FOREST PARAMETERS INVERSION USING POLARIMETRIC AND INTERFEROMETRIC SAR DATA

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ABSTRACT

In this paper we discuss some aspects of the forest height estimation using Polarimetric and Interferometric (POLINSAR) SAR data. Three main issues limit the inversion of the POLINSAR coherence from repeat-pass POLINSAR systems: temporal decorrelation, terrain slope distortions and effects of wave penetration. We show that, if temporal decorrelation is not severe, the distortions due to terrain slope can be removed and the wave penetration can be compensated using the predictions of the scattering simulator PolSARProSIM. A detailed procedure that applies to any POLINSAR data is presented and illustrated using ALOS/PALSAR data and the SRTM digital elevation model (DEM).

1. INTRODUCTION

Polarimetric SAR Interferometry [1] has the potential to estimate trees height from POLINSAR data and to retrieve the worldwide forest biomass.

POLINSAR technique uses the interferometric degree of coherence estimated at different polarizations. Different polarizations make possible to discriminate among the scattering mechanisms inside the resolution cell and interferometric processing associate to them a scattering phase height. The combination of the two information allows to retrieve information along the vertical structure of forests and in general the retrieval of bio- and geo-physical parameter from vegetated areas. Several airborne sensors, such as the DLR E-SAR, and recent spaceborne missions, such as ALOS-PALSAR, have been dedicated to the demonstration of POLINSAR technique at L-band over forested areas.

We recognize three main sources of errors that make this demonstration a challenging task.

1. *Temporal artifacts* decorrelate the measurements, hence the coherence reduces and the phase height is less reliable.
2. Scattering *volume interactions* and the effects of the wave penetration in the canopy make the top of the canopy and the ground difficult to identify.
3. *Terrain slope* distorts the coherence and further complicates the retrieval.

The effects of temporal decorrelation (TD) has been observed from repeated acquisitions over the same area with different temporal baseline. In POLINSAR applications, temporal artifact modifies the coherence region in the complex plane (i.e. the set of coherence values while changing the polarization) as shown fig. 1a. If temporal decorrelation is not modeled properly, the inversion process results difficult. However, while the coherence reduces, the mean phase extension of the region remains unchanged. Hence, in absence of a TD model and up to a certain extent, we can focus on the coherence phase to estimate the forest height.

The difference between top- and bottom-phase of the coherence region, is related to forest height but does not allow a direct retrieval due to the slope distortion and the wave penetration effects. These two effects can be assessed using the coherent POLINSAR scattering simulator PolSARProSIM [2]. Next sections show how their assessment can be exploited to correct for the coherence distortions on real data. Once corrected, the coherence may be exploited by current POLINSAR inversion approach.

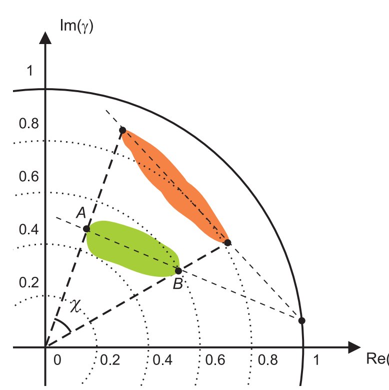


Fig. 1. Coherence region in the complex plane and effect of temporal decorrelation.

2. THEORETICAL BACKGROUND

A monostatic, fully polarimetric interferometric system observes the scene from two slightly different look angles to yield two complex 2×2 scattering matrices. By combining the elements of each scattering matrix, the SAR response at any TX/RX polarization configuration can be calculated. Let S_1 and S_2 be the interferometric SAR images obtained at a generic polarization. The complex degree of coherence between the two images is

$$\gamma = \frac{\langle S_1 S_2^* \rangle}{\sqrt{\langle S_2 S_2^* \rangle \langle S_2 S_2^* \rangle}} \qquad 0 \leq |\gamma| \leq 1 \tag{1}$$

wherein the spatial averaging $\langle \cdot \rangle$ aims at reducing the speckle noise. Over forested areas the coherence changes according to polarization as shown in Fig. 1a. The objective of POLINSAR techniques is the exploitation of the information content of that coherence region. As mentioned above, the angular extension of the region is related to the vertical extent of the imaged target. Suppose that two scattering mechanisms (A) and (B) located respectively at the top and the bottom of the vegetation exist. I we are able to identify these scattering mechanisms and to estimate their coherence $\gamma_v^{(A)}$ and $\gamma_v^{(B)}$, the vegetation height would be readily obtained by

$$h_v = \frac{1}{k_z} \arg\left[\gamma_v^{(A)} \gamma_v^{*(B)}\right] \tag{2}$$

where k_z is the vertical wavenumber of the interferometric acquisition. Fig. 2 illustrates how the position of the top scattering center changes. The optimal condition is represented by a phase centers located on the top of trees (Fig. 2a). As the target is a vertical distribution of scatterers, the interactions among the scatterers and the wave penetration change the position of the scattering center (Fig. 2b). Finally, the presence of the ground modifies the target and hence introduces a further distortion (Fig. 2c). These considerations suggests that,

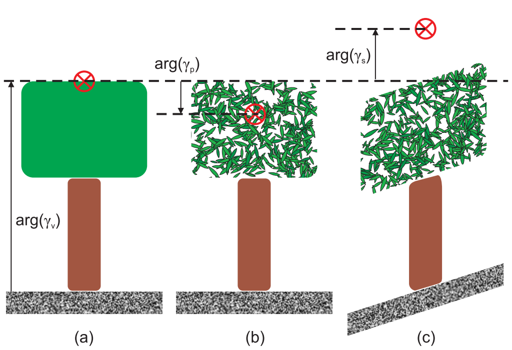


Fig. 2. Effects of the wave penetration and terrain slope on the top-phase scattering center.

for the scattering mechanisms (A) and (B), the measured coherence γ can be broken into three polarization-dependent contributions

$$\gamma = \gamma_{vsp} = \gamma_v \gamma_s \gamma_p \tag{3}$$

where γ_p represents the effect of the volume interactions with respect to the optimal condition (i.e. top or bottom of vegetation), γ_s the distortion induced by terrain slope and γ_v represents the optimal (phase) condition, including temporal and SNR decorrelation. From (3), it follows that $\arg\left[\gamma_v^{(A)}\right]$ is located at the top of the canopy and $\arg\left[\gamma_v^{(B)}\right]$ is located at the bottom, which is in accordance with (2).
Now, if we have knowledge of the terrain slope α and we are able to quantify the amount of distortion $\gamma_s(\alpha)$, the slope-free estimate of the coherence is

$$\gamma_{vp} = \frac{\gamma_{vsp}}{\gamma_s(\alpha)}. \tag{4}$$

The relationship $\gamma_s(\alpha)$ can be estimated using PolSARProSIM and the details are given in the next section. Fig. 4 shows the phase of $\gamma_s(\alpha)$ scaled by the vertical wavenumber in the case of range and azimuth slope. The simulation parameters are in Tab. 1. As the plots confirm, the amount of phase bias due to the terrain is significant. For some polarizations, the bias can reach several meters, yielding to large errors in the estimation of forest height. A first estimate of forest height

Parameter	Value
Altitude	700000 m
Incident angle	21.5 degrees
Horizontal baseline	200 m
Vertical baseline	0 m
Central frequency	$1.3 \cdot 10^9$ Hz
Area of the forest	220000 m^2
Tree species	Pine
Density	300 stems/Ha

Table 1. Values of the simulation parameters.

can be derived using γ_{vp} estimated in (A) and (B)

$$h_{vp} = \frac{1}{k_z} \arg\left[\gamma_{vp}^{(A)} \gamma_{vp}^{*(B)}\right]. \tag{5}$$

A coherence optimization algorithm can be used to identify the best coherence values [3]. This height estimate is used for correcting the wave penetration $\gamma_p(h_v)$ which depends on forest height. Assume that $h_v \simeq h_{vp}$, a better estimate of the vegetation height can be derived

$$h_v = \frac{1}{k_z} \arg\left[\gamma_v^{(A)} \gamma_v^{*(B)}\right] = \frac{1}{k_z} \arg\left[\frac{\gamma_{vp}^{(A)} \gamma_{vp}^{*(B)}}{\gamma_p^{(A)}(h_{vp}) \gamma_p^{*(B)}(h_{vp})}\right]. \tag{6}$$

where factors $\gamma_p^{(A)}(h_{vp})$ and $\gamma_p^{(B)}(h_{vp})$ are derived from PolSARProSIM simulations, as described in the following section. Fig. 3 shows the phase of $\gamma_v p(h_v)$ at different polarizations. From that plot the correction $\gamma_p(h_v)$ is derived. The curves confirm that the penetration is height-dependent and that can be significant (several meters) leading to an underestimation of the height.

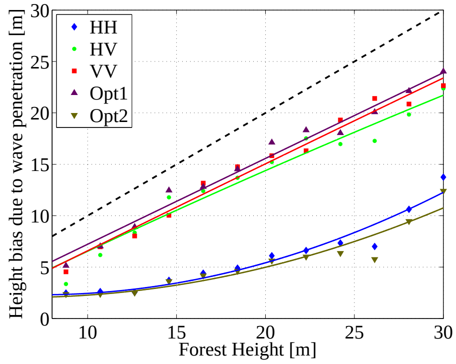


Fig. 3. POLINSAR coherence phase versus forest height generated by PolSARProSIM simulations of Tab. 1. Optimized coherence are calculated using the algorithm in [4].

3. HEIGHT ESTIMATION APPROACH AND RESULTS

The theory outlined in Sec. 2 makes possible to develop the procedure described hereafter. The procedure estimates forest height from repeat-pass InSAR system, without knowledge of the amount of temporal decorrelation. The "ingredients" are: an InSAR dataset of dual- or full-pol acquisitions; the slope map of the area (e.g. derived from an SRTM DEM); a set of PolSARProSIM simulations with the sensor characteristics of the dataset.

1. Perform the classical InSAR processing with the real dataset in order to obtain two flattened interferograms that correspond roughly to two scattering mechanisms located at the top and bottom of vegetation, (A) and (B) respectively.

2. Estimate the terrain slope from external DEM coded on the slant range geometry (or, alternatively, from the unwrapped bottom phase center (B) if a DEM is not available).

3. Generate a set of PolSARProSIM simulations using the viewing geometry of the real acquisition by changing forest height and terrain slope. Other information (e.g. soil roughness) can be set to an average value (or properly included, if available).

4. From the simulated dataset with different slope α_{sim}, estimate the coherence (A) and (B) in the central part of the output images (i.e. the forested area) in order to obtain a set of discrete values $\gamma'_{s_{\mathrm{sim}}}(\alpha_{\mathrm{sim}})$. From these values, calculate the discrete corrections $\gamma_{s_{\mathrm{sim}}}(\alpha_{\mathrm{sim}}) = \gamma'_{s_{\mathrm{sim}}}(\alpha_{\mathrm{sim}})/\gamma_{s_{\mathrm{sim}}}(0)$ for both interferograms.

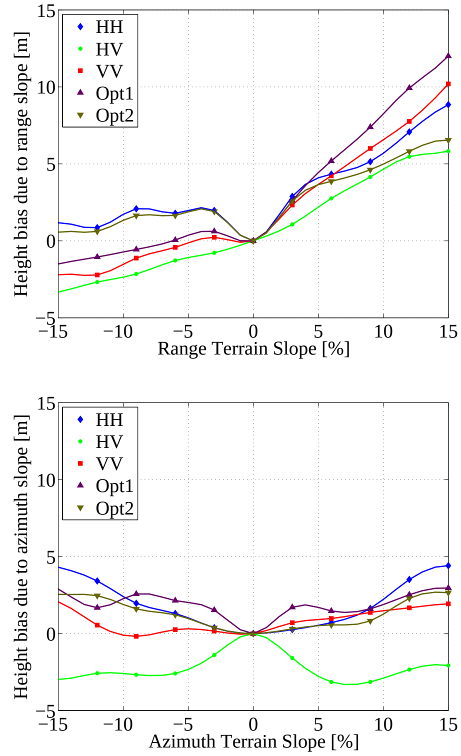


Fig. 4. POLINSAR coherence phase versus range and azimuth terrain slope generated by PolSARProSIM simulations of Tab. 1. Optimized coherence are calculated using the algorithm in [4].

5. Interpolate $\gamma_{s_{\mathrm{sim}}}$ over the real slope α to generate the maps of slope correction $\gamma_s(\alpha)$ for the coherence (A) and (B).

6. Obtain a first estimate h_{vp} of vegetation height by combining (5) and (4).

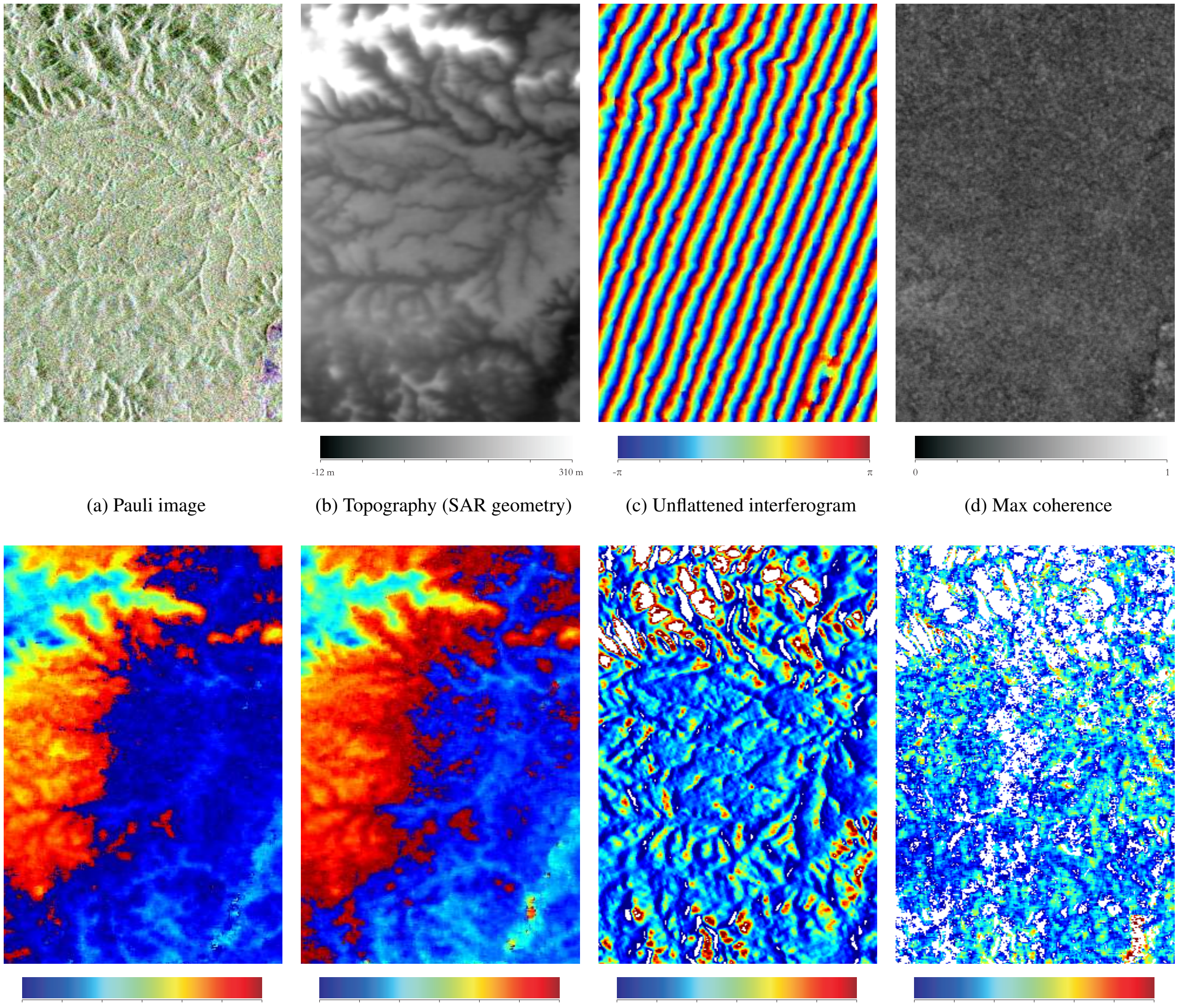
7. From the simulated dataset with different heights $h_{v_{\mathrm{sim}}}$, estimate the coherence (A) and (B) in order to obtain a set of discrete values $\gamma'_{p_{\mathrm{sim}}}(h_{v_{\mathrm{sim}}})$. From these values, calculate the discrete corrections $\gamma^{(A)}_{p_{\mathrm{sim}}}(h_{v_{\mathrm{sim}}}) = \gamma'^{(A)}_{p_{\mathrm{sim}}}(h_{v_{\mathrm{sim}}})e^{-jk_z h_{v_{\mathrm{sim}}}}$ and $\gamma^{(B)}_{p_{\mathrm{sim}}}(h_{v_{\mathrm{sim}}}) = \gamma'^{(B)}_{p_{\mathrm{sim}}}(h_{v_{\mathrm{sim}}})$.

8. Interpolate the discrete corrections over h_{vp} to generate the maps of slope correction $\gamma_p(h_{vp})$ for the coherence (A) and (B).

9. Obtain a second estimate of vegetation height by using (6) and iterate the procedure if necessary.

10. Mask out the pixels with low coherence and with strong terrain variation.

A preliminary test of this inversion procedure on ALOS-PALSAR data acquired over Amazon forest is shown in Fig. 4a. The associated SRTM DEM of the area reveals different slope values and is shown in Fig. 4b. The top- and



(a) Pauli image (b) Topography (SAR geometry) (c) Unflattened interferogram (d) Max coherence

(e) Low phase (f) High phase (g) Height correction map (h) Estimated vegetation height

Fig. 4. Example of POLINSAR processing using ALOS/PALSAR data over Amazon forest.

bottom-phase have been calculated using the optimization algorithm in [4]. The slope correction map associated with the range slope and the top-phase is in Fig. 4g. Finally, the height map is in 4h.

4. CONCLUSIONS

We have discussed a procedure to estimate the forest height using the POLINSAR phase difference and PolSARProSIM simulations. The role of PolSARProSIM simulation is to quantify the terrain slope distortions and the penetration depth in the canopy. A simple model allows to take into account and correct the coherence for these effects in order to get a better estimate of the phase difference.

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