Sensitivity of radar backscatter to mangrove forest structure and AIRSAR imaging parameters.

Abstract

NASA JPL AIRSAR data, acquired over the Alligator Rivers of Kakadu National Park (KNP) in Australia’s Northern Territory, were used to investigate the potential of SAR data for retrieving forest structural and biomass information. The area was imaged during two independent PACRIM missions (in November 1996 and September 2000), with fully polarimetric data acquired at P- (0.44 GHz), L- (1.25 GHz) and C- (5.3 GHz) bands at a mean incidence angle of 42° and 69.8° respectively. Mangroves within KNP are most prevalent along the intrusive and tidally dominated creeks that dissect the northern coastline. The focus of this study was on the West Alligator River, where extensive mangrove forest was encountered. Notable differences in radar backscatter at all frequencies and polarisations were also observed between forest of differing height and species composition, as determined using a combination of stereo aerial photography and hyperspectral data. Enhanced backscatter on the seaward margin was associated with tidal inundation beneath the canopy on both dates. To better understand the interaction of microwaves with mangrove forest structures, field data collected in October 2002 were used to parameterize the wave scattering model of Karam et al. (1995) and decompose the backscatter in different channels. The decomposition showed a greater return from the canopy rather than trunks with increasing biomass, which questions the use of SAR data for biomass retrieval in mangrove forests. Differences in backscatter with incidence angle were also observed. The study emphasized the benefits of using finer spatial resolution AIRSAR data and the results of scattering analysis to better interpret and understand the complex scattering response over mangrove forest, and has implications for the future characterisation, mapping and monitoring of mangroves from both airborne and spaceborne SAR data.

I. INTRODUCTION

Numerous studies have exploited the unique imaging capabilities of multifrequency radar for baseline mapping of the world’s forested ecosystems and for quantifying their changing extent, structure and above ground biomass [1, 2]. However, only a few have focused on mangrove forest [3, 4]. Digital baseline data of mangrove extent and structure is essential for forest inventory and evaluation of the response of mangroves to coastal environmental and climate change, including sea level variations.

The overall paucity of studies that utilise radar data, in part, reflects the inherently complex nature of the data and the difficulties associated with processing and interpretation. Radar image brightness and texture vary according to surface type and structure (including dielectric and roughness properties), and sensor configuration. Understanding the complex radar response requires either the establishment of empirical relationships (2D) between forest structure and radar backscatter ($\sigma^0$) or the application of forest backscattering models (3D) that simulate and decompose $\sigma^0$ into the dominant scattering mechanisms (e.g., volume, soil, interactions) associated with forest structures (e.g., leaves, branches, trunks).

This paper outlines an approach to the interpretation of airborne synthetic aperture radar (AIRSAR) data, acquired over mangroves of Northern Australia on two independent PACRIM missions in 1996 and 2000. The variability in scattering response across the mangroves is related to forest structure, biomass and composition, as determined using field measurements and reference to optical remote sensing data. Comment on the potential of multifrequency SAR for baseline inventory, mapping and detection of change is also given.

II. STUDY SITE

The research focused on the extensive and relatively undisturbed mangroves within KNP in Australia’s Northern Territory, and in particular, those of the West Alligator River (WA; Fig. 1). The mangroves of the WA are expansive along coastal facing shores but more scattered along the numerous intruding tidal creeks that dominate the coastal lowlands. Distinct zonation patterns are observed across the community, which is attributable to their response to tidal inundation, soil type and salinity and wave action [5]. A typical coastal distribution would include Sonneratia alba on the seaward edge, Rhizophora stylosa further inland, and Avicennia marina on the landward edge.
III. FIELD AND REMOTE SENSING DATASETS

Representational structural data of the dominant mangrove zonations at WA was acquired in October 2002 for thirteen field plots. From these data, the mean tree height, diameter, crown dimensions and density were obtained. Using available allometric equations, the total above ground and component biomass for all mangrove stands was quantified.

NASA JPL AIRSAR data was acquired over KNP on 23 November, 1996 and 9 September, 2002. Fully polarimetric data were acquired simultaneously at a mean incidence angle of 42°and 69.8° respectively. WA scenes were extracted from both AIRSAR strips and georeferenced to a 1 m spatial resolution orthomosaic. These field measurements were used to parameterize the scattering model of [6] and hence, decompose the radar signal. For both years, mean AIRSAR data for all channels were extracted from regions of interest (ROIs) identified in areas proximal to field sampling locations.

Compact Airborne Spectrographic Imager (CASI) data of the WA mangroves was also available to assist in species identification and interpretation of the SAR data. Additionally, a 1 m DEM of mangrove canopy height, previously generated from stereo aerial photography [7], was available for the study. Although generally reliable, the DEM was unable to consistently retrieve the height of trees towards the seaward edge, as the photogrammetric processing for canopy height retrieval was limited in areas of low texture, where for example, bare ground or water was viewed between the sparser canopies.

IV. RADAR BACKSCATTERING FROM MANGROVE FOREST

A. Variation in $\sigma^o$ with species and zonation

At WA, three broad mangrove zones were identified through differences in $\sigma^o$ across the landward to seaward edge of the community (Fig. 2), which were evident in all channels. Extensive mudflats with scattered Samphires bordered the landward edge of the mangroves and typically exhibited a low $\sigma^o$ in all channels relative to the mangroves themselves. Within the landward mangrove zone, which was relatively open and dominated almost exclusively by a high density of low (~ 6 m) A.marina trees, $\sigma^o$ was variable but relatively high (Fig. 3). An abrupt change was observed between the landward A.marina forest and the tall (typically > 20 m) R.stylosa forest, as $\sigma^o$ reduced significantly in the latter and particularly at L-band HH. However, the seaward side of this zone, which was dominated by S.alba, exhibited values of $\sigma^o$ that were equivalent or even higher than those on the landward margin. This was attributable, in part, to inundation beneath the canopy and an increase in double bounce interactions. Within the CASI data but also the AIRSAR data, a fourth zone comprised of young S.alba regrowth was observed seaward of the coastal edge forest. This zone was not evident within 1991 aerial photography of the area. Similar spatial variations in $\sigma^o$ were also observed in the AIRSAR data for 1996, although differences were of lower magnitude.

B. Variation in $\sigma^o$ with forest structure and biomass

To determine how forest structure and biomass influenced $\sigma^o$, the spatial profiles across the mangroves were compared against the height profiles and tree species maps generated from stereo photography and CASI data respectively. In general, the tallest mangroves (with the lowest $\sigma^o$ at P and L-band) were those dominated by R.stylosa. Either side of this central R.stylosa zone, $\sigma^o$ was higher (particularly on the seaward margins), which was attributable to inundation as well as structure. In these seaward margins, trees were generally of greater stature compared to those of the landward margin.

Empirical relationships were also established between $\sigma^o$ and total above ground biomass (AGB) for sample plots (Fig. 4). As an example, L-band $\sigma^o$ exhibited increasing sensitivity to AGB up to ~ 100 Mg ha$^{-1}$ (Fig. 4). Similar sensitivity was evident at P-band. C-band $\sigma^o$ exhibited limited sensitivity to AGB however, with high, relatively constant backscatter across the range in biomass, and saturation occurring at ~ 60 Mg ha$^{-1}$. Microwaves are increasingly attenuated with increases in canopy closure and AGB, which leads to the observed saturation of $\sigma^o$ above certain levels of AGB [8]. The sensitivity of L-band displayed here was considered adequate to identify and determine the biomass of young/regrowth stands only. However, the marked reduction in L-band $\sigma^o$ complicates retrieval where knowledge of community distributions is not available, although does indicate that AGB may be retrieved using measures of reduction in backscatter.

C. Incidence angle effects

At larger incidence angles, the vertical tree components (i.e., tree trunks and branches) present a greater surface area to the radar and, in cases where the incident radiation (in particular at longer wavelengths) travels orthogonal to the trunk and ground, the signal is enhanced and produces a high overall backscatter response [9]. Furthermore, volume scattering from the canopy tends to contribute a greater proportion of total $\sigma^o$ at longer wavelengths and higher...
incidence angles [10] particularly above the AGB saturation level. Higher $\sigma^0$ was observed for all mangroves and at all wavelengths and polarisations in the 2000 AIRSAR data, where the mean incidence angle approached 70° (Fig. 3). In the case of the R. stylosa forest, the steeper incidence angle enabled greater penetration and interaction with underlying trunks and large branches. At smaller incidence angles, there tends to be greater interaction with the upper canopy and hence greater attenuation by the branches. Viewing angle may also be significant, and in particular, where the canopy is viewed side-on as opposed to across the community. These data may provide useful information on canopy structure for retrieval of component biomass.

D. Scattering mechanisms

To better understand the underlying reasons for the sensitivity of $\sigma^0$ to forest structure and biomass the forest scattering model of [6] was parameterized using the available field measurements. Comparison with actual AIRSAR and simulated backscatter suggested that the model provided a realistic assessment of the dominant scattering mechanisms.
An example of the decomposed result at L-band is given in Fig. 5.

The simulation suggested that, as AGB increases, changes in the magnitude of certain scattering mechanisms, including a shift from predominantly canopy-ground interactions to volume scattering, and a reduction in their diversity are typically observed [11]. In young/regrowth forest (AGB < 100 Mg ha⁻¹), L-band HH and VV were associated with a greater number of double bounce interactions between the larger branches and trunks and also ground surface, but these declined as the AGB increased. Volume scattering (by the branches) dominated in the mature forest of high AGB which were typically dominated by R.stylosa. The low backscatter response and lack of interactions observed from these forests was attributed to the denser canopy and reduced capacity for penetration, even at the longer wavelengths. For all channels, σ° was enhanced within the inundated forest at the seaward edge.

V. MAPPING POTENTIAL OF SAR

A. Observed patterns in SAR imagery

Within the AIRSAR images, the zones associated with different values of σ° were linked closely with the different mangrove zones and were a direct reflection of the influence of forest structure and biomass. Indirectly, σ° was also influenced by inundation and the dielectric properties of the vegetation and soil, which could not quantified in this study. An increasing sensitivity of backscatter to forest AGB, up until the level of saturation, was revealed and the decline in σ° within the larger AGB forests was similar to that observed by [3]. Through backscatter modeling, it was evident that the magnitude of the response at a given frequency or polarization could be attributable to the different scattering mechanisms (e.g., volume, soil interactions) associated with different volumes and configuration of leaves, branches and trunks. The modeling also helped explain the reduced SAR backscatter at L-band and P-band within the R.stylosa zone.

How SAR backscatter is related to forest structure and total and component biomass may ultimately assist in understanding the observed patterns in SAR imagery, and ultimately for developing inversion algorithms that facilitate retrieval of component biomass and structural attributes. These parameters are linked closely to productivity, which is an important indicator of forest condition and status. A decline in total AGB and compromised forest structure, for example, may reveal incidences of storm damage or longer term changes to physical conditions that limit plant growth.

B. Potential for mapping and detection of change

The capacity to map the broad extent of mangroves and discriminate between high and low biomass, and open and closed canopy forest from AIRSAR data was demonstrated in this paper. Single channel data was useful for mapping the spatial distribution of mangrove forest and detecting inundation (typically at L-and P-band HH) beneath the canopy. Multiple channels are better used to understand the radar response to total above ground and component biomass and also forest structure and composition. However, the consistency of algorithms for retrieving forest structure and biomass needs to be considered, particularly given the observed variations with incidence angle and look direction.

By using SAR data of varying frequency and polarisation, the structure of the forest and hence the growth stage and community composition can be inferred. However, optical datasets, including those derived from aerial photography and hyperspectral sensors, if available, should be used to fill in the information gaps where SAR cannot contribute. Through their integration, the optimal retrieval of forest structural parameters and AGB at a resolution relevant to the scale of mapping can be achieved. However, the study has also noted that changes in structural attributes need to consider the factors such as incidence angle and look direction as well as levels of tidal inundation and differences in structure between zones.

VI. CONCLUDING REMARKS

With the increasing sensitivity of low frequency radar measurements to forest structure and woody AGB, and conversely, the sensitivity of high frequency measurements to canopy structure and leaf and small branch biomass, there is considerable potential for regional scale mapping of mangrove AGB and structural attributes and hence monitoring of change over time. By using forest scattering models to understand the interaction of microwaves, the SAR channels of most use can be carefully selected.

The AIRSAR instrument provides an invaluable capacity to provide simultaneous multifrequency measurement (through subsequent PACRIM missions) over extensive forested areas. Pending acquisition, the provision of multitemporal AIRSAR or similar data provides an ideal opportunity to map and quantify change in such dynamic and remote environments as mangroves. While data is provided at fine spatial resolution, the nature of SAR data however, is limiting to the detection of species composition, retrieval of tree height and mapping fragmented mangrove. Ideally, the integration of SAR and optical data at moderate or finer resolution is advocated.

REFERENCES


