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Mapping tropical forests and rubber plantations in complex landscapes by integrating PALSAR and MODIS imagery

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ABSTRACT

Knowledge of the spatial distribution of forest types in tropical regions is important for implementation of Reducing Emissions from Deforestation and Forest Degradation (REDD), better understanding of the global carbon cycle, and optimal forest management. Frequent cloud cover in moist tropical regions poses challenges for using optical images to map and monitor forests. Recently, Japan Aerospace Exploration Agency (JAXA) released a 50 m orthorectified mosaic product from the Phased Array Type L-band Synthetic Aperture Radar (PALSAR) onboard the Advanced Land Observing Satellite (ALOS). PALSAR data provides information about the land surface without cloud interference. In this study we use the fine beam dual (FBD) polarization PALSAR 50 m mosaic imagery and a Neural Network (NN) method to produce a land cover map in Hainan Island, China. Subsequently, forest areas are classified into evergreen and deciduous forests and rubber plantations are mapped using vegetation and land surface water indices derived from 250 to 500 m resolution MODIS products. The PALSAR 50 m forest cover map, MODIS-based forest types and rubber plantation maps are fused to generate fractional maps of evergreen forest, deciduous forest and rubber plantation within 500 m or 250 m pixels. PALSAR data perform well for land cover classification (overall accuracy = 89% and Kappa Coefficient = 0.79) and forest identification (both the Producer's Accuracy and User's Accuracy are higher than 92%). The resulting land cover maps of forest, cropland, water and urban lands are consistent with the National Land Cover Dataset of China in 2005 (NLCD-2005). Validation from ground truth samples indicates that the resultant rubber plantation map is highly accurate (the overall accuracy = 85%). Overall, this study provides insight on the potential of integrating cloud-free 50 m PALSAR and temporal MODIS data on mapping forest types and rubber plantations in moist tropical regions.

1. Introduction

Tropical forests play an important role in the terrestrial carbon cycle and reduce the amount of greenhouse gases such as carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen monoxide (NO) in the atmosphere (Lelieveld et al., 2008). Tropical forests also provide many ecosystem services that substantially affect human well-being (Foley et al., 2005; Pielke, 2005). Both human-induced deforestation (primarily to convert land to agricultural uses) and natural disturbance (e.g. fire, drought, wind blow-down) occur extensively in tropical regions (Bond-Lamberty et al., 2007; Kummer and Turner, 1994; Page et al., 2002; Sakaguchi et al., 2011). Plantations used for production of biofuels (e.g. oil palm) and industrial resources (e.g. rubber, *Hevea brasiliensis*) have expanded rapidly in tropical regions in the last 50 years (Fox and Vogler, 2005). This expansion has brought along a detrimental cascade of environmental effects including increasing threats to biodiversity and reduction in forest carbon stocks (Li et al., 2007; Ziegler et al., 2009). Accurate information on the area and spatial distribution of natural and planted forests in tropical areas is necessary for the implementation of Reducing Emissions from Deforestation and Forest Degradation (REDD) (Achard et al., 2007) and for modeling global carbon cycles (Dixon et al., 1994).

During the past few decades, optical remote sensing has been widely utilized for forest mapping (Asner et al., 2005; Collins et al., 2004; Thessler et al., 2008; Xiao et al., 2009, 2002). Previous studies have explored the potential for tropical forest mapping using imagery from the Advanced Very High Resolution Radiometer (AVHRR) (Achard and Estreguil, 1995; Achard et al., 2001), SPOT4-VEGETATION (Stibig et al., 2004; Stibig and Malingreau, 2003) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Miettinen et al., 2012). Most of these studies employed

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unsupervised classification due to the difficulty of ground truth sampling in tropical forest regions. Landsat Thematic Mapper (TM) images with 30 m spatial resolution and a 16-day revisit cycle are an important data source (Huang et al., 2009; Townshend and Justice, 1988); however, it is often difficult to obtain cloud-free Landsat images in tropical regions due to frequent cloud cover and moist climate (Asner, 2001). The images from the MODIS sensors have been used to map forest and detect deforestation at regional and global scales (Friedl et al., 2002; Giri et al., 2005; Morton et al., 2005; Tottrup et al., 2007; Xiao et al., 2009). Daily image acquisition by the MODIS sensors partly reduces cloud problems as compared to Landsat, providing valuable information to identify and map different forest types (Friedl et al., 2002; Xiao et al., 2009, 2002). However, its relatively coarse spatial resolution (250–1000 m) makes it difficult to accurately quantify and map forest areas at the regional scale due to mixture of land cover types within pixels. High spatial resolution remotely sensed imagery (e.g. SPOT-5, IKONOS, and aerial photographs), on the order of 1–50 m, are a very effective data source for local land use and land cover classification (Kabir et al., 2010; Perea et al., 2010; Su et al., 2010), but are not widely used in regional level monitoring due to the high cost of image acquisition and intensive computation resource requirements.

Images from synthetic aperture radar (SAR) offer an alternative data source for mapping tropical forests (Ardila et al., 2010; Simard et al., 2000). The radar illuminates vegetation types with microwave energy, recording return energy that is related to aboveground biomass and structure. Longer radar wavelength L-band SAR is better suited to the delineation of forest than other wavelengths because of its greater penetration through the canopy (Baghdadi et al., 2009). The Phased Array Type L-band Synthetic Aperture Radar (PALSAR) data is not subject to cloud interference, making it a more effective data source for forest mapping at the regional scale in moist tropical regions. PALSAR is onboard the Advanced Land Observing Satellite (ALOS) launched by the Japan Aerospace Exploration Agency (JAXA) in January of 2006, and it provides polarimetric radar images for most of the global land surface. PALSAR images have been used for many applications, including forest, crop, and ice mapping (Torbick et al., 2011; Xiao et al., 2010; Xie et al., 2010; Yang et al., 2010). The PALSAR team has developed two data products for the public: (1) the PALSAR 50 m Orthorectified Mosaic Product, and (2) the PALSAR 500 m Browse Mosaic Product. The publically released PALSAR 50 m mosaic product covers a large portion of Asia, and has recently been evaluated for regional forest monitoring potential in insular Southeast Asia (Longepe et al., 2011; Miettinen and Liew, 2011) with positive results. However, further evaluation of the potential of PALSAR 50 m mosaic product for mapping tropical forests in many regions is needed along with the development of new methodologies to challenges in those regions with complex landscapes and land use.

Hainan Island, the most representative tropical region in China, underwent dramatic changes in land use and land cover during the past few decades (Liu et al., 2010; Xu et al., 2002; Zhang et al., 2010). With the increasing demand for rubber products, rubber plantations continue to expand in Southern China (Qiu, 2009; Ziegler et al., 2009). It is necessary to develop an accurate and updated rubber distribution map for improving our understanding of land use change and carbon and water cycles (Li and Fox, 2011, 2012). Hainan Island is now thought to have the largest area of rubber plantation in China (Chen et al., 2010). There is an increasing need

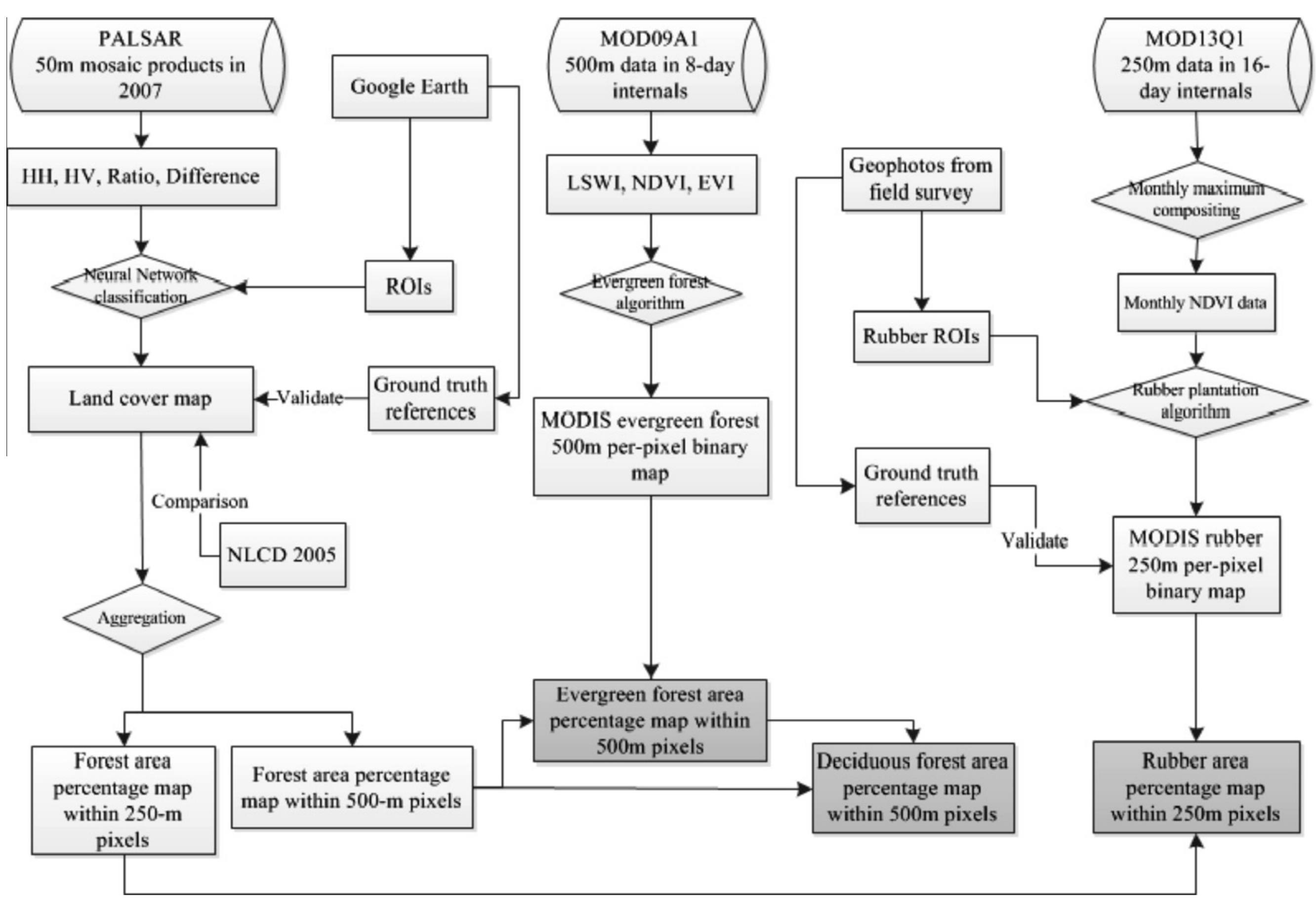

Fig. 1. The workflow of this study.