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Investigating the use of Alos Prism data in detecting mangrove succession through canopy height estimation

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ABSTRACT

Mangroves have been massively degraded and deforested throughout the world, despite their known ecological and economic values. This study demonstrates the use of ALOS Global Digital Surface Model World (AW3D30) DSM dataset acquired between 2006 and 2011 to map canopy height of different succession stages of mangroves. We employed our previously developed canopy height model for assessing mangrove canopy height in three sites that vary in latitudinal position and mangrove degradation levels, ranging from relatively pristine mangrove ecosystems in Mimika Papua, Indonesia and Sundarbans, Bangladesh to severely degraded mangrove ecosystems in the Mahakam Delta, Indonesia. The study demonstrates good agreement between modeled and measured canopy height from these three sites as indicated by small mean absolute errors of 3.38 m at Mimika, 2.54 m at Sundarbans, and 2.89 m in the Mahakam Delta site. These findings further showed that, in the absence of synthetic aperture radar (SAR) based elevation data (such as SRTM and TanDEM-X), the ALOS PRISM data can be used to map mangrove heights (or in combination with SAR-based elevation data). Our results also pointed out that the ALOS data can differentiate the variability of canopy height estimation between an intact mangrove and severely degraded mangrove ecosystem.

1. Introduction

Mangroves are coastal ecosystems that provide important ecological and economic benefits. Along the ocean shorelines of the tropics and subtropics, they form a natural barrier against storm surges and tidal impacts. Mangroves have a high capacity to break the forces of waves, thus, protecting inland and ocean shoreline areas from natural hazards, such as hurricanes, cyclones, and tsunamis (Alongi, 2008; Barbier, 2012; Cochard et al., 2008; Danielsen et al., 2005; Kathiresan and Rajendran, 2005; Vermaat and Thampanya, 2006). In addition, mangroves support aquatic life and food chain through the formation of habitats for marine fauna, which include offshore fish, reef fish, juvenile crabs, prawns, and larvae (Cannicci et al., 2008; Mumby et al., 2004; Nagelkerken et al., 2008; Naylor et al., 2000; Primavera, 1997). Mangroves are also important for sequestering carbon (known as blue carbon) in highly organic soil and roots that is mainly stored below ground (Chmura et al., 2003; Donato et al., 2011; Lovelock, 2008). Thus, mangroves play an important role in preserving stored carbon and protecting coastal ecosystems.

Unfortunately, mangroves are being lost worldwide due to anthropogenic and natural disturbances. Studies have shown that high demand on shrimp industry resulted in significant loss of mangroves in the Asian countries, and consequentially, environmental tragedies occur in coastal areas due to loss of protection they provide to the environment (Primavera, 1997). Nearly one-third of the world's mangrove forests have been lost to deforestation over the last 50 years (Alongi, 2002), with a decline rate estimated greater than or equal to that of terrestrial tropical forests and adjacent coral reefs (Duke et al., 2007). There are other causes of mangrove losses too, such as tsunamis, cyclones, and global warming. The greenhouse gas emissions of the stored blue carbon from coastal soils into the atmosphere as a derivative impact of deforestation and degradation of mangroves along shorelines may contribute in the short-term changes of climate. Hence, it is essential to preserve the remaining mangroves and prevent further loss of this precious coastal ecosystem from natural and man-made disturbances by involving mangrove conservation management strategy in climate mitigation programs (e.g., the Ramsar Convention on Wetlands, Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Blue Carbon) (Kuenzer et al., 2011; Mcleod et al., 2011; Pendleton et al., 2012). To support such climate mitigation program, it

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is crucial to utilize an efficient system in collecting and retrieving updated information on mangroves forest status and their spatial distribution to assist in policy and decision making.

Remote sensing studies on mangrove forest stand attributes are very important because they can help us understand the details and successional changes in production and competition within mangrove ecosystem as well as predict future change due to climate change and overall to manage this ecosystem in a sustainable manner (Komiyama et al., 2008). Currently, the majority of satellite-based studies of canopy height were based on Shuttle Radar Topographic Mission (SRTM) data collected in 2000 (e.g., Aslan et al., 2016; Fatoyinbo and Simard, 2013; Kellndorfer et al., 2004; Simard et al., 2008). However, the potential of using recent remote sensing data from other type of sensor to study canopy height has been pointed out by Heumann (2011). Fortunately, since 2015 the Japan Aerospace Exploration Agency (JAXA), released a free-of-charge product of ALOS PRISM, called the ALOS World 3D–30 m Digital Surface Model (AW3D30 DSM), to be globally available (Tadono et al., 2014). The ALOS PRISM images used to create AW3D30 datasets were collected in the period between 2006 and 2011. The AW3D30 DSM data were produced using stereophotogrammetric techniques with vertical accuracy of ~5 m (Tadono et al., 2014), which is even better than ~10 m height accuracy of SRTM. Even though ASTER Global DEM (GDEM2) data is also freely available with similar 30 m spatial resolution, a recent study demonstrated that GDEM2 data have poor vertical accuracy (~12 m) compared to AW3D30 and SRTM data when examined to 5 different land cover types (Santillana et al., 2016). Therefore, ASTER GDEM2 data is less suitable for tree height estimation studies.

Numerous remote sensing studies have been conducted to inventory, monitor, and map threatened areas of mangrove ecosystems (see Kuenzer et al., 2011; Heumann, 2011); however, to our knowldege, there is no published study yet in examining the utility of AW3D30 of ALOS PRISM product for estimating mangrove height, including studies about their succesion stages (maturity). Therefore, the objective of this study was to examine the reliability of extracting canopy heights at different succesion stages of mangroves derived from AW3D30 DSM data using canopy height model developed in Aslan et al. (2016) in three locations. The three study locations vary in latitudinal positions and mangrove degradation levels, ranging from relatively pristine (Mimika and Sundarbans) to severely degraded mangrove ecosystems (Mahakam Delta).

2. Study area

The study was carried out in three locations to better understand the potential use of the AW3D30 DSM data for characterizing and mapping mangroves with a broad range of conditions. Mangroves in our three study sites also contain a variety of structures associated with different tree species composition, growth stages, and forms.

2.1. Mimika

The southern coast of Indonesian Papua contains some of the largest contiguous pristine mangrove forests on Earth (Fig. 1). An estimated 186,291 ha of mangrove forest covers the coastal lowlands of Mimika, a southern district of Papua Province, Indonesia (Aslan et al., 2016). The Mimika coastal plains are characterized by extensive swampy areas spreading from the coast in a northeast direction with mountains rising abruptly from the edge of the plains. The swamps are interconnected into narrow catchments by some north-south parallel rivers flowing from the mountains to the sea. The tidal range is between 3.3 and 3.6 m and influenced by a diurnal to semidiurnal patterns (Ellison, 2005). The dry and wet seasons are not clearly separable, but the southeast monsoons typically increase rainfall from June to mid-September (Pouwer, 1970). There are 20 mangrove species representing 6 major groups (*Avicennia sp., Bruguiera sp., Camptostemon sp., Ceriops sp., Sonneratia sp., and Rhizophora* sp.) growing in Mimika forest which accounts for half of the total 43 mangrove species reported in Papua and New Guinea (Duke et al., 1998).

2.2. Sundarbans

The Sundarbans mangrove forest is located in the southwest of Bangladesh and was listed by UNESCO in 1997 as a World Heritage Site. It is a Ramsar Site, one of the largest contiguous relatively intact mangrove forests in the world and covers approximately 140,000 ha on the Bay of Bengal (Fig. 1). The Sundarbans forest is mainly divided into two areas. The largest part covers nearly two-thirds of the forest. The other third consists of rivers and creeks with high seasonal variation in their discharge. The ground surface of the Sundarbans forest is very flat with maximum ground elevation only 3 m above average sea level with tidal height variation from 2 m to 6 m. The salinity gradient of the Sundarbans soils is also varied and show decreasing pattern from west to east. Soil salinity in the region has been classified into three salinity zones: less saline ($< 2\,dSm^{-1}$), moderately saline ($2–4\,dSm^{-1}$), and heavily saline ($> 4\,dSm^{-1}$) (Siddiqi, 2001). The typical subtropical climate of Sundarbans is characterized with an average 1800 mm of annual rainfall occurring between May and October with summer temperatures vary from 18.50 to 35.20 °C and between 12.20–28.80 °C in winter, respectively (Siddiqi, 2001). There are 30 species representing 22 families of mangroves growing in Sundarbans forests. The majority of these species including *Heritiera fomes, Nypa fruticans, Bruguiera gymnorrhiza, Rhizophora apiculata, Rhizophora mucronata, Xylocarpus granatum, and Xylocarpus .mekongensis* (Iftekhar and Saenger, 2008).

2.3. Mahakam delta

The Mahakam Delta of East Kalimantan Province, Indonesia covers an area of approximately 110,000 ha (Fig. 1). The delta consists of 46 small islands separated by narrow channels. According to Schmidt-Fergusson climate classification system, the delta belongs to type A climate (tropical rainforest) with minimum temperature ≥18 °C and rainfall of the driest month in typical year ≥60 mm (Peel et al., 2007). The dry season falls between May and January, whereas the rainy season begins in December until April, with dominant western and eastern monsoon. Similar to Mimika site, tide records in Mahakam Delta show diurnal and semidiurnal patterns, but relatively low in the tidal range, i.e., about 2.5 m height (Zain et al., 2014). Initially, Mahakam Delta comprised of four vegetation zones, namely the perennial tree of lowland tropical forest near the apex, palm tree mixed with lowland forest, Nypa and swamp forest in the central areas, and mangroves in the near shore areas (Allen and Chambers, 1998). However, since the late 1980′s, mangroves in the delta has experienced massive land clearing due to shrimp/fish ponds development which leads to severely degraded mangrove ecosystem (Bosma et al., 2012; Dutrieux et al., 2014). In addition to mangrove ecosystem, small patches of seagrass beds and coral reef ecosystems exist beneath the coastal waters.

3. Materials and methods

3.1. Defining study area boundary

Defining the boundary of the study sites is necessary before producing mangrove canopy height map and conducting further analysis in each study sites (Fig. 1). For Mimika, we used the mangrove boundaries published in Aslan et al. (2016), whereas for Sundarbans, we used a geographic information systems (GIS) shapefile of mangrove boundary that was based on forest inventory data published in Revilla et al. (1998). For Mahakam Delta, we used land cover map of 2015 derived from SENTINEL-1A data as the study site boundary (Aslan, 2017). This