Potential of TanDEM-X for forest parameter estimation

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Abstract

It was demonstrated that interferometric volume coherence is sensitive to vertical forest structure. This is true even for high frequencies as X-band. Resent Experiments demonstrated the potential of X-band to estimate key forest parameters like forest height. The main limitations at X-band are the high extinction values (up to 1dB/m and larger) for forests and the high sensitivity of X-band to temporal decorrelation. With the launch of the TanDEM-X satellite, for the first time single pass interferometric X-band data from a space borne system become available. In this paper the potential of X-band for forest height inversion is discussed and experimental results from different relevant campaigns are introduced and discussed.

1 Introduction

Model based forest height inversion from PolInSAR data is today an established and well validated approach [1][2][3][4][5][6][7][9]. The inversion results have been primarily addressed at low frequencies like L- and P-band and the obtained estimates have been validated over a variety of temperate, boreal and tropical test sites. X-band is expected to be less sensitive to vertical forest structure, but in [6][9][10] forest height inversion has been successfully demonstrated confirming a sufficient penetration capacity of X-band in vegetation going along with a sensitivity to vertical forest structure. In this paper the forest height inversion results using X-band in different test sites are summarized: 1. Traunstein test site (temperate forest), 2. Kobernausser Wald test site (temperate forest) and 3. Mawas test site (tropical forest).

Table 1: Data base test sites

Test Site	Acquistion Mode	Vertical wavenumber
Mawas, Indonesia	Single Pass VV Half Baseline	0.07 – 0.13
Kobernausser Wald, Austria	Single Pass VV Half Baseline	0.07 – 0.13
Traunstein. Germany	Single Pass VV Full Baseline	0.07 – 0.13
Traunstein. Germany	Single Pass VV Half Baseline	0.13 – 0.25

2 X-band Inversion

Forest height inversion at X-band is based on the random volume over ground (RVoG) model [1][2][3] describing interferometric coherence $\tilde{\gamma}_V$ as:

$$\tilde{\gamma}_V = \exp(i\kappa_z z_0)\frac{\tilde{\gamma}_{V0}+m}{1+m} \qquad \text{-1)}$$

where $\phi_0 = \kappa_z z_0$ is the phase related to the ground topography z_0, and κ_z is the vertical wavenumber

$$k_z = n\frac{2\pi}{\lambda}\frac{\Delta\theta}{\sin(\theta)} \qquad \text{- 2)}$$

with $n=2$ for monostatic and $n=1$ for bistatic acquisitions. The effective ground-to-volume amplitude ratio m accounts for the attenuation through the volume. $\tilde{\gamma}_{V0}$ is the volume decorrelation caused in the absence of the ground layer and corresponds to:

$$\tilde{\gamma}_V = \exp(i\kappa_z z_0)\frac{\int_0^{h_V}\exp(i\kappa_z z')\exp\left(\frac{2\sigma z'}{\cos\theta_0}\right)dz'}{\int_0^{h_V}\exp\left(\frac{2\sigma z'}{\cos\theta_0}\right)dz'} \qquad \text{-3)}$$

where σ is the mean extinction coefficient and θ the angle of incidence.

At higher frequencies the mean extinction increases, attenuating more and more the ground scattering contribution. Coherence dependency on polarization becomes rather limited as the strongly polarized ground scattering gets lost. One possible approximation towards a simplified inversion scenario is to ignore completely the ground scattering component (by assuming *m=0* in Eq. 1) in all polarizations. Using the interferometric coherence at a single polarization channel leads to an underdetermined inversion problem with 3 unknowns and only 1 (complex) observable. Fixing the ground phase allows obtaining a determined problem:

$$\min_{h_V,\phi_0}\left\|\tilde{\gamma}(\vec{w}) - \tilde{\gamma}_V(h_V,\sigma \mid \phi_0 = \phi_{DEM})\right\|. \qquad \text{-4)}$$

A second possibility is to fix the extinction value reducing further the inversion problem to a single parameter (height) problem by neglecting the ground phase:

$$\min_{h_V}\left\| \, |\tilde{\gamma}(\vec{w})| - |\tilde{\gamma}_V(h_V,\phi_0 \mid \sigma = \sigma_0)| \, \right\| \qquad \text{-5)}$$

3 Test Sites & Results

3.1 Data base

Interferometric SAR data used in this paper have been acquired by DLR's ESAR system in a single pass mode and are summarized in Table 1. Dependent on the acquisition mode (Full or Half baseline) two different spatial baselines with analogous different vertical wavenumbers κ_z are available. A Full baseline acquisition was only done for Traunstein test site. For validation Lidar H100 was used as described in [11].

3.3 Traunstein Test Site

The Traunstein test site is situated in the south east of Germany (47°52' north, 12°39' east) and represents typical temperate forest conditions. Topography is flat but crossed by some steep canyons. Main tree species is spruce followed by fir and beech. It is a managed forest; hence there are stands with forest heights from 1m to 40m. Biomass ranges between 40t/ha and 450 t/ha. For validation Lidar data are available.

For Traunstein test site two baselines are available (see Figure 1). Going from the half baseline acquisition to the full baseline acquisition coherence drops significantly over forested areas but remains high (close to one) for surface areas. This clearly indicates the presence of volume decorrelation in X-band.

Both inversion scenarios result in a high correlation coefficient: r^2 of 0.90 for the half baseline acquisition with a root mean square error (RMSE) of 3.54m and an r^2 of 0.89 for the full baseline acquisition with a root mean square error of 3.67m.

As indicated by the RMSE both baselines tend to underestimate heights larger than 25m; this effect appears stronger in the half baseline scenario, probably because of the limited sensitivity as a result of the larger vertical wavenumber k_z. Scattering phase centre is with an RMSE of 9.2m (half baseline) and 8.9m (full baseline) which corresponds to the mean penetration depths, clearly below the canopy (see Figure 2 middle). The lower correlation coefficients for scattering phase centre reflect the larger variance in the height measurements. Extinction fluctuates between 0.3dB/m and 1 dB/m (Figure 2 right).

3.2 Kobernausser Wald Test Site

Test site Kobernausser Wald is located in upper Austria (48°04'north, 13°14'east). The terrain of the test site is gently sloped and covered with temperate coniferous dominated forest (spruce, pine and fir). Kobernausser Wald is a managed forest with several stands of different age and forest height. Measured forest heights range from 5m to 40m. In a strip diagonal across the image Lidar data were acquired which are used for validation.Inversion results for Kobernausser Wald test site can be found in Figure 3. InSAR inversion results using Eq. 4 are displayed in Figure 3 on the left. A correlation coefficient r^2 of 0.95 with an RMSE of 2.1m underlines a good estimation performance in X-band using Eq.4. The position of the scattering phase centre is with an RMSE of 9.9m about 30 % lower than Lidar reference height as indicated by Figure 3 middle. Going from InSAR height estimates (Eq. 4) to scattering phase centre heights variance increases. Considering extinction as an indicator for canopy closure/density then extinction values reflect forest management strategy (see Figure 3 right). With tree heights around 25m forest management starts harvesting activities thinning the canopy, harvesting activities are repeated in regular time intervals. This trend is reflected in the measured extinction values. Extinction increases up to 25m heights (with extinction values close to 1dB/m) and then it decreases until the maximum heights (~ 0.5 dB/m) are reached.

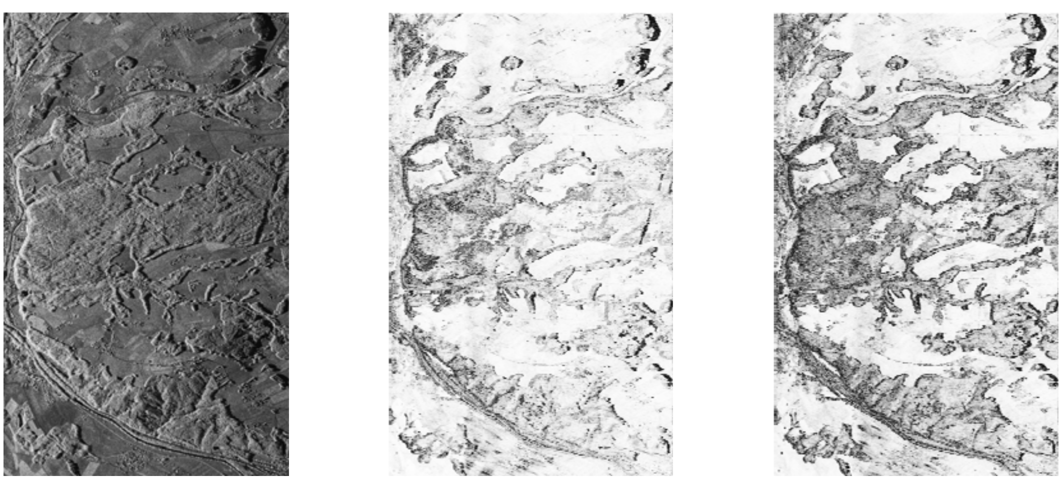

Figure 1: Radar images Traunstein test site; left: amplitude VV polarisation; middle: interferometric coherence full baseline; right: interferometric coherence half baseline; coherence scaled from 0 (black) to 1 (white)

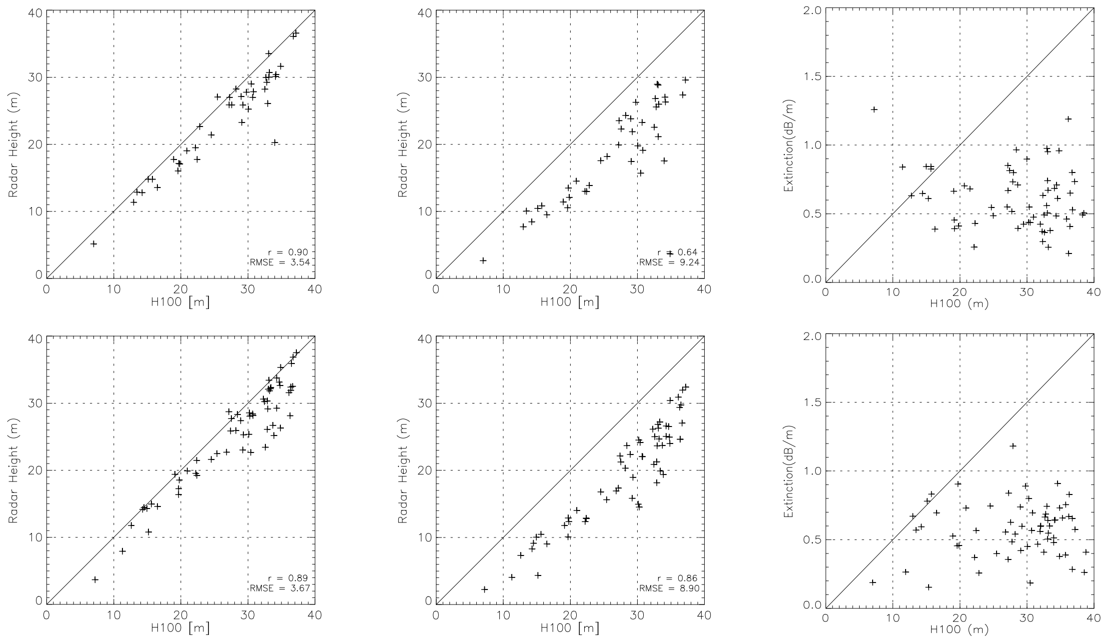

Figure 2: Traunstein test site; top: Half baseline; bottom: Full baseline; left: InSAR height estimates Eq. 4 vs. Lidar H100 validation plot; middle: InSAR phase centre height vs. Lidar H100 validation plot; right: Extinciton from Eq. 4 vs. Lidar H100 plot

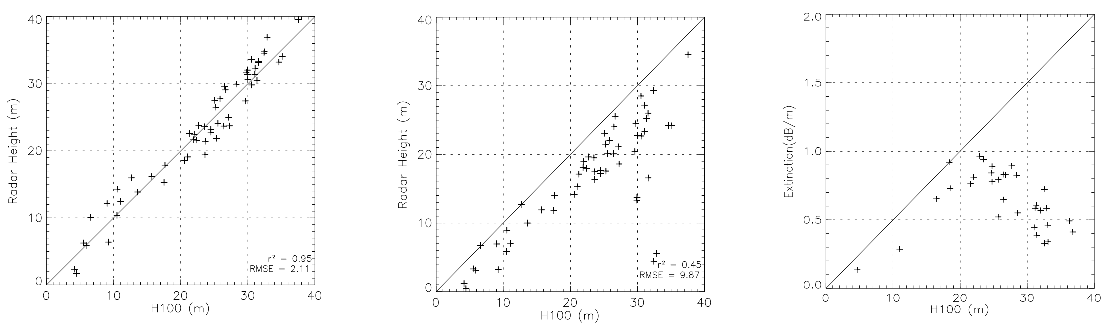

Figure 3: Kobernausser Wald test site; left: InSAR height estimates Eq. 4 vs. Lidar H100 validation plot; middle: InSAR phase centre height vs. Lidar H100 validation plot; Extinction from Eq. 4 vs. Lidar H100 plot

3.1 Indrex-II Mawas Test Site

The *Mawas* test site is located in central Kalimantan (latitude: -2.15° longitude: 114.45°). It is in general flat and is covered by tropical peat swamp forest. Forest height varies gradually from relatively tall (30 m) and dense forest towards small (15 m or lower) and open (disturbed) forest with biomass levels from 20 t/ha up to 250t/ha (see also [9]). Validation was done using Lidar measurements delineated into 100 homogeneous stands.

Mawas inversion results are summarized in [5] the corresponding X-band plots can be found in Figure 4. Applying InSAR inversion as described by Eq. 4; results in a correlation coefficient r^2 of 0.94 and an RMSE of 1.77m for a height range from 5m to 29m (Figure 4 left). This proves the good estimation performance at X-band. The estimated extinction values range from 0.1 up to 0.9dB/m with a mean extinction value on the order of 0.3dB/m. Comparing the estimated phase centre heights with the Lidar reference height yields to an RMSE of 9m (Figure 4 middle) and makes it obvious that the phase scattering centre of X-band is located clearly below the forest canopy. The correlation coefficient r^2 of 0.87 indicates a higher variance compared to InSAR forest height by means of Eq. 4.

In the absence of an external ground DEM, an alternative way to enforce a balanced inversion problem is to fix the extinction value (Eq. 5). Inversion has been performed using an extinction of 0.3dB/m that corresponds to the mean extinction value obtained from Eq 4. Figure 4 right shows the validation plot for the forest height estimates obtained by applying Eq. 5. The r^2 of 0.52 and a RMSE of 4.24m indicate a clearly inferior performance when compared to the inversion results obtained by means of Eq. 4

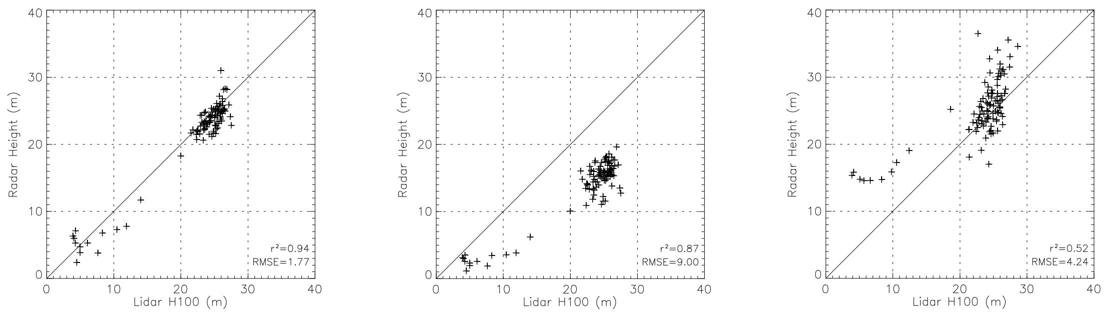

Figure 4: Mawas test site; left: InSAR height estimates Eq. 4 vs. Lidar H100 validation plot; middle: InSAR phase centre height vs. Lidar H100 validation plot; right: InSAR height estimates Eq. 5 vs. Lidar H100 validation plot

5 Outlook

The feasibility of forest height inversion in X-band using a single polarization was demonstrated by means of airborne data on three different test sites. Good results were obtained for a full inversion using an estimate of the ground phase as input information. TanDEM-X allows the acquisition of several independent baselines (partial coherent tomography [12]) which can be used for multi baseline inversion and probably makes a priori information about ground phase ϕ_0 obsolete. With the start of TanDEM-X the mentioned inversion methods will be applied to TanDEM-X data.

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