International Journal of Applied Earth Observation and Geoinformation 47 (2016) 30–39

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Major forest changes and land cover transitions based on plant functional types derived from the ESA CCI Land Cover product

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ARTICLE INFO

Article history:
Received 27 June 2015
Received in revised form 2 December 2015
Accepted 3 December 2015
Available online 12 December 2015

Keyword:
Forest change
Land cover transition
ESA land cover map
PFT map

ABSTRACT

Land use and land cover change are of prime concern due to their impacts on CO_2 emissions, climate change and ecological services. New global land cover products at 300 m resolution from the European Space Agency (ESA) Climate Change Initiative Land Cover (CCI LC) project for epochs centered around 2000, 2005 and 2010 were analyzed to investigate forest area change and land cover transitions. Plant functional types (PFTs) fractions were derived from these land cover products according to a conversion table. The gross global forest loss between 2000 and 2010 is 172,171 km^2, accounting for 0.6% of the global forest area in year 2000. The forest changes are mainly distributed in tropical areas such as Brazil and Indonesia. Forest gains were only observed between 2005 and 2010 with a global area of 9844 km^2, mostly from crops in Southeast Asia and South America. The predominant PFT transition is deforestation from forest to crop, accounting for four-fifths of the total increase of cropland area between 2000 and 2010. The transitions from forest to bare soil, shrub, and grass also contributed strongly to the total areal change in PFTs. Different PFT transition matrices and composition patterns were found in different regions. The highest fractions of forest to bare soil transitions were found in the United States and Canada, reflecting forest management practices. Most of the degradation from grassland and shrubland to bare soil occurred in boreal regions. The areal percentage of forest loss and land cover transitions generally decreased from 2000–2005 to 2005–2010. Different data sources and uncertainty in the conversion factors (converting from original LC classes to PFTs) contribute to the discrepancy in the values of change in absolute forest area.

1. Introduction

As the second major source of anthropogenic CO_2 emissions to the atmosphere, land use change significantly impacts changes in climate. The net CO_2 emissions from the human-induced land use change were estimated in the IPCC AR5 report to be 0.9 ± 0.8 PgC yr^{-1} during the past decade (Ciais et al., 2013) based on land cover data from the United Nations Food and Agricultural Organization's (FAO) Global Forest Resource Assessment (FRA) (FAO, 2010). Ecosystem services including biodiversity and water preservation are also affected by the land cover changes including deforestation and grassland degradation (Foley et al., 2005). Deforestation, as the predominant type of land cover change, has raised a lot of concerns and has therefore been extensively studied at both regional and global scales (Hansen et al., 2008, 2010, 2013; Harris, 2012; Ernst et al., 2013). Hansen et al. (2013) published high-resolution (30 m) global maps of forest cover change from 2000 to 2012, and estimated the net forest loss area of 1.5 million km^2 during this period. Another recognized dataset of global forest resources is from FAO FRA, which reported a decreasing trend of net forest loss rate and a significant amount of forest gain through afforestation and reforestation from 1990s to 2000s (FAO, 2010).

Spatially explicit maps of land cover and land cover change are of key importance in land surface models. Driven by climate forcing data (temperature, precipitation, radiation etc.), land surface models simulate the processes of terrestrial biosphere related to the global carbon, water and energy cycles, like photosynthesis, respiration, fire, latent and sensible heat flux (Krinner et al., 2005 Sitch et al., 2015). To describe the global vegetation distributions in land surface models, land cover maps are required and are usually characterized using earth observation data, such as the MODIS Collection 5 Land Cover Product (Friedl et al., 2010), the GlobCover

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http://dx.doi.org/10.1016/j.jag.2015.12.006
0303-2434/

2009 product based on MERIS (Bontemps et al., 2011), and Global Land Cover 2000 (GLC2000) map based on SPOT VEGETATION (Bartholomé and Belward, 2005). However, the accuracy differs between these land cover products due to differences in sensor design, classification procedure and validation method (Bontemps et al., 2012). The capability of the various land cover maps used in the climate modeling have been examined, and the limitations of accuracy and stability are progressively being improved (Bontemps et al., 2012). These maps can also be used to drive carbon cycle models in order to estimate the carbon emission from land cover change, and these estimates can thus be compared with those from bookkeeping models and process-based ecosystem models (Houghton et al., 2012). Typically, a bookkeeping model calculates the carbon dynamic in the vegetation and soils by tracking the land use changes including deforestation for cultivation and pastures and afforestation after abandonment of cropland (Houghton, 2003). The land use transitions in bookkeeping models are usually derived from statistics of forestry and agriculture like FAO FRA report (FAO, 2010) and FAOSTAT (2015).

In 2009 the European Space Agency (ESA) launched their Climate Change Initiative (CCI) programme with the aim of providing high quality satellite-derived products of Essential Climate Variables (ECVs), including land cover. The principal objective of the CCI Land Cover (CCI LC) project was to provide stable and comprehensive land cover datasets for the climate modeling community. At the end of Phase 1 the project released the latest version (v1.4) of the global land cover products for three 5-year epochs, centered on 2000 (1998–2002), 2005 (2003–2007) and 2010 (2008–2012) (ESA, 2014). The multi-year integration strategy was chosen for its better performance in reducing variability and improving stability (Bontemps et al., 2012). These new maps depict the geographical distribution of global land cover at a resolution of 300 m, which is valuable for land-surface modeling and climate modeling community, due to the feedbacks of land cover change on climate change. However, temporal consistency was considered to be the most important requirement in the first phase of the CCI LC project, and therefore only major macroscopic changes for the forest classes were easily detected and depicted between the three epochs. Even so, it is interesting for modellers to evaluate the impact of land cover change on the climate using these maps. For modellers aiming to calculate CO_2 emissions from land cover change, the full land cover transition matrix between different periods needs to be converted into the plant functional types (PFTs) used by the dynamic global vegetation models (DGVMs) used in the global carbon budget (Le Quéré et al., 2015). PFTs are an essential concept in the land surface models which features a group of plant species with similar phenology and physiology. In a model grid cell with mixed PFTs with a typical size of 100 by 100 km that is representative of global models, knowledge of the net (rather than gross) change of PFT fractional coverage between two successive time intervals is not sufficient to discriminate each specific transition and thus to accurately calculate CO_2 fluxes exchanged with the atmosphere. This is because within the grid cell, transitions of opposite directions can happen, for instance deforestation and reforestation, leading to an offset of each other, which can not be reflected using the net transitions. It is particularly true in regions with managed forests or shifting agriculture. The translation from LC maps with high resolution (like 300 m in ESA's products) to PFTs in a typical model grid cell (usually 100 by 100 km), however, provides the explicit gross transitions of different PFTs.

The objective of this study is to evaluate whether the PFT transitions derived from the new ESA CCI LC products can be used in land-surface models. The spatial distributions and temporal trends of forest area, major forest change as detected by these products, and the land cover transitions, are characterized and compared with those from other datasets.

2. Methods

The ESA CCI LC products include land cover maps for ≈5 year epochs centered around 2000, 2005 and 2010 respectively, with a spatial resolution of 300 m or coarser (ESA, 2014). This set of global land cover maps was generated from the MERIS surface reflectance archive between 2003 and 2012. The data were pre-processed to correct for radiometric, geometric and atmospheric effects, as well as screening for clouds. Supervised and unsupervised classification algorithms were combined in an automated procedure to derive the land cover classes (ESA, 2014). Backdating and updating techniques based on the SPOT-VGT time series were adopted to obtain the three different epoch maps. The 22 primary and 16 sub-level land cover classes were defined based on the United Nations Land Cover Classification System (UN-LCCS, http://www.fao.org/docrep/003/x0596e/x0596e00.HTM). The ESA CCI LC project provides both global validation based on expert verification of a network of 2600 points, or Primary Sampling Units (ESA, 2014) and a pixel-based uncertainty value. The latter is a measure of the confidence of the assigned class for each pixel that is based on the uncertainty calculated for the two classification algorithms (CCI LC CERC, 2014). Ideally we would use this information to derive an estimate of the accuracy of the transition calculations in this study. This is a non-trivial task, but a method for doing so is still being investigated.

In order to obtain the initial PFT-based forest area in 2000, the area of each land cover class in the 2000 epoch map was calculated and then converted into the area of 14 different PFTs (Poulter et al., 2011) based on the conversion factor table (Table S1) given in the ESA Land Cover Product User Guide (ESA, 2014). The derivation of this table, and the LC to PFT conversion procedure are described in Poulter et al. (2015). The CCI LC user tool that can be used to perform the conversion (as well as to aggregate the maps to coarser resolution) is also available from the visualization interface (http://maps.elie.ucl.ac.be/CCI/viewer/).

The transitions between PFTs were calculated as follows. Firstly, the land cover maps between different years were compared in order to find the classes that changed between epochs. Only 15 land cover classes were involved in the pixels that changed (the classes with stars in Table S1). The possible transitions among these 15 land cover classes were then calculated. In order to reduce the computing load and time, transitions with an area of less than 0.5% of the global total transition area were ignored. Consequently, the total coverage of global transitions was 95% from 2000 to 2005 and 92% from 2005 to 2010, respectively. The transitions in the original land cover classes of the CCI maps were then translated to the transitions in the 14 PFTs using the conversion factor table (Table S1).

3. Results

3.1. Forest area

The global total forest area estimated by ESA CCI LC map of 2000 is 30.01 million km^2. This result is lower than the estimation of 32.69 million km^2 in year 2000 by Hansen et al. (2010) using MODIS and Landsat Enhanced Thematic Mapper Plus (ETM+) data. However, the FAO reports that the world's total forest area is 40.85 million km^2 in 2000 (FAO, 2010), much higher than the estimates from ESA and Hansen et al. (2010). The disparity is mainly caused by the different data sources and the difference in the forest definition. FAO collected forest resource data from the member countries (FAO, 2010), using contrasting methods such as satellite imagery based estimation or from field survey in different countries (Grainger, 2008; Harris et al., 2012). High spatial resolution