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Editorial

Global land cover mapping using Earth observation satellite data: Recent progresses and challenges

1. Introduction

Land cover is an important variable for many studies involving the Earth surface, such as climate, food security, hydrology, soil erosion, atmospheric quality, conservation biology, and plant functioning. Land cover not only changes with human caused land use changes, but also changes with nature. Therefore, the state of land cover is highly dynamic. In winter snow shields underneath various other land cover types in higher latitudes. Floods may persist for a long period in a year over low land areas in the tropical and subtropical regions. Forest maybe burnt or clear cut in a few days and changes to bare land. Within several months, the coverage of crops may vary from bare land to nearly 100% crops and then back to bare land following harvest. The highly dynamic nature of land cover creates a challenge in mapping and monitoring which remains to be adequately addressed. As economic globalization continues to intensify, there is an increasing trend of land cover/-land use change, environmental pollution, land degradation, biodiversity loss at the global scale, timely and reliable information on global land cover and its changes is urgently needed to mitigate the negative impact of global environment change.

2. Recent progresses in global land cover mapping and change monitoring

Remote sensing has been widely recognized as the most economic and feasible approach to derive land-cover information over large areas (Cihlar, 2000; Gong, 2012). Land cover is enlisted as one of the essential climate variable in the global climate observation system (GCOS) (Bojinski et al., 2014) that can be technically and economically feasible for systematic observation. Despite the fact that a large amount of research on land cover mapping at various spatial scales has been carried out (Lu and Weng, 2007; Yu et al., 2014), there are only a handful of land cover maps produced at global scale. To meet the need for global climate change studies, several global land cover (GLC) map products have been developed at spatial resolutions ranging from 100 km to 300 m (DeFries and Townshend, 1994; Loveland et al., 2000; Hansen et al., 2000; Bartholomé and Belward, 2005; Friedl et al., 2010; Arino et al., 2008; Tateishi et al., 2011). However, it has soon been realized that these data products are difficult to harmonize in terms of classification system and the large errors in areas with rapidly changing ecotones (Giri et al., 2005; Herold et al., 2008; Verburg et al., 2011). Furthermore, previous global land cover products derived using time series optical satellite data at coarse spatial resolution (300 m–1 km) did not provide sufficient thematic detail or change information for global change studies and for resource management (Giri et al., 2013). Following a survey on the land cover data requirements of climate system modelers, Bontemps et al. (2012) found that higher spatial resolution and more temporal frequent data products were needed. In the meantime, requirement for finer resolution land cover mapping at the global scale has emerged in the field of biodiversity, food security and forest carbon studies (Dobson, 2005; Buchanan et al., 2009; Fritz et al., 2013; Giri et al., 2013; Pereira et al., 2013). Higher resolution (~30 m) land cover characterization and monitoring permits detection of land change at the scale of most human activity and offers the increased flexibility of environmental model parameterization needed for global change studies. However, there are a number of challenges to overcome before producing such data sets including unavailability of consistent global coverage of satellite data, sheer volume of data, unavailability of timely and accurate training and validation data, difficulties in preparing image mosaics, and high performance computing requirements (Giri et al., 2013).

Thanks to the free availability of Landsat imagery, global land cover mapping at 30 m resolution has become possible. Based on the Landsat Thematic Mapper (TM) images acquired around 2010, China produced the world's first 30 m global land cover maps in two versions, namely Finer Resolution Observation and Monitoring of Global Land Cover (FROM-GLC) and GlobeLand30. FROM-GLC contains two levels of land cover classes (10 Level-1 classes and 29 Level-2 classes) and was produced using four per-pixel image classification approaches (can be freely downloaded at: data.tsinghua.edu.cn). While efforts had been made in selecting images from the "greenest" and "wettest" seasons, the end results exhibited considerable "mosaic" effect due to different acquisition dates among neighboring images. The overall accuracies of Level-1 FROM-GLC range from 53.88% (Maximum Likelihood Classifier) to 64.89% (Support Vector Machine) while the best overall accuracy of Lavel-2 FROM-GLC is 52.76%. Several classes including impervious areas, croplands, grasslands, and shrublands were poorly classified (Gong et al., 2013). Such low accuracy is possibly attributable to significant spectral confusion among different land cover types (Chen et al., 2015) due to the lack of temporal features in the single-date Landsat images used (Yu et al., 2013a). Recognizing the difficulties of fully automated classification techniques to attain GLC maps at sufficiently high accuracy for operational use, a pixel-object-knowledge based classification approach (POK) was developed to produce GlobeLand30, an operational 30 m global land cover dataset. GlobeLand30 consists of 10 major classes and two base-line years, 2000 and 2010 with an overall classification accuracy at 80.33% (Chen et al., 2015). It

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should be noted that (1) the accuracies of FROM-GLC and GlobeLand30 were derived from different validation datasets thus are not directly comparable; and (2) the knowledge-based verification and refinement process in the POK method is rather labor intensive and time consuming. The GlobeLand30 dataset was donated to the United Nations on September 22, 2014 and available for open access (www.globeland30.org, Chen et al., 2014). This is a milestone achievement in the Earth Observation and open geo-information access.

Attempts were also made to use coarser resolution time-series Moderate Resolution Imaging Spectrometer (MODIS) data and auxiliary data to improve the FROM-GLC classification results and an overall classification accuracy of 67.08% was obtained (Yu et al., 2013a), a moderate improvement from the original 64.89%.

Although a number of single-category global data products such as cropland, urban and water bodies have been developed based on coarser resolution satellite data (Ramankutty and Foley, 1998; Schneider et al., 2009; Carroll et al., 2009), single-category land-cover data product derived from Landsat data are still rare. One of the early attempts to develop single-category land cover product at the global scale with Landsat TM data is the mapping of global mangrove distribution (Giri et al., 2011). A 30 m global cropland map has been developed following an integrated analysis of the FROM-GLC cropland results with time-series MODIS data (Yu et al., 2013b). Recently, a number of fractional products on forest cover at the global scale were developed using Landsat TM data (Hansen et al., 2013; Sexton et al., 2013) and synthetic aperture radar data (ALOS PALSAR) at 25 m level for 2007–2010 (Shimada et al., 2014). For global urban mapping, automated urban extraction still remains a challenging task. Several efforts were made to develop methods for global human settlements extraction using high and very high resolution (0.5–10 m) optical data (Pesaresi et al., 2013), TanDEM SAR data at 18 m resolution (Esch et al., 2013), and ENVISAT ASAR wide swath mode at 75 m resolution (Gamba and Lisini, 2013). In response to a strong need of robust and operational methods for global urban extraction with a small number of SAR images at medium resolution, Ban et al. (2015) evaluated ENVISAT ASAR data for global urban mapping at 30 m resolution using a robust processing chain, the KTH-Pavia Urban Extractor. The overall average accuracy for 10 global cities was achieved at 85.4% using a single SAR image.

Change detection at global scale is more difficult than land cover classification for a single time instant. Due to random errors and the lack of sufficiently high classification accuracy for most land-cover products, it is generally not advised to compare land-cover maps produced at different times to derive land-cover change information (Friedl et al., 2010). Moreover, these data sets were produced using different data sources, classification system, and classification methodologies. However, in recent years a number of change detection and trajectory analysis algorithms have been proposed for single-category land-cover types such as forest change and urbanization (e.g., Kennedy et al., 2010; Huang et al., 2010; Xian et al., 2011; Wang et al., 2012; Yousif and Ban, 2013; Hu and Ban, 2014). New algorithms are being developed based on trajectory analysis to derive changes for multiple land-cover types (Zhu and Woodcock, 2014). Nevertheless, most of these algorithms have not yet been applied to the global level due to their requirement of large volume of data and/or intensive computation. At the global scale, Hansen et al. (2013) derived annual forest loss and gain maps from 2000 to 2012 with Landsat data while Song et al. (2014) determined annual forest loss with MODIS data for 2000–2012.

3. Remaining challenges and opportunities

Mapping land cover over large areas is considerably more difficult than mapping small areas. For small areas, it is easier to collect data because a single-date image may cover the entire area of interest thus reducing inter-scene variability. In addition, it is possible to use manual interpretation which is usually more accurate when the image interpreter is familiar with the area. It is easy to conduct field visit on those areas that are hard to interpret. It is also easier to conduct validation and refinement of preliminary mapping results. As the study area increases to the continental and global scale, we face with a number of challenges at both the cognition and technology levels. At the cognition level, some of the challenges include:

- Can the design of classification system meet the need of a specific application and take advantage of the available remotely sensed data? Different application requires different classification scheme. For example, to model the carbon sequestration by the terrestrial ecosystem or the energy and water exchange between land and atmosphere, the research community requires that the land cover classes include classes as specific as plant functioning types. However, to help plan for meeting the Aichi Biodiversity Targets, conservation specialists and policy makers require information on land cover categories as broad as settlement, cropland, forest, wetland, water, etc.

- Can the image analyst(s) correctly associate each class with remotely sensed data? In supervised image classification, this capability determines the quality of training sample and in turn the quality of the outcome of the classification algorithm used. In unsupervised image classification, this capability also determines quality of cluster labeling. As the spatial scale increases, the level of requirement on the geographical knowledge and interpretation skill of an image analyst increases considerably because it is not practical to verify every uncertain land cover class on site.

- Can we collect sufficient representative samples for training and validation? More image analysts are needed at large spatial scale as the size of training or validation sample increases. Differences always exist in image interpretation by several analysts. Large inconsistencies among different image analysts would increase confusions in algorithm calibration and in accuracy assessment. How to reduce the inconsistencies among different image analysts is both an educational problem and a project management problem. Accumulation of successful global knowledge on land cover classification and building and maintaining a high quality team of image analysts are key elements in global land cover mapping and change monitoring.

Since minimizing the involvement of image analyst may help increase the objectivity of final image classification results and has potential for increased efficiency and reproducibility, there are tendencies of relying on technological advancement to overcome the shortcoming of land cover mapping methods involving large amount of human intervention. At regional and continental scale, a number of maps have been produced with unsupervised classification approaches (Cihlar, 2000; Bartholomé and Belward, 2005; Hu et al., 2014). However, so far supervised classification or image interpretation still has its superiority in terms of final classification accuracies (Zhang et al., 2014). Thus, the amount of efforts made by expert analysts determines to a large extent the quality of final map product. To reduce the involvement of image analysts in the classification process, it is important to accumulate samples that can be used for signature extension and validating multiple land-cover data products (Demir et al., 2013; Zhao et al., 2014).