POLARIMETRIC SAR INTERFEROMETRY (POL-INSAR) FOR GLOBAL FOREST BIOMASS MONITORING

K. Papathanassiou (1), S. Cloude (2), G. Krieger (1), I. Hajnsek (3,1) and A. Moreira (1)

1. German Aerospace Centre (DLR)
Institute of Radio Frequency Technology and Radar Systems (DLR-HR)
P.O. Box 1116, D-82230 Wessling, Germany
Tel/Fax: ++49- 8153-28-2367 / 1449, Email: Kostas.Papathanassiou@dlr.de

2.AEL Consultants (AELc)
Tel/Fax :+44 (0)131 248 3777/3001
Email: aelc@mac.com

3. ETH Zürich,
Institute of Environmental Engineering
HIF D22-28, Wolfgang-Pauli-Str. 15, CH-8093 Zurich, Switzerland
Email: ihajnsek@ethz.ch

ABSTRACT

A central parameter to the terrestrial carbon budget is forest biomass which represents a proxy for carbon. Despite its crucial role in the terrestrial carbon budget, forest biomass is poorly quantified across most parts of the planet due to the great difficulties in measuring biomass on the ground and consistently aggregating measurements across scales. Today's information is largely based on ground measurements on a plot basis and for many regions is still missing. Accurate and reliable estimation of forest biomass is today one of the "hot topics" within the remote sensing community. In this paper, we discuss the contribution of multi-baseline polarimetric SAR interferometry (Pol-InSAR) techniques in the context of global biomass estimation and evaluate potential space-borne mission implementations.

Biomass a Function of Vertical Structure and Height

The first approach in terms of structure based biomass estimation was based on the allometric relationship between biomass and forest height

$$B = a \ H^{b} \tag{1}$$

where *B* is the Biomass in Mg/ha and *H* the forest top height. Eq. 1 has been used to estimate forest biomass using forest height estimates obtained from Pol-InSAR data inversion. This approach provides reliable results for closed canopy forest systems without strong density variations. The main error is caused by the missing information on stand density (basal area): changes in forest density and structure caused for example by tree species composition, management system or disturbance can introduce large deviations. With increasing horizontal and/or vertical forest heterogeneity the variance of the biomass to height relationship increases. The most promising option to overcome this limitation is to extend the height to biomass allometry by integrating (vertical) forest structure information. Different approaches for this are recently under development. One of these is based on a series extention of the vertical (biomass) structure according to

$$B = a * \sum_{i=0}^{H} \sum_{j=1}^{N} a_j \cdot P_j \tag{2}$$

where H is the he forest top height and $\sum_{j=1}^{N} a_j \cdot P_j$ the vertical forest biomass distribution expressed in terms of a (orthogonal) set (or series) of shape functions P_j.

Estimation of forest vertical structure by means of Pol-InSAR

The estimation of vertical structure from interferometric SAR (InSAR) measurements relies on the fact that one of the contributions of the interferometric coherence, the so called volume decorrelation $\tilde{\gamma}_{Vol}$, is directly linked to the vertical distribution of scatterers *F(z)* through a (normalized) Fourier transformation relationship

$$\tilde{\gamma}_{Vol} = \exp(i\kappa_z z_0) \frac{\int_0^{h_V} F(z') \exp(i\kappa_z z') dz'}{\int_0^{h_V} F(z') dz'} \qquad (3)$$

where h_V is the height of the volume and κ_z the effective vertical (interferometric) wavenumber that depends on the imaging geometry and the radar wavelength λ

$$\kappa_z = \frac{\kappa \Delta\theta}{\sin(\theta_0)} \quad \text{and} \quad \kappa = m\frac{2\pi}{\lambda} \qquad (4)$$

$\Delta\theta$ is the incidence angle difference between the two interferometric images induced by the baseline. z_0 is a reference height and $\varphi_0 = \kappa_z z_0$ the associated interferometric phase. Accordingly, $\tilde{\gamma}_{Vol}$ contains the information about the vertical structure of the scatterer and is the key observable for quantitative forest parameter estimation from Pol-InSAR measurements. The estimation of $F(z)$ (and/or corresponding structure parameters as forest height) from the inversion of $\tilde{\gamma}_{Vol}$ measurements is a unique opportunity provided by Pol-InSAR observations. Two different approaches are recently discussed:

1. The first one is to decompose $F(z)$ in a orthogonal function basis (or function series). The available $\tilde{\gamma}_{Vol}$ measurements are then used to estimate the coefficients of the individual components. The advantage of this technique is that there is no assumption on a given shape of $F(z)$. This allows the estimation of a rather large variety of shapes.

2. The second approach is to model $F(z)$ parameterising its shape and its scattering properties. In this case the possible shapes of $F(z)$ are restricted by the model used. A very successful modelisation of $F(z)$ is the so called Volume over Ground (VoG), a two layer model consisting of a volume and a ground layer, which can be described as

$$F(z) = \tilde{m}_V \, e^{\left(\frac{2\sigma}{\cos(\theta_0)} z\right)} + m_G \, e^{\left(\frac{2\sigma}{\cos(\theta_0)} h_V\right)} \delta(z - z_0) \qquad (5)$$

m_V and m_G are the ground and volume scattering amplitudes, h_V is the volume height and $\sigma > 0$ a mean extinction coefficient for the volume. Robust inversion of both approaches – across a wide range of forest conditions – requires a observation space that combines:

■ Baseline diversity: The dependency of $\tilde{\gamma}_{Vol}(\kappa_z)$ on the vertical wave number (see Equation 3) is essential not only for increasing the observation space ($F(z)$ does not change with κ_z) but also for optimizing the inversion performance.

■ Polarimetric diversity: The variation of $\tilde{\gamma}_{Vol}(\vec{w})$ with polarization is due to the polarization dependency of $F(z)$. The fact that this dependency is physically related to certain components of $F(z)$ and can be modeled using a reduced number of parameters makes Polarimetric Interferometry a powerful combination.

In this paper we:

1. Discuss the individual approaches of estimating vertical forest structure from Pol-InSAR observations and show results achieved in the frame of different relevant and actual experiments;
2. Derive the main observation requirements with respect to structure based biomass estimation;
3. Indicate the critical points arising from a space-borne implementation;
4. Discuss possible mission implementations and scenarios.

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