A STUDY OF FOREST VERTICAL STRUCTURE ESTIMATION USING COHERENCE TOMOGRAPHY COUPLED TO A MACRO-ECOLOGICAL SCATTERING MODEL

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1. INTRODUCTION

This paper is concerned with a study of the use of single-pass radar interferometry to estimate vertical structure variations in forested environments. It has been shown in many previous studies that forest height and surface topography can be estimated using polarimetric interferometry or POLInSAR [1], but here we show that there is potential also for estimating vertical structural parameters related to species variations and growth conditions. Key to our study is a fusion of two ideas, the first is use of a macro-ecology model for forest structure and its coupling to a radar backscatter simulation to obtain a vertical scattering profile. We then couple this to a 3-D radar imaging technique called coherence tomography (CT), which enables reconstruction of the vertical profile up to a resolution dependent on the number of baselines available. We show calculations at both P and L bands for a variation of forest types and conclude as to the potential of this technology for application in future single-pass interferometer missions such as Tandem-L.

2. METHODOLOGY

In this study we make extensive use of a macro-ecological vegetation model first developed by West Brown and Enquist [2] (the WBE model) and developed for radar applications by Woodhouse [3]. The WBE model characterizes the geometric structure of a plant, and by extension to a collection of plants in mutual competition, through a number of power laws derived from biological and biomechanical considerations. In summary, it proposes a 6-parameter model to represent variations in both horizontal and vertical structure. These parameters are described below:

1) a= scale factor (how radii of branches change within the plant). For example, a = 1 is the area preserving pipe model. A more typical value is around 2/3, but variations occur between species. Generally speaking, low values of a are associated with 'bushy' canopies while large values with bulky stems.

2) N = number of branching levels (level 0 is trunk, level N is the petiole)

3) n = branching ratio (number of daughter branches from the parent), for example, n = 2 for broadleaf species and n= 6 for conifers

4) r_k – radius of cylinder at scale k, so r_0 = radius of trunk and r_N the radius of the petiole.

5) L/r = length-to-radius ratio of cylinders. The WBE proposes an optimum power law relationship between branch length and radius.

These five are augmented by an additional parameter governing horizontal scale variations. These are of particular importance for any remote sensing technique that measures spatial average parameters rather than individual tree properties. Such is the case, for example, for low-to-moderate resolution space borne SAR systems. This parameter derives from the stem density (number of stems/ha) and often relates to the thinning in a forest. It can be parameterized as follows.

6) d = thinning exponent. This ranges from 0 for constant number density (no thinning) to 3 for situations with a high rate of stem mortality not driven by competition alone. Within this model, d does not effect the shape of the vertical volume profile, only the magnitude, but it does impact on the surface-to-volume ratio.

These structure parameters have an impact on the estimation of biomass from height for example. According to the WBE model height h is related to average biomass M by a power relation of the following form:

$$M \propto h^{(6a+2-3da)/2} = h^{x} \qquad - 1)$$

We see that the relationship depends on structure, primarily via the two parameters a (relating to vertical structure) and d (relating to horizontal structure). We conclude from this that knowledge of vertical structure would help the accuracy of biomass estimation from height and that, on the contrary, absence of knowledge about forest structure will lead to errors in the estimation of biomass, even for a 'perfect' height measurement system.

3 CONCLUSIONS AND INITIAL RESULTS

To estimate structure, we propose a technique for 3-D radar imaging called coherence tomography (CT), which can be used to estimate a band-limited form of the vertical scattering profile [3]. This technique, in distinction to other tomographic approaches, requires data for only 1 or 2 baselines and hence is well suited for application to future single-pass space sensors such as Tandem-L. Details of the coherence tomography approach can be found in the references [1,4]. The key novel feature of this paper is to calculate the Legendre spectrum of the profiles, as CT can only estimate the low frequency components of this spectrum. In this study we therefore calculate the spectra for varying parameters and forest structures using a numerical EM scattering code with a view to assessing the potential for structure retrieval based on radar measurements. As an example, Figure 1 shows a sample L-band vertical profile (in black on the left) and its corresponding 7^{th} order Legendre spectrum (on the right). In red we show the single, in magenta the dual and in blue the triple baseline reconstructions of this profile.

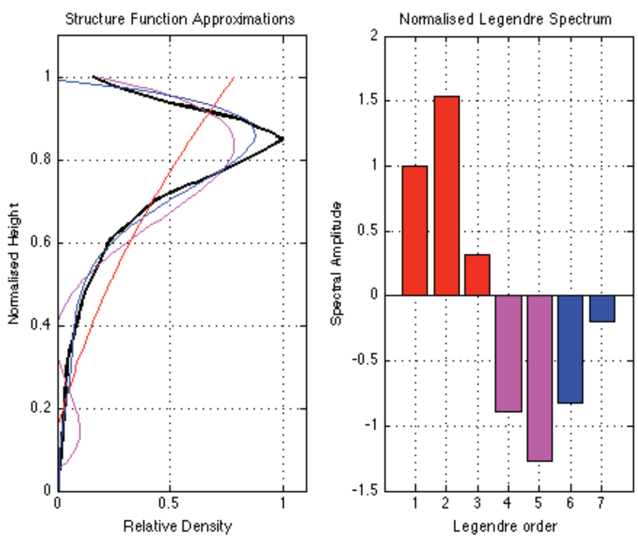

Figure 1 : Sample L-band Vertical profile (left) and corresponding Legendre spectrum (right)

In this case we see that at least a dual baseline sensor would be required to reconstruct the main features of the profile. In the final paper we will explore this relationship across a wider parameter space of the WBE model and conclude as to the potential for CT to extract important structural parameters and hence aid biomass estimation and provide new forestry related products.

4. REFERENCES

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