ALOS / PalSAR Pol-InSAR for Forest Height Estimation : Potential and Limitations

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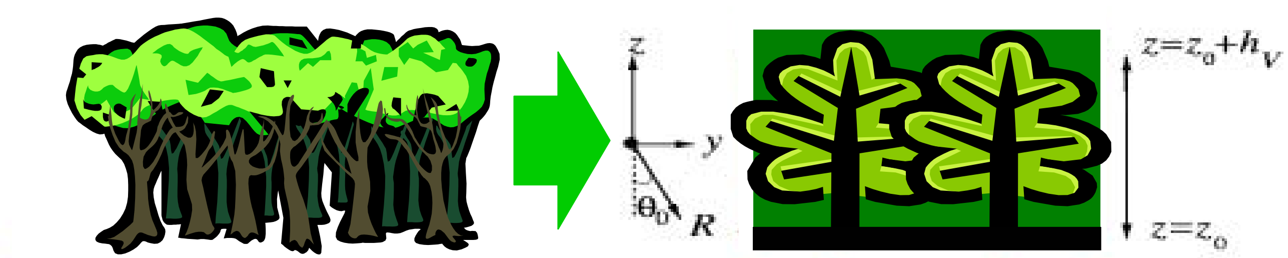
Random Volume over Ground (RVoG) Scattering Model



$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\,\frac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$$

Volume Coherence: $\tilde{\gamma}_V = \dfrac{I}{I_0}$

$$I = \int_0^{h_V} \exp(i\kappa_z z')\exp\left(\frac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'$$

$$I_0 = \int_0^{h_V} \exp\left(\frac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'$$

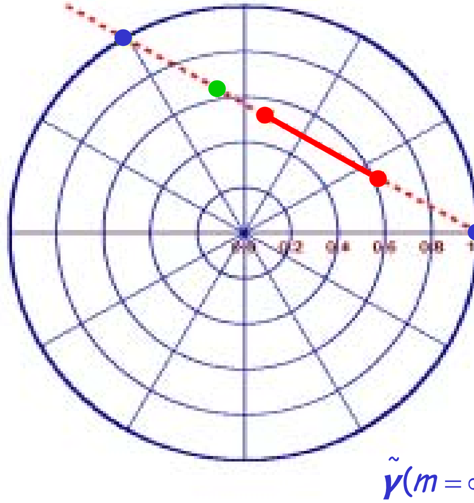
4 Parameters:

- Volume height h_V
- Extinction σ
- Topography φ_0

Interferometric Coherence: $\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\dfrac{\tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\left[\tilde{\gamma}_V + \frac{m(\vec{w})}{1 + m(\vec{w})}(1 - \tilde{\gamma}_V)\right]$$

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)[\ B \ + \ X(\vec{w})\ \ A\ ]$$



Equation of a straight line in the complex plane !!!

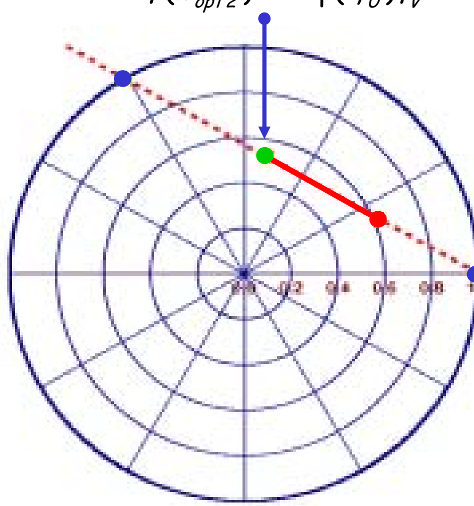
- *Line Slope* := **f** *(Baseline, Vegetation Height, and, Extinction)*
- *Line Length* := **f** *(Baseline, Vegetation Height, Extinction, and, Ground Scat. Amplitude)*

Frequency Dependent Parameters

The optimal polarisations represent the limiting points of the "visible" line part

Random Volume over a 2-dim Surface

$\tilde{\gamma}(\vec{w}_{opt2}) = \exp(i\varphi_0)\tilde{\gamma}_V$



Assumtion: *The ground is a 2-dimensional scatterer*

There is a polarisation where the ground is not vissible
(not necessarily the HV polarisation)

1st Opt. Coherence: $\tilde{\gamma}_1(\vec{w}_1) = \exp(i\varphi_0)\dfrac{\tilde{\gamma}_V + m_1(\vec{w}_1)}{1 + m_1(\vec{w}_1)}$

$m_1(\vec{w}_1) < \infty$

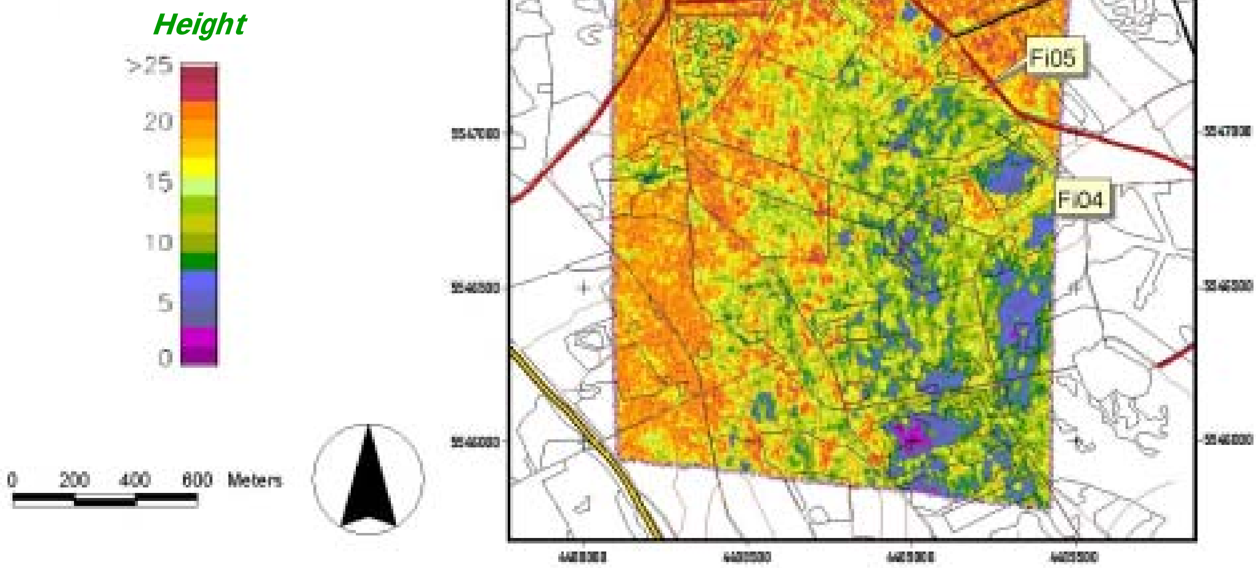
2nd Opt. Coherence: $\tilde{\gamma}_2(\vec{w}_2) = \exp(i\varphi_0)\tilde{\gamma}_V$

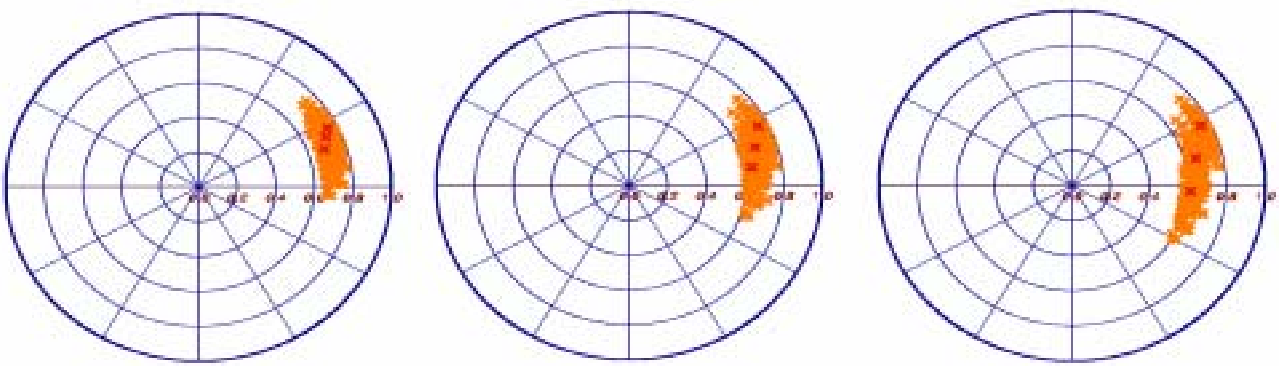
$m_2(\vec{w}_2) = 0$

3rd Opt. Coherence: $\tilde{\gamma}_3(\vec{w}_3) = \exp(i\varphi_0)\dfrac{\tilde{\gamma}_V + m_3(\vec{w}_3)}{1 + m_3(\vec{w}_3)}$ ➡ *Unique solutions for all five parameters:*

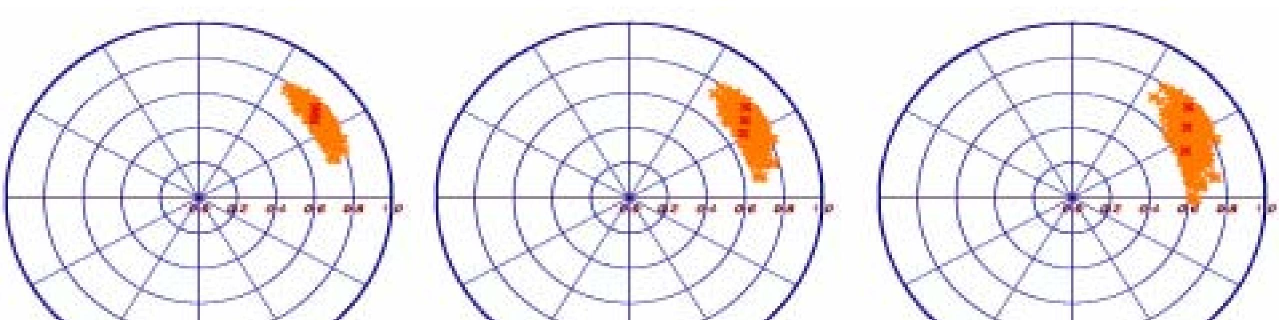
Forest Height Map

Fichtelgebirge Test Site



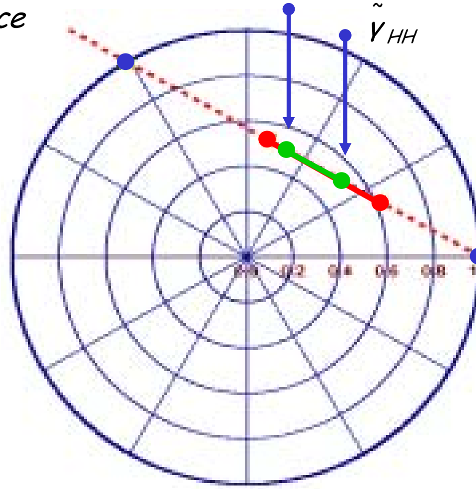


Pol-InSAR Lite: HH or VV and HV



Assumtion: *The ground is a 2-dim scatterer in HH-VV Sub-space*

In HV the ground is not visible



HH (or VV) Coherence:
$$\tilde{\gamma}_{HH}(\vec{w}_{HH}) = \exp(i\varphi_0)\frac{\tilde{\gamma}_V + m(\vec{w}_{HH})}{1 + m(\vec{w}_{HH})}$$
$$0 < m(\vec{w}_{HH}) < \infty$$

HV Coherence:
$$\tilde{\gamma}_{HV}(\vec{w}_{HV}) = \exp(i\varphi_0)\tilde{\gamma}_V(h_V,\sigma)$$
$$m(\vec{w}_{HV}) \stackrel{!}{=} 0$$

The two points allow (in principle) to estimate the line and to resolve the RVoG problem

Unique solutions for : Volume height h_V *Extinction* σ *and Topography* φ_0

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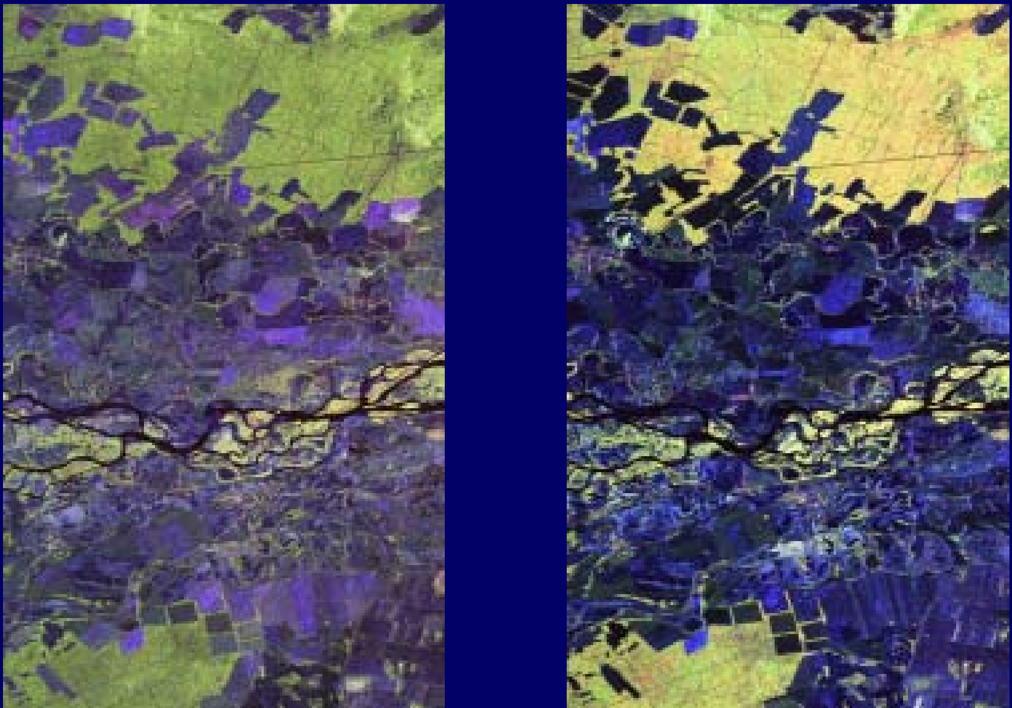
Pauli Images

Temporal Baseline: 48 Hours

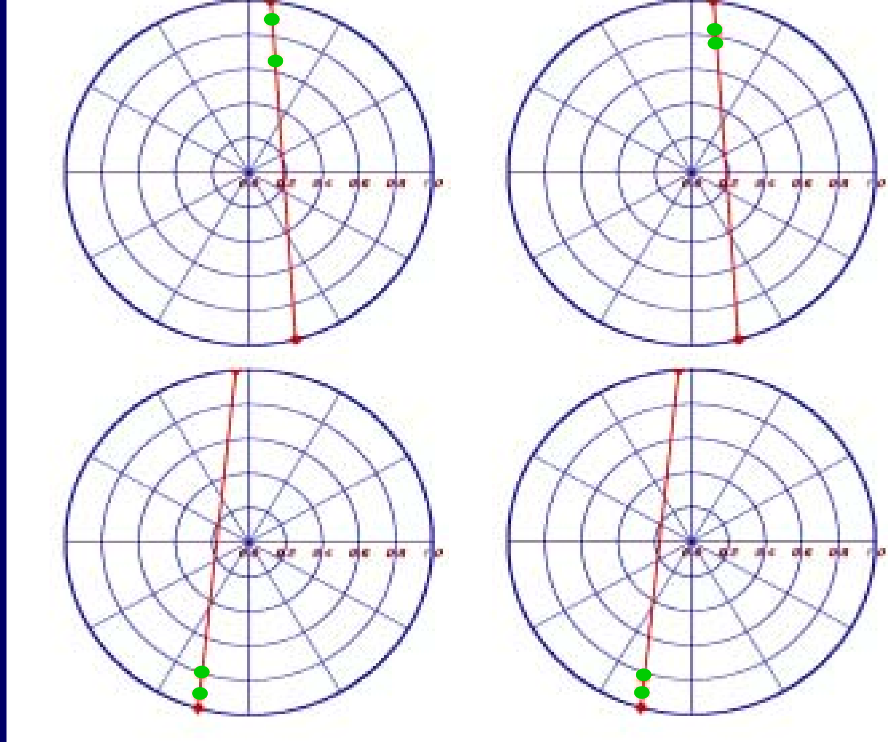
SIR-C / Test Site: Kudara,Russia



RGB - Codin

HH - VV

2HV



Range L-band Quad-Pol Dual-Pol (HH-HV)

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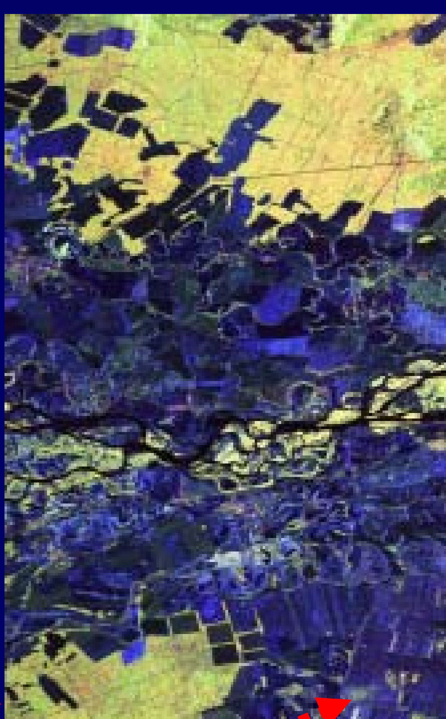
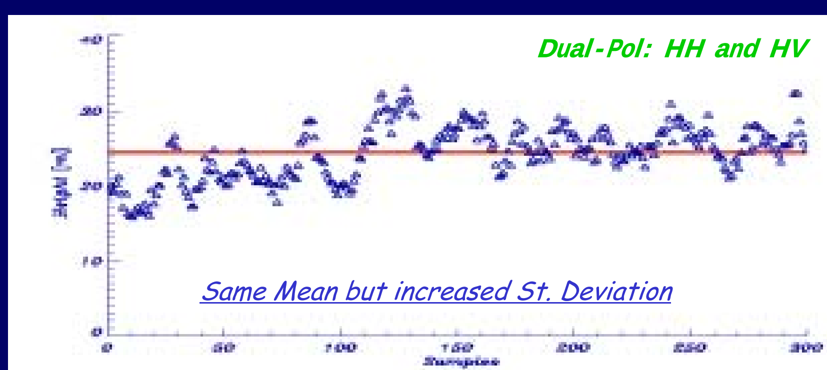
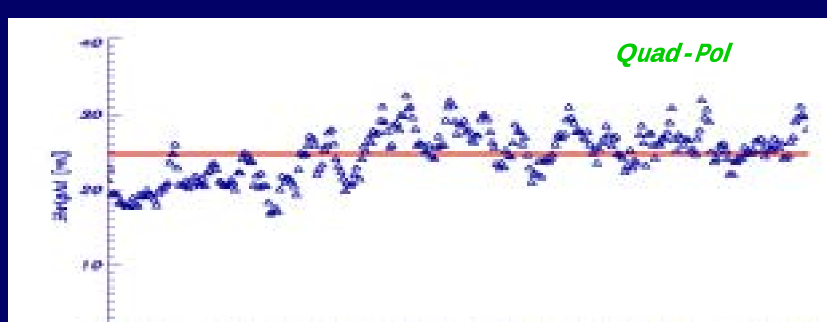
Forest Height Estimation: Quad-Pol vs.Dual-Pol

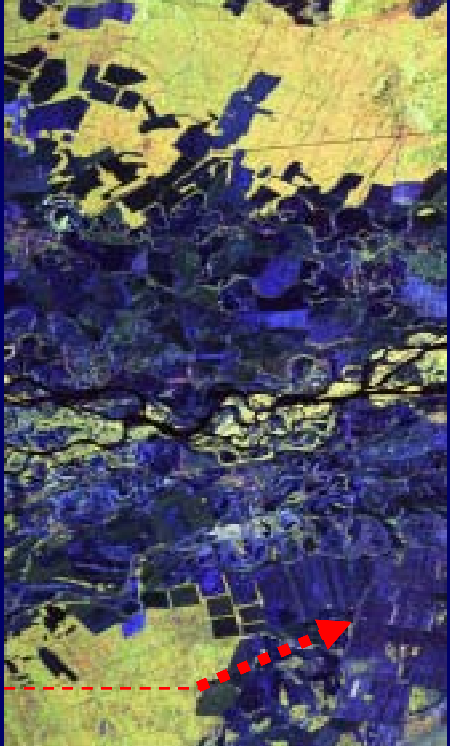
HR

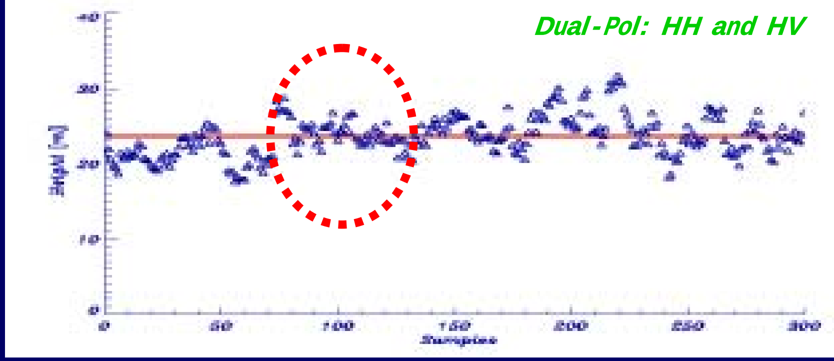
SIR-C / Test Site: Kudara,Russia

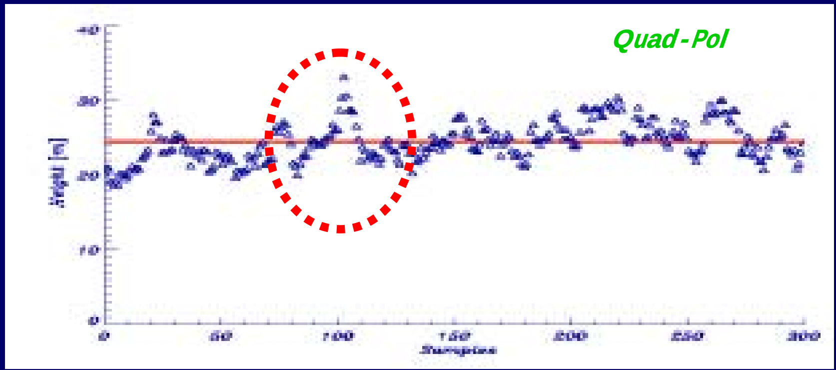




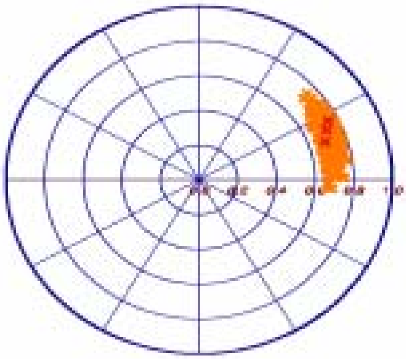


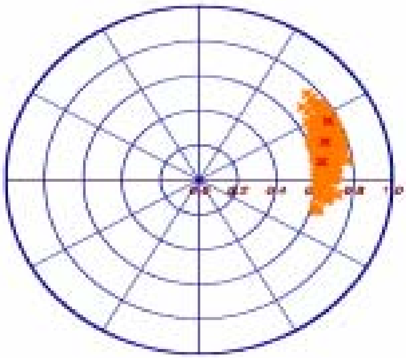


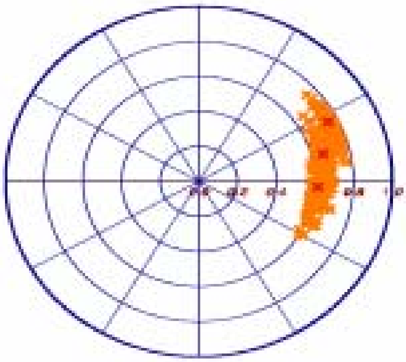




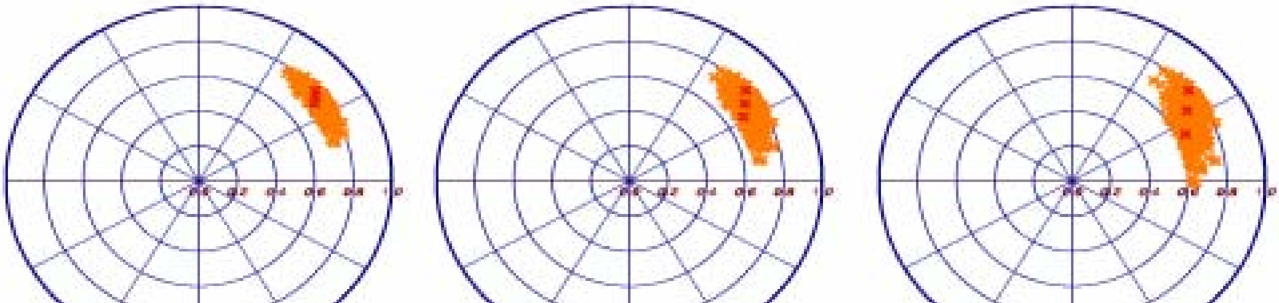
Temporal Baseline: 48 Hours



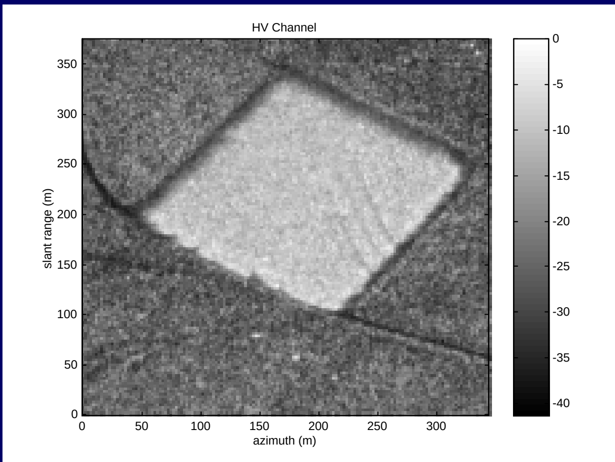




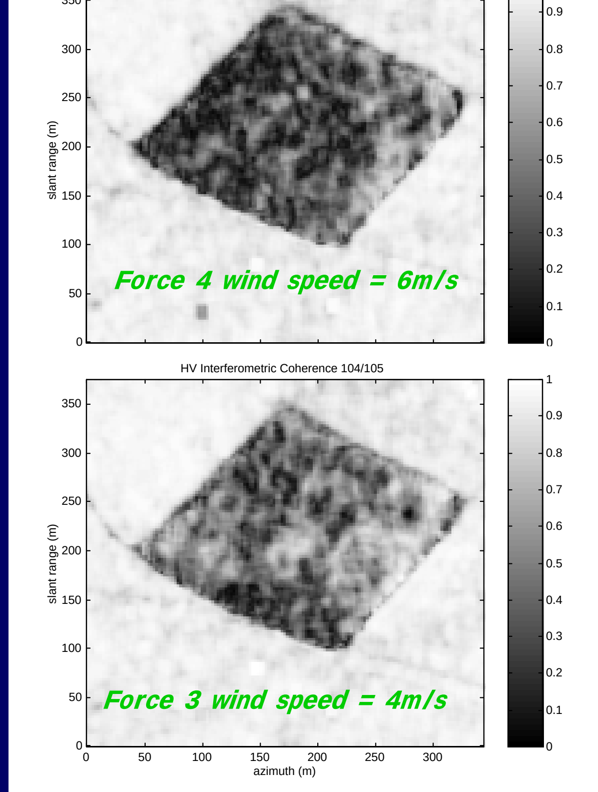
Temporal Decorrelation



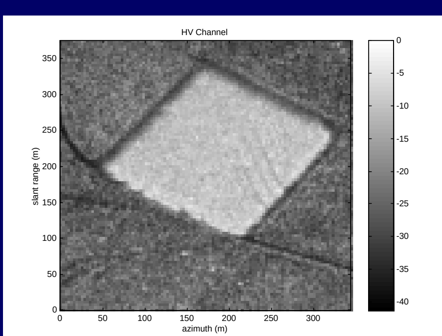
E-SAR / Test Site: Fox Covert,England



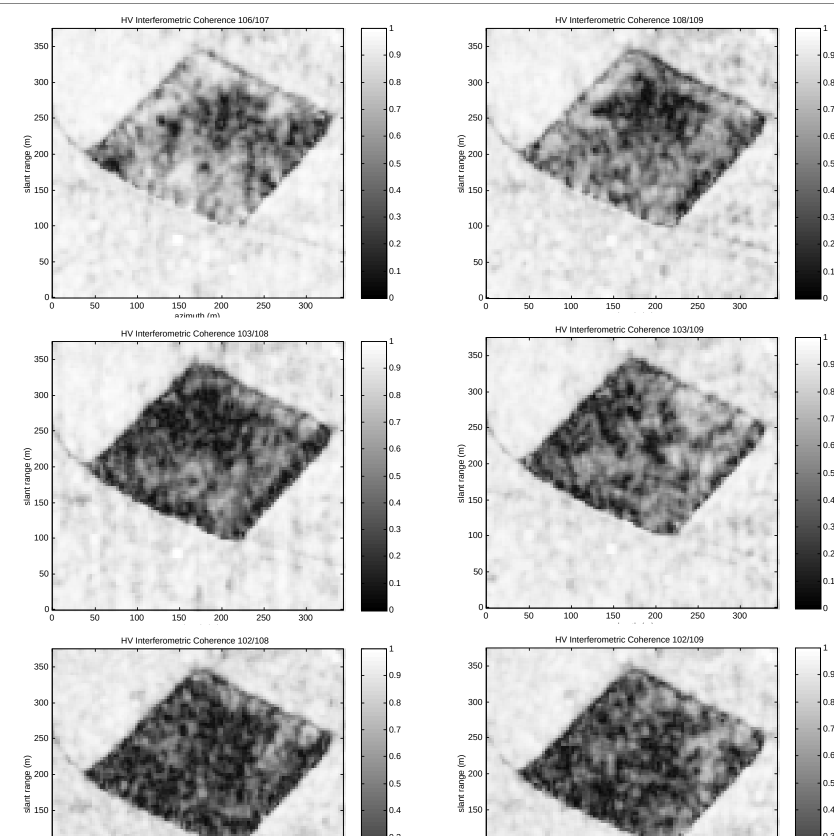
L-band HV Image



E-SAR / Test Site: Fox Covert,England

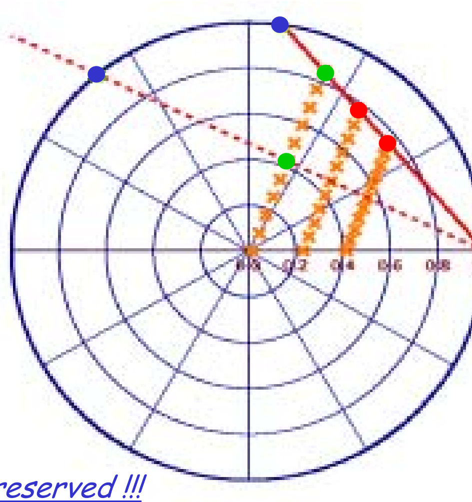


L-band



Temporal Effect: Random movement of the scattering particles in the volume : Wind Effects.

The 2nd order polarimetric properties of the ground $[T_G]$ and the volume scatterer $[T_V]$ remain the same:



- Ground / Volume amplitude ratios $m(\vec{w})$ are unaffected
- $0 \leq \gamma_T \neq f(m(\vec{w})) \leq 1$ is equal for all polarisations !!!

Interferometric Coherence: $\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\dfrac{\gamma_T \tilde{\gamma}_V + m(\vec{w})}{1 + m(\vec{w})}$

$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\left[\gamma_T \tilde{\gamma}_V + \frac{m(\vec{w})}{1 + m(\vec{w})}(1 - \gamma_T \tilde{\gamma}_V)\right]$$

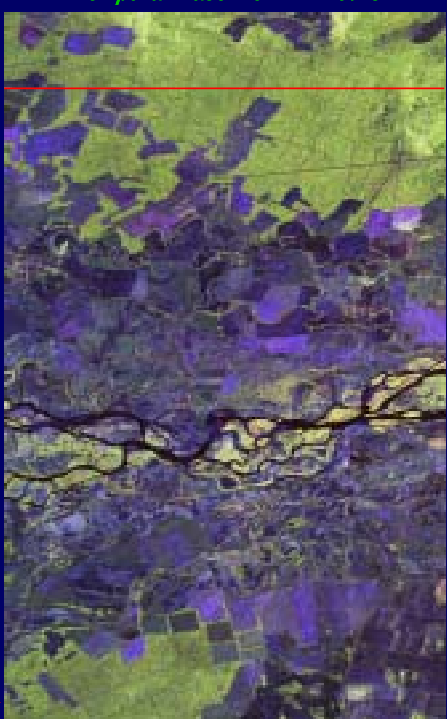
the line is preserved !!!

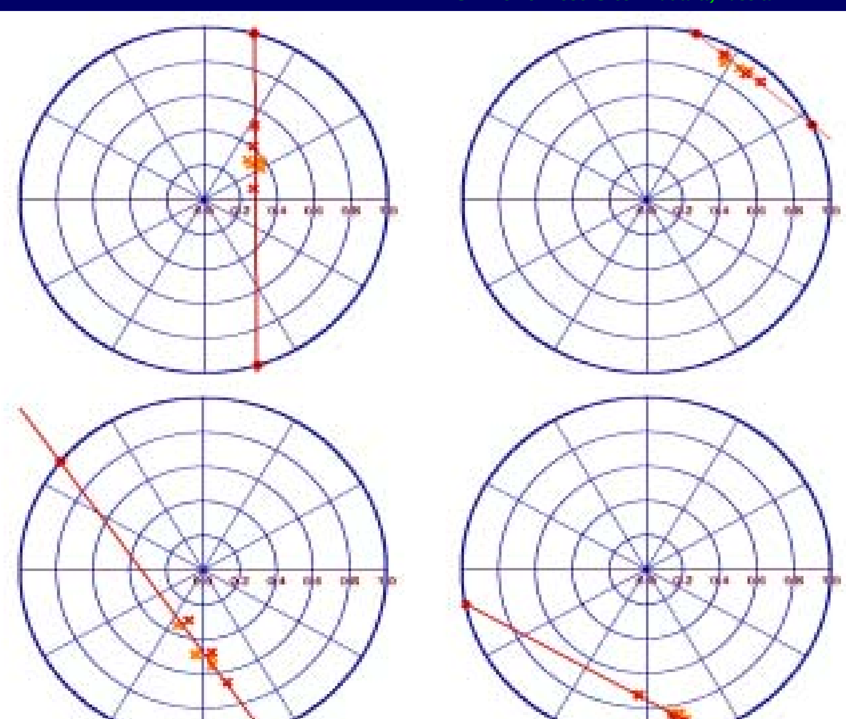
- γ_T affects slope of the line but not the position of the points on the line.
- φ_0 remain invariant under variations of γ_T. The estimation of φ_0 is still possible !!!
- γ_T leads to an underestimation of $\tilde{\gamma}_V$ and thus a overestimation of volume height.

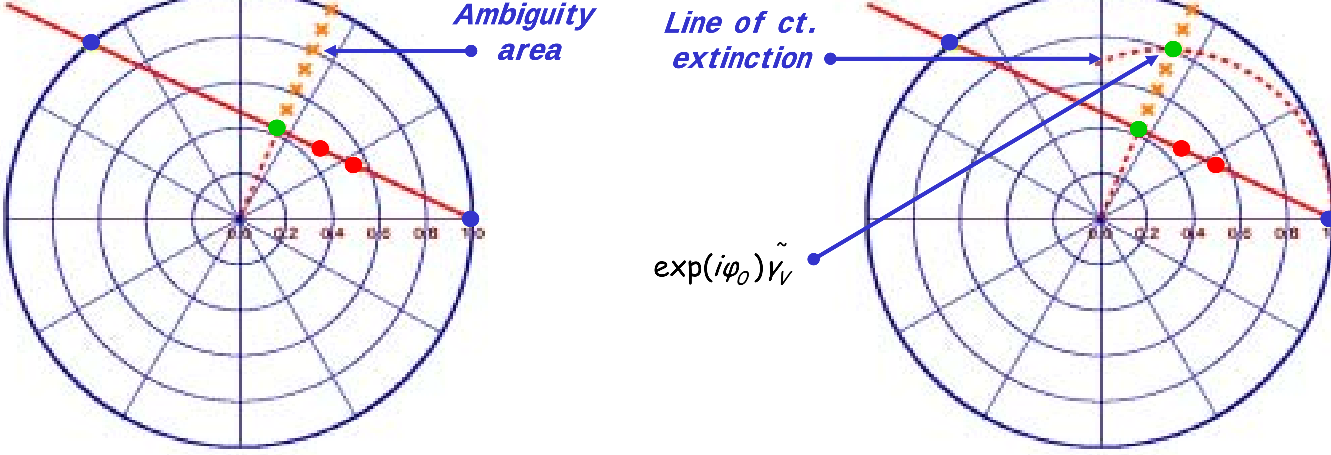
Line Comparison: C-Band vs. L-Band

Temporal Baseline: 24 Hours

SIR-C / Test Site: Kudara,Russia







Volume Height Estimation:

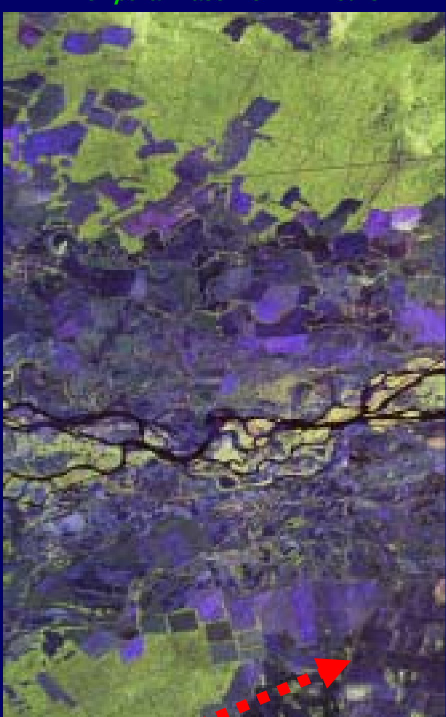
- *Assumption of the mean extinction value* $\boldsymbol{\sigma}$
- *Estimate the corresponding* $\tilde{\gamma}_V$ *value* ⟶

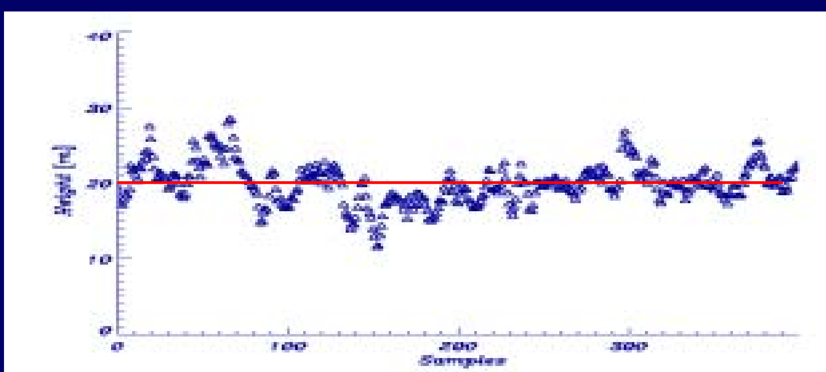
$$\tilde{\gamma}_V = \frac{\int_0^{h_V} \exp(i\kappa_z z')\exp\left(\frac{2\,\sigma\, z'}{\cos\theta_0}\right)dz'}{\int_0^{h_V} \exp\left(\frac{2\,\sigma\, z'}{\cos\theta_0}\right)dz'} \longrightarrow h_V$$

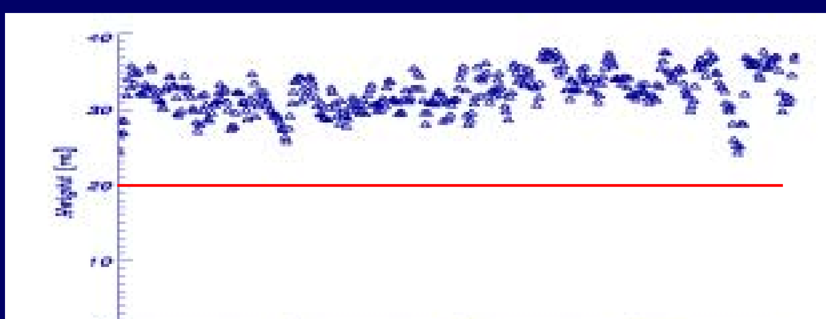
Forest Height Estimation: C-Band vs. L-Band

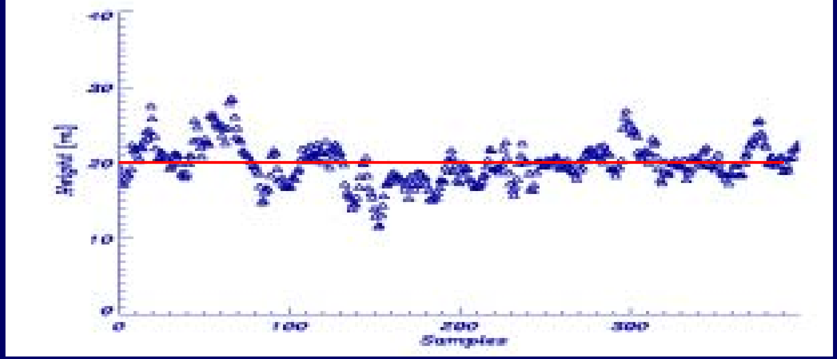
Temporal Baseline: 24 Hours

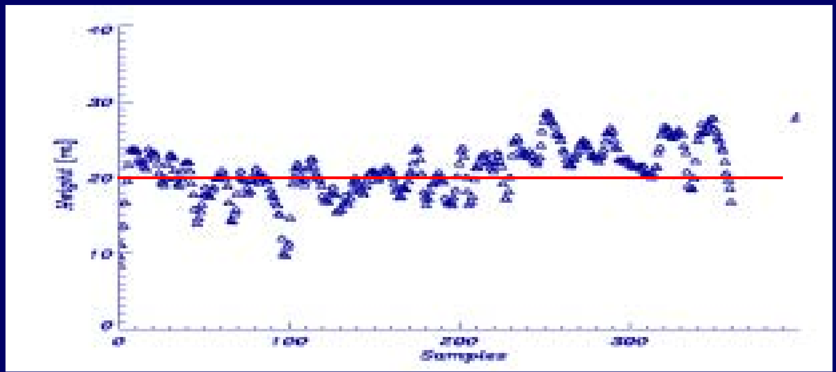
SIR-C / Test Site: Kudara,Russia











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Conclusions

IHR

- Unbiased estimation of forest height and underlying topography is in principle possible in a dual-pol (HH or VV and HV) Pol-InSAR scenario.
- The estimation accuracy is expected to drop especially in terrain with topographic variations. The availability of a DEM may be advantageous.
- Temporal decorrelation makes - in general - accurate unbiased parameter inversion impossible.
- Moderate temporal decorrelation of the volume layer can be accounted in the RVoG inversion model and compensated.
- However additional regularisation is required in order to obtain unique estimates.
- The availability of multiple-baselines (temporal and spatial) may allow a more flexible / accurate regularisation and is a serious option for increasing est. accuracy