CONSISTENT GLOBAL LAND COVER MAPS FOR CLIMATE MODELLING COMMUNITIES: CURRENT ACHIEVEMENTS OF THE ESA' LAND COVER CCI

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ABSTRACT

Led by the European Space Agency, the Climate Change Initiative land cover project focuses on the land cover observed as an Essential Climate Variable. Consultation mechanisms were established with the climate modelling community in order to identify its specific needs in terms of satellite-based global land cover products. Key finding was the needs for stable land cover data and a dynamic component in form of time-series. An innovative land cover concept is proposed, along with an new global land cover mapping approach, based on multi-year earth observation datasets. The corresponding products are presented, which consist of three successive and consistent global LC maps centred to the epochs 2000, 2005 and 2010.

1. INTRODUCTION

The demand for information on climate has never been greater than today [1, 2]. In order to define the need for information in support to climate science, the Global Climate Observing System (GCOS) established a list of Essential Climate Variables (ECVs), selected to be critical for a full understanding of the climate system and currently ready for global implementation on a systematic basis [2, 3].

In response to the ECV list, the European Space Agency (ESA) initiated a new program - namely the Climate Change Initiative (CCI) –to develop global monitoring data set to contribute in a comprehensive and timely manner to the need for long-term satellite-based products in the climate domain [4]. Among the 14 ESA-CCI components respectively addressing the atmospheric, oceanic and terrestrial domains, the ESA CCI Land Cover (CCI-LC) project is dedicated to land cover (LC) characterization. LC is indeed referred to as one of the most obvious and commonly used indicators for land surface and the associated human induced or naturally occurring processes, while also playing a significant role in climate forcing.

This project builds on the ESA-GlobCover projects experiences [5, 6]. It aims at critically revisiting all algorithms required for the generation of a global LC product from various Earth Observation (EO) instruments and that matches the needs of key users' belonging to the climate modelling community (CMC).

In the first stages of the CCI-LC project, consultation mechanisms were established with the CMC in order to identify its specific needs in terms of satellite-based global land cover products. The main findings of this climate users' consultation process is presented in the following section. Then, the paper presents the developed classification methodology and the resulting products.

2. REQUIREMENTS FROM THE CLIMATE MODLLING COMMUNITY

During six months, a user requirements analysis has been conducted to derive the specifications for a new global land cover product to address the needs for a range of climate model communities and for applications of existing and future modelling approaches [7].

2.1. User consultation plan

As part of the requirements analysis, an user consultation mechanism (Fig. 1) was set-up to actively involve different climate modelling groups by setting out surveys to different type of users: i) a group of key-users, most of them also participating in the Climate Modelling User Group (CMUG) of the ESA-CCI programme, ii) associated climate users who are involved in the CCI-LC project and are leading the development of relevant key climate models and applications and iii) the broad land cover data user community reflected in the scientific literature and

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represented by users of the ESA GlobCover product.

The surveys were carried out in September and October 2010 and focused on three major ways land cover observations are used in climate models:

- as proxy for a set of land surface parameters that are assigned based on Plant Functional Types (PFTs);
- as proxy for human activities in terms natural versus anthropogenic and tracking human activities, i.e. land use affecting land cover (land cover change as driver of climate change);
- as datasets for validation of model outcomes (i.e. time series) or to study feedback effects (land cover change as consequence of climate change).

The evolution of requirements for the three indicated aspects from current models to future new modelling approaches was specifically taken into account.

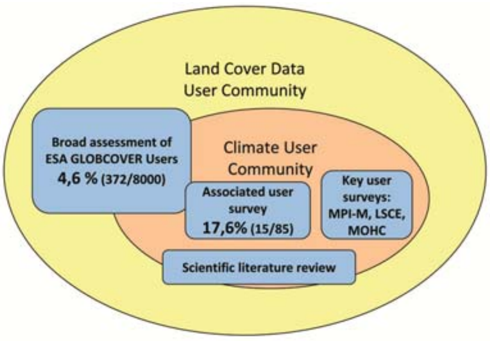

Figure 1. User consultation mechanism established to assess land cover requirements of general land cover user community and climate modelling community

Next to the surveys, requirements from the GCOS Implementation Plans 2004 and 2010 [2, 3] and associated strategic EO documents for land cover [8, 9, 10] were considered and reviewed. Finally, a detailed literature review was carried out with special attention to innovative concepts and approaches to better reflect land dynamics in the next generation climate models.

2.2. Main findings

Globally, the user requirements analysis shows that although the range of requirements coming from the climate modelling community is broad, there is a good match among the requirements coming from different user groups and the broader requirements derived from GCOS, CMUG and other relevant international panels. In more detail, the findings of the User Requirement (UR) analysis highlight that:

- *UR1* – There is need for both stable land cover data and a dynamic component in form of time-series and changes in land cover;
- *UR2* – Consistency among the different model parameters is often more important than accuracy of individual datasets;
- *UR3* – Providing information on natural versus anthropogenic vegetation (disturbed fraction), tracking human activities and defining history of disturbance;
- *UR4* – Land cover products should provide flexibility to serve different scales and purposes both in terms of spatial and temporal resolution;
- *UR5* – The relative importance of different class accuracies varies significantly depending on which surface parameter is estimated;
- *UR6* – Future requirements for temporal resolution refer to intra-annual and monthly dynamics of land cover including also remote sensing time series signals;
- *UR7* – More than 90% of the general land cover users find the United Nations Land Cover Classification System (UN-LCCS) a suitable approach for thematic characterization, the UN-LCCS being also quite compatible with the PFT concept of many models;
- *UR8* – Quality of land cover products need to be transparent by using quality flags and controls.

2.3. Revisiting the land cover concept

The most critical requirement expressed by the users is the need for both stable and dynamic information about land cover (*UR1*). From a remote sensing point of view, this requirement led in turn in rethinking the whole LC concept into ***LC state*** and ***LC condition*** components [11].

The LC state concept refers to the set of LC features remaining stable over time which define the LC independently of any sources of temporary or natural variability. It is agreed that the LC state is well described using the United Nations Land Cover Classification System (UN-LCCS), which is also quite compatible with the PFT concept of many models.

The LC condition concept relates directly to the temporary or natural variability of LC features that can induce some variation in land surface over time without changing the LC in its essence. This LC condition is typically driven by biogeophysical processes. It encompasses different observable variables such as the green vegetation phenology, snow coverage, open water presence, and burnt areas occurrence, etc.

This paper focuses on the LC state component, with the generation of global LC maps. The LC condition component is described in [12].

3. CLASSIFICATION METHODOLOGY

Since the early nineties, several global LC products have been delivered, all based on "single-year" and "single-sensor" approaches. More recently, the accumulation of global long-term time series of EO data has allowed the delivery of several global maps derived from the same sensor (e.g. MODIS land cover and GlobCover products). However, these products are affected by significant year-to-year variations in LC labels not associated with land cover change, thus demonstrating that current land cover mapping approaches are not able to efficiently extract the stable land cover component [13, 14]. Specific analysis illustrated that, using multi-year EO dataset as input contributes to make the classification less sensitive to the period of observation assuming that no LC change has occurred during the multi-year period [14]. A global classification chain has thus been set-up in a multi-temporal framework.

3.1. Input data

The input dataset is made of global time series acquired by the Envisat MERIS Full and Reduced Resolution (FR and RR respectivel) and from SPOT-Vegetation (SPOT-VGT) sensors. Their specificities are detailed in Tab. 1.

Table 1. Characteristics of the CCI-LC processing chain

Sensor	Spatial resolution	Period	Size
MERIS FR	300m	2003-2012	~15TB/year
MERIS RR	1000m	2003-2012	~2.5TB/year
SPOT-VGT	1000m	1998-2002	~450GB/year

3.2. Pre-processing

Pre-processing includes the following steps: geometric and radiometric corrections, cloud and snow identification, land and water re-classification, atmospheric correction, map projection and temporal compositing (Fig. 2).

It is run over the MERIS FR and RR L1 dataset and produces global composited mosaics of land surface reflectance values with a 7-day resolution. As for the SPOT-VGT sensor, the daily S1 dataset is used and averaged into 7-day composites. These 7-day time series constitute the input to the classification module, which interprets them into land cover classes.

3.3. Classification

The classification process aims at transforming the cloud-free 7-day mosaics generated by the pre-processing into a land cover map. The classification process is based on a-priori stratification of the world in equal-reasoning areas from an ecological and a remote sensing point of view. The stratification 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 classification process has been designed to run independently for each delineated equal-reasoning area. The great but much controlled flexibility of this strategy allows defining a classification process valid at global scale while tackling both the regional heterogeneity of the land cover characteristics.

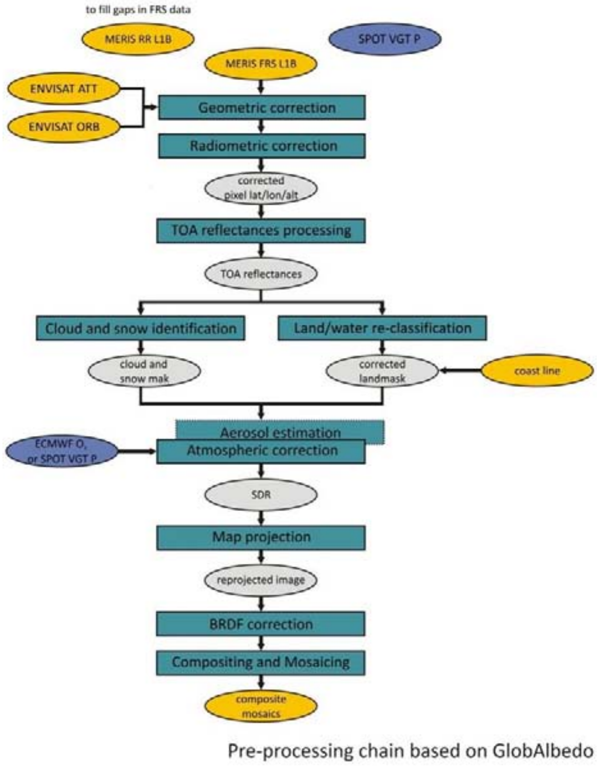

Figure 2. Schematic representation of the pre-processing chain

Before the classification process, two preliminary steps are performed. First, a reference LC database is built, which consists of a set of existing global, regional and local land cover maps which are translated into the CCI-LC legend, resampled at 300m spatial resolution and merged together. The reference LC database is a key auxiliary dataset for the classification chain. Second, seasonal composites are produced from the 7-day composites. For each equal-reasoning area, 1 or 2 periods within the year are defined to allow the optimal discrimination between the expected land cover classes.

The classification process in itself is organised in 4 major processing steps (Fig. 3), which thus run independently for each equal-reasoning area with specific parameters. In the first and second steps, both machine learning and unsupervised classification algorithms are run using the spectral properties of seasonal composites as input. The 2 first steps result in two different classifications which are then merged in a third step based on objective rules. The fourth step finalizes the CCI-LC map through a set of post-classification editions, amongst which the addition of the CCI WB product.

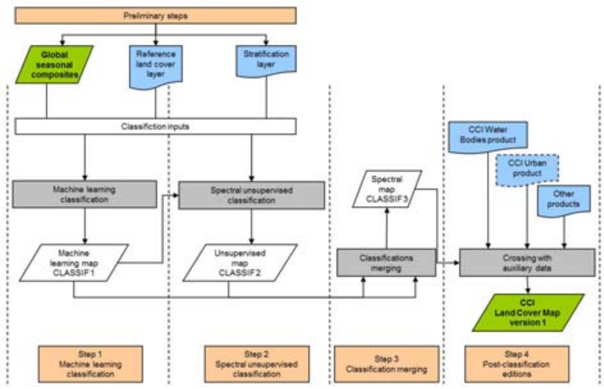

Figure 3. Activity diagram for the classification processing chain

3.4. Multi-temporal approach

In order to meet the requirement to have successive global LC maps stable over time (*UR1*), several years of EO dataset are used to generate a LC map. Using a multi-year input dataset has indeed proved to increase the classification algorithms' performance [14]. This is related to single years but which are representative of 5-year epochs: 1998-2002, 2003-2007 and 2008-2012.the reason why the project delivers maps which are not

These 3 successive maps are not produced independently but are derived from a "baseline" LC map generated using the full MERIS archive which is then back- and up-dated. This back- and up-dating procedure is based on a post-classification approach comparing annual classifications pixel-by-pixel to derive information on the pixel trajectories. This process is currently applied only to identify deforestation changes in tropical basins.

4. RESULT

Based on this innovative classification approach, three different global LC maps (standing for the LC state products) are delivered, centred to the epochs 2000, 2005 and 2010. The maps are made with a dominance of MERIS FR imagery. MERIS RR and SPOT-VGT dataset are used to compensate for a possible lack of MERIS FR acquisitions and to increase the temporal coverage until 1998. Fig. 4 presents the CCI global land cover map from the 2010 epoch and Fig. 5 shows the classification obtained over the 3 epochs in the Amazon region.

The global LC map from 2010, which is the more recent product, is aimed to be the "best existing map", both in terms of accuracy and stability.

The legend counts 21 classes defined using the UN-LCCS.

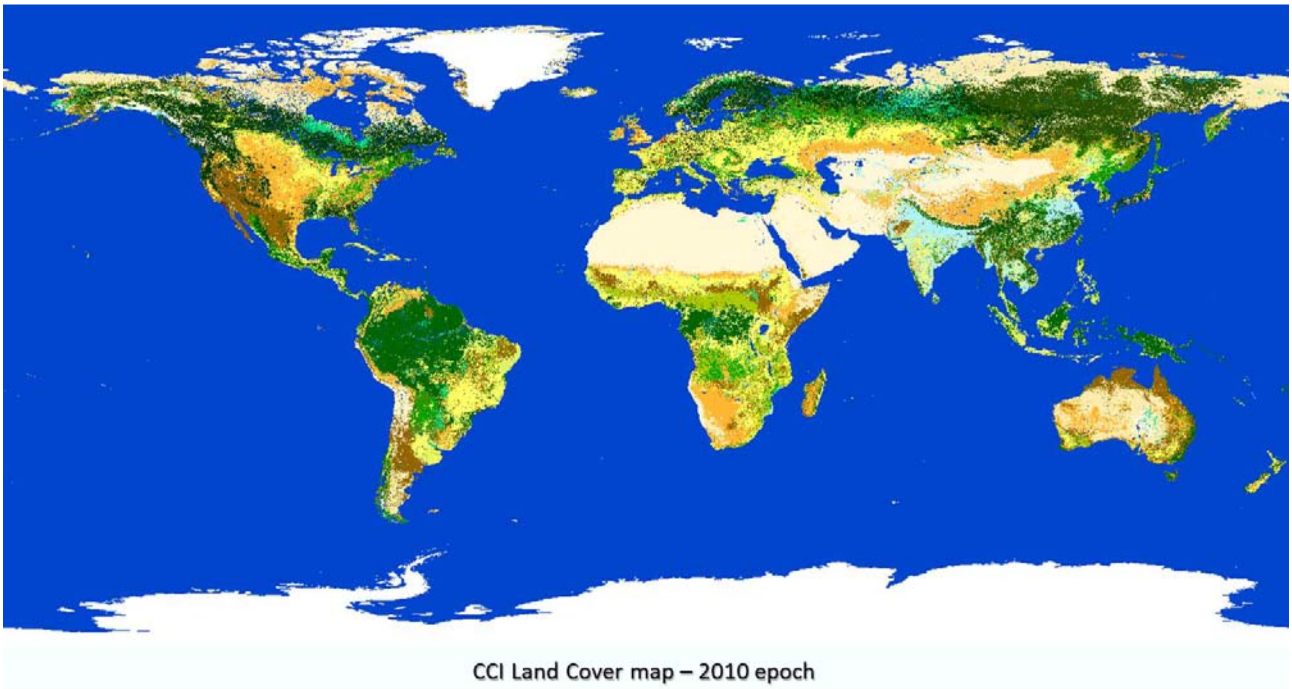

Figure 4. The CCI global land cover map from the 2010 epoch (2008-2012), at 300m spatial resolution

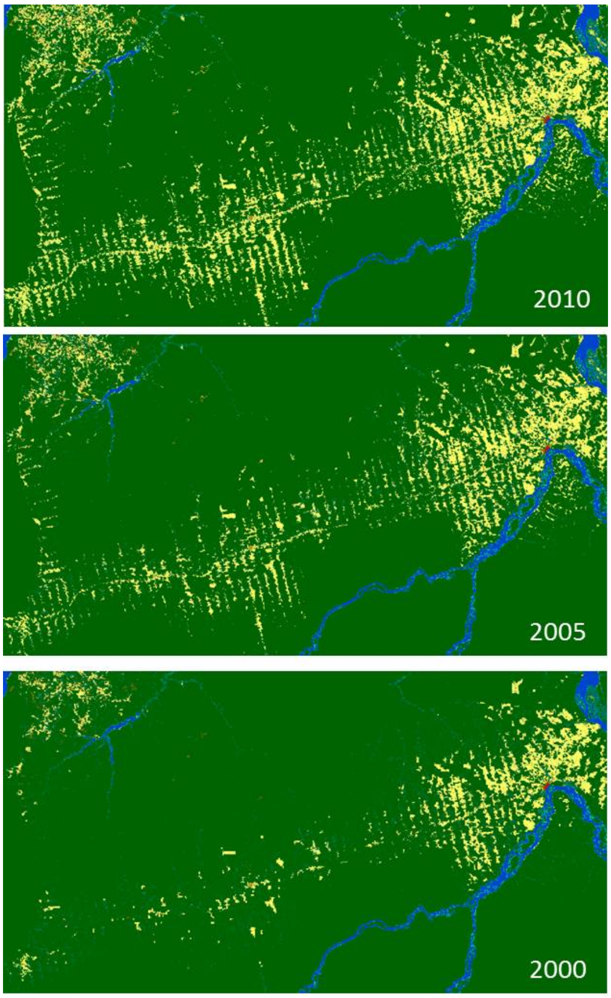

Figure 5. The CCI global land cover map from the 2010 epoch (2008-2012) on the left, from the 2005 epoch (2003-2007) at center and from the 2000 epoch (1999-2002) on the right, over the Amazon

The LC maps are delivered in the NetCDF-4 format, i.e. the "classic model" of NetCDF since most tools can handle them. Global LC products are also delivered in the GeoTiff format for specific users of the land cover community.

The products are delivered with an aggregation tool, enabling the users to adjust the map projection and spatial resolution to their needs and to convert the LCCS classes into Plant Functional Types.

5. VALIDATION AND USER ASSESSMENT

A quantitative and independent product validation exercise is under implementation through (i) a confidence-building procedure to reduce macroscopic errors, (ii) a statistical accuracy assessment which should allow users to determine the "map's fitness for use" for his/her application, (iii) a comparison with other global land cover products and (iv) a temporal consistency assessment. The statistical accuracy assessment aims at assessing the accuracy of the CCI land cover maps using an independent reference dataset, built by a network of international experts. Experts are asked to interpret validation samples overlaid in Google Earth thanks to a dedicated on-line environment for "ground truth" data collection.

In parallel, the impact of these new global LC products on the climate models is assessed. The project indeed relies on continuous interactions with climate modelling research team, as end-users of the CCI-LC products.

6. NEXT STEP

The public release of the three global LC products is planned for December 2013. These products corresponding to the stable component of the land cover will be delivered with land cover condition products [12], and with a global Water Bodies product derived from the Envisat ASAR archives [15].

In the three coming years, a new Phase of the project will allow us improving the developed algorithms, extending the timeline of the products both in the past (with a 1990 LC map based on AVHRR time series) and in the future (with the new missions, PROBA-V and Sentinel-3) and preparing the Sentinel-2 mission with prototypes LC maps and LC change products.

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