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Forest classification and height indicators using L-band SAR

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ABSTRACT: This paper presents an analysis of optimised coherence produced from airborne L-band SAR at 10m and 20m baselines. It is shown that a supervised classification based on coherence appears to produce an improved differentiation between tree heights and densities when compared to a backscatter classification. The relationship between coherence and tree height is also considered, and is found to be not as consistent as would have been expected. An explanation of why this may be is given.

1 INTRODUCTION

The use of remote sensing techniques in operational forestry and vegetation studies has, until recently, been limited to visual interpretation of aerial photographs. This process is time consuming, both for data acquisition and the analysis, which requires many person-hours per data set. Advancements in technologies have seen the introduction of digital systems on airborne and satellite platforms. This has allowed extensive research over large areas. Other optical sensors, both airborne and satellite based, have been at the front of recent research initiatives, and have proven promising for estimating several forest parameters. Optical sensors still however suffer from weather restrictions and in particular cloud cover, with many data scenes cloud covered for many days a year, and data sets are characterised by generally having some cloud cover present, or they are limited to a small time-window each year. This issue is particularly pertinent in tropical climates and temperate Europe.

Synthetic Aperture Radar (SAR) is increasingly approaching a cost effective alternative for data capture in operational forestry. SAR, being an active microwave instrument, is independent of light conditions and is minimally attenuated by cloud cover. Additionally, interferometry and polarimetry techniques mean that previously unobtainable information can be gathered, such as tree height and below canopy terrain. These techniques will be briefly discussed in the following sections.

The current study is assessing the capabilities of L-Band ESAR data to aid forest management, with validation in Glen Affric, an area of mountainous terrain in Northern Scotland that includes both plantation and natural forest. This paper will present results of quantifying the success of different classification methods using a range of SAR data channels to identify the optimal configuration for mapping different forest characteristics. Results will be assessed by comparison with ground truth and forest management data.

The mapping products assessed will be of interest to parties concerned with the management of forests. As such, estimates of forest structure parameters are possible and fall into two classes; qualitative maps provide indication of forested area, forest cover type and species, and quantitative maps potentially giving estimates of tree height, dbh and tree densities. These parameters can then be used as inputs to current models to produce improved estimates of age, timber volume, biomass and change detection (e.g. fires, deforestation and planting, which will assist forest certification).

2 BACKGROUND

2.1 *SAR*

SAR operates in the microwave part of the electromagnetic spectrum, and as such has wavelengths ranging from cm to metres (Table 1). SAR, being an active microwave instrument, is independent of light conditions and cloud cover, and thus can be operated when other sensors cannot. One further advantage of SAR over other sensors is the ability to penetrate through the canopy. This enables more information about the target area to be gathered compared to optical systems. The size of the wavelength is important when deciding what needs to be measured, as the signal may interact with a target scatterer that is of similar size to the wavelength. The amount of signal penetration through a vegetation canopy is therefore dependent on wavelength. As such, C-band receives a return from the upper part of the canopy (commonly referred to as the "top" of the canopy, although some penetration occurs) as the wavelength is on the same scale as the leaves and smaller branches; whereas P-band receives returns from the ground and larger branches and trunks (Figure 1). This study utilises L-band system data as decimetre wavelengths allow good penetration through the canopy to the ground.

Table 1. SAR wavelengths used in vegetation studies

Radar Band	Frequency (GHz)	Wavelength Range (cm)	Typical Wavelength (cm)
X	8.0 - 12.5	2.4 - 3.8	3
C	4.8 - 8.0	3.8 - 7.5	5.6
L	1.0 - 2.0	15.0 - 30.0	23.5
P	0.3 - 1.0	30.0 - 100.0	75

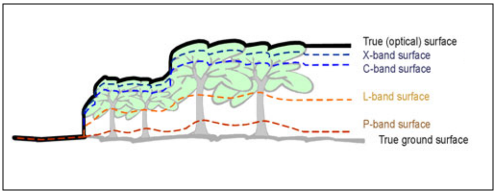

Figure 1. SAR penetration through canopy

2.2 *Techniques*

There are currently four techniques being used to assess the potential of SAR for forestry applications, these are: backscatter intensity, interferometry (InSAR), polarimetry (PolSAR) and polarimetric SAR interferometry (PI). These will be briefly outlined below.

2.2.1 *Interferometry*

Interferometry utilises phase measurements and the differences in phase between two sensor positions (temporal or spatial separation) to make accurate estimates of scatterer location. It does this by making precise measurements of the relative path length distance to the object from two positions. This coupled with the time-delay geometry of the SAR system can be used to estimate the location of a target, an in particular, to estimate the height of the target (see Madsen and Zebker, 1998).

2.2.2 *Polarimetry*

Polarimetry uses information on the orientation of the transmitted and received electromagnetic wave, and thus information on the orientation or shape of the target can be gathered. Knowing the orientation of the signal, it is possible to differentiate between orientation effects of the target, and therefore differentiate between types of scatterer. For example, between ground (polarising) and canopy (depolarising) (Cloude and Pottier, 1996).

2.2.3 *Polarimetric SAR Interferometry*

PI combines the advantages of interferometry in estimating location with the differentiating properties associated with polarimetry to separate signals returned from the ground and the canopy to give improved tree height estimations (see Cloude and Papathanassiou, 1998; Stebler *et al*., 2002).

3 DATA SETS

SAR data for the study was collected by DLR using airborne L-band fully polarimetric dual-baseline interferometry which formed part of the E-SAR SHAC campaign during June 2000. Ground data has been gathered from the corresponding area comprising plantation and semi-natural remnants of Caledonian Scots pine (*Pinus sylvestris*) forest in Glen Affric, Northern Scotland. Glen Affric offers a unique opportunity to assess the capabilities of SAR, as the area is characterised by rapidly undulating terrain, as well as varied vegetation composition (Cloude *et al*., 2001).

Polarimetric SAR Interferometry (PI) techniques (Cloude and Papathanassiou, 1998) were used to produce optimised coherence images from the initial data. In this case, the polarisations are varied to find the optimum transmit and receive pair. These comprised three optimised images for both a 10 and 20 metre baseline.

4 APPROACH

The use of backscatter to classify SAR images has been used to map forests with varying degrees of success. This technique does not necessarily use the data to its optimum, and produces little more detail than that of optical sensors. Research has more recently been assessing the capabilities of coherence (correlation between images) to produce more detailed information (Luckman *et al*., 2000; Gaveau *et al*., 2003; Fransson et al., 2001; Castel *et al.,* 2000). The parameters which govern coherence (e.g. vegetation height, density, structure) may tell us more about the land cover than other techniques. The current study took a three stage approach to assess the optimised coherence from our test site.

A visual interpretation of the optimised coherence images was undertaken. This involved comparing the 10m and 20m images as RGB colour composites of the three optimised images per baseline (Figures 2a and 2b). Coherence ranges from low (black) to high (white).

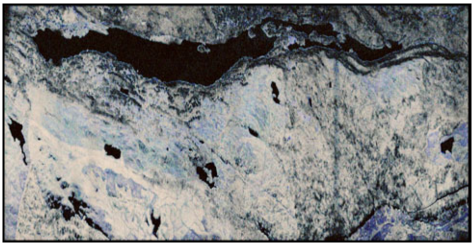

Figure 2a. RGB colour composite of the three optimised coherences for 10m baseline.

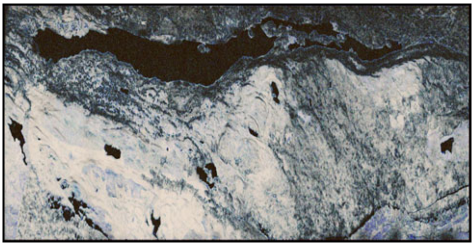

Figure 2b. RGB colour composite of the three optimised coherences for 20m baseline.

When visually analysing the coherence, it can be seen that when increasing the spatial baseline, the sensitivity to vegetation increases. It is possible to attain a qualitative impression of vegetation structure in Glen Affric by comparing the two baselines. The10m baseline allows discrimination of the most dense or largest vegetation (Figure 2a), with the 20m baseline being additionally sensitive to smaller or less dense vegetation (Figure 2b).

Classification

The next stage was to classify the optimised coherence images, a supervised maximum likelihood classification utilising all six images was undertaken to create a structure map comprising four classes (Figure 3). The resulting classification was then compared to a supervised maximum likelihood classification of the backscatter (Figure 4, Wallington et al, 2002). It should be noted that this image was created from a georectified RGB colour composite of the HH, HV and VV channels.

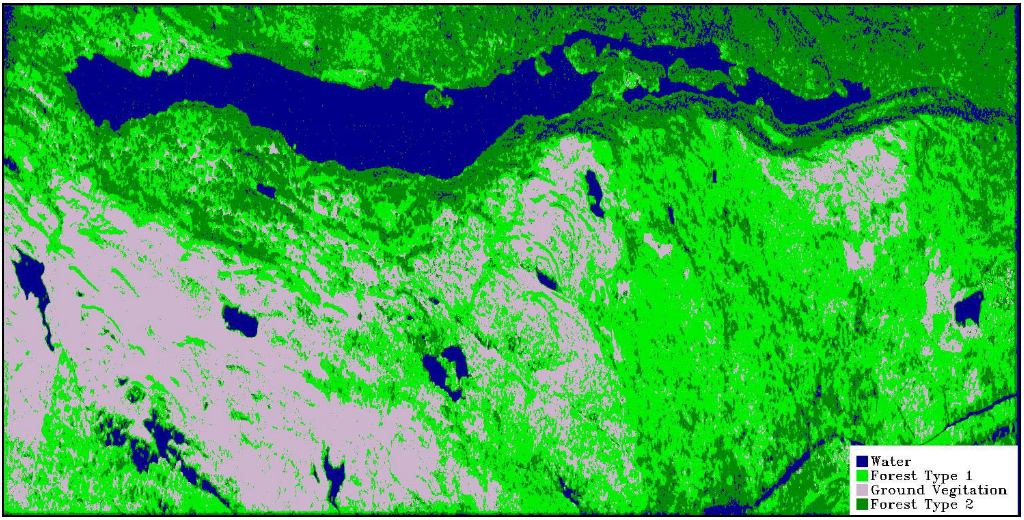

Figure 3. Supervised classification of 6 optimised coherence images

Classification of the six image data set (Figure 3) has proven to give a more detailed view of the vegetation structure than that of the backscatter image (Figure 4). The most noticeable improvement is the differentiation between vegetation density, whereby plantation and semi-natural areas are more apparent. This is also true for differentiation of high and low trees around the test sites.

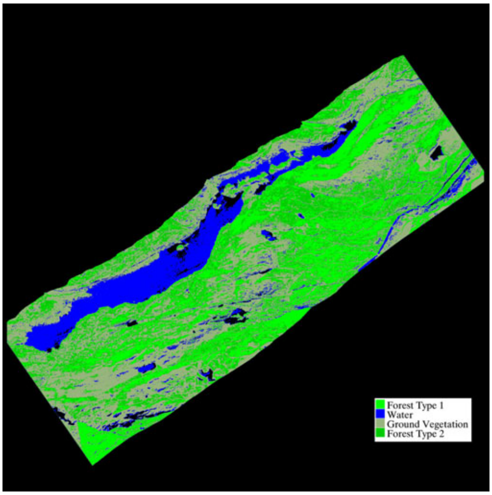

Figure 4. Supervised classification of backscatter (georectified)

Some interesting differences in the classifications are apparent. One of which is the opposite of what may be expected. For example, the triangular block of plantation in the south-west of the images (Figures 3 and 4), appears as a solid block of forest in the backscatter image (Figure 4), but in the coherence image (Figure 3), the block is more broken up. This is not as you would expect, as the coherence is anticipated to be low for dense vegetation, however areas classified as ground vegetation are found. One possible explanation for this is that the trees are so dense, there is little movement between them, and hence show a relatively high coherence, and have thus been classified as ground vegetation.

Height indicators

The final stage was an assessment of the relationship between coherence and average stand height. This was carried out using the optimal coherence image for each of the 10 and 20m baselines, and compared to ground data. Table 2 shows the values obtained for each plot.

Table 2. Plot data

Plot Number	Avg. Tree Height (m)	Coherence 10m	20m	Difference	Ratio
1	10.76	0.81	0.54	0.26	0.67
2	13.87	0.84	0.72	0.12	0.86
3	13.84	0.87	0.76	0.11	0.87
4	15.50	0.81	0.72	0.08	0.90
5	13.10	0.81	0.71	0.10	0.88
6	13.79	0.80	0.75	0.05	0.94
7	14.25	0.90	0.85	0.05	0.94
8	12.35	0.86	0.74	0.12	0.86
9	16.25	0.66	0.54	0.12	0.81
10	0.50	0.93	0.91	0.02	0.98
11	0.50	0.93	0.92	0.01	0.99
12	0.50	0.94	0.90	0.05	0.95

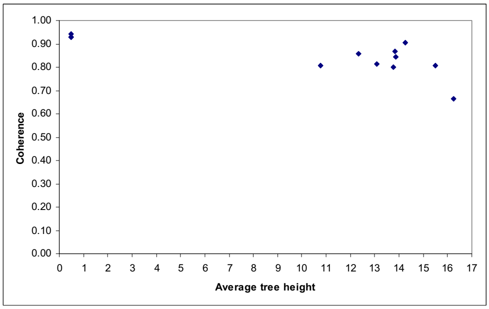

Figure 5. Coherence values for 10m baseline

A first indication of the trend is shown in Figure 5, which appears to show the expected pattern of decreased coherence for increasing tree height. For a more detailed indication of the relationship between average tree height and coherence, analysis was carried out in areas of plantation stands only, so as to compare within areas of similar tree structure (plots 1-8).

The coherence values for the 10m and 20m baselines were compared to ground data (Figures 6 and 7). A trend line was applied to each dataset. It was found that with increasing tree height coherence increased, with the 20m baseline increasing at a steeper rate than the 10m. This is somewhat unexpected. This increase is believed to be due to there being a decreased contribution to the returned signal from the ground, and more contribution from the canopy as the trees grow in height, i.e. a returned signal from tall trees is comprised of primarily canopy return. This explains why at the 10m baseline, it is observed that an increase in tree height gives a slight increase in coherence, and at 20m the increase is larger, as the proportion of ground return contributing to the coherence increases and canopy coherence decreases.

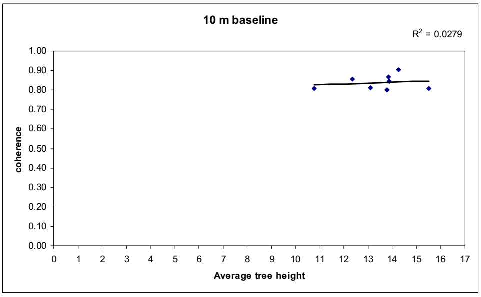

Figure 6. Coherence against height comparison at 10m baseline

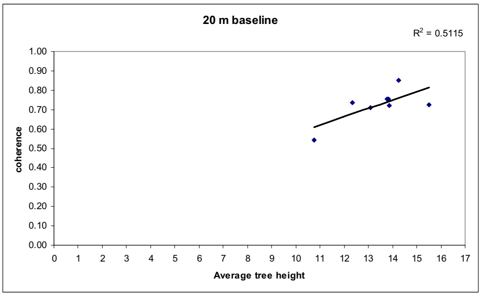

Figure 7. Coherence against height comparison at 20m baseline

When the difference between the coherence values of the 10m and 20m baselines were assessed, the difference was found to decrease with increasing tree height (Figure 8). As tree height increases, a larger contribution to the return signal comes from the canopy, and so the coherence will be more similar for the two baselines. The ratio between the two baselines was found to increase with increasing tree height (Figure 9). This corresponds to a decreasing difference.

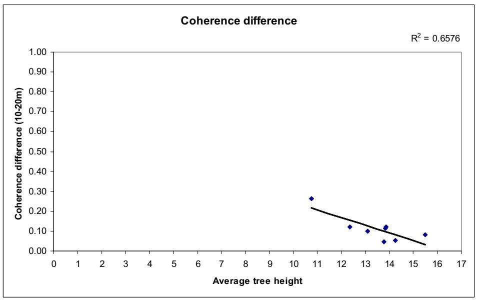

Figure 8. Coherence difference between 10m and 20m baselines

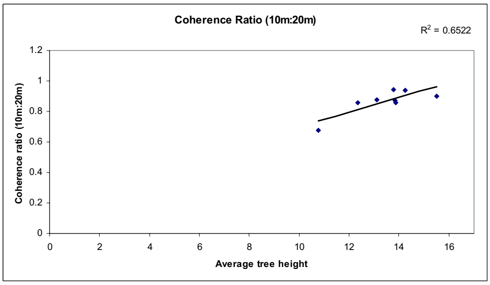

Figure 9. Coherence ratio between 10m and 20m baselines

5 CONCLUSION

This paper has explored the use of L-band fully polarimetric dual-baseline interferometry for use in forest studies. The use of optimised coherence has improved differentiation between vegetation densities and heights when compared to backscatter intensity. The trend of coherence when compared to average tree height is shown to be acting in a way that is not expected, and reasons for this have been suggested. A complete explanation of this effect will probably require comparison to a coherent backscatter model.

It has been concluded that coherence is of potential use for forest mapping and height discrimination, and future studies will be focused on assessing single and multiple data sets.

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