CHARACTERIZING THE BACK-SCATTERING PROPERTIES OF A FOREST BY POLARIMETRIC SAR TOMOGRAPHY AT L- AND P-BAND

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ABSTRACT

In this paper, a short summary of our findings from analyzing SAR tomography data products obtained by tomographically focusing two airborne multibaseline SAR data sets of a partially forested area, one at L-band and another at P-band, is given. In particular, the following aspects are highlighted: 1) The forest structure as obtained from vertical profiles of intensities at sample plot locations within the forest is compared to the height distribution of the top of the forest canopy as derived from airborne laser scanning data. Profiles are presented for all polarimetric channels, for three different tomographic focusing techniques, as well as at both frequencies. 2) Type and location of scattering mechanisms are analyzed as a function of height for the two frequencies, L- and P-band, by using the polarimetric channels, as well as the Cloude-Pottier-decomposition thereof.

Index Terms— SAR Tomography, Multibaseline SAR, Beamforming, Capon, MUSIC, E-SAR, L-Band, P-Band, Forest, Remote Sensing

1. INTRODUCTION

Forest biomass estimation based solely on radar back-scattering is not feasible for dense forested areas due to saturation levels around 100 t/ha at L-band and 200 t/ha at P-band [1–4].

Additional parameters, such as the forest height (involving the extraction of the underlying terrain height) and structural information about the forest, need to be measured in order to approach a reliable estimate of forest biomass. Thus, research towards improving the knowledge about the back-scattering behavior of forests with the goal of estimating biophysical parameters by means of synthetic aperture radar (SAR) tomography has become a major topic within the SAR remote sensing community.

With three prospective spaceborne SAR remote sensing missions, BIOMASS [5, 6] at P-band, Tandem-L [7, 8], and DESDynI [9], both at L-band, which are all aimed at a global mapping and monitoring of carbon stock by assessing the above ground biomass of forests as well as forest dynamics such as the amount of deforestation and re-growth, these two frequency bands have even gained in importance.

	P-band	**L-band**
Carrier frequency	350 MHz	1.3 GHz
Chirp bandwidth	70 MHz	94 MHz
Sampling rate	100 MHz	100 MHz
PRF	500 Hz	400 Hz
Ground speed	90 m/s	90 m/s
No. of data tracks	11+1	16+1
Nominal track spacing d_n	57 m	14 m
Horizontal baselines	40 m	10 m
Vertical baselines	40 m	10 m
Synthetic aperture in normal direction L	570 m	210 m
Nominal resolution in normal direction δ_n	3 m	2 m
Approx. unambiguous height H	30 m	30 m

Table 1. E-SAR system specifications and nominal parameters of the tomographic acquisition patterns.

With the aim to contribute to a better understanding of radar back-scattering properties of forested areas an airborne SAR tomography campaign was conducted over a test site in Switzerland [10], in September 2006. Two fully polarimetric tomographic data sets (P-band and L-band) of a partially forested area were acquired by the German Aerospace Center's E-SAR system (see Table 1).

In this paper, the latest findings obtained from analyzing these tomographic SAR data sets of a forest are summarized (a detailed description of the time-domain back-projection based SAR tomography approaches pursued to focus the multibaseline data is given in [11], and an extended version of this summary paper is provided in [12]).

2. DATA AND METHODS

The analyses presented in this paper start at the product level of the 3D focused SAR data sets. The data cubes occupy an area of 400m x 900m in easting and northing, respectively.

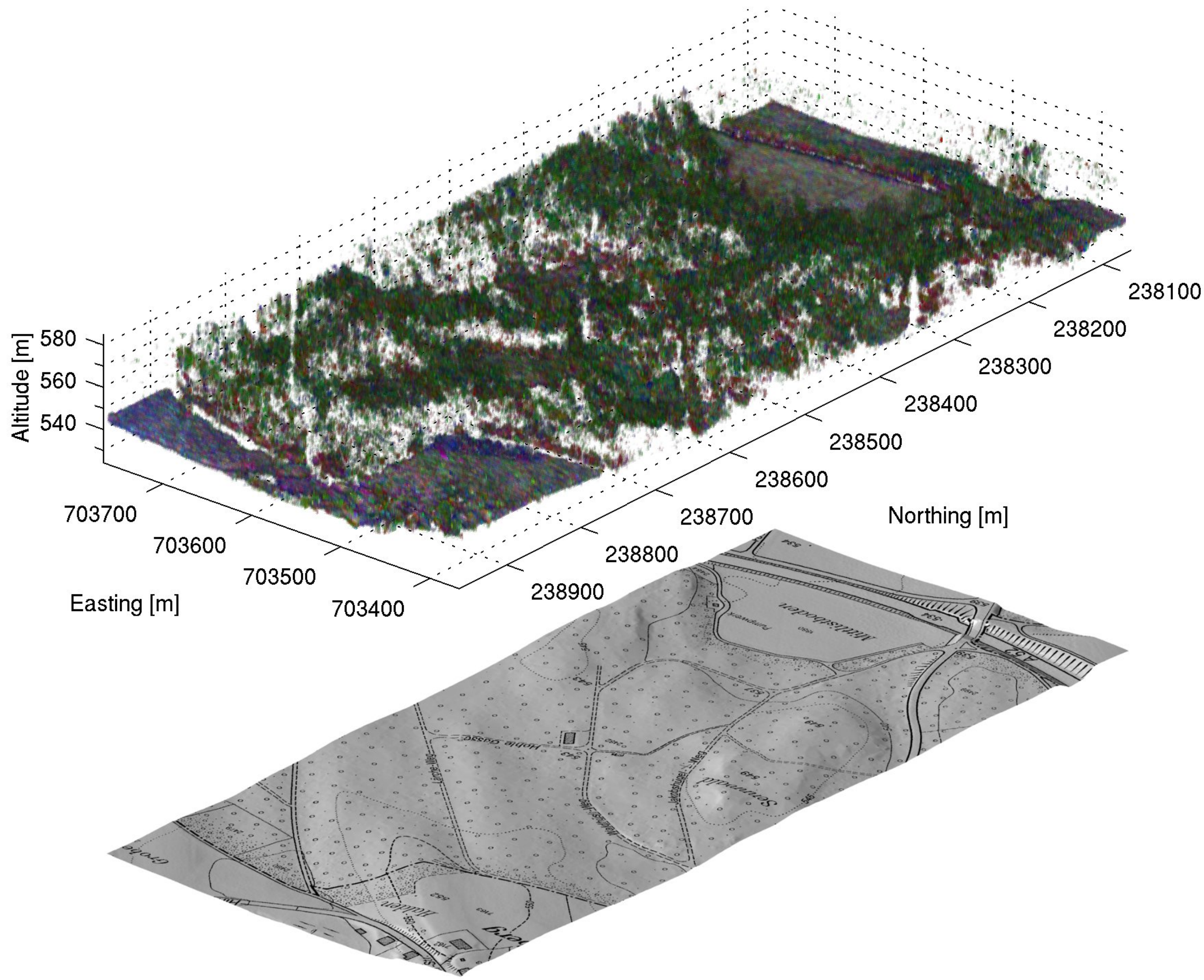


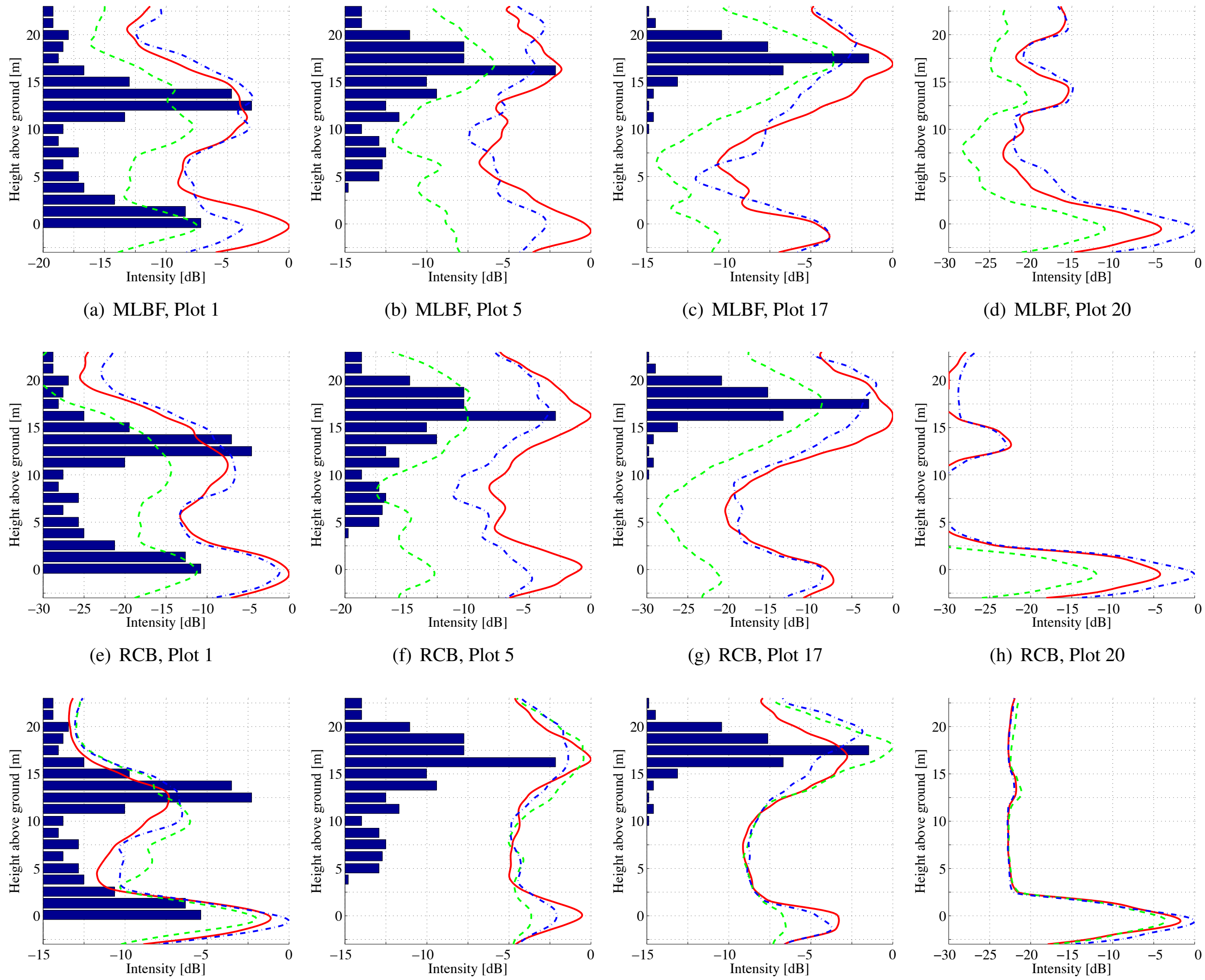
Fig. 1. Tomographic image (3D voxel plot) of a partially forested area obtained from combined TDBP and MUSIC beamforming of polarimetric airborne repeat-pass multibaseline SAR data at L-band. For visualization purposes each channel has been scaled individually. Red (HH), green (HV), blue (VV). Low intensity = high transparency of the voxel. Beneath, a 1:5000-scale digital map of the same area, warped on a DEM obtained by airborne laser scanning, is shown to give a comparative picture of the outer boundaries of the forested area, the underlying terrain, and additional features, such as forest roads. Map reproduced by permission of the Cantonal Office of Spatial Planning and Surveying, Zurich (20100019).

For both multibaseline data sets, three data products were generated using a TDBP based approach in combination with

1. multilook beamforming (MLBF)
2. robust Capon beamforming (RCB)
3. multiple signal classification (MUSIC).

A description of the time-domain based focusing methods is given in [13] for MLBF and in [11] for RCB and MUSIC, respectively. In each case, the sample covariance matrix was estimated using approximately 20 looks obtained by spatial averaging.

External reference data in the form of a digital elevation model (DEM) derived from airborne laser scanning (ALS) (Falcon II, Toposys GmbH) is available for a comparison of the ground level. A digital surface model (DSM) acquired by the same sensor is also at hand (see [11]). Both data sets are given at a sample spacing of 1m x 1m. The forest within the test site is dominated by evergreen coniferous trees (80% of the trees within the sample plots in the area of study are evergreen coniferous trees, predominantly norway spruce ‘picea



(a) MLBF, Plot 1 (b) MLBF, Plot 5 (c) MLBF, Plot 17 (d) MLBF, Plot 20

(e) RCB, Plot 1 (f) RCB, Plot 5 (g) RCB, Plot 17 (h) RCB, Plot 20

(i) MUSIC, Plot 1 (j) MUSIC, Plot 5 (k) MUSIC, Plot 17 (l) MUSIC, Plot 20

Fig. 2. Vertical profiles of relative intensities from L-band tomographic data of a forest (Plot 1, 5, and 17) and grass land (Plot 20), respectively, averaged over a circular sample plot of 300m^2 for the polarimetric channels HH (—), HV (– –), and VV (·–), MLBF, RCB, and MUSIC. For comparison, histograms of height differences between the ALS DSM and the ALS DEM are underlaid as an external estimate of the distribution of tree heights.

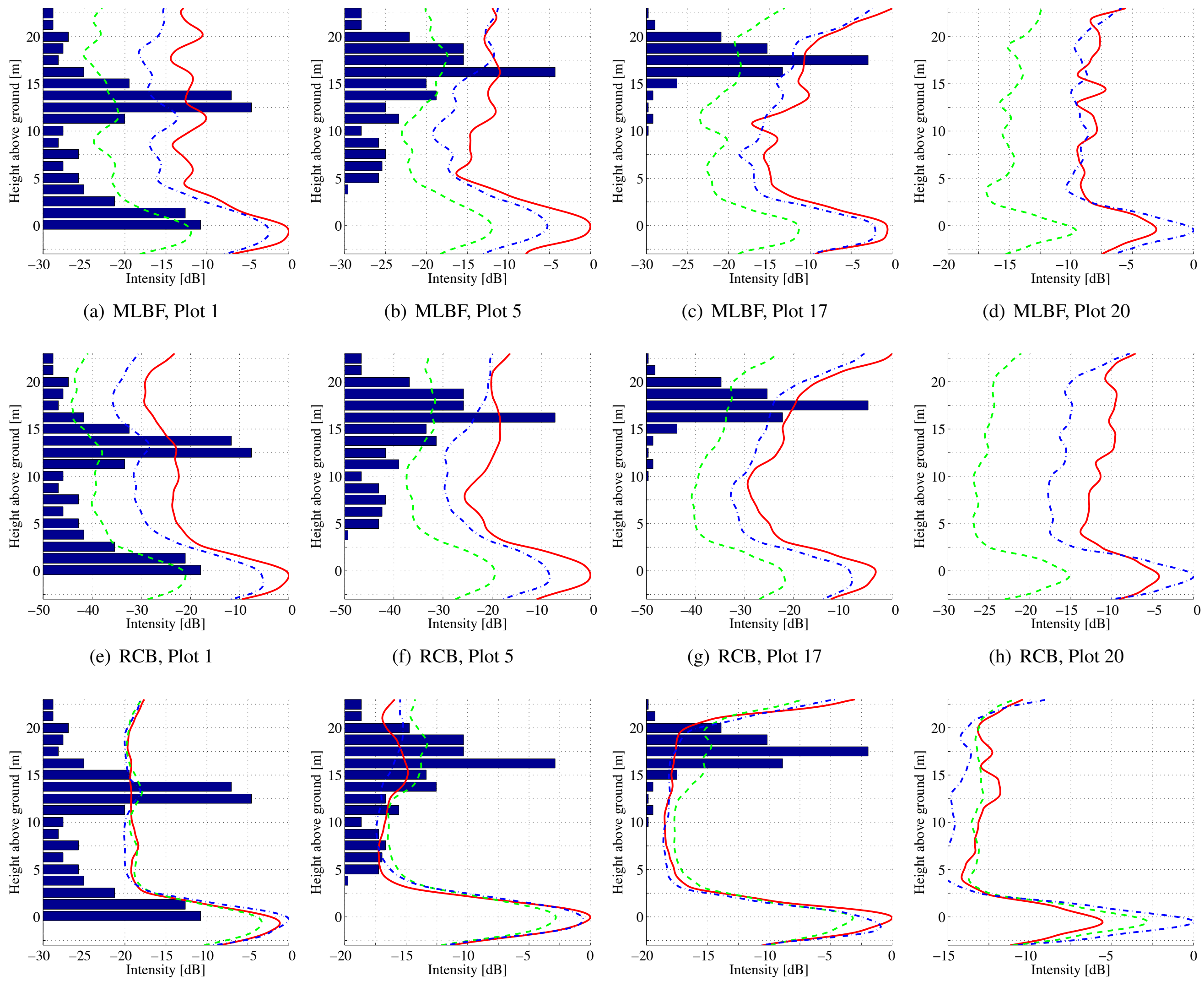
abies' and european silver fir 'abies alba', which make up 59% and 20% of all trees, respectively).

In order to analyze the back-scattering behavior as a function of height above ground the additional information contained in the polarization channels was exploited. In particular, the Cloude-Pottier decomposition (entropy/anisotropy/α) [14] of the polarimetric data was calculated and evaluated as a function of height above ground.

All height values given in the comparison of SAR tomography profiles and ALS scanning data are given relative to the ALS DEM. This means that a relative height = 0m, is equivalent to "0m above the reference DEM from ALS".

3. RESULTS

Fig. 1 depicts a three-dimensional voxel plot representation of the partially forested area under study obtained from combined TDBP and MUSIC beamforming of the polarimetric MB SAR data at L-band using the full synthetic aperture in normal direction. The polarimetric channels HH (red), HV (green), and VV (blue) are given in an RGB color scheme scaled by a transparency value to represent the signal intensity. A very detailed reconstruction of the forest is obtained (compare the tomography data with the map underneath, in Fig. 1). Even details, such as small forest roads, are well visible as gaps in the canopy cover.



(a) MLBF, Plot 1 (b) MLBF, Plot 5 (c) MLBF, Plot 17 (d) MLBF, Plot 20

(e) RCB, Plot 1 (f) RCB, Plot 5 (g) RCB, Plot 17 (h) RCB, Plot 20

(i) MUSIC, Plot 1 (j) MUSIC, Plot 5 (k) MUSIC, Plot 17 (l) MUSIC, Plot 20

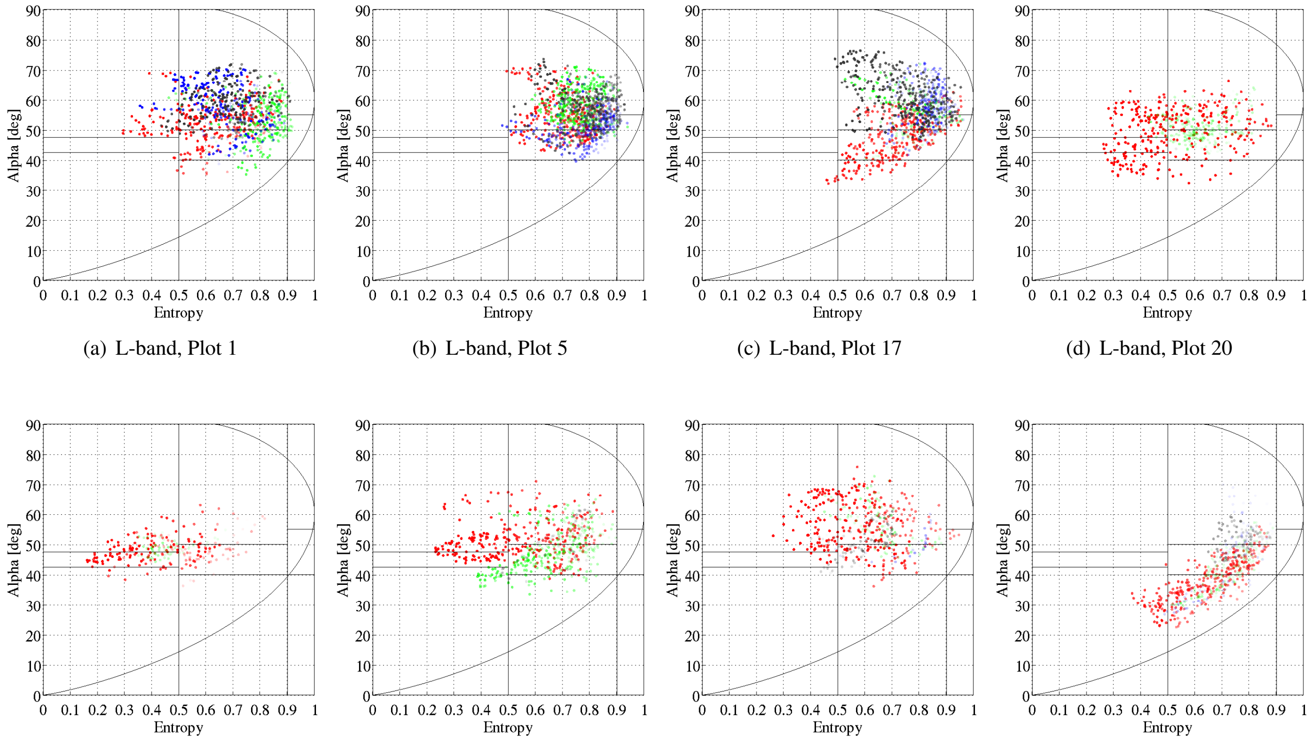
Fig. 3. Vertical profiles of relative intensities from P-band tomographic data of a forest (Plot 1, 5, and 17) and grass land (Plot 20), respectively, averaged over a circular sample plot of 300m^2 for the polarimetric channels HH (—), HV (– –), and VV (·–), MLBF, RCB, and MUSIC. For comparison, histograms of height differences between the ALS DSM and the ALS DEM are underlaid as an external estimate of the distribution of tree heights.

In Fig. 2 & 3, vertical profiles of relative intensities obtained by averaging the focused tomographic data over a circular sample plot of 300m^2 are depicted. Profile plots are given for the polarimetric channels HH, HV, and VV, for the three beamforming techniques used for focusing in the normal direction, MLBF, RCB, and MUSIC. For comparison, histograms of the difference between a DSM and a DEM obtained from airborne laser scanning were calculated, which are used as a cross-reference estimate of tree heights occurring within a sample plot.

In Fig. 4, entropy/α scatter plots are depicted for different horizontal layers at 0m (red), 5m (green), 10m (blue), and 15m (black) above ground.

4. DISCUSSION

The back-scattering properties of a forest were characterized by means of polarimetric SAR tomography using multibaseline L- and P-band data sets: At L-band, main back-scattering contributions are observed at both the ground level and around the tree top region. RCB and MUSIC beamforming based vertical profiles exhibit a more distinct tomographic image by increasing the signal-to-clutter ratio and the resolution in normal direction. Thus, in order to just detect the location of the main back-scattering contributions they provide an improved performance compared to MLBF. At L-band, coherent back-scattering from the canopy (mostly in the tree-top region) is



(a) L-band, Plot 1 (b) L-band, Plot 5 (c) L-band, Plot 17 (d) L-band, Plot 20

(e) P-band, Plot 1 (f) P-band, Plot 5 (g) P-band, Plot 17 (h) P-band, Plot 20

Fig. 4. Entropy/α scatter plot for different horizontal slices centered at 0m (red), 5m (green), 10m (blue), 15m (black) above ground (using the ALS-derived DEM as a reference). The entropy/α data points of each slice are plotted using transparency scaling based on the sum of the eigenvalues of the $\mathbf{T3}$ coherence matrix: 0dB $\rightarrow$ opaque, $\leq$-25dB $\rightarrow$ transparent.

present in all polarization channels, whereas at P-band, the canopy of the forest under study is virtually transparent to the microwaves. At L-band, both the forest canopy as well as the ground level are detected (see Fig. 2). At P-band, the main scattering within the forest occurs at the ground level not only in the HH and VV channels, but *also in the cross-polarized channels*. The same behavior was also observed by Tebaldini et al. [15] for a different P-band data set.

Within the forest, surface scattering is very limited even at L-band. Interestingly, the entropy/α back-scattering classification does not change much as a function of height within the forest volume at L-band. Thus, back-scattering sources at ground level and within the canopy layer are not necessarily distinguishable only by their polarimetric signature.

In view of the potential upcoming mission BIOMASS, it is interesting to note that, at P-band, coherent back-scattering occurs at the ground level. Thus, mapping of the terrain underneath foliage by means of SAR interferometry is a potential scenario. On the other hand, repeat pass interferometry at P-band is limited, due to the small bandwidth assigned at this frequency range, due to the resulting moderate resolution, and to some extent also due to temporal decorrelation effects.

Looking at the fact that, at L-band, two main locations of back-scattering sources could be identified—canopy top and ground level—a single-pass interferometric system, such as sketched in the Tandem-L proposal, appears to be favorable compared to a pure repeat-pass imaging system at L-band.

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