy**
3167 'certain' points	73.14%
2115 'certain' and 'homogeneous' points	79.25%

Table 7. Accuracy of Globcover on a global scale based on surface area figures per class (level 1) and the user's accuracy

These final accuracy results document the quality of the Globcover product. These figures appear quite satisfactory for a global product.

Bare areas, Forests and Snow and Ice are classes that perform the best. This is surely not surprisingly, as these classes are homogeneous, unambiguous and recognisable. We have to add though that Snow and Ice do seem to be hampering the view on the underlying land cover from time to time.

The interpretation and subsequent classification of pastures and meadows proves to be a difficult issue. In the image processing line the pastures have been regarded as semi-natural vegetation, but some of the experts have interpreted the pastures as meadows.

Count	Reference																									
Product	10	11	14	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	SUM	User's
10	29	24	98			1	1					5			14	5					1	1			179	84,40%
11	2	150	9				2					2			9	10				5					189	79,40%
14		6	14													3									23	60,90%
20	24	29	62		1	3	1					5			7	9					2				143	98,60%
30	53	10	29			11	5		1	1		4			16	18	4			4	2	3			161	91,90%
40	2		4	1	1	128	3		2		1	17	1		1	2		2					1		166	87,30%
50	16	2	9			15	29	1	3	1		20			3	4				2					105	46,70%
60			6			1	7	1				1	3		4								1		24	8,30%
70	7		2				4	2	19		2	25			5	4						1		1	72	61,10%
80																									0	N/A
90		1				1	4		4	18	3	40			3	11	1			1		1			88	48,90%
100	2		1				3		1	1		9			2	1					1				21	42,90%
110	17	2	18			2	4	1		2		2	2		20	18	6			1	1	3	1		100	51,00%
120	8		1				2				2	3			11	12	3					4			46	65,20%
130	9		14			1	4	1	3			8	1		39	7	1			2	2	2		2	96	40,60%
140	36	3	25			1	1		1		2	2	1		23	22	8				4	5			134	16,40%
150	2	1	14									5	1		3	38	13				1	36	1	4	119	10,90%
160						10						1						3							14	21,40%
170	1					5														6					12	0,00%
180		1				1	2									4	1			1			1		11	9,10%
190	1	2													1						14		2		20	70,00%
200		2	1									1			4	3	8				1	233	2	3	258	90,30%
210		1														1				3	2	1	85		93	91,40%
220	1															2						3	2	33	41	80,50%
SUM	210	234	307	1	2	180	72	6	34	23	10	150	9	0	165	174	45	5	0	25	31	293	96	43	2115	
Prod. Acc.	50,50%	91,00%	66,10%	0,00%	50,00%	80,00%	56,90%	33,30%	58,80%	13,00%	50,00%	84,00%	22,20%	N/A	56,40%	45,40%	28,90%	60,00%	N/A	4,00%	45,20%	79,50%	88,50%	76,70%		67,10%

Table 8. Adjusted contingency matrix that considers the product and the validation dataset. Green cells are cells that show agreement between classification and validation. Light green cells show cells that have been considered to show agreement. Yellow cells mark cells that have been deemed to represent samples that do not disagree with the classified result. The value in the red cell shows the overall accuracy.

The result for the Kappa index is found to be:

$$C_{Kappa} = 0.656$$

The experts identify more urban areas than the Globcover product portrays. This could be due to the heterogeneous character of built up areas. However the statistical basis for clear conclusions or explanation is meagre, as we have just 63 built up areas in the complete validation dataset (out of 4258 points).

Classification patterns of wetlands, grasslands and shrublands show clear discrepancies with interpretations of experts. This may be due to the absence of a mid-infrared channel that may affect the ability to identify these land cover types on the MERIS data.

In this project we have used on-line datasets in a fruitful way for validation exercises. This is probably the first time that such new data sources are being used for this purpose. There is a huge potential of these datasets for this kind of purposes and we have merely started to tap this potential. With more high resolution data coming on-line, be it on Google Earth or Virtual Earth, these sources get more and more interesting, especially if one considers the possibilities of adding dedicated data to the standard datasets.

The Globcover product at level 1 has 22 classes. It is obvious that the real world is far more heterogeneous than this model of the world. This aspect of a global land cover product needs to be emphasised and users of the product need to realise this!

6. Recommendations - Discussion - Conclusion

This document reports on the quality of the MERIS FR global mosaics and on the accuracy of the first 300-m land cover product delivered for the period December 2004- June 2006 in the course of this Globcover project. These deliverables clearly demonstrate the operational service provided by the automated processing chain set up by the Globcover consortium. Furthermore, a comprehensive validation exercise has been completed providing quantitative figures of the product accuracy.

Several major issues related to the acquisition and the pre-processing of the MERIS FR time series had first to be successfully addressed. These concern mainly the MERIS FR ortho-rectification leading to a final geometric accuracy of about 70 m, the cloud and water masking and the atmospheric correction. One also should consider the huge amount of data that has been processed. On the other hand, unlike initially designed, a global coverage of MERIS FR acquisition was also operationally set up providing an increasing volume of data. However, the Globcover dataset for the 19 months period between December 2004 - June 2006 still missed the minimum number of valid observations in some areas. These data gaps required to supplement the Globcover land cover product by GLC2000 for an area corresponding to 2 % of inland surfaces.

From the classification point of view, there were at the beginning of the project four challenges which have all been met:

- Implementing a globally consistent while regionally-tuned classification processing, in order to move away from ad hoc interpretation strategies often developed in the past,
- Developing an automatic and repeatable processing strategy, with the onset of an automatic system enabling the capacity to reprocess other years of data with the same system
- Building on GLC2000 and other existing Land Cover products to capitalize on previous experiences,
- Developing a legend documented using the UN Land Cover Classification System, with the view that the latter becomes an international standard.

The concept of a global Land Cover service operational at global scale first requested by ESA has been developed and validated. Indeed, as discussed during the Third Globcover End User Meeting at the European Environmental Agency in Copenhagen (9-10 September 2008), the Globcover Land Cover map is a significant step forward. This success surely opens new avenues for the land cover community as well as for downstream applications.

An independent validation of the 22-classes land cover product was also carried out to provide a quantitative estimate of its thematic accuracy. Thanks to a set of 16 land cover experts coming from all continents to work in a very customized environment, a reference dataset of more than 3000 points globally distributed was compiled based on the LCCS classifiers, making them reusable.

The overall accuracy weighted by the class area reaches 73 % using 3167 points globally distributed and including homogeneous and heterogeneous landscapes. This accuracy is slightly higher than that of GLC2000 with yet a spatial resolution improved by a factor 3,3 resulting in a product ten times better if the pixel area is accounted for. This very positive figure must be balanced by the fact that the Globcover map quality varies according to the thematic class and to the region of interest. Looking at the number of valid observations available over a region (*Figure 8*) gives a first indication about the input data quality and the expected classification reliability. Similarly, land cover classes such as the evergreen and semi-deciduous forest, the irrigated croplands, the bare areas, the water bodies and the snow were found quite accurately mapped. On the other hand other classes such as the urban areas, the sparse vegetation and the herbaceous vegetation can be affected by errors.

It is important to recall that such land cover map accuracy surely prevents any use of the map for land cover change detection or comparison with older maps to depict the change area. Indeed, the change rate will always be much lower than the land cover dynamics, thus hampering any relevant use for change mapping. Alternatively, the MERIS FR surface reflectances products could be used in processing using dedicated change detection algorithm.

The limitation of the Globcover product can mainly be explained by several strategic choices. Only MERIS data can be used, always missing the critical SWIR band for the flooded patterns. The automation of the interpretation chain requires relying for the class labelling on the already existing but sometimes coarser land cover products. From the end users point of view, too many mosaic classes were finally mapped limiting the thematic sharpness of the Globcover product and its relevancy to derive very specific products. Last but not least, the overall accuracy of such a global product strictly prevents to attempt to detect or assess any land cover change.

In spite of some limitations, it is clear that the Globcover product can be considered as a major step towards operational global land cover mapping on a regular basis. It therefore provides a major reference for many applications such as climate or ecological habitat modelling. Furthermore, the system is designed with an embedded cumulative knowledge process allowing the improvement of the quality of each subsequent product. In the near future, Globcover should remain an open dynamic process (for instance, emphasizing a better articulation between classification automation and interactive contribution from the experts). New release of more advanced Globcover maps is expected in the future.

7. Data policy

The Globcover products are made available to the public by the POSTEL Service Centre with the agreement of ESA.

The Globcover products are available through two access points:

- ESA GCAT web site (http://www.esa.int/due/ionia/globcover).
- POSTEL web site (http://postel.mediasfrance.org)

You may use the Globcover products for educational and/or scientific purposes, without any fee on the condition that you credit ESA and the ESA Globcover Project, led by MEDIAS-France/POSTEL, as the source of the Globcover products:

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Should you write any scientific publication on the results of research activities that use Globcover products as input, you shall acknowledge ESA and the ESA Globcover Project led by MEDIAS France/POSTEL in the text of the publication and provides MEDIAS-France/POSTEL (postel-contact@medias.cnes.fr) and ESA with an electronic copy of the publication (due@esa.int).

If you wish to use the Globcover products in advertising or in any commercial promotion, you shall acknowledge ESA and the ESA Globcover Project, led by MEDIAS France and you must submit the layout to MEDIAS-France/POSTEL (postel-contact@medias.cnes.fr) and ESA for approval beforehand (due@esa.int).

Appendix I – Surface reflectance products: data format

Nomenclature

The surface reflectances products have the following nomenclature:

GLOBCOVER-L3_MOSAIC_***[YEAR]***_V2.0_***[PERIOD]***_H***[XX]***V***[YY]***.hdf.gz

The [YEAR] indicates the year over which the composite has been computed (2004, 2005 or 2006).

The [PERIOD] indicates the compositing period, either bimonthly (shortened by "BIMONTH_x" where x varies from 1 to 6) or annual (mentioned by "ANNUAL").

[XX] and [YY] indicate the tile location, [XX] and [YY] referring to the horizontal (from 0 to 71) and the vertical (0 to 35) positions, respectively.

Data format and content of surface reflectance composites

The surface reflectance products are available for downloading by tiles and by compositing period. 13 spectral bands are available (bands 11 and 15 have been removed since they are used for the atmospheric correction) described below:

Band number	***Band Centre (nm)***	***Band width (nm)***
1	412.5	10
2	442.5	10
3	490	10
4	510	10
5	560	10
6	620	10
7	665	10
8	681.25	7.5
9	708.75	10
10	753.75	7.5
12	778.75	15
13	865	20
14	885	10

The hdf files contain the following bands:

Band name	***Description***	***Precision***	***Range***
SM	Status Map containing 0: LAND: No (cloud, shadow, cloud edge) and land flag 1: FLOODED (L1b_landocean or (not L1b_landocean and alt>-50m)) and not land flag and no (cloud, shadow, cloud edge) 2: SUSPECT (cloud shadow or edge) 3 : CLOUD (cloud flag) 4: WATER (not L1b_landocean and not land flag)	None	[0 6]

	5: SNOW (snow flag) 6: INVALID		
NMOD	Number of valid observations in the temporal synthesis. 'Valid' means that the observation has the same status as that given in the status map.	1	[0 255]
NDVI	Normalized Difference Vegetation Index	4*10e-3	[-.1 0.9] x 250 +25
MEAN_1	Normalized reflectance for band 1	5*10^{e}-4	[0 1.2]
MEAN_2	Normalized reflectance for band 2	5*10^{e}-4	[0 1.2]
…	…	..	…
MEAN_14	Normalized reflectance for band 14	5*10^{e}-4	[0 1.2]
ERR_1	Sum of absolute deviation between measured and modelled reflectance divided by the number of valid observations for band 1	1/500	[0 0.5]
ERR_2	Sum of absolute deviation between measured and modelled reflectance divided by the number of valid observations for band 2	1/500	[0 0.5]
...	…	…	…
ERR_14	Sum of absolute deviation between measured and modelled reflectance divided by the number of valid observations for band 14	1/500	[0 0.5]

The flags used in the composite are derived from daily reflectance status described below:

Parameter	***Description***
L1b.land_ocean	MERIS FRS original land flag: **'Land'=1 or 'Water'=0**
land_flag	land flag from Land/Water – Water/Land reclassification: **'Flooded'=0 or 'Land'=1**
cloud_flag	cloud flag computed in Cloud processing
cloud_shadow	cloud shadow flag from this module
cloud_edge_flag	cloud edge computed in cloud processing
snow_flag	snow flag computed in cloud processing

Appendix II – Global and regional Globcover legends

Global Globcover legend (level 1)	Regional Globcover legend (level 2)	Value
Post-flooding or irrigated croplands (or aquatic)		11
	Post-flooding or irrigated shrub or tree crops	12
	Post-flooding or irrigated herbaceous crops	13
Rainfed croplands		14
	Rainfed herbaceous crops	15
	Rainfed shrub or tree crops (cash crops, vineyards, olive tree, orchards…)	16
Mosaic cropland (50-70%) / vegetation (20-50%)		20
	Mosaic cropland (50-70%) / grassland or shrubland (20-50%)	21
	Mosaic cropland (50-70%) / forest (20-50%)	22
Mosaic vegetation (50-70%) / cropland (20-50%)		30
	Mosaic grassland or shrubland (50-70%) / cropland (20-50%)	31
	Mosaic forest (50-70%) / cropland (20-50%)	32
Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (> 5m)		40
	Closed (>40%) broadleaved evergreen and/or semi-deciduous forest (>5m)	41
	Open (15-40%) broadleaved semi-deciduous and/or evergreen forest with emergents (>5m)	42
Closed (>40%) broadleaved deciduous forest (>5m)		50
Open (15-40%) broadleaved deciduous forest/woodland (>5m)		60
Closed (>40%) needleleaved evergreen forest (>5m)		70
Open (15-40%) needleleaved deciduous or evergreen forest (>5m)		90
	Open (15-40%) needleleaved deciduous forest (>5m)	91
	Open (15-40%) needleleaved evergreen forest (>5m)	92
Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)		100
	Closed (>40%) mixed broadleaved and needleleaved forest (>5m)	101
	Open (15-40%) mixed broadleaved and needleleaved forest (>5m)	102
Mosaic forest or shrubland (50-70%) / grassland (20-50%)		110

Mosaic grassland (50-70%) / forest or shrubland (20-50%)		120
Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)		130
	Closed to open (>15%) broadleaved or needleleaved evergreen shrubland (<5m)	131
	Closed to open (>15%) broadleaved evergreen shrubland (<5m)	132
	Closed to open (>15%) needleleaved evergreen shrubland (<5m)	133
	Closed to open (>15%) broadleaved deciduous shrubland (<5m)	134
	Closed (>40%) broadleaved deciduous shrubland (<5m)	135
	Open (15-40%) broadleaved deciduous shrubland (<5m)	136
Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)		140
	Closed (>40%) grassland	141
	Closed (>40%) grassland with sparse (<15%) trees or shrubs	142
	Open (15-40%) grassland	143
	Open (15-40%) grassland with sparse (<15%) trees or shrubs	144
	Lichens or mosses	145
Sparse (<15%) vegetation		150
	Sparse (<15%) grassland	151
	Sparse (<15%) shrubland	152
	Sparse (<15%) trees	153
Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water		160
	Closed to open broadleaved forest on (semi-) permanently flooded land - Fresh water	161
	Closed to open broadleaved forest on temporarily flooded land - Fresh water	162
Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water		170
Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water		180
	Closed to open (>15%) woody vegetation on regularly flooded or waterlogged soil - Fresh or	181

	brackish water	
	Closed to open (>15%) woody vegetation on temporarily flooded land	182
	Closed to open (>15%) woody vegetation on permanently flooded land	183
	Closed to open (>15%) woody vegetation on waterlogged soil	184
	Closed to open (>15%) grassland on regularly flooded or waterlogged soil - Fresh or brackish water	185
	Closed to open (>15%) grassland on temporarily flooded land	186
	Closed to open (>15%) grassland on permanently flooded land	187
	Closed to open (>15%) grassland on waterlogged soil	188
Artificial surfaces and associated areas (Urban areas >50%)		190
Bare areas		200
	Consolidated bare areas (hardpans, gravels, bare rock, stones, boulders)	201
	Non-consolidated bare areas (sandy desert)	202
	Salt hardpans	203
Water bodies		210
Permanent snow and ice		220

Appendix III – LCCS & the Globcover legend

Value	Global Globcover legend (level 1)	LCCS Label	LCCS Entry
11	Post-flooding or irrigated croplands (or aquatic)	Irrigated tree crops // Irrigated shrub crops // Irrigated herbaceous crops // Post-flooding cultivation of herbaceous crops	A11 Cultivated Terrestrial Areas and Managed Lands
12	Post-flooding or irrigated shrub or tree crops	Irrigated tree crops // Irrigated shrub crops	
13	Post-flooding or irrigated herbaceous crops	Irrigated herbaceous crops // Post-flooding cultivation of herbaceous crops	
14	Rainfed croplands	Rainfed shrub crops // Rainfed tree crops // Rainfed herbaceous crops	
15	Rainfed herbaceous crops	Rainfed herbaceous crops	
16	Rainfed shrub or tree crops (cash crops, vineyards, olive tree, orchards…)	Rainfed tree Crops // Rainfed shrub crops	
20	Mosaic cropland (50-70%) / vegetation (20-50%)	Cultivated and managed terrestrial areas / Natural and semi-natural primarily terrestrial vegetation	
21	Mosaic cropland (50-70%) / grassland or shrubland (20-50%)	Cultivated and managed terrestrial areas / Closed to open shrubland (thicket) // Herbaceous closed to open vegetation	
22	Mosaic cropland (50-70%) / forest (20-50%)	Cultivated and managed terrestrial areas / Closed to open trees	
30	Mosaic vegetation (50-70%) / cropland (20-50%)	Natural and semi-natural primarily terrestrial vegetation / Cultivated and managed terrestrial areas	
31	Mosaic grassland or shrubland (50-70%) / cropland (20-50%)	Closed to open shrubland (thicket) // Herbaceous closed to open vegetation / Cultivated and managed terrestrial areas	
32	Mosaic forest (50-70%) / cropland (20-50%)	Closed to open trees / Cultivated and managed terrestrial areas	
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (> 5m)	Broadleaved evergreen closed to open trees // Semi-deciduous closed to open trees	A12 Natural and Semi-natural Terrestrial Vegetation – Woody / Trees
41	Closed (>40%) broadleaved evergreen and/or semi-deciduous forest (>5m)	Broadleaved evergreen closed to open (100-40%) trees // Semi-deciduous closed to open (100-40%) trees	
42	Open (15-40%) broadleaved semi-deciduous and/or evergreen forest with emergents (>5m)	Broadleaved evergreen (40-(20-10)%) woodland with emergents // Semi-deciduous (40-(20-10)%) woodland with emergents	
50	Closed (>40%) broadleaved deciduous forest (>5m)	Broadleaved deciduous closed to open (100-40%) trees	
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)	Broadleaved deciduous (40-(20-10)%) woodland	
70	Closed (>40%) needleleaved evergreen forest (>5m)	Needleleaved evergreen closed to open (100-40%) trees	

90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	Needleleaved evergreen (40-(20-10)%) woodland // Needleleaved deciduous (40-(20-10)%) woodland	
91	Open (15-40%) needleleaved deciduous forest (>5m)	Needleleaved deciduous (40-(20-10)%) woodland	
92	Open (15-40%) needleleaved evergreen forest (>5m)	Needleleaved evergreen (40-(20-10)%) woodland	
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	Broadleaved closed to open trees / Needleleaved closed to open trees	
101	Closed (>40%) mixed broadleaved and needleleaved forest (>5m)	Broadleaved closed to open (100-40%) trees / Needleleaved closed to open (100-40%) trees	
102	Open (15-40%) mixed broadleaved and needleleaved forest (>5m)	Broadleaved (40-(20-10)%) woodland / Needleleaved (40-(20-10)%) woodland	
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)	Closed to open trees / Closed to open shrubland (thicket) // Herbaceous closed to open vegetation	
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)	Closed to open shrubland (thicket) // Herbaceous closed to open vegetation / Closed to open trees	
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	Broadleaved closed to open shrubland (thicket)	**A12 Natural and Semi-natural Terrestrial Vegetation – Shrubs**
131	Closed to open (>15%) broadleaved or needleleaved evergreen shrubland (<5m)	Broadleaved evergreen closed to open thicket // Needleleaved evergreen closed to open thicket	
134	Closed to open (>15%) broadleaved deciduous shrubland (<5m)	Broadleaved deciduous closed to open thicket	
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	Herbaceous closed to very open vegetation // Closed to open lichens/mosses	**A12 Natural and Semi-natural Terrestrial Vegetation – Herbaceous**
141	Closed (>40%) grassland	Herbaceous closed to open vegetation	
143	Open (15-40%) grassland	Herbaceous open (40-(20-10)%) vegetation	
145	Lichens or mosses	Closed to open lichens/mosses	
150	Sparse (<15%) vegetation	Sparse trees // Herbaceous sparse vegetation // Sparse shrubs	**A12 Natural and Semi-natural Terrestrial Vegetation**
151	Sparse (<15%) grassland	Herbaceous sparse vegetation	
152	Sparse (<15%) shrubland	Sparse shrubs	
153	Sparse (<15%) trees	Sparse trees	
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	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	**A24 Natural and Seminatural Aquatic Vegetation**
161	Closed to open broadleaved forest on (semi-)permanently flooded land - Fresh water	Closed to open (100-40%) semi-deciduous woodland on permanently flooded land, water quality: fresh water	

162	Closed to open broadleaved forest on temporarily flooded land - Fresh water	Closed to open (100-40%) semi-deciduous woodland on temporarily flooded land, water quality: fresh water	
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	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 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 (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	Closed to open shrubs // Closed to open herbaceous vegetation	
185	Closed to open (>15%) grassland on regularly flooded or waterlogged soil - Fresh or brackish water	Closed to open herbaceous vegetation on permanently flooded land // Closed to open herbaceous vegetation on temporarily flooded land // Closed to open herbaceous vegetation on waterlogged soil	
190	Artificial surfaces and associated areas (Urban areas >50%)	Artificial surfaces and associated areas	**B15 Artificial Surfaces**
200	Bare areas	Bare areas	**B16 Bare Areas**
201	Consolidated bare areas (hardpans, gravels, bare rock, stones, boulders)	Consolidated materials	
202	Non-consolidated bare areas (sandy desert)	Unconsolidated materials	
203	Salt hardpans	Hardpans Soils: subsurface: solonetz	
210	Water bodies	Natural water bodies // Artificial water bodies	**B28 Inland Waterbodies, snow and ice**
220	Permanent snow and ice	Artificial perennial snow // Artificial perennial ice // Perennial snow // Perennial ice	

Appendix IV – Land Cover products: data format

The land cover product is available for downloading as a global mosaic and/or as a series of regional mosaics.

The maps are in geographic coordinates in a Plate-Carrée projection (WGS84 geoid).

Global land cover product

It is available through the download of a zip file named "Globcover_200412_200606_V2.2_Global.zip". This zip file contains:

- The full resolution data in a single-band GEO-TIFF format. The file is named "GLOBCOVER_200412_200606_V2.2_Global.tif". Each pixel is associated to an ID value, which is to relate to the Globcover land cover labels (found in this report or in the Excel and dbf files provided in the zip file and presented hereafter). The global land cover product is presented with the global (or level 1) legend, which counts 22 classes.
- The legend of the global land cover map into an excel file named "Glocover_Legend.xls". In this file, the ID values of the GEO-TIFF raster are linked with the land cover labels. The RGB codes associated with each Globcover land cover classes are also provided.
- A quicklook of the Globcover global land cover map, named "Globcover_Preview.gif".
- Globcover Global color maps in ArcInfo, ArcView, and Envi format

Regional land cover products

The global land cover map has been divided into regional mosaics, as shown in ***Figure 19***:

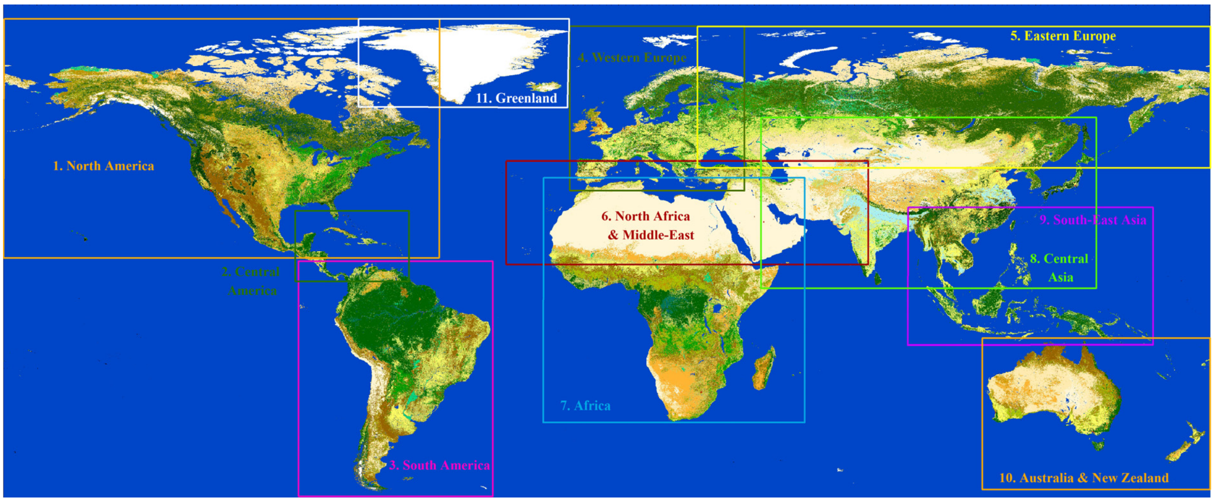

Figure 19. Regional windows of the world

Each regional land cover mosaic is provided associated with the global (or level 1) and the regional (or level 2) legends (cf. 4.2). Two raster files are therefore available for each regional mosaic, according to the detail of the legend.

Each regional mosaic is available through the download of a zip file named "Globcover_200412_200606_V2.2_***Region***.zip". This zip file contains:

- The full resolution data with the global (or level 1) legend in a single-band GEO-TIFF format. The file is named "GLOBCOVER_200412_200606_V2.2_***Region***_Glob.tif"

- The full resolution data with the regional (or level 2) legend in a single-band GEO-TIFF format. The file is named "GLOBCOVER_200412_200606_V2.2_***Region***_Reg.tif"
- The global and regional legends of the regional land cover map into an excel file named "***Region*** _Legend.xls". In this file, the ID values of the GEO-TIFF raster are linked with the land cover labels. As for the regional legend, the global class to which each regional class belongs is also indicated (in the field "Global class").The RGB codes associated with each Globcover land cover classes are also provided.
- A quicklook of the Globcover global land cover map, named "***Region***_Preview.gif".
- Globcover Regional and Global color maps in ArcInfo, ArcView, and Envi format.

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