FOREST PARAMETER RETRIEVAL FROM SAR DATA USING AN ESTIMATION ALGORITHM APPLIED TO REGROWING FOREST STANDS IN QUEENSLAND, AUSTRALIA

D. Clewley[1], *R. M. Lucas*[1], *M. Moghaddam*[2], *Pete Bunting*[1], *J. Dwyer*[3], *J. Carreiras*[4]

[1] Institute of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, UK, SY23 3DB
[2] Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109-2122
[3] The University of Queensland, The Ecology Centre, School of Biological Sciences, Queensland 4072, Australia
[4] Tropical Research Institute (IICT),Travessa do Conde da Ribeira, 9 1300-142 Lisboa, Portugal

1. INTRODUCTION

The desire to retrieve forest structural attributes and biomass from remote sensing data has been the motivation behind a large number of studies involving optical, radar and LiDAR sensors [1]. Key attributes of interest have typically been those that are commonly measured in forest inventory and include (at the stand level) stem density, basal area and mean/maximum height. Stem volume and biomass per unit area (typically hectares) are also relevant in assessing, site and habitat quality and environmental values (e.g., carbon stocks and biodiversity).

Using Synthetic Aperture Radar (SAR) data, many studies have established relationships between single or multi-channel data and the total above ground biomass, with most focusing on relatively homogeneous forests (in terms of structure). However, microwaves of different frequency and polarisation interact with different components of the forest volume. Hence, retrieval using a specific radar channel has been possible more because there is an inherent relationship between the magnitudes of the structural elements with which interaction takes place and total biomass [2].

Recognising the limitations of empirical relationships with backscattered intensity, a number of alternative avenues have been pursued for retrieving biomass, including the use of polarimetric classification, interferometry or polarimetric interferometry [3]. Many of these focus on the extraction of structural attributes (e.g., height) which relate to forest biomass, although such relationships are also variable and complex. A further technique which has been explored is a non-linear estimation algorithm for retrieving biomass [4]. Rather than attempting to establish a relationship with only one parameter, the algorithm utilises backscatter modelling to generate relationships between multiple parameters describing structure and dielectric properties (i.e., density, height and soil moisture). From these parameters AGB can be estimated. The approach is most similar to backscatter inversion. However instead of attempting to retrieve all the model parameters, the approach aims to establish links between parameters which have the greatest effect on overall backscatter and retrieve only these. From the retrieved structural attributes, biomass can be estimated using allometric relationships. Whilst the technique has not been widely developed, some promise in the retrieval of both structural attributes and the biomass of wooded savannas in Queensland, Australia, has been shown [4].

Following on from the study of [4], this research aimed to further demonstrate the use of the model for retrieving structural attributes and biomass, by focusing on woody regrowth dominated by *Acacia harpophylla* (Brigalow). This species was selected as it is a common component of regrowth occurring across the Brigalow Bioregion of Queensland, Australia, where land has been cleared previously for agricultural purposes. The regrowth is typically structurally homogeneous and often occurs in discrete and contiguous stands.

The study was undertaken in four stages. In the first, the wave scattering model of [5] was parameterised and used to simulate σ^0 from regrowth stands supporting a range of heights and densities. Next, non-linear curves were fitted to the simulated data to obtain functions relating scattering to a given number of unknowns (i.e., canopy depth and stem density). Scattering equations were then used iteratively to obtain canopy depth and stem density from AIRSAR data. Finally the allometric equations of [6] were used to estimate biomass.

2. THE STUDY AREA

The study focused on the Injune Landscape Collaborative Project study area which is located east of the township of Injune in central south-east Queensland (latitude 25°32', longitude 147°32'. Forests within the study area are structurally similar to 70 % of those found within Australia [7], as defined by the National Forest Inventory (NFI) classification and consist largely of woodlands and open forests. Within these areas, stem density and cover vary considerably.

The study area is located within the Southern Brigalow Belt (SBB) Bioregion, where Brigalow was a major component of the vegetation. However, extensive clearance of forests following European settlement and agricultural expansion has reduced the extent of the original Brigalow-dominated forests to less than 15 % of their original range [8]. Even so, Brigalow is dominant in many regenerating forests and while the recovery of Brigalow is welcomed, the high density of stems prevents regeneration of species with different dispersal mechanisms and can have negative impacts on the species diversity of forests. Brigalow favours clay soils and these occurred largely towards the south and west of the study area. Brigalow occurs in several forms including dense stands, with several thousand stems per hectare, whipstick and mature [6].

3. DATA COLLECTION

For the study area, on the 3rd September, 2000, the NASA Jet Propulsion Laboratory (JPL) acquired AIRSAR data in fully polarimetric mode at at C-band (5.6 cm wavelength), L-band (23.9 cm) and P-band (68 cm). For registration, ground control points (GCPs) were selected manually using georeferenced Landsat sensor data provided by the Queensland Department of Environment and Natural Resources.

From July to August 2000, plot-based inventories of forests and biomass (through destructive harvesting) were obtained for 34 plots in the study area, a full description is given in [2]. To support the parameterisation of the SAR simulation model of [5], additional field measurements were collected in April, 2009, with these including ground-based Terrestrial Laser Scans (TLS) obtained using a Leica ScanStation II. Structural measurements of regrowth dominated by Brigalow were also taken from 55 additional locations across the Southern Brigalow Belt (SBB) to further support model parameterisation.

4. METHODS

The wave scattering model of [5] was used, as in previous studies of wooded savanna [2] the simulated data corresponded well with actual SAR data. The model allows for calculation of backscatter at all polarisations and provides total backscatter in addition to component backscatter from the predominant scattering mechanisms of ground (single-bounce), volume (branch/foliage) and double bounce scattering (branch-ground and trunk-ground). The model takes multiple input parameters to characterise the size, geometric and dielectric properties of the forest. In parameterising the model it was assumed that the magnitude and of some parameters (e.g., leaf size and branch angle distribution) were constant. Parameters could also be related to each other through published allometric equation and relationships derived from fieldwork (e.g., height and canopy depth). Branch length and angle distribution are difficult to measure in the field. Therefore TLS data provided new opportunities to derive these measurements. Simulations were undertaken at an incidence angle of 42° and for C, L and P-band, equivalent to the average for

AIRSAR data acquired over Injune.

The modelling demonstrated C-band interactions were primarily attributable to volume scattering from foliage and small (< 1 cm diameter) branches in the upper canopy. At L and P-band scattering is primarily due to double bounce trunk-ground scattering and scattering from large branches. For young regrowth it was demonstrated in [**?**] stems and branches are not of sufficient size to evoke a response at longer wavelengths, subsequently the backscatter at L and P band is low. Therefore these bands were not considered further in this study.

In order to retrieve parameters from the SAR data it is assumed σ^0 can be expressed as closed form parametric equations relating total backscatter to a small number of unknowns, describing forest structure. The unknowns to be retrieved must be directly responsible for the dominant scattering mechanism. The backscatter modelling demonstrated that for young Brigalow regrowth canopy scattering was the dominant mechanism. The unknowns to be retrieved were canopy depth and stem density as these were considered to have the greatest impact on scattering.

With backscatter expressed in the form of a parametric scattering equation it was necessary to find values for the unknowns such the least-squared distance between predicted and measured σ^0 was minimised. A classification derived from a fusion of optical and SAR data [**?**] was used to identify areas of Brigalow regrowth. For these areas the estimation-algorithm was applied to generate pixel based estimates of canopy depth and stem density. The above ground biomass (Mg ha^{-1}), was estimated for each pixel using a relationship with canopy depth to provide total height, which was used in the allometric equation of [6] to give tree biomass. This was then multiplied by density to obtain total biomass (in Mg ha^{-1})

5. RESULTS

For the identified areas of regrowth, estimates of crown depth, stems density and biomass are presented in Figure 1. Estimated canopy depth varied from 0 to 2.2 m with an average of 1, stem density varied from 600 to 18,000 stems ha^{-1} with an average of 8,700 stems ha^{-1}. Biomass ranged from 0 - 35 Mg ha^{-1}, with an average of 5.2 Mg ha^{-1}.

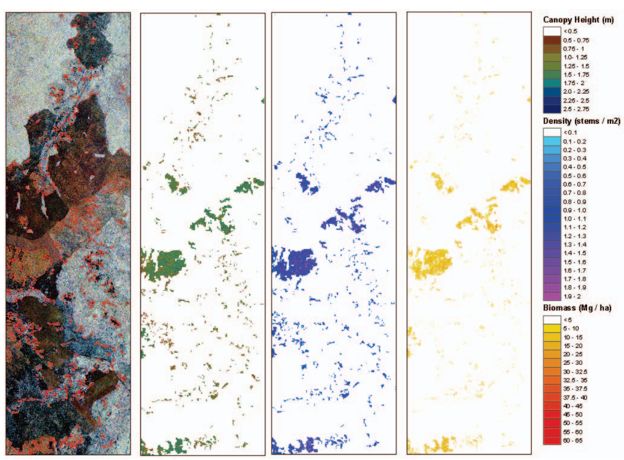

Fig. 1. a) Regrowth as observed in AIRSAR data using a combination of C-, L- and P-band Total Power (in RGB), b) Estimated canopy depth, c) Estimated stem density (stems ha^{-1}), d) Estimated biomass (Mg ha^{-1})

6. DISCUSSION AND CONCLUSIONS

The average biomass of 5.2 Mg ha^{-1} corresponded with an average biomass of 6.2 Mg ha^{-1} for brigalow of a similar age measured in others plots across the SBB. Lack of data with which to validate the results posed a problem mainly due to the limited coverage of the AIRSAR data. Expanding the approach to spaceborne data would provide wider coverage, allowing the use of additional field sites in the SBB for validation of not only biomass but estimates of canopy depth and stem density

This paper has demonstrated that an estimation approach to the retrieval of forest parameters is possible for Brigalow dominated regrowth, but the method could equally be applied to other forest types dominated by a particular structural formation provided that the SAR simulation model can be appropriately parameterised. Model parameterisation can be an issue as many of the required measurements are not typically recorded in the field. The use of TLS data has shown potential for the derivation of many model parameters, however further work is required to identify optimal methods for extracting these parameters.

The use of empirical relationships between a single structural attribute (e.g., density) and the SAR backscattering coefficient is limited because a number of factors combine to contribute to this value of σ^0. This research has demonstrated the potential of using a non-linear estimation algorithm for retrieving structural attributes, from which biomass might be estimated, as an alternative.

7. REFERENCES

[1] R. M. Lucas, A. Lee, and P. Bunting, "Retrieving forest biomass through intergration of CASI and LiDAR data," *International Journal of Remote Sensing*, vol. 29, no. 5.

[2] R.M. Lucas, M. Moghaddam, and N. Cronin, "Microwave scattering from mixed-species forests, Queensland, Australia," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 42, no. 10, pp. 2142 – 2159, 2004.

[3] T Mette, K Papathanassiou, and I Hajnsek, "Forest biomass estimation using polarimetric SAR interferometry," *2002 IEEE International Geoscience and Remote Sensing Symposium, 2002. IGARSS'02. Proceedings*, vol. 2, pp. 817– 819, 2002.

[4] M Moghaddam and RM Lucas, "Quantifying the biomass of Australian subtropical woodlands using SAR inversion models," *2003 IEEE International Geoscience and Remote Sensing Symposium, 2003. IGARSS'03. Proceedings*, vol. 3, 2003.

[5] S. L. Durden, J. J. van Zyl, and H. A. Zebker, "Modeling and observation of the radar polarization signature of forested areas," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 27, pp. 290 – 301, 1989.

[6] J. C. Scanlan, "Woody overstory and herbaceous understory in Acacia harpophylla (Brigalow) woodlands," *Australian Journal of Botany*, vol. 16, no. 521 - 529, 1991.

[7] P. K. Tickle, A. Lee, R. M. Lucas, J. Austin, and C. Witte, "Quantifying Australian forest and woodland structure and biomass using large scale photography and small footprint LiDAR," *Forest Ecology and Management*, vol. 223, no. 1-3, pp. 379–394, 2006.

[8] R.M. Lucas, N. Cronin, M. Moghaddam, A. Lee, J. Armston, P. Bunting, and C. Witte, "Integration of radar and Landsat-derived foliage projected cover for woody regrowth mapping, Queensland, Australia," *Remote Sensing of the Enviroment*, vol. 100, pp. 388 – 406, 2006.