MONITORING FOREST ABOVE-GROUND BIOMASS OF GUJARAT STATE USING MULTI-TEMPORAL SYNTHETIC APERTURE RADAR DATA

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ABSTRACT

Synthetic Aperture Radar (SAR) data has shown great potential in retrieval of forest above-ground biomass (AGB) due to the capability of SAR to provide more dynamic range for vegetation growth variables as compared to optical data. Estimations of forest AGB of Gujarat state was carried out for multiple years using C-band Radar Imaging Satellite-1 (RISAT-1) and L-band Advanced Land Observing Satellite Phased Arrayed L-band Synthetic Aperture Radar (ALOS-PALSAR 1/2) data. In the present study, topographically corrected Medium Resolution ScanSAR (MRS) data of Indian RISAT-1 acquired during 2015-16 and global SAR mosaic products in HH/HV polarizations produced from Japanese ALOS-PALSAR 1/2 data for the years 2007-10 and 2015-16 were used to retrieve temporal forest AGB of Gujarat through semi-empirical model based on multi-linear regression coefficients of HH and HV polarization backscatter with field measured forest biomass. Gujarat has four major forest types namely, (1) tropical moist deciduous forest, (2) littoral and swamp forest, (3) tropical dry deciduous forest and (4) northern tropical thorn forest. Different model coefficients were derived for these forest types based on extensive ground measured forest parameters and the biomass maps of Gujarat were generated. High correlations were observed between $\gamma°HV$ and $\gamma°HH/HV$ with field measured biomass over different forest vegetation types with biomass densities ranging from 20-120 t/ha. The study has also presented the advantages and limitations of C and L-band SAR data for estimation of forest AGB with varying biomass densities and has demonstrated how selection of suitable observation period of SAR data enhances retrieval of AGB of deciduous forests.

1.0 INTRODUCTION

Accurate measurement of vegetation biomass of forests and monitoring the changes in biomass is important for forest conservation and assessment of carbon stock and carbon fluxes from the forest ecosystems. In India, periodic estimation of forest above-ground biomass (AGB) in regional to national level has been a long standing requirement as the country is gearing up for implementation of UN's REDD+ programme (MOEFCC, 2014). There have been efforts to produce estimates of forest AGB at local levels by many using satellite remote sensing technology (Roy and Ravan, 1996; Nizalapur et al, 2010; Bijalwan et al., 2010; Kumar et al., 2012; Suresh et al., 2014; Hamdan et al., 2014; Kiran Chand et al, 2016). However, estimation of forest AGB at state level or national level and production of forest above-ground biomass maps of India are still at a nascent stage (Lu et al. 2014; Salunkhe et al., 2016; Sinha et al., 2016).
Synthetic Aperture Radar (SAR) data has shown great potential in retrieval of forest AGB due to the capability of SAR to provide more dynamic range for vegetation growth variables as compared to optical data. SAR signals in shorter wavelengths (such as X and C-band) are mostly scattered from the upper canopy layers of forest vegetation, and show saturation at higher levels of biomass associated with dense canopy. Hence SAR data in shorter wavelengths are reported to be sub-optimum for forest AGB estimation especially in the tropical regions where biomass densities are higher than the reported C-band saturation limits. On the other hand, longer wavelength signals (such as L and P-band) have ability to penetrate deeper inside the vegetation canopy and produce more sensitivity to the biomass of higher densities, hence are widely used for retrieval of forest AGB (Imhoff 1995; Pulliainen et al., 1996; Harrel et al., 1997; Rauste et al.,2005; Mohan et al., 2011; Huang et al., 2015). Several methodologies for biomass estimation have been reported in recent literatures (Austin et al., 2003; Kuplich et al., 2005; Hajnsek et al., 2009; Saatchi et al., 2011; Cartus et al., 2012; Carreiras et al., 2012; Hame et al., 2013; Suzuki et al., 2013) but no method has been projected to be robust for national level biomass estimation, especially for a country like India. There is also no clear view on how carbon pools and their fluxes should be reported and what the accuracy and uncertainty of biomass monitoring might be (Avtar *et al.,* 2013). Therefore, biomass mapping has become an urgent need to assess and produce data on forest carbon stocks and the change in these stocks at a national level. In the present study, C-band SAR data from Indian RISAT-1 and L-band SAR data products from Japanese ALOS PALSAR have been used to estimate temporal forest AGB of Gujarat state.

2.0 STUDY AREA AND DATA USED

Gujarat state of India has been considered for the present study (Figure 1). The state has vast grasslands and scrub forests in Kachchh, Central Gujarat and Saurashtra regions while coastal ecosystems such as mangroves, coral reefs and sea grasses are located in western parts of the state. Further, saline deserts are located in the north while moist deciduous tropical forests are found in southern areas. The hilly forests are found in eastern parts and Saurashtra regions. According to the estimate by the Forest Survey of India (FSI) for the year 2015, forest area of Gujarat is 21664.99 km^2 of which 14837.6 km^2 area is reserved forest, 2888.85 km^2 is protected forest and 4388.98 km^2 area is unclassified forest. This Constitutes 11.05% of the geographical area of the state (FSI, 2015).

As per the Champion and Seth classification system, out of 16 major forest types found in the country, following four main types of forest ecosystems are found in Gujarat (Gujarat forest department, https://forests.gujarat.gov.in/):
1.Tropical Moist Deciduous Forests (Type 3B): These forests are found in the southernmost part of the state in the districts of Surat, Valsad and Dangs. These forests form the main source of commercial timber in the state. Teak, Haldu, Sisam, Khair, Katas, Manvel etc. are the main species of these forests.
2. Littoral and Swamp Forests (Type 4B): These mangrove forests are distributed over 15 districts of the State and are represented by 15 mangrove species. However, more than 85% of the mangrove forests are represented by a single species i.e. *Avicenna marina*.
3. Tropical Dry Deciduous Forests (Type 5A): These forests are found in the central part of the state in the districts of Bharuch, Vadodara, Panchmahals, Sabarkantha and parts of Saurashtra in the districts of Amreli, Junagadh and Jamnagar.
4. Northern Tropical Thorn Forests (Type 6B): These forests are found are found in districts of Banaskantha, Rajkot and parts of Bhavnagar, Junagadh and Kachchh. These forests contain sparse and stunted growth of species like Acacia and thorn bushes etc.
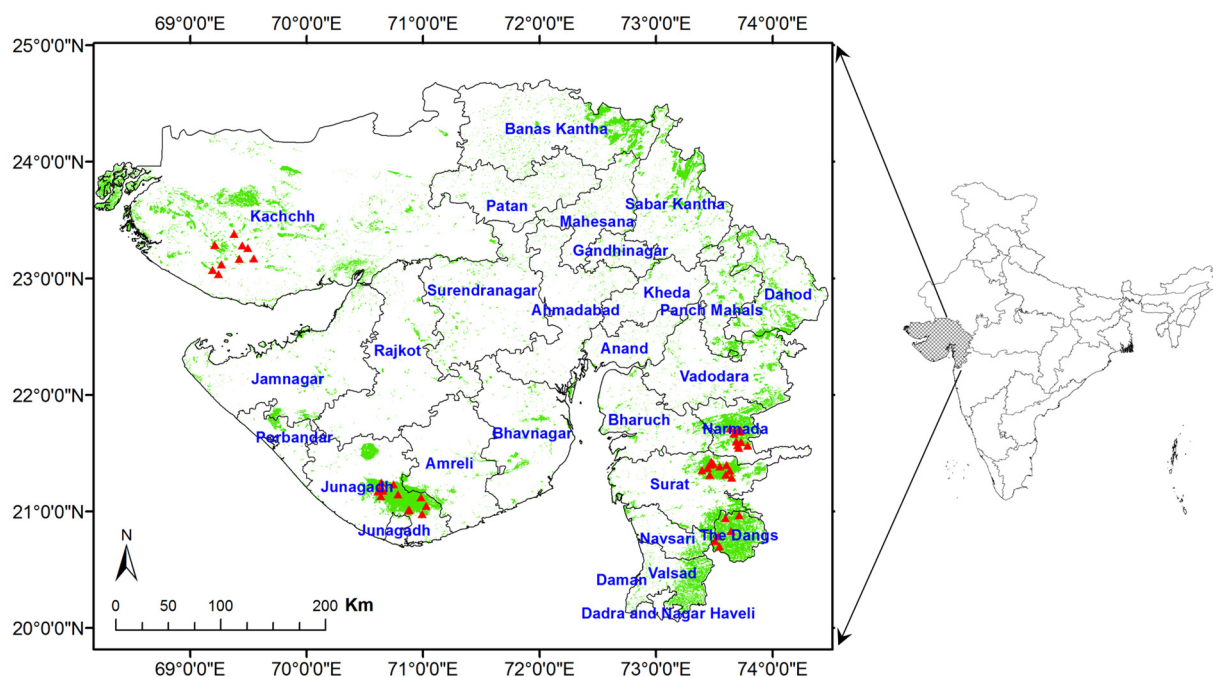

Figure 1: Map of Gujarat showing locations (in red triangles) of ground data collection. Green colour on the image shows 'forest mask' generated from SAR and optical satellite data

2.1 Data Used

The study was carried out using C-band SAR data from Indian RISAT-1 and L-band SAR data from Japanese ALOS-1/2 PALSAR-1/2. For L-band SAR data, global mosaics of ALOS PALSAR HH and HV polarization data generated at 25m spatial resolution were used (Shimada et. al., 2014). Digital Elevation Model (DEM) data of SRTM 30m (resampled to 25m) was used for topographic correction of SAR data. Forest inventory data over several sample plots of 0.1 hectare (ha) distributed over different forest types of Gujarat were collected for ground-based estimation of forest biomass over the sampled plots, which were used for development of biomass retrieval models. Details of SAR data used are given below in Table 1.

Table 1: Details of SAR data used in the study

SAR Data /Product	Sensor / Frequency band	Date of Observation	Polarization	Central Incident Angle	Pixel spacing
Level-2 Multi-look Geocoded product	RISAT-1 / C-band	Multi-date data acquired during Mar-Apr in 2015 and 2016	HH+HV (Medium Resolution ScanSAR data)	36.5°	18m (resampled to 25m)
25m global mosaic product	ALOS PALSAR-1/2 / L-band	Multi-date data acquired during May - Sep in 2007, 2008, 2009, 2010, 2015 and 2016.	HH+HV (Fine Beam Dual-pol data)	34.3°	25m

3.0 METHODOLOGY

3.1 Field Data
Forest inventory data including vegetation allometric parameters over 48 sample plots on 0.1ha size distributed over different forest types of Gujarat as described in section 2.0 were collected through ground measurements during 2015-16 (Figure 1). The above-ground dry biomass (AGB) of each of the inventoried forest patches of 0.1ha was computed using species specific local allometric equations (FSI, 1996).

For the calculation of ground measured biomass, species specific local volumetric equations developed by the Forest Survey of India (FSI) were used to estimate volume of each inventoried tree of trunk diameter greater than 10cm. Then the biomass of each inventoried tree was calculated by multiplying the specific gravity of the tree species (available in literature) with its volume. The tree species, for which volume equations were not available, area specific generalized volume equation and generalized wood density recommended by the FSI, were used.

The plot level biomass was calculated as sum of biomass of each tree with stem diameter of 10cm or above. Finally, the above-ground biomass was estimated over a hectare of land (in ton/ha or t/ha) by multiplying biomass expansion factor (as described below) into the plot level biomass.

The Biomass Expansion Factor (BEF) is the ratio of above-ground oven dry biomass of trees to oven-dry biomass of inventoried volume and is defined by (IPCC 2006):

$$
\begin{aligned}
\text{BEF} \quad &= \text{Exp} \, (3.213 - 0.506 \times \ln{(BV)}) \quad &\text{- for BV} < 190 \text{ t/ha} \\
&= 1.74 \quad &\text{- for BV} \geq 190 \text{ t/ha}
\end{aligned} \right\} \tag{1}
$$

Where, BV = biomass of inventoried volume in t/ha, calculated as the product of tree volume per hectare and wood density (t/m^3). These biomass values were used for development of biomass inversion models for estimation of biomass over unknown regions.

3.2 Satellite Data Analysis
RISAT-1 MRS level-2 geocoded products in HH and HV polarizations were integrated to form mosaic image of Gujarat state and the image was resampled to 25m pixel spacing from original pixel size of 18m. The digital numbers (DN) of SAR intensity data was converted to Normalized Radar Cross section (NRCS or gamma-0) data (in dB) using the following equation,

$$\gamma^0 (dB) = 10 \times \log_{10}(DN)^2 + CF \tag{2}$$

where CF is the calibration factor provided for each polarization data in the metadata file.

The backscatter data were topographically corrected with SRTM 30m DEM (resampled to 25m) as per the method shown in Das et al., 2014. The data is then processed for speckle reduction using adaptive filter (enhanced Lee) of 5×5 kernel size.

Similarly, ALOS-1/2 PALSAR-1/2 HH & HV dual polarization data in 25m pixel spacing was downloaded from Japan Aerospace Exploration Agency (JAXA), Earth Observation Research Centre (EORC) site. The pre-processing of PALSAR 25m mosaic data was done with the terrain corrections methodology suggested by Shimada 2010 to minimize the topographic effects on PALSAR data in the hilly areas. The PALSAR 25m mosaic data were ortho-rectified using the SRTM DEM 30m to correct the topography. The SRTM DEM with 30m pixels were resampled to 25m using bi-linear interpolation. The DN values of PALSAR image were converted to normalized backscatter values using the following equation (Shimada et al., 2009),

$$\gamma^0 (dB) = 10 \times \log_{10}(DN)^2 - 83 \tag{3}$$

where -83 is the calibration factor for PALSAR dual-polarization data.

The RGB colour composite images were generated from RISAT-1 MRS and ALOS-1 PALSAR images by stacking HH, HV and HH/HV backscatter images in red, green and blue planes, respectively (Figure 2).The HH/HV ratio (intensity ratio in normal scale or γ^0(HH-HV) in logarithmic scale) is a good descriptor of non-volume scatterers and separates the vegetation from other features in a SAR image. For both the datasets, study area mosaics were prepared by joining different images acquired on different dates. The variations in image radiometry due to this have not been considered for this study; however, care has been taken to acquire the adjacent images as close in time as possible.
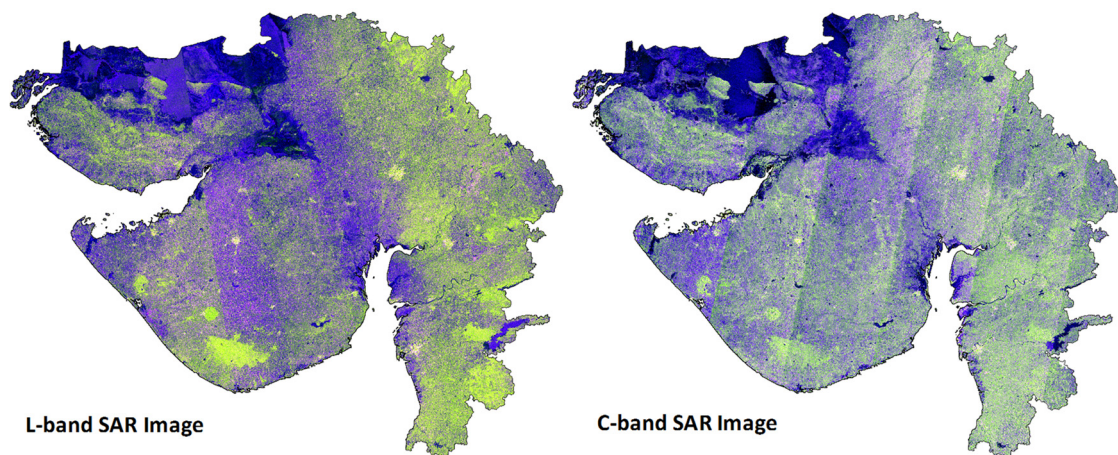

L-band SAR Image

C-band SAR Image

Figure 2: L-band (ALOS PALSAR-2) and C-band (RISAT-1) mosaic image of Gujarat generated from SAR images acquired during 2016. (FCC Image: γ°_{HH}; γ°_{HV}; $\gamma^\circ_{(HH-HV)}$ in R,G, and B planes, respectively).

3.3 Statistical Analysis

Multi-linear regression (MLR) analysis using the stepwise forward method was conducted relating the backscatter (γ^0) of SAR data to the corresponding field estimated biomass. It was used to analyze the relationship between the dependent variable (field estimated forest biomass) and the independent variables (SAR backscatter). The size of the sampling window was 3×3 pixels. Average value of 3×3 pixels of PALSAR data around the sampling plots were calculated to minimize spatial variability and satisfy the normal distribution based on spatial homogeneity. MLR model coefficients were developed based on field measured biomass and SAR backscatter for all the forest types in Gujarat. These MLR models were applied on the RISAT-1 and ALOS-PALSAR mosaic data to estimate the biomass of Gujarat. The detailed methodology is shown in the flow diagram (Figure 3).
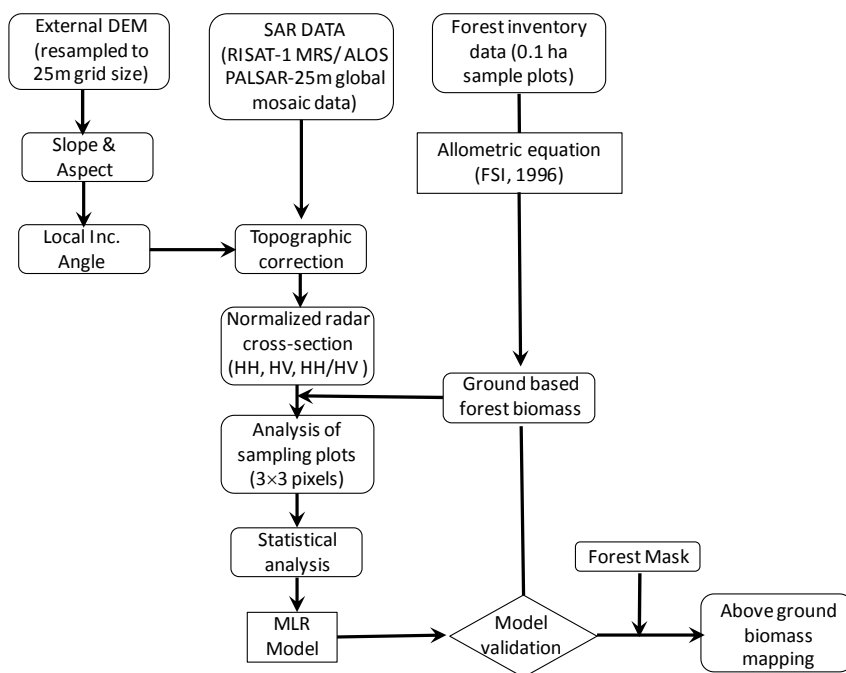

Figure 3: Flow diagram showing methodology for above ground biomass estimation.

4.0 RESULTS AND DISCUSSION

Time series data from RISAT-1 MRS acquired over Gujarat were studied for temporal relationship between SAR backscatter and field measured biomass (Figure 4). It was observed that due to distinct leaf-on (or wet season) and leaf-off (or dry season) period associated with the phenology of deciduous forests, SAR backscatter in HH and HV polarizations showed 2-3 dB lower values, yet higher dynamic ranges over vegetation during the leaf-off period spanning from December to April, as compared to the leaf on period. The effect was however, more prominently observed in HV polarization data than in HH polarization data, in C-band. That indicated, SAR data acquired during leaf-off period had higher sensitivity to wood biomass and could raise the biomass saturation levels and hence was more suitable for biomass estimation.
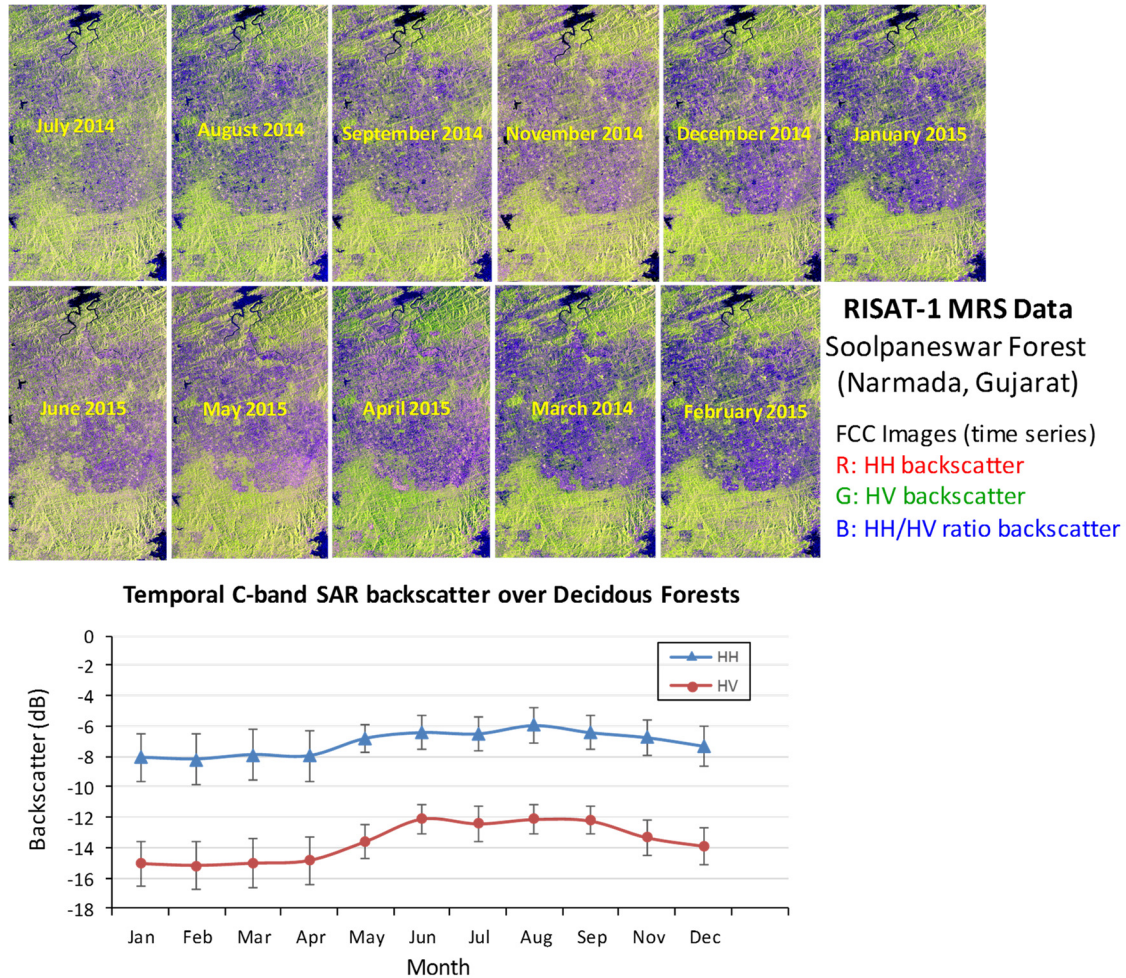

Figure 4: (Top) RISAT-1 MRS time series images over a part of mixed deciduous forest in Gujarat; (Bottom) Average temporal backscatter in C-band HH and HV polarizations observed over deciduous forests in Gujarat. The vertical bars show standard deviations.

SAR backscatter in C- and L-bands was plotted against field measured biomass over different forest vegetation types in Gujarat as shown in Figure 5. Field measured biomass showed significant relationship with the γ^0 HV ($R^2 = 0.63$ for C-band and 0.76 for L-band) as compared to γ^0 HH ($R^2 = 0.55$ for C-band and 0.44 for L-band) over all forest vegetation types in Gujarat. It was observed that the correlation between SAR backscatter and biomass improved when individual vegetation types were considered for analysis. Similarly, a significant relationship ($R^2 = 0.55$) was also observed between cross-polarization ratio γ^0(HH-HV) and field measured biomass in L-band. However, in C-band, the correlation between γ^0(HH-HV) and field measured biomass was not good ($R^2 = 0.30$). The reason for higher correlation of γ^0HV than γ^0HH with biomass is that the volume scattering in forest areas enhances the cross-polarization returns with the increase in biomass. Few studies have reported that the γ^0HV is more sensitive to forest biomass compared to γ^0HH as it is less influenced by topography and soil moisture (Le Toan *et al*, 1992; Van Zyl 1993; Harrell *et al*., 1995). Therefore, based on the above observations, for C-band SAR data γ^0HH and γ^0HV were considered, whereas for L-band SAR data, γ^0HV and γ^0(HH-HV) were considered for development of models for biomass estimation.

Also, as vegetation of different forest types over different physiographic zones show different response to SAR backscatter. Hence, it is important to derive separate model coefficients for different forest types for biomass retrieval models. The study has suggested separate coefficients generated for HH, HV polarisations and HH-HV polarization ratio over different forest types of Gujarat for the biomass inversion models.
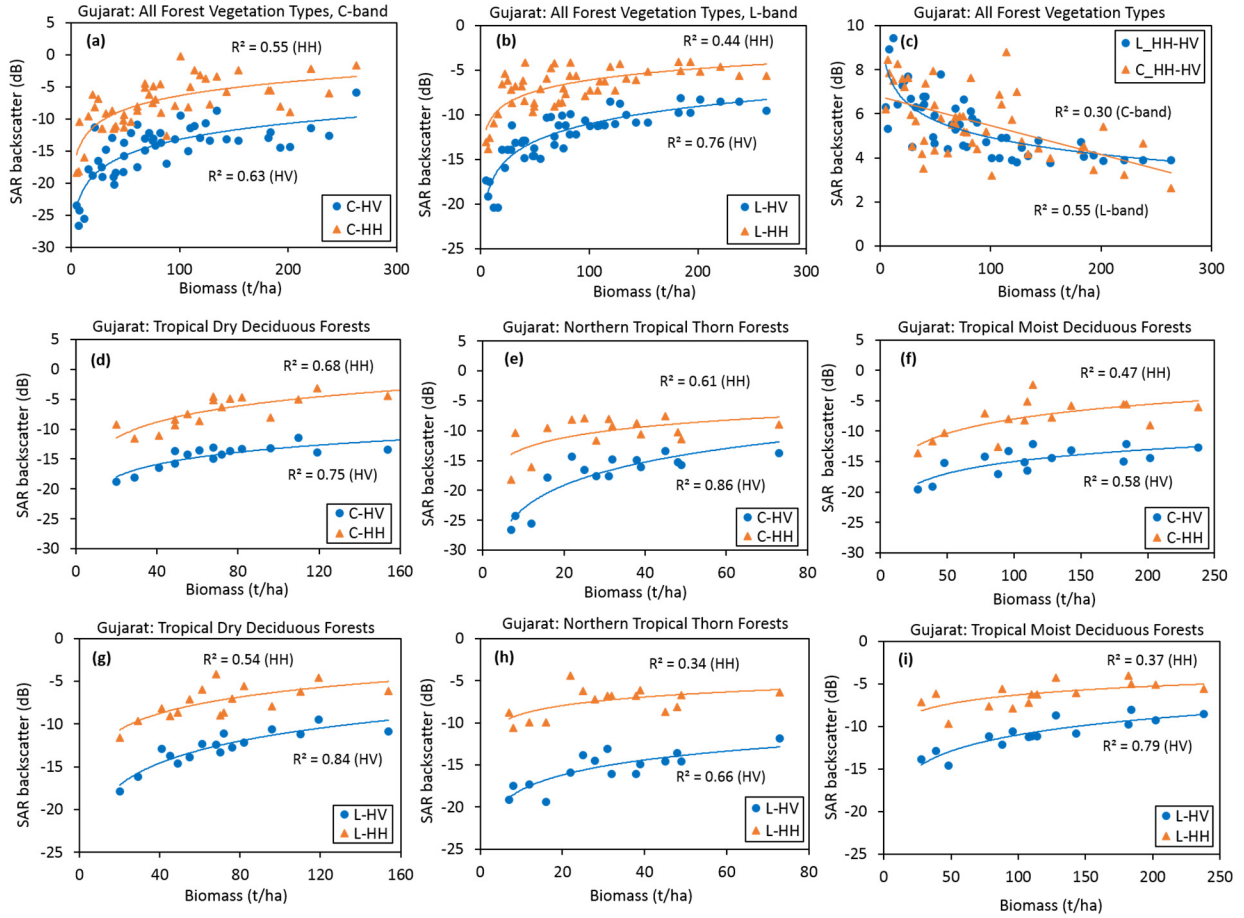

Figure 5: SAR backscatter (γ^0HH, γ^0HV and γ^0(HH-HV)) in C-band (a, c, d, e & f) and L-band (b, c, g, h & i) plotted against field measured biomass over different forest vegetation types in Gujarat. The trend lines show exponential functions.

Biomass inversion models based on multi-linear regression functions (MLR) using γ^0HH, γ^0HV and γ^0(HH-HV) parameters, depending on C-band and L-band SAR data, were considered for estimation of forest AGB of Gujarat. The models are given below:

$$Y_{BIOMASS\ (t/Ha)} = A + (B * \gamma^0_{HH}) + (C * \gamma^0_{(HV)}) \qquad \text{for RISAT-1 data} \qquad (4)$$

$$Y_{BIOMASS\ (t/Ha)} = A + (B * \gamma^0_{HV}) + (C * \gamma^0_{(HH-HV)}) \qquad \text{for ALOS PALSAR data} \qquad (5)$$

where γ^0 is backscattering coefficient in dB and A,B and C are the model coefficients whose values for different vegetation types of Gujarat corresponding to L and C-band SAR data of different years are given in Table 2. The model coefficients over Littoral and swamp forests such as mangroves could not be generated due to lack of field measured biomass data. For such vegetation, coefficients of northern tropical thorn forests have been used for AGB estimation.

The MLR models were applied on RISAT-1 MRS mosaic data and ALOS PALSAR 1/2 mosaic data of Gujarat state to generate above ground biomass maps for the years 2007, 2008, 2009, 2010, 2015 and 2016. While forest AGB maps of 2007 - 2010 were generated using only L-band SAR data, the biomass maps of 2015 and 2016 were generated using both L-band and C-band SAR data. All the biomass maps are not presented in this paper. Due to high similarity of radar backscatter values obtained over forest vegetation and agriculture crops, the estimation of forest AGB was made within forest mask generated for Gujarat state, including Daman and Diu using SAR and optical satellite data.

Table 2: MLR model coefficients for L- and C-band SAR data acquired in different years over different vegetation types of Gujarat (Coefficients of L-band SAR data for the years 2007 and 2009 are not presented here)

Year	Vegetation Types	L-band SAR (ALOS-PALSAR)				C-band SAR (RISAT-1)			
		A	B	C	R^2	A	B	C	R^2
2016	Trop. moist deciduous	385	20.45	-8.73	0.78	348	16.8	2.57	0.52
	Trop. dry deciduous	262	17.71	20.1	0.76	169	5.75	3.96	0.71
	Northern tropical thorn	132	5.04	1.58	0.59	92	1.92	-2.92	0.79
2015	Trop. moist deciduous	348	20.12	-2.75	0.72	364	2.69	15.1	0.45
	Trop. dry deciduous	122	6.02	-0.71	0.79	263	9.57	8.27	0.65
	Northern tropical thorn	236	15.1	-1.92	0.54	86	-2.94	4.83	0.72
2010	Trop. moist deciduous	435	29.3	3.8	0.55	-	-	-	-
	Trop. dry deciduous	202	12.4	0.82	0.81	-	-	-	-
	Northern tropical thorn	203	11.5	1.87	0.63	-	-	-	-
2008	Trop. moist deciduous	472	37.8	18.1	0.66	-	-	-	-
	Trop. dry deciduous	201	12.13	1.66	0.80	-	-	-	-
	Northern tropical thorn	183	9.5	0.78	0.64	-	-	-	-

Figure 6 shows forest AGB maps of Gujarat independently derived using C-band SAR data (RISAT-1) and L-band SAR data (ALOS PALSAR-2) acquired in the year 2015. It was observed that C-band SAR produced more accurate estimation of AGB over vegetation of lower biomass densities as the case in Kutch and Saurashtra regions of Gujarat. Whereas in higher biomass (>100 t/ha) regions such as south and eastern Gujarat encompassing districts of Sabar Kantha, Banas Kantha, Dahod, Narmada and The Dangs, saturation of C-band SAR signal was observed, which resulted into underestimation of biomass of higher densities. Regions with field measured biomass densities of 120 t/ha or above have not been correctly classified in C-band data. On the other hand, L-band SAR data produced better estimation of biomass in the southern and eastern Gujarat regions, which are characterized with forest vegetation of higher biomass levels. L-band SAR data appeared to produce underestimation of vegetation biomass in the Kutch and Bhavnagar districts dominated by grasslands and mangroves vegetation.

The temporal biomass maps of Gujarat suggested that there was no appreciable change in the forest cover as well as forest AGB of Gujarat state during the period 2007 and 2016. However, detailed analysis of the forests including mangrove cover and grasslands at higher scales will reveal whether there is any significant change in vegetation cover or biomass during the period.
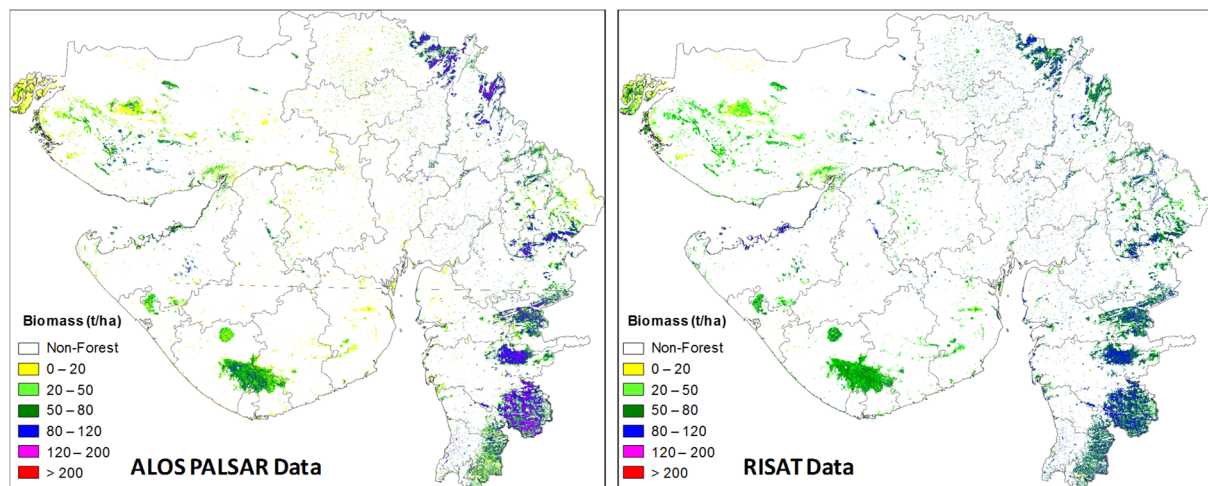

Figure 6: Forest aboveground biomass maps (expressed in tons per hectare) of Gujarat generated from (left) L-band (ALOS-PALSAR) and (right) C-band (RISAT-1) SAR data acquired in 2015.

Attempt was made to combine C-band and L-band SAR data to produce forest above-ground biomass of Gujarat as both the dataset showed better estimation of biomass over one or other vegetation types. While C-band data produced better estimation of AGB than L-band data, over lower biomass density region, L-band data showed higher sensitivity for vegetation with higher biomass densities and hence produced better estimation of AGB over eastern and southern Gujarat forests. The combined model for L- and C-band SAR data is given below (equation 6)

$$Y_{\text{BIOMASS (t/Ha)}} = A + (B * L\gamma^0_{\text{HV}}) + (C * C\gamma^0_{\text{HV}}) (D * L\gamma^0_{\text{(HH-HV)}}) \tag{6}$$

Where $L\gamma^0$ and $C\gamma^0$ are backscattering coefficients in dB in L-band and C-band, respectively and A,B, C and D are the model coefficients.

The forest AGB map of Gujarat generated using combinations of C-band and L-band SAR data acquired in 2016 is shown in Figure 7. The result shows that 28.3% of forest vegetation falls within the biomass density category of 20 t/ha or less; 19.9% of forest have biomass in the range of 20 -50 t/ha; 23.5% of forest have biomass in the range of 50 -80 t/ha; 21.9% of forest have biomass in the range of 80 -120 t/ha, while 6.4% of forests show biomass densities of 120 t/ha or more. The validation of the results has not yet been carried out due to the unavailability of sufficient number of forest inventory (ground truth) data, that has not been used in the model development. The validation exercise will be carried out in future. It may also be noted that the biomass inversion models have been developed based on small sampling points. More number of samples collected over forest inventory plots of 0.1 ha sizes is expected to increase the model performance and improve the estimation of forest ABG of Gujarat state.
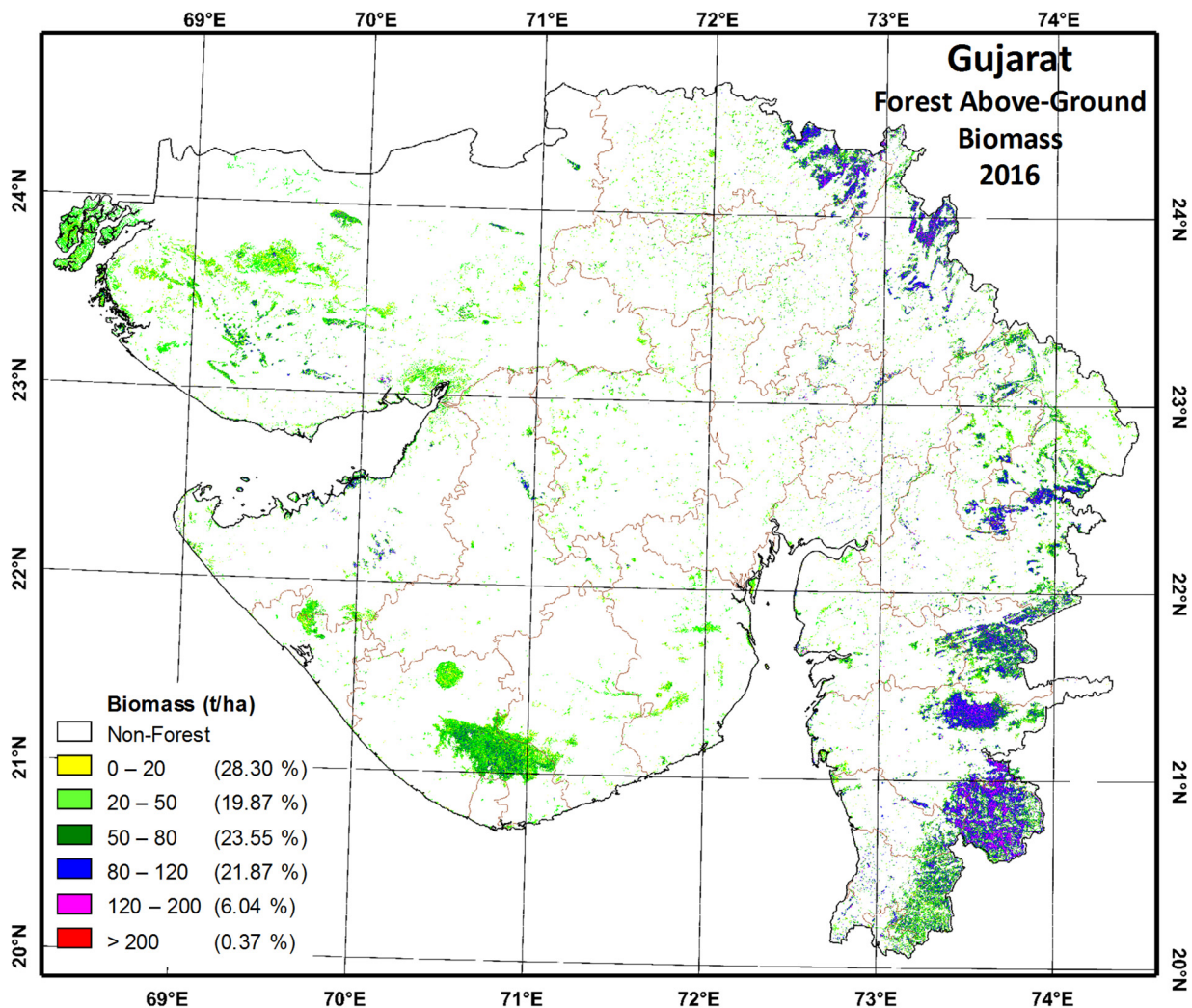

Figure 7:Forest above ground biomass (expressed in t/ha) map of Gujarat derived from combination of C-band (RISAT-1) and L-band (ALOS PALSAR-2) SAR data acquired in 2016.

5.0 CONCLUSION

The study demonstrated the use of C-band and L-band SAR data for estimation of forest above-ground biomass over tropical region and produced multi-temporal forest AGB maps of Gujarat state of India. The study brought out the advantages of C-band SAR data and L-band SAR data for characterising forest biomass with varying densities as C-band SAR is more optimum for grasslands and mangroves vegetation, whereas L-band SAR has advantage over C-band SAR in characterizing higher biomass densities associated with tropical moist deciduous forests in Gujarat. The study observed that SAR data, especially C-band SAR data acquired over dry season, which is associated with leaf off period of tropical deciduous vegetation, enables better estimation of forest AGB. This can

be attributed to the ability of SAR signal to interact with the tree woody matter such as trunk and branches during leaf off season, due to the absence of leaves. Also, during leaf off season, the effect of soil moisture and vegetation moisture on SAR backscatter is less.

It was also observed that, as vegetation of different forest types over different physiographic zones show different response to SAR backscatter, it is important to use separate model coefficients for different forest types for biomass retrieval models. The study has suggested separate coefficients generated for HH, HV polarisations and HH-HV polarization ratio over different forest types of Gujarat for the biomass inversion models.

The study brought out the usefulness of available SAR data from Indian RISAT-1 and Japanese ALOS PALSAR 1 and 2 with well calibrated backscatter values for estimation for forest above-ground biomass at regional level. The AGB maps of Gujarat state of India were generated at 25m grid spacing using C- band and L-band SAR data for multiple years. The study also suggested that there was no appreciable change in the forest cover as well as forest AGB of Gujarat state during the period 2007 and 2016. However, detailed analysis of the forests including mangrove cover and grasslands at higher scales will reveal whether there is any significant change in vegetation cover or biomass during the period. The study requires further improvement and validation with more ground measured forest biomass data.

6.0 ACKNOWLEDGMENT

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