Biomass Estimation using Texture Measurements of Dual Polarization SAR Data

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Abstract

This research investigates the potential of two-date dual polarization (HH and HV) SAR imagery for biomass estimation using different kinds of texture processing and different combinations of single and dual polarization ratios in a study area where biomass levels are beyond the previously recognized saturation levels for L-band SAR images, and forest is a mixture of native and non-native species and plantations. All processed images were compared with ground data from 50 plots. The accuracy from intensity data was low, with an adjusted r^2 of 0.221, but this increased somewhat to adjusted r^2=0.634 when texture parameters of the SAR data were included in the model. At the final stage of processing, above 90% accuracy (adjusted r^2 of 0.903 and RMSE 28.58) was achieved from the combination of single and two-date polarization ratios of texture parameters. The high accuracy achieved from the combination of images and processing steps is thought to be due to the synergistic use of texture processing, ratio, and dual polarization data, and indicates that L-band dual-polarization (HH&HV) SAR data of PALSAR has great potential for biomass estimation.

Keywords: *PALSAR, Dual Polarization, SAR image processing, Saturation level, Biomass*

1. Introduction

The estimation of forest biomass is one of the most persistent uncertainties in understanding and monitoring the carbon cycle. This is especially true in tropical forest because of its complicated stand structure and species heterogeneity (Lu 2006). Remote sensing data, properly linked to the biophysical properties of the forest, can address this problem by offering an effective method for forest biomass and carbon inventory at local, regional and global scales (LeToan et al. 1992).

The most promising sensing system appears to be Synthetic Aperture Radar (SAR) due to its sensitivity to forest structure and useful relationships have been established between radar backscatter and forest biophysical parameters (Dobson et al. 1992). Most previous studies using space borne SAR have been limited to single frequency and single polarization data. Currently the three most advanced satellite SAR sensors i.e. PALSAR (L-Band), RADARSAT-2 (C-Band) and TerraSAR (X-Band) provide data with different polarizations, different incidence angles and high spatial resolutions, and this has opened a new door of research in the field of biomass estimation using SAR data.

However, the improvement of biomass estimation depends not only on the SAR data but also requires efficient SAR data processing (Imhoff 1995), as the raw SAR backscattering coefficient becomes saturated at fairly low biomass levels (Dobson et al. 1992, Foody et al. 1997). Several ways have been suggested to estimate biomass beyond the saturation point. These include i) using longer wavelengths (Imhoff, 1995), ii) using SAR data processing such as texture (Kuplich et al. 2005), iii) using the ratio of SAR images as polarization ratios do not saturate as quickly (Dobson et al. 1995), and ratios can reduce topographic effects (Ranson et al. 1995, Shi & Dozier 1997), and forest structural effects (Dobson *et al*. 1995, Ranson & Sun 1994), iv) using several SAR images by averaging or other means, to reduce speckle-based error and other random errors (Kurvonen et al. 1996). Hence, it is predicted that biomass estimation maybe improved by using longer wavelength SAR data accompanied by different image processing techniques, and the main objective of this research is to investigate L-Band dual polarization SAR (PALSAR) data for biomass estimation in a complex sub-tropical evergreen forested region (Hong Kong).

2. Methodology

The methodology (Fig.1) of this study comprises two parts namely allometric model development for field biomass estimation, and processing of PALSAR images. Due to the lack of an allometric model for converting the trees measured in the field to actual biomass, it was necessary to harvest, dry and measure a representative sample of trees. Since tree species in Hong Kong are very diverse, the harvesting of a large sample was required. This was done by selecting the dominant tree species comprising a total of 75 trees in 4 DBH classes and standard procedures were followed for tree harvesting (Overman et al. 1994, Ketterings et al. 2001).

Regression models using dry weight (DW) as the dependent variable, and DBH and height as the independent variable, were tested, and the best fit model (Table 2) was found to be InDW = a + b * In DBH, with the adjusted coefficient of determination (adjusted r^2 0.932) and an RMSE of 13.50. Fifty circular plots with a 15m radius covering a variety of tree stand types were selected using purposive sampling for field biomass. The DBH of trees was measured at 1.3 m above ground. Using the measured parameter DBH, the biomass of each tree and biomass of all trees in a plot were estimated.

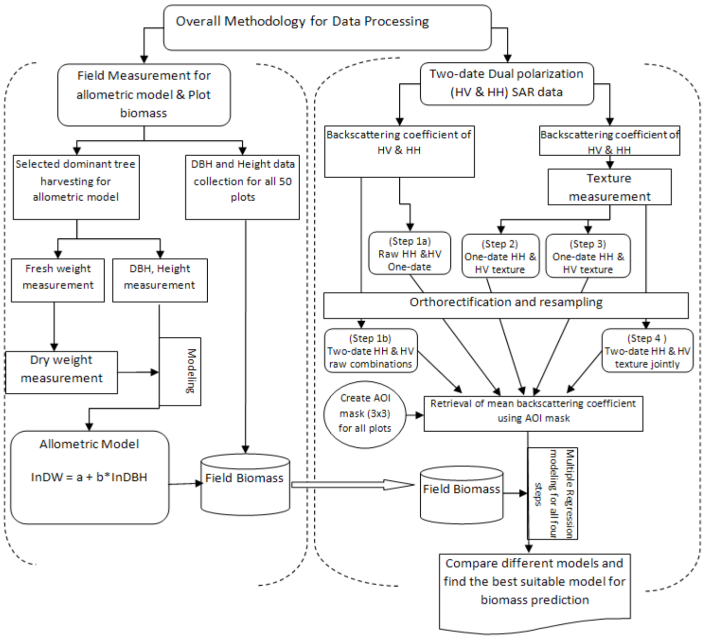

Figure 1: Methodology

PALSAR data were converted into Sigma naught in power image and this was then converted to amplitude to use as an input to texture measurement. Three categories of texture measurement were selected, to test their potential for biomass estimation namely i) the grey level co-occurrence matrix (GLCM) (Haralick et al. 1973) along with some Grey Level Difference Vector (GLDV)-based texture measurements, ii) the sum and difference histogram proposed by Unser (1986), and iii) the model-based log form texture parameter estimation, reported by Oliver, (1993). All texture measurements were performed using 5 small to medium window sizes from 3 x 3 to 11 x11. Geometric correction was carried out using the Toutin's Model of PCI Geomatica software. A reference image (Spot-5), high resolution DEM (10m) and 40 well distributed GCPs were used for the geometric correction to ensure overall RMSE less than 0.5 pixel.

The mean intensity of the 50 field biomass plots were extracted from all SAR datasets using an area of interest (AOI) mask of 3 x 3 pixels. The relationships between field biomass and remotely sensed data were established using stepwise multiple-linear regression approach. Necessary statistical parameters namely correlation coefficient (r), coefficient of determination (r^2), adjusted r^2, RMSE, p-level, Beta coefficient (B), Std. Error of B, tolerance (tol), variance inflation factor (VIF), and condition index (CI) were estimated for the selection of best model and to avoid multicollinearity effects.

3. Data

Two fine-beam dual polarization (HV and HH) images from the L-band PALSAR SAR sensor were processed for biomass estimation using four processing steps namely i) intensity data of two images with different combinations, ii) texture parameters of each polarization individually, iii) texture parameters with both polarizations, and iv) a combination of two-date texture parameters combination.

4. Results

In general, the relationships between field biomass and all raw (intensity) SAR derived parameters were found to be poor (Table 1, Fig 2), and only about 25% (r^2=25) (model 4 in Table 1) variability of field biomass can be explained from the intensity data processing. Texture parameters of HH & HV SAR data improved the biomass estimation substantially compared to all combinations of raw processing. The highest accuracies of 0.45 (r^2) and 0.54 (r^2) were obtained from the texture parameters of HH polarization (model-5 in Table 1) and HV polarization (Model-6 in Table 2) data respectively. Using the HH&HV texture parameters jointly in the model (without ratio), as well as the ratio, the highest accuracies (adjusted r^2) obtained were 0.634 and 0.783 (models 7 & 8 in Table 1) respectively. This indicates considerable improvement (Fig 2) compared to other processing. The two-date ratio of dual polarization (HH & HV) texture parameters was more effective, and the obtained accuracy (adjusted r^2) was 0.834 (model-9 in Table 1 & Fig 2). Finally we observed that it was possible to improve biomass estimation even further and very promising accuracy (adjusted r^2 0.903) was obtained (model 11 in Table & Fig 2) using the joint ratio of texture parameters. The result is considerably higher than for the previous processing steps in this analysis, and is much better than other results reported in the literature using L-band SAR in such a high biomass situation.

Processing types	Date-1 (20080511)		Date-2 (20080926)	
	R^2	AR^2	R^2	AR^2
Model-1: Raw_HH	0.05	0.03	0.04	0.03
Model-2: Raw_HV	0.13	0.11	0.06	0.04
Model-3:Raw_ratio	0.14	0.12	0.04	0.01
Model-4: Raw_HV&HH	0.25	0.22	0.07	0.03
Model-5: Texture_HH	0.35	0.31	0.45	0.39
Model-6: Texture_HV	0.54	0.49	0.51	0.45
Model-7: Texture_HV&HH	0.68	0.63	0.65	0.58
Model-8: Texture ratio (HV/HH)	0.82	0.78	0.75	0.68
	Two date together			
	R^2		AR^2	
Model-9: Two-date ratio (texture)	0.86		0.83	
Model-10: Joint ratio-1 (texture)	0.90		0.88	
Model-11: Joint_ratio-2 (texture)	0.92		0.90	

Table 1: Accuracy of biomass estimation using different processing parameters

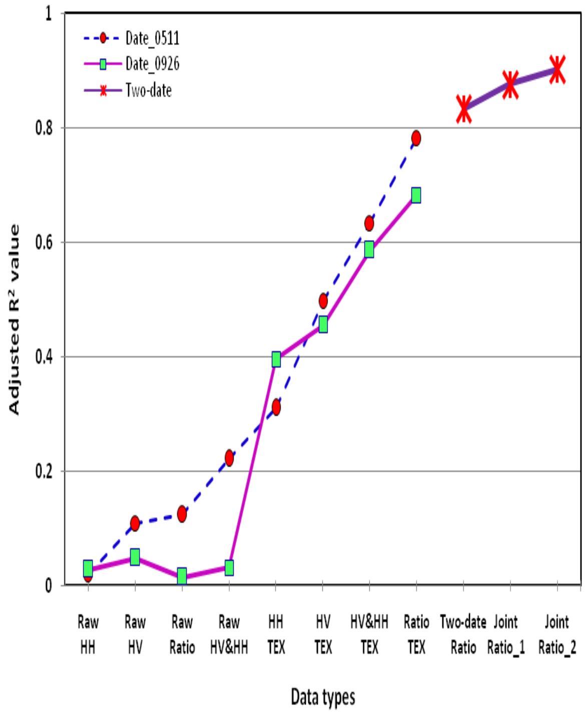

Figure 2: Change in accuracy among raw, HH & HV texture and HH & HV texture parameters jointly, and two-date texture parameter ratio combinations

5. Discussion

The biomass estimation accuracy was observed to increase with the number of processing steps (Fig 2) and above 90% accuracy with an RMSE ± 28.58 t/ha was obtained at final stage. The low and inconsistent accuracy using raw (intensity) data is in agreement with other researchers (Dobson et al. 1992, Foody et al. 1997) who found that the raw backscattering coefficient does not correlate strongly with biomass. Texture parameters of HH and HV polarization data were found to be more robust than intensity data, and the observed accuracy improvement using texture parameters agrees with previous research (Kuplich et al. 2005). This better performance using HV than HH polarization was also reported in many literatures (Ranson & Sun 1994, Dobson et al. 1995, Kasischke et al. 1995). Improvement of biomass estimation also observed using the both polarization texture parameters jointly (without ratio) and as well as ratio compared to any single polarization texture, probably because different polarizations provide complementary information, and agrees with previous research (Rignot et al. 1994, Kasischke et al. 1997). The ratio of HV and HH texture parameters was found to be more effective than HH and HV texture used as independent parameters together in the model without ratio probably because that ratio image combines both the complementary information from their use as independent parameters without ratio, as well the reduction of topographic effects (Ranson et al.1995, Shi & Dozier 1997) and forest type structural differences (Dobson *et al*. 1995, Ranson & Sun 1994, Foody et al.1997). The highest accuracy of biomass estimation was reached using the ratio of two-date dual polarization texture parameters and a combination of single and two-date ratios together as independent parameters in the model. This improvement agrees in principle with previous findings for multi-date SAR research (Kurvonen et al. 1996) that the use of several different dates of SAR, by averaging or other means can provide more reliable results than a single SAR image date, by reduction of speckle noise and other random errors.

6. Conclusions

This paper presents techniques which are able to achieve high accuracy of biomass estimation (adjusted r^2 0.903) in a study area where biomass levels are as high as 500t/ha. This high accuracy was achieved by combining four strategies which had already been used or suggested individually by other researchers. These include the use of i) a longer wavelength SAR sensor, ii) texture measurements, iii) dual polarization SAR data and iv) two-date SAR data. Hence, the good result obtained from this research is actually the outcome of image selection and processing together. Despite the potential of texture parameters of dual polarization data and different processing steps, we assume that other studies may find different results using similar processing steps to those described here because of different forest and environmental conditions but our processing steps can be used as a guideline for future work.

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