Multi-temporal PolInSAR Ground and Volume Separation and Analysis

Alberto Alonso-Gonzalez[1], Kostas Papathanassiou[1]

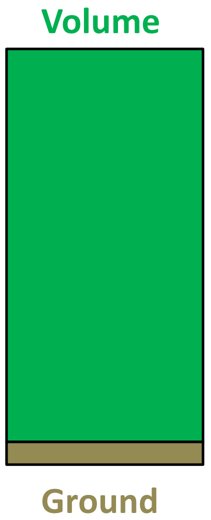
[1]German Aerospace Center, DLR

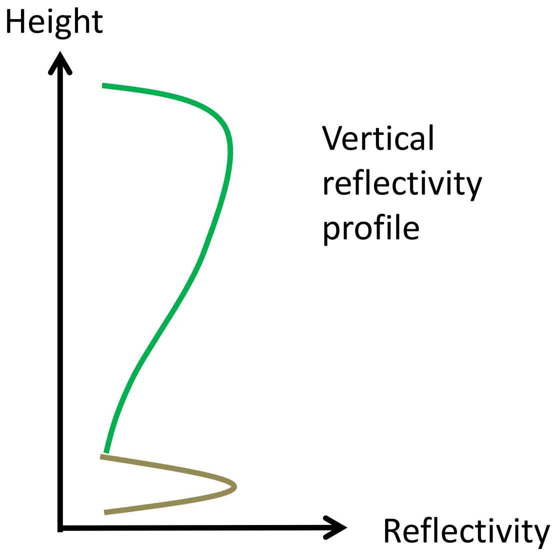
DLR

PolInSAR Two Layer Model

- 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**

DLR

MB PolInSAR Two Layer Model – Ground/Volume extraction

- A pre-whitening will be applied

$$\tilde{\mathbf{T}} = \mathbf{N}_T^{-\frac{1}{2}}\mathbf{T}\mathbf{N}_T^{-\frac{1}{2}} = \begin{bmatrix} \mathbf{I} & \mathbf{\Pi}_{12} & \cdots & \mathbf{\Pi}_{1N} \\ \mathbf{\Pi}_{12}^H & \mathbf{I} & & \mathbf{\Pi}_{2N} \\ \vdots & & \ddots & \vdots \\ \mathbf{\Pi}_{1N}^H & \mathbf{\Pi}_{2N}^H & \cdots & \mathbf{I} \end{bmatrix} \qquad \mathbf{N}_T = \begin{bmatrix} \mathbf{T}_{11} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{T}_{22} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{T}_{NN} \end{bmatrix}$$

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

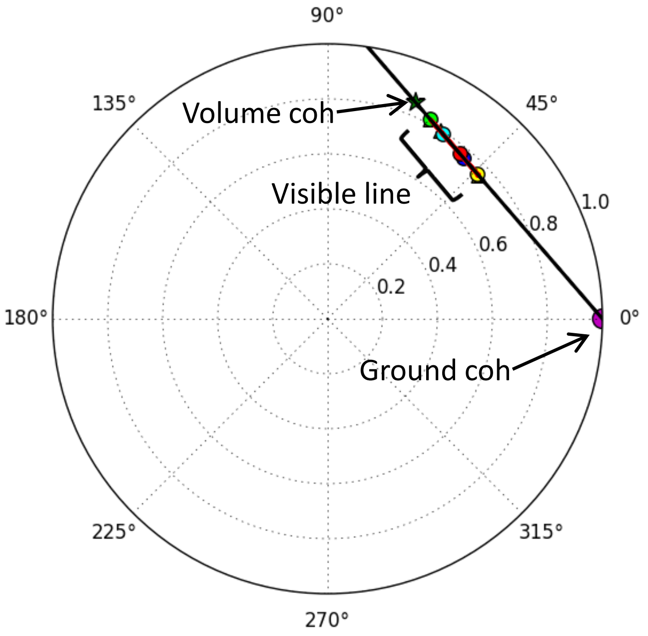
$$\mathbf{I} = \mathbf{T}_{gw} + \mathbf{T}_{vw}$$

$$\mathbf{\Pi}_{ij} = \gamma_{ij}^{g}\mathbf{T}_{gw} + \gamma_{ij}^{v}\mathbf{T}_{vw}$$

$$\tilde{\mathbf{T}} = \mathbf{R}_g \otimes \mathbf{T}_{gw} + \mathbf{R}_v \otimes \mathbf{T}_{vw}$$

$$\mathbf{T}_{ii} = \mathbf{T}_{ii}^{\frac{1}{2}}(\mathbf{T}_{gw} + \mathbf{T}_{vw})\mathbf{T}$$

$$\mathbf{\Pi}_{ij} = \mathbf{T}_{ii}^{\frac{1}{2}}\mathbf{\Omega}_{ij}\mathbf{T}_{jj}^{\frac{1}{2}}$$



- The ground and volume coherency matrices $\mathbf{T}_{gw}$ and $\mathbf{T}_{vw}$ may be extracted by fixing γ_{ij}^{g} and γ_{ij}^{v}

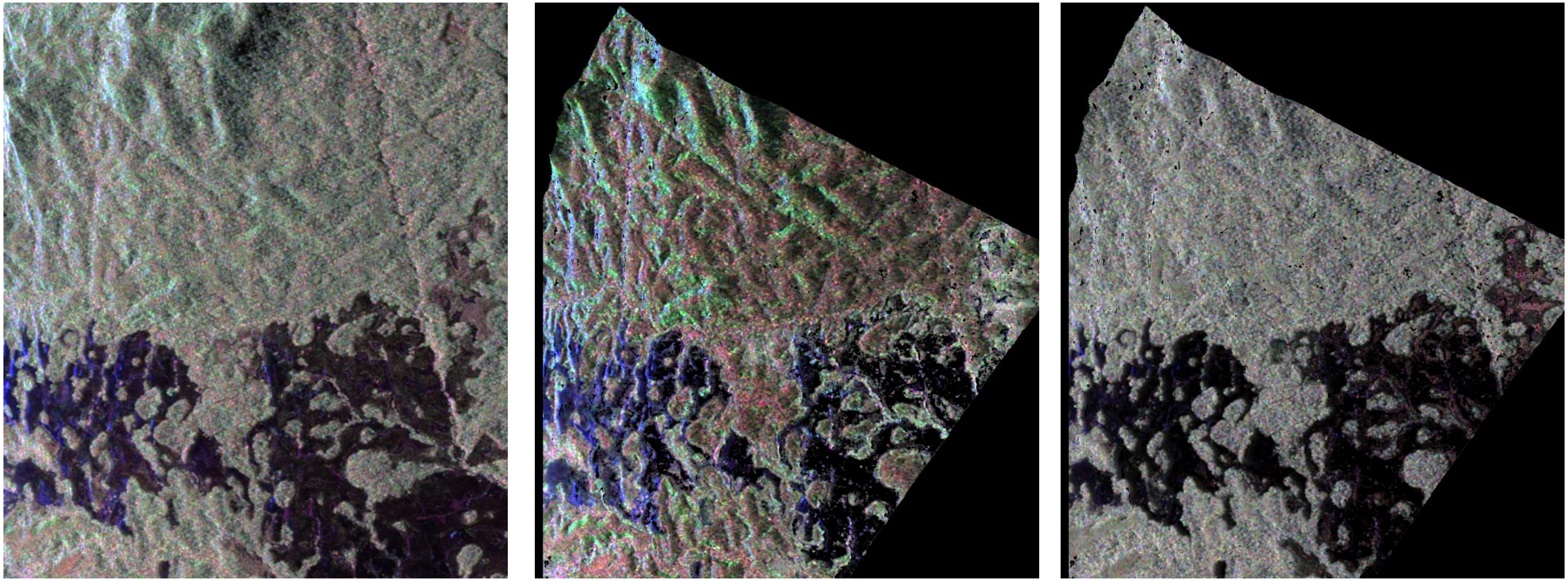
$$\mathbf{T}_{gw} = \frac{\mathbf{\Pi}_{ij} - \gamma_{ij}^{v}\mathbf{I}}{\gamma_{ij}^{g} - \gamma_{ij}^{v}} \qquad \mathbf{T}_{vw} = \frac{\mathbf{\Pi}_{ij} - \gamma_{ij}^{g}\mathbf{I}}{\gamma_{ij}^{v} - \gamma_{ij}^{g}}$$

[1] Alonso-Gonzalez, A., & Papathanassiou, K. P. (2018, June). Multibaseline two layer model polinsar ground and volume separation. In *EUSAR 2018; 12th European Conference on Synthetic Aperture Radar* (pp. 1-5). VDE.

AfriSAR campaign @ P-band – Lopè

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

11 baselines



Original | **Ground** | **Volume**

Pauli RGB

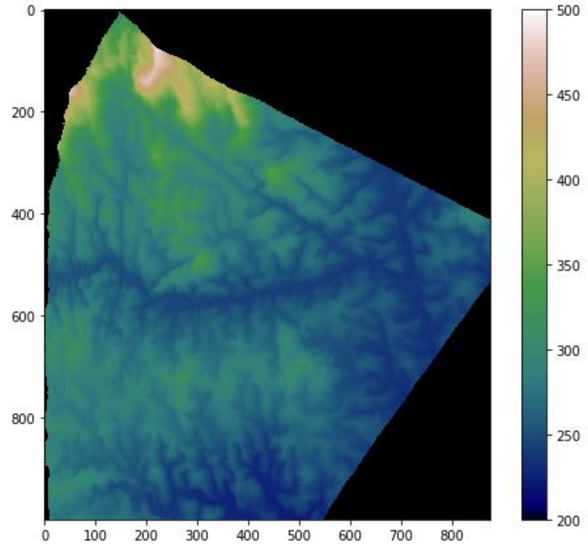
How to validate these results?

⇨ **Using Polarimetry!**

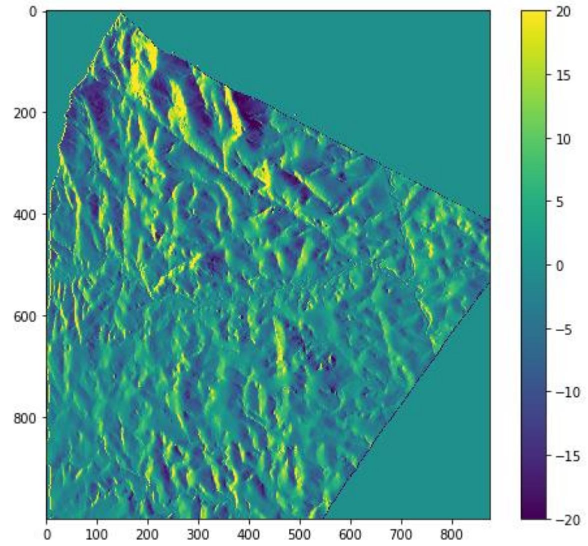
AfriSAR campaign @ P-band – Lopè

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

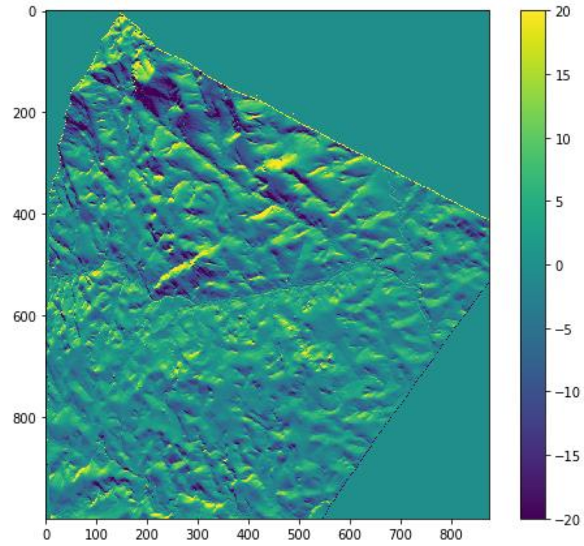
11 baselines



DTM



Rg. slopes



Az. slopes

POA from DTM:

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

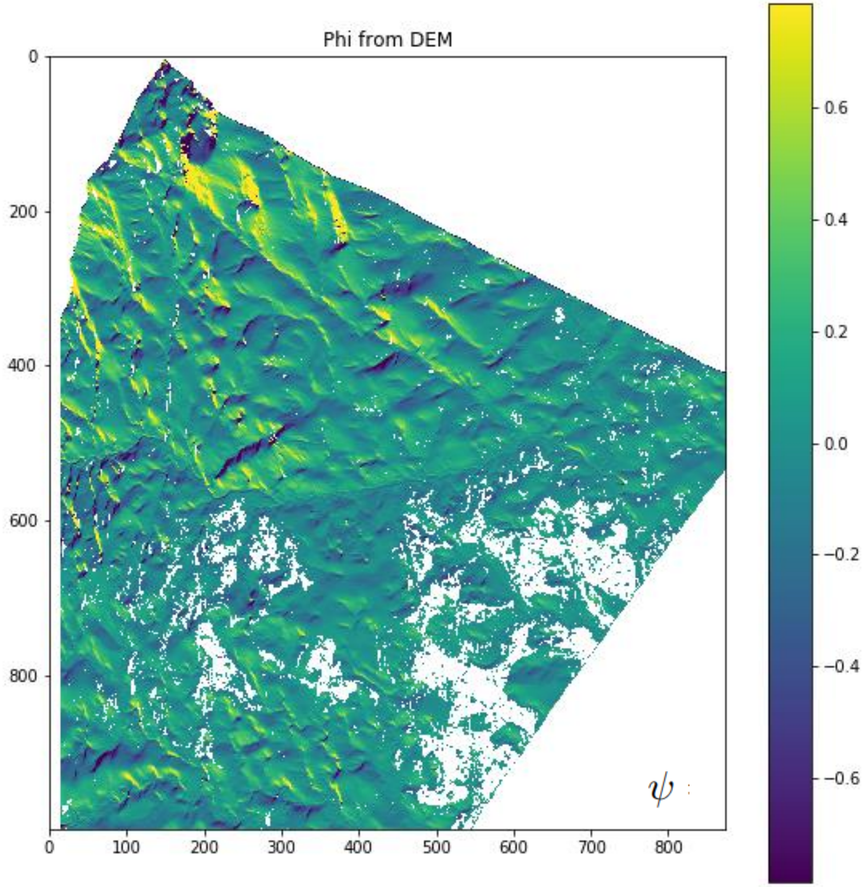
POA Estimated from data:

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

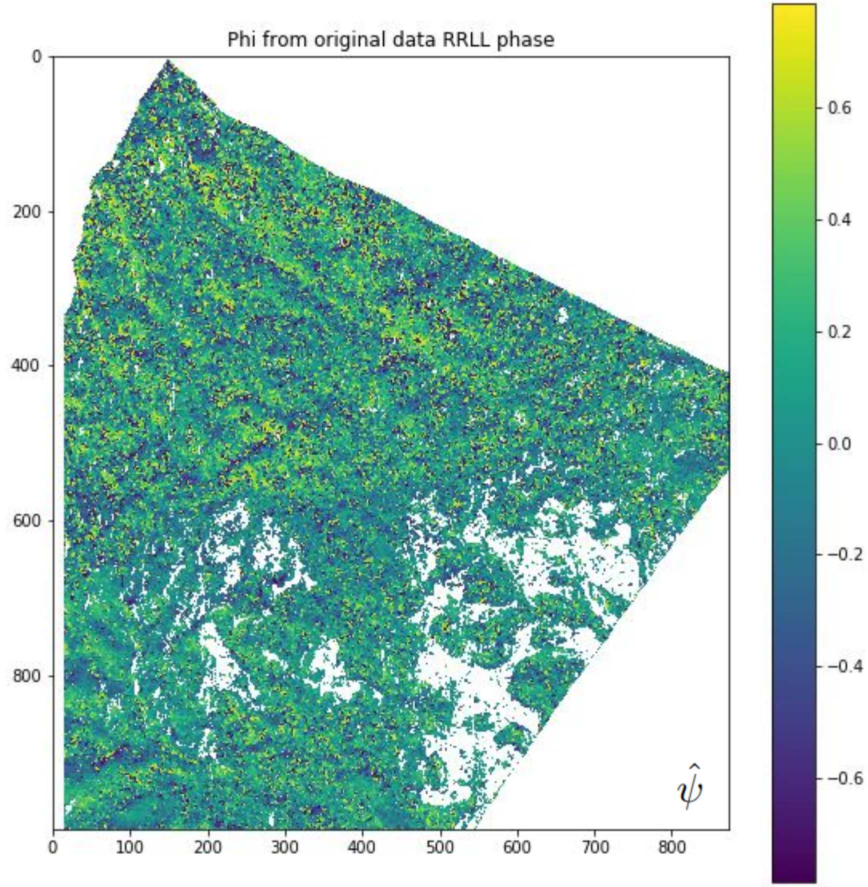
[3] Jong-Sen Lee, D. L. Schuler, and T. L. Ainsworth, “Polarimetric sar data compensation for terrain azimuth slope variation,” IEEE Transactions on Geoscience and Remote Sensing, vol. 38, no. 5, pp. 2153–2163, 2000.

AfriSAR campaign @ P-band – Lopè

- Compare POA calculated from DTM vs. estimated from data



DTM

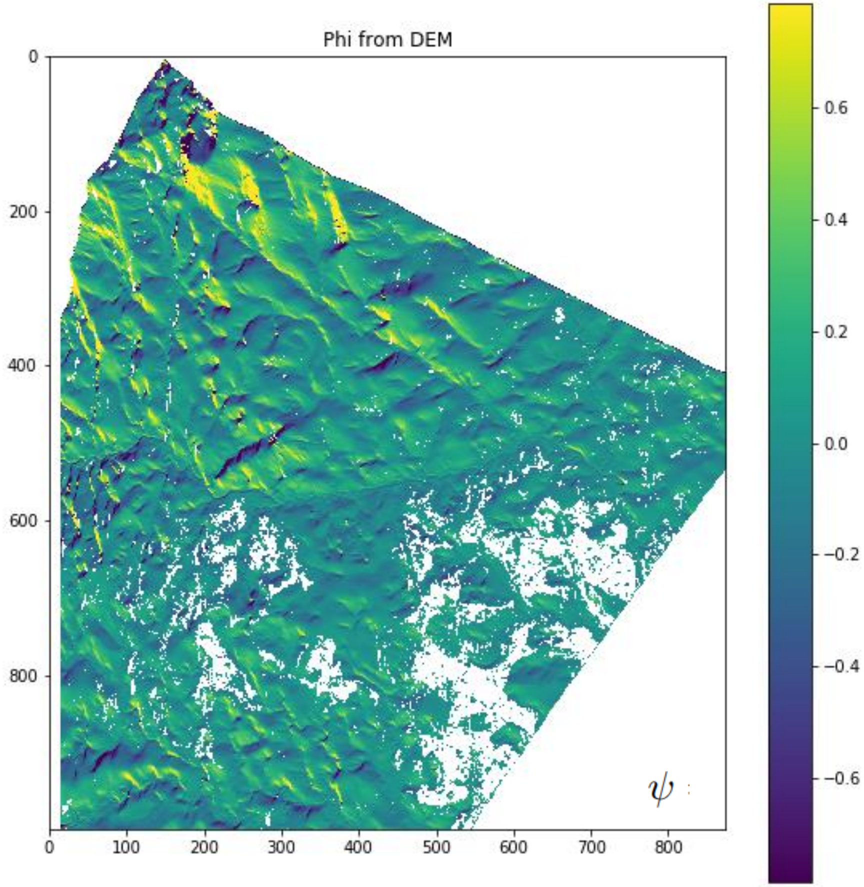


Original

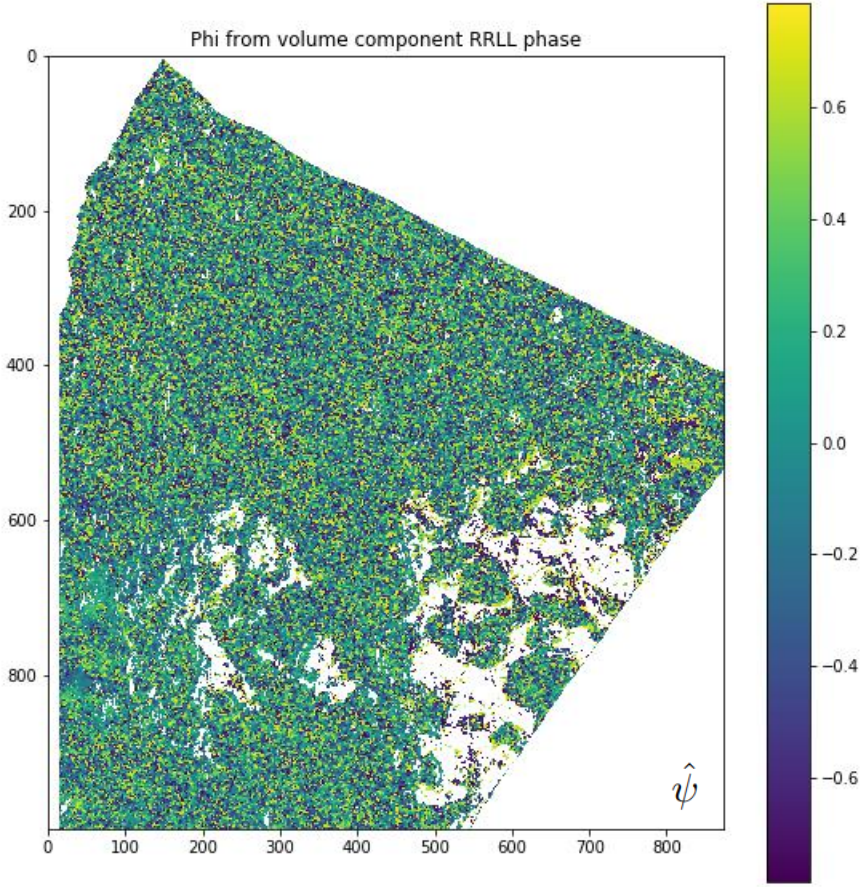
DLR

AfriSAR campaign @ P-band – Lopè

- Compare POA calculated from DTM vs. estimated from data



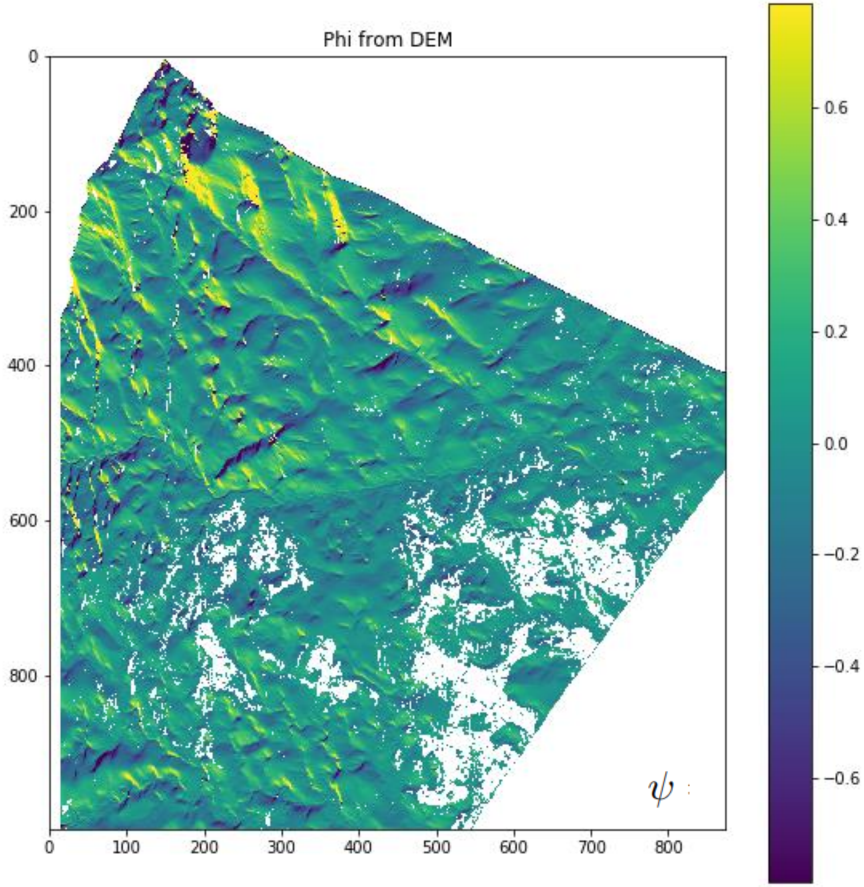
DTM



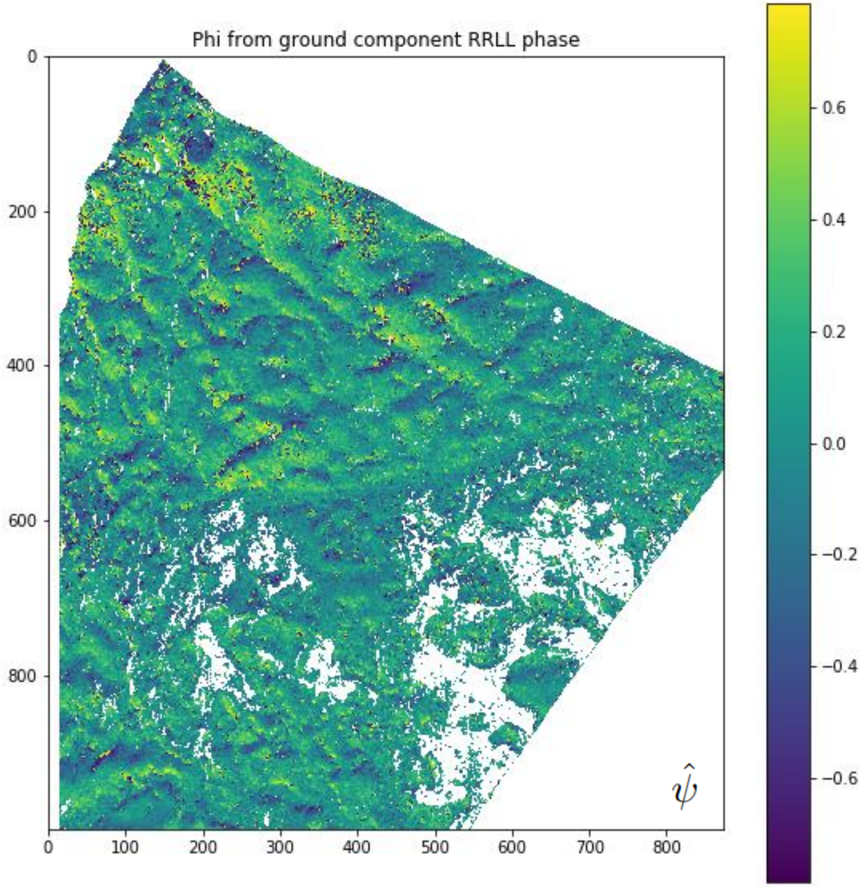
Volume

AfriSAR campaign @ P-band – Lopè

- Compare POA calculated from DTM vs. estimated from data



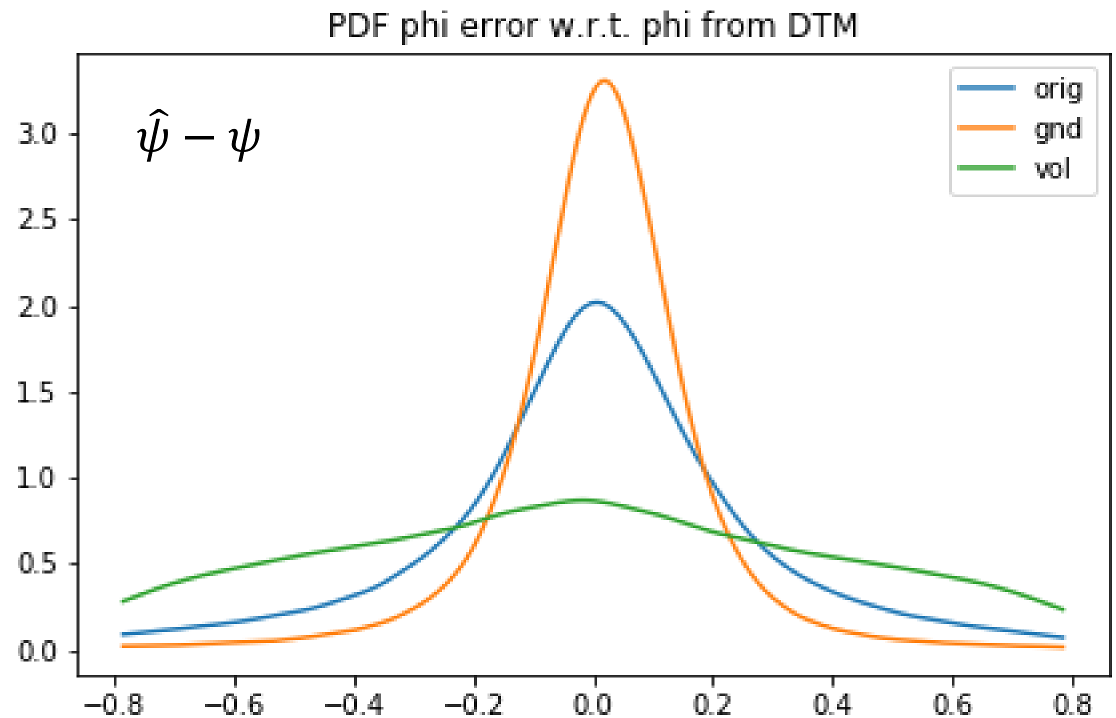
DTM



Ground

AfriSAR campaign @ P-band – Lopè

- Compare POA calculated from DTM vs. estimated from data

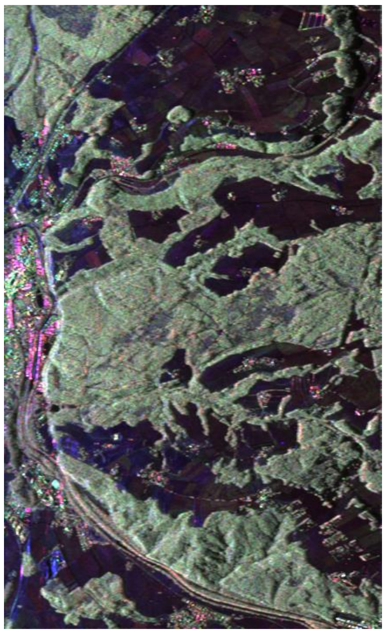


- The extracted ground component reflects much more clearly the POA variation of the ground slopes
- On the volume component the estimated POA presents almost no variation with respect to slopes

TMPSAR08 dry and wet acq. – Ground and Volume separation

E-SAR @ L-band

5 baselines each day

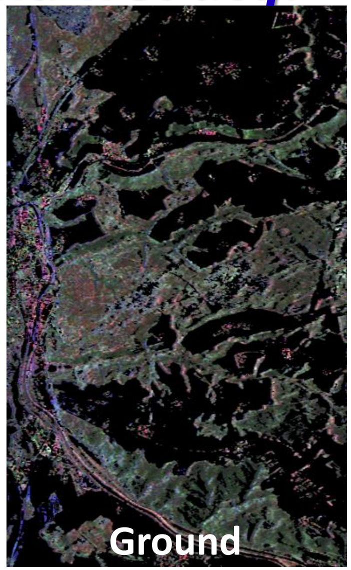


Dry

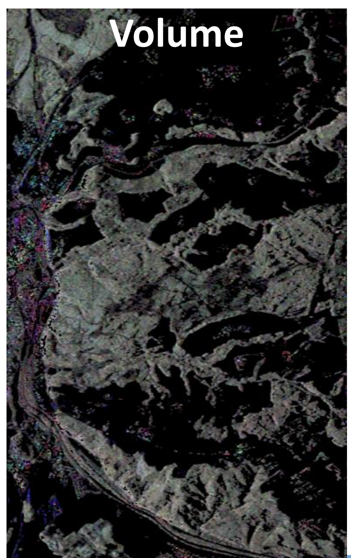
10^{th} June 2008

Pauli RGB

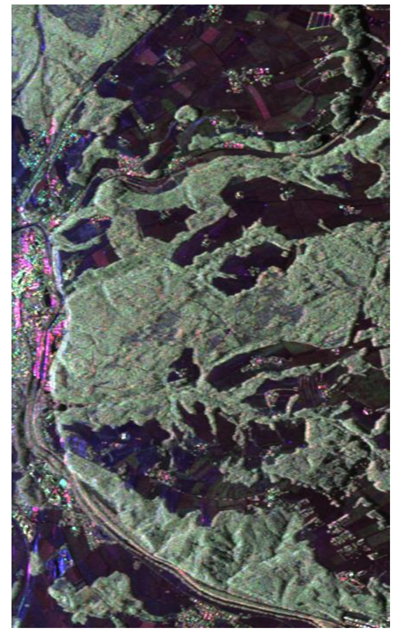
=



+



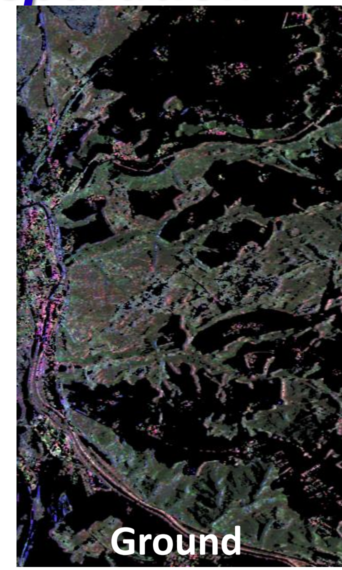
Traunstein forest,
Southern Germany



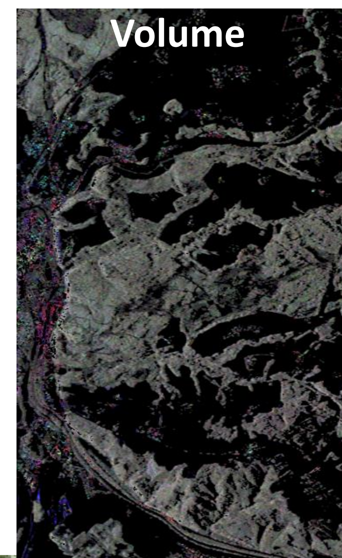
Wet

12^{th} June 2008

=



+

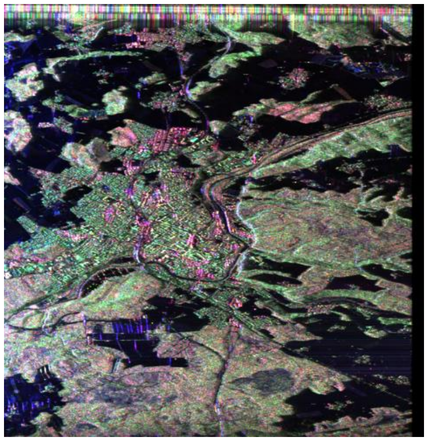


TMPSAR20 dry and wet acq. – Ground and Volume separation

F-SAR @ P-band

5/6 baselines each day

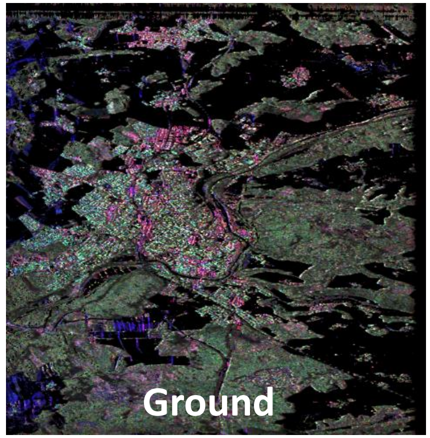
Traunstein forest,
Southern Germany



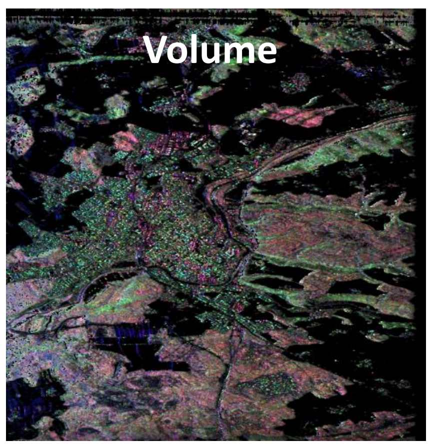
Dry
23rd October 2020

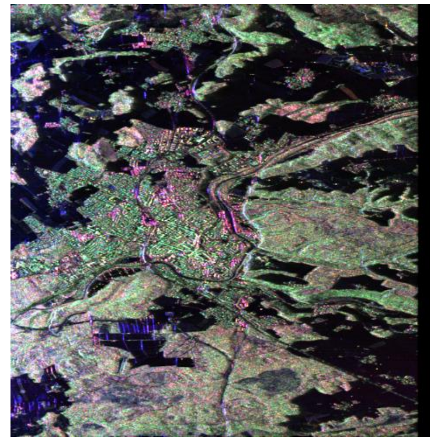
Pauli RGB

=



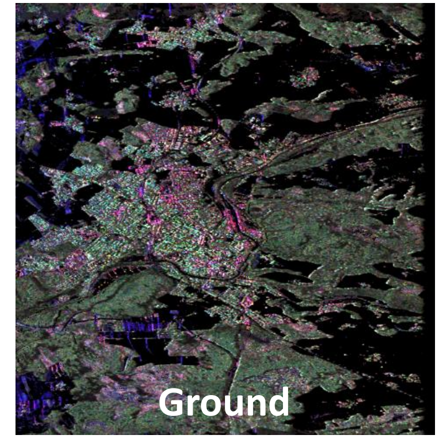
+



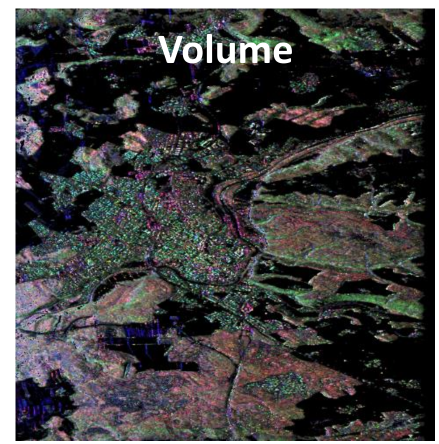


Wet
27th October 2020

=



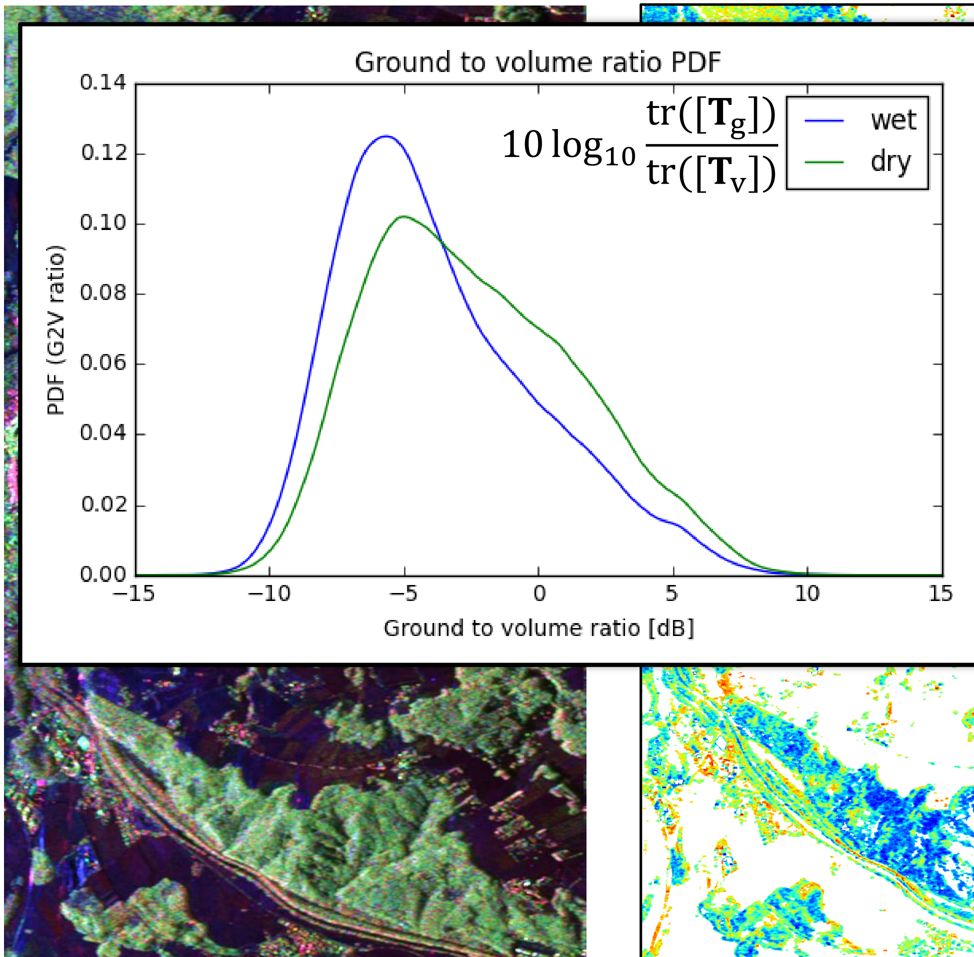
+



DLR

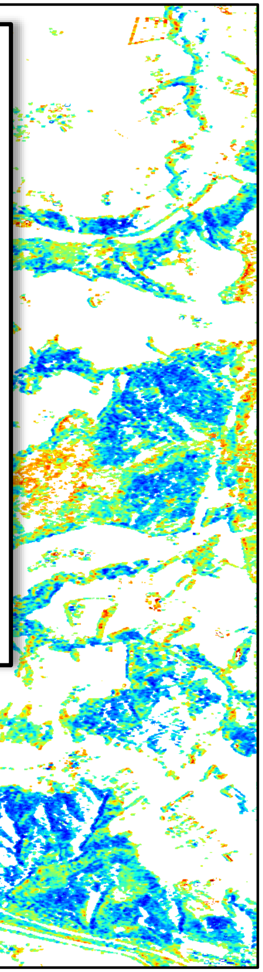
TMPSAR08 dry and wet acq. – Ground and Volume separation

L-Band

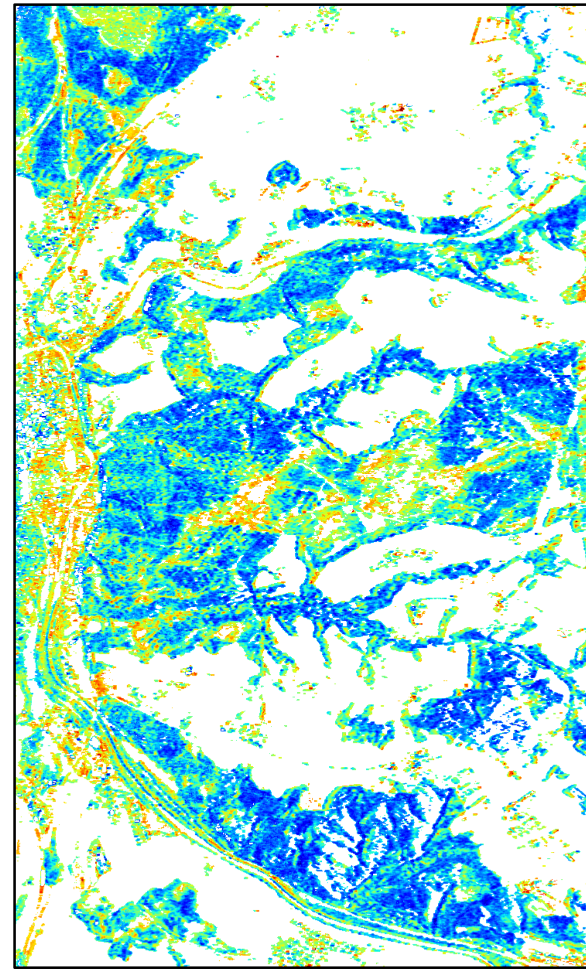


Pauli RGB

DRY



WET



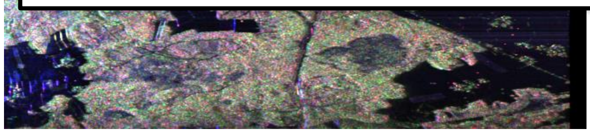
Ground to Volume ratio

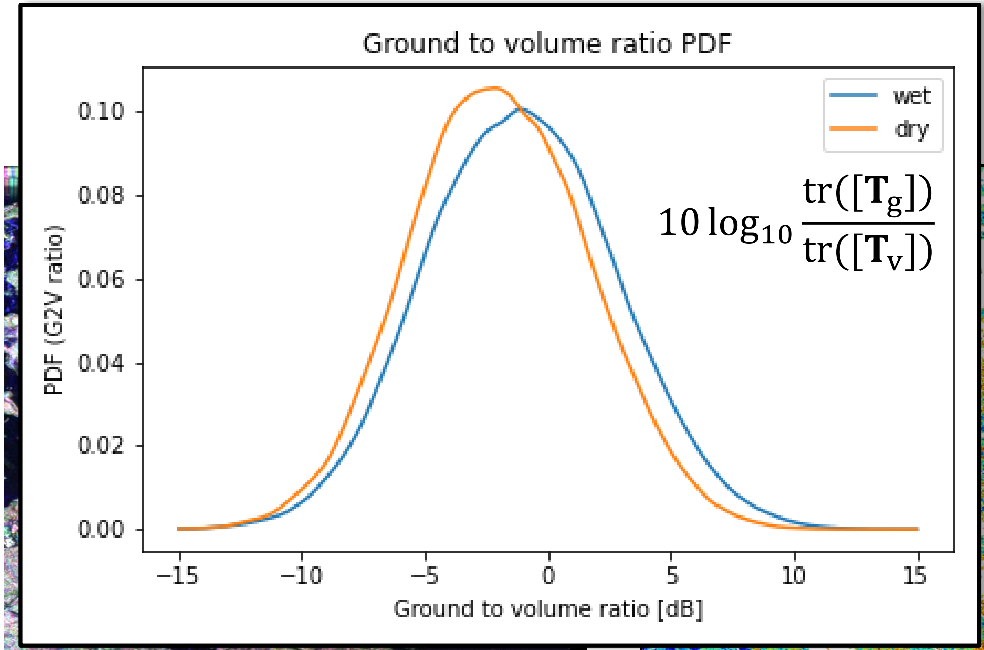
Ground to Volume ratio

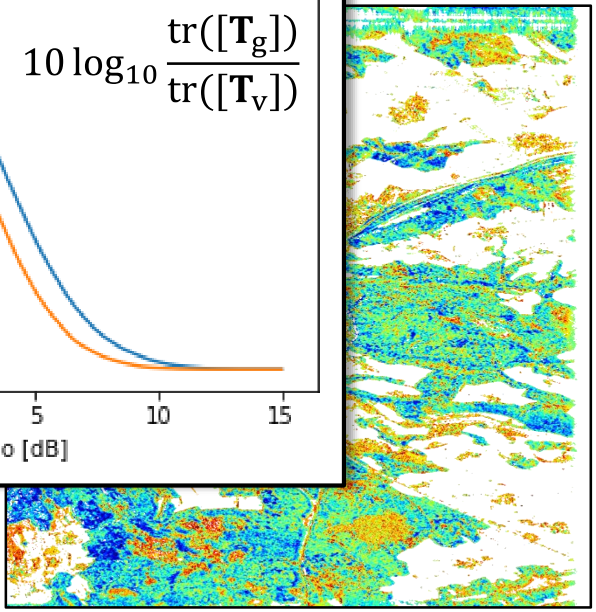
DLR

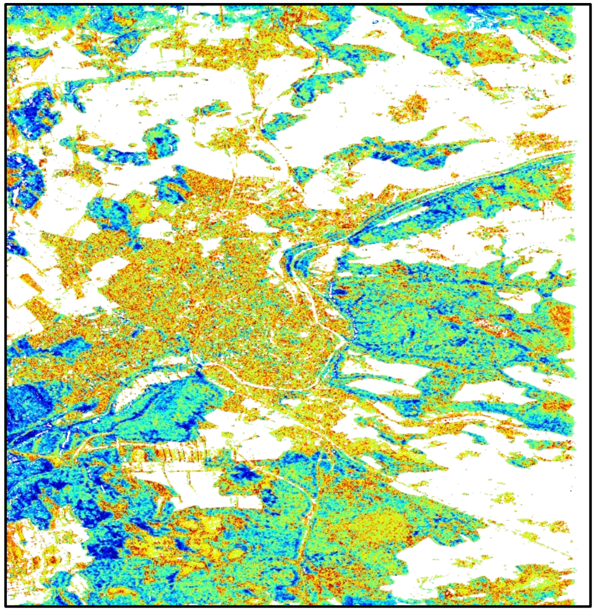
TMPSAR20 dry and wet acq. – Ground and Volume separation

P-Band **DRY** **WET**









Pauli RGB

Ground to Volume ratio

Ground to Volume ratio

DLR

Polarimetric Change Analysis

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

$$P_c(\mathbf{Z}_1, \mathbf{Z}_2, \mathbf{w}) = \frac{\mathbf{w}^H \mathbf{Z}_2 \mathbf{w}}{\mathbf{w}^H \mathbf{Z}_1 \mathbf{w}}$$

Polarimetric contrast

$$\det(\mathbf{Z}_2 - \lambda \mathbf{Z}_1) = 0$$

Generalized eigendecomposition

$\lambda_1 \geq \lambda_2 \geq \lambda_3$	Max & min contrast
$\mathbf{w}_1, \mathbf{w}_2, \mathbf{w}_3$	Polarization states

- Change representation based on this information

$$\mathbf{p}_{inc} = 10\left[\sum_{i \mid \lambda_i > 1} \left(\log_{10}(\lambda_i)\mathbf{p}_i\right)^2\right]^{\frac{1}{2}}$$

Increase

$$\mathbf{p}_{dec} = 10\left[\sum_{i \mid \lambda_i < 1} \left(-\log_{10}(\lambda_i)\mathbf{p}_i\right)^2\right]^{\frac{1}{2}}$$

Decrease

$$\mathbf{p}_i = \left(\left|w_i^1\right|, \left|w_i^2\right|, \left|w_i^3\right|\right)^T$$

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

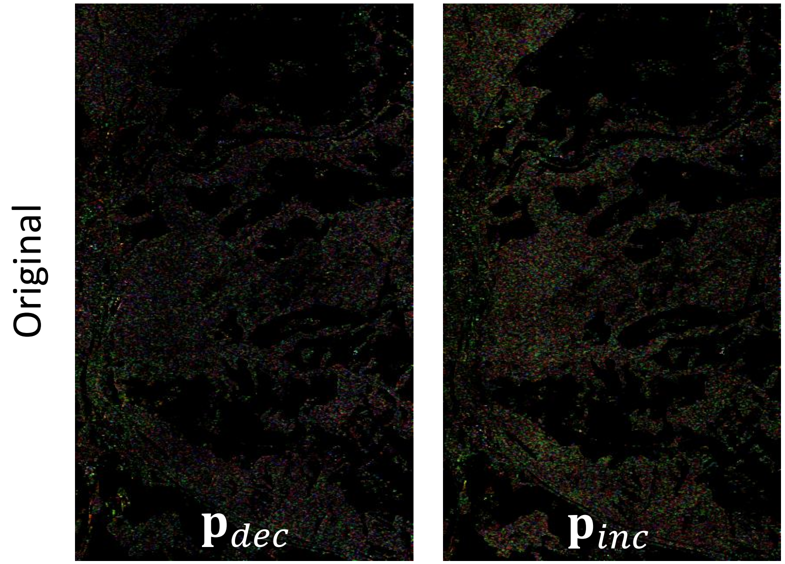
- This change analysis may be performed for every pair of acquisitions → also for Ground & Volume components

[2] Alonso González, A., López Martínez, C., Papathanassiou, K., & Hajnsek, I. (2020). Polarimetric SAR time series change analysis over agricultural areas. *IEEE transactions on geoscience and remote sensing*, *58*(10), 7317-7330.

TMPSAR08 @ L-band – Polarimetric Change Analysis

- Change representation over different components

L-Band

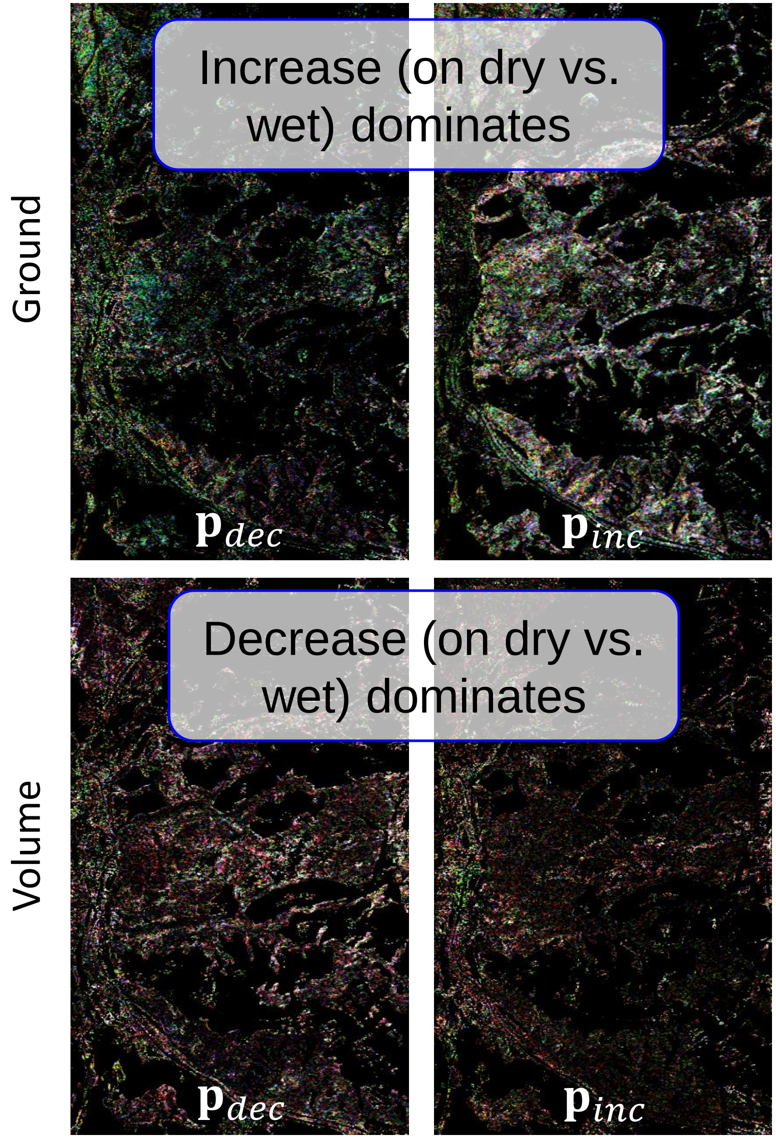


Much larger contrast observed in G&V components

Dry / Wet

Contrast range 1dB to 6dB

Pauli RGB

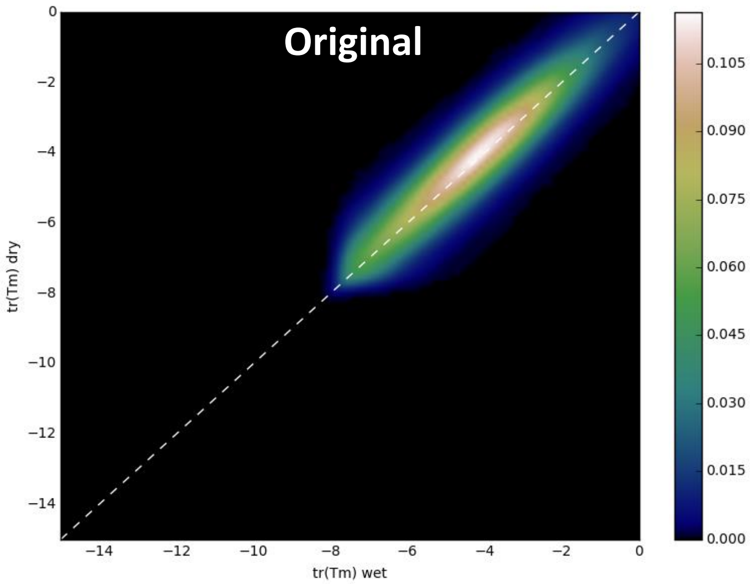


Increase (on dry vs. wet) dominates

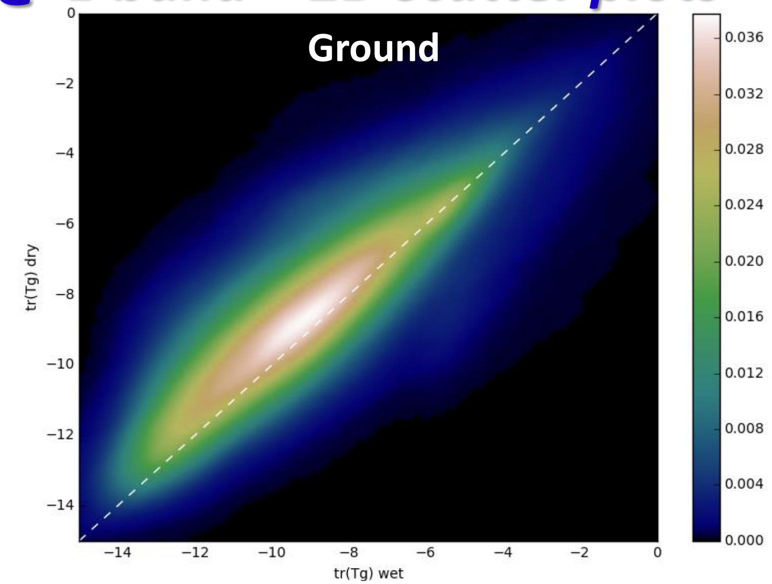
Decrease (on dry vs. wet) dominates

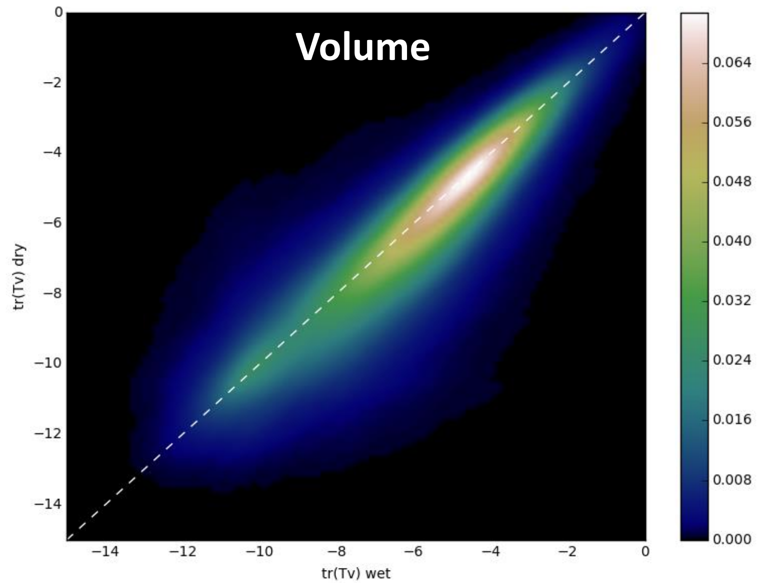
Polarimetric Change Analysis @ L-band – 2D scatter plots

- Scatter plot of dry vs. wet power over forested areas



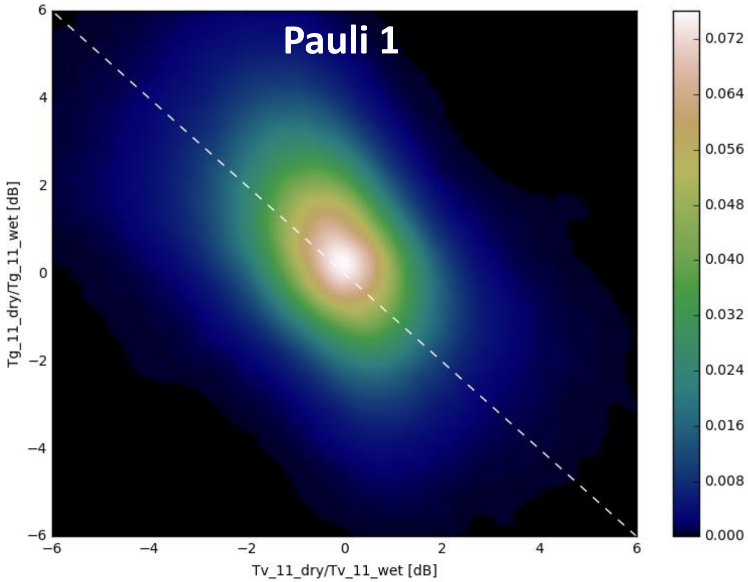
Dry vs. wet span of each component in dB

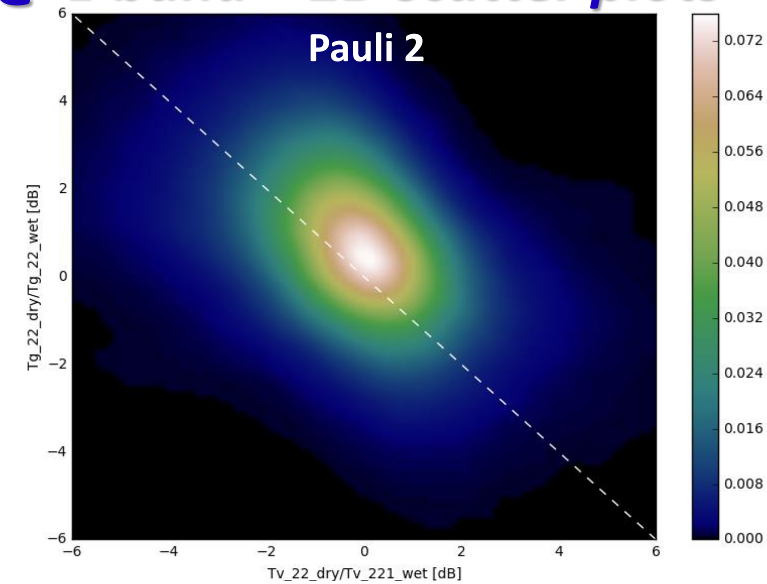


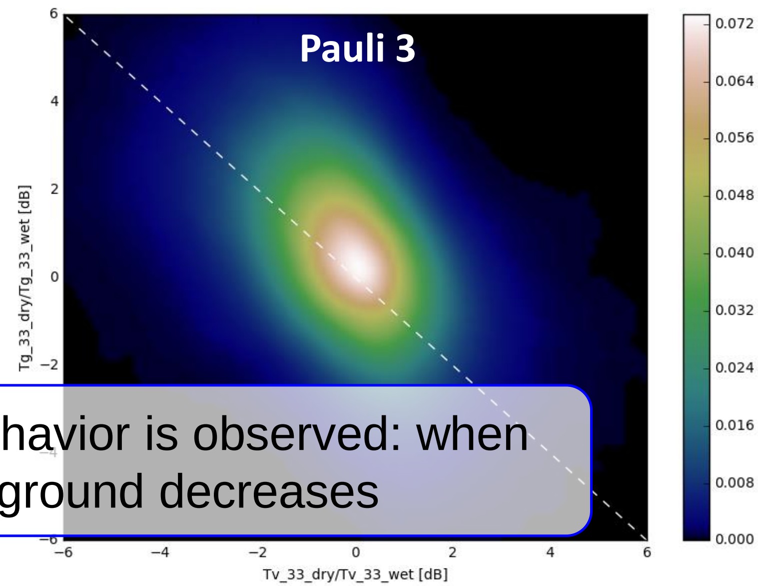


Polarimetric Change Analysis @ L-band – 2D scatter plots

- Scatter plot of ground vs. volume power ratios





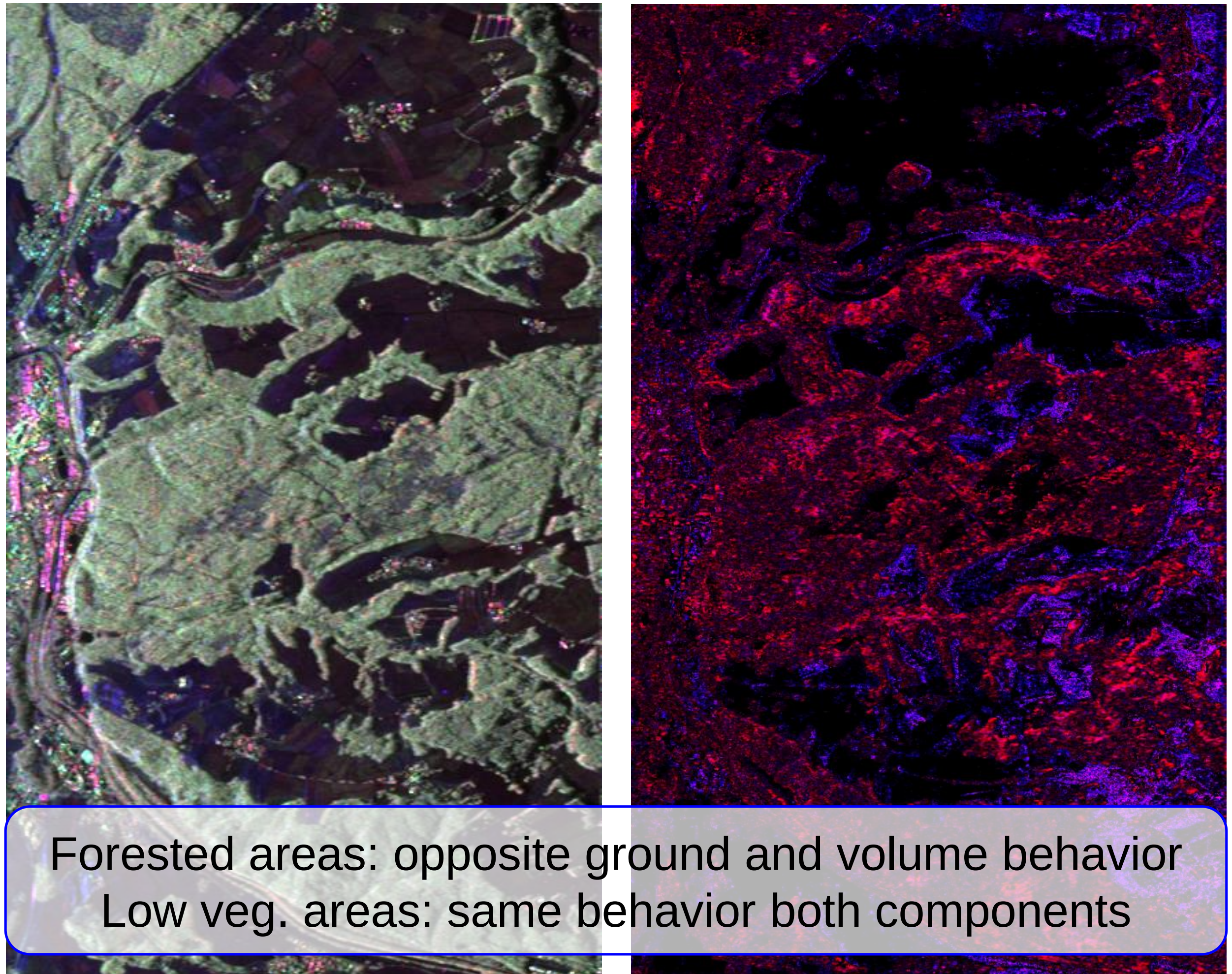


Ground vs. Volume dry to wet ratios in dB

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



Forested areas: opposite ground and volume behavior
Low veg. areas: same behavior both components

$$P_g = 10\log_{10}\frac{tr(\mathbf{T}_g^{dry})}{tr(\mathbf{T}_g^{wet})}$$

$$P_v = 10\log_{10}\frac{tr(\mathbf{T}_v^{dry})}{tr(\mathbf{T}_v^{wet})}$$

$|P_g+P_v|$

$|P_g-P_v|$

Blue indicates both increase/decrease

Red indicates opposite increase/decrease

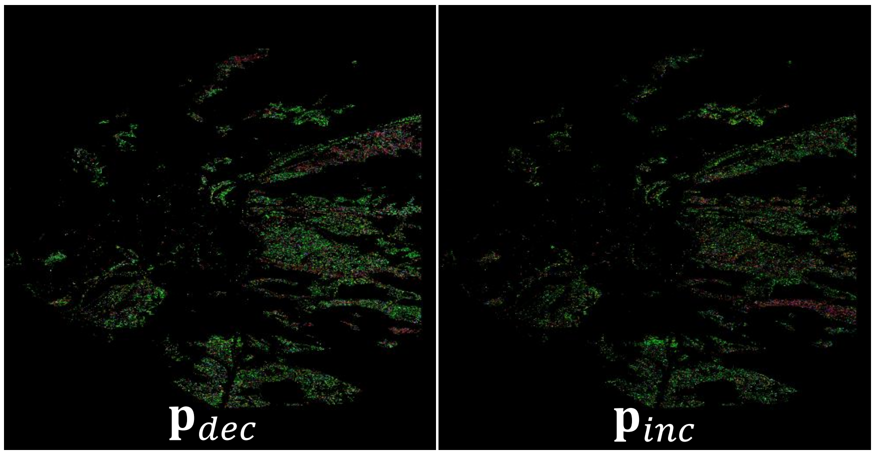
Scaled from 0dB to 4dB

TMPSAR20 @ P-band – Polarimetric change analysis

- Change representation over the different components (**P-band**)

P-Band

Original



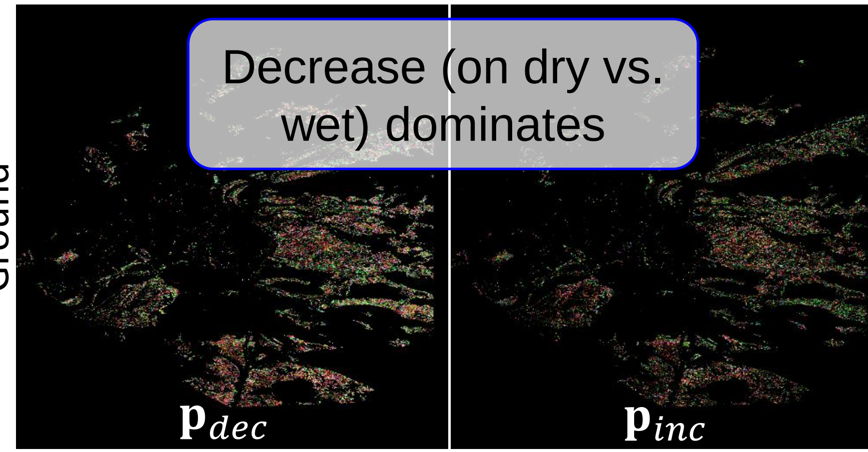
Larger contrast observed in G&V components

23rd – 27th October 2020

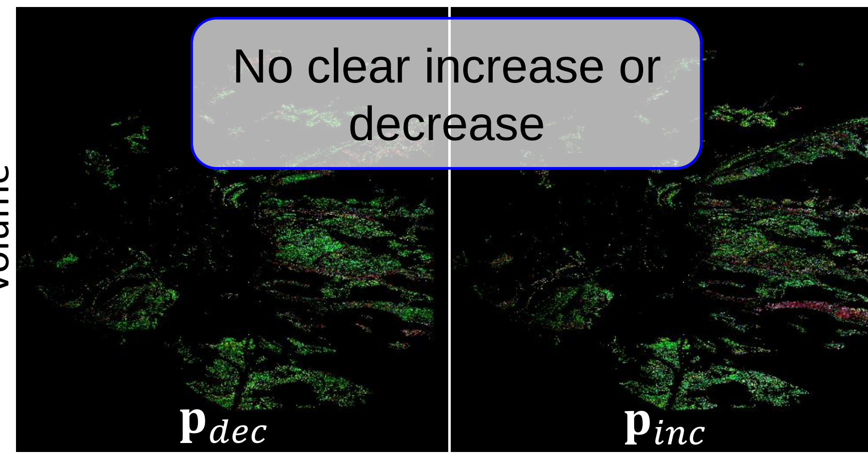
Dry / Wet

Pauli RGB

Ground



Volume

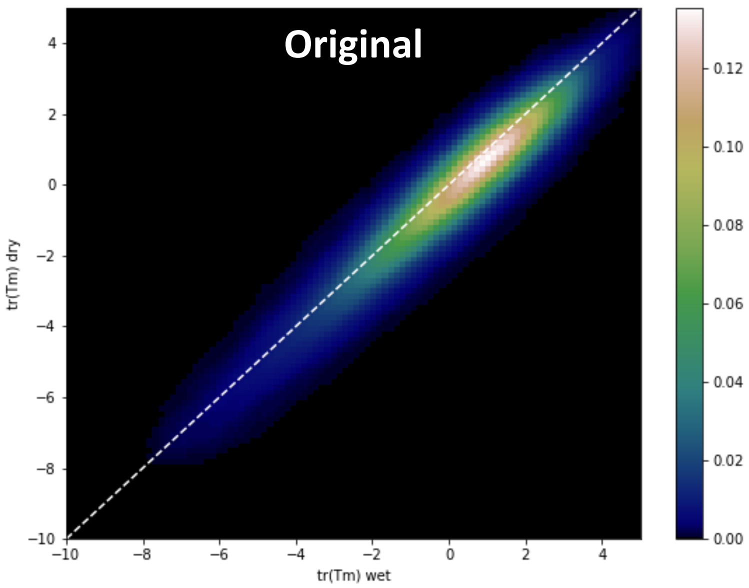


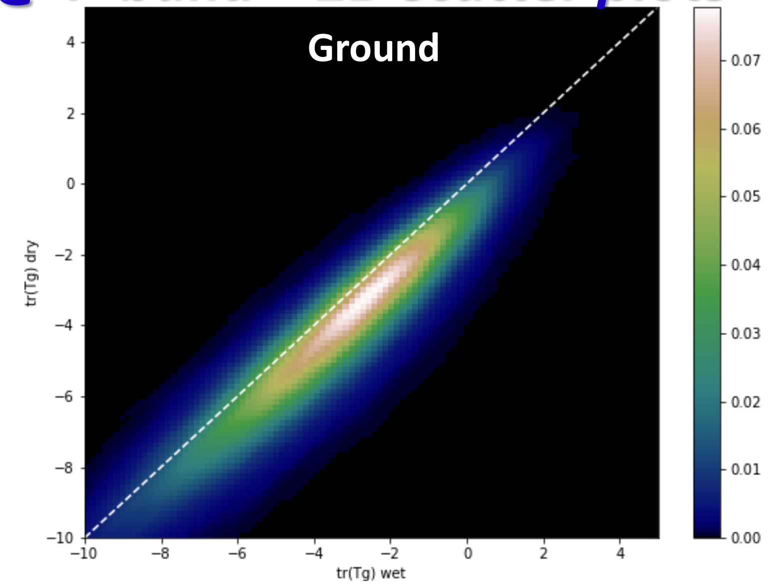
Contrast range 1dB to 6dB

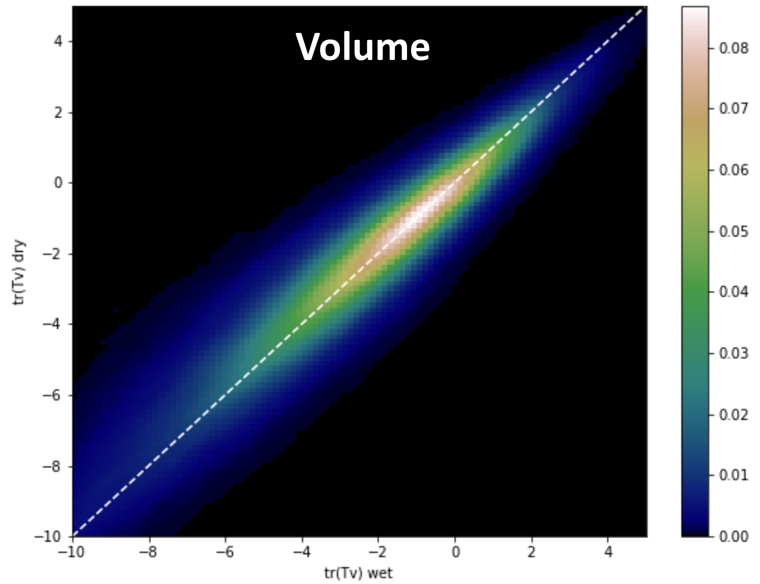
DLR

Polarimetric Change Analysis @ P-band – 2D scatter plots

- Scatter plot of dry vs. wet power over forested areas





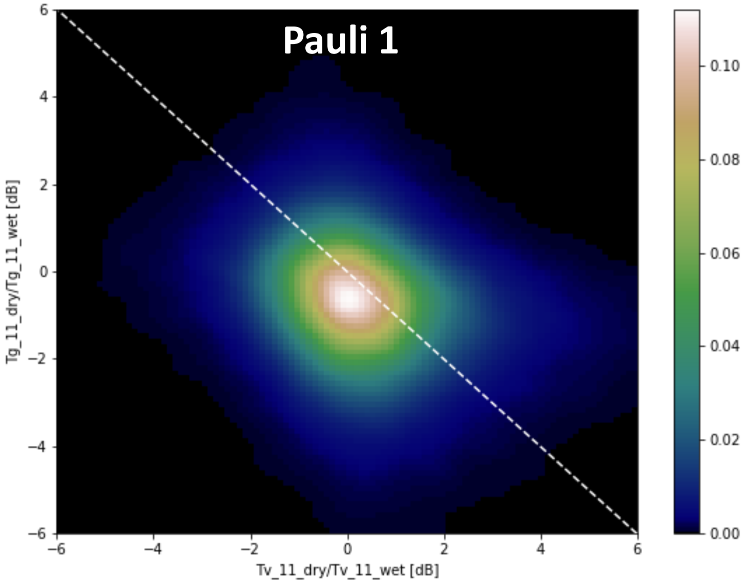


Dry vs. wet span of each component in dB

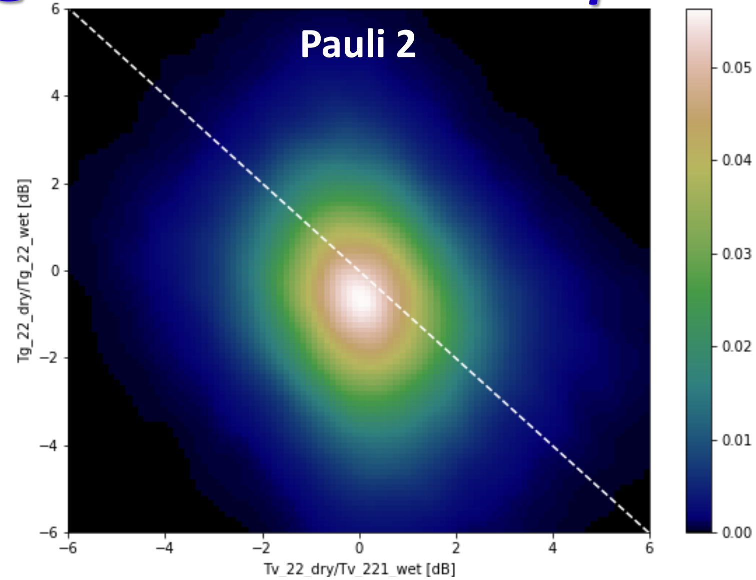
DLR

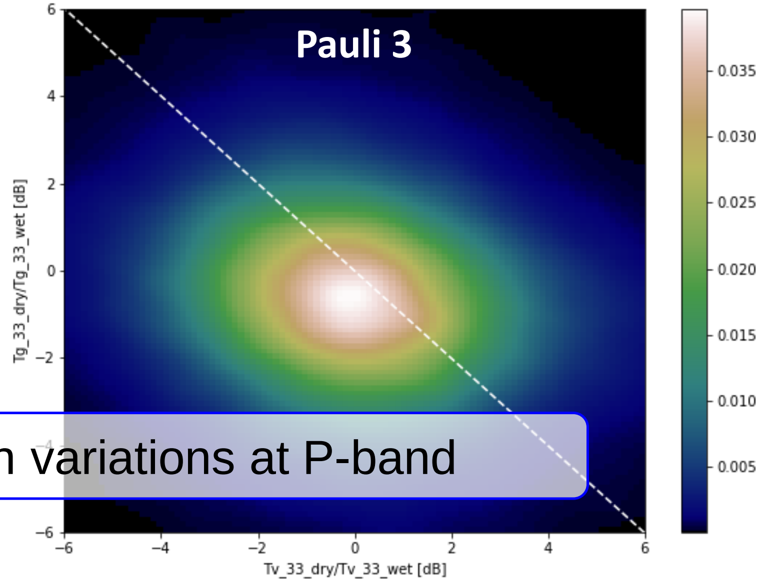
Polarimetric Change Analysis @ P-band – 2D scatter plots

- Scatter plot of ground vs. volume power ratios



Ground vs. Volume dry to wet ratios in dB

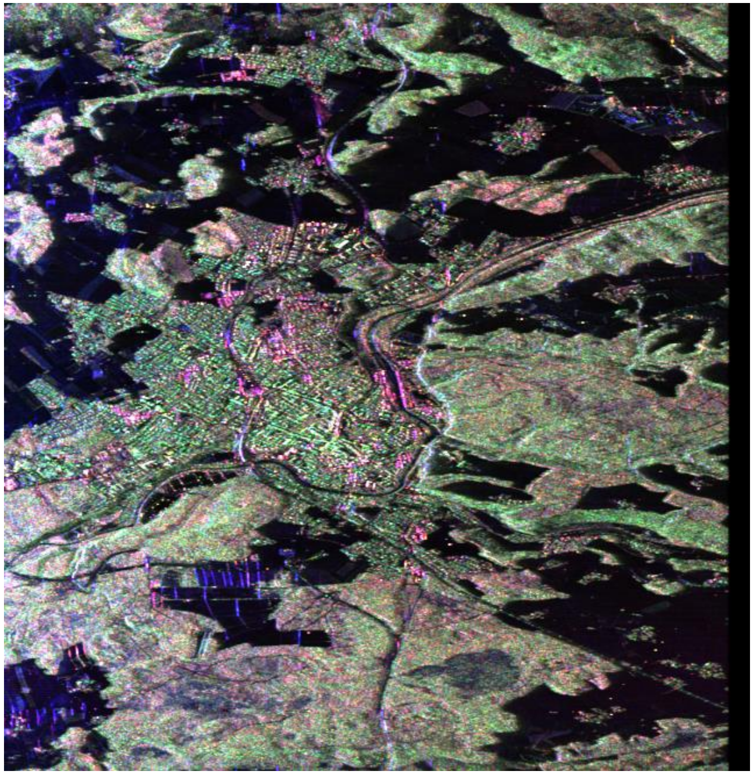


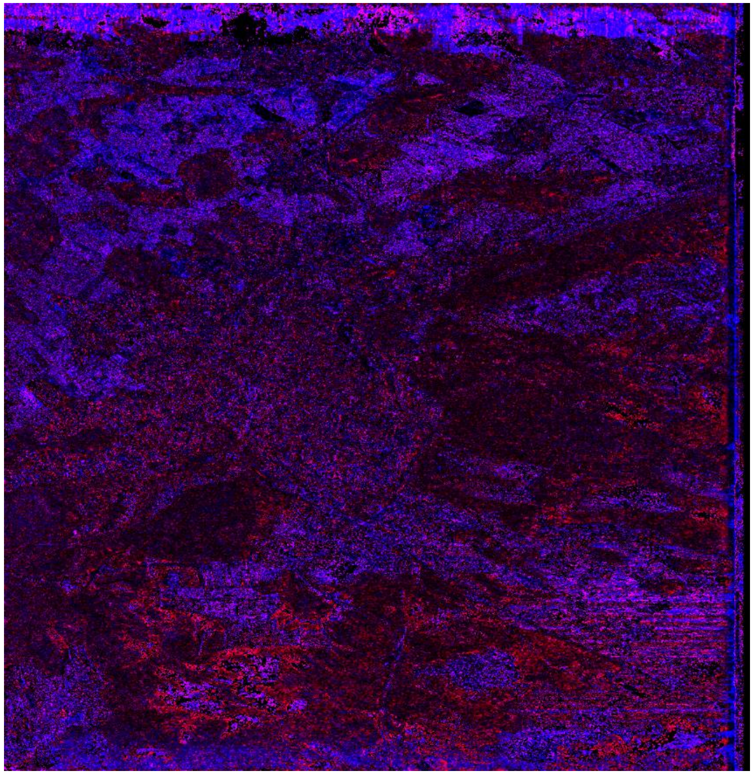


No correlation between variations at P-band

Polarimetric Change Analysis – Spatial distribution behavior

- Spatial distribution of sum and difference of ground and volume contrast





$|P_g+P_v|$

$|P_g-P_v|$

Blue indicates both increase / decrease

Red indicates opposite increase / decrease

Scaled from 0dB to 4dB

$$P_g = 10\log_{10}\frac{tr(\mathbf{T}_g^{dry})}{tr(\mathbf{T}_g^{wet})} \qquad P_v = 10\log_{10}\frac{tr(\mathbf{T}_v^{dry})}{tr(\mathbf{T}_v^{wet})}$$

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

L-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

P-band

  - **Volume component** is much more stable at P-band, showing no significant changes
  - **Ground component** increases on wet conditions, due to increased SM

- 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

www.biopal.org

github.com/BioPAL/BioPAL

Thank you for your attention!

DLR