Remote Sensing of Environment 155 (2014) 79–88

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Using time series PALSAR gamma nought mosaics for automatic detection of tropical deforestation: A test study in Riau, Indonesia

Takeshi Motohka [a,*], Masanobu Shimada [a], Yumiko Uryu [b], Budi Setiabudi [c]

[a] Earth Observation Research Center (EORC), Japan Aerospace Exploration Agency (JAXA), Tsukuba, Ibaraki 305-8505, Japan
[b] World Wildlife Fund, Washington DC 20037, USA
[c] Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP), Jl. Raya Tajur Km. 6, Bogor 16000, Indonesia

ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form 26 March 2014
Accepted 3 April 2014
Available online 1 May 2014

Keywords:
ALOS PALSAR
Gamma nought
Indonesia
REDD+
Deforestation
Automatic change detection

ABSTRACT

This study intended to demonstrate the effectiveness of phased array type L-band synthetic aperture radar (PALSAR) time series mosaics for automatic detection of tropical deforestation in Riau province, Indonesia. Using six time series PALSAR mosaics, the characteristics of HH and HV gamma nought (γ^0) in natural forests and deforested areas from 2007 to 2010 and the accuracy of deforestation detection by using a threshold were investigated. We obtained the following results: (1) Applying a simple thresholding method to time series differences of γ^0_{HV} was effective for fully automatic detection of deforestation areas. When we used a fixed threshold, the accuracy ranged from 72% to 96% (average of 87%). (2) γ^0_{HH} did not always show systematic changes after deforestation. (3) The temporal variation of γ^0 for deforested areas was larger than that for natural forests. These variations in γ^0 were correlated with 10-day accumulated precipitation. High accumulated precipitation decreased the γ^0 difference between deforested areas and natural forests, causing decreased accuracy of deforestation detection. (4) Integration of the results from two different dates in a given year can reduce the detection error due to time variations and provide highly accurate results (average accuracy of 91%, minimum of 82%). The accuracy values quoted except hilly areas, shadow, and lay-over. The proposed method is effective for detection of deforestation larger than 1 ha. The deforestation mapping method proposed in the study can be utilized for assessment of yearly changes in forested areas and is useful for tracking changes in forest cover on large scales.

1. Introduction

Mapping deforestation using satellite remote sensing has become essential in the assessment and management of forest resources at both regional and global scales. Spatial and temporal deforestation information detected by satellites has been utilized in various applications, including making an inventory of global forest coverage (FAO, 2010), early detection of illegal logging (Anderson, Shimabukuro, Defries, & Morton, 2005), and estimating carbon dioxide emissions from deforestation (DeFries et al., 2002; Harris et al., 2012). Recent REDD+ (which denotes reducing emissions from deforestation and forest degradation in developing countries and includes the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks) activities also require satellite-based monitoring of changes in forest areas to estimate forest carbon changes accurately (GOFC-GOLD, 2011). To advance these applications, satellite observations are expected to satisfy a wall-to-wall observation capacity, tens to hundreds of meters of spatial resolution, and less-than-one-year temporal intervals (Houghton, Hall, & Goetz, 2009). Automatic processing is also expected to aid analysis of large global data archives, semi-real-time processing, and the development of user-friendly software for REDD+ activities.

Optical sensors are used in many studies to detect deforestation. The Landsat series has been providing data sets since the 1970s with a spatial resolution of 15–120 m (mainly 30 m for visible bands), and its large data archive has been utilized to track forest changes (e.g., Gaveau, Wandono, & Setiabudi, 2006; Margono et al., 2012; Potapov et al., 2012; Skole & Tucker, 1993). However, particularly in tropical regions, frequent cloud cover and haze make it difficult to create a wall-to-wall deforestation map with less than one-year intervals (Broich et al., 2011). Statistical sampling can be used to assess forest area changes on a large scale without cloud noise (Hansen, 2008; Hansen et al., 2008, 2009), but this method cannot produce wall-to-wall maps.

One of the most promising approaches for mapping deforestation with finer temporal and spatial resolution is the use of synthetic aperture radar (SAR) data. SAR technology can be used to observe the ground surface even when clouds cover the ground because of the cloud penetration capability of microwaves. A Japanese satellite-based SAR, the phased array type L-band synthetic aperture radar (PALSAR), which was onboard the Advanced Land Observing Satellite (ALOS), provided global data several times a year based on a basic observation

* Corresponding author at: 2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan. Tel.: +81 50 3362 3079; fax: +81 29 868 2961.
E-mail addresses: motooka.takeshi@jaxa.jp (T. Motohka), shimada.masanobu@jaxa.jp (M. Shimada), yumuryu@yahoo.com (Y. Uryu), setiabudi@biotrop.org (B. Setiabudi).

http://dx.doi.org/10.1016/j.rse.2014.04.012
0034-4257/

scenario (Rosenqvist, Shimada, Ito, & Watanabe, 2007). The systematically gathered global PALSAR data are helpful for clarifying forest losses on the regional to global scale. Although operation of ALOS was ceased in 2011 and PALSAR data cover only the period from 2006 to 2011, PALSAR-2 is prepared to succeed PALSAR with observations beginning in 2014.

The most straightforward method for detecting deforestation using PALSAR data is to detect large changes in the time series difference of the backscattering coefficient by using a threshold value because the L-band microwave backscattering coefficient is correlated to aboveground biomass of forest trees to a certain level (Carreiras, Vasconcelos, & Lucas, 2012; Englhart, Keuck, & Siegert, 2011; LeToan, Beaudoin, Riom, & Guyon, 1992; Lucas et al., 2010; Mitchard et al., 2009; Sandberg, Ulander, Fransson, Holmgren, & LeToan, 2011; Watanabe et al., 2006). The thresholding also offers the advantage of full-automatic data processing. To evaluate the capability and stability of the thresholding method over time and space, we should first understand the behavior of the backscattering coefficient in forested and deforested areas, because it is affected not only by forest changes but also by other environmental conditions, especially ground surface moisture (Lucas et al., 2010; Rignot, Salas, & Skole, 1997; Salas, Ducey, Rignot, & Skole, 2002; Santoro, Fransson, Eriksson, & Ulander, 2010) and residual woody debris left after felling (Rignot et al., 1997; Salas et al., 2002; Takeuchi, Suga, Oguro, & Konishi, 2000). Although many studies have investigated the potential of deforestation detection by using multi-temporal differences of PALSAR backscatter (e.g., Santoro et al., 2010; Whittle, Quegan, Uryu, Stüewe, & Yulianto, 2012), there has been insufficient analysis of time series automatic deforestation detection using PALSAR data and its accuracy assessment to justify practical use.

This study aims to demonstrate the usefulness of multi-temporal PALSAR dual-polarization mosaics for the automatic detection of tropical deforestation. The present paper covers the following topics: (1) investigation of the behavior of PALSAR HH and HV backscattering coefficients for natural forests and deforested areas in Riau province, Indonesia; (2) evaluation of the accuracy of deforestation detection by using thresholding for time series changes in PALSAR data; (3) evaluation of the influence of ground surface moisture on the accuracy of deforestation detection; and (4) development of automated methods for mapping deforestation using PALSAR Fine Beam Dual (FBD) mode data based on results (1) to (3).

2. Materials and methods

2.1. Study area

The study area is in the Riau province on Sumatra Island, Indonesia (Fig. 1; 2°42′ N–1°12′ S latitude and 100°00′ E–104°00′ E longitude in the World Geodetic System, 1984). The climate is typical for the equatorial tropics with an annual average temperature of 22–31 °C and an annual precipitation between 2500 and 3000 mm. The dry season is usually from June to October, and the rainy season is from November to April/May. The mainland ground cover includes natural forests (dry forest on mineral soils, peat swamp forest, and mangrove), plantations (oil palm, rubber, acacia, coconuts, etc.), bare land, grassland, and urban areas. The main dominant species of the natural peat swamp forests are evergreen broadleaf trees such as *Shorea* spp. and *Swintonia* spp. (Momose & Shimamura, 2002). Recent deforestation has been caused mainly by conversion to acacia (for pulp and paper production) and oil palm plantations (Uryu et al., 2008). About 50% of the ground surface of Riau province is covered by peat soil, the majority of which is very deep (Wahyunto, Ritung, & Subagjo, 2003). The estimated peat carbon stock of Riau in 2002 was about 14,605 Mt (Wahyunto et al., 2003).

2.2. Processing of PALSAR time series mosaics

ALOS PALSAR time series mosaics covering the study area (Fig. 2) were created from JAXA PALSAR Level 1.0 data acquired in FBD mode at an off-nadir angle of 34.3° and an ascending orbit. The swath width for a single path is about 70 km, and eight long-strip path images were used to cover the study area. Six mosaics from 2007 to 2010 were created (2007A, 2008A, 2009A, 2009B, 2010A, and 2010B; Table 1). We created two mosaics for each of 2009 and 2010 to assess the impact of temporal variations. For 2007 and 2008, there were not enough FBD data to create two mosaics covering the entire study area.

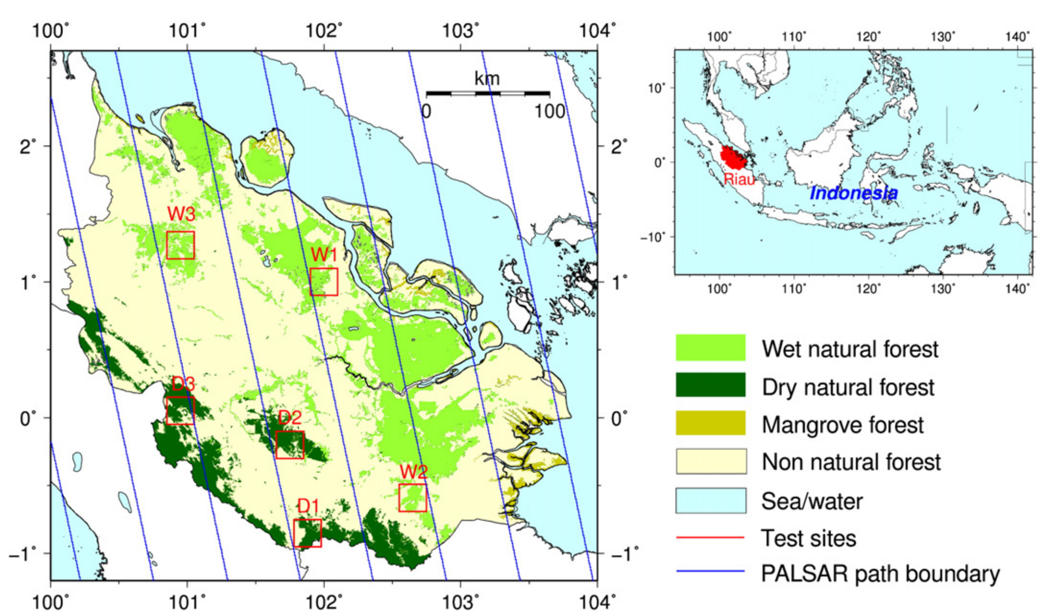

Fig. 1. The study area (Riau province, Sumatra, Indonesia). Background land cover data are from the WWF Indonesia land cover database 2007 made from Landsat TM/ETM+ images during 2006–2007 (Uryu et al., 2008). Solid lines are the boundaries of PALSAR path images used in the mosaics. The boxes indicate the sites used for sampling reference data (D1–D3 and W1–W3).