Model based forest height estimation with ALOS/PalSAR: A first study.

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Forest Height and Biomass Estimation

Conventional Biomass Estimation based on Backscatter Saturation:

	Biomass Saturation Limit [T/ha]	Biomass Saturation Limit [Kg/(m^2)]	% of Earths Vegetated Area	% of Total Biomass Stock
C-band	20*	2	25%	4%
L-band	40*- 60	4 - 6	35%	8%
P-band	100*-150	10 -15	60-65%	20-25%

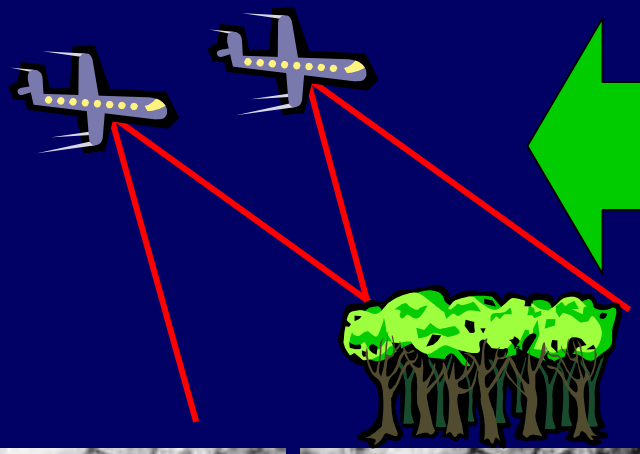
Biomass Estimation based on Forest Height:

Tree Height	250 - 400	25 - 40	75-95%	80-99%

The expected above ground biomass estimation accuracy is about 30%.
Information about species and/or forest structure can increase the estimation accuracy

* M. L. Imhoff, "Radar Backscatter and Biomass Saturation: Ramifications for Global Biomass Inventoty ",IEEE TGARS, Vol. 33, No. 2, March 1995

Forest Parameter Inversion using Pol-InSAR

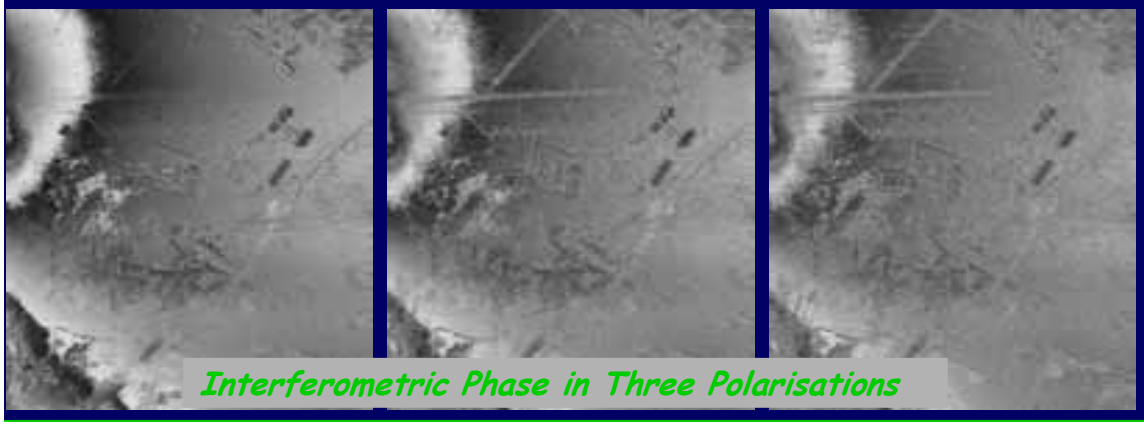


INTERFEROMETRIC
POLARIMETRIC
OBSERVABLES

Step I:
Modelling

COHERENT
SCATTERING
MODEL

FOREST PARAMETERS
Forest Height
Forest Extinction
Underlying Topography



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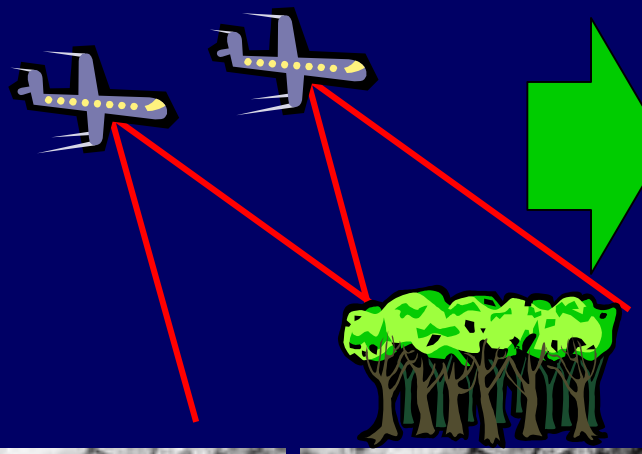

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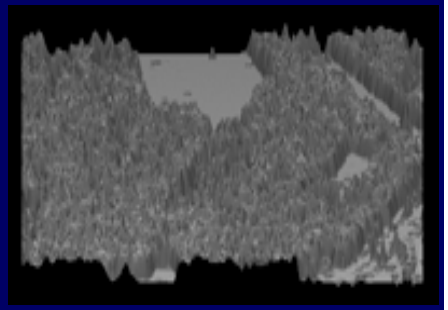
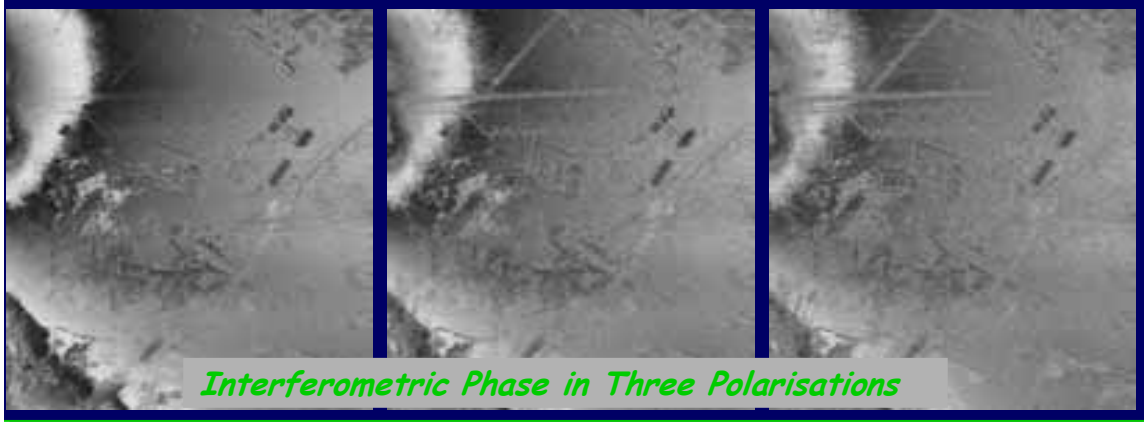




Polarimetric SAR Interferometry: Modeling

Nature

30-70K Leaves, ~ 2K Branches,
Leave Form, Branch Orientation Distribution,
Tree height, Ground Moisture and Roughness

Random Volume + Ground Model

Volume height: h_V
Topography: ϕ_0
Extinction: σ
G/V Ratio: m(polarisation)

Single Baseline Single Frequency Inversion Scenarios:

Single-Polarisation Interferometry

4 Parameters ↔ 2 Observables

Underestimated

Dual-Polarisation Interferometry

5 Parameters ↔ 4 Observables

Underestimated

Quad-Polarisation Interferometry

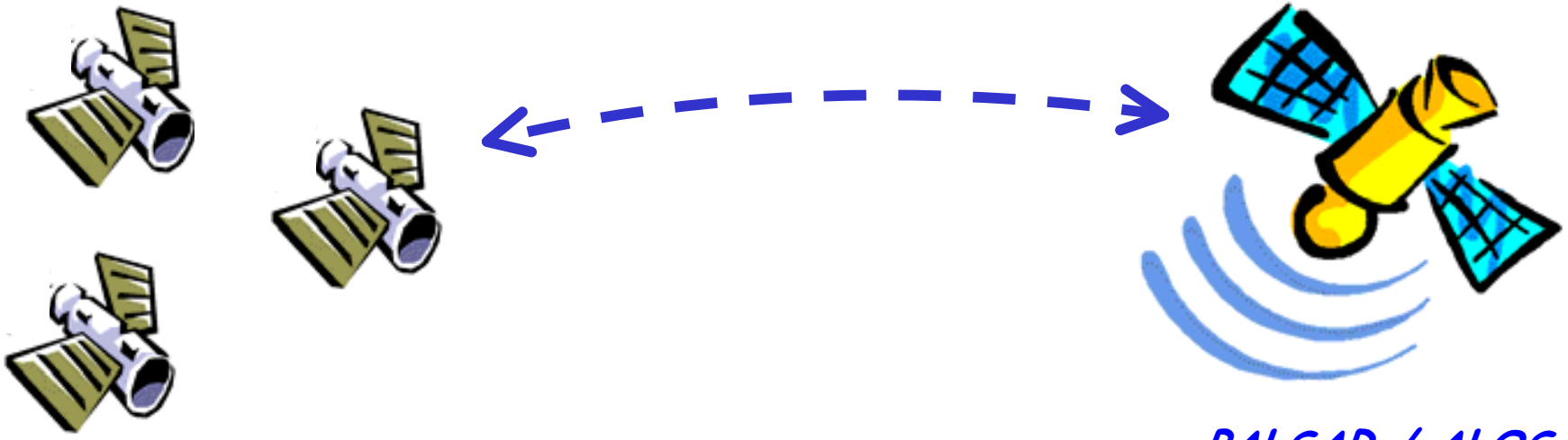
6 Parameters ↔ 6 Observables

Solvable !!!

Scenario for Spaceborne Single-Pass PolInSAR: Passive Micro Satellite Configuration

Receive-only micro satellites (€)

Illuminator (€ € €)

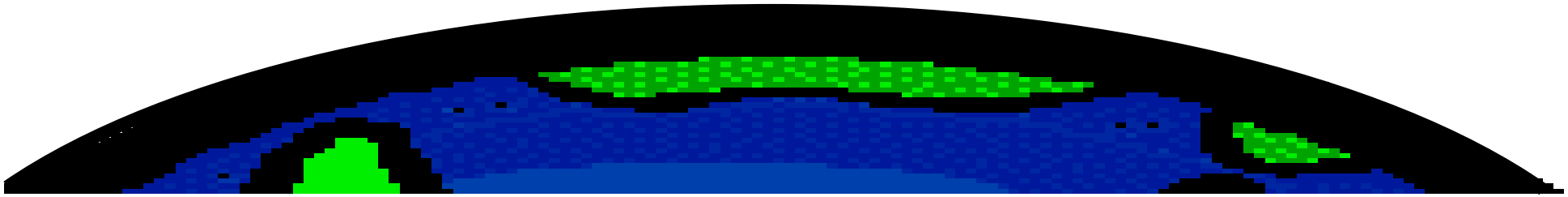


PInSAR

3 Passive Micro-satellites
Ant. Length (Rx): 3.0m
Ant. Width (Rx): 3.0m
Weight (each) 100-150Kg

PALSAR / ALOS

Bandwidth: 28MHz
Orbit Height: 691Km
Ant. Length (Tx): 8.9m
Ant. Width (Tx): 3.1m
Weight (ALOS): 4000Kg



Fichtelgebirge Test Site

L-band HH Image

X-band Single Pass Inteferometric DEM

Topography:

650-1051 m a.s.l. (Schneeberg)

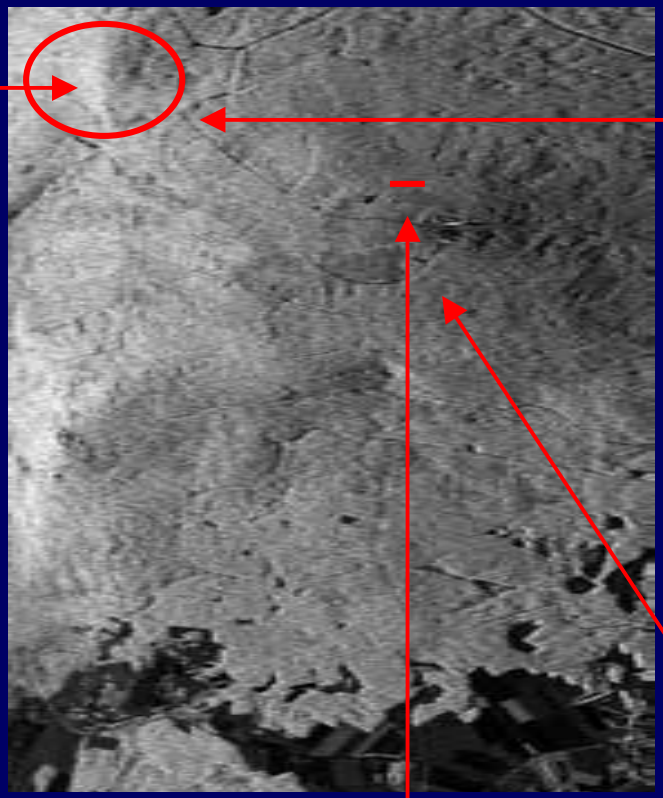
Vegetation:

typically even-aged stands up to 300 t/ha

- 95 % Norway spruce (Picea abies)
- 2 % european beech (Fagus sylvatica)

Test Site: Fichtelgebirge, Germany

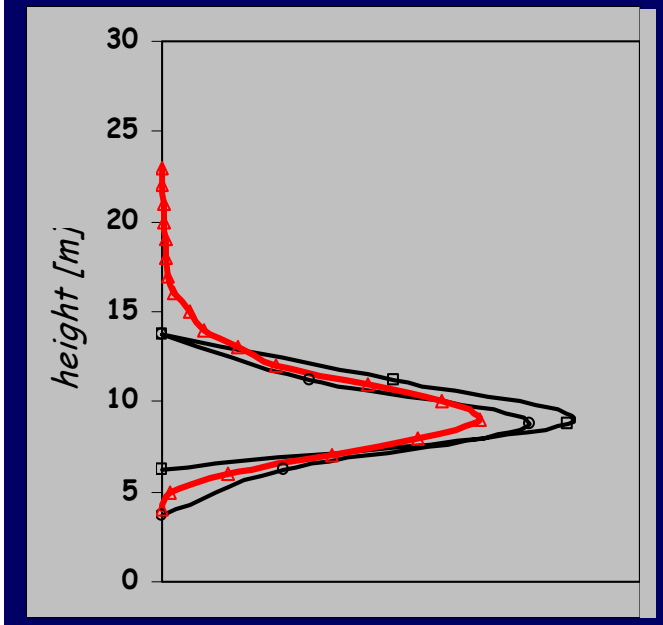
Beech Stands



Height Validation

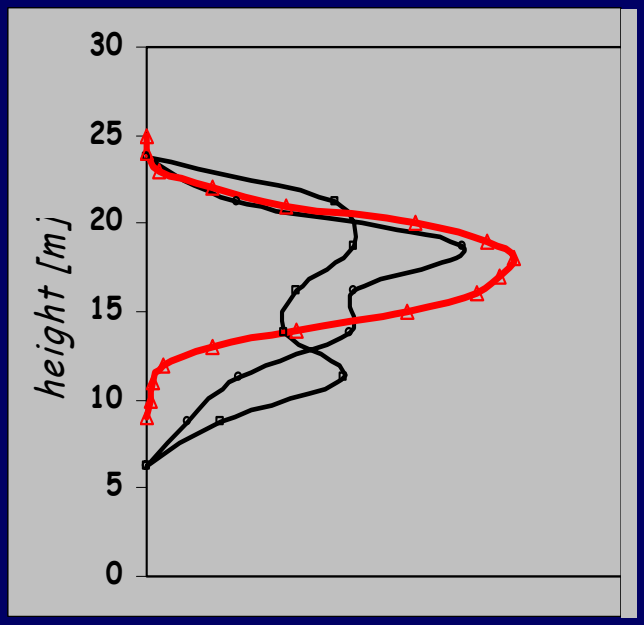
Fi04
Spruce afforestation

Height: 8-9 m



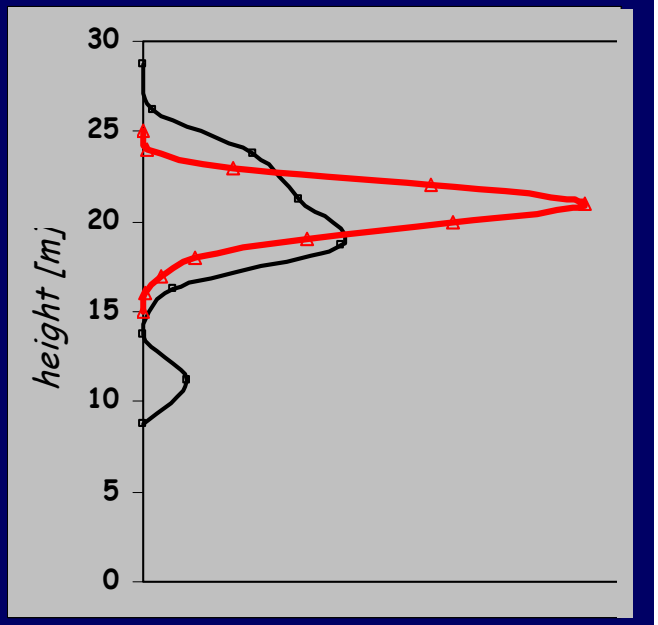
Fi05
Heterogeneous spruce stand

Height: 14-19 m



Fi_i
Homogeneous (rel.) mixed spruce beech stand

Height: 19-20 m

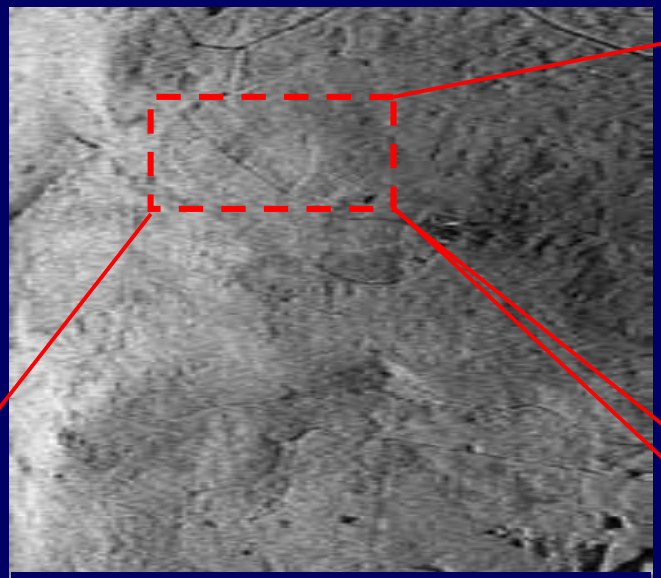


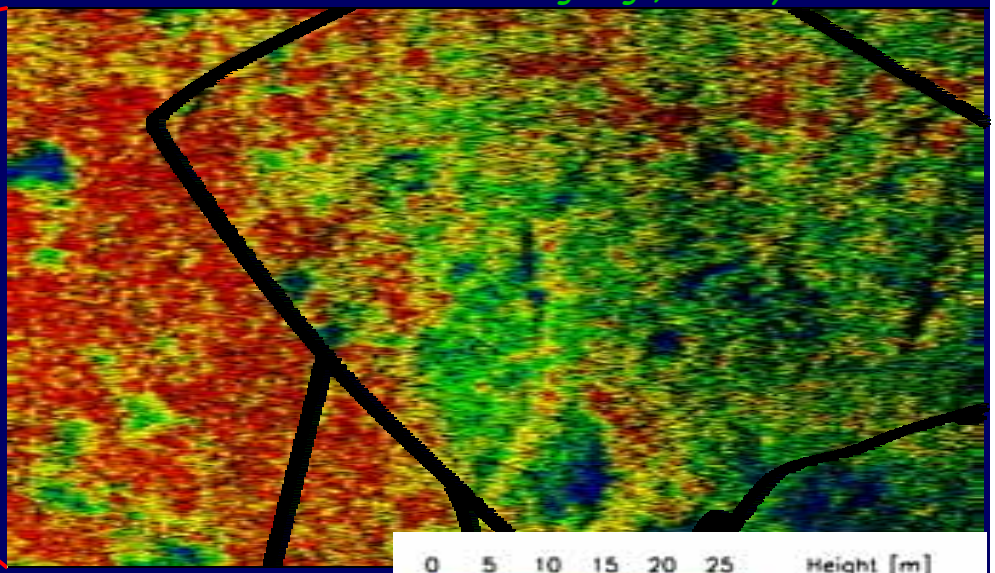
ESAR / Test Site: Fichtelgebirge, Germany

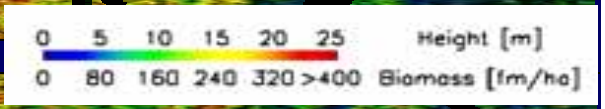
Groundtruth
Radar (Pol-InSAR)

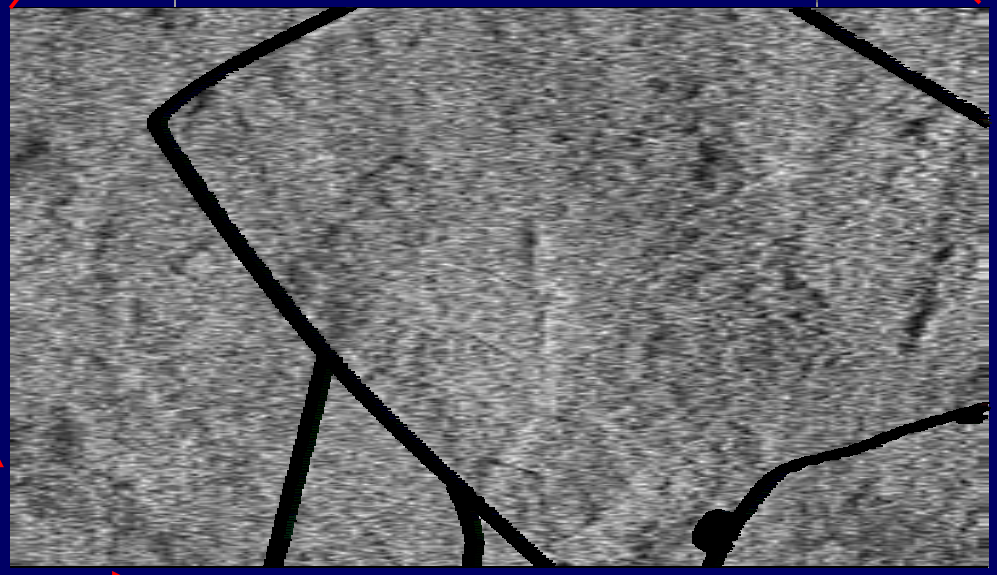
Forest Height & Biomass Maps

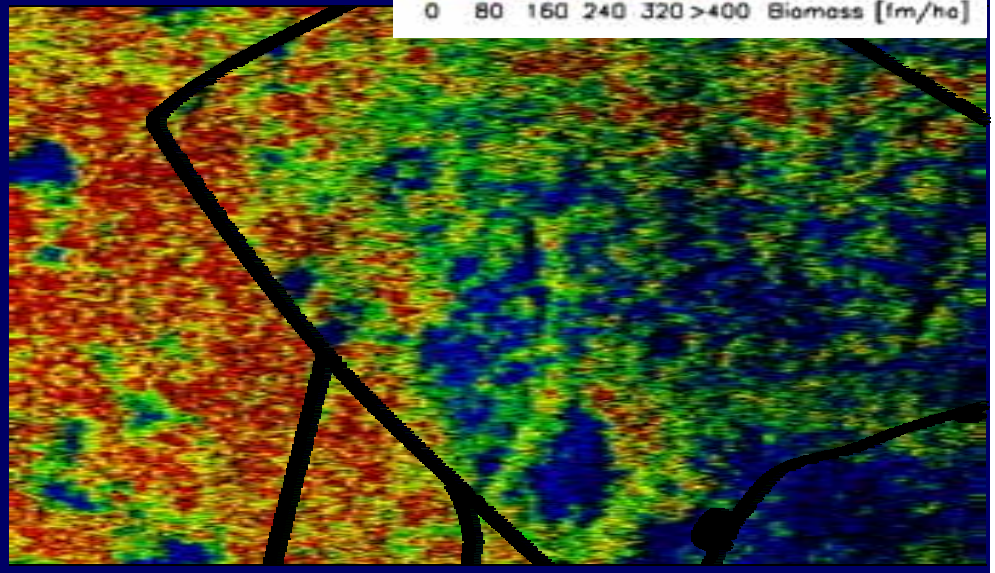
ESAR / Test Site: Fichtelgebirge, Germany











Azimut

Range

L-band HH

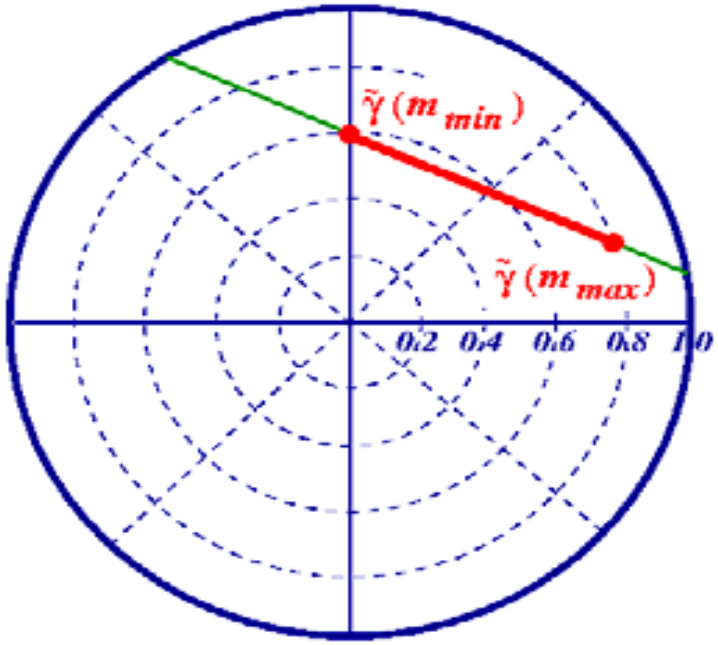
Scattering Model: Geometrical Interpretation

Interferometric Coherence:

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

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

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



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

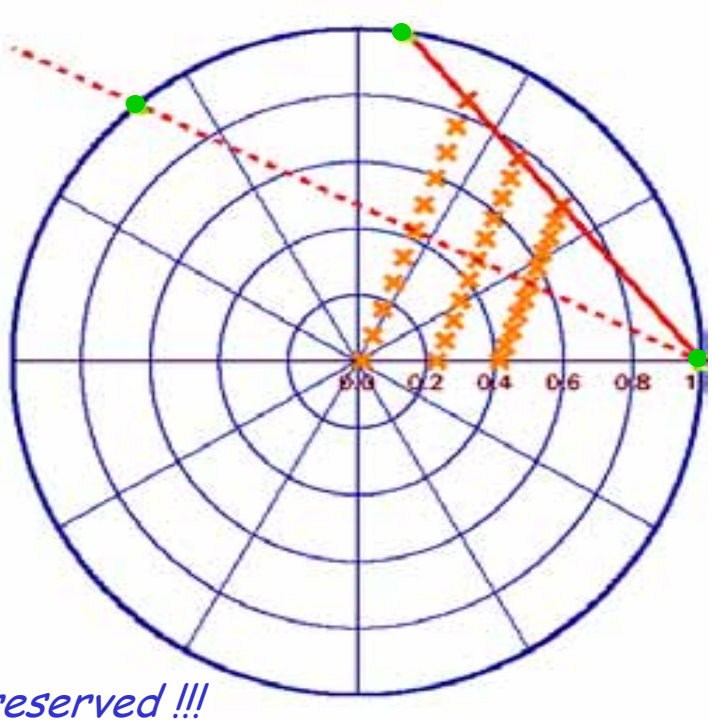
The optimal polarisations represent the limiting points of the "visible" line part

Temporal Decorelation of the Volume Scatterer

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
- $0 \le \gamma_T \ne f(m(\vec{w})) \le 1$ is equal for all polarisations !!!



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

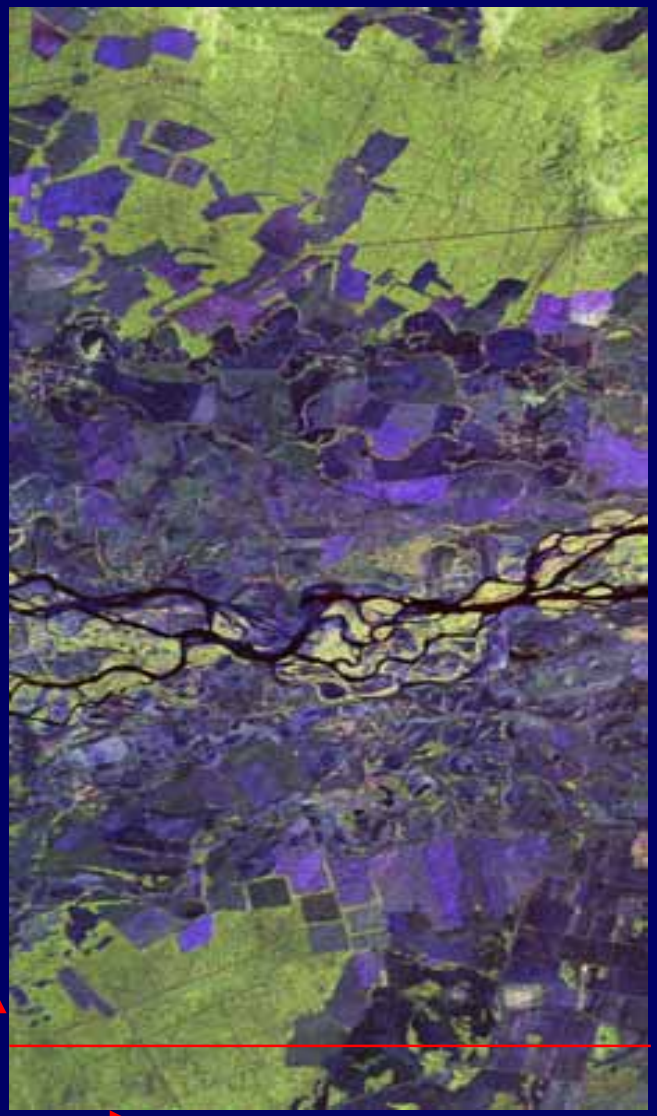
$$\tilde{\gamma}(\vec{w}) = \exp(i\varphi_0)\left[\gamma_T \tilde{\gamma}_V + \frac{m(\vec{w})}{1 + m(\vec{w})}(1 - \gamma_T \tilde{\gamma}_V)\right]$$ *the line is preserved !!!*

- γ_T affects slope of the line but not the position of the points on the line.
- φ_0 remains 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 an overestimation of volume height.

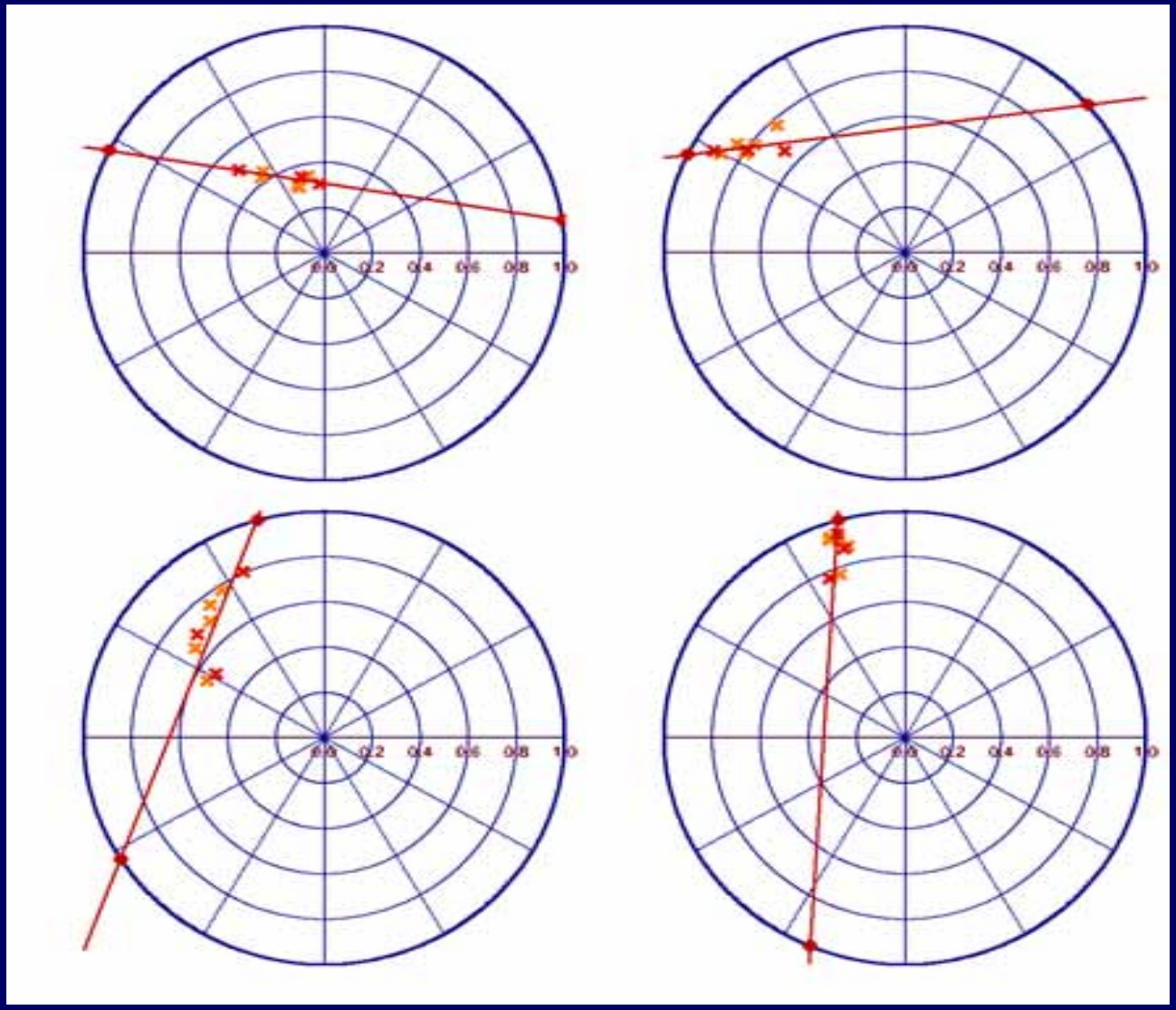
Line Comparison: C-Band vs. L-Band

Temporal Baseline: 24 Hours

SIR-C / Test Site: Kudara,Russia



Pauli RGB Image



C-band

L-band

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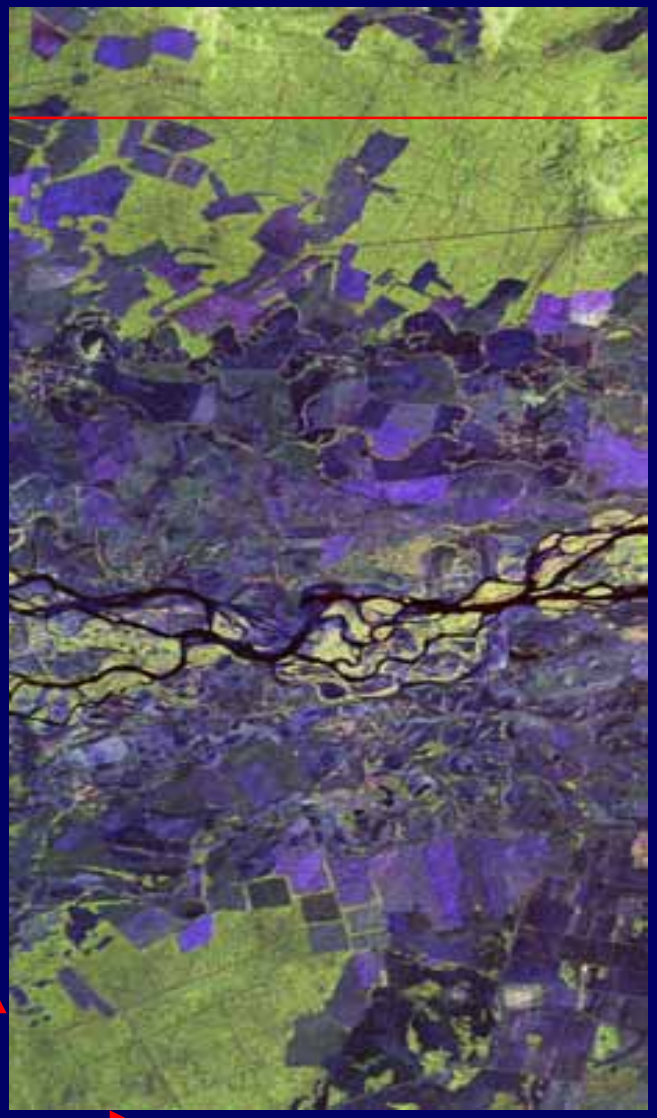

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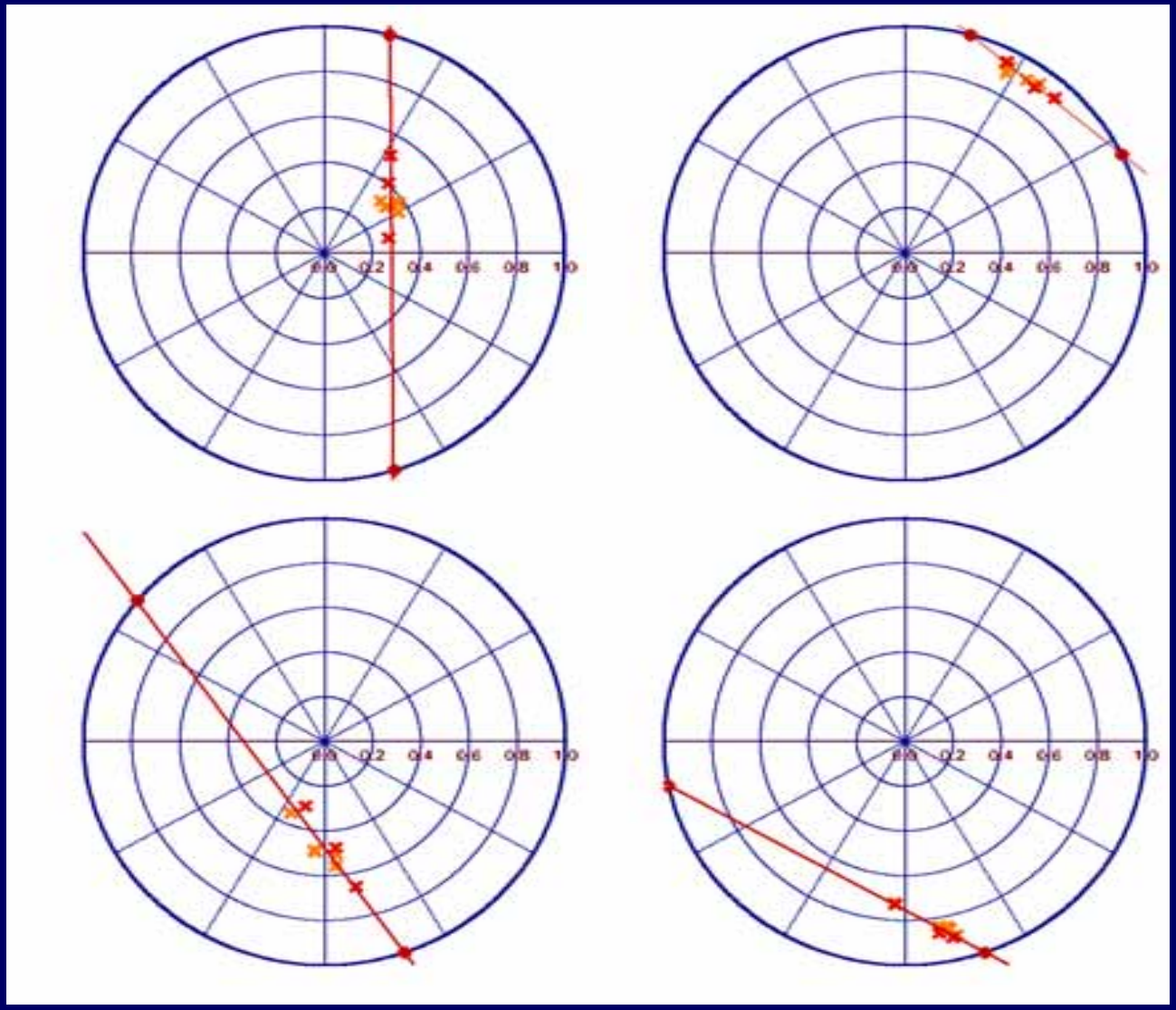


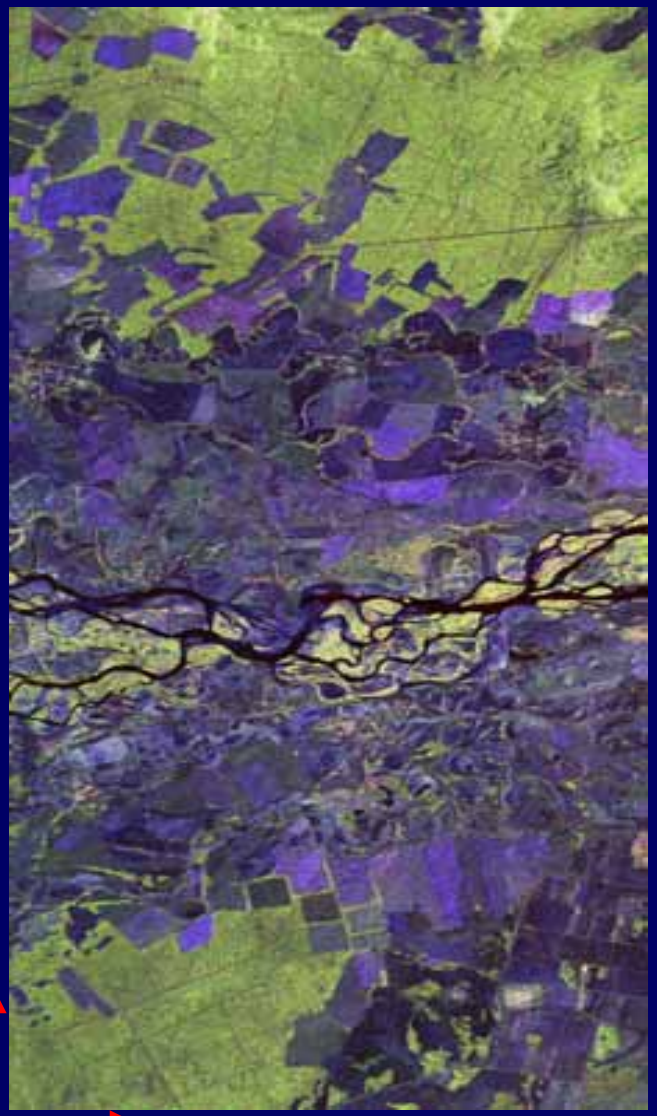
C-band

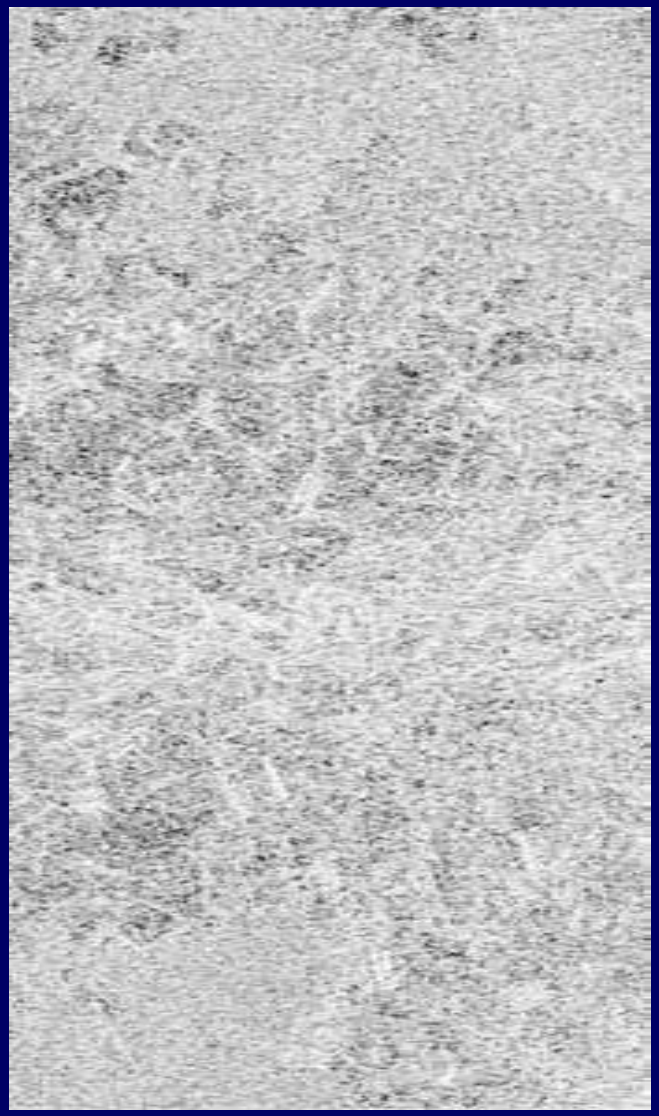
L-band

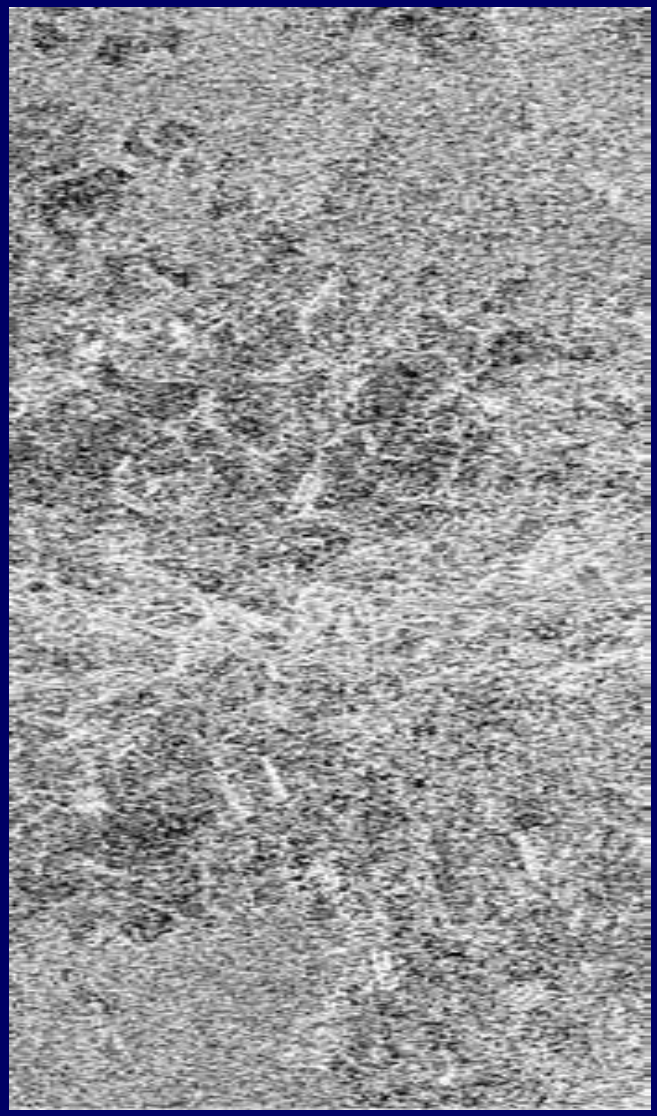
Line Validation: Boreal Forest

C-band

SIR-C / Test Site: Kudara,Russia







Azimuth

Range

Pauli RGB Image

Chi-Square Image

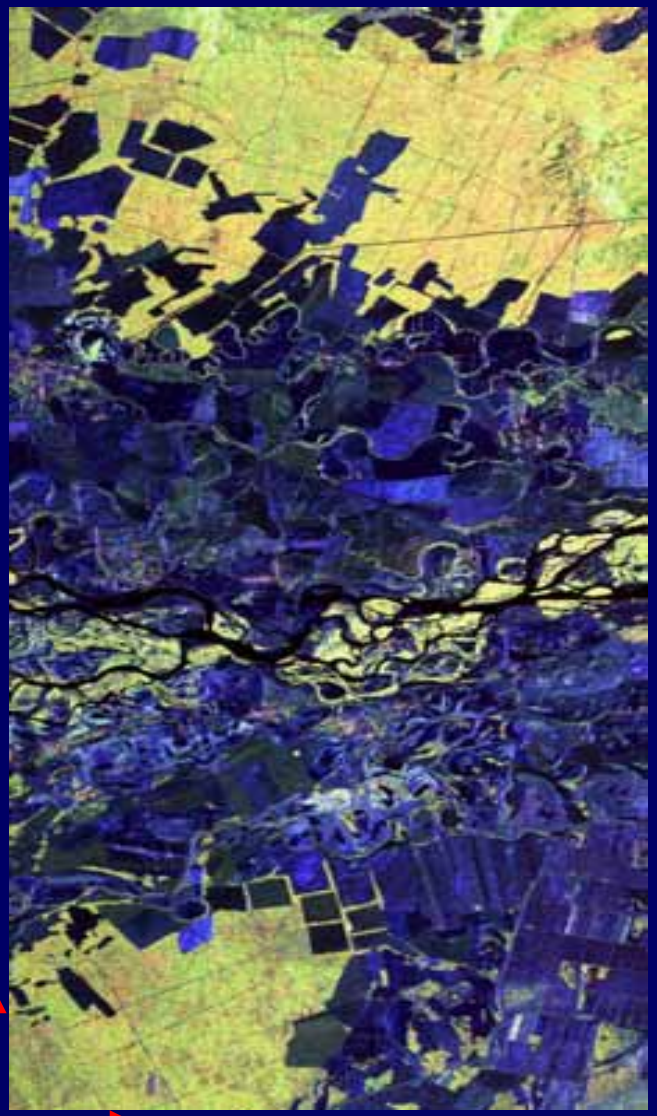
Validity Mask: Q > 80%

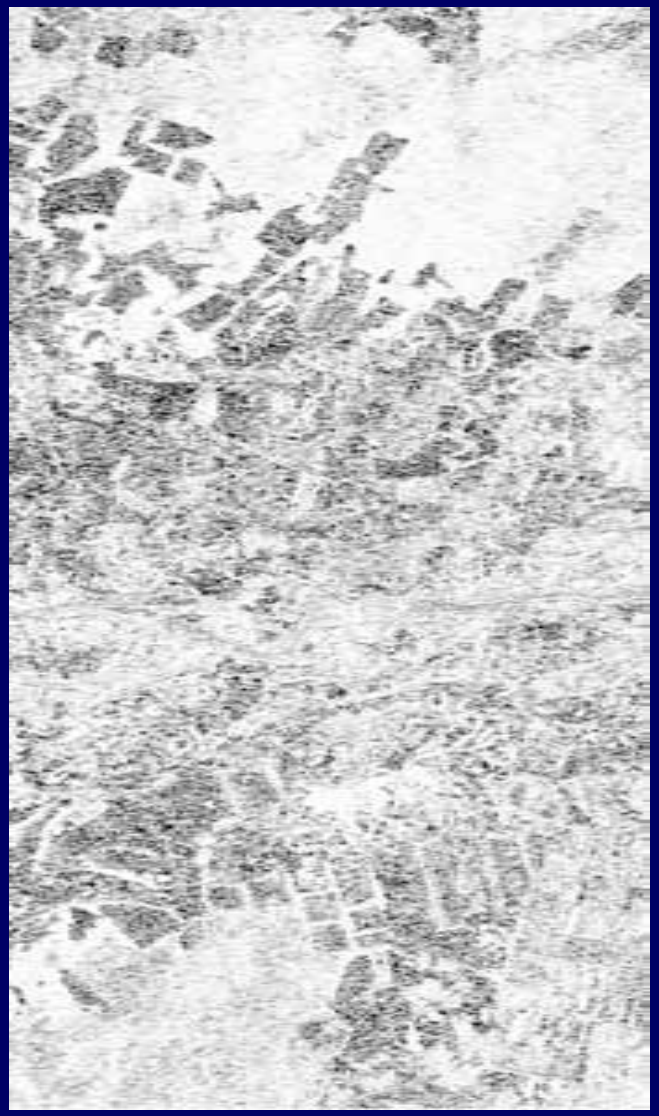
Line Validation: Boreal Forest

DLR

L-band

SIR-C / Test Site: Kudara,Russia





Azimuth

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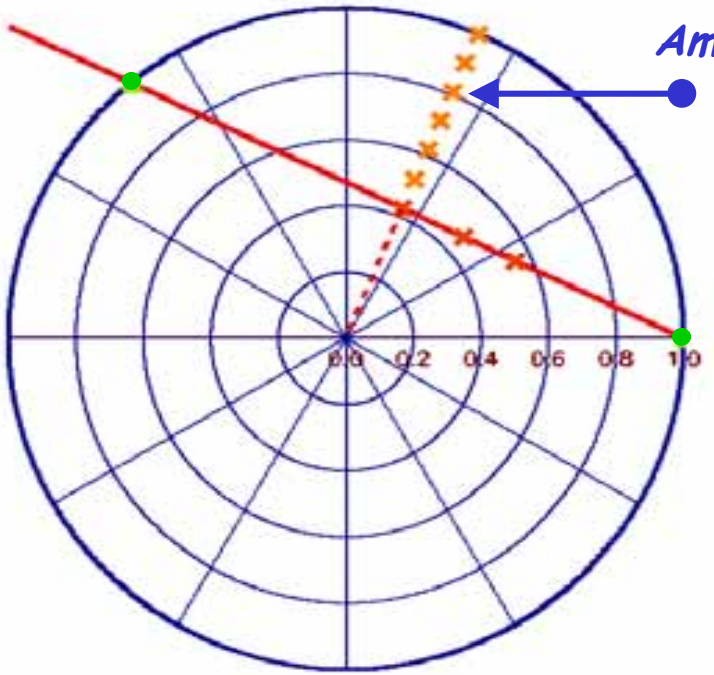
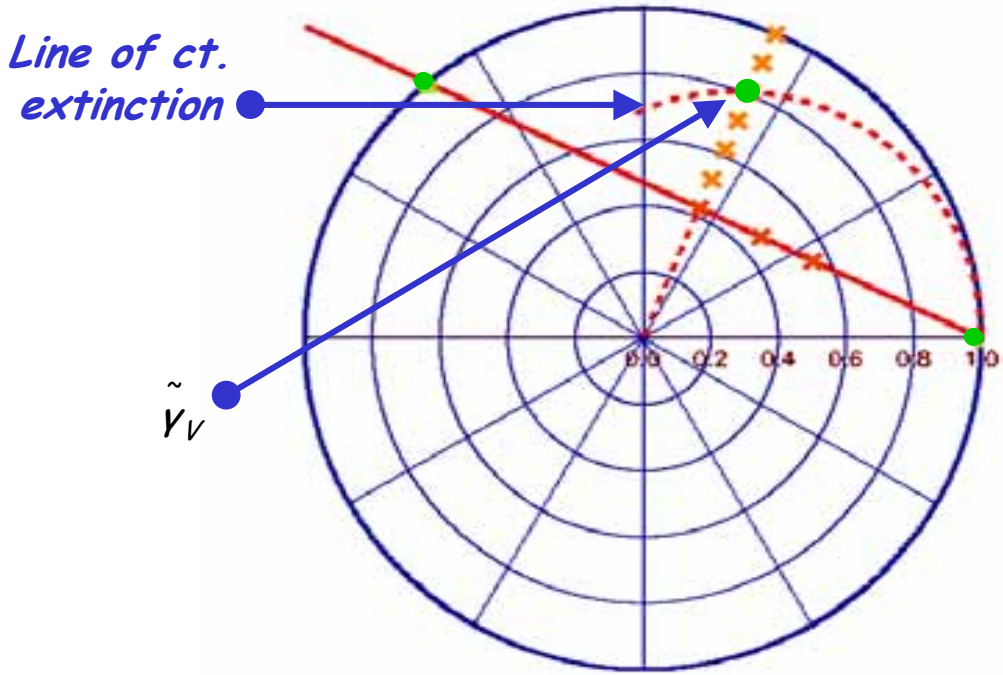
Temporal Decorelation of the Volume Scatterer

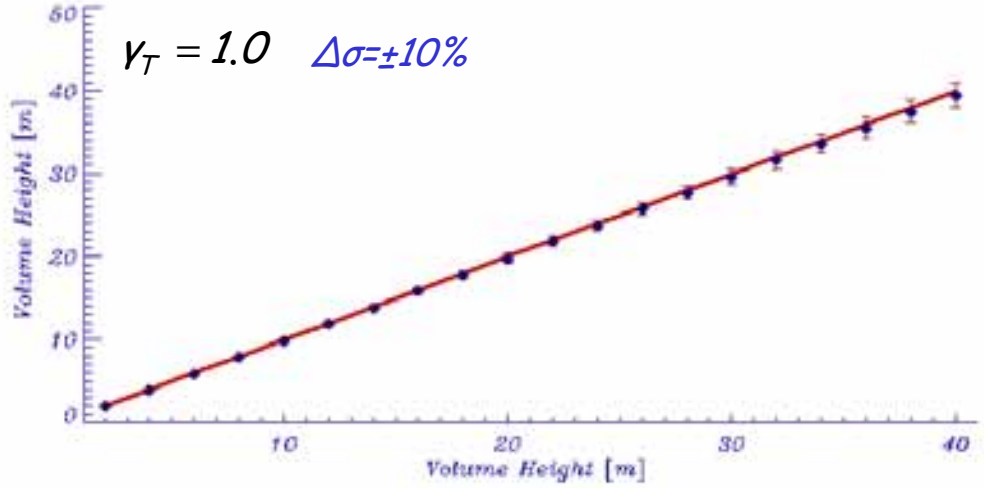


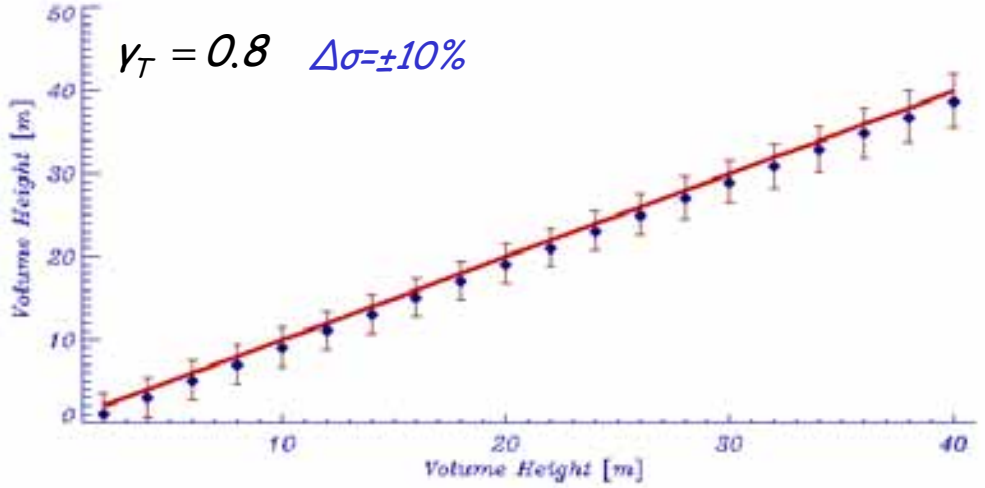


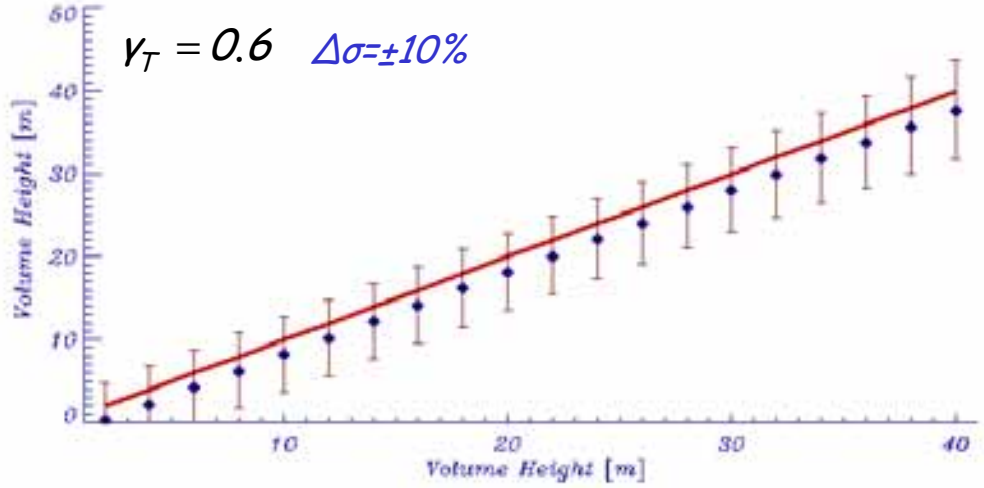
Volume Height Estimation:

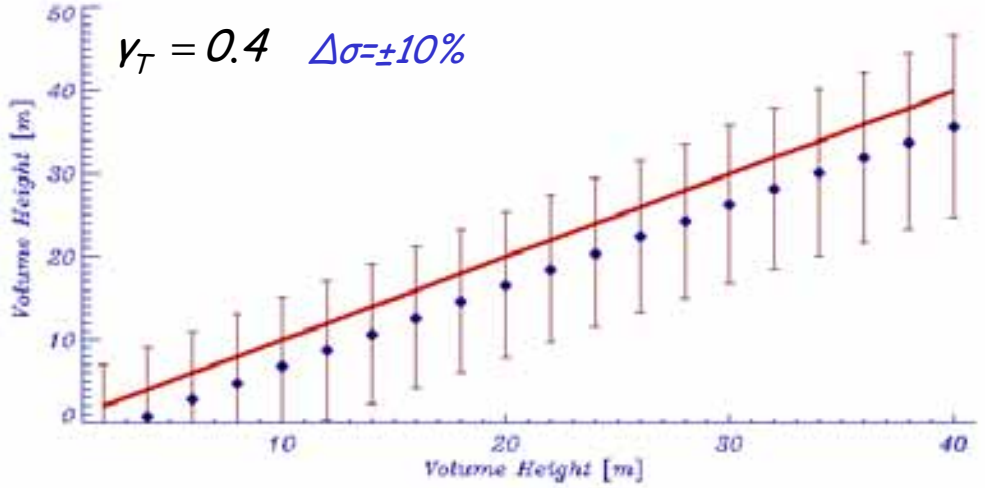
- *Assumption of the mean extinction value σ*
- *Estimate the corresponding* $\tilde{\gamma}_V$ *value* → $\tilde{\gamma}_V = \dfrac{\int_0^{h_V} \exp(i\kappa_z z')\exp\left(\dfrac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'}{\int_0^{h_V} \exp\left(\dfrac{2\,\sigma\,z'}{\cos\theta_0}\right)dz'}$ → h_V

Inversion Performance Analysis



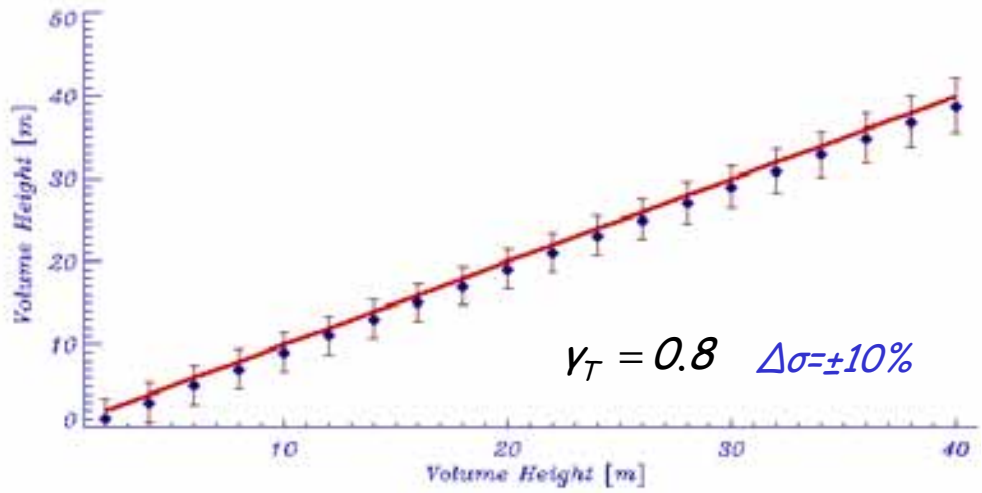


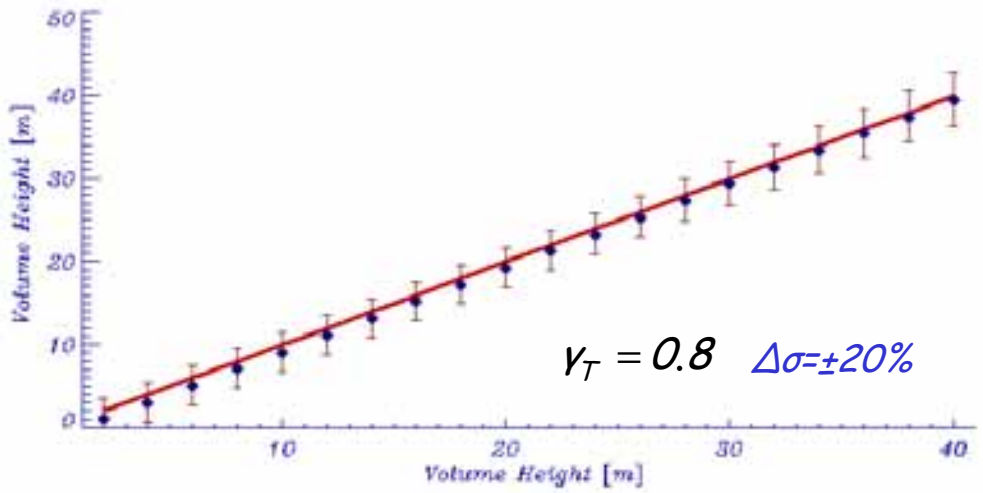


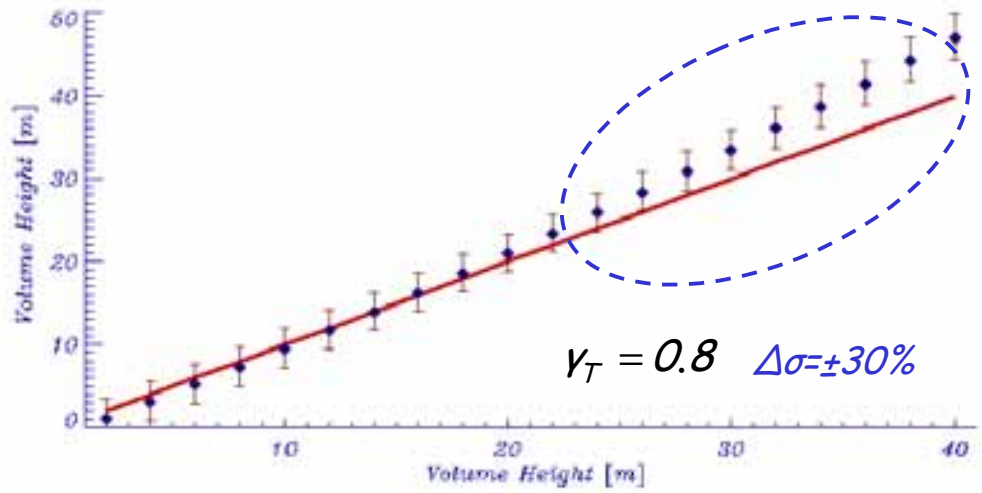


k_z=0.06 (2π-Height~ 100m), Look angle θ=40°, Looks=32

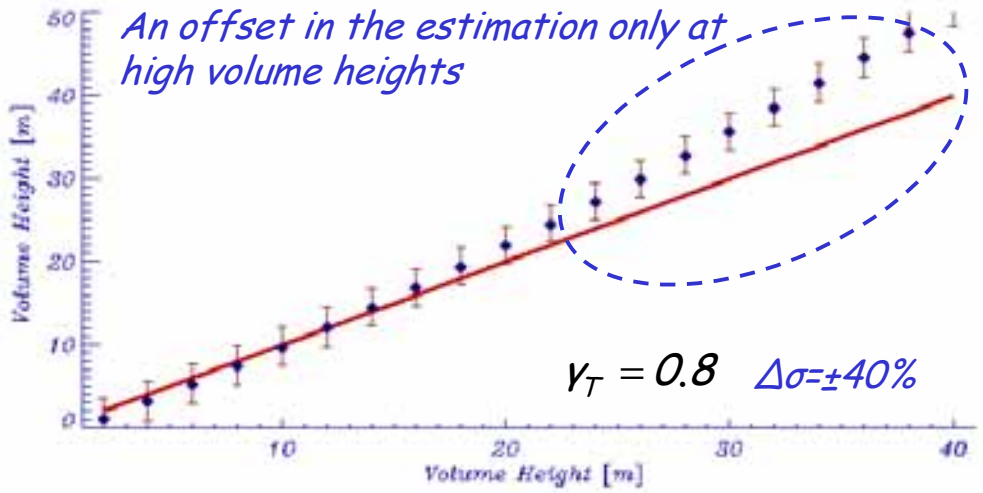
Inversion Performance Analysis







Erroneous extinction values lead to An offset in the estimation only at high volume heights



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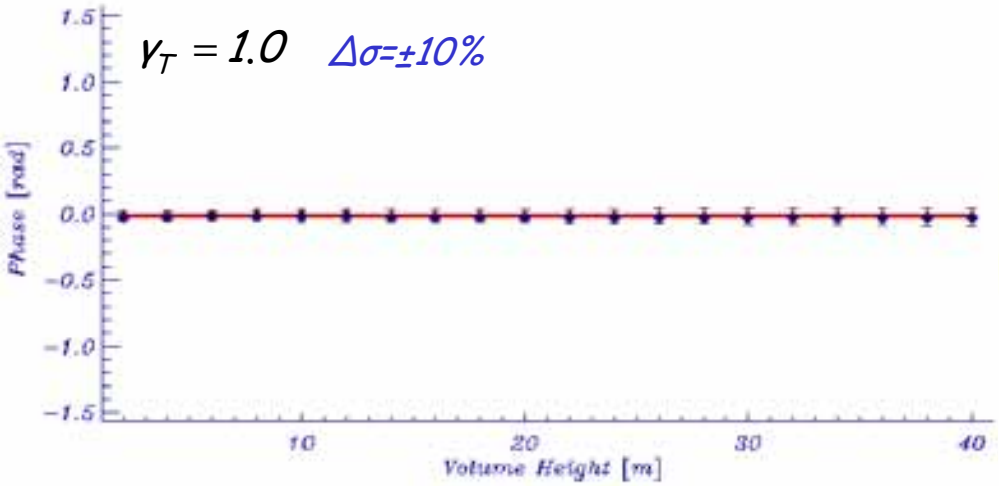
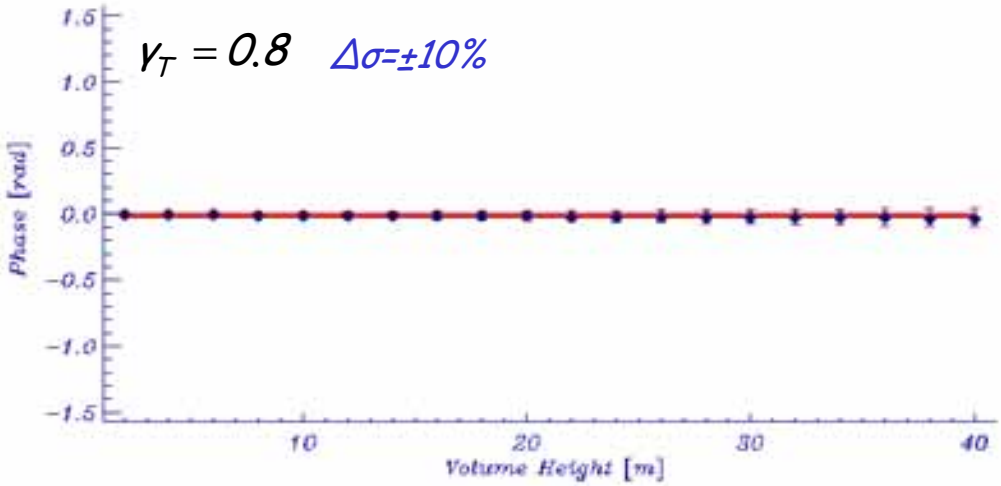
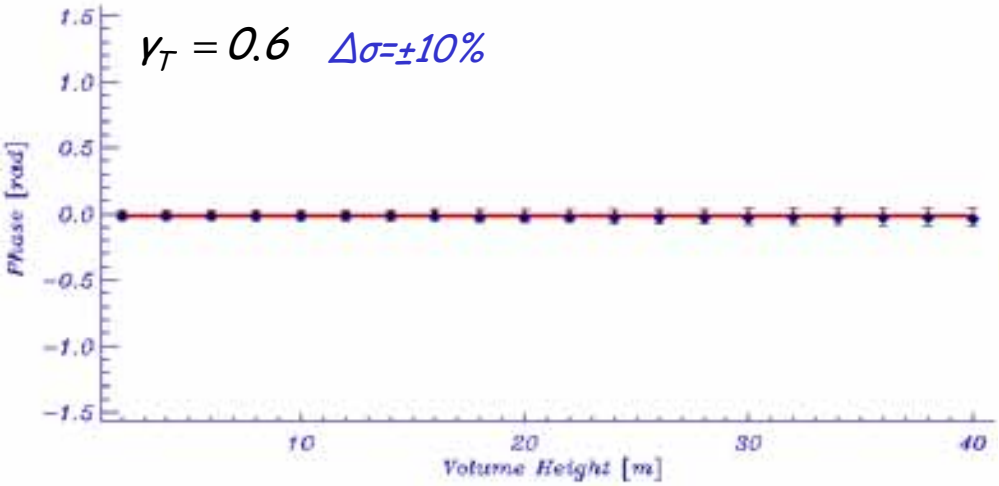
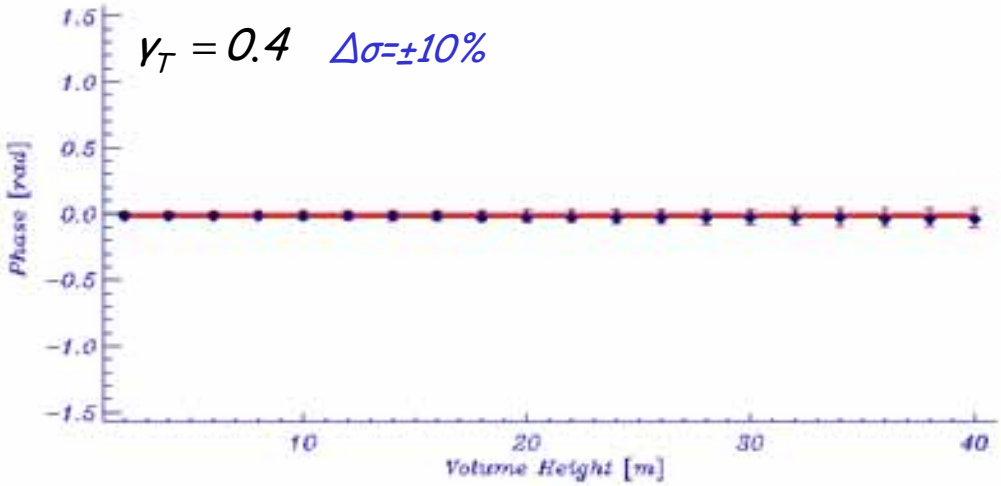








k_z=0.06 (2π-Height~ 100m), Look angle θ=40°, Looks=32

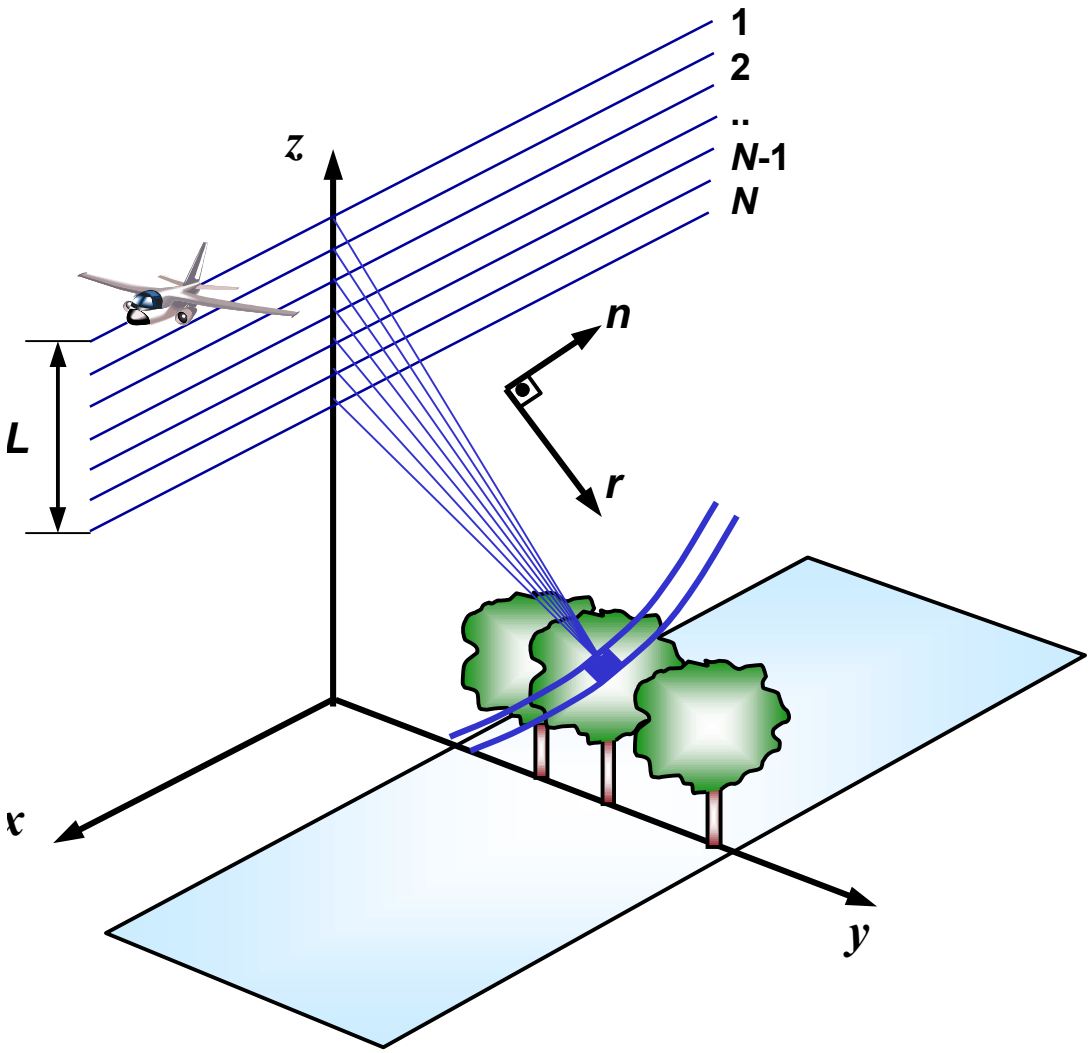
Conclusions

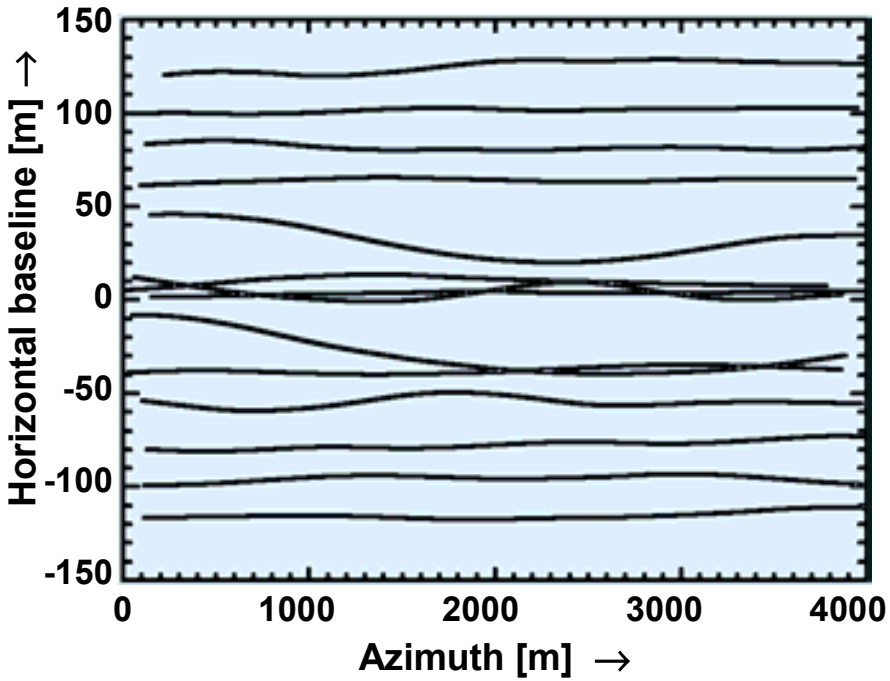
- *Temporal decorrelation makes – in general – accurate parameter inversion impossible.*
- *Moderate temporal decorrelation of the volume can be accounted in the RVoG inversion model.*
- *Experimental data demonstrate the validity of the model predictions -The line is preserved !*
- *The temporal decorrelation in the RVoG model cannot be inverted in a unique way without regularisation.*
- *Regularisation by fixing the extinction coefficient is considered as a "widely robust" first approach*
- *The availability of a second temporal / spatial baseline may allow a more flexible / accurate regularisation*

Experimental Airborne SAR: E-SAR

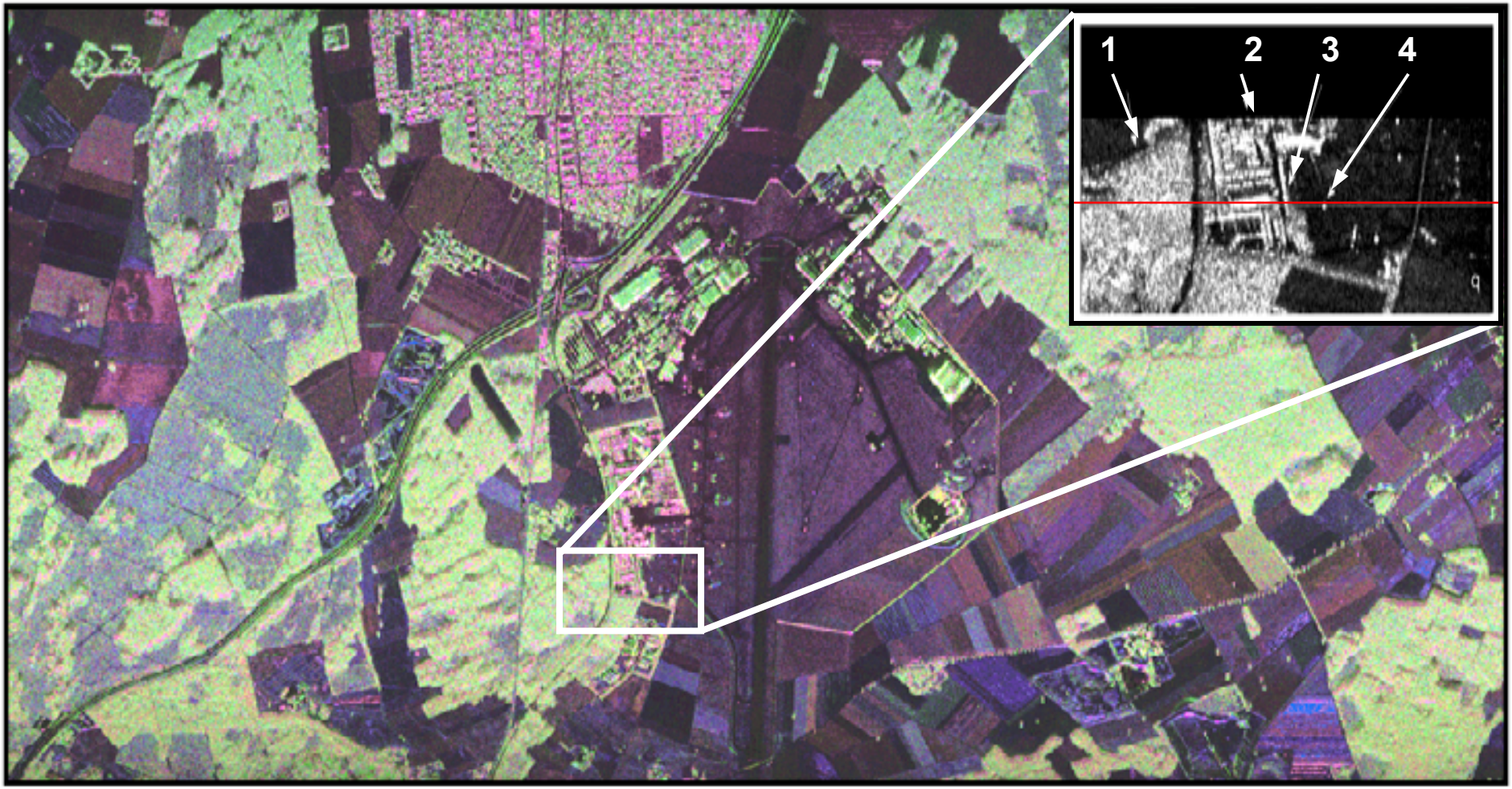
- Flexible multi-channel SAR-System
- P-, L-, S-, C- and X-Band
- Full polarimetric in P- and L-Band
- High-resolution Imaging (up to 0.5 m resolution in azimuth,
- Along- and Across-Track Interferometry
- Real-time SAR Processing
- Innovative Imaging Modes (polarimetric SAR interfero-metry and tomography)

Basic Imaging Geometry for SAR Tomography

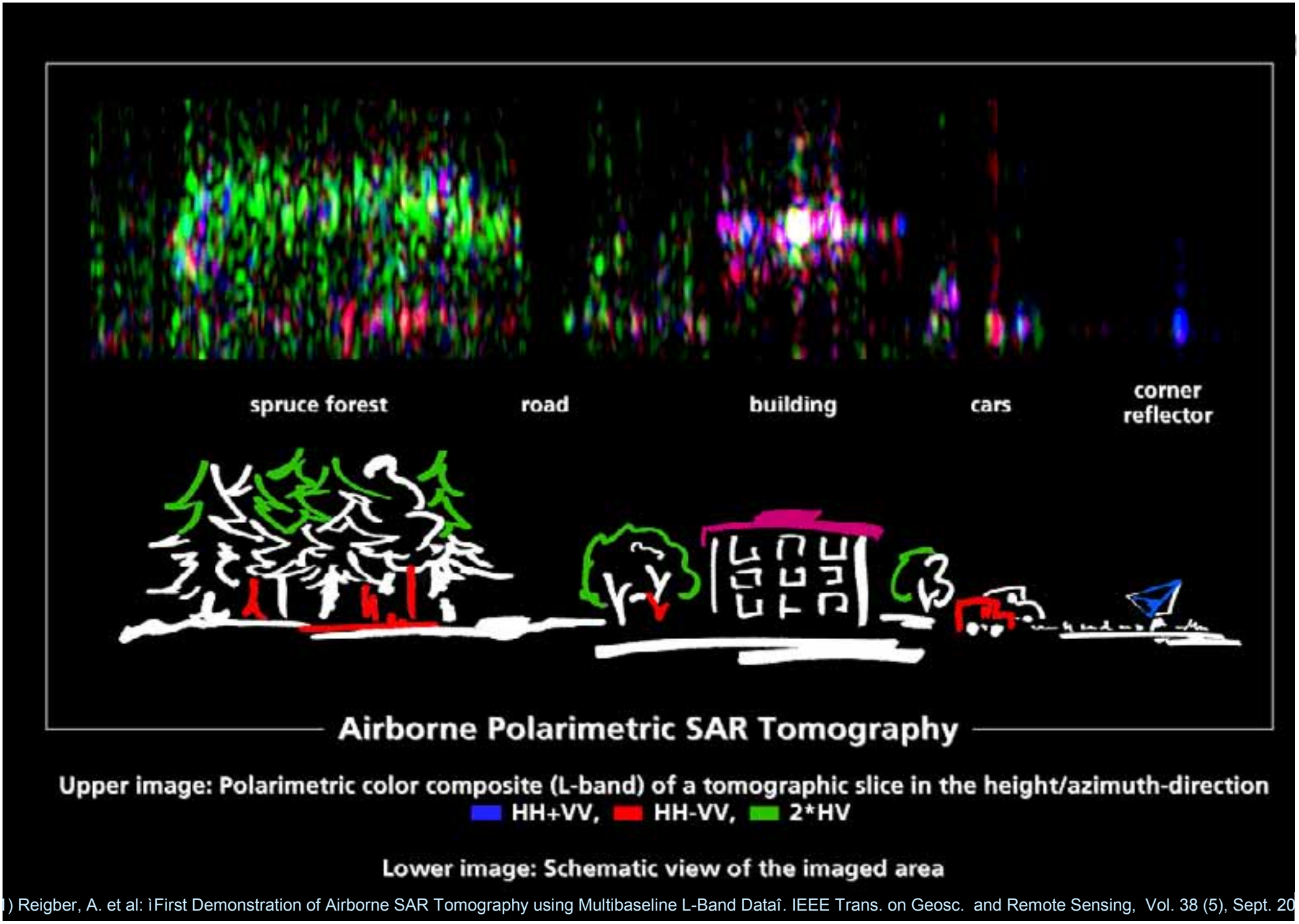




Polarimetric E-SAR Image, L-Band



1) spruce forest
2) buildings
3) cars
4) corner reflector



l) Reigber, A. et al: ìFirst Demonstration of Airborne SAR Tomography using Multibaseline L-Band Dataî. IEEE Trans. on Geosc. and Remote Sensing, Vol. 38 (5), Sept. 20

Spruce Forest Backscattering Profiles (15 - 20 m height)