EVALUATING POLINSAR TREE HEIGHT AND TOPOGRAPHY RETRIEVALS IN GLEN AFFRIC

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Abstract– In this paper we summarise recent results from the Glen Affric radar project aimed at evaluating polarimetric radar interferometry for providing vegetation canopy height and bald-earth topography. We present a comparison of results from L-band repeat pass SAR imagery with detailed in-situ measurements of forest height and topography.

1 INTRODUCTION

In May/June 2000 the BNSC and NERC sponsored a radar measurement campaign in the UK over a range of test sites (SHAC). Glen Affric in Northern Scotland was one of selected sites and 6 radar passes were gathered with offset baselines of 10 and 20m enabling single and dual baseline interferometric analyses. The key approach taken in this study was to investigate the use of fully coherent polarimetric SAR data in the important role of widespread and frequent monitoring of natural and semi-natural habitats of the countryside.

SAR is sensitive to structural parameters of vegetation and, in particular, L-band polarimetric SAR is especially suited to vegetation mapping because it is sufficiently sensitive to both canopy and sub-canopy parameters. Repeat pass interferometry therefore has the potential to produce a true ground DEM of the test site (with minimal vegetation bias), estimate forest height and potentially canopy extinction [1,2].

Forest height is an important ecological parameter as well as a key indicator of above ground biomass. The underlying topography of a forest is another important parameter that at present is only partially known for many areas of highly important and widespread ecosystems. The ability to measure such forest parameters quickly and efficiently is becoming more and more important as forest resources come under increasing pressure and as the need for accurate forest inventory data for climate modelling grows [3,4]. Apart from forest management having an accurate digital elevation model (DEM) of a forested area is important in several fields, from predicting the distribution of plant species and animal behaviour, to providing inputs for climate models. Components of terrain that can be provided by a DEM include elevation, aspect and gradient. These can be used for mapping out drainage networks and separating water catchments, especially in poorly surveyed areas [5]. These features also determine a plethora of other factors such as soil water and nutrient content, temperature and number of day degrees/year. Areas of study requiring elevation and derived data include ecology, hydrology, soil science, geology, archaeology, forestry and meteorology. In ecology DEMs are important in modelling and predicting species distributions, for example using hydrology and soils data as inputs (e.g. [6,7,8,9]).

Forestry applications include planning timber extraction operations (e.g. planning skid trails to minimise erosion) predicting seedling establishment, soil water regime and chemistry and modelling the effects of fire and wind. At larger scales topography is used as input into catchment models at various scales (often through hydrological models), and these in turn are integrated into larger models e.g. coupled GCMs.

2 THE GLEN AFFRIC TEST SITE

The test area is located in the North West Highlands of Scotland. It is mountainous and combines several important challenges for radar remote sensing, including heterogeneous forest cover, sloped terrain and a broad distribution of tree heights. The Glen is important in Scotland as a conservation area and focus of the natural regeneration of the Caledonian forest (consisting principally of Scots pine, *Pinus sylvestris*). Figure 1 shows a photograph of the forest test as well as an

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example of nearby small plantations and understory. Tree heights vary from a few metres up to 30m or more for the

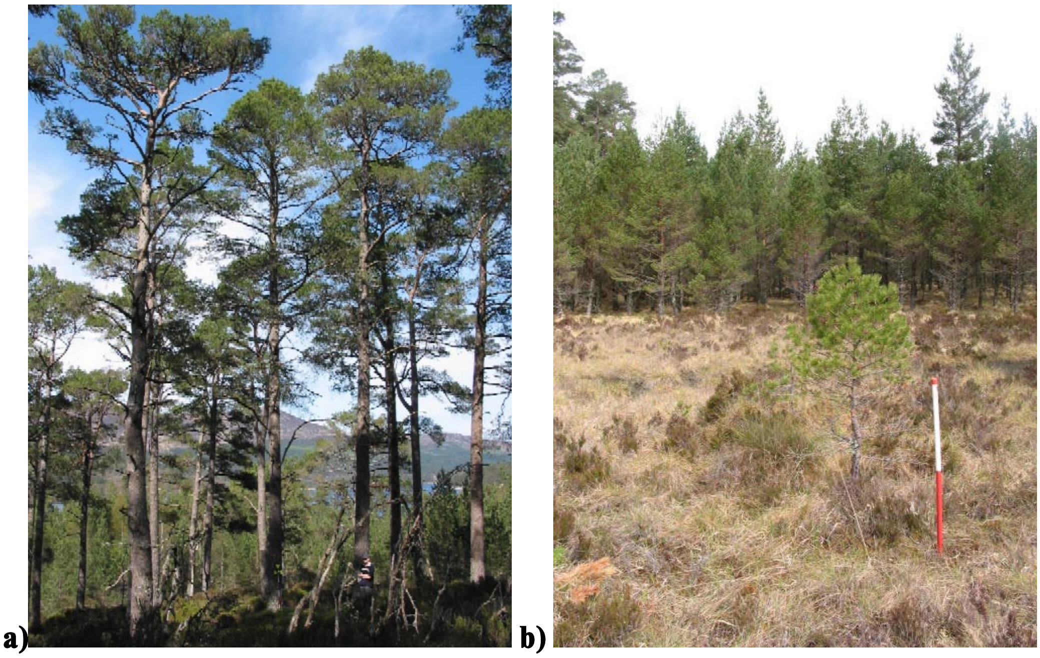


Figure 1 : (a) Forest test stand in Glen Affric test site illustrating the high sparse canopy typical of the Caledonian pine forest. (b) At the edge of the test site lie some small plots of cultivated Scots pine.

larger Scots pines. Further information on the test site can be found in [10].

3 MULTI-BASELINE DEM OPTIMISATION

One of the limitations of repeat-pass single polarisation interferometry is that vegetation volume scattering effects reduces the phase coherence and can also contribute a height bias (in proportion to the canopy height). By choosing the transmit and receive polarisations that results in the highest local phase coherence, the effects of vegetation should be reduced. A novel additional technique was to incorporate information from both baselines (10 and 20m). The shorter baselines provides higher coherence than the longer baseline, but is less sensitive to topographic variation. The technique employed here was to first unwrap the 10m baseline phase using a region growing algorithm with a local (7x7) least squares solution. The 20m phase was then unwrapped relative to the 10m solution.

Such a dual-baseline technique uniquely gives the high sensitivity of the larger baseline by utilising the higher coherence of the smaller baseline. This study is the first investigation of this method in an area of varied topography.

4 FOREST SCATTERING MODEL

To interpret the coherence information for the test site a multi-layer coherent model of forest scattering was employed. According to the 2-layer model derived in [1,2,11], the complex interferometric coherence for a random volume over a ground can be described by a function of polarisation scattering mechanism, with 4 unknown parameters, namely

m_1 – the ground to volume scattering amplitude
σ – the mean volume extinction
h_v – the height of the forest
ϕ – the ground topographic phase

However with only two measurements (the amplitude and phase of the coherence) a single channel interferometer is not able to provide unambiguous structural information. The addition of a second polarimetric channel adds two new measurements while adding only one new unknown (m_2). Similarly, by adding a third channel we obtain 6 measurements for 6 unknowns so that by employing full polarimetric interferometry we should be able to obtain quantitative parameter estimates. The inversion procedure is described in detail in [3].

The model normally assumes a uniform density of scatterers from ground to crown, which has been appropriate for previous test sites [3]. However, from Fig. 1 we can see that this is not typical of the Scots pine tree structure. The effect of such high canopies will be to overestimate the extinction and the tree height. Dual baseline techniques are expected to resolve this canopy structure problem but here we concentrate on the errors caused in single baseline inversions. The model was therefore modified so that we assume that σ is known: in this case it is set to 0.1 dB/m for L-band, although for shallow canopies the value chosen does not strongly influence the results. A new free parameter is introduced that represents the phase elevation of the canopy. It is therefore feasible to estimate the canopy depth, ground topography and tree height using the inversion scheme.

5 Validation Data

Since the test site was heterogeneous and rather sparse, with ground variations of 20m, simple stand averaging of tree heights was inappropriate. Detailed survey transects were therefore taken over two test sites, taking measurements of x, y and z of the tree base (and occasional spot heights), diameter at breast height (dbh) and tree height. Crown size was also measured. Two main transects were made – one in approximately the SAR range direction, the other in azimuth.

The relative accuracy of the tree measurements are less than 1m (x, y, z) for the ground locations and approximately +/- 2m for height. As can be seen from Fig. 1, a major source of error can simply be deciding what constitutes the top of the tree. Two corner reflectors located at either end of the complete data take were used to help correlate the image co-ordinates to map co-ordinates. We estimate final locational uncertainties (for ground points) between field data and SAR data to be in the region of +/- 3m in azimuth and +/- 5m in range (approx. 4 pixels). Crown locations are more uncertain and are considered below.

A UK Ordnance Survey (OS) DEM (Land-Form PANORAMA™, 10 m grid interpolated from 10 m contours) was available within the study for comparison with the survey points and radar data. The OS tile containing the test site is NH22SW. The Panorama DEM is the standard topographic product used by a number of agencies within the UK. Comparison with this data set was therefore a priority of this study.

5.1 Results: Tree Height

Fig. 2 shows the azimuth and range transects and clearly demonstrate that the retrieved height pattern is well correlated with the measured trees. The underlying topography of the test site is not shown in these plots. Trees that lie within 5m off the transect line are included in the comparison and are located in the figure by their true horizontal distance along the transect. The starred points and connecting line represent the retrieved height value for the crown slant range location in the retrieved data (i.e. spot heights will be unchanged, but trees of a given height are compared against the retrieved values corresponding to their slant range ("lay over" location). The retrieved points include the height of the scaled unwrapped phase. In order to help account for locational errors, the retrieved height shown is actually a 3x3 pixel average centred on the slant range location.

This way of comparing the data is required because the retrieved height will be located at the slant range location of the crown, not the tree base. This introduces another locational uncertainty since the height of the scattering centre will not be the same as the measured tree height. Such uncertainties may help explain the results of the range transect in Fig. 2 whereby some of the taller trees are not always well correlated in range to the higher retrieved values. Despite this, the correlation between measured and retrieved heights in the range transect give a linear Pearson's correlation coefficient R=0.88. For the azimuth transect the results also appear well correlated with R=0.90.

5.2 Results Topography

Fig. 3 shows the OSDEM overlain with contours representing the SAR retrieved topography. The data appears generally well-correlated, although there are some noticeable localised discrepancies. There is a good correspondence between the shape of the mound in the OSDEM data and its shape in the radar data, for instance, although it should be borne in mind that the final fine-scale co-registration of the two datasets was done using a global correlation routine. (This was considered appropriate since we focus here on vegetation bias, not geolocation accuracy).

The biggest anomaly that appears is the rise in the radar surface on the northern face of the mound. While there is a rise present here on the ground, it is greatly overestimated by the radar data. This is also an area of denser tree cover. The most encouraging thing from these results is that the retrieved topography generally follows the trend in the actual topography, rather than following the trends in tree height variation.

Fig. 4(a) shows the relationship between OSDEM heights and retrieved heights. The overall linear Pearson correlation coefficient is 0.70 with an RMS error of 6.5m. Numerous individual transects have also been considered (but not shown here) which have correlations range from R = 0.83 to 0.98. It is clear from the figure that there is also a positive bias in the results, giving a mean overestimate of the height by 5.7m. It is likely that this bias is a remnant effect of the vegetation cover since even the optimised polarisation signal will have some contribution from the canopy. However, analysis of the residuals between the OSDEM and retrieved values shows no obvious pattern with canopy height, as illustrated in Fig. 4(b). The low correlation coefficient (R=0.1) between the residuals and the canopy height may be a consequence of the heterogeneous canopy in this study area and will require further investigation to isolate the direct source of the bias. When the bias is removed, a posteriori, the resulting RMS error is only 3.3m.

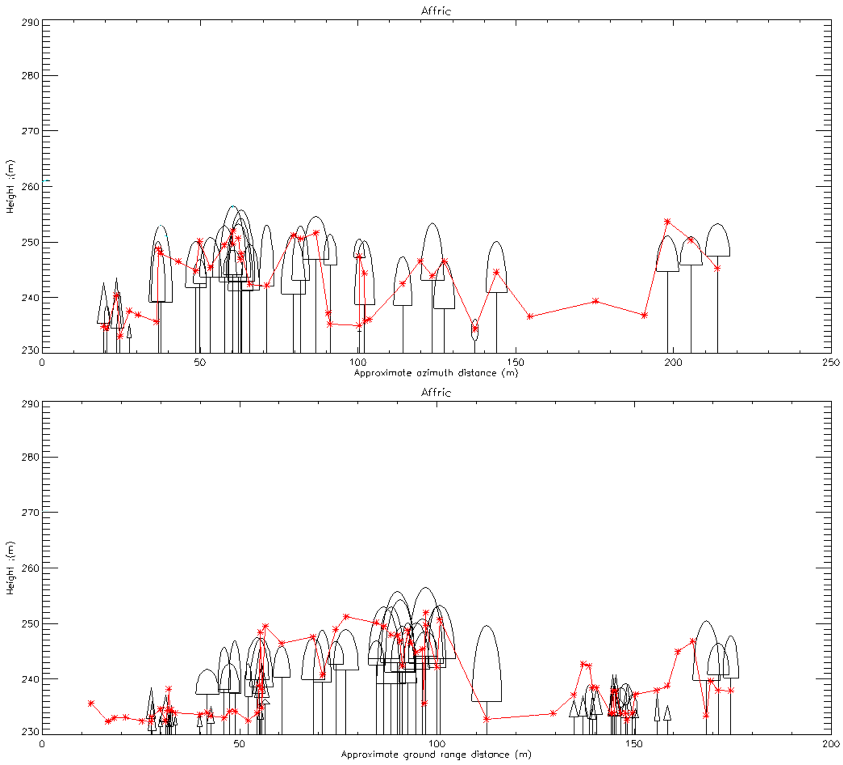
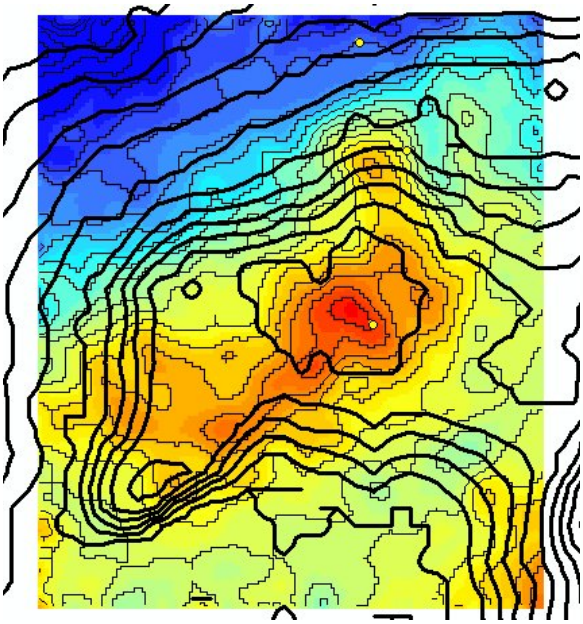
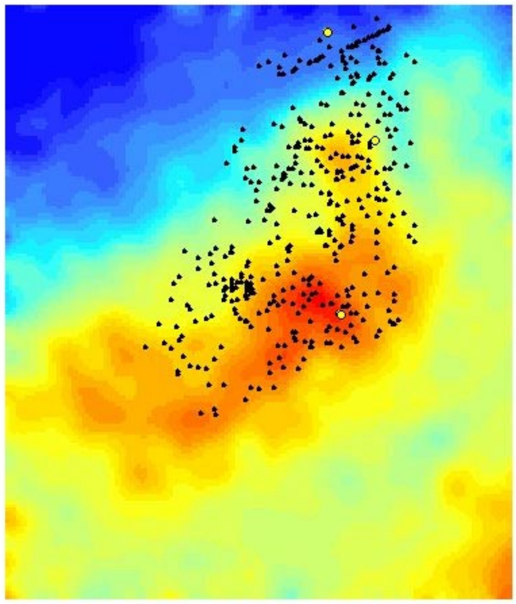


Figure 4 : Tree height and topography estimates vs. ground truth for the two transects: azimuth (upper) and range (lower). Retrieved heights include a contribution from the scaled unwrapped phase to provide a indication of the total retrieval capability.





a **b**

Figure 3. Comparison of matched radar data with OSDEM 2 me contours (a) and the location of all trees surveyed (b). The test area shown is 300m across.

6 DISCUSSION OF RESULTS

For tree heights, despite the reasonable correlation, there are three noticeable discrepancies between the radar results and ground data. The first is that the retrieval process generally appears to underestimate the tree heights. This is fully expected, as the L band response is sensitive to combined ground and canopy features in all polarisation channels.

The second is that where the field measurements imply no trees, the retrieval can indicate positive tree heights of greater than 5m. This may be caused by mismatching tree locations and heights in addition to SNR coherence problems in non-vegetated areas yielding spurious phase shifts in the data.

A third problem is that in some instances the retrieval *significantly* underestimates the tree height. For example, in the range transect, at around 20m, there is a sharp change between small pines and taller ones behind but the results do not reflect this until nearer 25m. The slant range distances for the shorter canopy at 15m coincide with the slant range to the taller crowns at 20-25m. With canopy scattering from two distinct locations and no clear ground response there is an ambiguity in the tree height.

For bald-earth topography retrievals, the results are very encouraging, since although there remains a positive bias of about 6m, the tree cover does not appear to have a significant influence on the retrieved interferometric height.

7 CONCLUSIONS

Following comparison with in situ data the results indicate that L-band PI is capable of providing an estimate of tree height and underlying topography, even when the forest is heterogeneous. Future studies will concentrate on further comparisons of the radar observations with ground data, especially for identifying trends with underlying ground topography and variations in canopy structure. Additionally we hope to make comparisons between the data presented here and other topographic data sets (retrieved from other instruments and from new field data).

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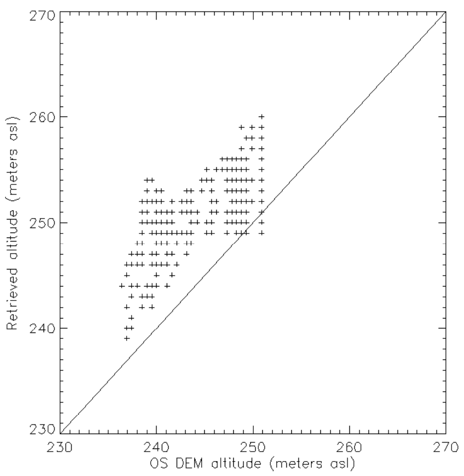

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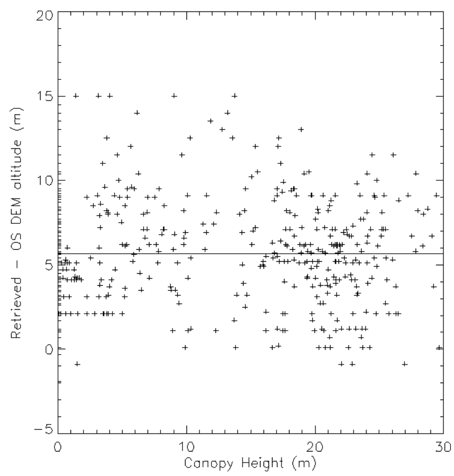

b)

Figure 4. (a) Correlation of OSDEM heights and radar retrieved height across the test stand. The correlation coefficient is R=0.70, with a RMS error of 6.5m. The positive bias is 5.7m. (b) When the canopy height is compared to the height residuals, there is no apparent pattern (R=0.1) suggesting that the canopy height is not the dominant source of error.