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Mapping tropical forests and deciduous rubber plantations in Hainan Island, China by integrating PALSAR 25-m and multi-temporal Landsat images

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ABSTRACT

Updated and accurate maps of tropical forests and industrial plantations, like rubber plantations, are essential for understanding carbon cycle and optimal forest management practices, but existing optical-imagery-based efforts are greatly limited by frequent cloud cover. Here we explored the potential utility of integrating 25-m cloud-free Phased Array type L-band Synthetic Aperture Radar (PALSAR) mosaic product and multi-temporal Landsat images to map forests and rubber plantations in Hainan Island, China. Based on structure information detected by PALSAR and yearly maximum Normalized Difference Vegetation Index (NDVI), we first identified and mapped forests with a producer accuracy (PA) of 96% and user accuracy (UA) of 98%. The resultant forest map showed reasonable spatial and areal agreements with the optical-based forest maps of Fine Resolution Observation and Monitoring Global Land Clover (FROM-GLC) and GlobalLand30. We then extracted rubber plantations from the forest map according to their deciduous features (using minimum Land Surface Water Index, LSWI) and rapid changes in canopies during Rubber Defoliation and Foliation (RDF) period (using standard deviation of LSWI) and dense canopy in growing season (using maximum NDVI). The rubber plantation map yielded a high accuracy when validated by ground truth-based data (PA/UA > 86%) and evaluated with three farm-scale rubber plantation maps (PA/UA >88%). It is estimated that in 2010, Hainan Island had 2.11×10^6 ha of forest and 5.15×10^5 ha of rubber plantations. This study has demonstrated the potential of integrating 25-m PALSAR-based structure information, and Landsat-based spectral and phenology information for mapping tropical forests and rubber plantations.

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1. Introduction

Tropical forests are of vital importance in maintaining biodiversity, sustaining the healthy functioning of ecosystems, and moderating atmospheric greenhouse gas concentration (Lelieveld et al., 2008; Shimada et al., 2014). Considerable amounts of natural forests have been lost due to increasing demands for food and energy (Shimada et al., 2014; Suratman et al., 2004). For example, plantations of rubber (*Hevea brasiliensis* (Wild. ex Adr. de Juss.) Muell Arg.) have expanded rapidly in tropical and subtropical regions in the last 50 years to meet the increasing consumption of natural rubber (Dong et al., 2012b). According to the Food and Agriculture Organization (FAO) of the United Nations Global Forest Resources Assessment (FRA) 2010 report, the global extent of rubber plantations has steadily increased by 25% during the past two decades (FAO, 2010). Although rubber expansion has economically benefited rubber-relevant industries and the owners/producers of rubber plantations, it has also created conflicts between agricultural production and forest management and conservation (de Blecourt et al., 2013; Guardiola-Claramonte et al., 2010; Li et al.,

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Table 1
Selected recent literatures for mapping forest and deciduous rubber plantations using MODIS/Landsat optical and PALSAR data.

Land cover	Optical data		PALSAR data		PALSAR/Optical data integration/fusion		
	MODIS	Landsat	50-m	25-m	PALSAR 50-m/MODIS	PALSAR 50-m/Landsat	PALSAR 25-m/Landsat
Forest	(Hansen et al., 2003; Razali et al., 2014; Senf et al., 2013)	(Gong et al., 2013; Hansen et al., 2013; Hermosilla et al., 2015)	(Dong et al., 2012a,b, 2014; Longepe et al., 2011; Santoro et al., 2009; Tenku et al., 2015)	(Motohka et al., 2014; Pantze et al., 2014; Shimada et al., 2014; Thapa et al., 2014; Walker et al., 2010)	(Dong et al., 2012a,b; Qin et al., 2015, 2016)	–	(Lehmann et al., 2011, 2012; Reiche et al., 2013, 2015)
Deciduous rubber plantation	(Li and Fox, 2012; Razali et al., 2014; Senf et al., 2013)	(Fan et al., 2015; Li et al., 2015; Li and Fox, 2011a; Suratman et al., 2004)	–	–	(Dong et al., 2012a,b)	(Dong et al., 2013; Kou et al., 2015)	This study

*Only a few optical-based forest mapping literatures were listed here.

2008; Liu et al., 2013; Qiu, 2009; Xu et al., 2014; Ziegler et al., 2009). Accurate and up-to-date maps of natural forests and rubber plantations can provide a better understanding of the consequences of land-cover and land-use change on biodiversity and carbon and water cycles and support decision makers in implementing sustainable management policies. However, a map of rubber plantation extent with high accuracy and spatial resolution is still unavailable in China or Southeast Asia, which currently accounts for approximately 97% of global natural rubber production (FAO, 2010). In addition, the yearly expansion and updating of old rubber plantations also calls for accurate mapping methods to monitor the changes in rubber plantations at local and regional scales.

Satellite remote sensing is a viable approach for large scale forest inventories. Based on the usage of data sources, mapping of forest and deciduous rubber plantations can be classified into three categories: 1) optical image-based approach, 2) Synthetic Aperture Radar (SAR) image-based approach and 3) SAR-optical image integration/fusion approach. The recent literatures from peer-reviewed journals for the most widely used optical and SAR data were summarized in Table 1. Since there are hundreds and thousands of studies employed optical remote sensing for forest mapping because of its early appearance, only a few of them were listed here. The Advanced Very High Resolution Radiometer (AVHRR) (Loveland et al., 2000) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Dong et al., 2012a,b; Hansen et al., 2003; Li and Fox, 2012; Razali et al., 2014; Senf et al., 2013) were the widely used at regional and global scales, but the resultant forest maps often had large uncertainties due to mixtures of land cover types within coarse to moderate resolution imagery pixels. For those medium resolution images such as Landsat Thematic Mapper/Enhanced Thematic Mapper Plus/Operational Land Imager (TM/ETM+/OLI) (Fan et al., 2015; Gong et al., 2013; Hermosilla et al., 2015; Li et al., 2015; Li and Fox, 2011a; Suratman et al., 2005; Zhang et al., 2010), Advance Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) (Li and Fox, 2011b) and SPOT (Mongkolsawat and Putklang, 2010), the major constraints for classification at large scales are the constant presence of clouds and cloud shadows in tropical areas and the long revisit cycles of these sensors (e.g., 16 day revisit for Landsat) (Wang et al., 1999; Watmough et al., 2011; Zhu and Curtis, 2012). Most of these MODIS- and Landsat-based studies have used time series vegetation indices, such as Normalized Difference Vegetation Index (NDVI) (Tucker, 1979), Enhanced Vegetation Index (EVI) (Huete et al., 2002) and Land Surface Water Index (LSWI)(Xiao et al., 2004), which tracks well phenology of vegetation canopy. High spatial resolution images (e.g., IKONOS, Worldview-2) are too expensive for mapping at regional and global scales due to the high image cost (Cho et al., 2015; Mallinis et al., 2008).

SAR data has the advantage of not subjecting to cloud interference, and therefore is a very important complementary data source for land use and land cover study. Long wavelength SAR like Phased Array type L-band SAR (PALSAR) can easily penetrate the forest canopy and capture structural information than short wavelength SAR data (e.g. C-band of ERS (Rosenqvist, 1996) and ENVISAT (Evans and Costa, 2013)). The Japan Earth Resources Satellite (JERS-1, 1992–1998), Advanced Land Observing Satellite (ALOS) PALSAR-1/2 (2006–2010, 2014-present), which are the only satellite-based L-band SAR right now, are widely used for forest mapping and biomass estimation from local to regional scales (Dong et al., 2012a,b, 2014; Liesenberg and Gloaguen, 2013; Longepe et al., 2011; Motohka et al., 2014; Pantze et al., 2014; Peregon and Yamagata, 2013; Shimada et al., 2014; Tenku et al., 2015; Thapa et al., 2014; Walker et al., 2010). In 2011, the Japan Aerospace Exploration Agency (JAXA) released the PALSAR 50-m Orthorectified mosaic image product for the globe to the public. Several studies have assessed the potential of PALSAR 50-m data