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ORIGINAL CONTRIBUTION

Computer vision and SAR image processing techniques for ALOS PALSAR and COSMO-Skymed data in retrieving forest carbon stock

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ABSTRACT

Forest aboveground biomass (AGB) is considered as a driving parameter for formulating global decision making policy targeting the impact of reducing emissions from deforestation and forest degradation (REDD) and climate change. Estimating forest AGB uses integrated geospatial techniques that are computer-based software application to process and analyze remote sensing data with cost and time effective means for accurate temporal monitoring over large synoptic extents at local to global levels in comparison to conventional methods. Synthetic Aperture Radar (SAR) has distinct intrinsic characteristics surmounting the constraints of optical remote sensing sensors. The study proposed optimal regression models for retrieving forest above-ground bole biomass (AGBB) over tropical deciduous mixed forests of Munger (Bihar, India) with synergic use of ALOS PALSAR (L-band) and COSMO-Skymed (X-band) sigma nought images. Coefficient of determination (r^2) of 0.89 and RMSE of 15.12 t/ha were calculated for the best fit integrated model. On validation, the integrated model produced a model accuracy of 78%, r^2=0.89, RMSE=16.64 t/ha and Willmott's index of agreement of 0.934. Resulting modeled AGB were converted to carbon (C) and carbon dioxide (CO_2) equivalents using conversion factors. This study shows that SAR sensors has exceptional capabilities in estimating tropical forest C and regression models are better means to do so. Hence, the study recommends the combined use of L- and X-band SAR for improved assessment of forest stand AGB and C with significant contribution towards operational forestry and policy making.

Key words: Remote Sensing ; Synthetic Aperture Radar ; ALOS PALSAR ; COSMO-Skymed ; Forest ; Biomass ; Carbon

1. INTRODUCTION

Worldwide carbon dioxide (CO_2) concentration exceeded the critical threshold of 400 ppm during 2016 [1]. This so called phenomenon known as '400 ppm World' is permanent not likely to revert back. Carbon (C) is the elementary factor of the global carbon cycle and hence responsible element for the modern climate change. Forests act both as source and sink of C. Among all terrestrial ecosystems, they are the greatest depot of C under natural conditions, while, under distressed conditions, they become large sources of C [2]. Addition of CO_2 in the atmosphere occurs due to several natural and anthropogenic activities. Sequestration of C in the vegetation is the only possible viable strategy in milieu of REDD to maintain the atmospheric C balance [3, 4].

CO_2 released from forests can be enumerated in terms of forest C emission that can in-turn be quantified through the assessment of forest biomass [2-5]. Remote sensing technology provides a reliable, easy, timely, effective and practical way to quantify the forest aboveground biomass (AGB) and C [6]. Optical sensors are frequently used for AGB estimation [3, 7] but they are less sensitive to forest parameters and saturate early, unlike Synthetic Aperture Radar (SAR) sensors [6]. Space-borne and air-borne SAR data are available in X, C, S, L and P bands. Longer wavelength SAR data, like L- and P-bands relate more to the forest biophysical parameters due to their greater penetration capabilities through the vegetation surfaces and are scattered/attenuated by trunk and main

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branches [6]. SAR cross-polarized longer wavelengths with are more sensitive to biomass than co-polarized short wavelengths [6, 8-10].

Integrating capabilities of both optical and SAR can prove beneficial over any single sensor types for AGB assessment [11]. Sarker [12] used integrated multi-sensor optical (SPOT-5 and AVNIR-2) and SAR (PALSAR and Radarsat-2) data for biomass assessment. Sinha *et al.* [11] also showed better biomass assessment with the synergic use of optical (Landsat TM) and SAR (PALSAR) data. Hyde *et al.* [13] used multi-sensor synergy of optical, SAR, InSAR and LiDAR for assessment of AGB and forest structural parameters. However, due to unique intrinsic capabilities, SAR is preferred over optical sensors when considering any single sensor for AGB assessment [6]. Alappat et al. [14] applied synergic model integrating SAR C- and L-bands and Englhart et al. [15] used SAR X- and L-bands for biomass assessment. A detailed review of SAR techniques for biomass estimation is mentioned in Sinha et al. [6].

The current study exploits the potentials of L-band ALOS PALSAR (HH/HV polarized) and X-band COSMO-Skymed (HH/VV polarized) data for AGB and C stock assessment over moist tropical deciduous heterogeneous forests of Munger (Bihar, India).

1. Material and methods

1.1. Study area

Files must be in MS Word only and should be formatted for direct printing, using the CRC MS Word provided. Figures and tables should be embedded and not supplied separately. The study area of tropical deciduous mixed forests of Munger situated in Bihar (India) has geographic coordinates of 25º19'30"N-24º56'50"N latitude and 86º33'33"E-86º11'51"E longitude, covering an area of approx 672.5 square kilometers (km2) has been considered as the test site (Figure 1). Details of the site are mentioned in Sinha et al. [11].

1.2. Data used

The study involves the use of SAR datasets from two SAR satellite sensors, namely, L-band ALOS PALSAR and X-band COSMO-Skymed. The X-band COSMO-Skymed data used in the study is HH/VV dual polarimetric data acquired through PINGPONG imaging mode with 15m spatial resolution and 30km swath width. The L-band ALOS PALSAR data used in the study are Fine Beam Dual (HH/HV) with 25 m spatial resolution and off-nadir angles of 34.3° and swath width of 70 km.

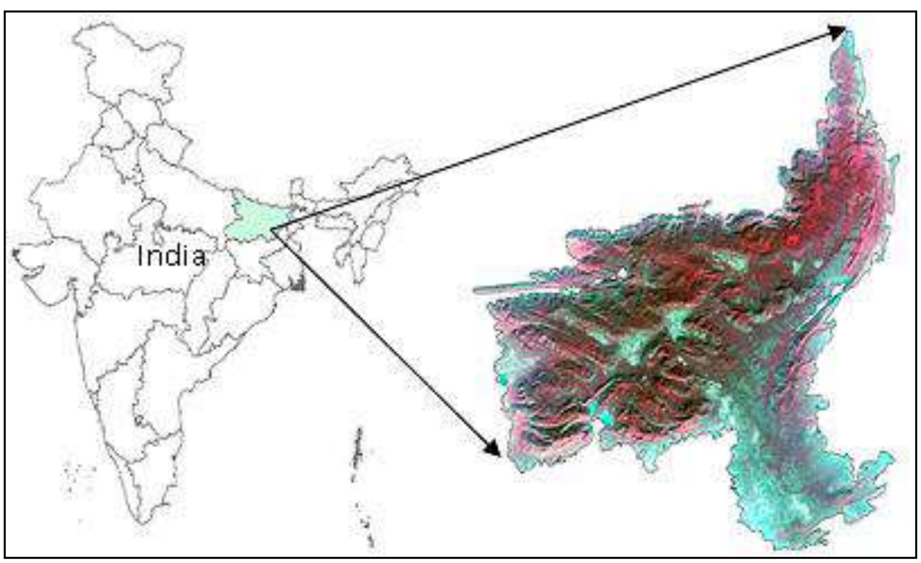

Figure 1: Location of the study area

1.3. Method

The methodology is subdivided into three parts: (a) field based above ground biomass estimation, (b) SAR data processing for extracting backscatter coefficients for predicting the same and (c) regression analysis using estimated and predicted AGB values from steps (a) and (b) respectively.

(a) Field information was generated from 45 random sample plots of 0.1 hectare area regarding forest types, species composition, stand height, and girth at breast height (GBH). Off these 45 sample points, 36 were used for establishing a relation between field-generated AGB and SAR-derived information; while the remaining 9 for model validation. Tree AGB was derived using tree-specific volumetric equation and specific gravity and then summed up to calculate the plot AGB [11].

(b) Raw SAR datasets were preprocessed, rectified, geocoded and calibrated using a series of standard steps in SARscape software to generate the backscatter image as follows [16]:

i) Slant to ground range conversion: The conversion of slant range image to ground range image is necessary to nullify the effect of the slant range distortions, redistributing Single Look Complex (SLC) data in range with equal pixel spacing. This process includes reprojecting SLC data from slant range to a flat ellipsoid surface by the following equation:

$$R_r = ct \div 2\cos\theta_d \quad (1)$$

where, is the ground range resolution, is the depression angle, is the velocity of light and is the pulse duration.

ii) Multi-looking: This technique converts SLC data from complex to real numbers (i.e., power or intensity). The data occurs in complex number format (x+iy), having one real (x) and one imaginary (y) component, representing the SAR signal that requires both the magnitude and phase information. After obtaining amplitude (AMP) data by Eq. 2, it is converted to power image by Eq. 3. The resultant image obtained through the following equations, is a floating point image representing the power of an amplitude image and its pixel values have real values.

$$AMP = \sqrt{x^2 + y^2} \quad (2)$$

$$Power = (AMP)^2 \quad (3)$$

Each of these looks is subjected to speckle, however, multi-looking reduces the speckles by summing and averaging the looks together to form the final output image however, at the expense of spatial resolution. The number of looks varies depending on the sensor and different pixel sampling in different incidence angles. It is 3:1 and 4:1 for COSMO-Skymed and ALOS PALSAR in Azimuth:Range respectively.

iii) Geocoding: The satellite data immediately after acquisition is not planimetrically true to the ground features and hence, it has to be rectified to remove the geometric errors using geocoding. Geocoding was carried out using the orbital parameters of the respective satellites with SRTM DEM resampled by nearest neighbourhood method to 25m pixel size; re-projected to UTM-WGS84 coordinate system using the Range-Doppler Approach for terrain correction.

iv) Radiometric calibration: Sigma nought (σ°) is a term for representing backscattering coefficient that is defined with respect to the nominally horizontal plane [16]. The calibrated value was transformed into db units by applying 10*log10. The following equation (Eq. 4) was used to calibrate backscattering coefficient, in terms of σ°, obtained in dB:

$$\sigma^0 = 10 \times a\log 10(DN) + A_0 \quad (4)$$

where, σ° = backscatter coefficient or sigma nought values in decibels (dB), DN is the power (or intensity) image, A_0 is the calibration factor that vary with sensor type.

(c) SAR backscatter values were regressed to the field-based AGB values to find the best fit model for calculating AGB. The field-based estimated AGB was correlated with modeled AGB for 9 additional random points for validation of the best-fit model. The model performance was evaluated based on coefficient of determination (r^2), Root Mean Square Error (RMSE), Slope, Average Absolute Accuracy (ς) and Willmott's index of agreement (d) [11]. Resulting modeled AGB (in t/ha) were converted to carbon (C) and carbon dioxide (CO_2) equivalents using conversion factors of 0.5 and 3.67 respectively [2].

2. RESULTS AND DISCUSSIONS

SAR polarization signals are sensitive to physical characteristics of the scattering objects on ground resulting to depolarization or attenuation of the backscattered signals. Backscatter values from Fine Beam Dual (HH/HV) ALOS PALSAR correlated to plot AGB resulted in a logarithmic relationship for the best-fit model with R^2 values of 0.849 and 0.564 respectively for HH and HV polarizations. Hence, for L-band, HH polarization showed greater interactions with the vertical structured trunk and main stem; thereafter revealing greater sensitivity towards the bole AGB. The range of backscatter values in forested areas was between −25dB and −7dB for HV polarization, which was higher than the range exhibited by HH polarization (i.e., −14dB to −1dB). HH backscatter had greater correlation to the field AGB, hence was used as an input for the integrated model.

Likewise, backscatter values from dual polarized (HH/VV) COSMO-Skymed correlated to plot AGB resulted in a logarithmic relationship for the best-fit model with very low R^2 values of 0.012 and 0.02 respectively for HH and VV polarizations. Hence, for X-band, VV polarization showed greater interactions with the canopy top. The range of backscatter values in forested areas was between −17dB and −5dB for HH polarization, which was higher than the range exhibited by VV polarization (i.e., −12dB to −3dB). VV backscatter had greater correlation to the field AGB, hence was used as an input for the integrated model.

Synergic model was developed using only those plots among the total 36 that were found in both the SAR datasets. The synergic regression model (Eq. 5) was designed using Multiple Linear Regression (MLR) analysis using inputs from both L-band HH polarization and X-band VV polarization data.

$$AGB = 88.5 * e^{\left(0.04 * \sigma^{o}_{X\_VV}\right)} + 988.3 * e^{\left(0.27 * \sigma^{o}_{L\_HH}\right)} - 53.1 \quad (5)$$

The accuracy in predicting AGB from the final synergic model was calculated. A coefficient of determination (r^2) of 0.89 and RMSE of 15.12 t/ha was calculated for the model. Validation of the model with additional 9 sample plot AGB data resulted in r^2 value of 0.89, RMSE of 16.64t/ha, slope of 0.905, model accuracy of 78% and Willmott's index of agreement of 0.934. Slope values nearing 1 suggest absence of over or under-estimation; while 'd' values nearing 1 imply that the modeled values fit the observed values better, and hence, shows greater agreement of the model. Eq. 5 was used to generate the AGB map in GIS platform.

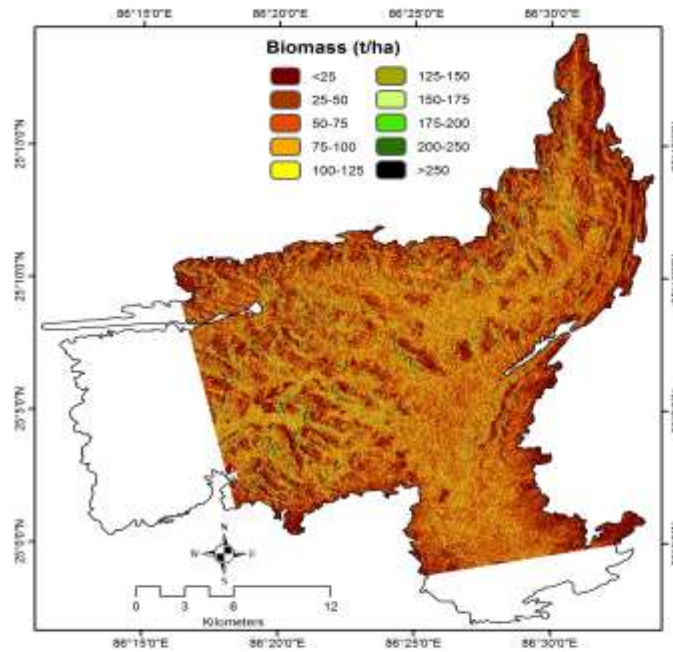

Figure 2: AGB spatial map

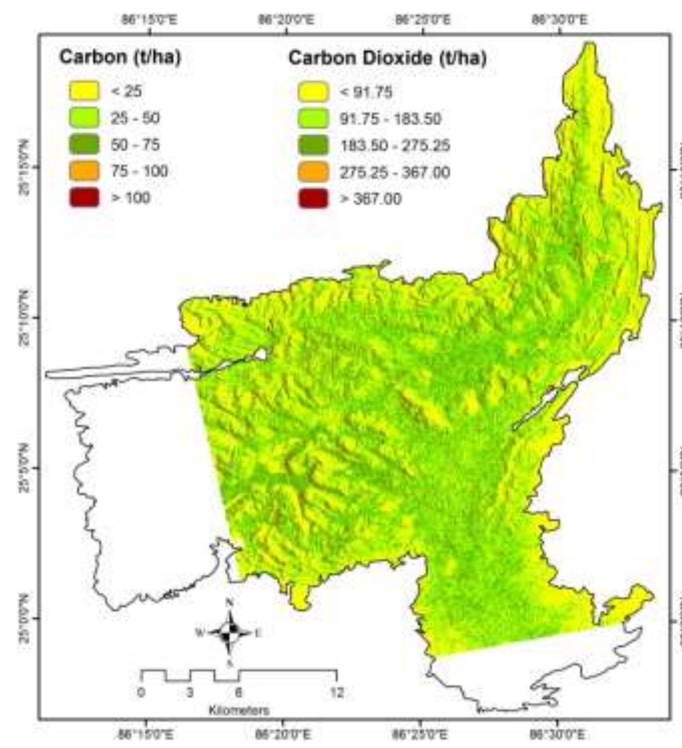

Figure 3: C and CO2 spatial maps

3. CONCLUSIONS

An optimal synergic regression model was developed for accounting forest biomass and carbon stocks from ALOS PALSAR and COSMO-Skymed SAR data over tropical deciduous mixed forests of Munger (Bihar, India). The AGB model produced a reliable accuracy of 78%, with moderately high correlation, and low RMSE. The modeled values fitted with the observed values, showing greater agreement and acceptability of the model. The combined use of both L- and X-band data in the analysis was justified as it produced far better results in comparison to the single use of the data. Resulting modeled AGB were converted to carbon and carbon dioxide equivalents using respective conversion factors. Average AGB, C and CO_2 was calculated to 33, 16.5 and 60.55 t/ha respectively. Hence, total CO_2 emission from the forest accounts to 28.46 lakh tonnes. The unique multi-frequency SAR combined approach adopted in the study gave valuable information of the spatial distribution and quantification of the forest biomass and carbon; important for REDD monitoring.

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