Multi-temporal PolInSAR Ground and Volume Separation and Analysis

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Polarimetric SAR Interferometry (PolInSAR) is sensitive to the vertical structure of vegetation.

- Vegetation scattering might be modelled as a superposition of two layers: **Ground** and **Volume**

  - Some assumptions are made:
    - Ground and volume have different vertical profile & polarimetric behaviour
    - Polarimetry & Interferometry are independent dimensions

The **goal** is to use PolInSAR to **separate the polarimetric response** of **Ground** and **Volume**
A pre-whitening will be applied

\[
\bar{T} = N_T^{-1} T N_T^{-1} = \begin{bmatrix} \begin{array}{cccc} I & \Pi_{12} & \ldots & \Pi_{1N} \\ \Pi^H_{12} & I & \ldots & \Pi^H_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \Pi^H_{1N} & \Pi^H_{2N} & \ldots & I \end{array} \end{bmatrix} \quad \text{with} \quad N_T = \begin{bmatrix} T_{11} & 0 & \ldots & 0 \\ 0 & T_{22} & \ldots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \ldots & T_{NN} \end{bmatrix}
\]

Then the definition of the individual matrices of the whitened coherency matrix

\[
I = T_{gw} + T_{vw} \\
\Pi_{ij} = \gamma_{ij}^g T_{gw} + \gamma_{ij}^v T_{vw} \\
\bar{T} = R_g \otimes T_{gw} + R_v \otimes T_{vw}
\]

The ground and volume coherency matrices \( T_{gw} \) and \( T_{vw} \) may be extracted by fixing \( \gamma_{ij}^g \) and \( \gamma_{ij}^v \)

\[
T_{gw} = \frac{\Pi_{ij} - \gamma_{ij}^v I}{\gamma_{ij}^g - \gamma_{ij}^v} \\
T_{vw} = \frac{\Pi_{ij} - \gamma_{ij}^g I}{\gamma_{ij}^v - \gamma_{ij}^g}
\]

AfriSAR campaign @ P-band – Lopè

F-SAR @ P-band, Gabon, Tropical forest
2m az. x 3.84m rg. resolution

11 baselines

How to validate these results?

Using Polarimetry!
**AfriSAR campaign @ P-band – Lopè**

F-SAR @ P-band, Gabon, Tropical forest

11 baselines

**DTM**

**Rg. slopes**

**Az. slopes**

**POA from DTM:**

\[ \tan \psi = \frac{\tan \phi_a}{-\tan \phi_r \cos \theta + \sin \theta} \]

**POA Estimated from data:**

\[ \hat{\psi} = \left( \arg \left( \langle S_{RR} S_{LL}^* \rangle \right) + \pi \right) / 4 \]

AfriSAR campaign @ P-band – Lopè

Compare POA calculated from DTM vs. estimated from data

DTM

Original

Phi from DEM

Phi from original data RLL phase
AfriSAR campaign @ P-band – Lopè

Compare POA calculated from DTM vs. estimated from data
AfriSAR campaign @ P-band – Lopè

Compare POA calculated from DTM vs. estimated from data
AfriSAR campaign @ P-band – Lopè

- Compare POA calculated from DTM vs. estimated from data

- The extracted ground component reflects much more clearly the POA variation of the ground slopes
- On the volume component the estimated POA presents almost no variation with respect to slopes
TMPSAR08 dry and wet acq. – Ground and Volume separation

E-SAR @ L-band
5 baselines each day

Dry
10th June 2008

Wet
12th June 2008

Traunstein forest, Southern Germany

Pauli RGB
**TMPSAR20 dry and wet acq. – Ground and Volume separation**

F-SAR @ P-band
5/6 baselines each day

Dry
23rd October 2020
Pauli RGB

Wet
27th October 2020

Traunstein forest, Southern Germany

Ground

Volume

Ground

Volume
**TMPSAR08 dry and wet acq. – Ground and Volume separation**

**L-Band**

![Ground to Volume ratio PDF](image)

10 log₁₀ \( \frac{\text{tr}([T_g])}{\text{tr}([T_v])} \)

- **Dry and Wet Ground and Volume separation**
- **DRY**
- **WET**

**Pauli RGB**

- **Ground to Volume ratio**

-13dB to 13dB
**TMPSAR20 dry and wet acq. – Ground and Volume separation**

**P-Band**

**DRY**

**WET**

**Ground to volume ratio PDF**

\[ 10 \log_{10} \frac{\text{tr}([T_g])}{\text{tr}([T_v])} \]

**Pauli RGB**

-13dB 13dB

Ground to Volume ratio

Ground to Volume ratio
Polarimetric Change Analysis

- Polarimetric change analysis technique to get the amount & type of change between 2 acquisitions

\[ P_c(Z_1, Z_2, w) = \frac{w^H Z_2 w}{w^H Z_1 w} \quad \text{det}(Z_2 - \lambda Z_1) = 0 \]

- Polarimetric contrast
- Generalized eigendecomposition

- Change representation based on this information

\[ p_{inc} = 10 \left[ \sum_{i \mid \lambda_i > 1} \left( \log_{10}(\lambda_i) p_i \right)^2 \right]^{1/2} \]
\[ p_{dec} = 10 \left[ \sum_{i \mid \lambda_i < 1} \left( -\log_{10}(\lambda_i) p_i \right)^2 \right]^{1/2} \]

- Increase
- Decrease

\[ p_i = \left( |w_i^1|, |w_i^2|, |w_i^3| \right)^T \]

- Intensity → amount of increase/decrease
- Color → type of change (Pauli RGB)

- This change analysis may be performed for every pair of acquisitions → also for Ground & Volume components

**TMPSAR08 @ L-band – Polarimetric Change Analysis**

- Change representation over different components

**L-Band**

original

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**Ground**

- Increase (on dry vs. wet) dominates
- Decrease (on dry vs. wet) dominates

**Volume**

- Much larger contrast observed in G&V components

**Dry / Wet**

- Contrast range 1dB to 6dB

**Pauli RGB**
Polarimetric Change Analysis @ L-band – 2D scatter plots

Scatter plot of dry vs. wet power over forested areas

Dry vs. wet span of each component in dB
Polarimetric Change Analysis @ L-band – 2D scatter plots

Scatter plot of ground vs. volume power ratios

In general an opposite behavior is observed: when volume increases, ground decreases.
Polarimetric Change Analysis – Spatial distribution behavior

Spatial distribution of sum and difference of ground and volume contrast

\[ P_g = 10 \log_{10} \frac{\text{tr}(T_g^{\text{dry}})}{\text{tr}(T_g^{\text{wet}})} \]

\[ P_v = 10 \log_{10} \frac{\text{tr}(T_v^{\text{dry}})}{\text{tr}(T_v^{\text{wet}})} \]

\[ |P_g + P_v| \]
\[ |P_g - P_v| \]

Blue indicates both increase/decrease

Red indicates opposite increase/decrease

Scaled from 0dB to 4dB

Forested areas: opposite ground and volume behavior
Low veg. areas: same behavior both components
**TMPSAR20 @ P-band – Polarimetric change analysis**

Change representation over the different components (P-band)

- Decrease (on dry vs. wet) dominates
- No clear increase or decrease

Larger contrast observed in G&V components

23rd – 27th October 2020

Dry / Wet

Pauli RGB

Contrast range 1dB to 6dB
Polarimetric Change Analysis @ P-band – 2D scatter plots

.scatter plot of dry vs. wet power over forested areas

Ground

Volume

Dry vs. wet span of each component in dB
Polarimetric Change Analysis @ P-band – 2D scatter plots

- Scatter plot of ground vs. volume power ratios

Ground vs. Volume dry to wet ratios in dB

No correlation between variations at P-band
Polarimetric Change Analysis – Spatial distribution behavior

Spatial distribution of sum and difference of ground and volume contrast

\[ P_g = 10 \log_{10} \frac{\text{tr}(T_g^{\text{dry}})}{\text{tr}(T_g^{\text{wet}})} \]

\[ P_v = 10 \log_{10} \frac{\text{tr}(T_v^{\text{dry}})}{\text{tr}(T_v^{\text{wet}})} \]

Blue indicates both increase / decrease

Red indicates opposite increase / decrease

Scaled from 0dB to 4dB
Conclusions

- PolInSAR Ground & Volume decomposition may overcome some PolSAR decomposition limitations
  - Full-rank covariance matrices are obtained from G & V components
  - May be applied to more complex volume vertical distributions

- The analysis of the extracted components over Traunstein forest at dry/wet conditions reveals some changes, not easily visible on original data, which are different at L- and P-band

  - **Volume component** increases on wet conditions, increasing also its extinction
  - **Ground component** decreases on wet conditions over forest, as seen through the volume with increased extinction ... however, on areas with low vegetation the Ground increases

- However, these observations **may depend on forest type & structure**!

- PolInSAR Ground & Volume decomposition may be very useful to gain a better insight of the changes over vegetation
Polarimetric Change Analysis available at BioPAL

Welcome to BioPAL - The BIOMASS Product Algorithm Laboratory

an ESA sponsored project

www.biopal.org  github.com/BioPAL/BioPAL
Thank you for your attention!