Coherence Tomography for Boreal Forest: Comparison with HUTSCAT Scatterometer Measurements

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Abstract

In this paper we report on X- and L-band polarization coherence tomography in boreal forest structure mapping. We take advantage of HUTSCAT ranging scatterometer measurements and compare E-SAR derived vertical structure profiles with measured vertical scattering profiles. HUTSCAT measurements provide vertical scattering profile of the canopy and also provide supplemental forest height and ground phase estimates, allowing calculation of coherency profiles with alternative initial values. We present single baseline tomography for X-band and multibaseline tomography for L-band calculated with various initial values and compare the results with actual measurements of scattering profiles.

1 Introduction

SAR polarimetric interferometry (POLInSAR) has shown its potential in forest remote sensing. Polarimetric interferometric coherence measurement allows estimation of canopy parameters. The methods are based on modeling the coherence inside the forest canopy. The Random Volume over Ground (RVoG) model [1] inversion [2] for fully polarimetric coherence data has been used in several studies to successfully estimate forest height [1], [3], [4]. Our results from the FINSAR campaign showed that even X-band single polarization interferometric coherence can be successfully used to invert the RVoG model for forest height [5]. Recently Cloude [6] has taken a step forward and suggested a method to estimate the shape of the coherence function inside canopy in more detail. This is done by approximating the vertical structure function with Legendre polynomial series. The method is called Polarization Coherence Tomography (PCT). The approximation accuracy is dependent on the available amount of measurements, in this case interferometric baselines. Cloude [6] has shown that even for one baseline the general shape of single layered volume can be calculated. The FINSAR campaign material provides a good basis for coherence tomography study as together with E-SAR polarimetric interferometric measurements also vertical scattering profiles of the forest were measured with the HUTSCAT scatterometer [8]. The scatterometer measurement provides supplemental initial values (forest height and ground phase) for tomography and gives an opportunity to compare vertical structure profiles with actual scattering profiles.

2 Material

The material in our study was collected during Fthe INSAR campaign [5], carried out in autumn 2003 in Finland. The main instruments of the campaign were E-SAR [7] and HUTSCAT ranging scatterometer [8]. On 29 September the E-SAR sensor collected from 3 km altitude four L-band (1.3 GHz) repeat pass fully polarimetric interferometric images and an X-band (9.6 GHz) single-pass single-pol (VV) interferometric image pair. The images were processed to a 2×2 m (range and azimuth) resolution grid. The helicopter-borne HUTSCAT scatterometer measurement was carried out two days later, providing a vertical backscattering profile at C-band (5.4 GHz) and X-band (9.8 GHz) along the 36 km flight track. The incidence angle was vertical and the helicopter location was measured by a GPS receiver. Most of the HUTSCAT measurements were concentrated on a 2×2 km area covering the E-SAR near and mid range. The HUTSCAT range resolution is 0.65 m, antenna beam width is 3.8^0 and the system along-track sampling distance is 1.25 m when helicopter moves with the ideal speed 25 m/s. The HUTSCAT and E-SAR slant range images were co-registered according to the pixel coordinates. The test site in southern Finland (N $60^0\ 11'$, E $24^0\ 29'$) comprises forest, fields and lakes. The forest in the area is heterogeneous and consists of rather small stands. The dominant tree species are Scotch pine, Norwegian spruce, birch and alder. Ground measurements provided data on soil moisture, temperature and leaf area index. Forest inventory data were made available by the local forest authority for 76 stands, covering a 136 ha area. The forest stand information was collected in April 2001.

3 Methods

In this study we have chosen HUTSCAT scattering profile coordinates for presenting PCT results. The HUTSCAT scattering profiles are vertically profiled sections of the forested area and comparison between tomography and scattering profiles is straightforward in HUTSCAT coordinates. Interferometric SAR images and ancillary data are interconnected by geographical coordinates and converted to HUTSCAT profile coordinates.

Forest height and ground phase are initial values for polarization coherence tomography (PCT). It is proposed in [6] that forest height and ground phase can be retrieved by RVoG model inversion from the same measurements. However, forest height estimate from model inversion can be very noisy, also usage of RVoG model for initial value derivation can forces the PCT profile to follow the RVoG model. For comparison we estimate forest height and ground phase also from HUTSCAT measurements and use also those values as initial values for PCT. The forest height is obtained as the difference between HUTSCAT detected tree crown and ground line range coordinates. As the X-band data is not fully polarimetric, the ground phase estimation is not possible by RVoG model inversion. For X-band the ground phase is estimated by HUTSCAT detected ground topography and X-band coherency phase for open areas. Unfortunately this method is not very accurate, because HUTSCAT system does not have accurate attitude measurement system.

For PCT we have available single polarization X-band data and fully polarimetric L-band data for three baselines: 5 m, 10 m, and 15 m. We have calculated single baseline PCT for all available data and dual baseline PCT for L-band data for both baseline combinations. The Legendre series functions and parameters are calculated according to available baselines [6]. The vertical structure function profile estimate is calculated and converted to HUTSCAT profile coordinates in order to provide a convenient basis for comparison. Because the vertical profile estimate given by PCT is ambiguous by a multiplier, all functions are normalized by function maximum for the current profile. We do not use the normalization by function integral, because it makes the vertical profile minimum tree height dependent.

4 Results and Discussion

Figure 1 presents a fragment of HUTSCAT X-band scattering profile. The treetop line and ground line are detected by a pattern recognition algorithm. The ground line is presented on top of the profile. We can distinguish different forest types based on the scattering. Mature pine forest has typically strong scattering around the crown top whereas spruce forest scattering is distributed more evenly along the tree height.

Figure 2 presents a vertical coherence profile for E-SAR X-band single baseline (0.8 m), single polarization (VV), calculated by using HUTSCAT derived tree height. The ground phase is calculated by using E-SAR X-band open area coherence phase and HUTSCAT ground line coordinate. Figure 2 shows that the vertical structure estimate is dominated by second order polynomial in most places, which is asymmetric depending on scattering center. This is typical for vegetation. It should be mentioned our ground phase estimation method underestimates probably the ground phase, because open areas in forest are often rough. Underestimated phase normally emphasizes the second order polynomial function in PCT profile.

Figure 3 presents a vertical coherence profile for E-SAR L-band, single bounce (HH-VV), single baseline (10 m), calculated by using HUTSCAT derived tree height. Figure 3 shows that vertical structure estimate is again dominated by second order polynomial in most places. However the curvature of the second order polynomial is much smaller than in X-band PCT. This is caused by canopy's smaller attenuation at L-band. Also the variation with forest type is more visible. This is probably caused by the L-band higher penetration depth compared to X-band. The general shape of PCT profile is in accordance with RVoG model. The single bounce mechanism (HH-VV) has higher values near the ground.

Figure 4 presents a vertical coherence profile for E-SAR L-band, dual baseline (5 m and 10 m), calculated by using HUTSCAT derived tree height. Here the vertical function shape is slightly different than in single baseline tomograms, the third order polynomial causes lighter region in the middle. Function is actually dominated by a strong peak at the ground level and the smooth rise in the middle can be just an artifact of third order polynomial. Strong peak on the ground level is in accordance with RVoG model. In some sparse areas function has high values also in tree crowns, this is probably just caused by of ill conditioned initial values. Two baseline PCT seems to be more sensitive to noise and errors in initial values.

Figure 5 presents a vertical coherence profile for E-SAR L-band (HH-VV polarization), dual baseline (5 m and 10 m), calculated by using tree height retrieved from RVoG model inversion. Figure 5 shows that vertical structure estimate is is very similar to **Figure 4**; however, more noise in the height estimate makes also the PCT look more noisy.

We calculated single and multibaseline PCT for fully polarimetric L-band in HH, VV, HV, and also HH-VV, HH+VV, HV, polarization basis. Surprisingly differences between polarizations were rather small. Also cohrenece and phase values for different polarizations were rather

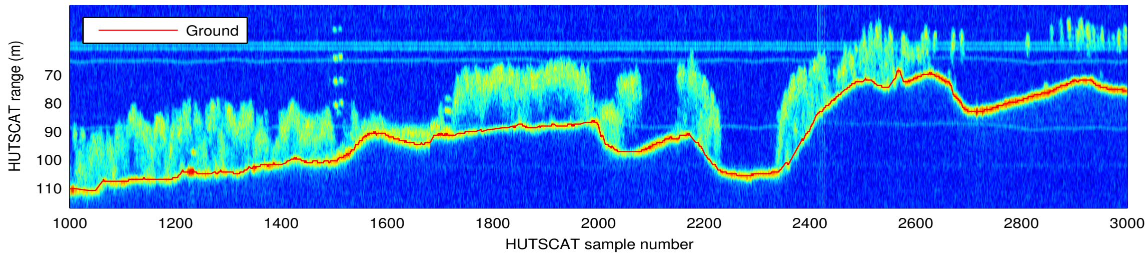

Figure 1: The forest vertical scattering profile at X-band, measured by HUTSCAT scatterometer. The ground line is indicated by a red line. Light areas are forest canopy. The x-axis is HUTSCAT sample number, corresponding to helicopter movement. One sample corresponds approximately to 1.25 m. The y-axis is HUTSCAT vertical range in meters. The length of track in the image is about 2.5 km. Flight direction is from right to left.

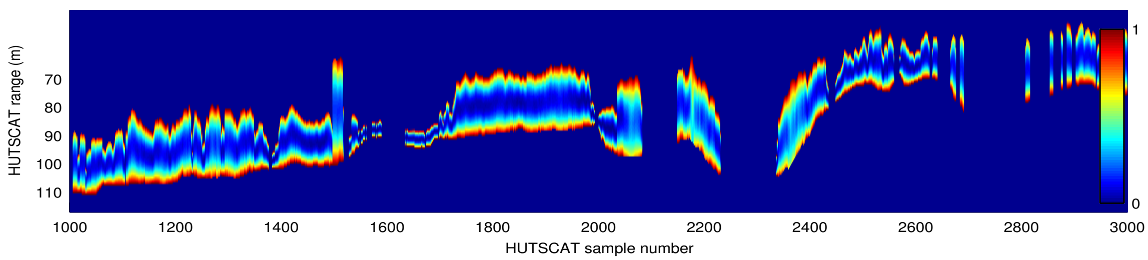

Figure 2: E-SAR X-band VV-polarization single baseline vertical coherence tomography. The x-axis and y-axis as in Fig.1.

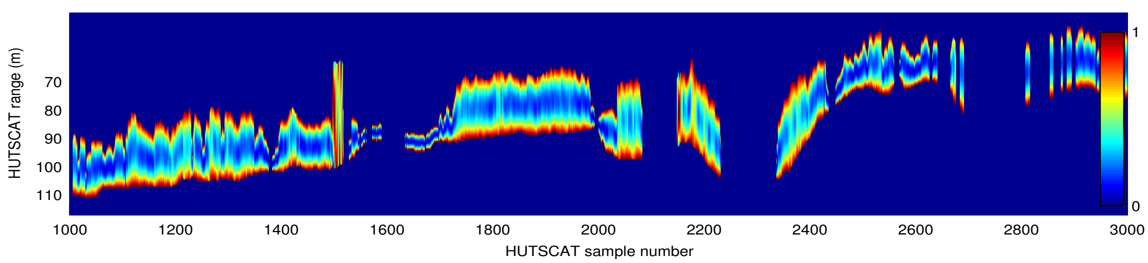

Figure 3: E-SAR L-band (HH-VV) polarization single baseline (10 m) vertical coherence tomography. The x-axis and y-axis as in Fig.1.

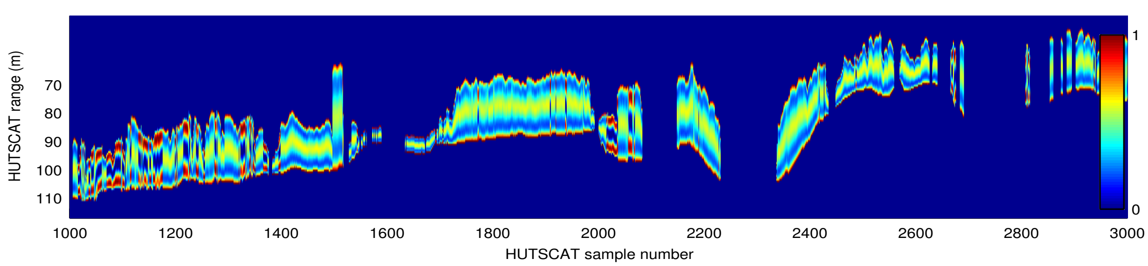

Figure 4: E-SAR L-band (HH-VV) polarization dual baseline (5 m and 10 m) vertical coherence tomography. In all above tomograms initial value of the tree height is derived from HUTSCAT measurement and all tomograms are presented in HUTSCAT coordinates. The ground phase is derived from RVoG model inversion for L-band. The x-axis and y-axis as in Fig.1.

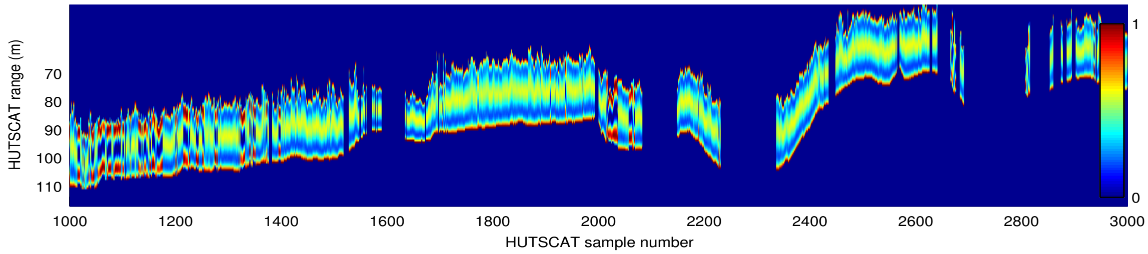

Figure 5: E-SAR L-band (HH-VV) polarization dual baseline (5 m and 10 m) vertical coherence tomography. The initial value of the tree height and ground phase is derived from RVoG model inversion. The tomogram is presented in HUTSCAT coordinates. The x-axis and y-axis as in Fig.1.

small. This can be caused by fact that forest in our test line was rather sparse or influence of temporal decorrelation. We have not taken into account the temporal decorrelation and its influence should be further studied. In our study we noticed that PCT is very sensitive to ground phase estimate noise and errors. More elaborated polarization coherence optimization would be a benefit in more accurate ground phase estimation.
Similarities between the HUTSCAT profile and PCT are not very strong, but some likeness can be found. A more detailed quantitative comparison between PCT and scattering profile remains as future work.

5 Conclusions and Future Work

In this work we have calculated single and dual baseline polarization coherence tomograms and compared the results with scatterometer measured vertical scattering profiles. Our results show that PCT is a feasible technique and it does give information about the structure of the forest. However, two or more baselines are needed to obtain close to real vertical structure function approximation, as forest is a layered structure and second order polynomial in the single baseline case is not able to give very much vertical resolution. Our coherence profiles are in accordance with RVoG model predictions.

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