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Mapping deciduous rubber plantations through integration of PALSAR and multi-temporal Landsat imagery

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ABSTRACT

Due to increasing global demand for natural rubber products, rubber (*Hevea brasiliensis*) plantation expansion has occurred in many regions where it was originally considered unsuitable. However, accurate maps of rubber plantations are not available, which substantially constrain our understanding of the environmental and socioeconomic impacts of rubber plantation expansion. In this study we developed a simple algorithm for accurate mapping of rubber plantations in northern tropical regions, by combining a forest map derived from microwave data and unique phenological characteristics of rubber trees observed from multi-temporal Landsat imagery. Phenology of rubber trees and natural evergreen forests in Hainan Island, China, was evaluated using eighteen Landsat TM/ETM+ images between 2007 and 2012. Temporal profiles of the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Land Surface Water Index (LSWI), and near-infrared (NIR) reflectance for rubber trees and natural forest were constructed. The results showed that rubber plantations are distinguishable from natural evergreen forests in two phenological phases: 1) during the defoliation (leaf-off) phase in late February–March, vegetation index (NDVI, EVI, LSWI) values were lower in rubber plantations than in natural evergreen forests; and 2) during the foliation (new leaf emergence) phase in late March–April, rubber plantations had similar NDVI and LSWI values but higher EVI and NIR reflectance values than in natural forests. Therefore, it is possible to delineate rubber plantations within forested landscapes using one to two optical images acquired in the defoliation and/or foliation period. The mapping technique was developed and applied in the Danzhou Region of Hainan. Phased Array type L-band Synthetic Aperture Radar (PALSAR) 50-m Orthorectified Mosaic images were used to generate a forest cover map and further integrated with the phenological information of rubber plantations extracted from Landsat TM images during the foliation phase. The resultant map of rubber plantations has high accuracy (both producer's and user's accuracy is 96%). This simple and integrated algorithm has the potential to improve mapping of rubber plantations at the regional scale. This study also shows the value of time series Landsat images and emphasizes imagery selection at appropriate phenological phase for land cover classification, especially for delineating deciduous vegetation.

1. Introduction

Plantation development by the agroforestry industry, such as the expansion of Pará rubber tree (*Hevea brasiliensis*) plantations, has been a critical driver of land cover change around the world, particularly in the tropics. The Food and Agriculture Organization (FAO) of the United Nations Global Forest Resources Assessment (FRA) 2010 reported that globally rubber plantation extent has steadily increased by 25% during the past two decades (FAO, 2010). Approximately 97% of global natural rubber supply comes from Southeast Asia (Li & Fox, 2012). This land use is a primary driving factor for the conversion from swidden to monocultural cash plantations in montane areas of mainland Southeast Asia (Fox & Vogler, 2005). This land use change process has both economic and environmental outcomes. On the one hand, local farmers can improve financial stability as rubber plantations provide greater agricultural profit due to the increased demand for rubber products. Further, rubber plantations tend to have greater agricultural resiliency compared to traditional cash crops that are more stressed by adverse weather. On the other hand, the

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expansion of rubber plantations plays an important role in altering regional environments that substantially affect human well-being and ecosystem services. For example, large-scale land surface change affects climate, carbon stocks, and biodiversity (Foley et al., 2005; Li, Aide et al., 2007; Ziegler, Fox, & Xu, 2009). Rapid expansion of rubber plantations has occurred in south China due to the increasing demand for rubber products. The rapid growth of rubber plantations in Hainan Province and the Xishuangbanna Region of Yunnan Province in China has received much attention (Qiu, 2009; Zhai et al., 2012; Ziegler et al., 2009); however, an accurate map of rubber plantation extent with high accuracy and resolution is still not available in these regions.

A number of studies have used optical remote sensing data to delineate rubber plantations and these studies can be categorized into two broad groups. The first group focuses on the use of spectral signatures with cluster analysis and traditional classifiers to identify and map rubber plantations. For example, Li et al. (Li, 2011; Li & Fox, 2011, 2012) applied Mahalanobis typicality method to identify rubber trees in mainland Southeast Asia by using spectral data from Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Landsat imagery. Zhang et al. (2010) used georeferenced field data and Landsat TM images in May-August of 2008 to conduct a maximum likelihood supervised classification that achieved an overall accuracy of 91% in Hainan Island, China, and the rubber plantation area was estimated at 4170 km^2. However, rubber trees have similar spectral characteristics compared to natural tropical forest, particularly secondary forest, as observed by single date multispectral data during peak growing season (Li & Fox, 2011). In addition, spectral characteristics of rubber trees vary in different regions or seasons, therefore, traditional spectral-based classifiers are challenging to repeat, scale, or transfer to other geographical regions. Moreover, frequent cloud coverage in the tropics presents a challenge for optical data to distinguish general forest, let alone rubber trees.

The second group of studies relies on the temporal signals of optical images to delineate rubber trees. For example, Normalized Difference Vegetation Index (NDVI) time series data from MODIS and China's Feng-Yun-3A (FY-3A) have been used to represent the phenological signatures of rubber plantations. Recently Chen et al. (2010) and Tan et al. (2010) utilized the intra-annual temporal profile of rubber plantations to delineate them in Hainan, China. This approach relied on phenological features of rubber plantations; however, the spatial resolution of MODIS is relatively coarse (250–500 m), which limits its suitability for rubber plantation mapping in fragmented landscapes. The frequent cloud cover in tropical regions also makes it difficult to construct consistent year-long MODIS time series with reliable data quality.

Therefore, the difficulty of mapping rubber plantations from optical images is two-fold: the first difficulty is the effect of frequent cloud cover on tree delineation; and the second is the similarity of spectral characteristics between rubber trees and other forest types. In comparison to optical sensors, synthetic aperture radar (SAR) can penetrate clouds and has advantages in mapping tropical forests, particularly longer wavelengths (e.g. L-band SAR) that are capable of penetrating tree canopies (Baghdadi et al., 2009). The Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard the Advanced Land Observing Satellite-1 (ALOS-1) was launched by the Japan Aerospace Exploration Agency (JAXA) in January 2006 is one such instrument. Several applications have utilized PALSAR observations to map tropical forest areas (Almeida et al., 2009; Longepe et al., 2011; Miettinen & Liew, 2011; Santoro et al., 2010; Walker et al., 2010; Xiao et al., 2010). In a previous study we combined a forest map derived from PALSAR 50-m orthorectified mosaics with a phenology-based map of rubber plantations from 250-m multi-temporal MODIS NDVI to generate a 250-m fractional cover map of rubber plantations in Hainan, China (Dong et al., 2012b). Our previous effort found that the use of cloud-free PALSAR data supported robust forest mapping and the integration of PALSAR 50-m forest maps and 250-m MODIS NDVI phenology helped to accurately map fractional cover of rubber plantation extent (Dong et al., 2012b). However, due to the heterogeneous landscapes in Hainan, the phenology information extracted from the MODIS time series included mixed pixels with signals from other land cover types, as small holder land management represents a large portion in the region. To overcome the challenge of mixed pixels, the use of time series Landsat imagery (30-m spatial resolution) could be valuable. The relatively fine resolution and free availability of Landsat images are potential sources of more phenology information at a higher spatial resolution that can substantially improve product accuracy. The advantages of multiple temporal Landsat data for land cover classification, for example, in discriminating temperate deciduous forests (Homer, Huang, Yang, Wylie, & Coan, 2004), have been well established. A simple and accurate algorithm to map rubber plantations with freely available Landsat imagery is of extreme value and urgently needed in complex landscapes across Southern China and Southeast Asia where rubber plantations continue to expand.

In this study we addressed two questions regarding mapping rubber plantations. First, is Landsat-based phenology analysis robust and capable of distinguishing rubber plantations from natural evergreen forests? Second, can delineation of rubber plantations be improved by combining PALSAR-derived forest maps with Landsat-based phenology? Our objective was to develop and apply a simple, phenology-based approach for mapping rubber plantations at a finer spatial resolution at regional scale that enables a rapid and repeated execution. The Danzhou region of Hainan Island, China was selected as the study area as this region has the largest rubber plantation area in Hainan. To achieve this objective we integrated cloud-free PALSAR and optical Landsat imagery to overcome the technical challenges faced in previous studies. This study is expected to provide a practical approach for the continental rubber plantation mapping in Southern China and Southeast Asia in the near future.

2. Materials and methods

2.1. Study area

The Danzhou region has the highest rubber production in the Hainan Province, China. According to data from the Hainan Statistical Yearbook, Danzhou produced 7.4×10^4 tons of rubber in 2011, which accounted for ~20% of rubber production in Hainan Province. It has a tropical monsoon climate with an annual mean temperature of approximately 25 °C and annual accumulated precipitation between 1800 and 2000 mm. The region is located in western Hainan and the influences of typhoons are relatively small compared with eastern regions of Hainan. Elevation increases from <50 m in the northwest to 752 m in the southwest (Fig. 1). Natural forests in Danzhou are mainly evergreen, while rubber trees show deciduous characteristics. Defoliation is an adaptation of rubber trees to low temperature and/or dry monsoon. When rubber trees were introduced in British Malaysia in the 20th century, the trees were considered unsuitable for northern parts of the tropics such as Hainan Island. However, rubber germplasm improvement enhanced the capability to adapt to frequent typhoons and low winter temperature (Li & Fox, 2012).

2.2. PALSAR data and pre-processing

PALSAR 50-m Orthorectified Mosaic data were used to generate a forest map. The PALSAR mosaic data are freely available through the ALOS Kyoto and Carbon Initiative (ftp://ftp.eorc.jaxa.jp/pub/ALOS/ftp/KC50/). The data have been geometrically rectified using a 90-m digital elevation model (DEM) and geo-referenced to geographical latitude and longitude coordinates (Longepe et al., 2011). Detailed algorithms and data processing including calibration and validation were reported in Shimada et al. (2008), Shimada and Ohtaki (2010).