POLARIMETRIC INTERFEROMETRY IN FORESTRY APPLICATIONS : A REVIEW

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ABSTRACT

In this paper we review of recent developments in the use of Polarimetric Radar Interferometry for tree height estimation and ground topography mapping. We first motivate the subject by demonstrating the importance of tree height in the remote sensing of global vegetation cover and biomass. We then summarise the main aspects of the technique, outline the use of a 2-layer coherence model widely used for data inversion and show data validations from three important forest test sites; Oberpfaffenhofen and Fichtelgebirde in Germany and Glen Affric in Scotland. We conclude with an assessment of the potential future applications of this technology.

INTRODUCTION

Radar Interferometry is a mature technology for remote sensing [1]. Airborne sensors are now capable of reliable repeat-pass interferometric measurements. In this way, data was collected at the three sites of interest using the DLR airborne multi-baseline repeat-pass L-band Polarimetric Interferometric [2] E-SAR system. All data was processed using the DLR-SAR processor combined with detailed flight track information from a hybrid GPS-INS navigation system. The calibrated SLC data was then used to obtain estimates of tree height across several different species and spatial distributions of forest cover. The algorithms employed are all based on a 2-layer coherence model accounting for the effects of ground scattering on the observed coherence [3,4,5]. Comparisons have then been made between the radar predictions and in-situ data, enabling quantitative estimates of the accuracy of the technique to be made.

The structure of vegetation is a key ecosystem factor that reflects biomass stock successions and growth dynamics. Parameters such as tree height, crown width, stand and canopy density and the underlying ground topography are direct inputs into biomass determination models and enable ecological process modelling, forest inventory and predictive modelling in hydrology. It should also be pointed out that global forest inventory and forest (above ground) biomass are currently critical missing parts in the global climate change debate. Hence there is a need for a reliable remote sensing technique to provide such information.

Radar is well suited to this problem as it provides penetration of vegetation cover and hence is inherently sensitive to volume effects.

The conventional approach to biomass estimation with radar has been based on empirical regression relationships between radar backscatter amplitude and biomass. In the simplest case, backscatter amplitude increases as biomass increases, because of increased volume scattering. Unfortunately this correlation saturates at levels well below those required for global monitoring. Although the saturation point increases with decreasing frequency, the range of biomass levels accessible at commonly used radar frequencies is limited. At C-band for example, the saturation occurs around 20 tons/ha and even at the much lower frequency of P-band saturation occurs at around 120 tons/ha. It is estimated that approximately 40% of the worldÕs vegetated surface containing nearly 80% of the above ground biomass are therefore above the saturation level even of P-band. Given the difficulties of operating space borne radars at P-band, this does not bode well for such an approach.

On the other hand, if tree height is known as a single parameter then reliable estimates of biomass up to 250 tons/ha become feasible using allometric relations. If species information is added to this, the saturation point rises to around 400 tons/ha. Even at the lower limit this would then enable mapping of 70% of the worlds vegetated surface containing 80% of the total biomass.

For this reason, radar interferometry offers great potential in biomass applications. The key observables in interferometry are not the scattering amplitude but the local phase and its variance (coherence) [1]. The local variance increases with increasing vegetation height and there is formally a Fourier Transform relationship between the vertical extent of the vegetation and the observed coherence, with the vertical wavenumber of the interferometer as the Fourier variable. This provides the basis for height estimation using radar interferometry. However there are three complicating factors to distort this simple model:

1. We must include the effects of wave extinction due to propagation through the volume, which tends to bias the contribution from upper layers of the volume, especially at high frequencies. The higher the extinction the higher the coherence, for a fixed tree height. This causes ambiguity in the estimation of height using coherence.

2. The penetrating properties of microwaves means that the ground also scatters some energy back to the radar. The effect of a direct ground or ground/volume dihedral signal mixed in with the volume return tends to bias the coherence upwards, especially at lower frequencies. Again this causes error in height estimation.

3. The vegetation is not located on a flat surface but on the varying topographic variations of the earthÕs surface. These topographic variations cause no change in the coherence but modulate the phase of the interferogram and are combined with the vegetation bias offset to provide a mixed phase signal.

These three effects mean that we face at least a four-parameter estimation problem in the inversion scheme. Not surprisingly this inversion is non-unique for a single channel interferometer and so a multi-parameter interferometer approach is required. Various solutions have been suggested to this problem, including dual frequency, multi-baseline [5] and tomographic processing [6]. However the only single baseline, single wavelength proposal has been through polarimetric interferometry (PI) [2,3,4].

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In PI, the scattering matrix is measured at either end of the baseline and coherent combinations of polarisation states used to separate the parameters required. It has been shown in [3] that under certain weak assumptions, PI is capable of providing estimates of all four important unknowns, namely tree height, ground topography without vegetation bias, mean wave extinction and ground-to-volume scattering ratio. Work so far has concentrated on providing accurate height estimates for biomass estimation and forest mapping applications.

The key requirement of this method is to have variation in the ground-to-volume scattering ratio with change of polarisation state. Hence the technique requires oblique incidence onto the surface (which is the usual case for imaging radar geometries) and a frequency low enough to guarantee enough ground scattering contribution to modulate the coherence. Importantly, this requirement seems to be met at much higher frequencies than the corresponding amplitude constraints. Data presented here shows good performance even at L-band, which is a well established radar frequency for space based remote sensing applications and suffers less from the problems inherent in P-band operation.

In this paper we present results from three very different European forest test sites. Two are located in Germany while the third is located in Glen Affric in the North West of Scotland and has been studied by the ScotSAR consortium [7]. Between them, these sites present significant variation in tree species, tree heights and underlying ground topography and hence provide a good test of the robustness of the algorithms. Figure1 shows sample results for forest height estimation in a test site in Bavaria. Figures 2 and 3 show combined tree height and ground topography estimates for the Scottish test site.

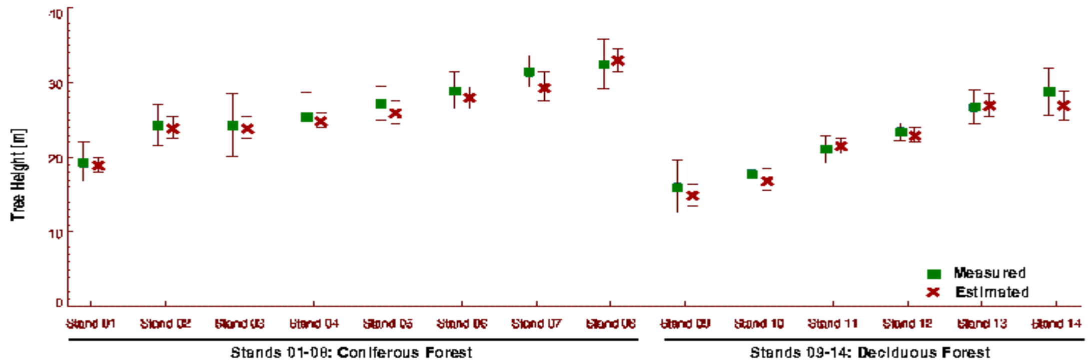

Figure 1 : Radar Derived Tree Heights vs. In-Situ Measurements for L-Band ESAR data (ref [4])

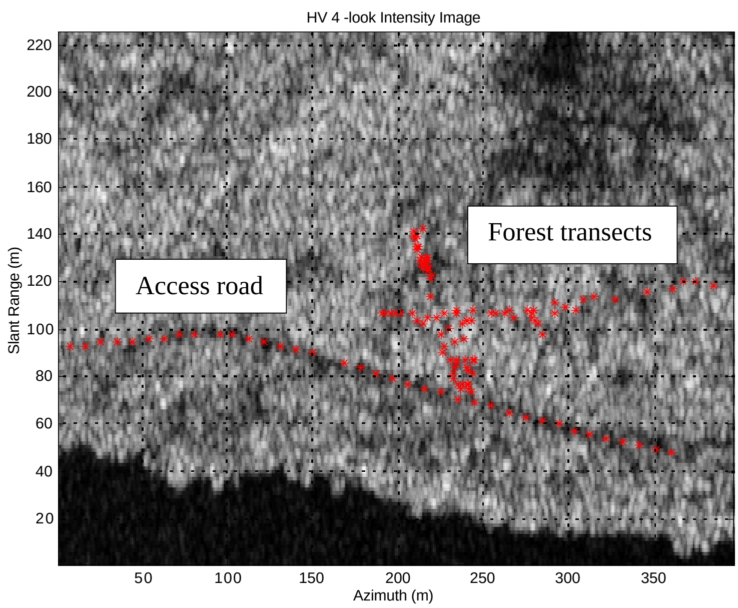

Figure 2 : L-Band SAR Image of Glen-Affric Test site with forest range and azimuth transects marked

CONCLUSIONS

In this paper we demonstrate the potential of Radar technology to provide day/night, all weather quantitative height estimates for use in important forestry applications such as biomass estimation and ecology studies. This is achieved by using Radar interferometry with polarisation diversity, a combination that is well suited to single pass airborne as well as satellite based global mapping applications.

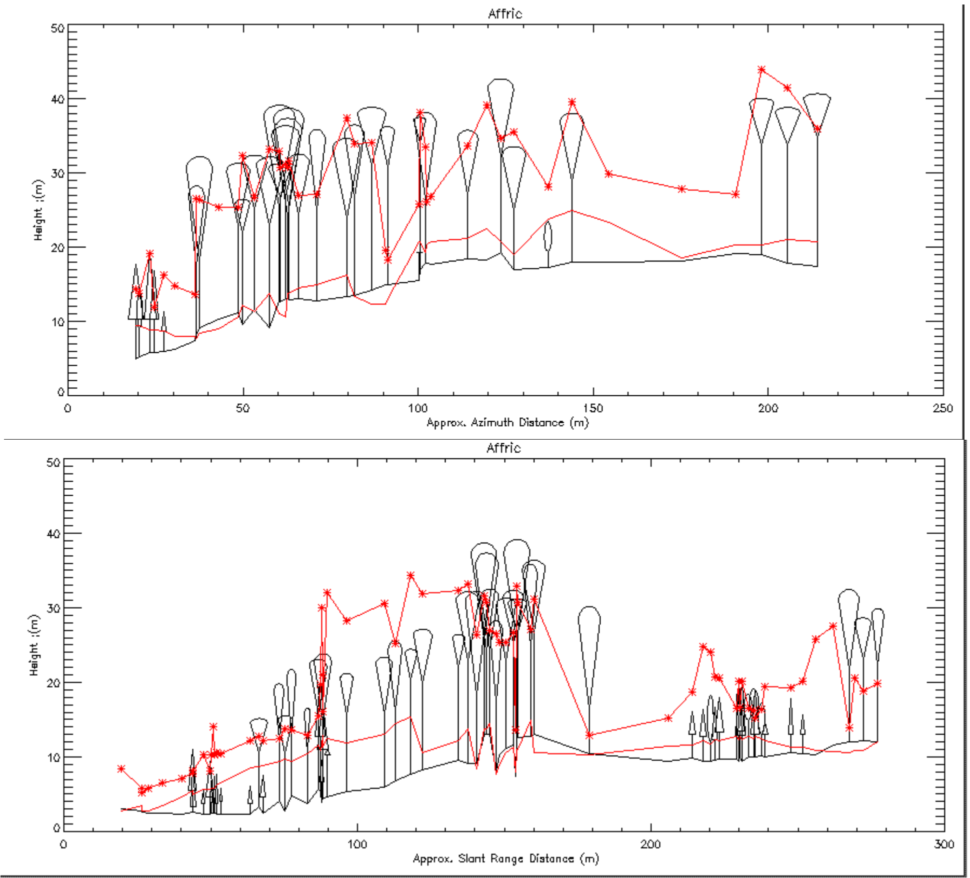

Figure 3 : Comparison of radar derived tree height and ground topography vs. In-situ measurements for range and azimith transects (reference [7])

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