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Sensitivity of the backscatter intensity of ALOS/PALSAR to the above-ground biomass and other biophysical parameters of boreal forest in Alaska

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Abstract

We investigated the potential of ALOS/PALSAR for estimating the above-ground biomass (AGB) and other biophysical parameters (tree height, diameter at breast height (DBH), and tree stand density) in the boreal forest of Alaska. In July 2007, forest surveys were conducted along a south–north transect (150°W) to profile the ecotone from boreal forest to tundra in Alaska. *In situ* parameters were measured in 29 forests by a combination of the Bitterlich angle-count sampling method and the sampled-tree measuring method. These *in situ* values were compared with the backscatter intensity of ALOS/PALSAR. A strong positive logarithmic correlation was found between the backscatter intensity and the forest AGB, with the correlation being stronger in the HV than in the HH polarization mode. No obvious saturation was found in the sensitivity of the HV mode backscatter intensity to the forest AGB up to 120.7 Mg ha^{-1}. Similarly, a robust sensitivity was found in the HV backscatter intensity to both tree height and DBH, but weak sensitivity was observed for tree density. The regression curve of HV backscatter intensity to the forest AGB appeared to be intensified by the uneven forest floor, particularly for forests with small AGB. The geographical distribution of the forest AGB was mapped, demonstrating a generally south-rich and north-poor forest AGB gradient.

Keywords: Synthetic aperture radar (SAR); Bitterlich method; Ecotone; Black spruce; White spruce; Allometry equation

1. Introduction

To better understand the global biogeochemical cycle, determining spatiotemporal variations in the carbon stock stored in forest biomass is important. The 10-year implementation plan (Group on Earth Observations, 2005) of an international framework, the Global Earth Observation System of Systems (GEOSS), stressed that terrestrial biomass is as an essential climate variable and a basic vegetation parameter of ecosystem structure and function. Forest biomass in Northern Hemisphere temperate and boreal forests was estimated to contain a carbon pool of roughly 61 Pg C, according to an analysis of satellite remote sensing data (Myneni et al., 2001), indicating that such forests play a major role in the global carbon cycle.

As summarized by Lu (2006), satellite-borne optical sensors and microwave radars are invaluable tools for

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retrieving forest above-ground biomass (AGB) data and mapping geographical distributions. Myneni et al. (2001) estimated the forest AGB in the Northern Hemisphere using normalized difference vegetation index (NDVI) data for the 19 years from 1981 to 1999, derived from observations of Advanced Very High-Resolution Radiometers (AVHRRs) on NOAA satellites. Chopping et al. (2008) estimated and mapped the distribution of the woody AGB in southeastern Arizona and southern New Mexico, USA, based on multi-angle optical reflectance data observed by the NASA Multi-angle Imaging Spectro-Radiometer (MISR) onboard the Terra satellite.

Recently, there has been growing interest in the use of microwave synthetic aperture radar (SAR) to estimate AGB. SAR transmits a microwave pulse to the Earth's surface and receives the backscattered signal that is determined by the surface and includes information regarding the land surface structure such as forest characteristics (e.g., Ulaby et al., 1986; Belchansky, 2004). Because microwaves are not affected by cloud cover, SAR has the advantage of providing satellite remote sensing in regions of high cloud cover, such as tropical and boreal zones.

The SAR backscatter is characterized by the polarized (horizontal or vertical) combinations of the transmitted and received signals. The "HH" mode indicates the combination of a horizontally (H) polarized transmitted signal and a horizontally (H) polarized received signal. Similarly, "HV" stands for the combination of a horizontally polarized (H) transmitted signal and a vertically polarized (V) received signal. Generally, the sensitivity of the backscatter intensity to the biophysical parameters of land surface vegetation is examined in different combinations of polarized modes.

Many previous studies have investigated the relationship between *in situ* AGB determined by field measurement and the backscatter intensity observed by space-borne or airborne SAR. A stronger correlation to forest AGB has generally been found in HV backscatter than HH backscatter, and in relatively long wavelength microwaves, such as P-band and L-band SARs (e.g., Le Toan et al., 1992; Paloscia et al., 1999; Coops, 2002; Watanabe et al., 2006; Englhart et al., 2011).

A limitation of SAR for estimating the AGB is that the backscatter intensity becomes saturated when the AGB (or above-ground vegetation volume) exceeds a certain critical value, even if HV backscatter intensity is used. For example, Luckman et al. (1997) reported that L-band backscatter showed no further sensitivity when AGB exceeded 60 Mg ha^{-1} in the Amazon tropical forest region, in a study using L-band SAR imagery from the Japanese Earth Resources Satellite (JERS)-1 and Spaceborne Imaging Radar (SIR)-C. Wagner et al. (2003) demonstrated that large-scale mapping of growing stock volume up to about 80 m^3 ha^{-1} was possible over boreal forest in central Siberia, using European Remote Sensing (ERS) satellite −1/2 tandem data and JERS L-band backscatter intensity (HH). Watanabe et al. (2006) found that the backscatter intensity in the HV mode became saturated over 100 Mg ha^{-1} using airborne L-band SAR remote sensing in a boreal forest in northern Japan. Nizalapur et al. (2010) showed that AGB prediction was possible with L-band experimental SAR (ESAR) (airborne) data for AGB up to 150 Mg ha^{-1} and with P-band data for up to 200 Mg ha^{-1} in Gujarat, India.

In January 2006, the Japanese Aerospace Exploration Agency (JAXA) launched the Advanced Land Observing Satellite (ALOS) carrying the Phased Array L-band SAR (PALSAR) (Rosenqvist et al., 2007). PALSAR data have been used to identify tree species in woody plantations in Southeast Asia (Miettinen and Liew, 2011) and to classify land cover in Borneo for monitoring deforestation (Yamagata et al., 2010). The PALSAR orthorectified mosaic product (50-m spatial resolution) over insular Southeast Asia, and a global forest/non-forest map, were also used to monitor changes in carbon quantity originating from forests (*http://www.eorc.jaxa.jp/ALOS/en/index.htm*).

Recently, the AGB of cashew plants in Cambodia was estimated by ALOS/PALSAR and showed a correlation between *in situ* biomass and the HV backscatter intensity which was stronger than the HH mode; however, the intensity saturated at 100 Mg ha^{-1} of AGB (Avtar et al., 2012). The present study used ALOS/PALSAR data to undertake a similar investigation, targeting boreal forest along a south–north transect from boreal forest to tundra vegetation in Alaska. Although previous studies have attempted to estimate and map boreal forest AGB and other biophysical parameters by satellite remote sensing (e.g., Fransson et al., 2001; Wagner et al., 2003; Santoro et al., 2006; Chen et al., 2012), published data remain insufficient, especially for forests in Alaska. In particular, few studies have investigated the sensitivity of the backscatter intensity of ALOS/PALSAR to the AGB and other biophysical parameters in Alaska, where black and white spruce forests are characteristic. Kasischke et al. (2011) investigated the sensitivity of ALOS/PALSAR for forests in Alaska. However only the AGB was examined and the forests