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# Potential of texture measurements of two-date dual polarization PALSAR data for the improvement of forest biomass estimation

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ABSTRACT

The recently available space-borne SAR sensor, PALSAR, is more promising than its predecessor JERS-1 for biomass estimation because of its long wavelength (L-band), and its ability to provide data with different polarizations, varying incidence angles and higher spatial resolutions. 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. The investigation is conducted in a mountainous, sub-tropical study area where biomass levels are far beyond the previously recognized saturation levels for L-band SAR images, and forest is a mixture of native and non-native species and plantations.

We analyzed two-date SAR data with four steps of image processing, including raw data processing in various combinations, texture measurement parameters of HH and HV polarizations, texture measurement parameters of HH and HV together (both jointly and as a ratio), and a ratio of two-date texture parameters along with a single and two-date ratio. When the processed images were compared with ground data from 50 plots, the performance from raw data processing was low, with adjusted $r^2 = 0.22$, but after all four processing steps, promising model accuracy (adjusted $r^2 = 0.90$ and RMSE = 28.58 t/ha) and validation accuracy (using the Leave-One-Out-Cross-Validation) with adjusted $r^2 = 0.88$ and RMSE = 35.69 t/ha, were achieved from the combination of single- and two-date polarization ratios of texture parameters.

The strong performance achieved indicates that L-band dual-polarization (HH and HV) SAR data from PALSAR has great potential for biomass estimation, far beyond the previously reported L-band saturation point for biomass. This result is attributed to the synergy among texture processing and dual polarization on the one hand, which were able to average out random speckle noise, and the use of ratio instead of absolute quantities, due to its well known ability to reduce forest structural and terrain effects. The additional use of two-date SAR data with these processing techniques was able to add complementary information derived from biomass response in both wet and dry seasons. Thus overall, undesirable image noise and terrain effects were reduced.



## 1. Introduction

The estimation of forest biomass is one of the most persistent uncertainties in understanding the carbon cycle. This is especially true in tropical forest because of its complicated stand structure and species heterogeneity (Lucas et al., 2000; Nelson et al., 2000; Steininger, 2000; Foody et al., 2003; Lu, 2005, 2006). Remote sensing data, properly linked to forest biophysical properties, can address this problem (Harrell et al., 1995) by offering an effective method for forest biomass estimation at local, regional and global scales (Brown et al., 1989; Le Toan et al., 1992; Rosenqvist et al., 2003; Foody et al., 2003).

The most promising type of sensor appears to be Synthetic Aperture Radar (SAR) due to its sensitivity to forest structure (Harrell et al., 1995; Castel et al., 2002) as well as all-weather capability, and useful relationships have been established between radar backscatter and forest biophysical parameters (Dobson et al., 1992; Le Toan et al., 1992). Many studies of biomass have been conducted using both airborne (Wu, 1987; Le Toan et al., 1992; Dobson et al., 1992; Ranson and Sun, 1994; Ranson et al., 1995;

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Dobson et al., 1995; Kasischke et al., 1995; Foody et al., 1997; Harrell et al., 1997; Luckman et al., 1997; Mougin et al., 1999; Santos et al., 2003) and space borne SAR (Luckman et al., 1998; Kurvonen et al., 1999; Fransson and Israelsson, 1999; Santos et al., 2002; Castel et al., 2002; Sun et al., 2002; Tsolmon et al., 2002; Kuplich et al., 2005; Lucas et al., 2007; Champion et al., 2008) and differing degrees of success have been obtained.

Most previous studies using space-borne SAR have been limited to single frequency and single polarization data. Although multi-polarization and multi-frequency airborne SAR has been used for biomass estimation, it has not been widely available or geographically extensive due to the lack of extensive and/or repeat data, though the results of these studies represent the foundation for most current and future SAR research (Townsend, 2002). Previous research recommends P-band SAR as the most suitable choice for measurement of woody biomass (Dobson et al., 1992; Le Toan et al., 1992; Rignot et al., 1994; Ranson and Sun, 1994; Kasischke et al., 1995; Imhoff, 1995; Harrell et al., 1997; Mougin et al., 1999; Kurvonen et al., 1999; Santos et al., 2003) but there is currently no space borne platform with P band radar. However, researchers also found L-band, particularly the cross polarized L-HV, to be effective for biomass estimation (Hussin et al., 1991; Le Toan et al., 1992; Dobson et al., 1992; Rignot et al., 1994; Ranson and Sun, 1994; Kasischke et al., 1995; Harrell et al., 1997; Luckman et al., 1997; Sun et al., 2002; Ranson et al., 1997; Lucas et al., 2007).

Until recently JERS-1 was the only Satellite SAR operating in L-band, but its single-band, single-polarization configuration was not optimal for forest biomass estimation (Townsend, 2002), and many researchers (Sun et al., 2002; Castel et al., 2002; Hese et al., 2005; Lucas et al., 2007) expected the new generation space borne SAR sensors particularly PALSAR to significantly improve biomass estimation. 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 provided new opportunities for research in 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 (Kurvonen et al., 1999; Dobson et al., 1992; Kasischke et al., 1994; Rauste et al., 1994; Rignot et al., 1994; Foody et al., 1997). Several ways have been suggested to estimate biomass beyond the saturation point. These include (i) using longer wavelengths (Imhoff, 1995) due to their better canopy penetration than shorter wavelengths, enabling more backscatter from the woody components, (ii) using SAR data processing such as texture, as texture can maximize the discrimination of spatial information independently of tone (i.e. backscatter) and increase the biomass range that can be measured, thus increasing the saturation level (Kuplich et al., 2005; Luckman et al., 1997; Salas et al., 2002; Champion et al., 2008), (iii) using the ratio of SAR images, as polarization ratios do not saturate as quickly (Dobson et al., 1995). In addition, ratios can reduce topographic bias (Ranson et al., 2001; Ranson et al., 1995; Shi and Dozier, 1997), and forest structural effects (Foody et al., 1997; Dobson et al., 1995; Ranson et al., 1995; Ranson and Sun, 1994) and thus enhance the relationship between radar backscatter and biomass beyond observed saturation levels. Furthermore, it has been suggested to estimate biomass (iv) using several SAR images by averaging or other means, to reduce speckle induced error and other random errors in the estimation process (Kurvonen et al., 1999; Fransson and Israelsson, 1999). It therefore seems reasonable to expect that biomass estimation could be improved by using longer wavelength SAR data accompanied by different image processing techniques. This research takes into consideration recommendations from previous SAR biomass studies, in the context of newly available advanced SAR sensors and SAR processing algorithms.

### 1.1. Objectives

The main objective of this research is to investigate the potential of L-Band dual polarization SAR (PALSAR) data for biomass estimation in a complex sub-tropical evergreen forested region, where biomass levels are far beyond the previously stipulated saturation levels of L-band. Other more specific objectives are to

- investigate the performance of two-date raw SAR data using a variety of combinations of HH & HV polarization, both individually and jointly, for biomass estimation,
- explore the potential of texture parameters of HH & HV polarization SAR data for biomass estimation,
- investigate the potential for biomass estimation using HH & HV texture parameters both jointly (without ratio), and as ratio, and
- investigate the ratio of two-date dual polarization (HV & HH) texture parameters, along with a combination of single and two-date ratios for biomass estimation.

## 2. Study area and data

The study area for this research is the Hong Kong Special Administrative Region (Fig. 1) which lies on the southeast coast of China, just south of the Tropic of Cancer. The total land area of Hong Kong is 1100 $km^2$ and includes 235 small outlying islands. Although the population is over 7 million, only about 15% of the territory is built-up and less than 1% is still actively cultivated. Approximately 40% of the total area is designated as Country Parks which are reserved for forest succession under the management of the Agriculture, Fisheries and Conservation Department (AFCD). The native sub-tropical evergreen broad leaf forest has been replaced by a complex patchwork of regenerating secondary forest in various stages of development, and plantations. Forest grades into woodland, shrubland then grassland at higher elevations.

Two dates of images with dual polarization (HV and HH) from the L-band fine-beam PALSAR SAR sensor were used in this study (Table 1).

## 3. Methodology

The methodology (Fig. 2) of this study comprises two parts, i.e. allometric model development for field biomass estimation, and SAR image processing.

### 3.1. Allometric model development

Due to the lack of an allometric model for converting the measurable tree parameters to actual biomass, it was necessary to harvest 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 (diameter at breast height) classes (less than 10, 10–15, 15–20 and 20 cm and above) and standard procedures were followed for tree harvesting (Overman et al., 1994; Brown, 1997; Ketterings et al., 2001).

The harvested trees were separated into fractions including leaves, twigs, small branches, large branches, and stem. After measuring the fresh weight, representative samples (Fig. 3) from every part of the tree were taken for dry weight measurements in an oven at 80 °C until a constant dry weight was obtained (Fig. 3). The weight of every sample was estimated using the same electric