



P-Band SAR Tomography of the Remningstorp Forest Site*

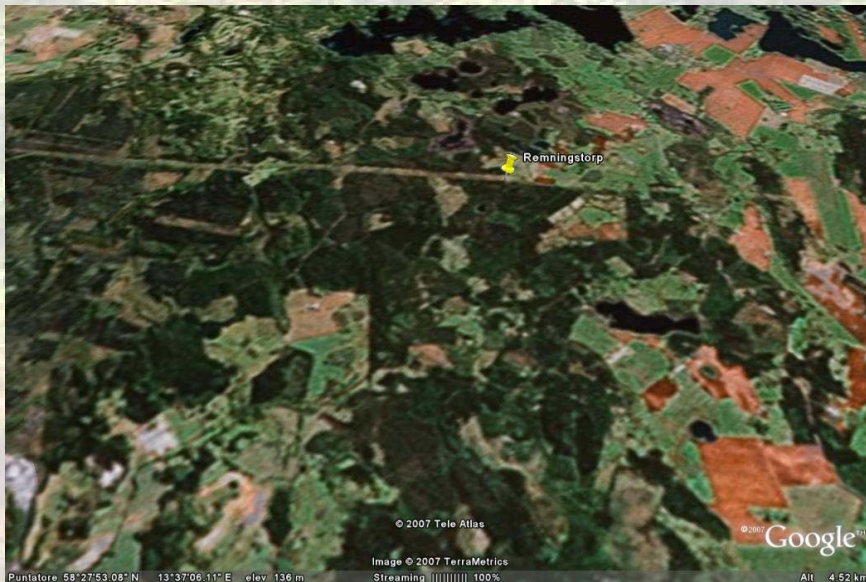
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* This work has been developed as a part of the ESTEC contract 20755/07/NL/CB (BioSAR)

The Remningstorp forested area

- The forest area of Remningstorp, mid south Sweden, has been the object of thorough SAR analyses, conducted in the framework of the ESA campaign BioSAR 2007
 - Boreal like forest; Tree heights up to 30 m; Diameter at breast height ranges from 10 to 50 cm
 - The area is fairly flat with variations between 120 and 145 m above the sea level
- 9 P-Band fully polarimetric airborne SAR images* available for SAR Tomography
 - Slant range resolution in the order of 3 m
 - 80 m horizontal baseline aperture
 - Azimuth resolution in the order of 1 m
 - acquisitions from March to May 2007



* Image acquisition, focusing, and co-registration performed by the German Aerospace Center (DLR)

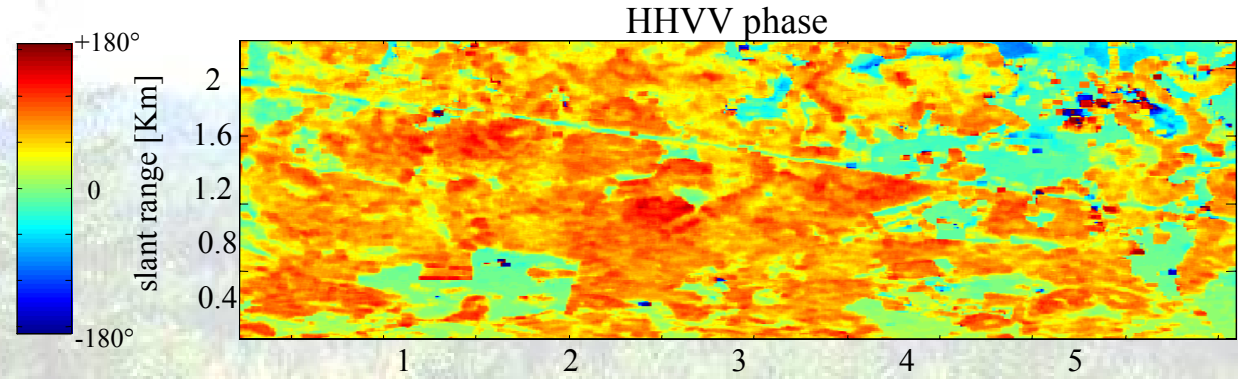
Preliminary analysis

HHVV coherence

- Phase:

Forest: $\varphi_{HH} - \varphi_{VV} \approx 80^\circ$

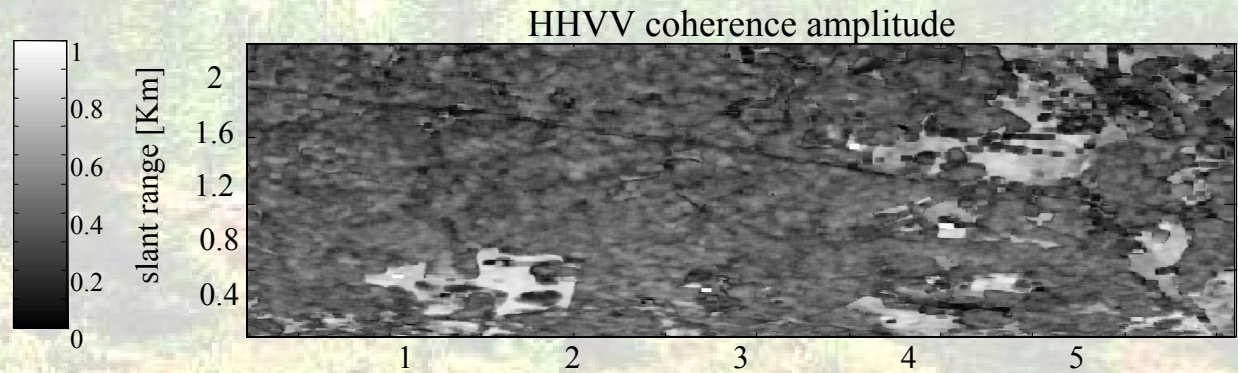
Open areas: $\varphi_{HH} - \varphi_{VV} \approx 0^\circ$



- Amplitude:

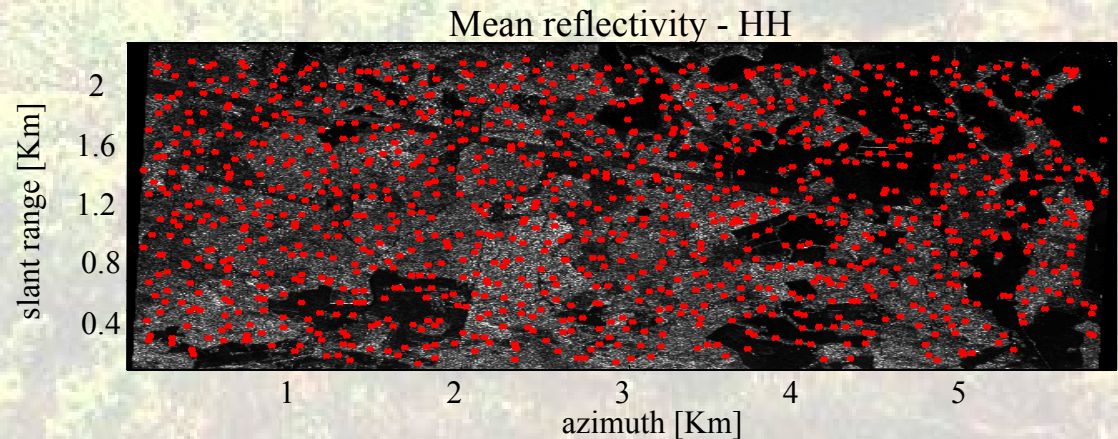
Forest: $|\gamma_{HHVV}| \approx 0.45$

Open areas: $|\gamma_{HHVV}| \approx 0.8$



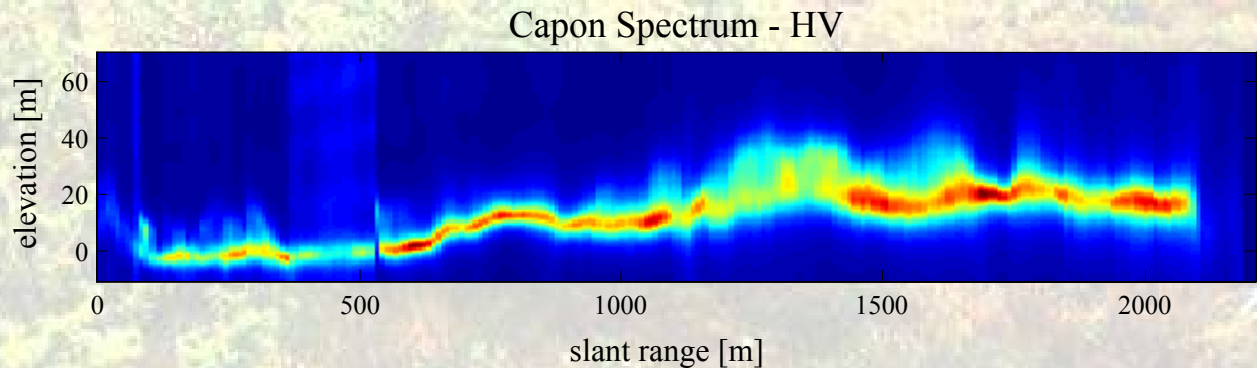
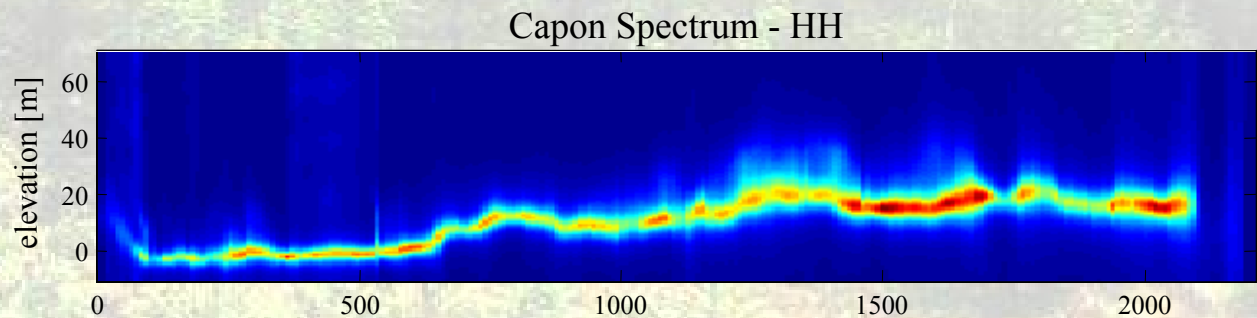
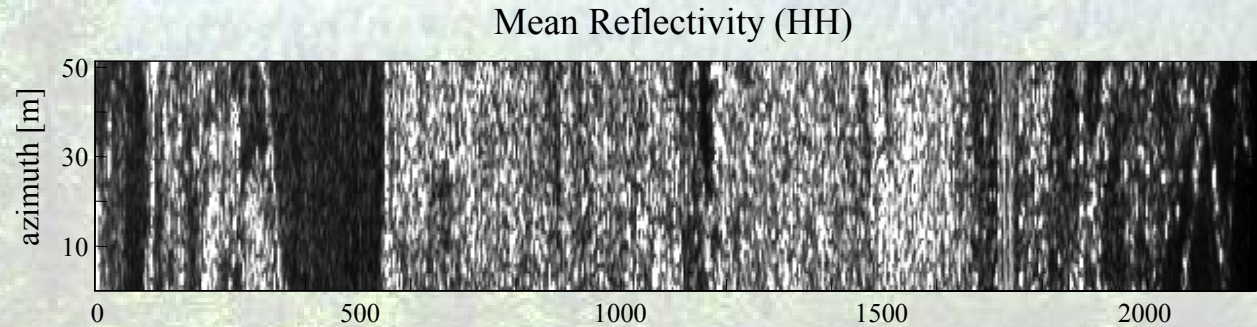
Amplitude Stability Analysis

- Presence of a high number of amplitude stable points in the co-polar channels



Non Parametric Tomographic Analysis

- Evaluation of the Capon Spectra in each polarization
- The analyzed area is almost totally forested, except for the dark areas
- HH:
 - Dominant phase center is ground locked
 - Vegetation is barely visible
- Similar conclusions may be drawn for the VV channel
- HV:
 - Dominant phase center is ground locked as well (!)
 - Vegetation is slightly visible



Discussion



To sum up:

- Amplitude and phase HHVV coherence losses w.r.t. the ideal dihedral case
- Ground locked phase centers in the three polarizations
- Good amplitude stability

These results have been interpreted as follows:

- Scattering from ground level is determined by an imperfect dihedral contribution from ground-trunk interactions, perturbed by understory and topography oscillations

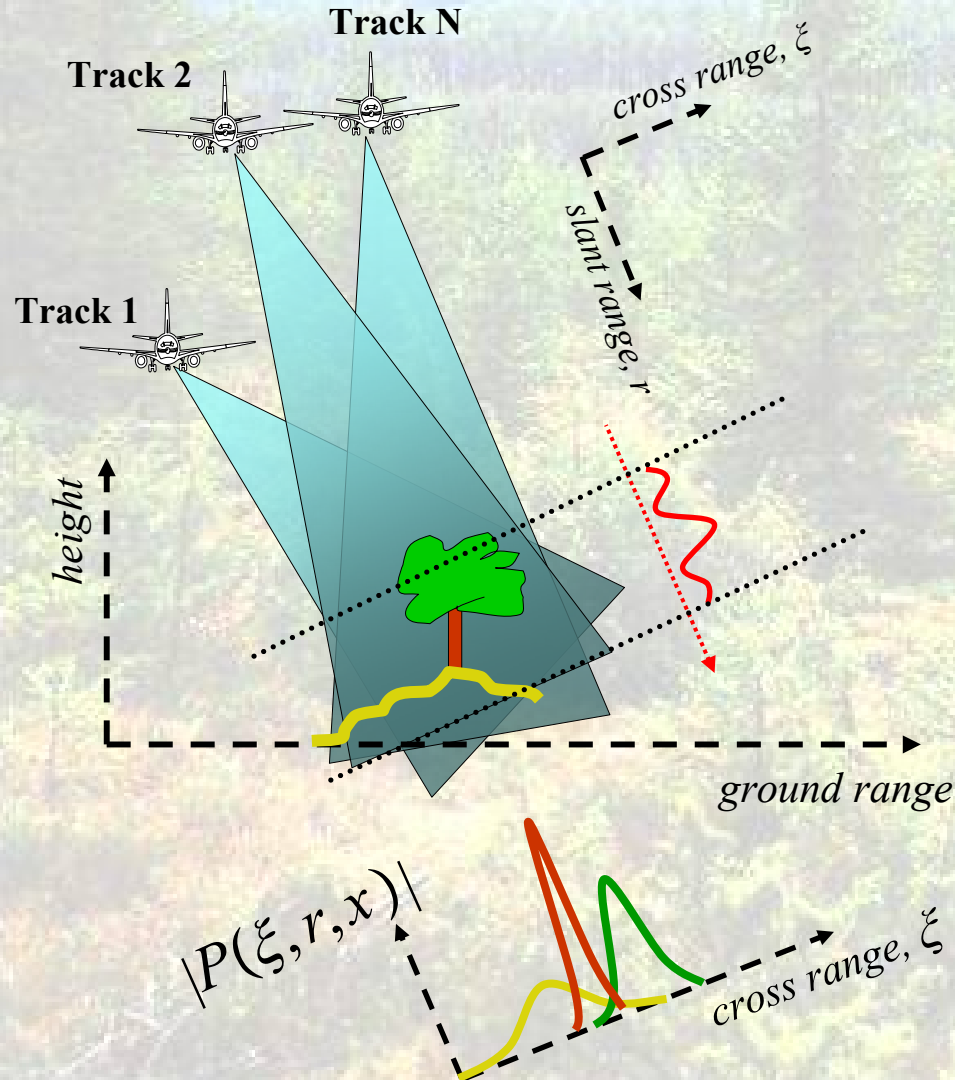
Possible presence of canopy-ground interactions

- Scattering from above the ground, due to canopy backscattering, is extremely weak

Can Model Based SAR Tomography help better characterize the Remningstorp site by providing quantitative arguments?

Problem Statement

Development of a model based SAR Tomography (T-SAR) algorithm for the characterization of the forest structure through multi-baseline PolINSAR data



Mathematical Model

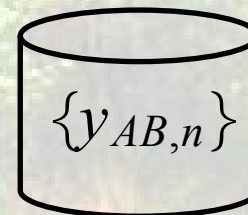
$$y_{AB,n}(r, x) = \int P_{AB}(r, x, \xi) \exp\left(j \frac{4\pi}{\lambda r} b_n \xi\right) d\xi$$

$y_{AB,n}(r, x)$: SLC SAR image at slant range, azimuth location (r, x) in the AB channel

b_n : normal baseline for the n-th image

$P_{AB}(r, x, \xi)$: projection of target reflectivity within the slant range resolution cell along the cross range coordinate, ξ , in the AB channel

Inversion



Ground properties
Canopy properties

Problem Statement

Four possible scattering mechanisms (SMs) from forested areas:

Back scatter from the canopy

- Distributed SM – scattered power is spread along the cross range axis (angular spreading)
- Phase center is located above the ground, depending on canopy elevation

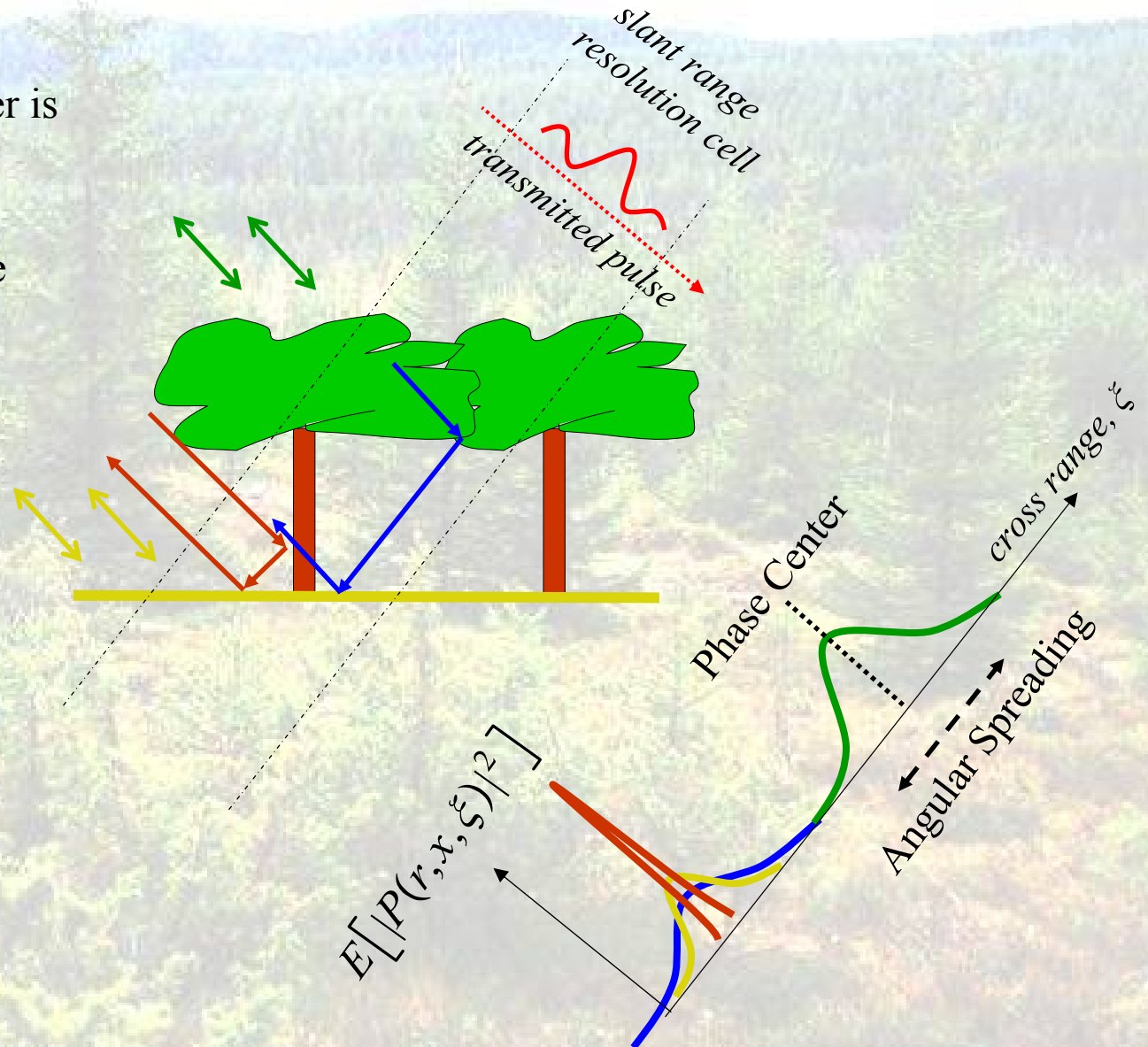
Back scatter from the ground

- Distributed SM
- Phase center is ground locked

Double bounce forward scatter

- **trunk - ground**, **canopy - ground** interactions
- **Point (distributed)** SM
- Phase center is ground locked

These SMs are supposed to be independent of each other



Problem Statement

The concepts of phase center and angular spreading constitute an attractive model for the characterization of the spatial structure of each SM

- Simplicity: only two unknowns per target
- Generality: the model is capable of representing a wide range of targets

Problem inversion is posed in the following terms:

- identification of bald and forested areas
- estimation of target elevation (q_k) and decorrelation constant (ρ_k) for each detected target
- estimation of the polarimetric signature for each detected target

Inversion Method: Covariance Matching Estimation Technique (COMET)

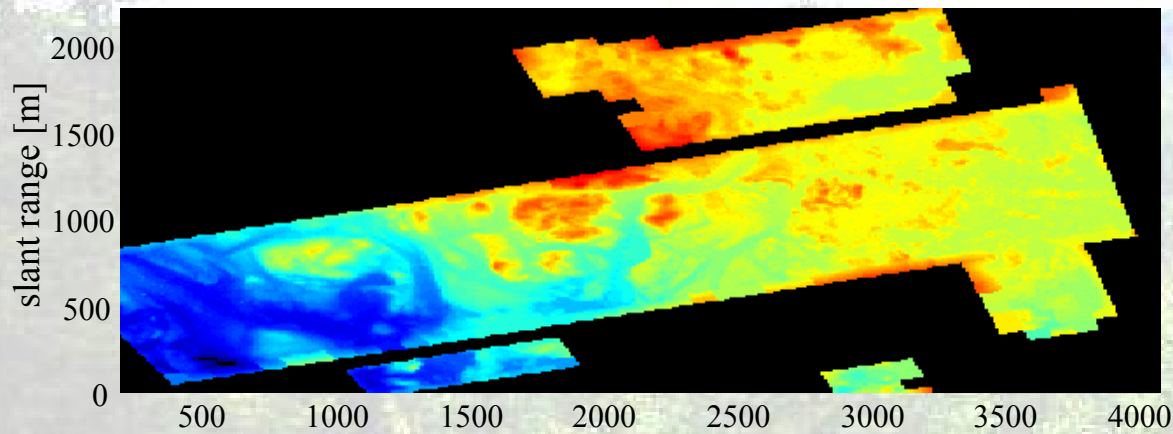
- Asymptotically equivalent to Maximum Likelihood estimation
- **The estimates of the polarimetric signatures are obtained in closed form**
- Requires proper initialization and constraints

A wide-angle photograph of a dense forest landscape. The foreground shows a mix of green and brownish trees, possibly indicating a transition or a specific forest type. The middle ground is filled with a thick canopy of green trees, and the background shows rolling hills under a bright, slightly hazy sky.

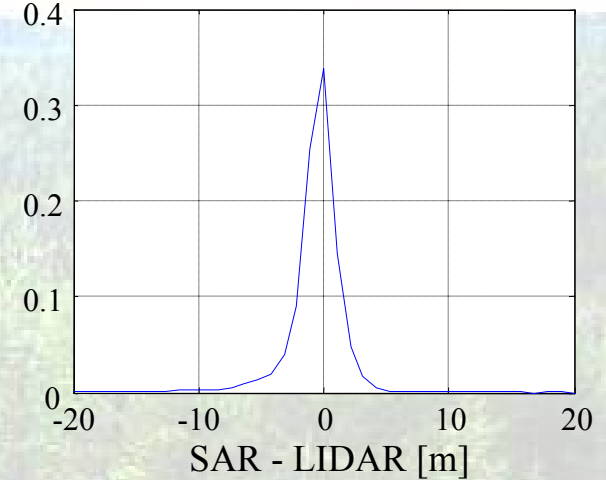
Model based SAR Tomography of the Remningstorp Forest Site: Results

Elevation Estimates

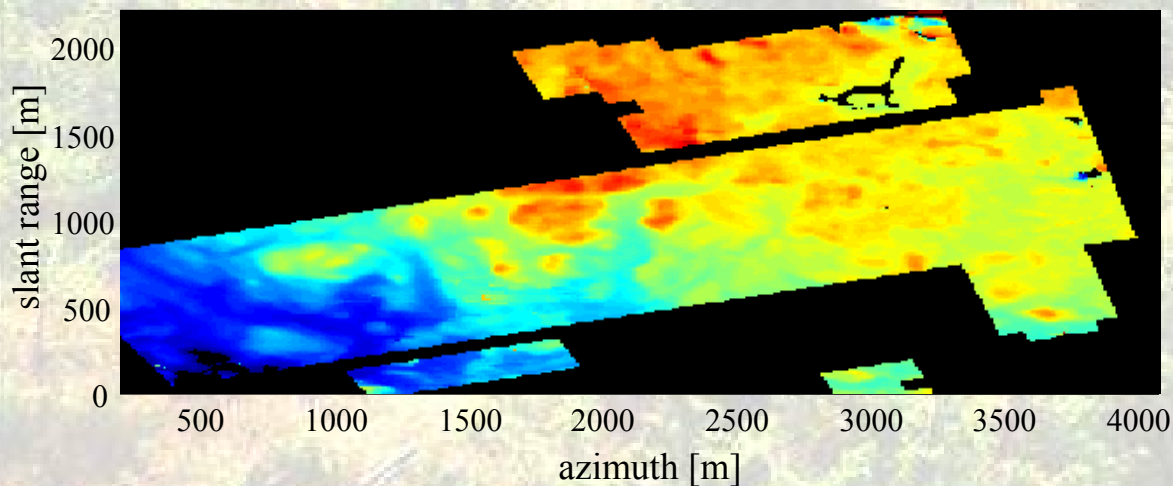
LIDAR: Ground Elevation



Histogram



SAR: Ground Elevation



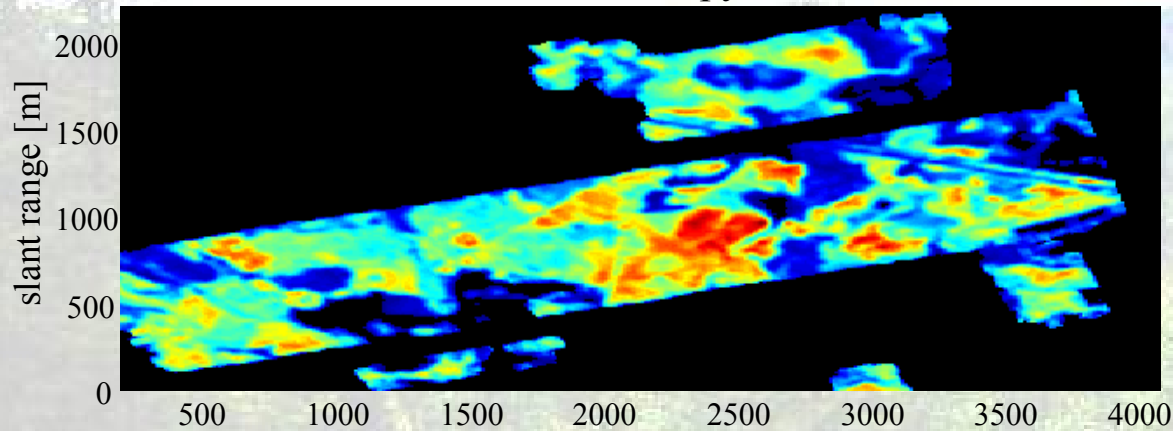
Remarks:

- Very good agreement
 $\sigma_{SAR-LIDAR} \approx 1 \text{ m}$
- Black areas correspond to totally incoherent targets, such as small lakes

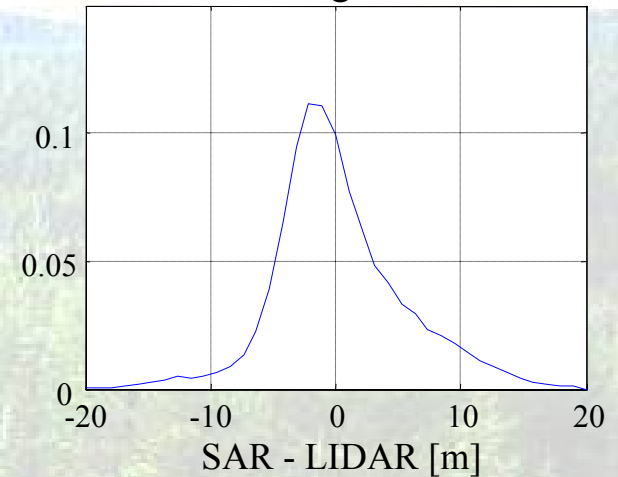
(* LIDAR Elevation Estimates provided by the Swedish Defence Research Agency (FOI)

Elevation Estimates

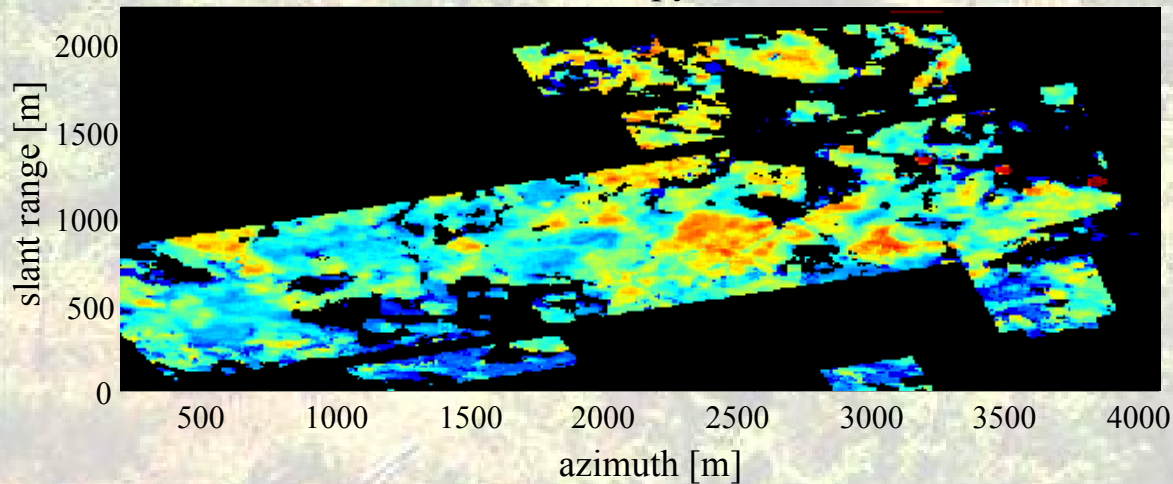
LIDAR: Canopy Elevation



Histogram



SAR: Canopy Elevation



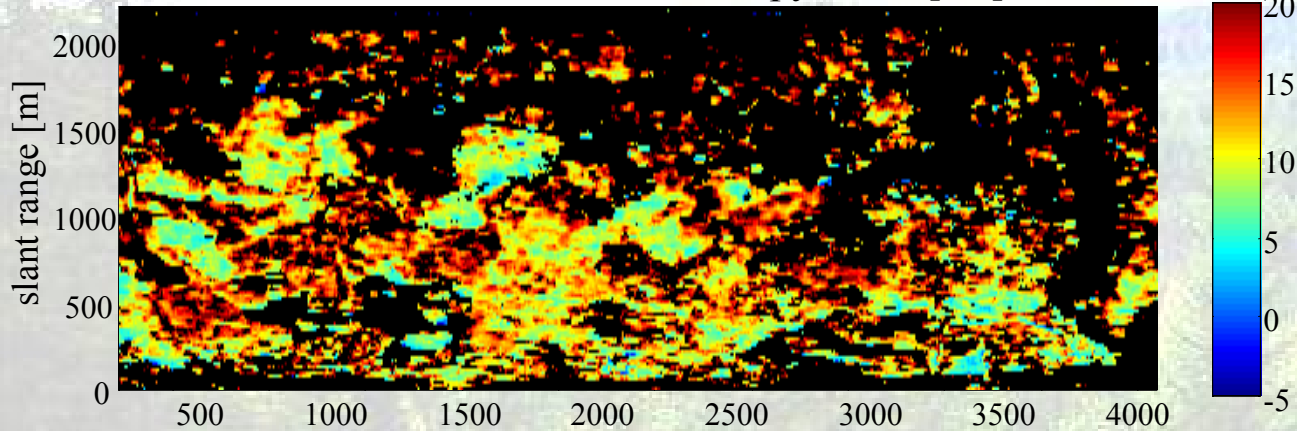
Remarks:

- Good overall agreement between canopy top heights (LIDAR) and phase centers (P-Band SAR)
- Black areas correspond to absence of vegetation above the ground

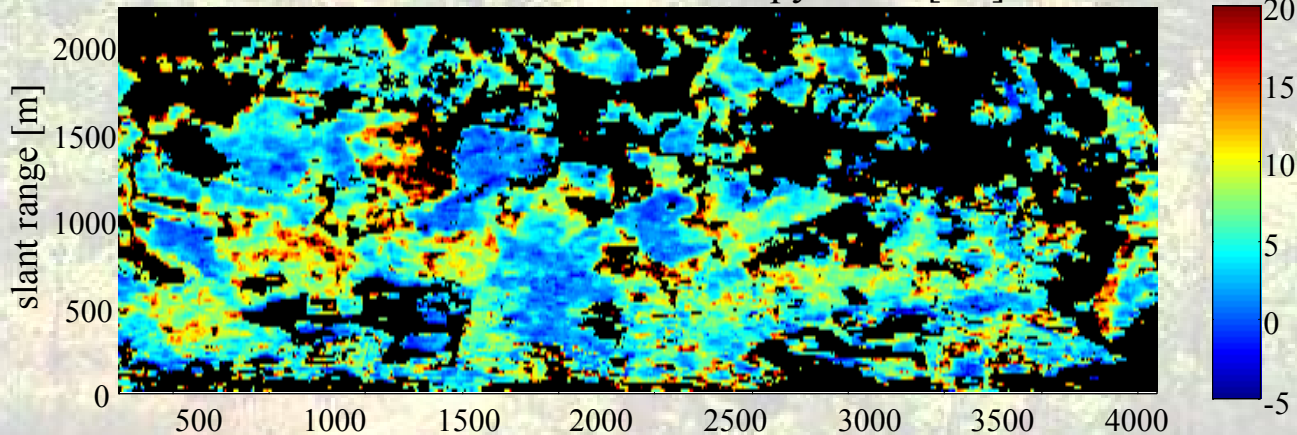
(* LIDAR Elevation Estimates provided by the Swedish Defence Research Agency (FOI)

Backscattered Power Estimates

HH – Ground to Canopy Ratio [dB]



HV – Ground to Canopy Ratio [dB]



Remarks:

- In the HH and VV channels contributions from ground level dominates that from canopy level by about 10 dB

Interpretation:

Relevant ground-trunk interactions

- Contributions from ground level are dominant also in the HV channel.

Interpretation:

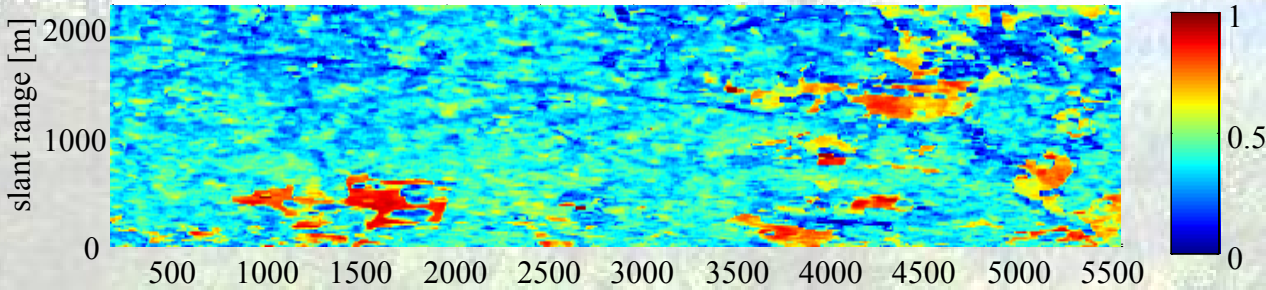
Weak canopy backscattering

Canopy-ground interactions

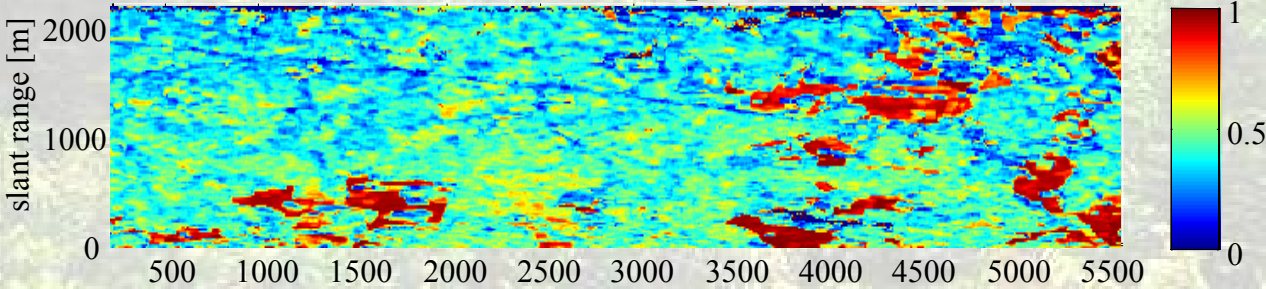
Ground-trunk interactions due to topography oscillations and understory

HHVV coherence estimates

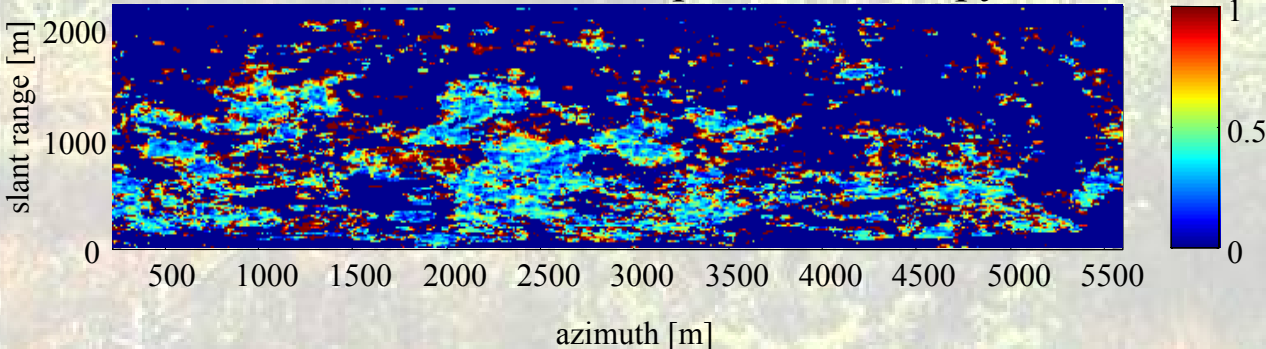
HHVV coherence amplitude – Original data



HHVV coherence amplitude – Ground



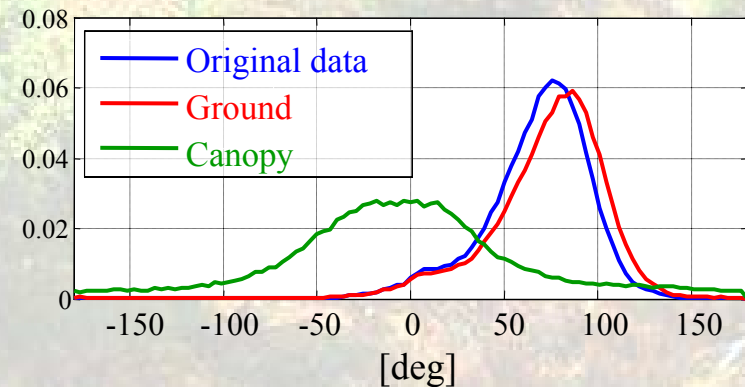
HHVV coherence amplitude – Canopy



Remarks:

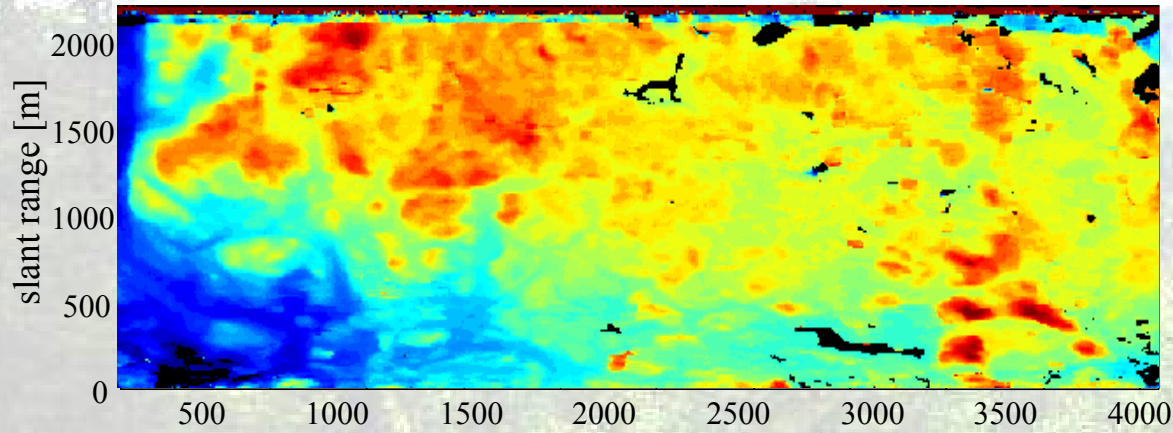
- Ground HHVV coherence has increased throughout the whole scene, witnessing that ground contributions have been actually isolated from the others
- Ground HHVV phase has increased by about 10°

HHVV phase histogram

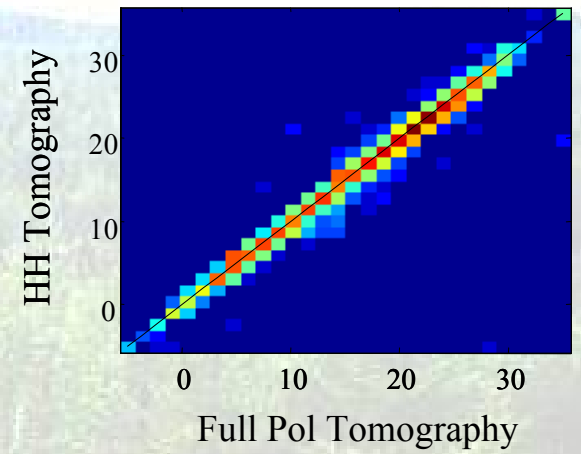


Single Channel Tomography - HH

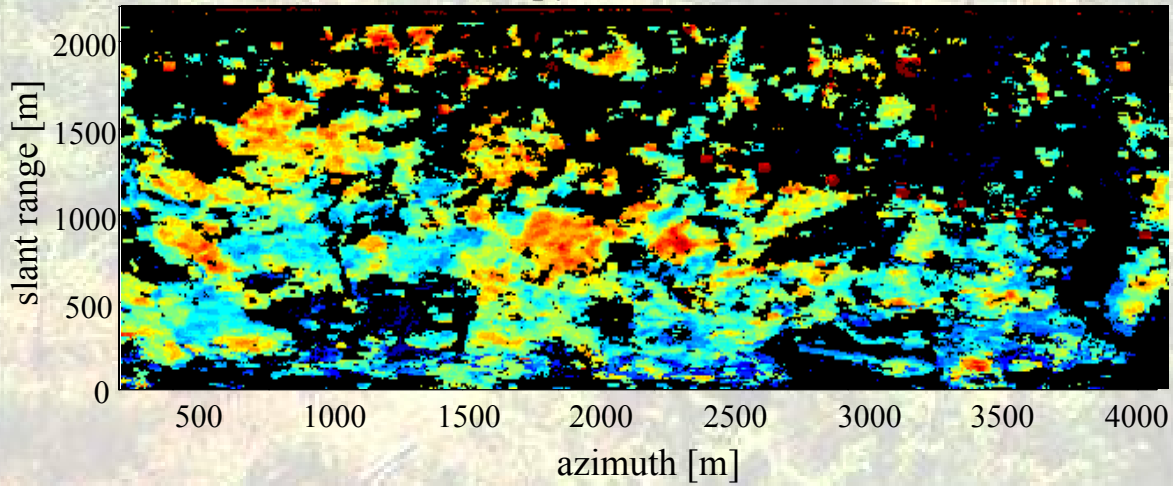
Ground Elevation from HH



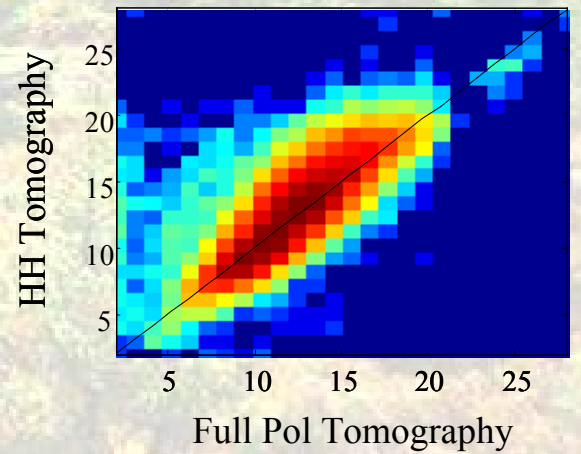
Ground Elevation [m]



Canopy Elevation from HH

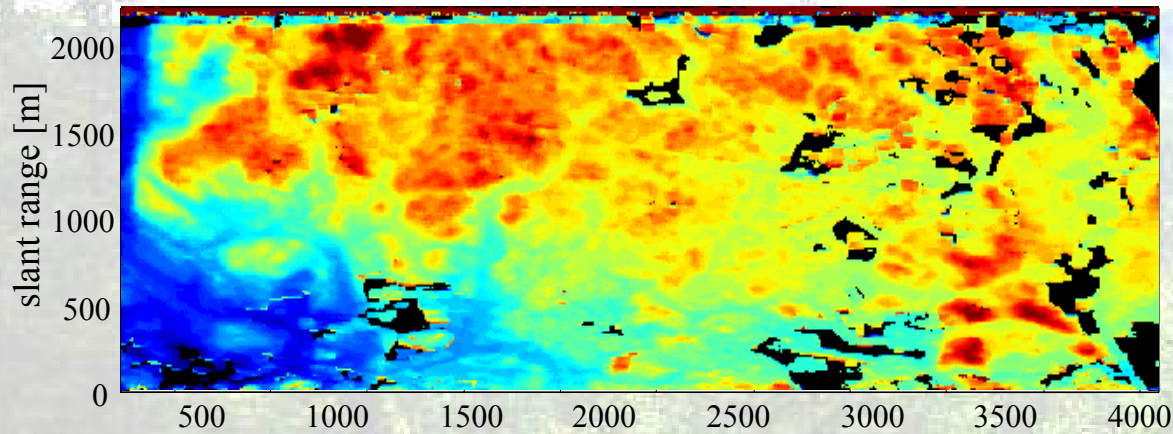


Canopy Elevation [m]

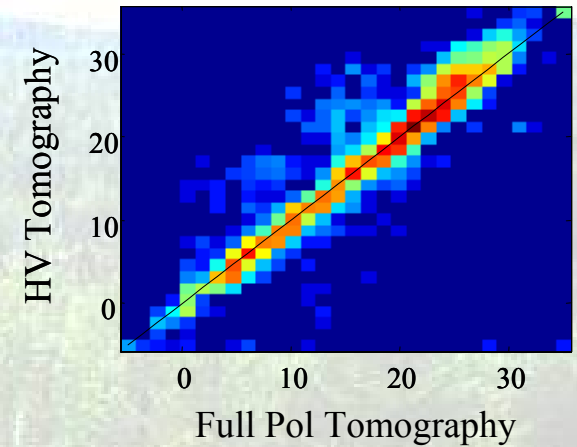


Single Channel Tomography - HV

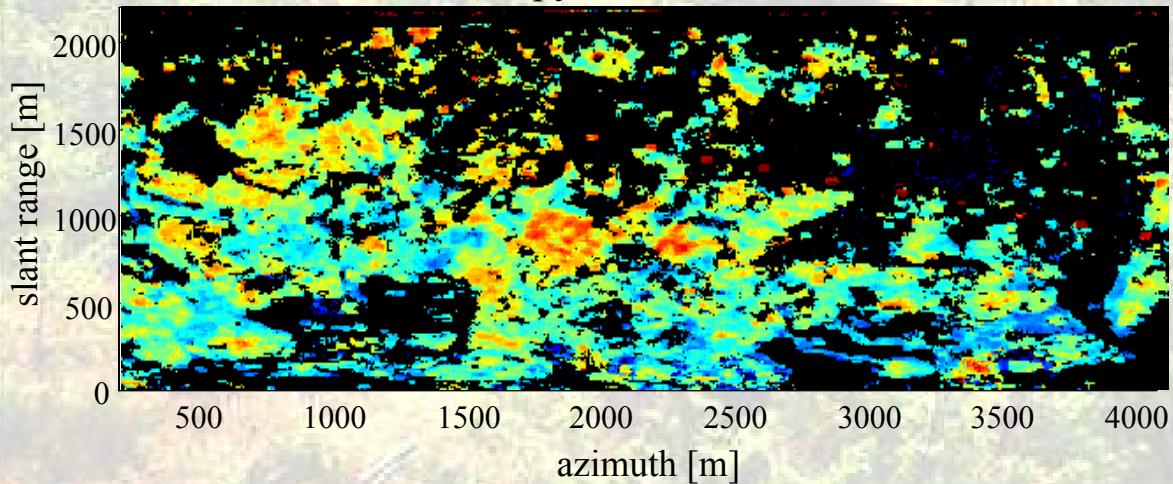
Ground Elevation from HV



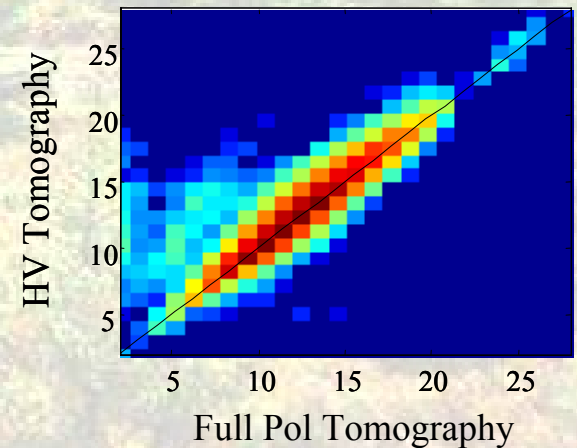
Ground Elevation [m]



Canopy Elevation from HV



Canopy Elevation [m]

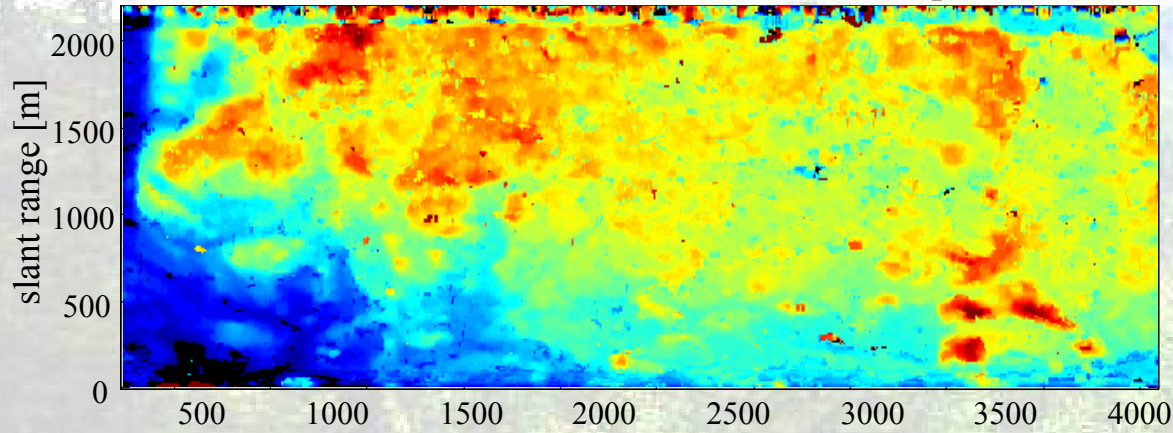


Remarks:

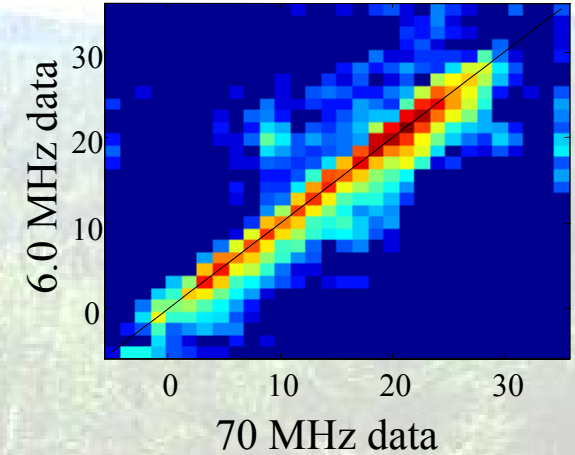
- Many open areas are sensed as noise in HV, consistently with the Small Perturbation Model

6 MHz Tomography

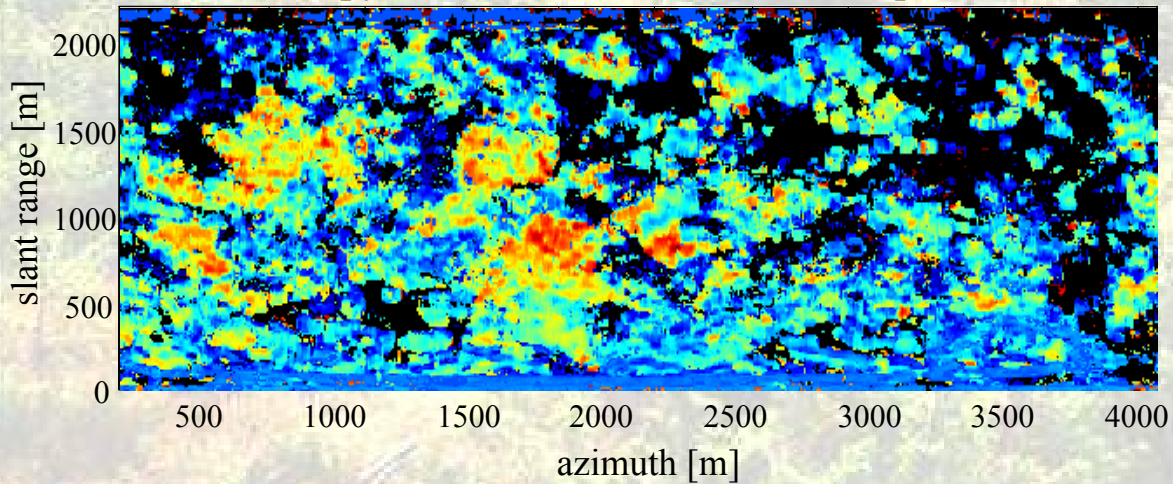
Ground Elevation from 6 MHz – Full pol data



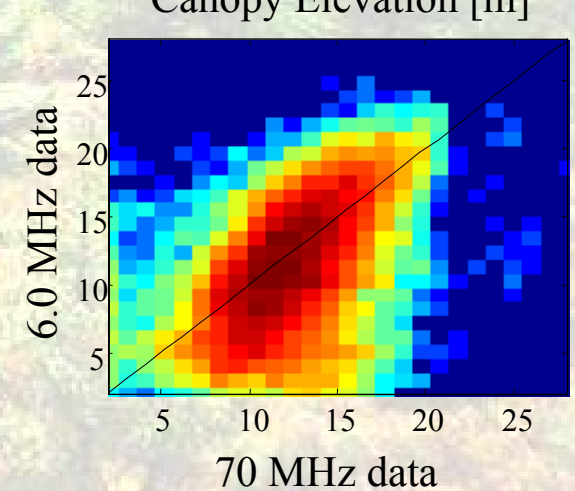
Ground Elevation [m]



Canopy Elevation from 6 MHz – full pol dataHV



Canopy Elevation [m]



Remarks:

- Increased dispersion

Conclusions

About T-SAR

Model based T-SAR has provided the following products:

- Identification of bald and forested areas
- Ground elevation
- Canopy phase center elevation
- Estimation of the polarimetric signatures associated to ground and canopy scattering

All the results have turned out to be consistent with those obtained through non tomographic or non model based techniques

Forest structure retrieval from single-polarimetric data is possible

Forest structure retrieval from 6 MHz data is possible

About the Remningstorp forest site

Contribution from the ground have been shown to dominate those from the canopy not only in the co-polar channels, but also in the cross-polar channel

This result indicates that the Small Perturbation Model and the ideal dihedral scattering model do not provide a sufficient description of the ground contributions under the forest