# Accuracy Assessment of a 300 m Global Land Cover Map: The GlobCover Experience

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**Abstract – The GlobCover project supported by ESA has developed an operational service dedicated to the generation of global land cover maps through an automated classification of MERIS FRS time series. This paper reports the independent accuracy assessment of the global GlobCover product as the first global exercise implemented according to the CEOS Land Product Validation group recommendations. Based on a network of 16 international experts and on-line tools, a unique, globally distributed reference data set was collected in a standardized manner and used to derive mapping accuracy figures. The overall accuracy, weighted by the area proportions of the various land cover classes, is 73 % based on a set of 3167 samples. These results are discussed with regards to the previous experiences.**

**Keywords:** MERIS, GlobCover, land cover mapping, global monitoring, accuracy assessment.

## 1. INTRODUCTION

The global GlobCover land cover product, which was derived from data acquired by the ENVISAT MERIS instrument, is a scientific and technical demonstration of the first automated mapping of land cover on a global scale. This product, having spatial resolution of 300 m, is made available to a broad-level stakeholder community from the ESA website (Bicheron et al. 2008). This was achieved by the GlobCover consortium (MEDIAS, UCL-Geomatics and Brockman Consult), sponsored by the European Space Agency (ESA) and supported by an international partnership including EU-JRC, FAO, EEA, UNEP, GOFC-GOLD and IGBP. It was found essential to also deliver detailed information on the GlobCover product accuracy in order to allow a potential user determining the map's "fitness for use" for a given application.

The accuracy of a land cover map has two components: the geometric accuracy and the thematic accuracy. In the GlobCover context, the geometric navigation of the MERIS Fine Resolution full Swath (FRS) images was the very first challenge because the technical accuracy specification of this ocean color instrument was 2 km. Fortunately the GlobCover preprocessing chain achieved an absolute geo-location rms error of 77 meters (Arino et al. 2008; Bicheron et al., 2008) making useable both the MERIS time series for the classification and the final land cover product for the end-users. The thematic accuracy assessment of the 300 m global land cover was another challenge. This was also the opportunity to implement for the first time at global scale the CEOS Land Product Validation group recommendations (Strahler et al., 2006).

The quantitative validation of the thematic accuracy aims at assessing the accuracy of the 22-classes land cover map from an independent reference data set. For the IGBP DISCover global land cover map (Loveland et al. 2000) as for GLC2000 map (Bartholomé et al. 2005), the reference data set was based on visual interpretation of 50 m orthorectified Landsat color composite.

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For the GLC2000 land cover map Mayaux et al. (2006) assessed the overall accuracy based on 544 blocks dominated by one land cover class (>80% of the area) and selected on two-stage sampling using the Landsat World Reference 2 System. The area weighted overall accuracy of GLC2000 map (21 classes with a spatial resolution of 1 km) is 68,6±5% for a 95% confidence interval which was very similar to the IGBP DISCover accuracy for 17 classes at 1,1 km.

Based on the CEOS recommendations (Strahler et al. 2006), the validation process was designed to be scientifically sound, internationally acceptable and feasible from a cost and a time point of view. From the very beginning of the GlobCover project, the validation plan was adopted before any GlobCover map production. An independent stakeholder, namely the private company Infram B.V., has developed the data collection tool and completed the data analysis for the accuracy assessment.

## 2. METHODOLOGY

The validation process includes three different steps: collecting reference data, elaborating the sampling strategy and assessing the product's accuracy. A dozen of GlobCover land cover maps including both global and regional products were produced using the MERIS FRS time series acquired from December 2004 to June 2006 based on the same automatic processing chain.

The land cover typology fully described according to the UN Land Cover Classification System (LCCS) (Di Gregorio, 2005) consists in 22 land cover classes for the global level and is extended to 51 land cover classes with those consistently discriminated only at the regional level. The validation process reported here concerns only the global GlobCover map.

### 3.1 Reference data source

The reference data collection could only rely on already existing expertise distributed all over the world. The creation of an international expert network is the key element of the validation process. 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, complementarities to the other experts and belonging to well-known international network. 16 international experts from all over the world have been invited for 6 different 5-day workshops hosted by UCL (Louvain-la-Neuve, Belgium). The experts have truly committed themselves to build the GlobCover reference data set. Some of them could not join the working session but was familiar enough with the LCCS system and the validation process to complete their job form distance using the same tools.

All experts have used a dedicated working environment for on-screen collection of 'ground truth' data. They 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. For each validation sample, the NDVI profiles were extracted from the 1 km 10-day SPOT VEGETATION time series acquired from 2000 to 2007 and composited by UCL (Vancutsem et al. 2007). The eight annual profiles and the corresponding average profile were displayed for each validation point complementing the interpretation of the high resolution imagery by its seasonal dynamics. In addition the expert could also support his work using any additional sources of information such as detailed maps or so.

### 3.2 Sampling design

In order to ensure that each pixel has an equal chance of being sampled, the GlobCover product is projected 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 then selected using a stratified random sampling.

For a given sample the expert saw not only the sample point but also a box that coincided with the so-called observational unit corresponding to 5x5 MERIS pixels (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. The experts label a single dominant land cover type when more than 75% of the observational unit belongs to the same type. 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. In addition, their level of confidence for the labelling was requested according three levels.

### 3.3 Accuracy assessment

To enhance the potential use of the GlobCover validation data set it was strongly recommended gathering most of the LCCS classifiers in order to characterise the land cover of each validation sample independently to the current GlobCover typology. Therefore is the reason why this validation data set 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.

For validation points or observational units where the international experts 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. In case of 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, it may be also necessary to consider assigning the sample to a mosaic class. As the combinations of three land cover types allow various interpretations, the Infram B.V. team assigned up to 2 different mosaics to some of the samples.

For illustration purpose, Table 1 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 2.

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,

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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.

Table 1. Three sets of LCCS classifiers that describe the land cover for an observational unit out of the validation data set.

| **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 2. GlobCover classes to which the land cover types from table 1 have been assigned.

| **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) |

In addition, 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 set 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 data set.

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.

## 3. RESULTS

The GlobCover validation data set contains 4258 samples. This number includes, in addition to the expert efforts, 341 samples corresponding to river basins ground truth which originate from International Water management Institute (IWMI) to fill partially a gap in the Indian subcontinent.

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

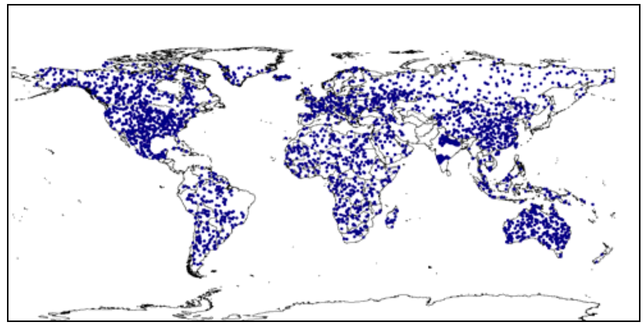

Figure 1. Geographic distribution of the ‘certain’ points in the reference data set.

The reference data set is then matched to the GlobCover map codes extracted for all the validation points in order to build a confusion matrix (Table 7). As the dominance between land cover types was not quantified for a given sample, the dominance is not taken in account in the validation process. As recommended by the CEOS recommendations, the overall accuracy values derived from the confusion matrix 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 3 reports the results.

Table 3**.** Accuracy of the global GlobCover map.

| **GlobCover validation data set** | **Global accuracy** |
|---|---|
| 3167 ‘certain’ points | 73.14% |
| 2115 ‘certain’ & ‘homogeneous’ points | 79.25% |

These final accuracy results document the quality of the GlobCover product. This accuracy is 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 region of interest. Looking at the number of valid observations available over a region (**Error! Reference source not found.**e 2) gives a priori information about the input data quality and the expected classification reliability**.**

From a thematic point of view, 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

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urban areas, the sparse vegetation and the herbaceous vegetation are more affected by errors.

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. 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 data set.

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.

## 4. DISCUSSION

Generally speaking the classification methodology is still constrained by the quality and especially the amount of the reference database product. 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!

There are still a number of known issues and artefacts which GlobCover v 2.2 users should consider. There are still some regions of the world (e.g. some areas in Amazonia) where MERIS FRS data coverage is quite limited. The limited number of valid MERIS FRS observations can have several effects on the land cover map. In areas of very low data coverage (about 2% of the terrestrial areas), the pixel values were derived from the reference datasets. When the data coverage is poor, there is still a tendency for GlobCover to overestimate forest areas.

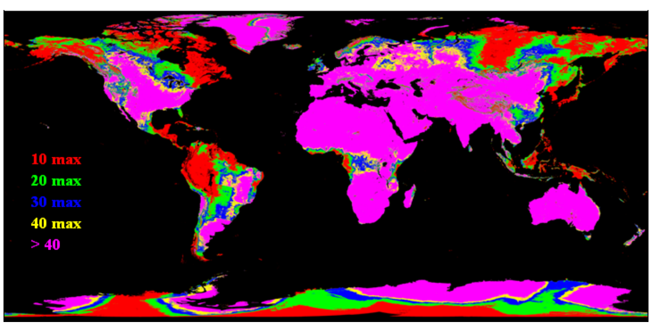


Figure 2. Number of valid MERIS FRS observations obtained after 19 months of acquisitions. Magenta areas are defined as well covered (>40 observations).

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.

## 5. CONCLUSIONS

The concept of a global Land Cover service operational at global scale first requested by ESA has been developed and successfully validated. Implementing a globally consistent while regionally-tuned classification processing system allowed moving away from ad hoc interpretation strategies often used in the past. This system is an automatic and repeatable process allowing to produce land cover map for other years. This significant step forward probably opens new avenues for the land cover community as well as for downstream applications.

Similarly, the validation data set can be used to validate the forthcoming products assuming that the most of the reference sample will not change.

The current GlobCover assessment used on-line data sets in a structural way for validation. This was probably the first time these new sources were applied at global scale for this purpose. There is a huge potential of these data sets for this kind of purposes and we have merely started to tap this potential.

## REFERENCES

Arino O., Bicheron P., Achard F., Latham J., Witt R. and Weber J.L.. GlobCover: the most detailed portrait of Earth, ESA Bulletin 163, ESA, 2008.

Bartholomé E., Belward A.S., 2005. GLC2000: a new approach to global land cover mapping from Earth observation data. International Journal of Remote Sensing, 26 (9), 1959-1977.

Bicheron P., Defourny P., Brockmann C., Schouten L., C. Vancutsem, M. Huc, S. Bontemps, M. Leroy, F. Achard, M. Herold, F. Ranera and O. Arino, "GlobCover : products description and validation report", ESA GlobCover project, 2008. ftp://uranus.esrin.esa.int/pub/GlobCover _v2/

Di Gregorio A..UN Land Cover Classification System (LCCS) - Classification Concepts and User Manual for software version 2, 2005. Available online at: www.glcn-lccs.org.

Loveland T.R., Reed B.C., Brown J.F., Ohlen D.O., Zhu Z., Yang L. et al., 2000. Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. *International Journal of Remote Sensing*, 21, 1303-1330.

Mayaux, P., Eva H., Gallego J., Strahler A., Herold M., Shefali A., Naumov S., de Miranda E., di Bella C., Johansson D., Ordoyne C., Kopin I. and Belward A., 2006, Validation of the Global Land Cover 2000 Map. *IEEE Transactions on Geoscience and Remote Sensing* 44(7-1), pp. 1728-1739, 2006.

Strahler, A.H., Boschetti L., Foody G.M., Friedl M.A., Hansen M.A., Mayaux P., Morisette J.T., Stehman S.V. and Woodcock C.E., Global Land Cover Validation: recommendations for evaluation and accuracy assessment of global land cover maps, *Office for Official Publications of the European Communities*, Luxembourg, 2006.

Vancutsem C., Peckel J.-F., Bogaert P., and Defourny P., Mean Compositing, an alternative strategy for producing temporal syntheses. Concepts and performance assessment for SPOT

.

VEGETATION times series, *International Journal of Remote Sensing*, 28, 5123-5141, 2007.

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