DETERMINING TREE HEIGHT BY POLARIMETRIC SAR INTERFEROMETRY: METHODOLOGY.

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Objectives and Expected Results

The main objective will be the development of required experience and tools to allow extracting tree height estimates from SARAT data using polarimetric SAR interferometry (PolInSAR) techniques:

- ✓ Theoretical and practical expertise in canopy height extraction using advanced PolInSAR techniques.
- ✓ PolInSAR tool tailored to SAOCOM and SARAT specificities allowing these estimates to be made.
- ✓ PolInSAR products and canopy height estimates over the test site of interest.

1.Introduction

1.1 Full Polarimetric SAR Interferometry

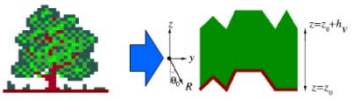
•InSAR = scalar SAR Interferometry:
- Pair of acquisitions of same scene
  - ⇨ Height information on observed surface

• PolSAR = SAR Polarimetry:
- Signal is transmitted/received in different polarizations
  - ⇨ Information on scattering mechanisms

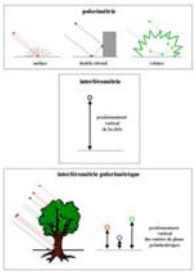
• PolInSAR = vectorial full-polarimetric SAR Interferometry:
- Polarimetric techniques are introduced into SAR interferometry applications
  - ⇨ Combined sensitivity to vertical distribution of scattering mechanisms

1.2 Random Volume over Ground Model

Two-layer model:
- ➢ Ground = impenetrable scattering surface
- ➢ Vegetation = homogeneous layer of randomly oriented scatterers characterized by
  - height h_v
  - constant extinction coefficient σ
- ➢ Ground-to-volume ratio $m = m_g/m_v$ dependent on polarization



Bottom of canopy = ground surface: z_0
Top of canopy: $z = z_0 + h_v$ ⟶ phase $\varphi_{bottom\ canopy} = \varphi(z0) =$ topographic phase φ_1



2. Polarimetric Interferometry + RVoG Model

Complex interferometric coherences for various polarizations from PolInSAR data ⟷ Model parameters:
- Ground topographic phase
- Vegetation height
- Extinction coefficient
- Ground to volume amplitude ratio

$\tilde{\gamma}_1, \tilde{\gamma}_2, \tilde{\gamma}_3$
$\tilde{\gamma}_{HH}, \tilde{\gamma}_{VV}, \tilde{\gamma}_{HH+VV}, \tilde{\gamma}_{HH-VV}$

$\varphi_1, h_v, \sigma, m = m_g/m_v$

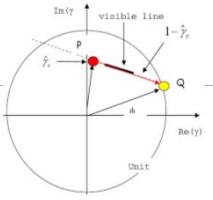
$$\tilde{\gamma}(\omega) = \exp(i\varphi_1)\left[\tilde{\gamma}_v(h_v,\sigma) + \frac{m(\omega)}{1+m(\omega)}\left[1-\tilde{\gamma}_v(h_v,\sigma)\right]\right]$$

RVoG model inversion ⇒ Ground phase retrieval; Vegetation height evaluation

- **useful way of interpreting the mixture of ground and vegetation.**
- **demonstrated to be performing for forest scattering, especially for L-band SAR.**

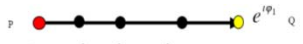
3. RVoG Model Inversion

According to RVoG model: Complex coherence follows a straight-line segment in complex plane with respect to the transmitted and received polarization choice



1. Best fit line through observed coherence values.
   - Using full-pol interferometric optimized coherences $\tilde{\gamma}_1, \tilde{\gamma}_2, \tilde{\gamma}_3$ → better conditioning
   - Works also with dual-pol interferometric coherences
2. Ground phase retrieval: intersection point nearest from highest coherence $\tilde{\gamma}_1$ (or $\tilde{\gamma}_{HH}$) = closer to the ground
   → It gives the topographic phase φ_1 (Q point on fig.)
3. Height inversion
   2 assumptions:
   - one measured channel is considered as a pure volume coherence ($m_v = 0$): $\tilde{\gamma}_v$ *is used for* $\tilde{\gamma}_{vv}$
   - phase center of pure volume coherence ($m_v = 0$) is assumed to be located exactly at top of vegetation.

   Exact location depends on mean wave extinction & vertical structure of canopy



$$\Rightarrow \quad h_v = \frac{\arg(\tilde{\gamma}_v) - \varphi_1}{k_z} + \varepsilon\frac{2\sin c^{-1}(|\tilde{\gamma}_v|)}{k_z} \qquad k_z = \frac{4\pi\Delta\theta}{\lambda\sin\theta}$$

Altitude differencing (φ_1 = topographic phase)
Compensation for height underestimation
L-Band SAR: ε = 0.4

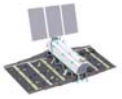
4. Compact Polarimetric SAR

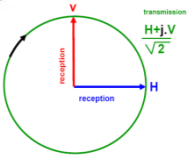
4.1 SAOCOM Hybrid CL-Pol Mode

- ✓ Circular polarization at emission
- ✓ *H* and *V* polarizations at reception

$$\vec{k}_{CL-POL} = \begin{pmatrix} S_{RH} \\ S_{RV} \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix}\begin{pmatrix} 1 \\ -j \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} S_{HH} - jS_{HV} \\ S_{VH} - jS_{VV} \end{pmatrix}$$

Advantages:
- swath enlarged by 2 while keeping downloading data rate
- circular polarization less sensitive to Faraday rotation





4.2 Faraday Rotation in CL-POL Mode

CL-POL mode: Faraday rotation only affects the return signal

⇨ CL-POL calibration = more efficient as compared to other C-POL or dual-POL modes

Evaluation of Ω for CL-POL calibration:
- using data acquired on bare surfaces
- from calibration of F-POL also available onboard

4.3 Extension of CL-POL to PolInSAR Processing ad RVoG Model Inversion

Compact Polarimetry: less information as compared to F-POL (2 measurements instead of 4)

For dense forests: lack of information can be compensated by symmetry properties
= **Azimuthally symmetric scatterers**

↳ F-POL information = redundant

↳ C-POL information = sufficient

→ **reconstruction of full-pol information**

⇨ For azimuthally symmetric media: pseudo-full-PolInSAR 6x6 matrix can be reconstructed → RVoG model inversion

✓Applicable when volume scattering dominates:
- Dense forests, negligible underlying ground contribution

✓ RVoG model inversion
- Line model of coherence still valid but coherence region smaller ⇨ best line fit : to be optimized
- Next steps of are similar to F_PolInSAR RVoG inversion

5. Results - Conclusion

- ➢ **Full-PolInSAR technique + RVOG model inversion**
  - → ***Retrieval of ground topographic phase and forests height***
- ➢ **RVOG model inversion adapted to Dual-Pol mode**
- ➢ **CL-Pol mode available on SAOCOM**
  - → ***Calibration guidelines***
  - → ***Applicability & Usefulness of PolInSAR/RVoG model inversion for canopy height retrieval***

CSL Full/Dual-PolInSAR processor **applicable to**

+

RVoG model inversion module under development

SAOCOM/SARAT
ALOS PALSAR
COSMO-SKYMED

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