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Polarimetric scattering model for estimation of above ground biomass of multilayer vegetation using ALOS-PALSAR quad-pol data

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ABSTRACT

Forests are important biomes covering a major part of the vegetation on the Earth, and as such account for seventy percent of the carbon present in living beings. The value of a forest's above ground biomass (AGB) is considered as an important parameter for the estimation of global carbon content. In the present study, the quad-pol ALOS-PALSAR data was used for the estimation of AGB for the Dudhwa National Park, India. For this purpose, polarimetric decomposition components and an Extended Water Cloud Model (EWCM) were used. The PolSAR data orientation angle shifts were compensated for before the polarimetric decomposition. The scattering components obtained from the polarimetric decomposition were used in the Water Cloud Model (WCM). The WCM was extended for higher order interactions like double bounce scattering. The parameters of the EWCM were retrieved using the field measurements and the decomposition components. Finally, the relationship between the estimated AGB and measured AGB was assessed. The coefficient of determination (R^2) and root mean square error (RMSE) were 0.4341 and 119 t/ha respectively.

1. Introduction

Forests makeup a major part of the vegetation on the Earth and are home for more than 300 Million people around the world. They account for the major part of carbon present in living beings and occupy about one-third of the Earth's land area, while more than 200 gigatonnes of carbon alone is stored in forests in the form of biomass (FAO, 2012). A forest acts as both a carbon sink and a carbon pool and this role is influenced by many human and non-human activities. For example, FAO (2012) reports an annual total of decline in the forests at the rate of 13 M ha across the globe in the last decade. As a measure of organic matter present in both living and dead vegetation, biomass is considered an important estimate to measure the forest's contribution to the carbon cycle. The biomass of the forests is mainly divided into above ground biomass, which accounts for leaves, twigs, branches and trunks; and below ground biomass, which accounts for roots and litter. Traditional ground based forest inventory techniques like harvesting or field measurements combined with allometric equations are used for monitoring forests (Gibbs et al., 2007). For forests with a wide variety of species and vast coverage, these traditional methods of estimating biomass could be time consuming, tedious and labour intensive.

Meanwhile, optical remote sensing is widely implemented for monitoring the forest cover. Measuring the reflectance from the forest or vegetation, optical remote sensing is dependent on the sunlight, visibility and many other atmospheric parameters. Vegetation indices like NDVI, RVI are more useful in monitoring the vegetation cover rather than the carbon stocks i.e., biomass (Patenaude et al., 2005; Watanabe et al., 2006). Also, LiDAR remote sensing technique which measures the height of the vegetation over the ground can be used directly for biomass estimation along with the allometric equations (Boudreau et al., 2008; Drake et al., 2002).

In contrast to the optical systems, SAR systems have the advantage of all-weather capability and penetration through cloud and canopy (for L and P bands). Therefore, SAR is preferred for the estimation of forests parameters. Previous studies have already shown the potential of polarimetric SAR in the estimation of forest parameters using single and dual polarised SAR data for estimation of AGB (Le Toan et al., 1992; Lo Seen et al., 1998; Mitchard et al., 2009; Morel et al., 2011).

In order to understand the interaction of the microwaves with the vegetation and for the estimation of bio-physical parameters of the vegetation, semi-empirical models like the Water Cloud Model (WCM) (Attema and Ulaby, 1978), and the Michigan

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Microwave Canopy Scattering (MIMICS) model (Ulaby et al., 1988) have been developed. The WCM assumes that the vegetation canopy is a homogenous cloud and that the vegetation matter can be modelled as water droplets over a horizontal ground surface (Attema and Ulaby, 1978). In the WCM, the total forest backscatter was expected to have contributions from the vegetation canopy and the ground, with the energy being attenuated as the wave is transmitted through the layers. Higher order scattering mechanisms like ground stem interaction are not considered, although these are not negligible at longer wavelengths (Richards et al., 1987). A model similar to WCM which includes the scattering through the gaps in the canopy, has been used for the estimation of the stem volume and biomass in the studies by Kumar et al. (2012), Santoro et al. (2003), Cartus et al. (2012) and Santoro et al. (2006). In studies of Tan et al. (2011), Xu et al. (2011), AGB is retrieved using model based decomposition components.

The Orientation Angle (OA) is the angle of rotation of the radar wave with respect to the radar line of sight. Schuler et al., (1996) proposed a method for the measurement of a topographic profile using PolSAR data by determining the shifts in the OA. Lee and Ainsworth (2011) studied the effect of OA shifts on the coherency matrix and the model based decomposition techniques. The radar look angle and variations in terrain slope, distribution and alignment of the scatterers to the radar wave causes a shift in the OA (Lee and Ainsworth, 2011). This OA shift results in an increase of cross-polarisation intensity, which results in an increase of the volume scattering and decrease of double bounce scattering, possibly leading to erroneous estimates of forests biophysical parameters (Lee and Ainsworth, 2011). Elimination of these OA effects would reduce the effect of slope and target alignment. However, polarimetric incoherent target decomposition techniques based on coherency and covariance matrices have been developed for better interpretation of natural and distributed targets, by considering different scattering mechanisms (Boerner and Lee, 2007). In the present study, a decomposition model which was compensated for the OA shifts was utilised for the parameter estimation.

In this paper, we retrieved the AGB of tropical forest ecosystem using fully polarimetric ALOS-PALSAR data. For this purpose, the semi-empirical WCM, extended to include higher order interactions, was implemented on the decomposition components to estimate forest parameters. These decomposition components were compensated for any OA shifts prior to their utilisation in the modelling approach. The forest inventory data collected over the study area was used for the accuracy assessment and validation. This approach will be demonstrated for the Dudhwa National Park tropical forest.

2. Study area and data

The Dudhwa National Park (DNP) in the Northern Indian state of Uttar Pradesh is a part of a highly diverse and productive Terai ecosystem. The park stretches over vast, fertile alluvial plains of the upper Ganges river along the Indo-Nepal border covering an area of 68,032 ha and lies between latitude 28°18′–28°42′N and longitude 80°28′–80°57′E. The DNP is home to diverse flora and fauna supported by the Mohana and Suheli rivers flowing through the northern and southern boundaries of the park. It also forms a part of Dudhwa Tiger Reserve along with the Kishanpur wildlife sanctuary and Katemaighat wildlife sanctuary. The DNP contains one of the finest Sal forests in India, including four different types of forest: the Northern Tropical Semi Evergreen forest, the Northern Indian Moist Deciduous forest, the Tropical Seasonal Swamp forest and the Northern Tropical Dry Deciduous forest (Champion and Seth, 1968). The park includes Sal forests (*Shorea robusta* Gaertn), mixed Sal forests, prominent species like Teak (*Tectona grandis* L.f), Eucalyptus plantations (*Eucalyptus hybrid*), Jamun (*Syzigium cumini* L.), Shisham, and Asidha (*Lagerstroemia parviflora* Roxb.) plantations. By virtue of the well diversified tropical forest (with dense canopies and longer trunks with varied range of biomass estimates), the DNP is a well suited area to identify different scattering mechanisms and to test the present methodology.

3. Data used

ALOS-PALSAR quadrature polarisation data acquired over the DNP on 31 October 2009 with an incidence angle of 25.6° and a swath width of 30 km in ascending mode was utilised for the study. Fig. 1 shows the forest cover map of the DNP generated from Landast ETM+ data based on forest type, agriculture area, wetland, grass land and water resources. The information on the number of plots in each forest type is provided in Table 1.

Fig. 2 shows the locations of the plots where the field data was collected. Forest inventory data consisting of CBH and tree height was collected by the Forestry and Ecology division, IIRS for Dudhwa National Park area. Data was collected during the years 2008-2009, over the 39 site clusters, each consisting of 4 plots and a total of 152 plots, using a stratified random sampling plan. Each plot had an area of 0.1 ha and the AGB was calculated using the allometric equations developed by the Forest Survey of India (FSI, 1996) and Biomass Expansion Factors (BEF) of Chhabra (2002).

4. Methodology

4.1. PolSAR data processing

The complex scattering matrix [*S*] was generated from the PALSAR quad-pol data consisting of amplitude and phase information for all the four channels: *HH* and *VV* subscripts indicate the horizontal and vertical like-polarisation channels, respectively, and *VH* and *HV* indicate the cross polarisation channels, see Eq. (1). The coherency matrix was generated from the vector form of the scattering matrix [*S*] by multiplying Pauli's target vector representation of the scattering matrix k_p (2) with its complex conjugate $k_p^\dagger$ using Eqs. (3) and (4).

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \tag{1}$$

$$k_p = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix} \tag{2}$$

$$T = k_p \cdot k_p^\dagger \tag{3}$$

$$[T] = \begin{bmatrix} \frac{1}{2}\langle |(S_{HH}+S_{VV})|^2 \rangle & \frac{1}{2}\langle (S_{HH}+S_{VV})(S_{HH}-S_{VV})^* \rangle & \langle (S_{HH}+S_{VV})S_{HV}^* \rangle \\ \frac{1}{2}\langle |(S_{HH}-S_{VV})(S_{HH}+S_{VV})^*| \rangle & \frac{1}{2}\langle |S_{HH}-S_{VV}|^2 \rangle & \langle |(S_{HH}-S_{VV})S_{HV}^*| \rangle \\ \langle |S_{HV}(S_{HH}+S_{VV})^2| \rangle & \langle |S_{HV}(S_{HH}-S_{VV})^*| \rangle & 2\langle |S_{HV}|^2 \rangle \end{bmatrix} \tag{4}$$

4.2. Polarisaion Orientation angle shift compensation

In the next step, the coherency matrix generated by Eq. (4) was used to estimate the orientation angle (OA) shifts and was then de-oriented by rotating it to compensate for these shifts. These OA shifts resulted in the increase of volume scattering and in the decrease of double bounce scattering. Therefore, the coherency matrix was de-orientated before decomposition so as to reduce its effects on the final estimates of the AGB. Lee et al., (1999)