Quantifying Temporal Decorrelation over Boreal Forest at L- and P-band

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Abstract

Temporal decorrelation is probably the most critical factor towards a successful implementation of Pol-InSAR parameter inversion techniques in terms of repeat-pass InSAR scenarios. In this paper the effect and impact of temporal decorrelation at L- and P-band is quantified. For this, data acquired by DLR's E-SAR system in the frame of the BioSAR campaign (initiated and sponsored by the European Space Agency (ESA)) over boreal forest with variable temporal baseline in 2007 in Sweden are analyzed. For validation lidar data and ground measurements data are used.

1 Introduction

Polarimetric Synthetic Aperture Radar Interferometry (Pol-InSAR) is a radar remote sensing technique, based on the coherent combination of SAR interferometry and radar polarimetry [1]. The combination of polarimetric and interferometric information provides sensitivity to the vertical distribution of different scattering processes and makes the investigation of the 3-D structure of volume scatterers by means of Pol-InSAR a challenge. However, temporal decorrelation reduces the performance of Pol-InSAR configuration by biasing the volume decorrelation contribution that is used for parameter inversion. This leads to a larger standard deviation of the InSAR phase – for the same number of looks – and increases the error bars of the parameter estimates. The BioSAR data set provides some insight into the nature of different temporal decorrelation mechanisms over boreal forest areas at L- and P-band. Two kinds of temporal baselines are available in the BioSAR data sets: short temporal baselines of about 15-60 min (short term repeat pass decorrelation) and large temporal baselines of 30/32 up to 58 days (long term repeat pass decorrelation). In this paper, the level of coherence loss due to temporal decorrelation at L- and P-band is investigated.

2 Test site and Data sets

BioSAR's Remningstorp test site is located in southern Sweden (58º28′N, 13º38′E). The dominant species are Norway spruce, Scots pine and birch. The area is fairly flat with very gentle topographic variations (ranging between 120 and 145 meters above sea level).
DLR's E-SAR system carried out three campaigns over the Remningstorp forest in early March, early April and early May 2007. During these three dates data acquisition at L- and P-band in a repeat pass fully polarimetric mode were performed. The configurations flown and the available data sets are summarized in **Table** 1. The spatial baselines at P-band vary from 0 to 80 m with a spatial spacing of 10 m. The temporal baselines are between 15 and 60 min. L-band records were done with a 0, 8, 16, and 24 m spatial baseline and a temporal baseline between 15 and 50 min.
For validation lidar and ground measurements were collected. Lidar data collection was conducted on 24 April 2007. Ground measurements were done on 11 plots during spring 2007. Four plots with an extent of 80 m by 80 m and 7 plots with an extent of 20 m by 50 m. Measurements were limited to trees with a dbh

Table 1: Selected E-SAR modes for the BioSAR campaign.

Flight Date		L-Band Quad Pol		P-Band Quad Pol	
		Temporal [min]	Spatial [m]	Temporal [min]	Spatial [m]
Campaign 1	**09 March 2007**	40, 25	0, 8	50, 15, 25	0, 10, 80
Campaign 2	**31 March 2007**	50, 15, 25, 40	0, 8, 16, 24	-	
	02 April 2007	-		60, 15, 25, 40	0, 30, 40, 50
Campaign 3	**02 May 2007**	50, 15, 25, 40	0, 8, 16, 24	60, 50, 40, 30	0, 20, 60, 70

larger than 5 cm.

3 Pol-InSAR Inversion Method

Forest heights from radar data were inverted using the Random Volume over Ground (RVoG) model at L- and P-band [2]. DLR's E-SAR system has a large variation in incidence angle (and thus effective baseline) from near to far range. Therefore, the inversion performance also varies with range. For a good inversion performance, large baselines ($kz > 0.15$) in near range and small baselines ($kz < 0.05$) in far range need to be excluded [4]. Low coherence levels make reasonable inversion results difficult. Therefore, areas with coherence levels lower than 0.3 have also been excluded.

After masking all non-valid areas, forest height inversion was performed using each baseline individually at P- and at L-band. Then, in a second step the inversion results obtained at each baseline were combined. The final forest height maps were validated against the lidar data and the ground measurements. As reference height the so called "H_{100}" was used. The H_{100} is a forestry standard parameter described by the 100 tallest trees per hectare and represents the tree top height of the trees that form the canopy. From the lidar data the H_{100} was estimated from the highest height within a 10 by 10 m window [3].

After height inversion, the loss of coherence in the large temporal baselines is investigated. The observed coherence consists of 3 main decorrelation contributions:

$$\gamma_{obs} = \gamma_{volume} \cdot \gamma_{temporal} \cdot \gamma_{system}$$

System effects can be compensated during processing [4]. In order to focus on temporal decorrelation effects, the 0 m (nominal) spatial baselines are investigated. In this case, volume decorrelation is minimized and the observed loss of coherence is associated to temporal effects.

4 Results and Discussion

4.1 Height Inversion

Figure 1 shows forest height maps derived from P-band data, scaled for 0 to 50 m. The first image shows the result from the May acquisitions, the second from the April and the third from the March acquisitions. All three forest height maps show quite similar results. Best results were obtained for the May acquisitions, while in the April and March acquisitions some forest sites seem to be overestimated, here temporal effects biases the estimates. However, **Figure 1** makes in an impressive way clear that Pol-InSAR forest height

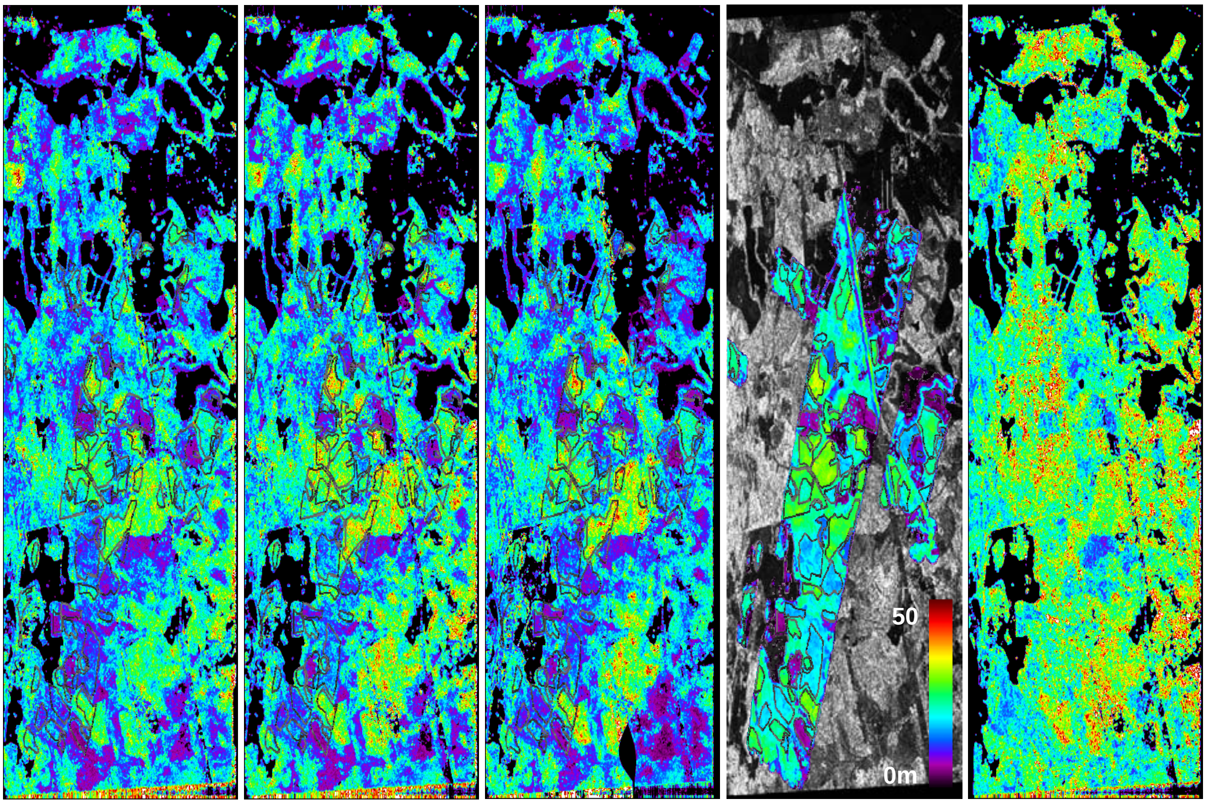

Figure 1: P-band forest height maps for Remningstorp forest, scaled from 0 to 50 m, 2): 1) The result acquired in May, 2) April, 3) March, 4) Lidar height map; P-band SLC image is combined with lidar height (H100) and polygons (red), and 5) Inversion height map with 1 month temporal decorrelation.

inversion provides consistent forest height maps at different times and at different weather and ground conditions. The left image of **Figure 2** shows the inversion result at L-band in April obtained by combining the results of several baselines, scaled from 0 to 50 m. Comparing the P- and L-band height maps no significant differences appear. Both images cover the same height range and reflect the same forest structure.

4.2 Validation

Validation was done on two different levels with lidar data (see **Figure 3)** and with ground measurement (see **Figure 4)**. For validation with lidar data (**Figure 1** image 4, **Figure 2** right), the forest was divided on the basis of lidar height into several stands with similar forest height (see black polygons in **Figure 1** & **2**). Validation plots using lidar data can be found in **Figure 3** left side for P-band and right side for L-band. In the case of P-band a correlation coefficient (R^2) of 0.63 with a root mean square error (RMSE) of 3.97m is reached, indicating a quite good correlation between lidar and radar measurements. Forest height varies mainly between 10 and 35 m. P-band in general tends to underestimate forest height. L-band derived forest heights reach an R^2 of 0.91 with an RMSE of 2.04m. The relation between lidar and radar measurements is highly significant reaching an error in the order of 10 % of the mean forest height.
The validation based on ground measurements is illustrated in **Figure 4**, on the left P-band, on the right L-band. The red points represent the 80 m by 80 m plots while the blue points the 20 m by 50 m plots. Here the correlation coefficient of P-band (R^2 = 0.67) improved compared to lidar validation while for L band the correlation coefficient drops to 0.82. Main reason for changes in the correlation coefficient could be the difference in the number of samples available, but the result is still quite good. Looking on the ground measurement plots (**Figure 4**) then large areas (80 m by 80 m; red dots) seem to fit better than the small areas (20 m by 50 m; blue dots)

4.3 Temporal decorrelation

A critical decorrelation source in repeat-pass interferometry is temporal decorrelation. Temporal effects are difficult to quantify and can appear in a more or less stochastic way within the scene. Temporal decorrelation decreases the interferometric coherence and increases the variation of interferometric phase and biases forest height estimates. A separation of temporal and volume decorrelation is - due to the stochastic nature of temporal disturbance effects - difficult if not impossible. Effects of temporal decorrelation are shown in **Figure 5**, here coherence histograms of HH, VV, and HV polarisations over the whole scene for

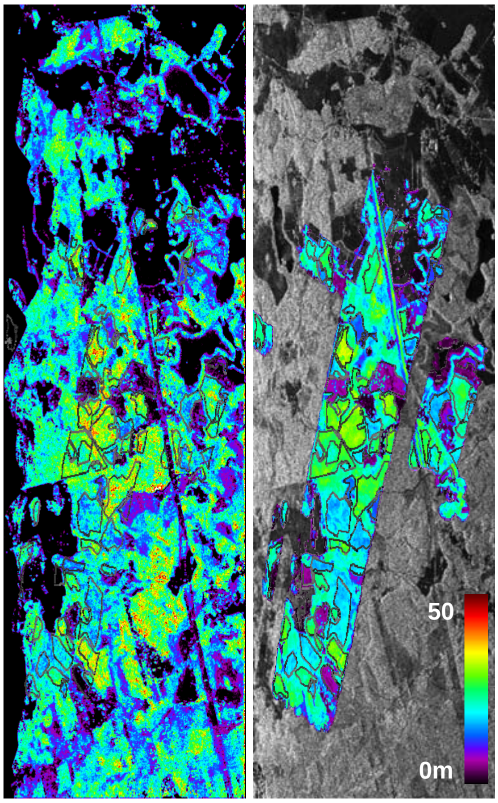

Figure 2: L-band forest height maps for Remningstorp forest, scaled from 0 to 50 m. Left: Multibaseline inversion result from April, Right: L-band amplitude image overlaid with lidar height (H_{100}).

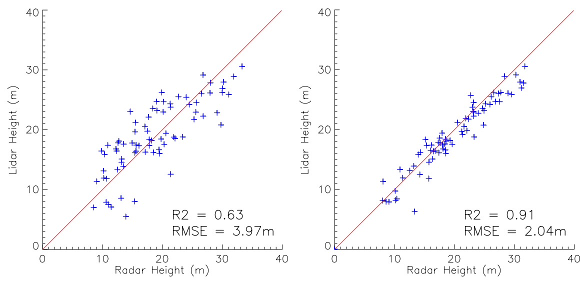

Figure 3: Validation plots between inversion height from E-SAR and H_{100} from lidar. Left: P-band, Right: L-band.

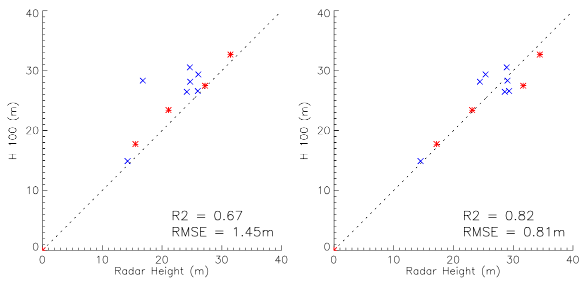

Figure 4: Validation plots between inversion height from E-SAR and H_{100} form ground measurements; 20 m by 50 m plots blue; 80 m by 80 m plots red. Left: P-band, Right: L-band.

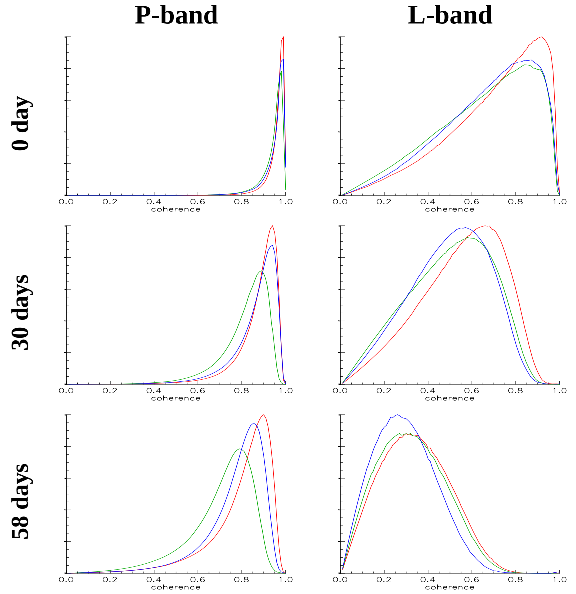

Figure 5: Coherence histograms of 0 day (May), 30 days (May-April) and 56 days (May-March) temporal baselines; HH(red), HV(green), and VV(blue).

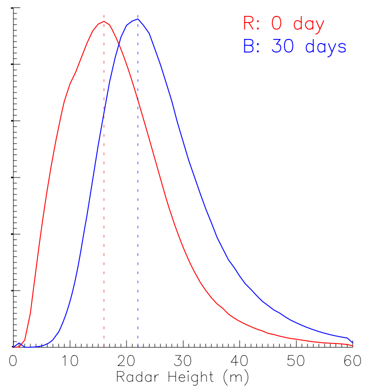

Figure 6: Histogram of the height distribution for 0 day (May) temporal baseline (red) and for a 30 days (May-April) baseline (blue).

three temporal baselines (all acquired with 0 m spatial baseline) are plotted.

As expected, temporal decorrelation increases with time at L- as well as at P-band independent from polarisations. Even in the 0 day scenario some decorrelation effects can be observed. Also here the data are acquired in a repeat pass mode with temporal baselines on the order of one hour. However, in an airborne scenario 0 m baseline is difficult to fly as there are always some deviations in the baseline (flight track). Deviations from the nominal baseline (0 to 3 m) cause volume decorrelation which drops coherence over forested areas whereas L-band is more affected than P-band due to the shorter wavelength [4]. As seen in **Figure 5** L-band (coherence of 0.65) decorrelates much faster than P-band (coherence of 0.9). P-band still allows height inversion after 30 days while at L-band the coherence level is already very low. Therefore, height inversion was done for the 30 days baseline only at P-band (see **Figure1** image 5). Compared to the short time inversion scenarios (**Figure 1** image 1 to 3) forest height is overestimated all over the image. In **Figure 6** forest height histograms of the whole scene for 0 day and 30 days temporal baseline are plotted. In this case 30 days of temporal decorrelation result in a height overestimation of 6 m but locally it can be much higher. Mean height changed from 16 m (0 day) to 22 m (30 days).

5 Conclusion

For this study a required amount of Pol-InSAR were available in L- and P-band in various spatial and temporal baselines, and for validation lidar data and ground measurements were obtained.

Temporal decorrelation is present in both frequencies even for repeat-pass time intervals on the order of minutes (BioSAR's smallest temporal baseline: 15min). Uncompensated temporal decorrelation introduces a height bias, need to be corrected. Stable and consistent inversion heights for short temporal baselines are obtained in both frequencies.

The level of temporal decorrelation with the 30 days repeat-pass cycle of BioSAR makes a height inversion still feasible. Especially, the coherence included for 30 days scenario at P-band was on a high level (0.9). As expected, L-band was more affected by temporal decorrelation. Temporal decorrelation introduced height error of about 6 m at P-band in the 30 days scenario.

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