QUANTIFICATION AND COMPENSATION OF TEMPORAL DECORRELATION EFFECTS IN POLARIMETRIC SAR INTERFEROMETRY

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ABSTRACT

Temporal decorrelation is a critical issue for a successful Pol-InSAR inversion in case of repeat-pass SAR data, as provided by conventional satellite or airborne SAR systems. This paper proposes estimation and compensation of temporal decorrelation effects by using multi-baseline Pol-InSAR data. A new approach to quantify different temporal decorrelation levels (one for volume and the other for the ground layer) is performed without resort to the special case of zero spatial baseline interferograms. Both temporal decorrelation coefficients were separately estimated at temporal baselines ranging from 1 to 15 days and compared to height inversion errors caused by them.

Index Terms— Pol-InSAR, temporal decorrelation, multi-baseline, forest height inversion

1. INTRODUCTION

Several studies showed that Pol-InSAR data especially at lower frequencies such as L- and P-band, are sensitive to the vertical distribution of scatterer along forest height. A model-based inversion of forest height and structural parameters was introduced and demonstrated in [1][2][4][5].

However, in repeat-pass airborne/spaceborne SAR system, temporal decorrelation is the most critical parameter for a successful Pol-InSAR forest parameter inversion. Temporal decorrelation is caused by the dynamic changes and/or the variation of the dielectric properties of the scatterers within the scene occurring in the time between the two SAR acquisitions [5][6]. Temporal decorrelation lowers the estimated coherence and therefore also the estimated volume decorrelation which is directly related to the vertical distribution of scatterers. Biased volume coherence leads to a biased forest parameter estimation in Pol-InSAR inversion [9][10][11]. Due to its random character it is difficult to estimate and compensate temporal decorrelation contribution from the complex interferometric coherence.

In this paper, a quantitative analysis of temporal decorrelation as a function of time using experimental data acquired by DLR's E-SAR system is performed. Then the implementation of a "coherent" multi-baseline inversion technique for compensating temporal decorrelation is evaluated. The behavior and compensation of temporal decorrelation is demonstrated by means of three campaign data sets: BioSAR 2007 [8] and TempoSAR 2008/2009 [10][11].

2. POL-INSAR INVERSION & TEMPORAL DECORRELATION

A widely and successfully used two-layer model, the so-called Random Volume over Ground (RVoG) model [3][4][5] represents coherently two scattering mechanisms: one from the volume and the other from the ground layer. The RVoG model is characterized by having a smaller number of independent physical parameters (assuming no response from the ground in one polarization channel) than observables so that these parameters can be estimated form Pol-InSAR data. However, the model does not account for temporal decorrelation contributions which are a critical factor for forest parameter estimation in case of a conventional repeat-pass SAR system. With a two-layer (volume/ground) scattering model, two different temporal decorrelation processes can be introduced: γ_{TV} denotes the correlation coefficient describing the temporal decorrelation of the volume layer and γ_{TG} represents the correlation coefficient describing temporal decorrelation of the underlying surface scatterer. Both temporal decorrelation effects can be incorporated in the RVoG model as [6][7]

$$\tilde{\gamma}(\vec{w}) = e^{i\phi_0} \frac{\gamma_{TV}\tilde{\gamma}_V + \gamma_{TG} m(\vec{w})}{1 + m(\vec{w})} \quad (1)$$

where $\tilde{\gamma}_V$ is the complex volume decorrelation and m represents the effective ground-to-volume amplitude ratio accounting for the attenuation through the volume. Equation (1) cannot be solved using a quad-polarization single baseline acquisition due to the additional two unknown parameters (γ_{TV} , γ_{TG}). However, even if the general temporal decorrelation scenario of Equation (1) leads to an underdetermined problem, special temporal decorrelation scenarios under certain assumptions may be accounted for with multi-baseline acquisitions.

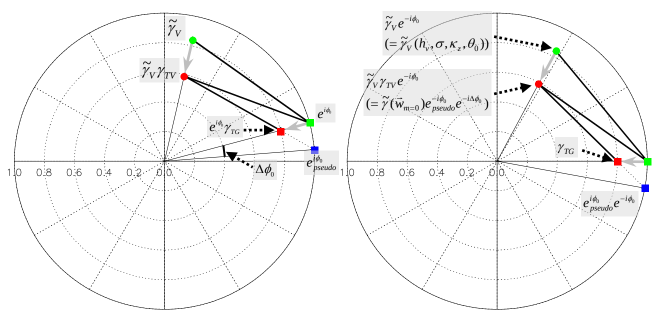
When the temporal baseline is considerably short (i.e. smaller than one hour), it is possible to assume that surface scatterers on the ground are stationary, and dielectric constants are unchanged (i.e. γ_{TG} = 1). Thus, the most common temporal decorrelation contributions over forest are mainly wind-induced movement of scatterers only within the volume layer. In the complex plain, the ground point (green rectangular point in Figure 1 (a)) remains unchanged, while the volume coherence $\tilde{\gamma}_V$ is shifted towards the origin by the factor γ_{TV} as shown in Figure 1 (a). Height errors increase with increasing temporal decorrelation of γ_{TV} and the estimation errors are significantly higher for low than for high forest heights [10].

For temporal baselines on the order of days, temporal decorrelation contributions induced by the change of scattering properties on the ground layer cannot be neglected (i.e. γ_{TG} < 1). Two temporal decorrelations , γ_{TV} and γ_{TG} result in a shift of the volume decorrelation $\tilde{\gamma}_V$ and the ground point $e^{i\phi_0}$ radially towards the origin as shown in Figure 1 (a). Note that the coherence loci decorrelated by both temporal decorrelations determine the biased ground point $e^{i\phi_0}_{pseudo}$ (blue rectangular point) and cause a ground phase error $\Delta\phi_0$ (see Figure 1 (a)). As a consequence of $\Delta\phi_0$, the phase center of the volume decorrelation $\tilde{\gamma}_V$ is overestimated and leads to a height error in the Pol-InSAR inversion.

Figure 2 shows the ground phase error and the height error induced by different levels of temporal decorrelation on the ground layer (γ_{TG} = 1.0 to 0.8) as a function of forest height assuming a vertical wavenumber of κ_z = 0.12 rad/m and the temporal decorrelation in volume γ_{TV} of 0.9. While no ground phase error appears for γ_{TG} = 1.0, $\Delta\phi_0$ increases as γ_{TG} decreases and forest height decreases. Figure 2 (b) shows the height error resulting from the phase error shown in Figure 2 (a). Compared to the impact of temporal decorrelation in volume γ_{TV} [10], a phase error caused by γ_{TG} introduces a smaller bias in the Pol-InSAR inversion.

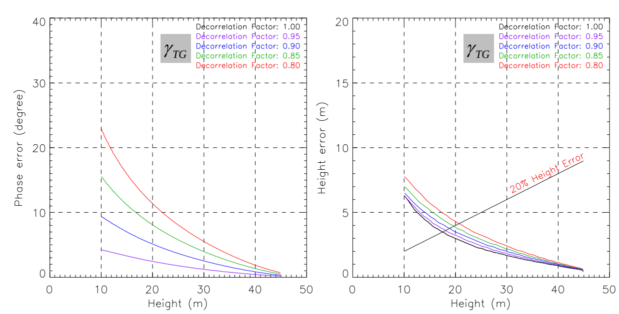
2.1. Experimental result for temporal decorrelations

The TempoSAR campaigns were preformed over the Traunstein test site in 2008 and 2009 to collect L-band Pol-InSAR data sets with a variety of spatial and temporal baselines. A forest height map obtained from multi-baseline inversion and incoherent combination of the single baseline results was presented in [12]. Using these results (i.e. forest height h_v and extinction σ), the volume coherence $\tilde{\gamma}_V(h_v,\sigma,\kappa_z,\theta_0)$ can be calculated (setting ϕ_0 = 0) and plotted (the green circle in Figure 1 (b)). For any Pol-InSAR acquisitions, the associated volume-only coherence $\tilde{\gamma}(\vec{w}_{m=0})$ and the biased ground point $e^{i\phi_0}_{pseudo}$ are obtained. The ground phase error $\Delta\phi_0$ is estimated by the phase difference between $\tilde{\gamma}_V(h_v,\sigma,\kappa_z,\theta_0)$ and $\tilde{\gamma}(\vec{w}_{m=0})e^{-\phi_0}_{pseudo}$. The temporal decorrelation on the ground layer γ_{TG} is obtained by the x-intercept of the line defined by $\tilde{\gamma}(\vec{w}_{m=0})e^{-\phi_0}_{pseudo}e^{-\Delta\phi_0}$ and $e^{-\Delta\phi_0}$ (red circle and blue rectangular points in Figure 1 (b)):



(a) (b)

Figure 1: (a) Coherence loci for the RVoG model with temporal decorrelations of γ_{TV} and γ_{TG} . (b) Coherence loci rotated by the ground phase $e^{-i\phi_0}(=e^{-i\phi_0}_{pseudo}e^{-i\Delta\phi_0})$; Temporal decorrelation on the ground layer γ_{TG} is located on the x-axis.



(a) (b)

Figure 2: Errors caused by γ_{TG} . (a) Ground phase error and (b) height error induced by different levels of temporal decorrelation γ_{TG} as a function of forest heights assuming a vertical wavenumber of κ_z = 0.12 rad/m and temporal decorrelation of γ_{TV} = 0.9.

$$\gamma_{TG} = \mathrm{Re}(\tilde{\gamma}(\vec{w}_{m=0}) e^{-i\phi_0}_{pseudo} e^{-i\Delta\phi_0}) - \mathrm{Im}(\tilde{\gamma}(\vec{w}_{m=0}) e^{-i\phi_0}_{pseudo} e^{-i\Delta\phi_0}) / \tan\theta_{gr} \quad (2)$$

where $\tan\theta_{gr}$ represents the gradient of the line.

As mentioned, temporal volume decorrelation γ_{TV} reduces the amplitude of the volume decorrelation $\tilde{\gamma}_V$ in Equation (1). Therefore, γ_{TV} can be obtained by the amplitude ratio of $\tilde{\gamma}_V(h_v, \sigma, \kappa_z, \theta_0)$ and $\tilde{\gamma}(\vec{w}_{m=0}) e^{-\phi_0}_{pseudo} e^{-\Delta\phi_0}$ (green and red circle points in Figure 1 (b)).

The quantitative estimation of γ_{TG} and γ_{TV} was performed by using Pol-InSAR data sets with temporal baselines up to 15 days. The results are shown in Figure 3. Overall temporal decorrelations of γ_{TV} and γ_{TG} decreases with an increase of the temporal baseline. However, the decorrelation processes within the volume layer occur much faster than the ones on the ground layer. The reason for this is that the scatterers in the vegetation layer are less stable against wind disturbances than the ones on the ground layer. But, the temporal decorrelations of γ_{TV} and γ_{TG} depend not only on the wind conditions but also on the rain-induced dielectric changes of volume and ground layer. Looking on the results for one day temporal baseline (Scene_ID: 01xx/02xx, 04xx/05xx and 08xx/09xx) of TempoSAR 2009, temporal decorrelations between 04xx and 05xx image pair show a much lower coherence level (γ_{TV} = 0.60 and γ_{TG} = 0.76) than the others. This may result from changes of dielectric properties caused by the precipitation just before the 05xx acquisition on 12th May 2009.

For the validation of the obtained results, a simulated height error for the estimated γ_{TV} and γ_{TG} obtained from each temporal baseline for a κ_z of 0.1 rad/m and a forest height of 26 m (mean height value in test site) is calculated and plotted against the real height error of the individual temporal baselines from 1 to 15 days [11]. Figure 4 shows this plot: on the x-axis is the real height error while on the y-axis the simulated height error obtained by using the estimated temporal decorrelations (γ_{TV} and γ_{TG}) from Figure 3 are given. The comparison shows a surprisingly high r^2 of 0.94 with an RMSE of 3.34 %. This means that the estimations of γ_{TV} and γ_{TG} are in accordance with the experimental results achieved.

3. MULTI-BASELINE POL-INSAR INVERSION

For the compensation of at least the γ_{TV} component a coherent dual baseline inversion is suggested.

In case of multi-baseline Pol-InSAR data, each of the available spatial baselines with its corresponding vertical wave numbers κ_{zi} (where $i \in \{1,2\}$) provides a set of three different complex coherences $[\tilde{\gamma}(\vec{w}_1) \ \ \tilde{\gamma}(\vec{w}_2) \ \ \tilde{\gamma}(\vec{w}_3)]^i$. One way to compensate for temporal decorrelation γ^i_{TV} is to estimate first for each single baseline the complex coherence $\tilde{\gamma}(\vec{w} \mid \kappa^i_z)$ without ground contribution in the signal ($m_3 = 0$). Then, for all baselines the h_v, σ and γ^i_{TV} are collected, i.e. the one associated with $\tilde{\gamma}(\{h_v, \sigma, m_3 = 0, \gamma^i_{TV}\} \mid \kappa^i_z)$. In a second step, h_v, σ (that are baseline invariant) and γ^i_{TV} are estimated from

$$\min_{h_v, \sigma, \gamma^i_{TV}, \phi_0} \left\| \begin{bmatrix} \tilde{\gamma}(\vec{w}_3 \mid \kappa^1_z) \\ \tilde{\gamma}(\vec{w}_3 \mid \kappa^2_z) \end{bmatrix} - \begin{bmatrix} \tilde{\gamma}(\kappa^1_z, \{h_v, \sigma, \gamma^1_{TV}\}) \\ \tilde{\gamma}(\kappa^2_z, \{h_v, \sigma, \gamma^2_{TV}\}) \end{bmatrix} \right\|. \quad (3)$$

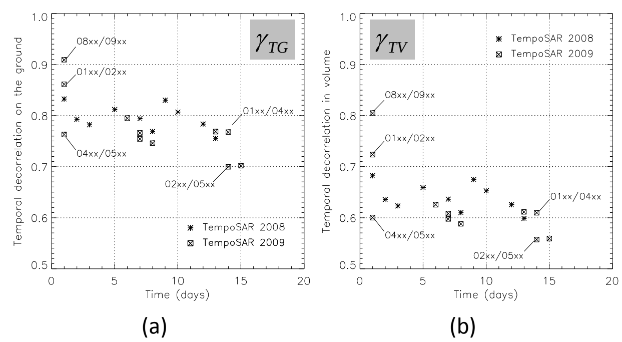


Figure 3: Mean estimated temporal decorrelations (a) on the ground layer γ_{TG} and (b) in volume γ_{TV} against temporal baseline of up to 15 days for TempoSAR 2008 and 2009. Asterisk point: TempoSAR 2008 and rectangular point: TempoSAR 2009.

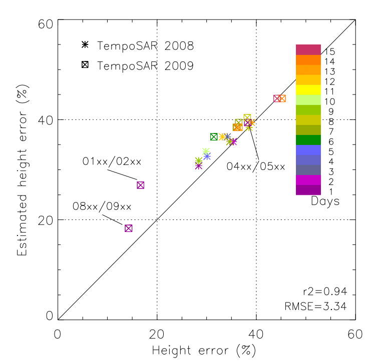


Figure 4: Validation of the estimated height error. X-axis: Height errors obtained directly from Pol-InSAR height inversion with temporal baselines. Y-axis: Height errors estimated by inverting Equation (1) with γ_{TG} and γ_{TV} from Figure 3 (a) and (b). Color represents the temporal baselines.

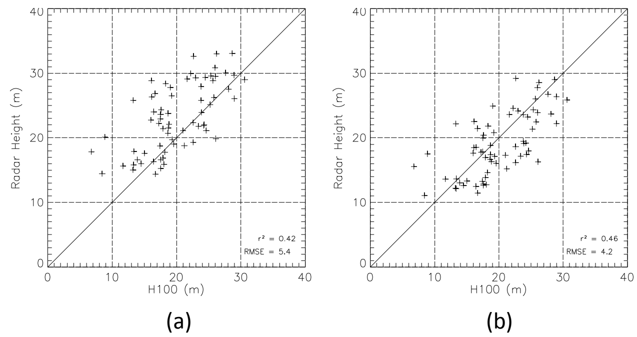


Figure 5: Estimated forest height vs. lidar derived H100. (a) non-compensation and (b) compensation of temporal decorrelation in the volume layer.

This algorithm is now demonstrated by means of a Pol-InSAR data set at P-band acquired during the BioSAR 2007 campaign. During the campaign data acquisitions were done on three different dates over the Remningstorp test site: 9^{th} March, 2^{nd} April and 2^{nd} May 2007 [8]. From these three data acquisitions, two temporal baselines on the order of one month could be generated: 9^{th} March – 2^{nd} April (24 days) and 2^{nd} April – 2^{nd} May 2007 (30 days). The Ground component in P-band is dominated by double bounce scattering and has a higher temporal stability than a ground component dominated by surface scattering. Therefore temporal decorrelation of the ground layer at P-band was neglected (i.e. $\gamma_{TG} \cong 1$ in Equation (1)) in the inversion. Dual baseline height inversion was done by means of Equation (3) for the two temporal baselines of the Remningstorp test site and validated against Lidar reference measurements. Figure 5 (a) shows inversion results for the same data set without compensating for temporal decorrelation effects (r^2=0.42 RMSE=5.4 m) with a significant overestimation of forest height. Figure 5 (b) shows the validation plot for the dual-baseline inversion as described by Equation (3) accounting for two different scalar temporal decorrelation coefficients for the volume part (γ_{TV}^1 and γ_{TV}^2). The inversion performance is significantly improved (r^2=0.46 RMSE=4.2 m) and the height bias is removed.

4. CONCLUSIONS

In this paper, Pol-InSAR temporal decorrelation model with two different temporal decorrelation coefficients was discussed. The estimation of different temporal decorrelation in time was quantitatively achieved. In order to overcome the impact of temporal decorrelation in the volume layer a "coherent" dual-baseline Pol-InSAR inversion was suggested. First results showed that a compensation of two scalar temporal decorrelation factors (one for each baseline) is feasible.

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