FOREST HEIGHT ESTIMATION FROM TANDEM-X INSAR COHERENCE MAGNITUDE TOWARDS LARGE SCALE APPLICATIONS

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ABSTRACT

TanDEM-X experiments have shown that forest height can be estimated with single polarization X-band interferometric coherences. An external digital terrain model (DTM) not only allows to use both coherence magnitude and phase information, but also to overcome X-band penetration limitations. However, DTM information is not available for large areas. Using coherence magnitudes makes height inversion feasible, but it requires a model relating coherence to height. Here we report an experiment using the X-band local phase center variations. Results over a tropical forest site show that in those stands in which the low X-band penetration is not a limitation, the there is a good correlation between the obtained TanDEM-X heights and the heights from Lidar measurements.

***Index Terms*—** Forest height, SAR interferometry, TanDEM-X.

1. INTRODUCTION

The TerraSAR-X add on for Digital Elevation Measurement (TanDEM-X) mission forms a space borne X-band single-pass interferometer that allows the global acquisition and analysis of Interferometric Synthetic Aperture Radar (InSAR) data over vegetated areas without temporal decorrelation. In this case, the volume decorrelation is the main coherence contribution. This makes possible the development of forest height estimation methods based on InSAR and polarimetric InSAR (PolInSAR) techniques. The investigation of TanDEM-X interferometric coherence data for forest applications has been increasing in the last years especially concerning forest height estimation [1-4], biomass estimation and classification [5-6]. The main techniques for forest height estimation are based on the using scattering phase center [3] or the volume coherence magnitude [4].

It has been shown that the availability of a digital terrain model enables forest estimation with TanDEM-X complex coherences without being affected by limitations in penetration [1]. Additionally, external ground (phase) information allows one free parameter for modelling the underlying vertical reflectivity profile even in single polarimetric cases (e.g. by further assuming the absence of ground scattering). However, external DTMs are not available everywhere.

TanDEM-X coherences have been reported to have a good sensitivity to forest height and its (horizontal) structure [7-8]. Even in the case of single channel acquisitions, coherence magnitudes may be sufficient for forest height estimation [4]: external DTMs are not needed anymore, and large scale forest height mapping is enabled. However, a single polarization coherence magnitude is only one parameter from which forest height must be estimated. Therefore, the (unknown) underlying vertical reflectivity profile must be fixed. Although the X-band penetration capability is the main limitation, several models including sinc- [9] and exponential functions have been investigated.

In this paper, an experiment is reported in which the local TanDEM-X phase center variation is used as a proxy to the reflectivity profile underlying the coherence magnitude, and in this way to estimate forest height. The proposed methodology has been applied in Lopé, Gabon in Africa. NASA's Land, Vegetation, and Ice Sensor (LVIS) Lidar data acquired over the same area are used for validation.

2. HEIGHT INVERSION FROM X-BAND INTERFEROMETRIC COHERENCE

The interferometric coherence γ in one polarization channel can be expressed as

$$\gamma = \gamma_{SNR}\, \gamma_B\, \gamma_{temp}\, \gamma_{Vol} \qquad (1)$$

where γ_{SNR}, γ_B, γ_{temp} are the Signal to Noise Ratio (SNR), baseline and temporal decorrelation contributions, respectively. In the TanDEM-Xcase, $\gamma_{temp} = 1$. γ_{SNR} and γ_B can be predicted and compensated [1]. As a consequence, $\gamma \cong \gamma_{Vol}$. γ_{Vol} is the volume coherence and it represents the decorrelation caused by volume scattering over vegetated areas. γ_{Vol} can be written as

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$$\gamma_{Vol} = \exp(ik_z z_0) \frac{\int_0^{h_v} f(z) \exp(ik_z z) dz}{\int_0^{h_v} f(z) dz} \quad (2)$$

where k_z is the vertical wavenumber, z_0 is the reference height (ground level), $f(z)$ is the radar vertical reflectivity profile and h_v is the wanted volume (forest) height. In this equation, there is one complex measurement, γ_{Vol} , and three unknown real parameters, i.e. $f(z)$, z_0 and h_v. A (low-dimensional) model for $f(z)$, an external z_0 and additional assumption contribute to make the estimation problem determined. The magnitude of (2) is

$$|\gamma_{Vol}| = \left| \frac{\int_0^{h_v} f(z) \exp(ik_z z) dz}{\int_0^{h_v} f(z) dz} \right| \quad (3)$$

Consequently, the inversion of h_v does not depends on the availability of z_0. However, the observation space reduces to only one measurement $|\gamma_{Vol}|$ with two unknown parameters, i.e. $f(z)$ and h_v. As the objective is the estimation of h_v, there are no free parameters left to model the behavior of $f(z)$. In absence of any a priori information, one possibility is to assume that all scattering contributions within h_v have the same power, i.e. a "box"-shaped profile. This leads to a sinc-shaped change of coherence magnitude as a function of height [9]. Alternatively, a different shape can be used, e.g. by fixing an extinction coefficient.

Here, a way to change $f(z)$ adaptively in space by using the local interferometric phase center variability is experimented. First of all, the local topographic contribution is reduced by compensating a low resolution (in the order of 100 m) interferogram from a high resolution (in the order of 10 m) one [7]. Histograms of the so obtained relative phase centers are calculated at a larger resolution (e.g. 50 m). The use of large scales allows collecting a statistically significant amount of samples for characterizing the profiles. After normalization of the height axis, these histograms, which change spatially, are then used in lieu of $f(z)$ in (3) to model $|\gamma_{Vol}|$ as a function of h_v. h_v is finally estimated by fitting the modelled coherence to the estimated one. It is worth remarking that the objective is not to obtain an (accurate) estimate of $f(z)$, but to "guess" spatial changes of the vertical distribution of scattering elements.

3. FIRST RESULTS OVER AFRICAN TROPICAL FORESTS

The methodology outlined in Section 2 has been applied to TanDEM-X bistatic data acquired over a part of the Lopè National Park (Gabon) on January 25, 2016. It is a single co-pol acquisition (HH), at 45° incidence angle and with height of ambiguity of around 65 m. On March 3, 2016, LVIS acquired Lidar waveforms and canopy height information. The top tree height is often around 50 m and it sometimes reaches 60 m.

The estimated TanDEM-X volume coherence is shown in Fig. 1(a). Forest areas decorrelate more than savannah areas (middle part). In the estimation of forest height, high slope (> 15 degree) areas are masked out.

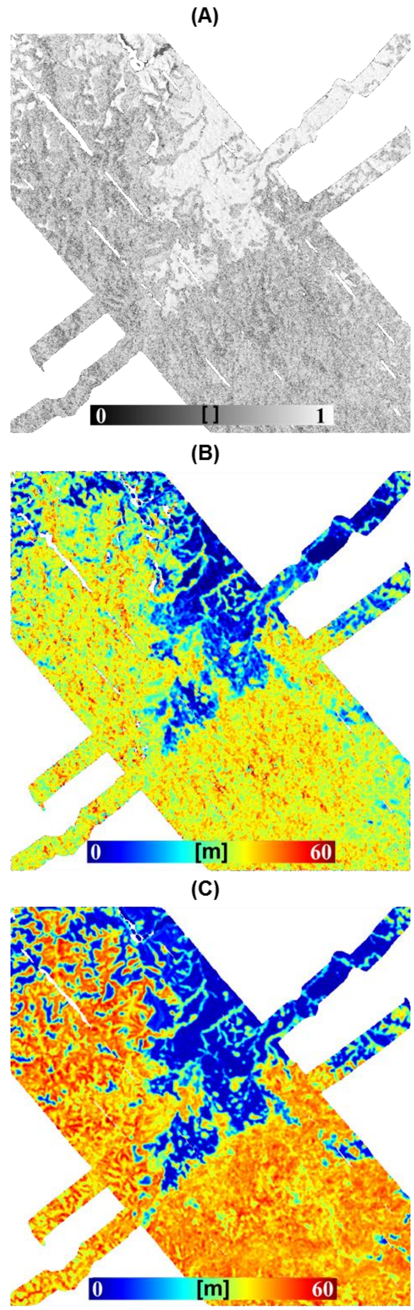

Fig. 1 – Lopé: (a) TanDEM-X volume coherence magnitude, (b) Estimated height from TDX coherence, (c) LVIS RH100 (geographic UTM coordinates).

Fig. 1(b) shows the estimated height from TanDEM-X coherence at 100m scale. Fig. 1(c) shows the map of LVIS RH100 (i.e. the height at which the total energy is received) at 100m resolution. Both maps were obtained by smoothing the 25 m TanDEM-X estimates and LVIS RH100. The estimated tree height map was validated with LVIS RH100 (see Fig. 2). Although the estimated heights show some overestimation in low canopy height areas and underestimation in dense forests, the estimated TanDEM-X heights and the reference RH100 heights are in agreement.

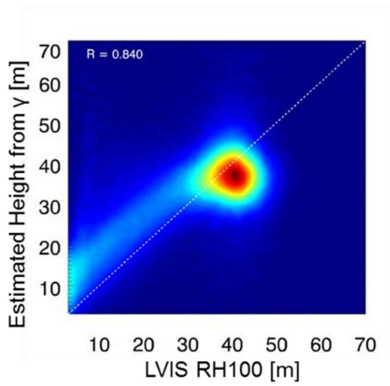

Fig. 2 – 2D histogram of the estimated TanDEM-X heights compared to the LVIS RH100.

4. OUTLOOK

The experiments in this work confirm that TanDEM-X coherence magnitudes can be used to estimate forest height without the need of an external DTM. As a particular case, the local variation of the phase centers can potentially be used as a proxy to the vertical reflectivity profiles for predicting the TanDEM-X coherence as a function of height in the estimation process. It has been found that the estimated heights are in agreement with the Lidar heights.

The mismatch between the phase center profiles and the actual reflectivity affect height estimation, especially in shorter stands, leading to height overestimation. This is likely due to the fact that phase center profiles predict a coherence higher than the observed one as a significant amount of scattering contribution close to the ground are missed. In contrast, in dense forest stand, the limited penetration leads to underestimated forest heights. Filtering unreliable height estimates is the actual open challenge. Both the final height estimation performance and the choice of the profile to be used for the inversion are the result of the trade-off between estimation accuracy and spatial density of the remaining estimates. Understanding this trade-off enables the use of TanDEM-X coherences for large scale forest height mapping.

5. REFERENCES

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