Forest Characterisation by Means of TerraSAR-X and TanDEM-X Polarimetric Interferometric Data

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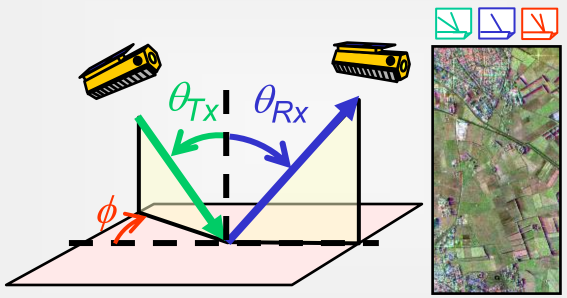
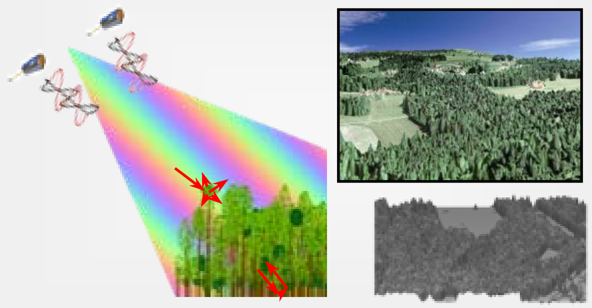
PolInSAR 2011 Workshop
25/01/2011

Secondary Mission Objectives: New Techniques Demonstration

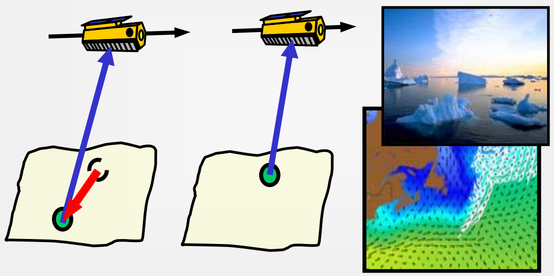
Bistatic SAR Imaging



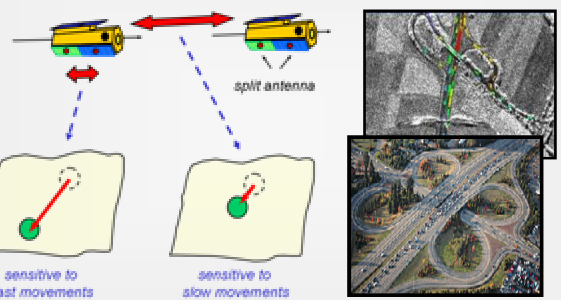
Polarimetric SAR Interferometry



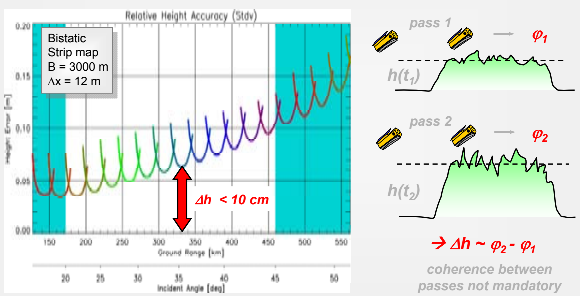
Along-Track Interferometry



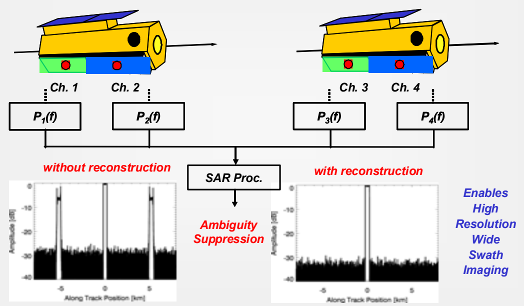
Ground Moving Target Indication



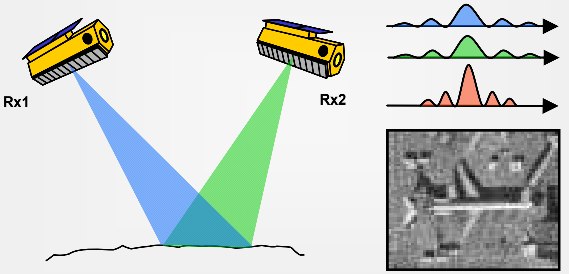
Double Differential Interferometry



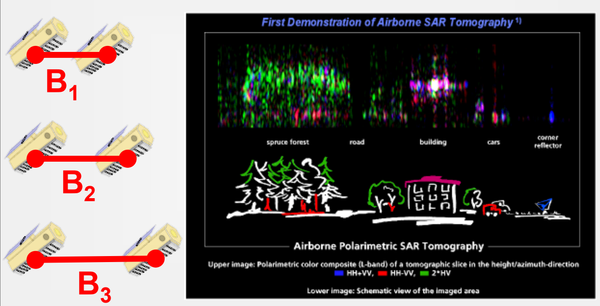
Digital Beamforming



Super Resolution



SAR Tomography



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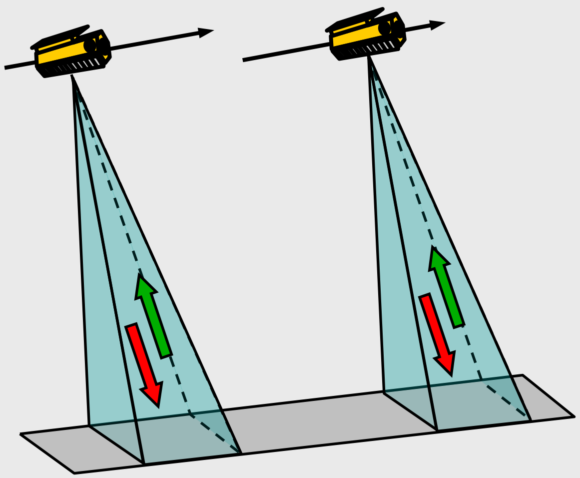
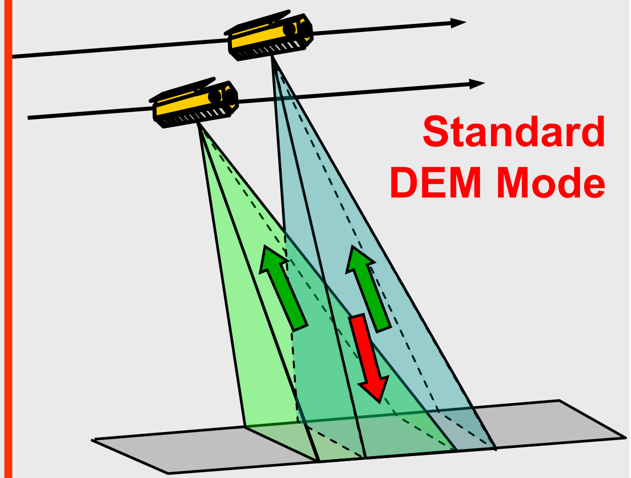
TanDEM-X Data Acquisition Modes

Pursuit Monostatic



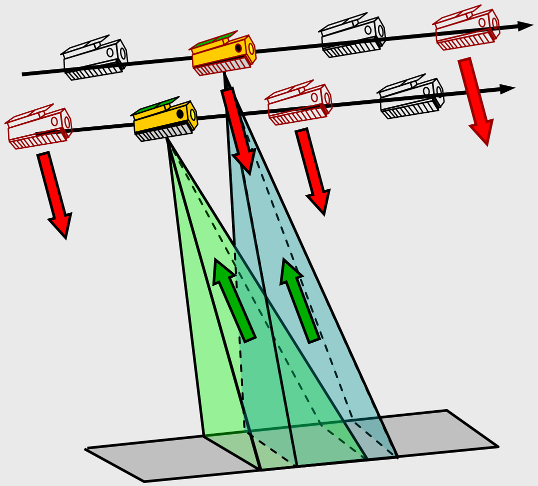
- **both satellites transmit and receive independently**
- susceptible to temporal decorrelation and atmospheric disturbances
- no PRF and phase synchronisation required (backup solution)

Bistatic



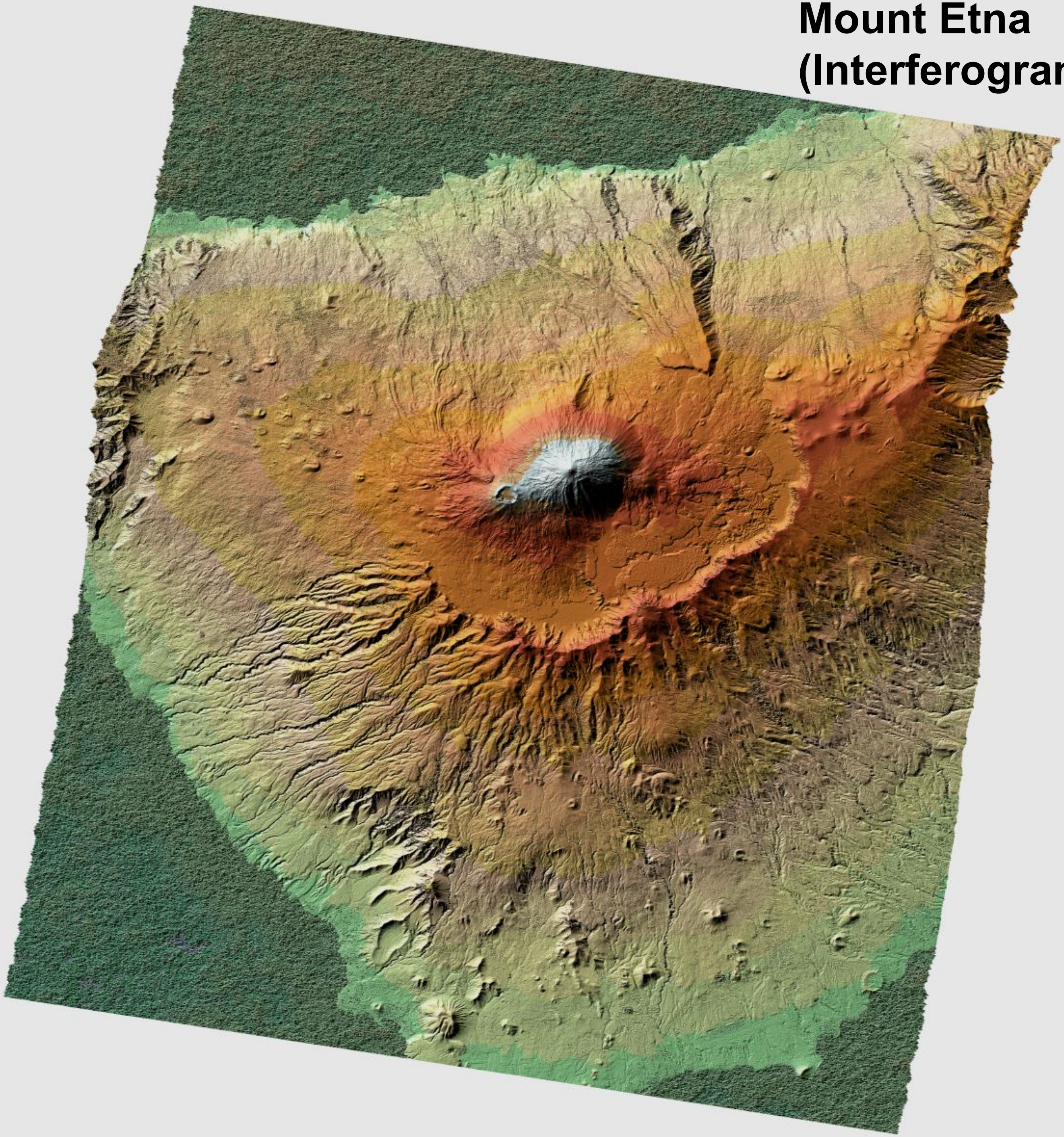
- **one satellite transmits and both satellites receive simultaneously**
- small along-track displacement required for Doppler spectra overlap
- requires PRF and phase synchronisation

Alternating Bistatic

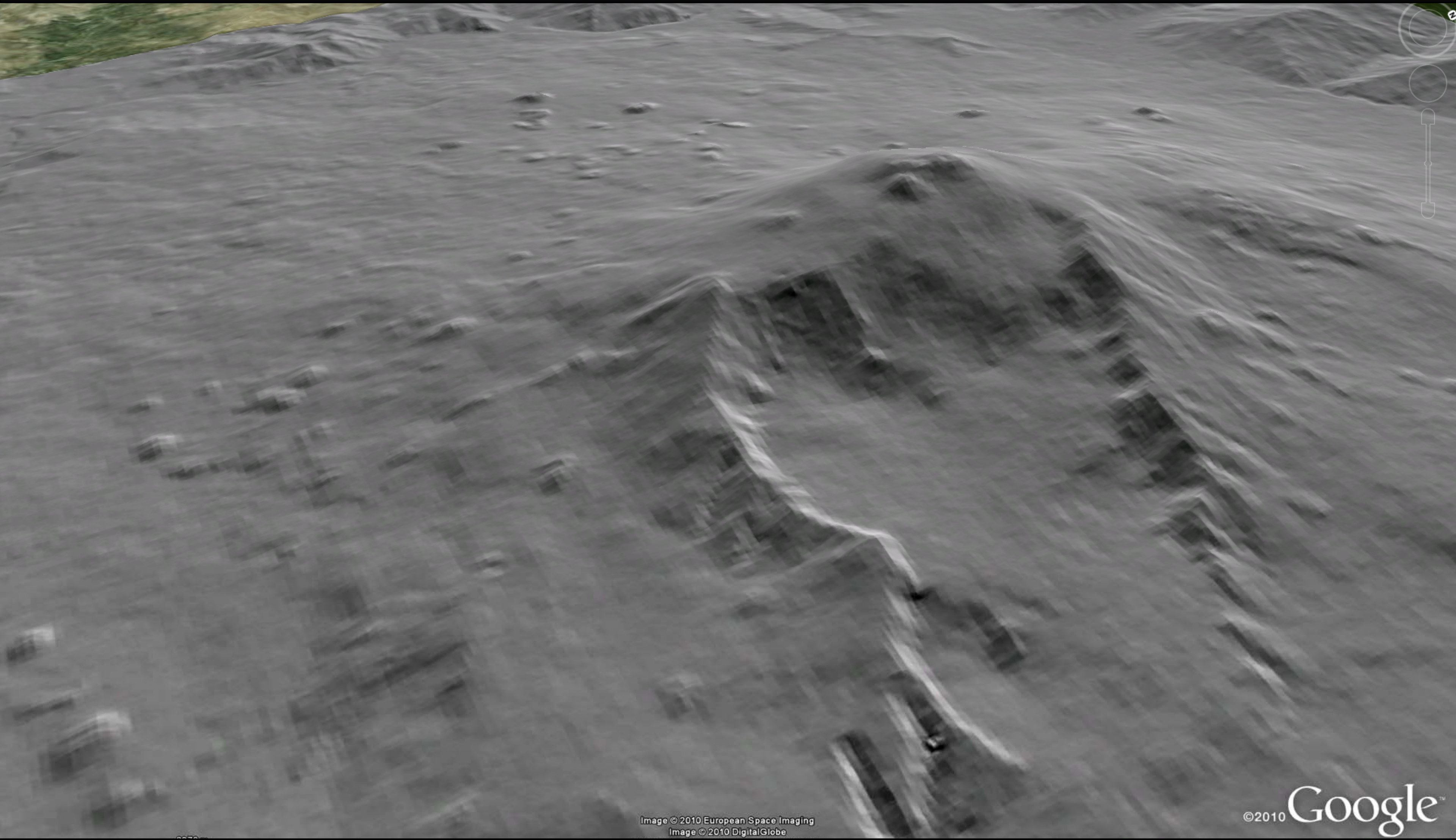


- **transmitter alternates between PRF pulses**
- provides three interferograms with two baselines in a single pass
- enables precise phase synchronisation, calibration & verification

Mount Etna (Interferogram)

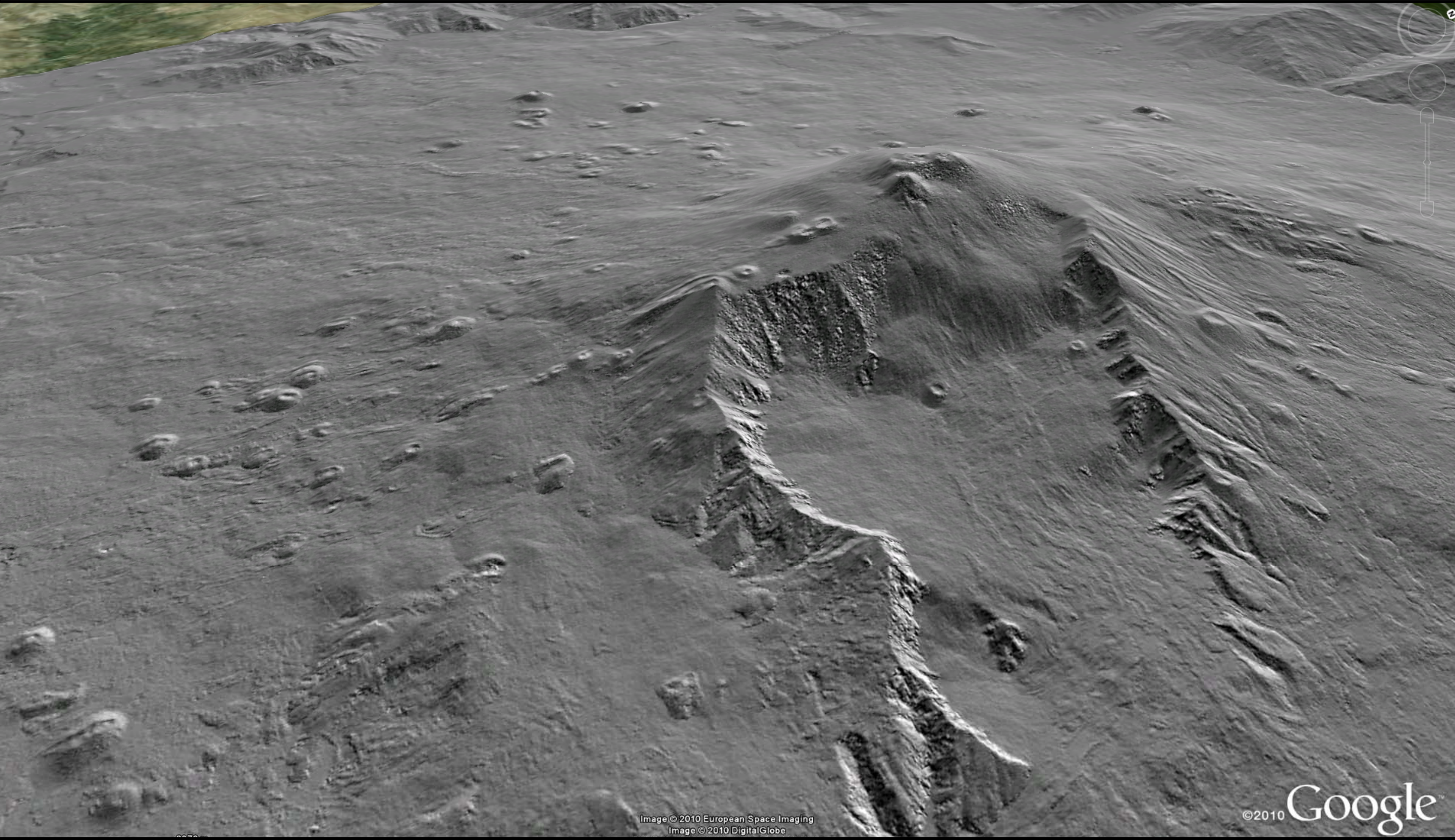


Shuttle Radar Topography Mission - 10 years ago -



DLR

TanDEM-X - Today -



DLR

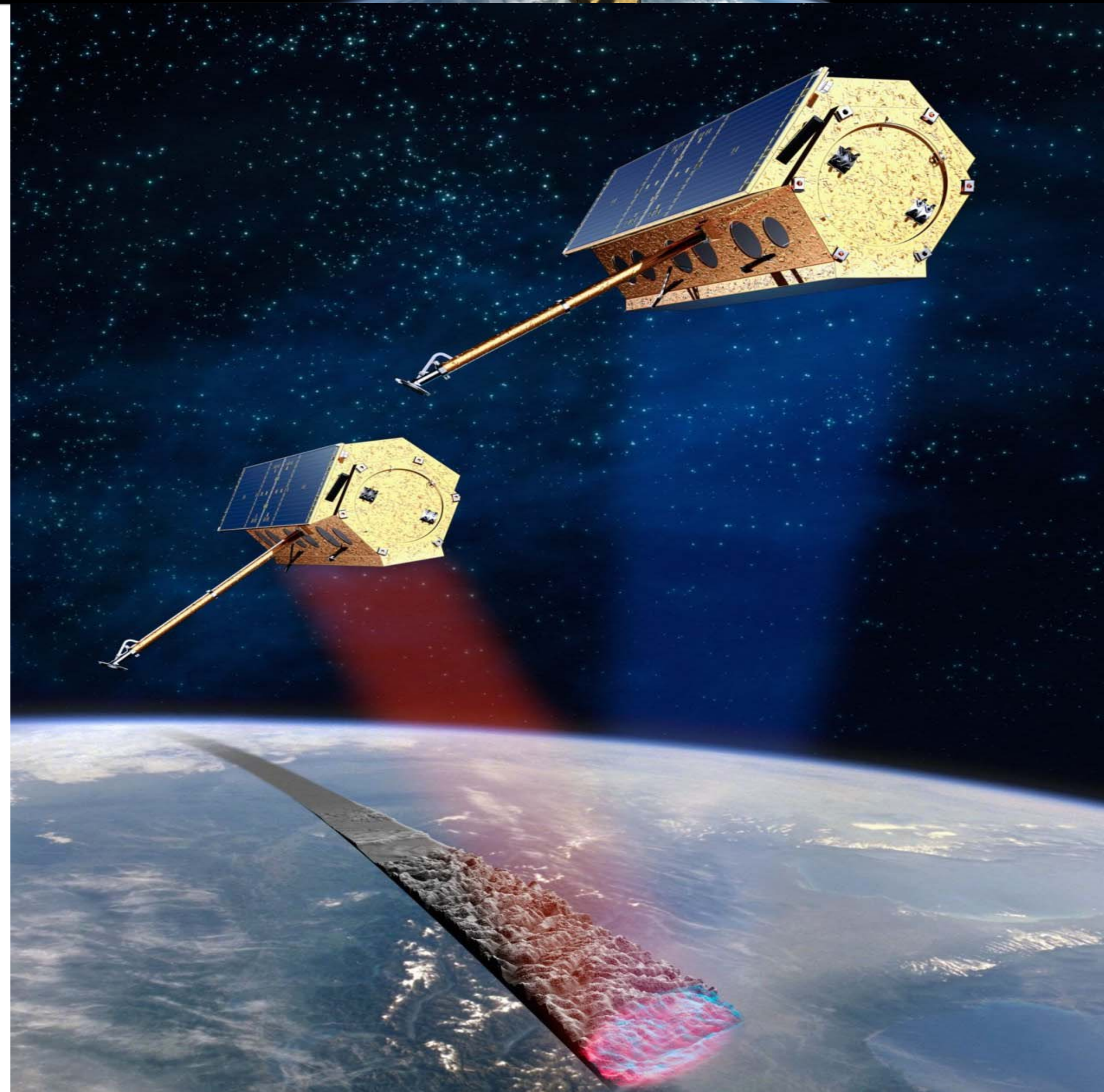
TanDEM

Tandem-X Polarimetric SAR Interferometry (Pol-InSAR)

Pursuit Monostatic Phase
Temporal baseline: 2-3 sec (20km)

Bistatic Phase
No temporal baseline

Acquisition Modes
Stripmap
Single Pol (HH,VV)
Dual Pol (HH/VV,HH/HV,VV/VH)



Krycklan Test Site (Biosar II – Campaign 2008)

Krycklan forest:

Location:

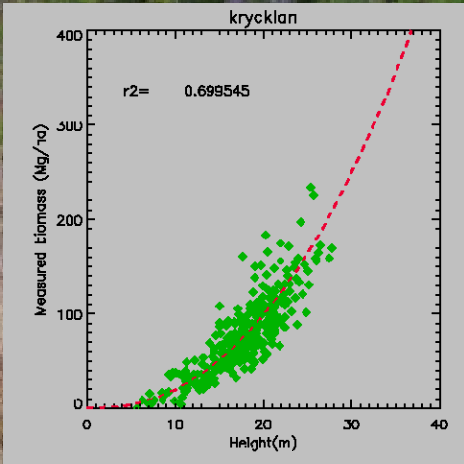
- middle Sweden
- boreal forest
- hilly topography
- strong slopes

Composition

- maximum forest height: ~ 30m
- mean forest height: 17m
- mean biomass: 90t/ha
- maximum biomass: 220 t/ha
- domintated by Coniferous trees

Lidar Reference Measurements available (2008)

Uniform structure

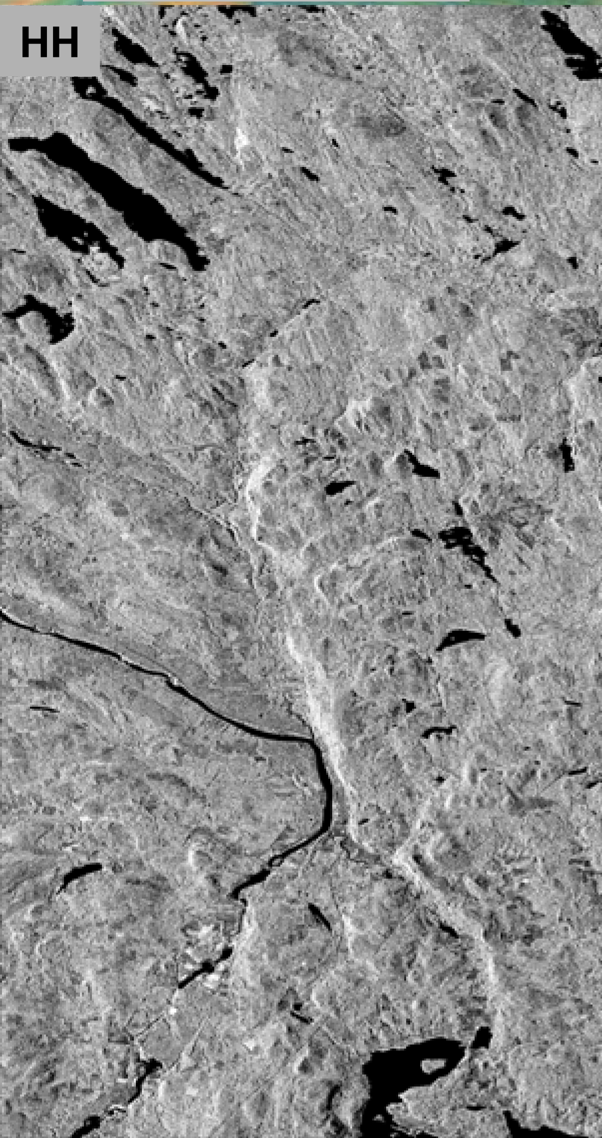


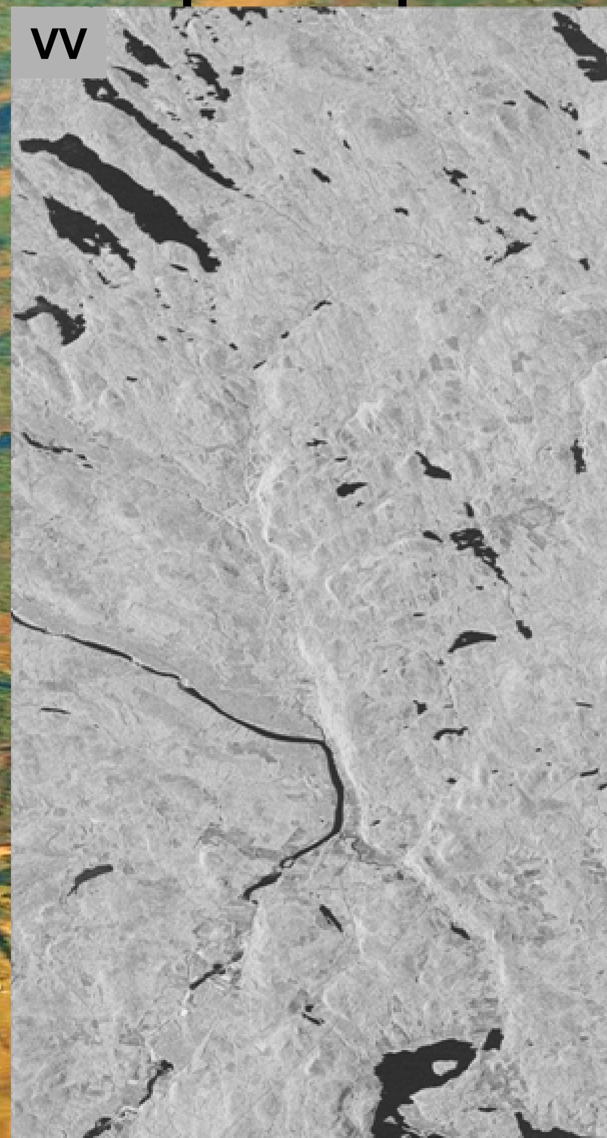
Data Base

Vertical Wavenumber:

$$\kappa_z = \frac{4\pi}{\lambda}\frac{B}{R\ \sin(\theta_0)}$$

Date	Baseline [m]	Incidence angle	K_z	Height of ambiguity	Polarisation
28. July 2010	141	32°	0.18	35m	HH / VV
8. August 2010	125	32°	0.15	41m	HH / HV
19. August 2010	137	32°	0.17	38m	HH / VV





Coherence HH

Vertical Wavenumber:

$$\kappa_z = \frac{4\pi}{\lambda}\frac{B}{R\ \sin(\theta_0)}$$

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28. July 2010	141	32°	0.18	35m	HH / VV
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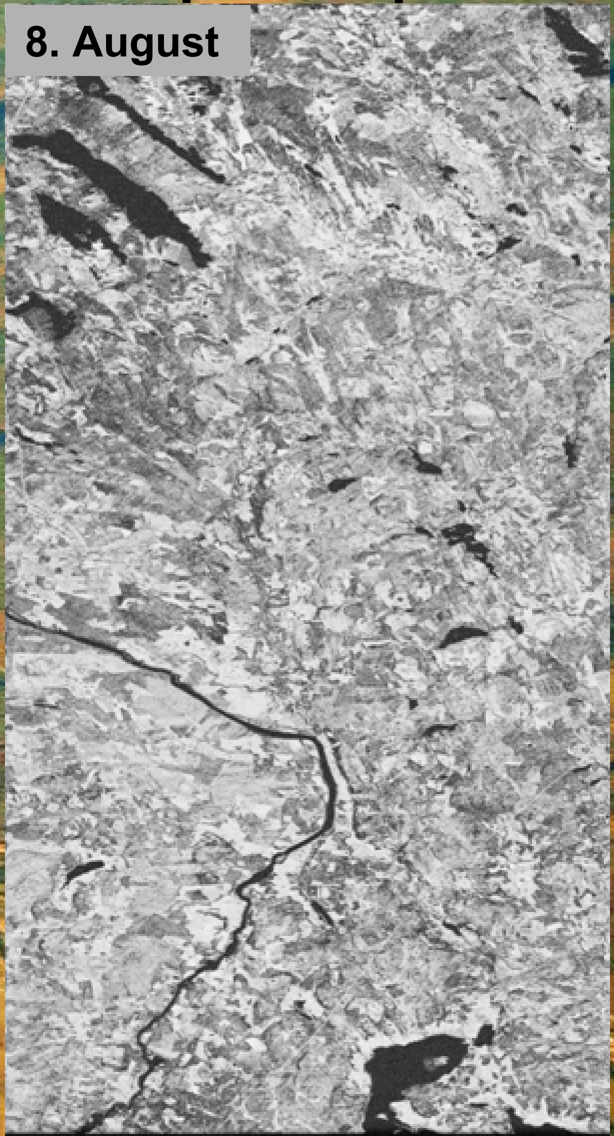
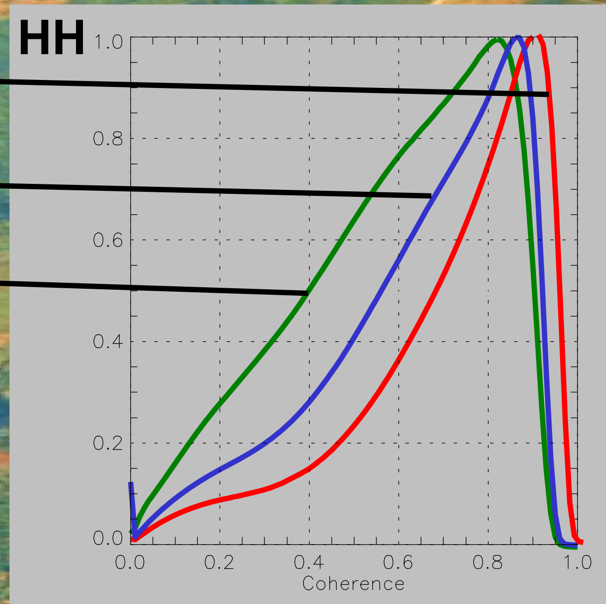


Temporal Decorrelation

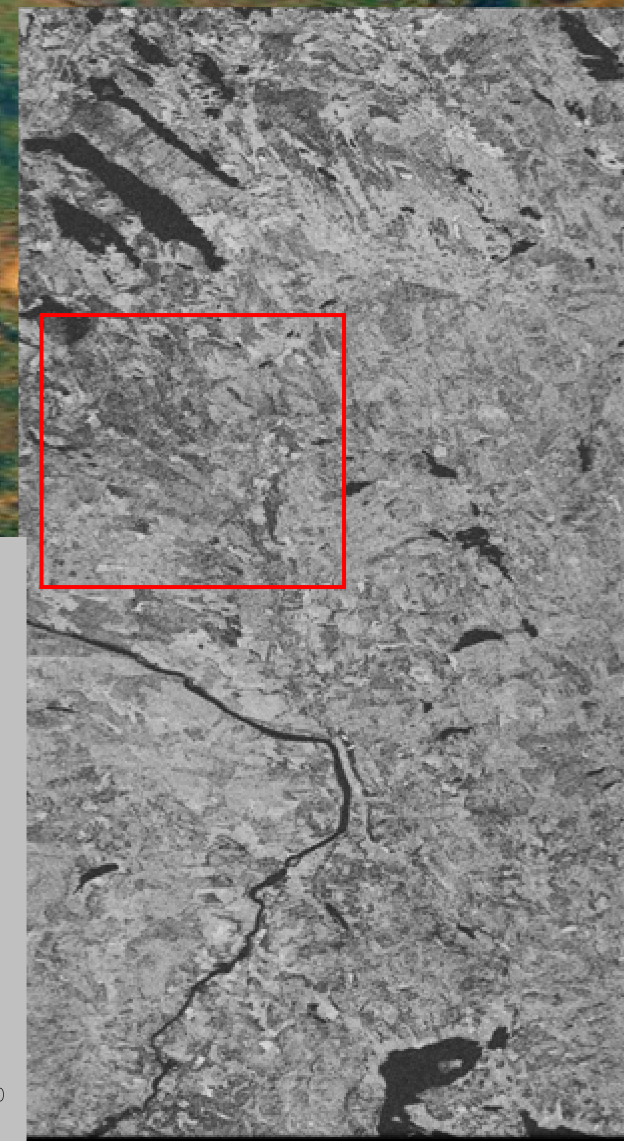
28. Juli $K_z = 0.18$

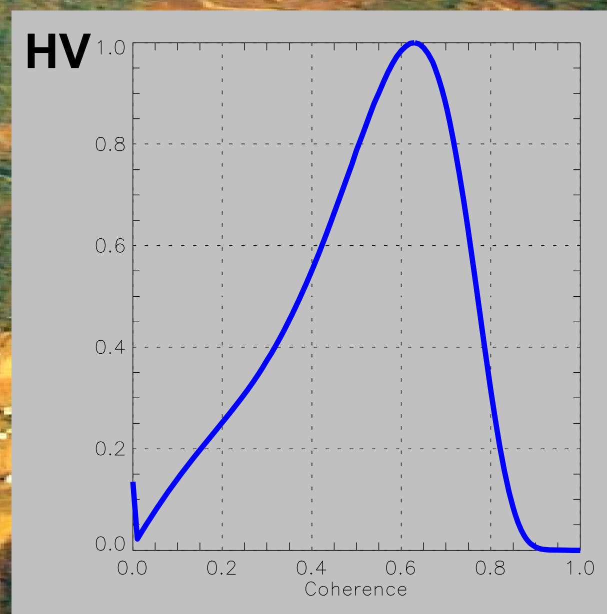
8. August $K_z = 0.15$

19. August $K_z = 0.17$



HV 8. August





- 3 sec of Temporal Baseline may lower interferometric coherence significantly

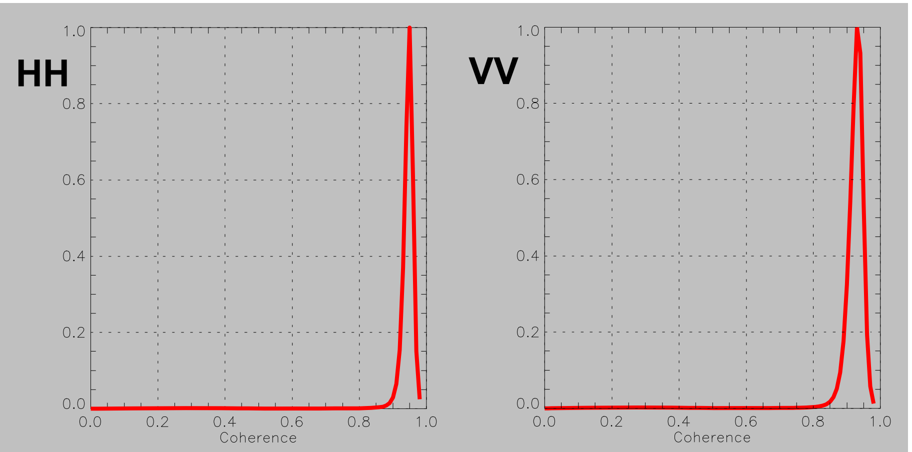
- Two Acquisitons are highly decorrelated

SNR Decorrelation

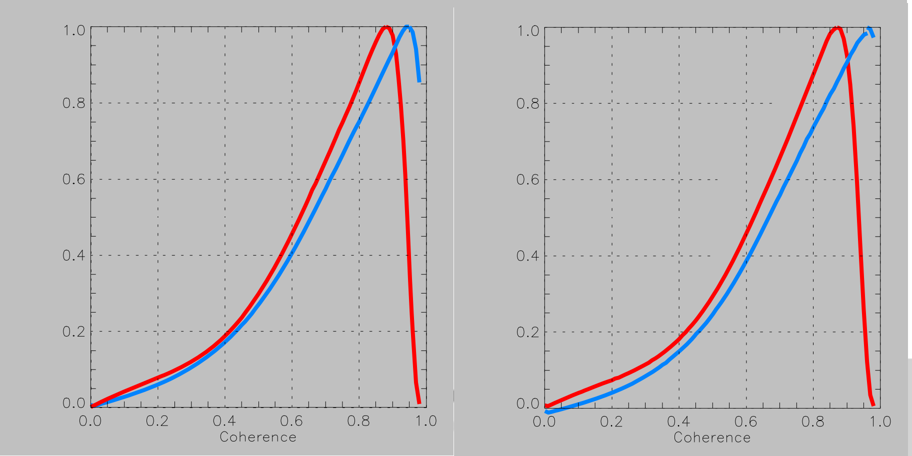
27. July 2010 K_Z =0.17

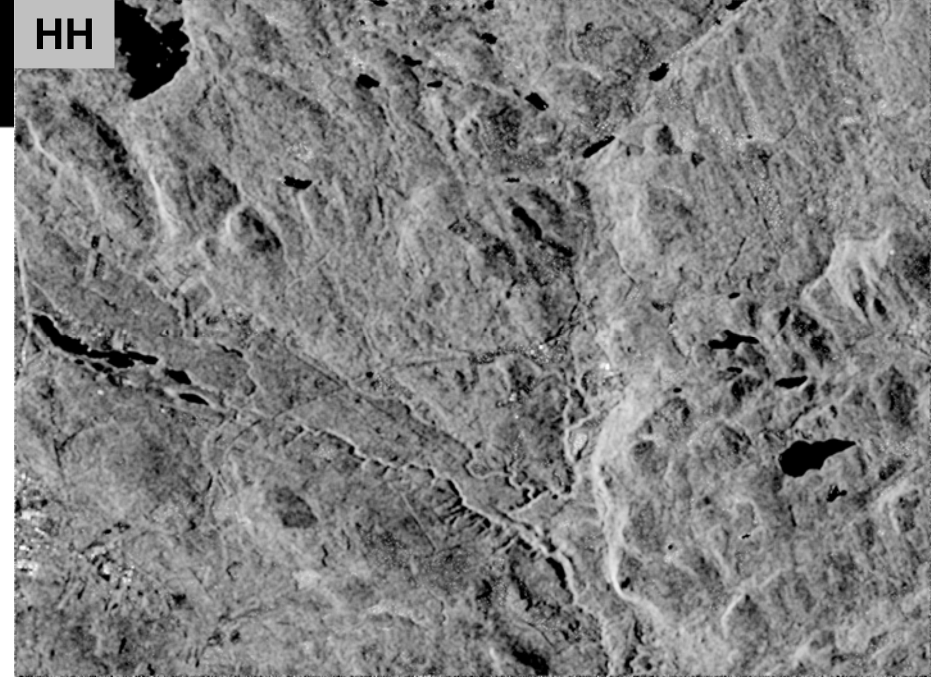
NESZ ~ - 20dB to -22dB

$$\gamma_{SNR} = \frac{SNR}{1+SNR}$$

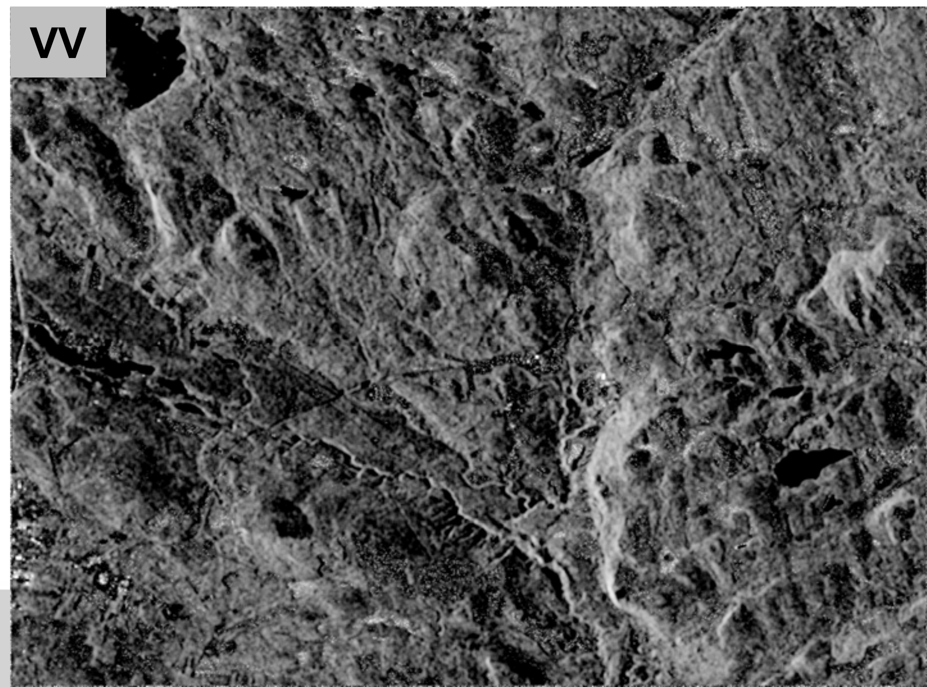


Interferometric Cohrerence before (red) and after (blue) SNR Correction



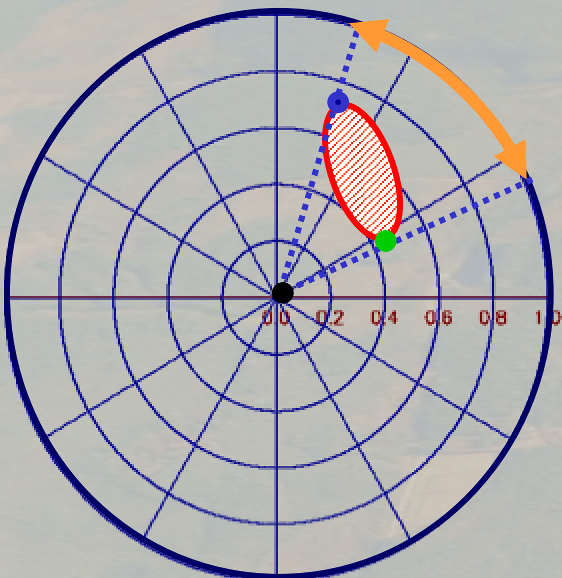


Scaled from 0.9 (black) to 1 (white)



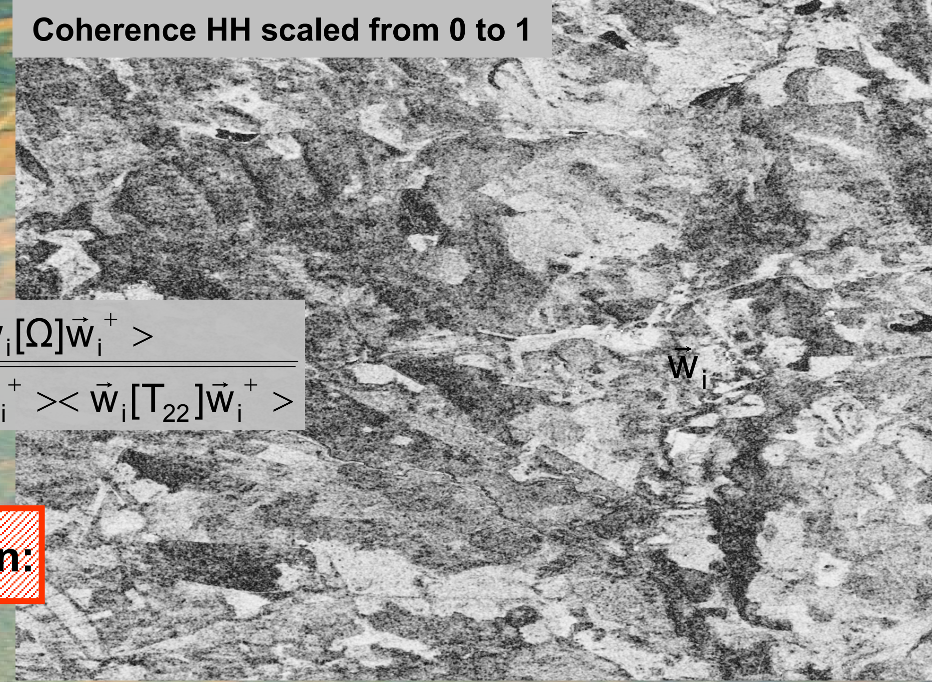
Forest Characterisation by means of Pol-InSAR

Interferometric Coherence: $\tilde{\gamma}(\vec{w}_i, \vec{w}_i)$ at polarisation



$$\tilde{\gamma}(\vec{w}_i, \vec{w}_i) = \frac{\langle \vec{w}_i [\Omega] \vec{w}_i^{+} \rangle}{\sqrt{\langle \vec{w}_i [T_{11}] \vec{w}_i^{+} \rangle \langle \vec{w}_i [T_{22}] \vec{w}_i^{+} \rangle}}$$

Coherence Region:

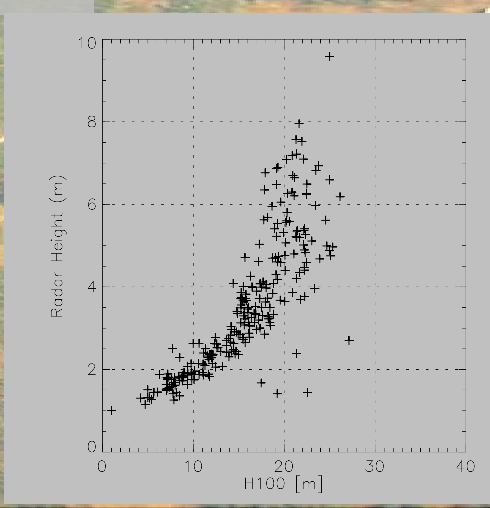


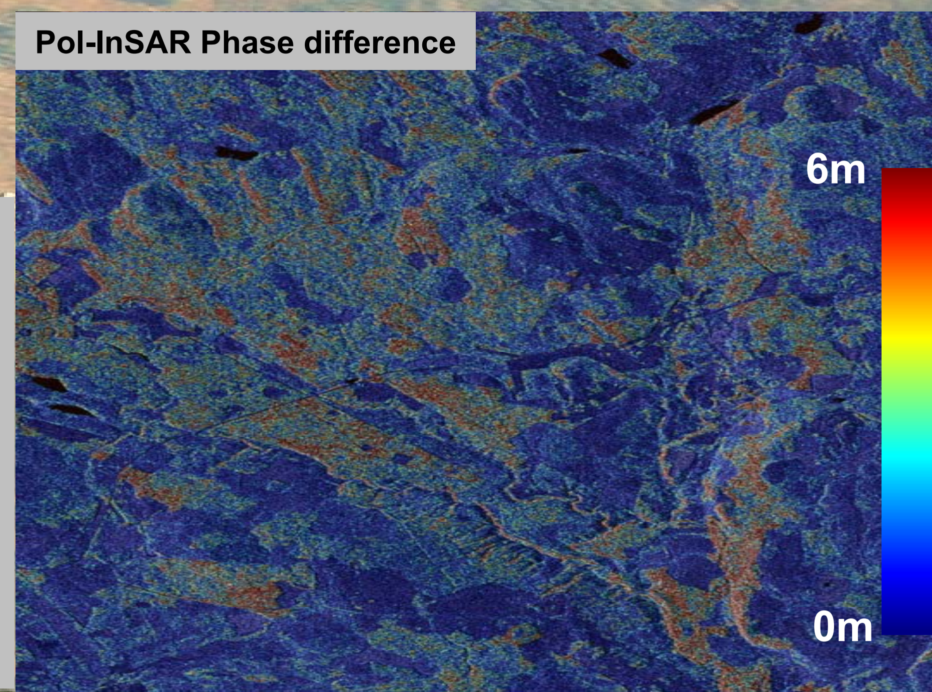
$\tilde{\gamma}(\vec{w}_{max}, \vec{w}_{max})$

$\tilde{\gamma}(\vec{w}_{min}, \vec{w}_{min})$

Pol-InSAR Phase difference

Number of stands: 216





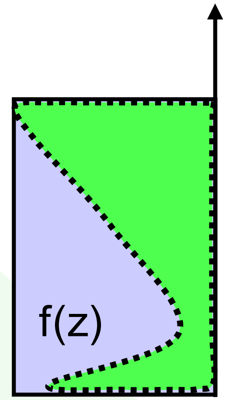
Interferometric Coherence

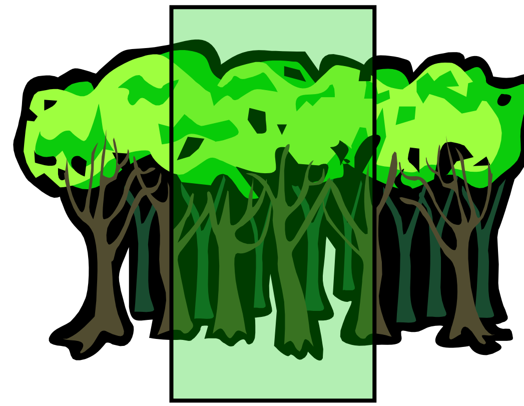
$$\tilde{\gamma}(S_1\ S_2) = \frac{< S_1\ S_2^* >}{\sqrt{< S_1\ S_1^* > < S_2\ S_2^* >}}$$

Single Channel X-band Inversion

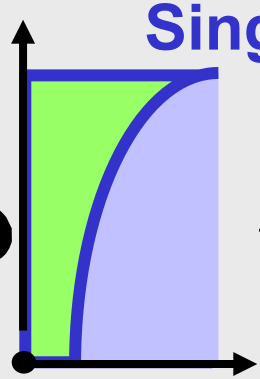
Volume Coherence

$$\tilde{\gamma}_{Vol}(f(z)) = e^{ik_z z_o} \frac{\int_o^{h_v} f(z) e^{ik_z z} dz}{\int_o^{h_v} f(z)\ dz}$$





Single pol ►1 Layer Scattering Model (m=0)



$$f(z) = \sigma_{V0} \exp\left(\frac{2\ \sigma\ z}{\cos\theta_0}\right)$$

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

Volume Coherence

$$\tilde{\gamma}_V = \frac{I}{I_0}$$

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

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

Vertical Wavenumber: $\kappa_z = \frac{\kappa\Delta\theta}{\sin(\theta_0)}$

Volume Height h_V

Extinction σ

Topography φ_0

Forest heights obtained from VV polarisation using Lidar ground phase

Number of stands: 216

Low (unsensitive) K_Z values due to topography are filtered out.

Unvalid points are filtered (15%)

$r^2 = 0.91$

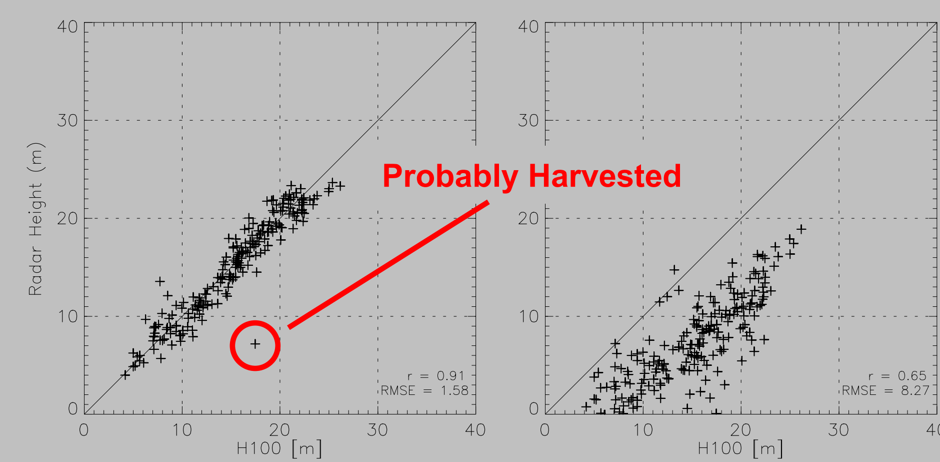
$r^2 = 0.93$ (harvested area removed)

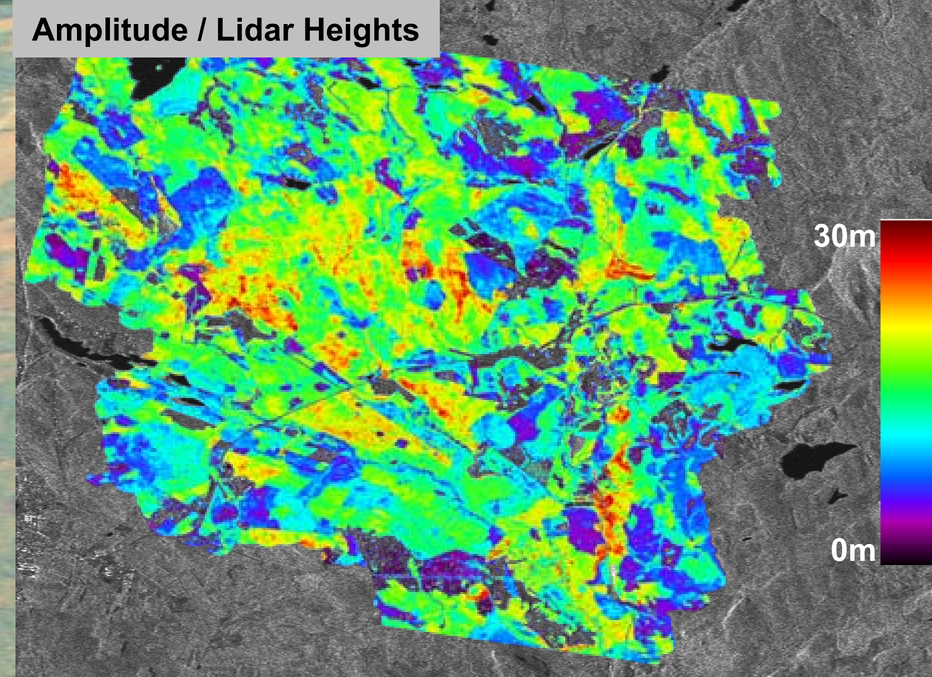
RMSE = 1.58

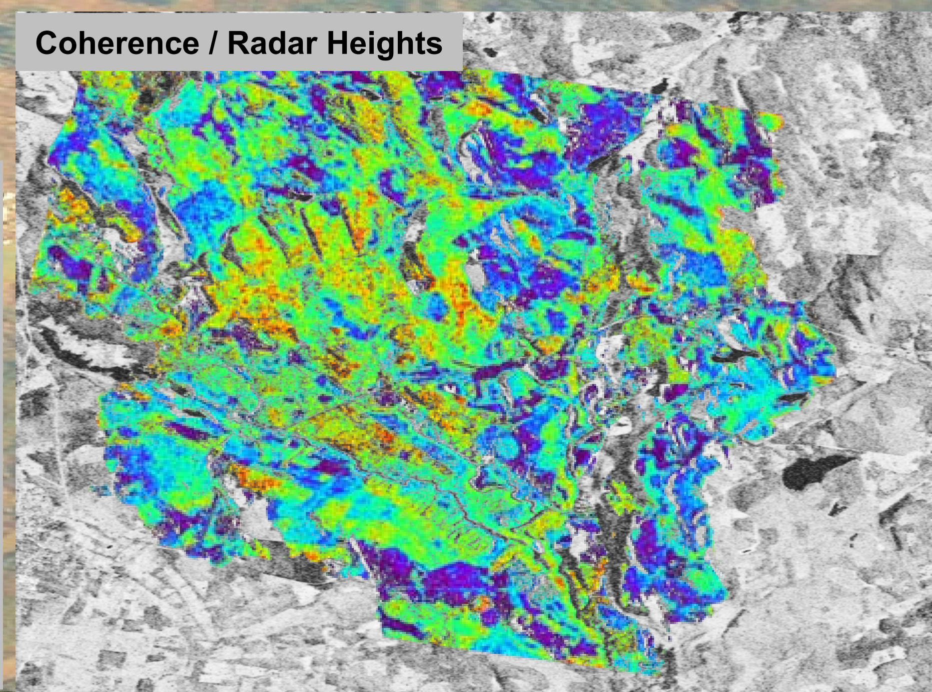
RMSE Phase Centre Height = 8.27 = penetration depth

Validation Plots Lidar vs Radar:

Radar Height Phase Centre Height





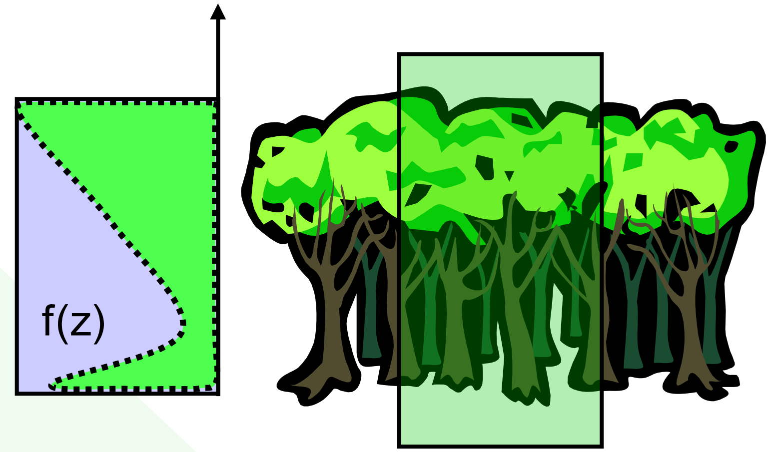


Interferometric Coherence

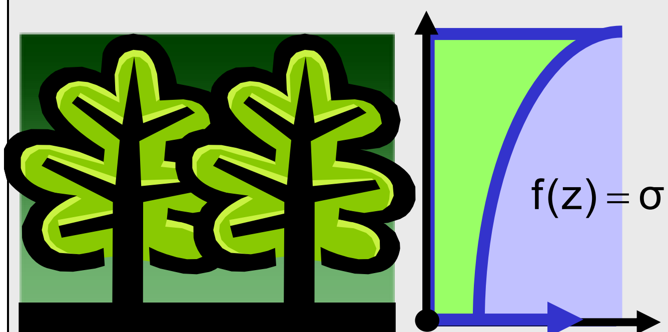
$$\tilde{\gamma}(S_1\ S_2) = \frac{< S_1\ S_2^* >}{\sqrt{< S_1\ S_1^* > < S_2\ S_2^* >}}$$

Volume Coherence

$$\tilde{\gamma}_{Vol}(f(z)) = e^{ik_z z_o} \frac{\int_o^{h_v} f(z)\, e^{ik_z z} dz}{\int_o^{h_v} f(z)\ dz}$$



Dual pol ► 2 Layer Scattering Model



$$f(z) = \sigma_{V0} \exp\left(\frac{2\ \sigma\ z}{\cos\theta_0}\right) + m'_G \delta(z - z_0)$$

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

Volume Coherence

$$\tilde{\gamma}_V = \frac{I}{I_0} \quad \begin{cases} I = \int_0^{h_V} \exp(i\kappa_z z')\exp\left(\frac{2\ \sigma\ z'}{\cos\theta_0}\right) dz' \\ I_0 = \int_0^{h_V} \exp\left(\frac{2\ \sigma\ z'}{\cos\theta_0}\right) dz' \end{cases}$$

G/V Ratio: $m(\vec{w}) = \frac{m_G(\vec{w})}{m_V(\vec{w}) I_0}$

Vertical Wavenumber: $\kappa_z = \frac{\kappa \Delta\theta}{\sin(\theta_0)}$

- *Volume Height* h_V
- *Extinction* σ
- *Topography* φ_0
- *G/V Ratio* $m(\vec{w})$

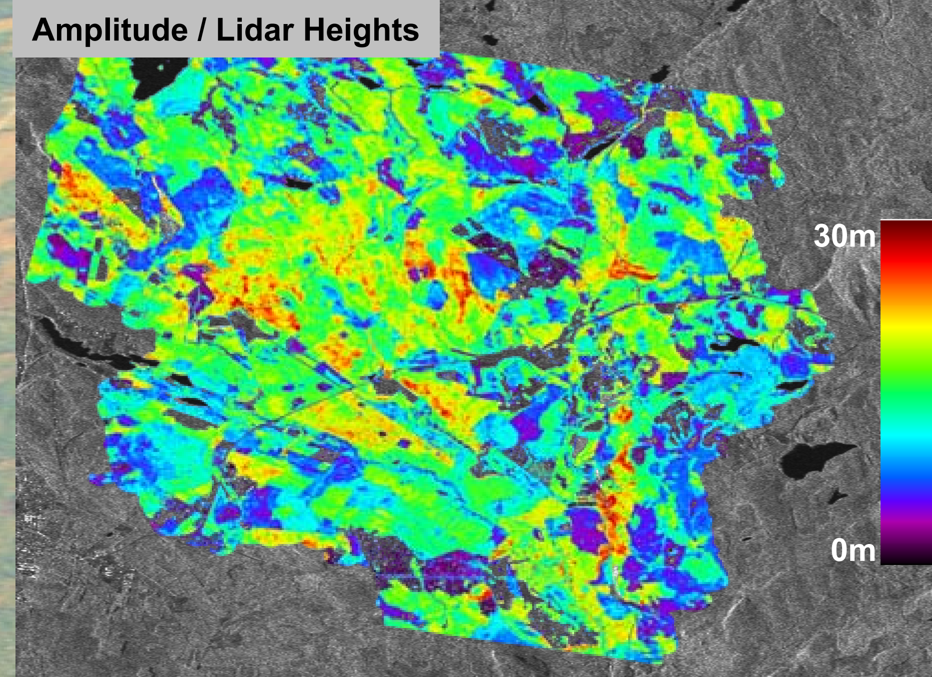
Forest heights using Dual Pol-InSAR (HH & VV)

Low (unsensitive) K_Z values (due to topography) are filtered out

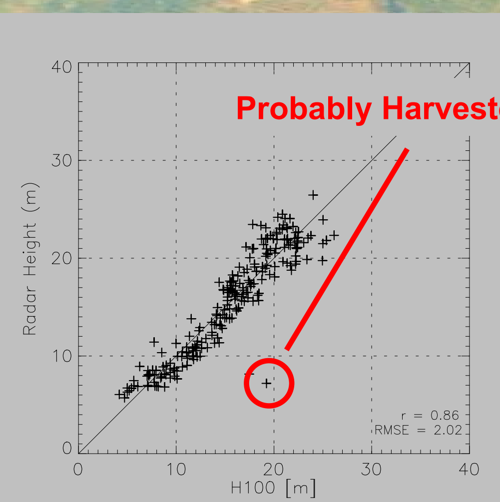
Unvalid points are filtered (21%)

$r^2 = 0.86$
RMSE = 2.02m
$r^2 = 0.90$ (without harvested areas)

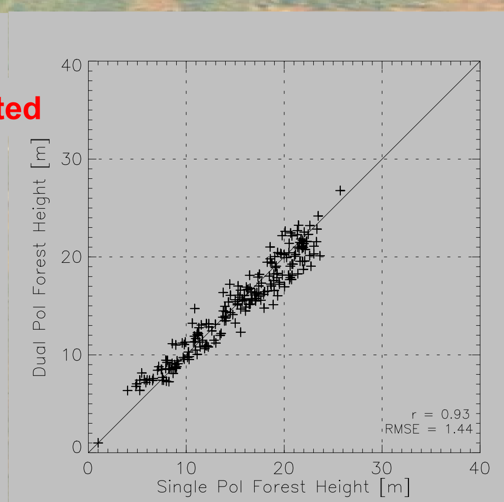
Number of stands: 216

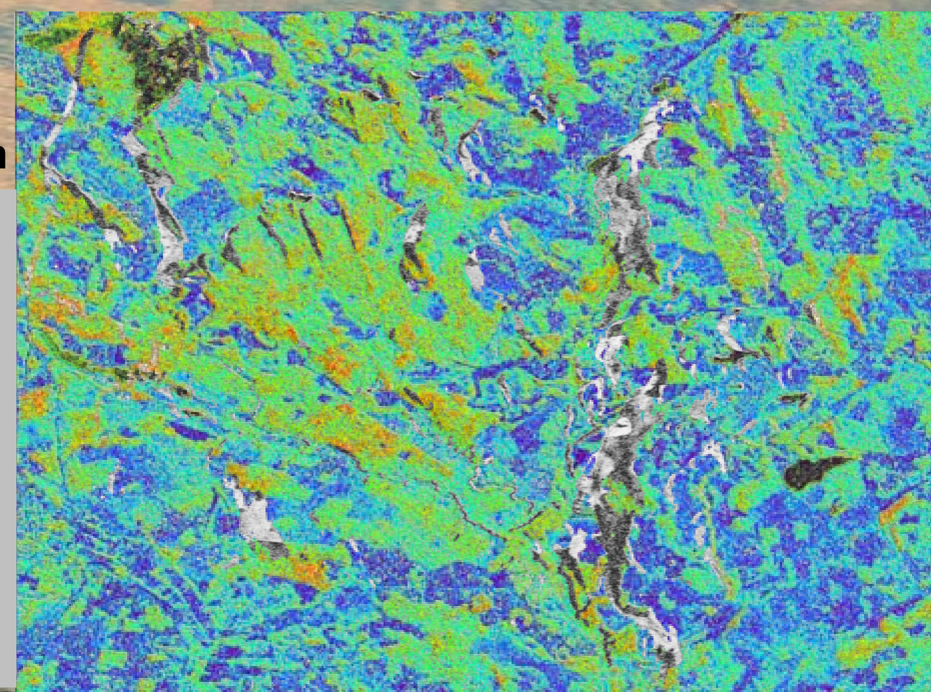


Validation Plot Lidar vs Radar:



Single-pol inversion vs Dual-pol inversion
r^2=0.93, RMSE = 1.44m



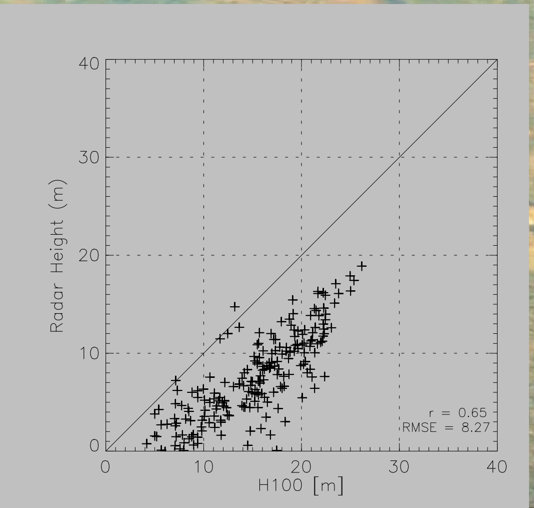


Interferometric phase centre heights HH vs VV, Juli vs Dezember

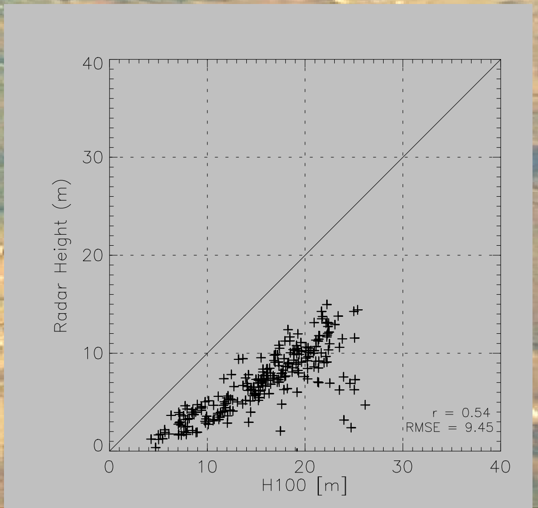
Date	Baseline [m]	Incidence angle	K_z	Height of ambiguity	Mode	Polarisation
19. August 2010	137	32°	0.17	38m	Monostatic	HH / VV
17. December 2010	69	19°	0.09	69m	Bistatic	HH

- **HH scattering centre height clearly below VV scattering centre**
  - **Proofs polarisation dependence of ground contribution**
- **December acquisition penetrates deeper than July acquisition**
  - **Incidence angle ?**
  - **Dielectric properties ?**

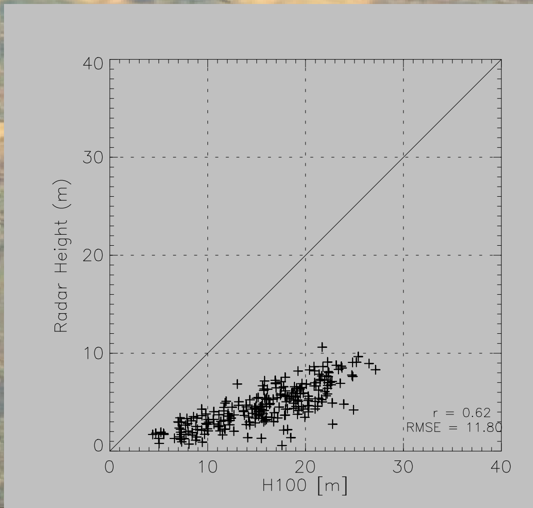
VV Juli θ=32°
r^2=0.65, RMSE = 8.27m



HH Juli θ=32°
r^2=0.54,RMSE=9.45m



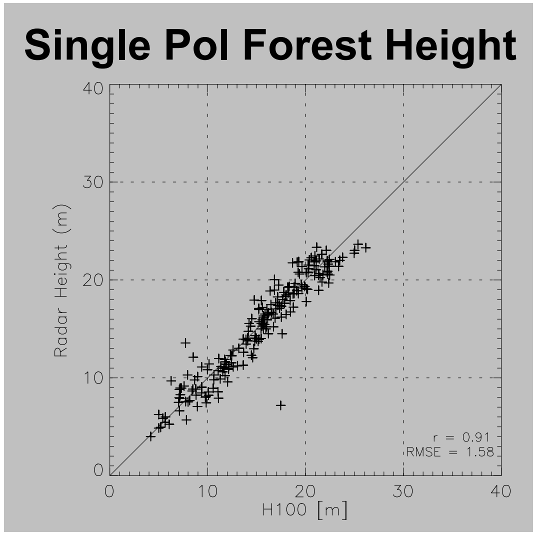
HH Dezember θ=19°
r^2=0.62, RMSE = 11.80m

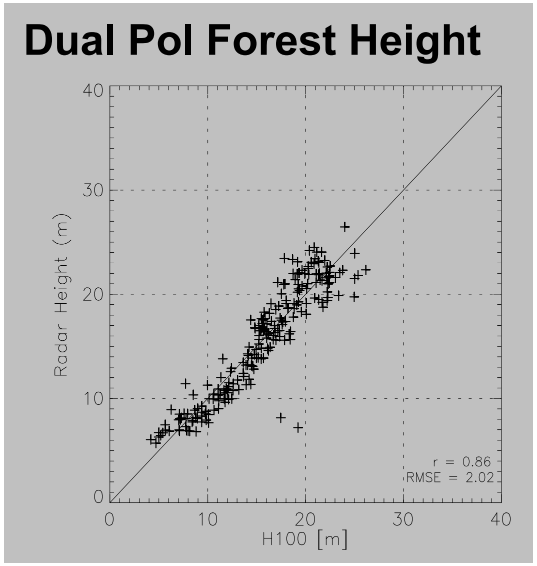


Conclusions

TanDEM-X

- 3 seconds temporal baseline can decorrelate interferometric coherence
- SNR limits inversion performance - needs to be corrected
- Single Pol TanDEM-X data (VV) are sensitive to forest height (with a priori ground phase r^2=0.91, RMSE = 1.58)
- Dual Pol TanDEM-X data (HH, VV) allow forest height estimation without any a priori information – at least for boreal forests as found in Krycklan test site (r^2=0.86, RMSE = 2.02)
- Forest height estimation is possible using TanDEM-X data
- Significant difference in penetration depth from December to Juli acquisition: Inducesd by: different incidence angles? or changing dielectric constant





TanDEM-X Proposal Submission

TanDEM Science Service System DLR

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- Evaluator
- Coordinator

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TanDEM-X Science Service System

The TanDEM-X Science Service System is a web interface for the submission and evaluation of scientific proposals. The portal is the main interface for Principal Investigators to define their acquisition requests. It is further used to monitor and track the status of submitted proposals and is a tool for the science coordination team to help organize the science user community of TanDEM-X.

PRE-OPERATIONAL AO: The Science Service System is now open for the submission of scientific proposals until **October 31st, 2010**. **This AO aims for user-specific experimental acquistion requests only**. All data assigned to an approved proposal for this call will be free of charge. We would like to encourage the science community to submit their proposals before the indicated date. The DEM products of the mission will be made available at a later date, for which a special AO will be launched in the future.

- New science users need to first **register** to get an account (see also the side menu link 'Investigators Registration'). After submission of the registration form an automated email is created, providing a link to a verification page. With the successful submission of the verification form the user account will be created, and the user is registered.
- Registered science users may login using the form fields on the left side menu. The proposal interface can be accessed after login by selecting the link 'Investigator' on the left side menu .
- **Evaluators** may access detailed information about the proposals they have been appointed to and submit their comments and rating.
- Anybody may access information about which proposals have been accepted and read their executive summaries **here**.
- Important documents can be accessed from the left side menu. The **TanDEM-X Science Plan** gives an overview about the scientific objectives of the TanDEM-X mission. The document **TanDEM-X Science Service System Manual** provides both a summary and a detailed description of the procedure for submitting a scientific proposal. In addition it guides users through the acquistion request for TanDEM-X image products.

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Please have a look @ http://tandemx-science.dlr.de

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