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Metsa kõrguse hindamine TanDEM-X radarsatelliiti interferomeetrilistelt piltidelt kasutades koherentsuse mudeleid

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Wide area forest height estimation from TanDEM-X interferometry with semi-empirical models

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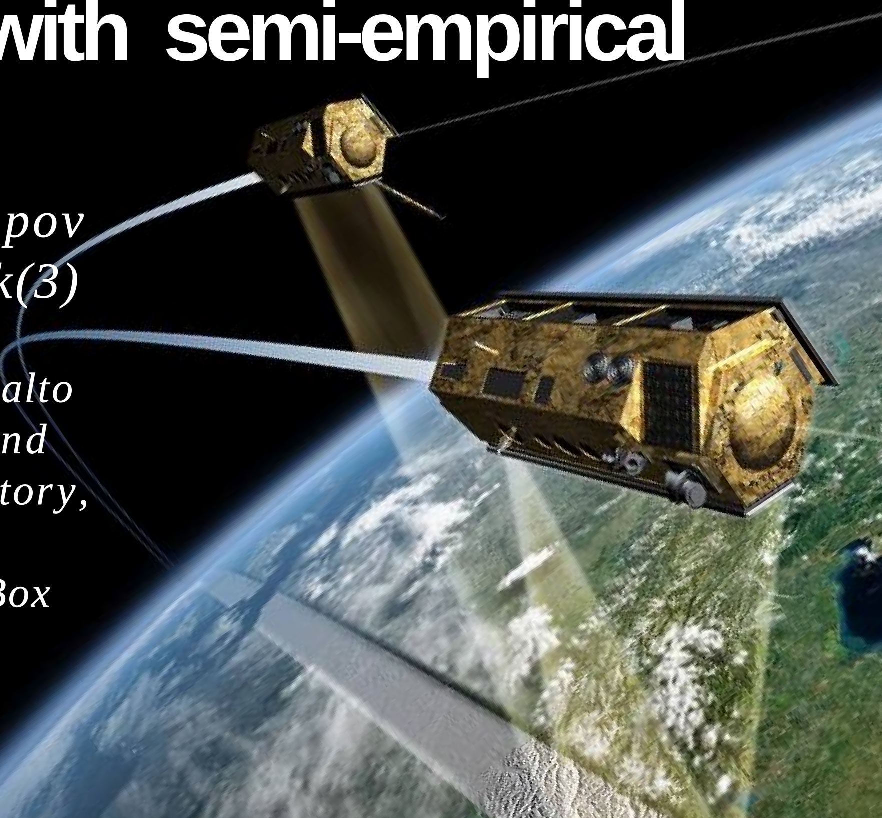

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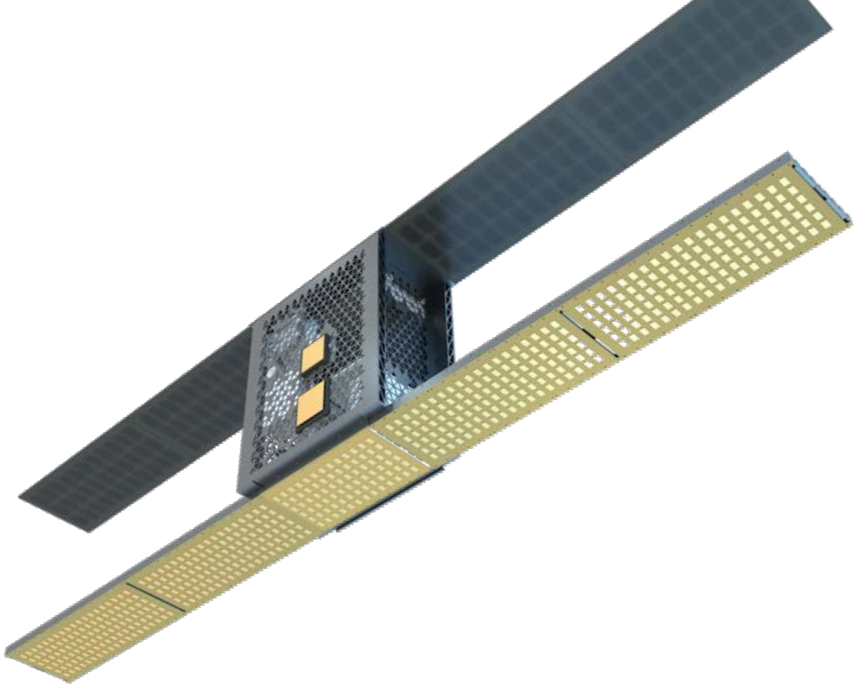
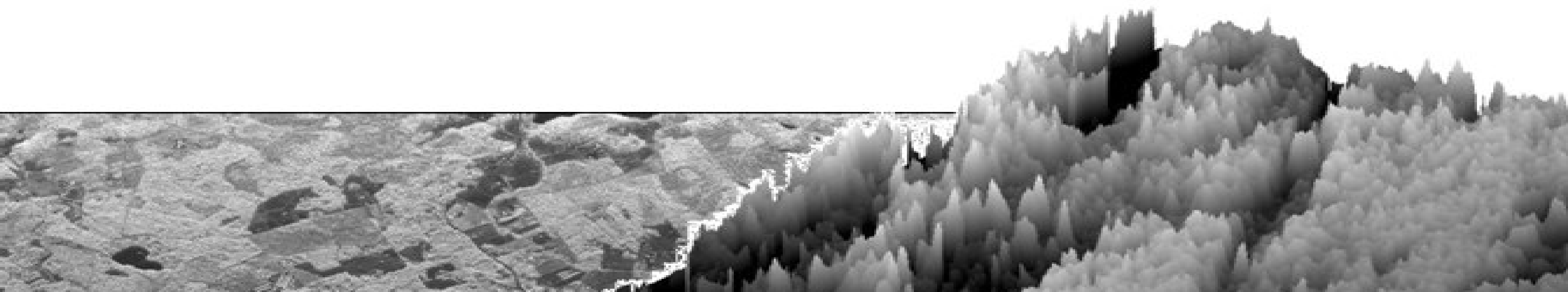
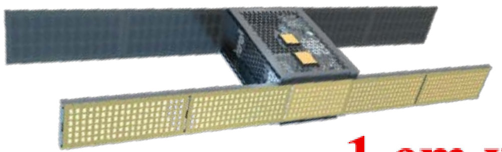
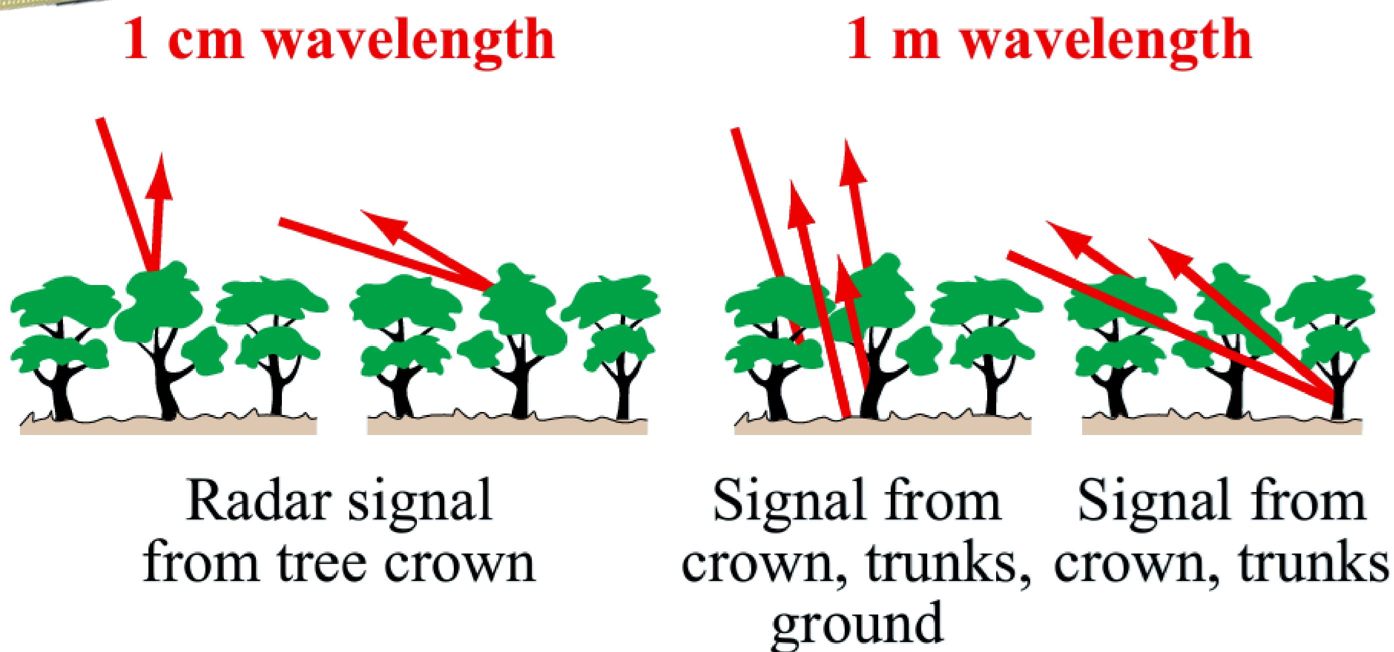
Forest Parameters with SAR?





Forest and SAR wavelenght

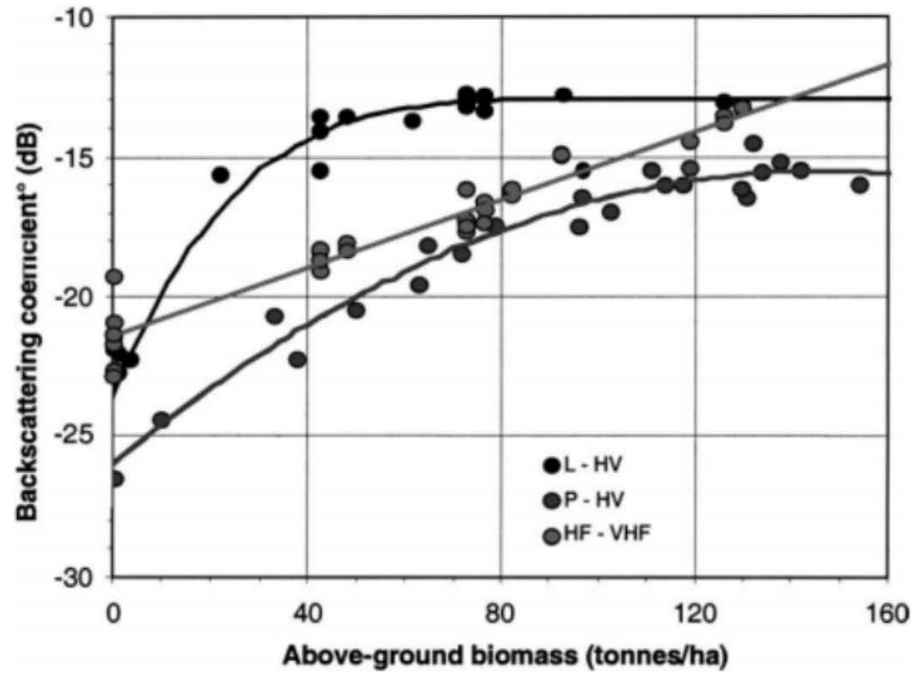




Ulaby and Long. Microwave Radar and Radiometric Remote Sensing,
Artech House 2014

Backscattering vs biomass saturates for shorter wavelengths

Figure 9. Saturation of SAR at High Forest Biomass



Note: This graph shows the saturation of SAR backscatter from the L-band (dark line, top), P-band (gray, bottom), and VHF-band (light gray, middle) over a forest in Landes, France. In this study, L- and P-band sensitivity to increasing biomass is limited after 100 Mg/ha; other studies have achieved higher sensitivity by combining polarizations.
Source: Le Toan et al. 2004.

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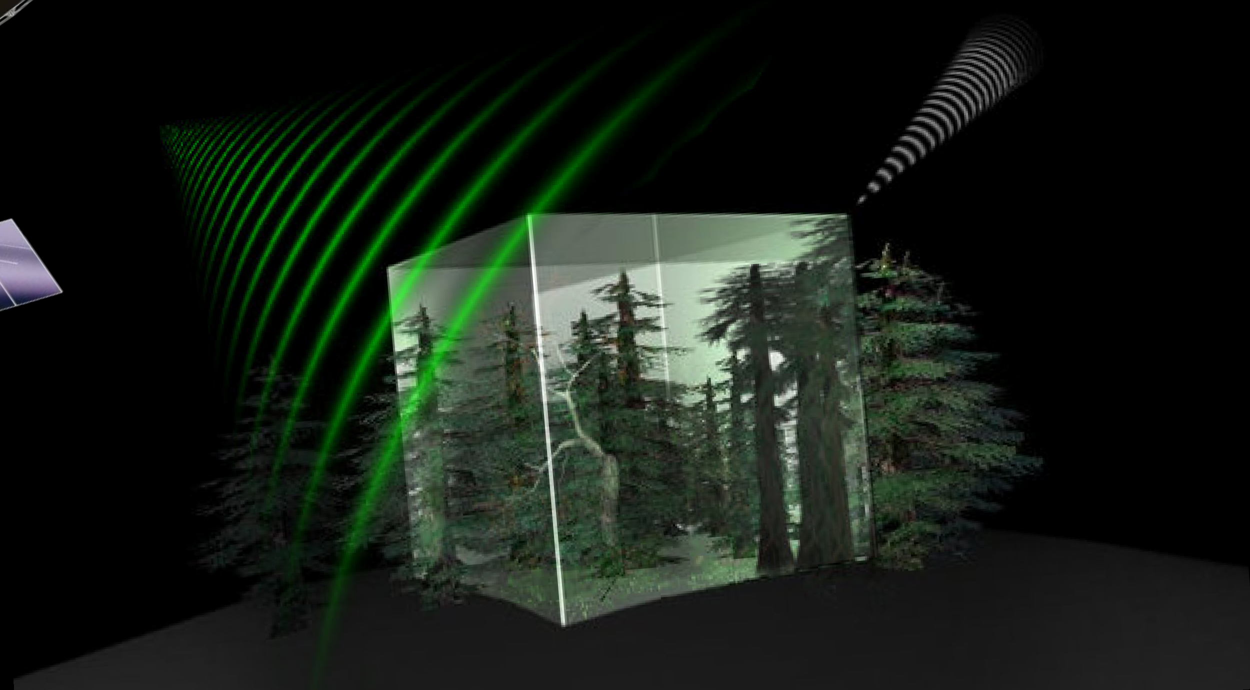
Biomass

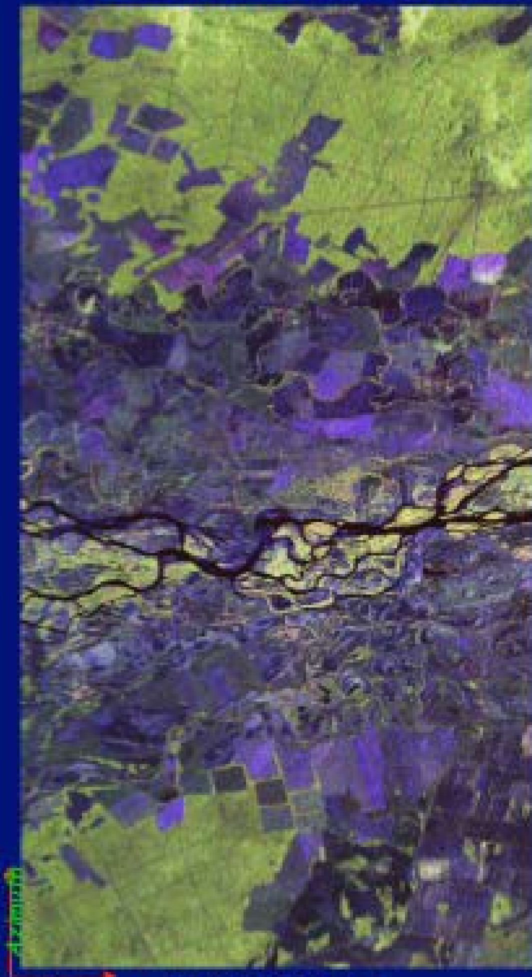
Earth Explorer 7



From SIR-C : Forest Height Estimation

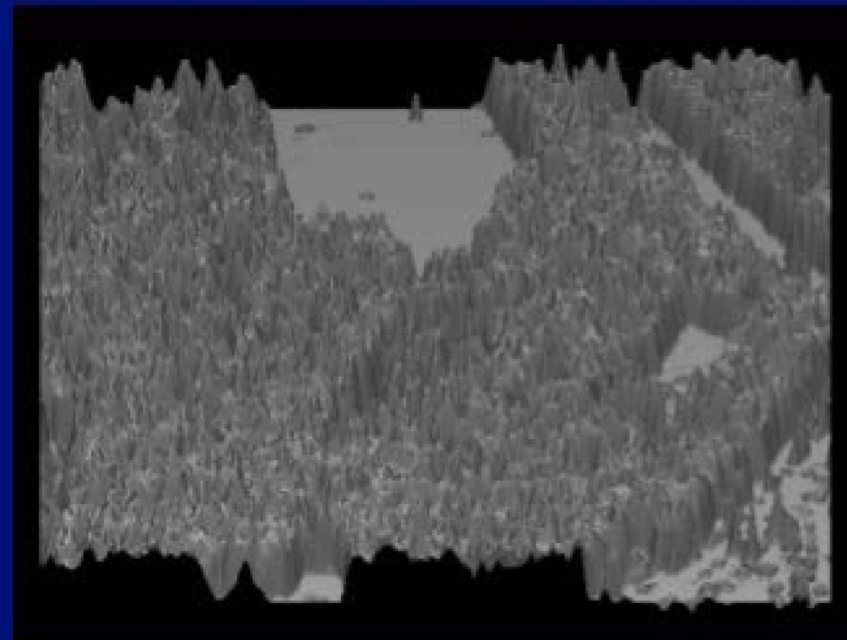
Temporal Baseline: 48 Hours

SIR-C / Test Site: Kudara, Russia



Pauli RGB Image

L-band



1. S.R Cloude, K P Papathanassiou, "Polarimetric SAR Interferometry", IEEE Transactions on Geoscience and Remote Sensing, Vol 36, No. 5, pp 1551-1565, September 1998

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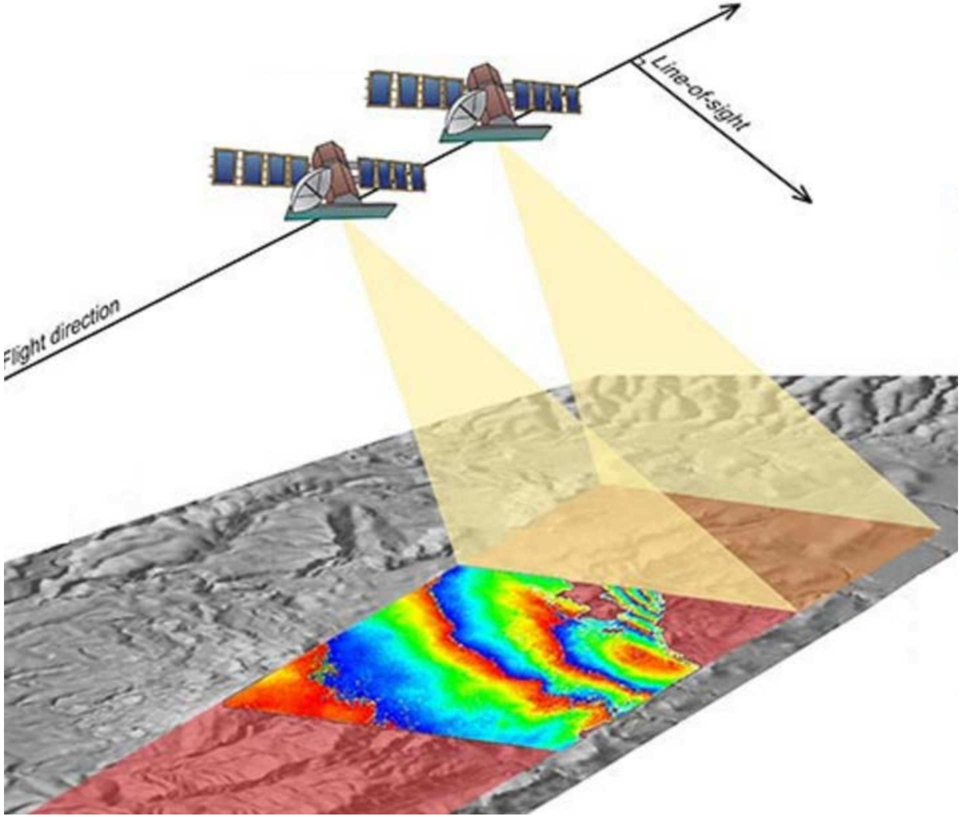
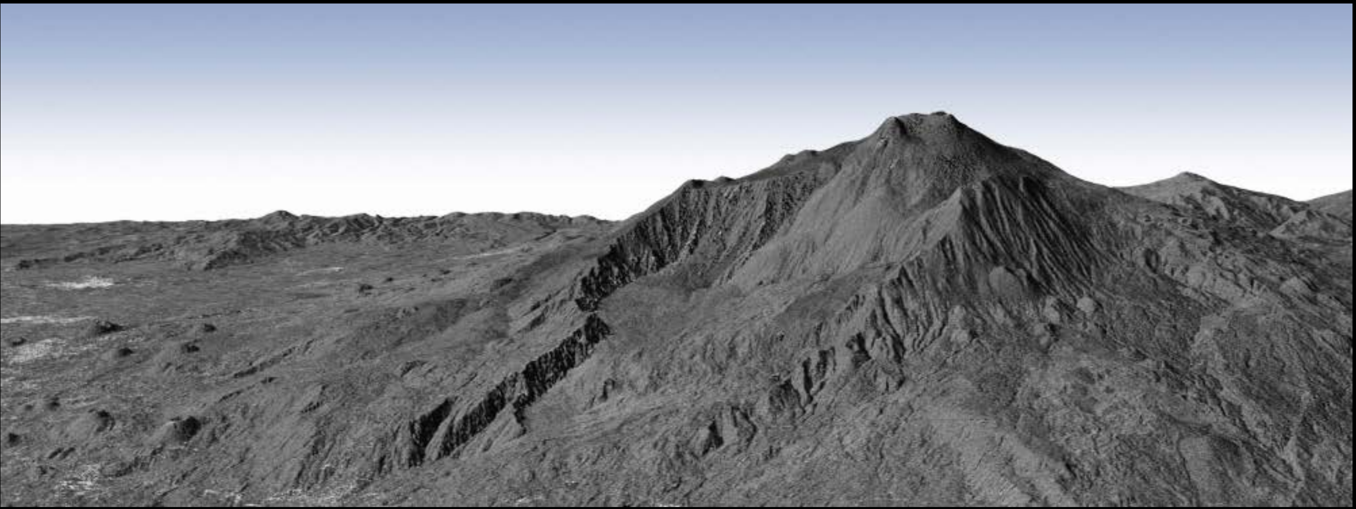
Interferometric SAR




TanDEM

Can we do any with 3 cm wavelength?



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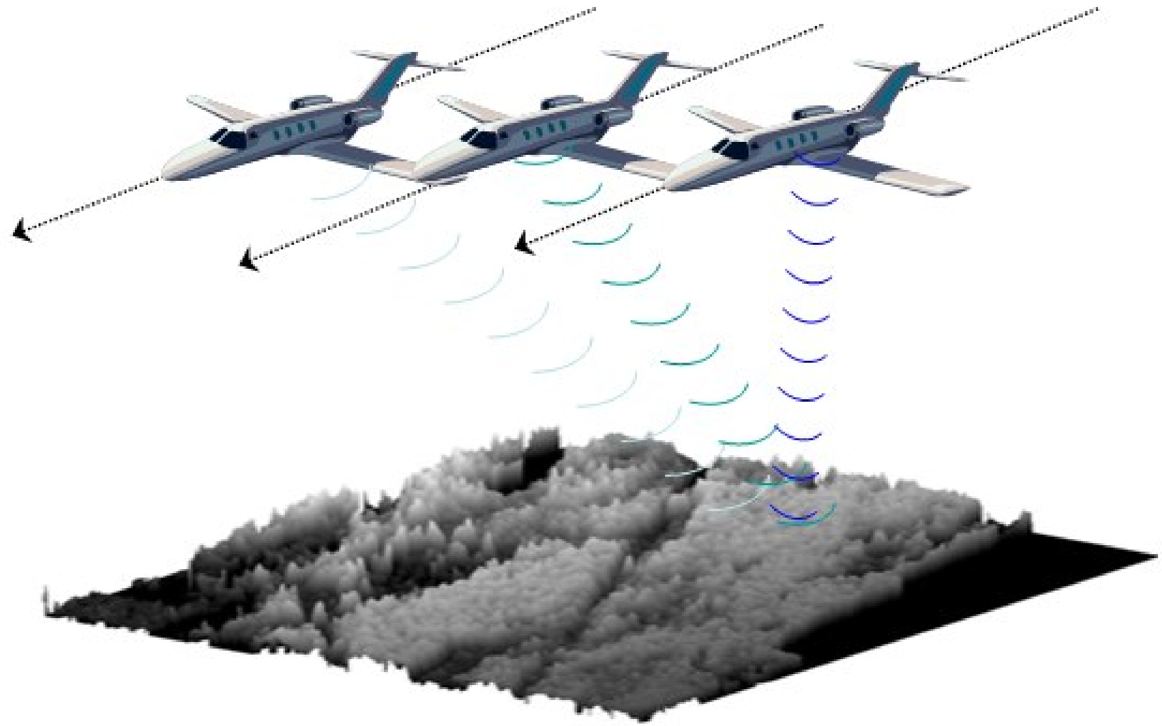
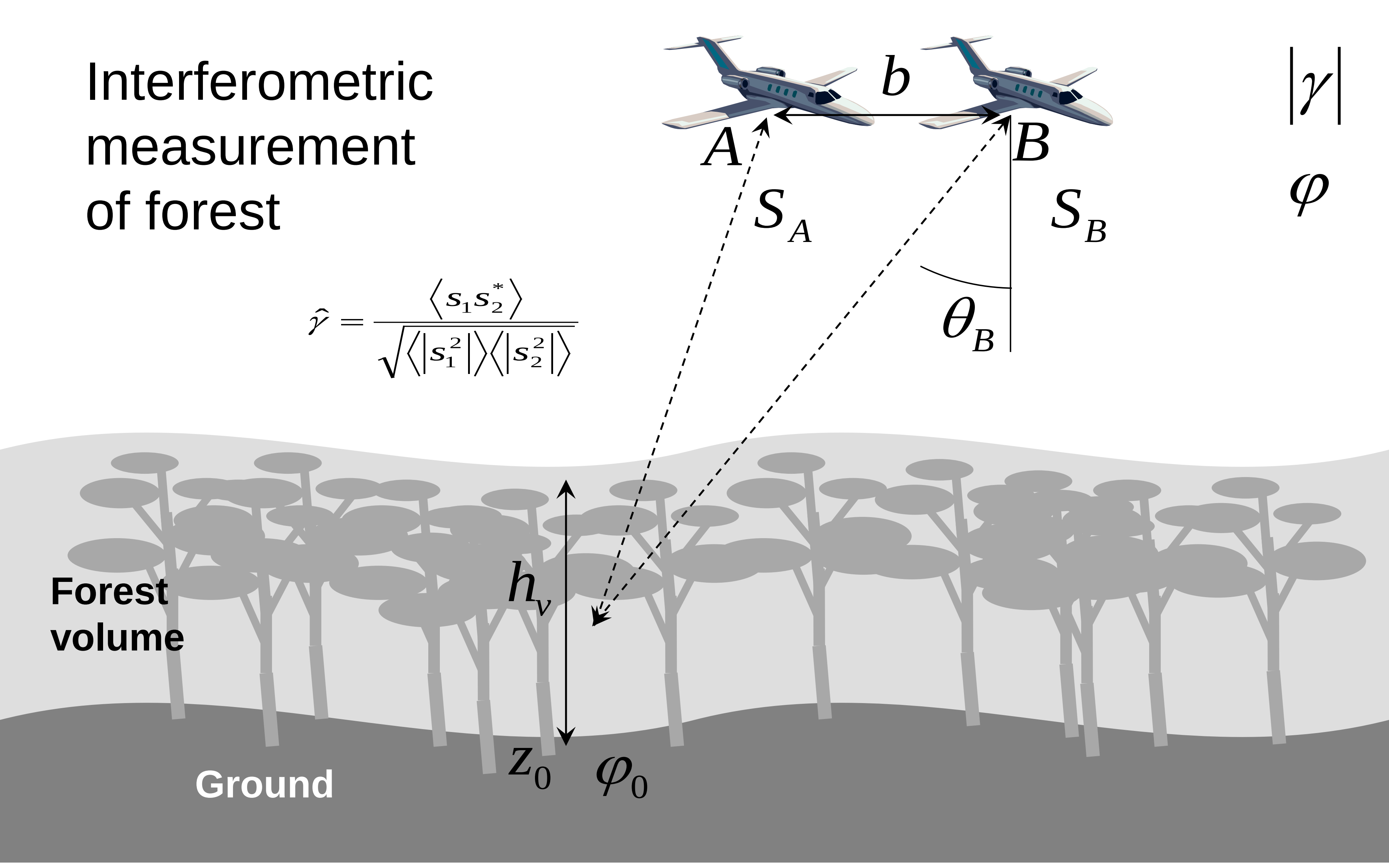
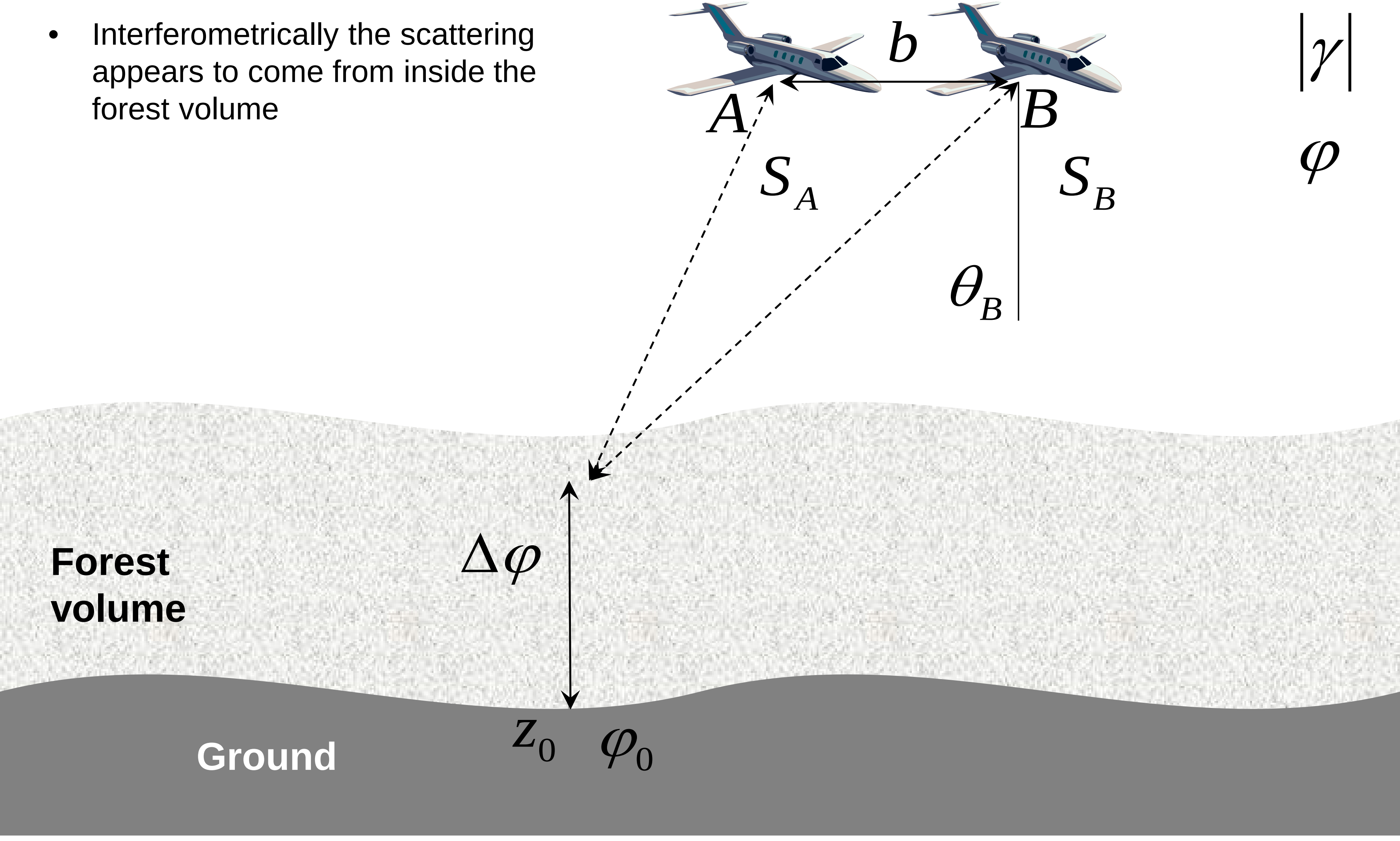
How InSAR works in forest?



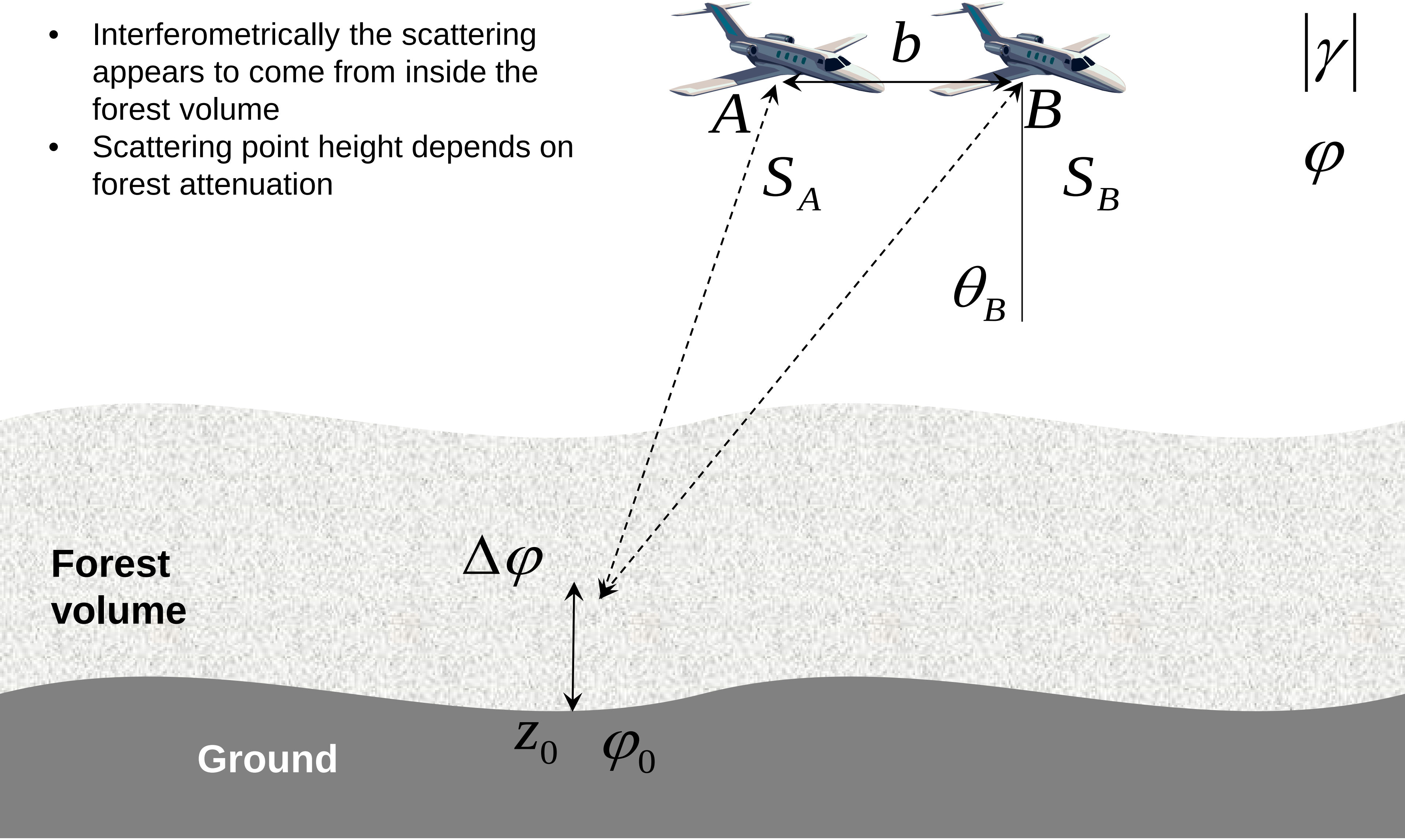


Interferometric measurement of forest
b
A
B
$|\gamma|$
φ
S_A
S_B
θ_B
$\hat{\gamma} = \frac{\langle s_1 s_2^* \rangle}{\sqrt{\langle |s_1^2| \rangle \langle |s_2^2| \rangle}}$
h_v
Forest volume
z_0
φ_0
Ground

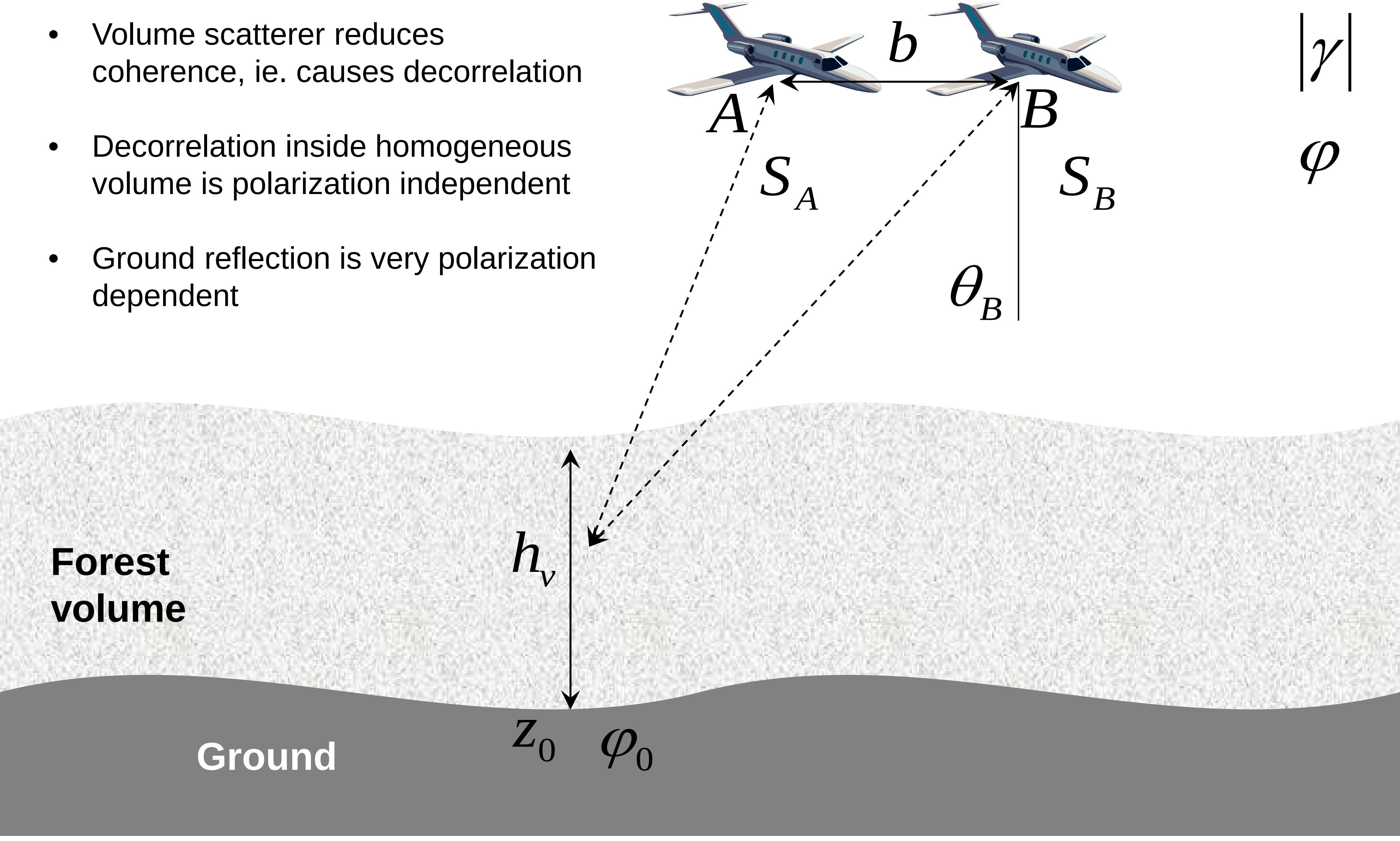
- Interferometrically the scattering appears to come from inside the forest volume



- Interferometrically the scattering appears to come from inside the forest volume
- Scattering point height depends on forest attenuation



- Volume scatterer reduces coherence, ie. causes decorrelation
- Decorrelation inside homogeneous volume is polarization independent
- Ground reflection is very polarization dependent



The coherence model (RVoG)

The volume decorrelation of the interferometric coherence is the **normalized Fourier transformation of the vertical distribution *F(z)* of scatterers.**

$$\gamma = \exp(i\kappa_z z_0)\frac{\int_0^h F(z)\exp(i\kappa_z z)dz}{\int_0^h F(z)dz}$$

The simples case is **random volume**

Variables

- ***h – forest height***
- *σ – mean extinction coefficient*
- *θ_0 – incidence angle*
- *κ_z – baseline parameter*
- *φ_0 – ground phase*
- *$M(\omega)$ – ground to volume ratio*

$$\gamma_{RVoG}(\vec{\omega}) = \exp(i\varphi_0)\frac{\gamma_V + m(\vec{\omega})}{1 + m(\vec{\omega})}$$

$$m(\vec{\omega}) = \frac{m_G(\vec{\omega})}{m_V(\vec{\omega})}$$

Inversion of the model

$$\begin{bmatrix} |\gamma|(\vec{\omega}_1) \\ \varphi(\vec{\omega}_1) \\ |\gamma|(\vec{\omega}_2) \\ \varphi(\vec{\omega}_2) \\ |\gamma|(\vec{\omega}_3) \\ \varphi(\vec{\omega}_3) \end{bmatrix}$$

Measurement vector, one pixel

$$|\gamma|(\vec{\omega})e^{i\varphi(\vec{\omega})} = F\begin{bmatrix} h \\ \sigma \\ \varphi_0 \\ M_1 \\ M_2 \\ M_3 \end{bmatrix}$$

Model parameter vector

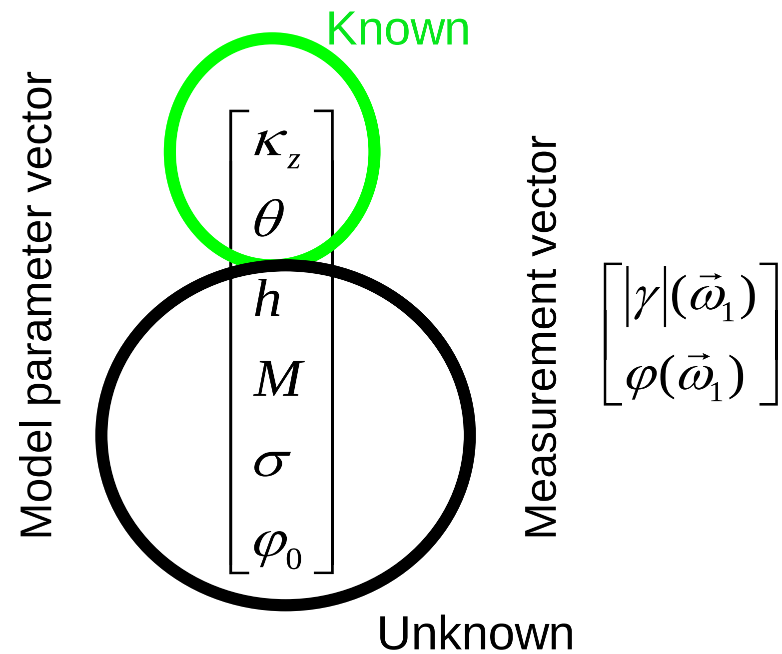
⇒

In case of fully polarimetric measurement the RVoG model can be inverted for any parameter

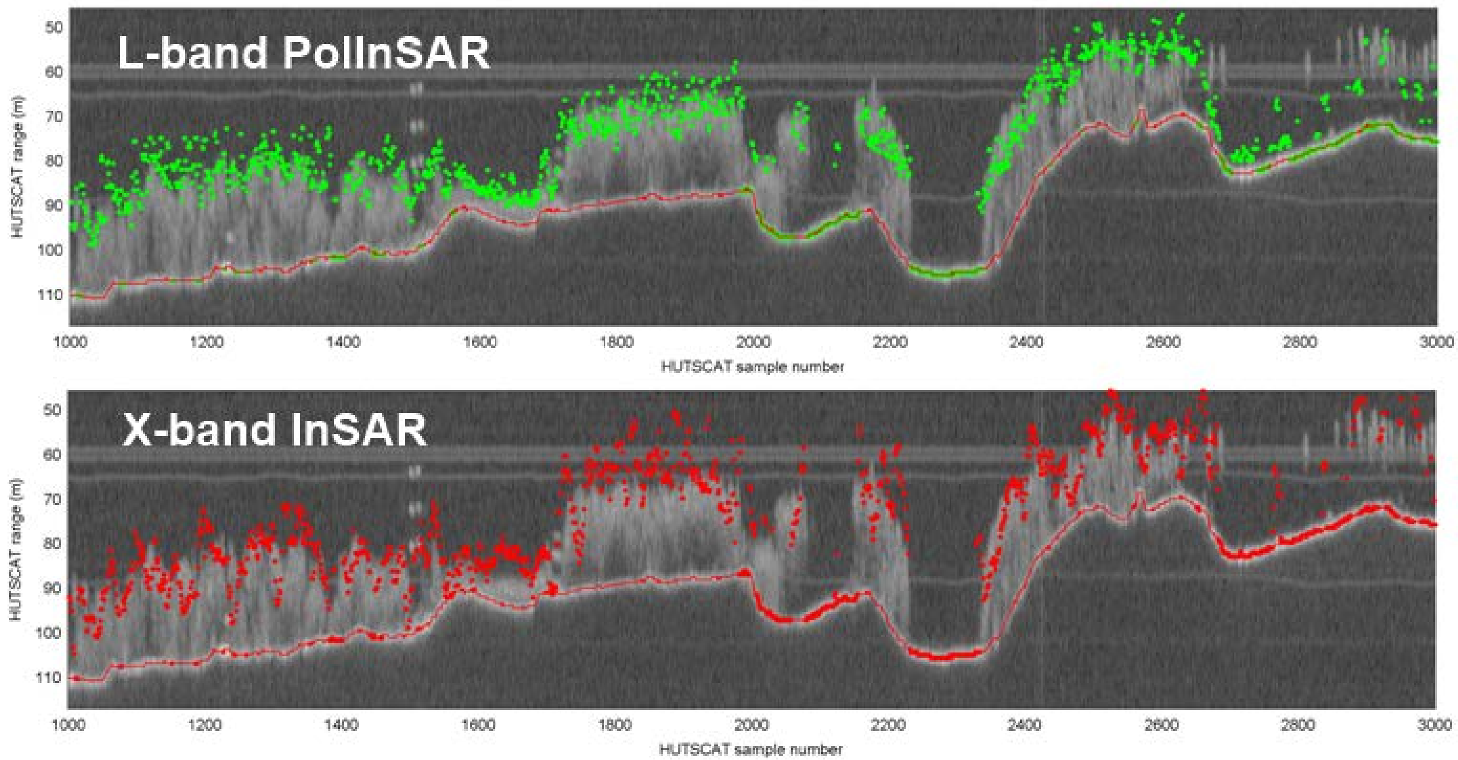
But if you don’t have fully polarimetric data?

Possibilities

- **Fix some parameters**
- **Use ancillary data**
- **Simplify the model**
- **Use semi empirical models**



Airborne X-band InSAR and forest height



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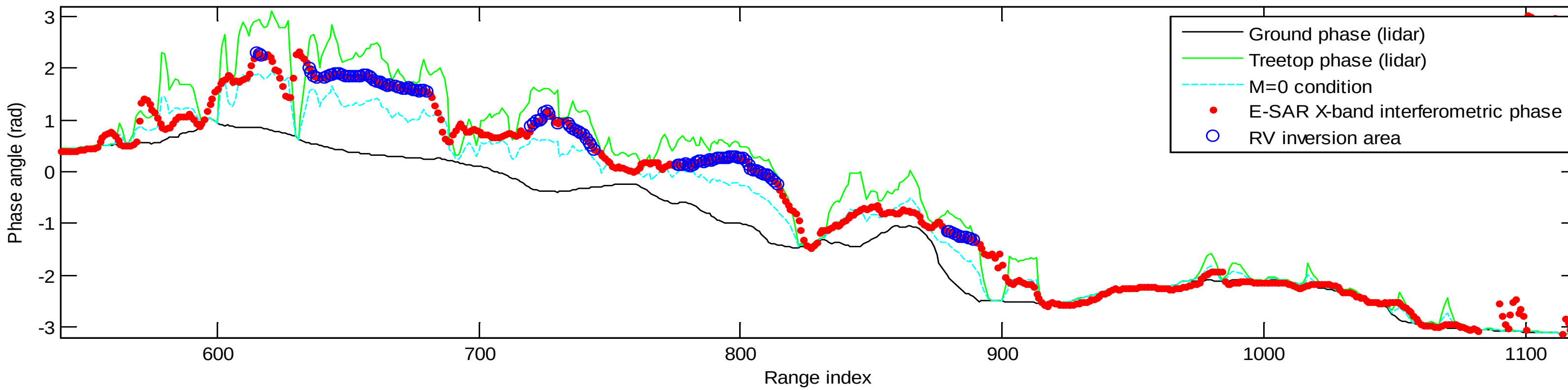
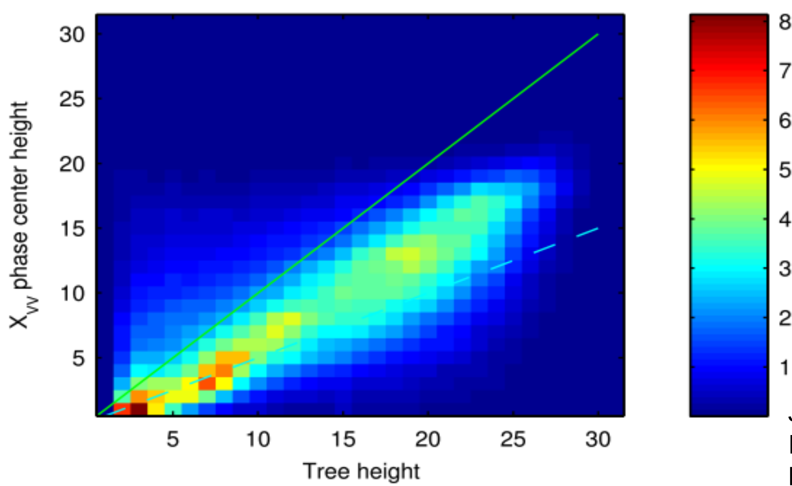
J. Praks, F. Kugler, K. P. Papathanassiou, I. Hajnsek, and M. Hallikainen. “Height Estimation of Boreal Forest: Interferometric Model-Based Inversion at L- and X-Band Versus HUTSCAT Profiling Scatterometer”. In: IEEE Trans. Geosci. Remote Sensing Letters 4.3 (2007), pp. 466–470.

Phase center location at X-band

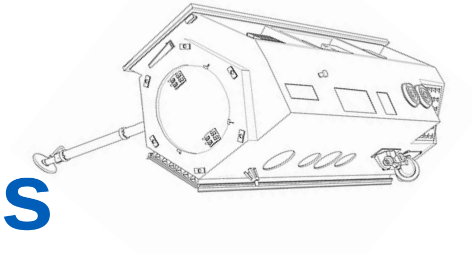




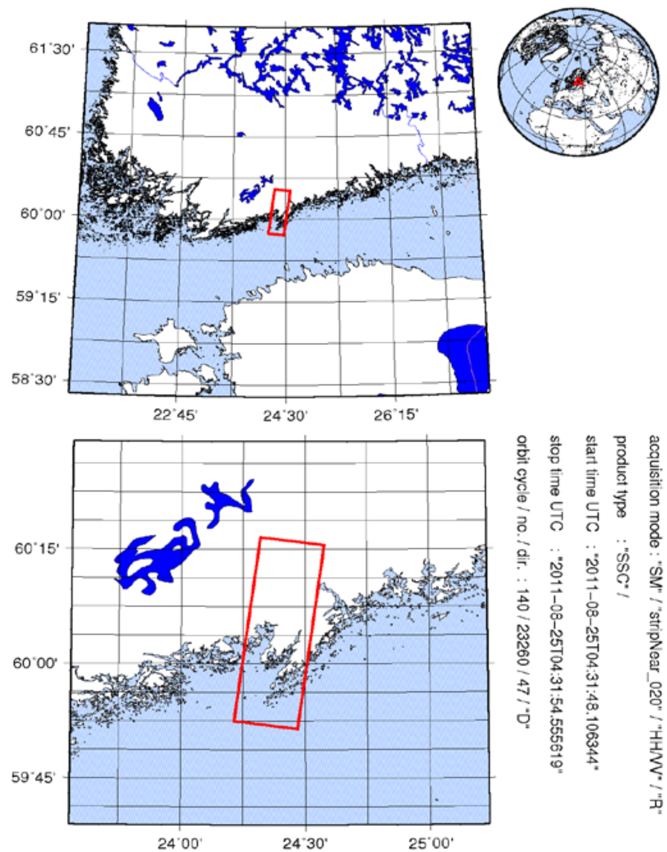
X-band phase center is in the upper quarter of the tree height and ground contribution to the signal is low.

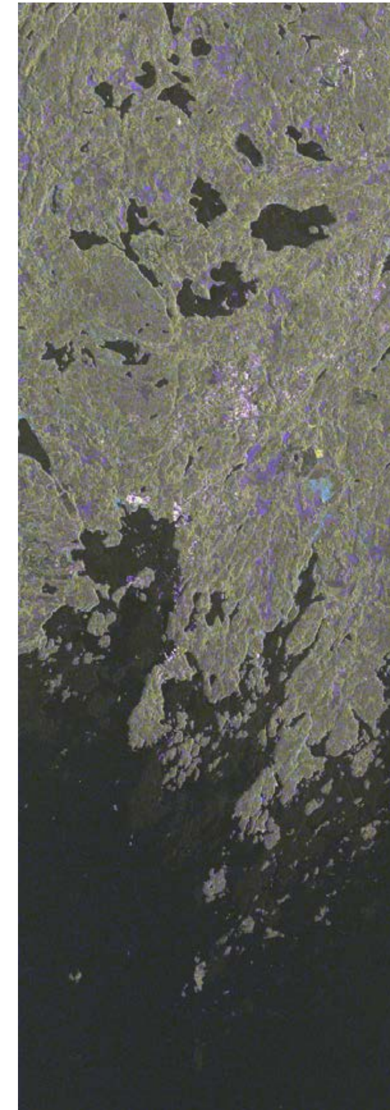
J. Praks, O. Antropov, and M. T. Hallikainen. “LIDAR-Aided SAR Interferometry Studies in Boreal Forest: Scattering Phase Center and Extinction Coefficient at Xand L-Band”. In: IEEE Transactions on Geoscience and Remote Sensing 50.10 (2012), pp. 3831–3843.

Material:
TanDEM-X images



August 25
2011





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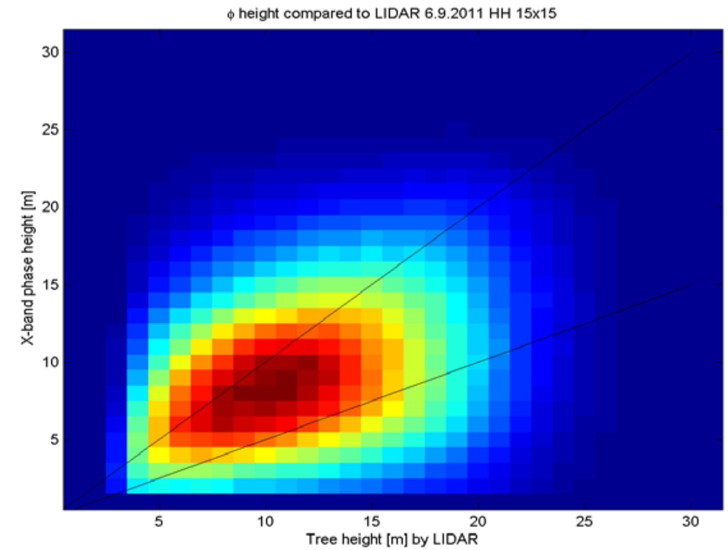
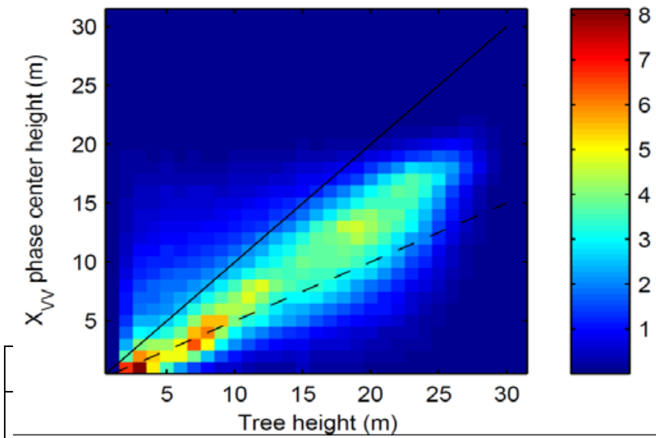
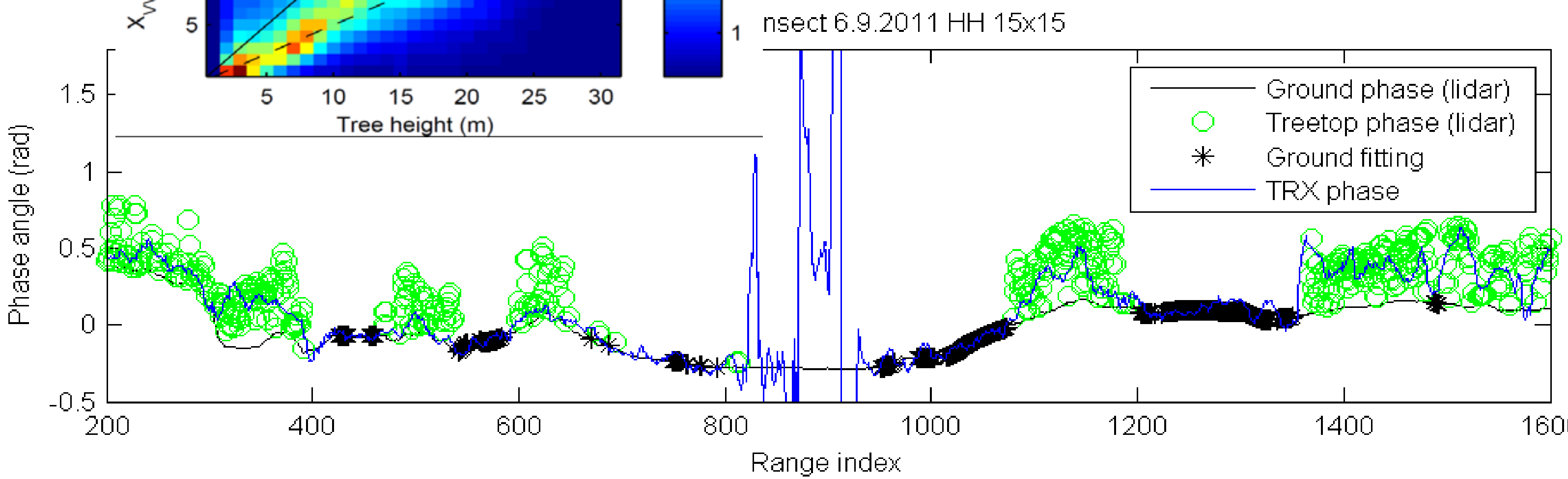
X-band scattering center in the forest







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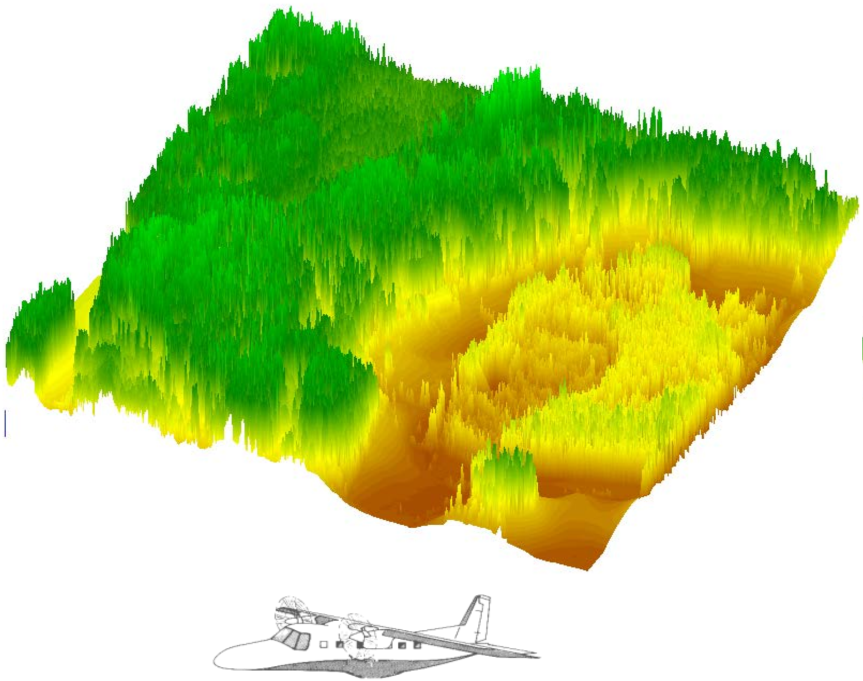
Jaan Praks, Martti Hallikainen, Oleg Antropov, Daniel Molina, "Boreal forest tree height estimation from interferometric TanDEM-X images,"*Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International*, pp.1262-1265, Munich, Germany, 22-27 July 2012

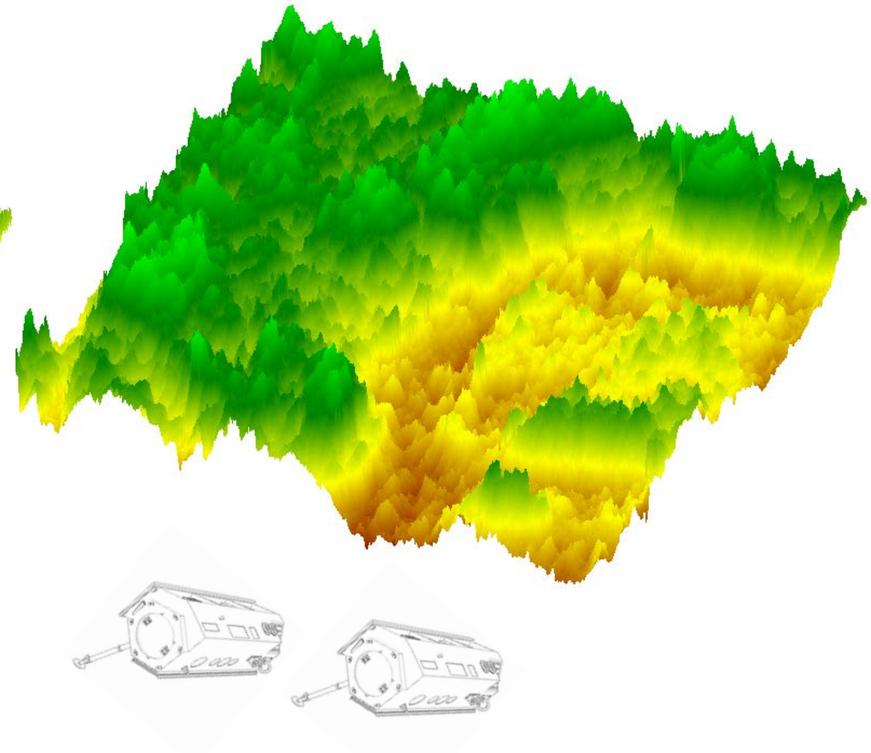
LIDAR ground model with trees

Airborne measurement



TanDEM-X ground model with trees

Spaceborne measurement



Jaan Praks, Martti Hallikainen, Oleg Antropov, Daniel Molina, "Boreal forest tree height estimation from interferometric TanDEM-X images,"*Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International*, pp.1262-1265, Munich, Germany, 22-27 July 2012

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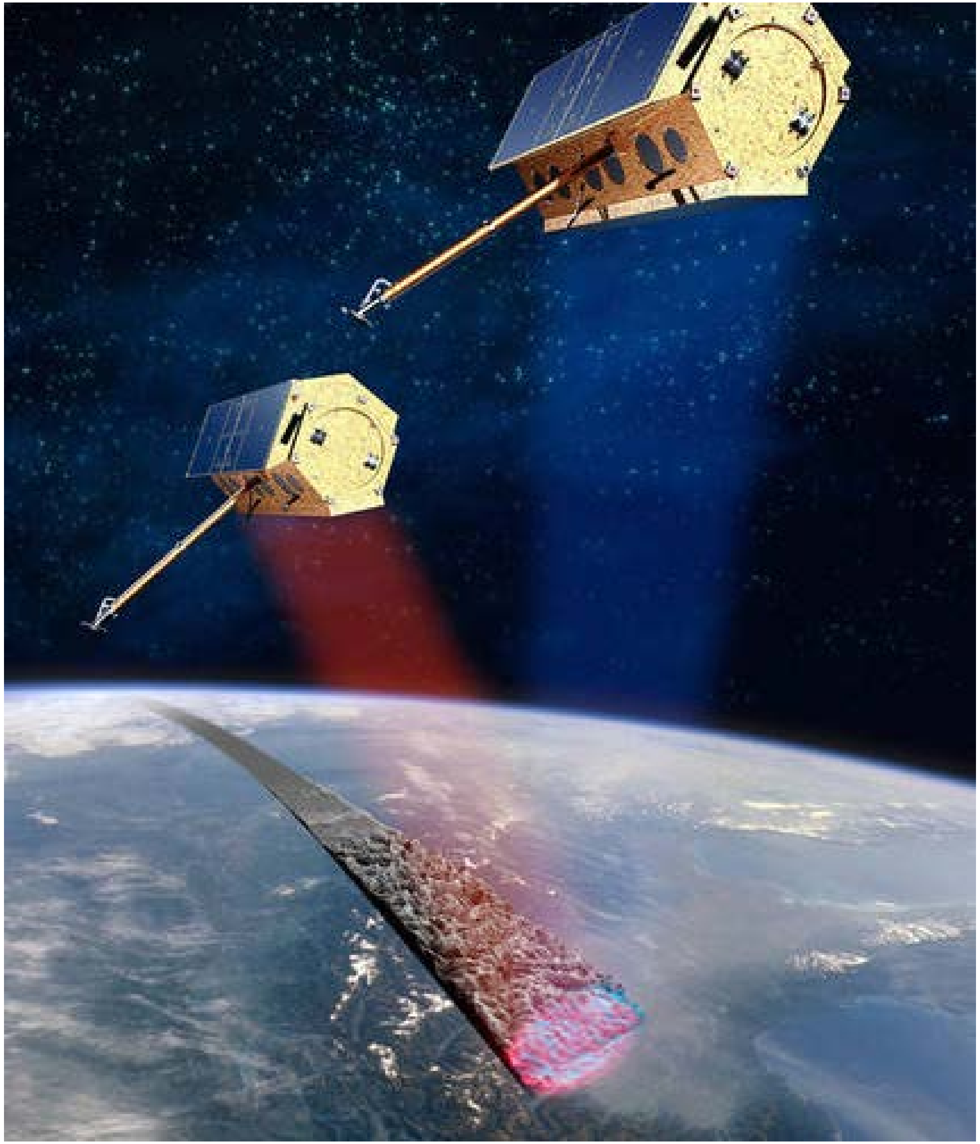
Using coherence amplitude of spaceborne SAR?

TanDEM-X mission



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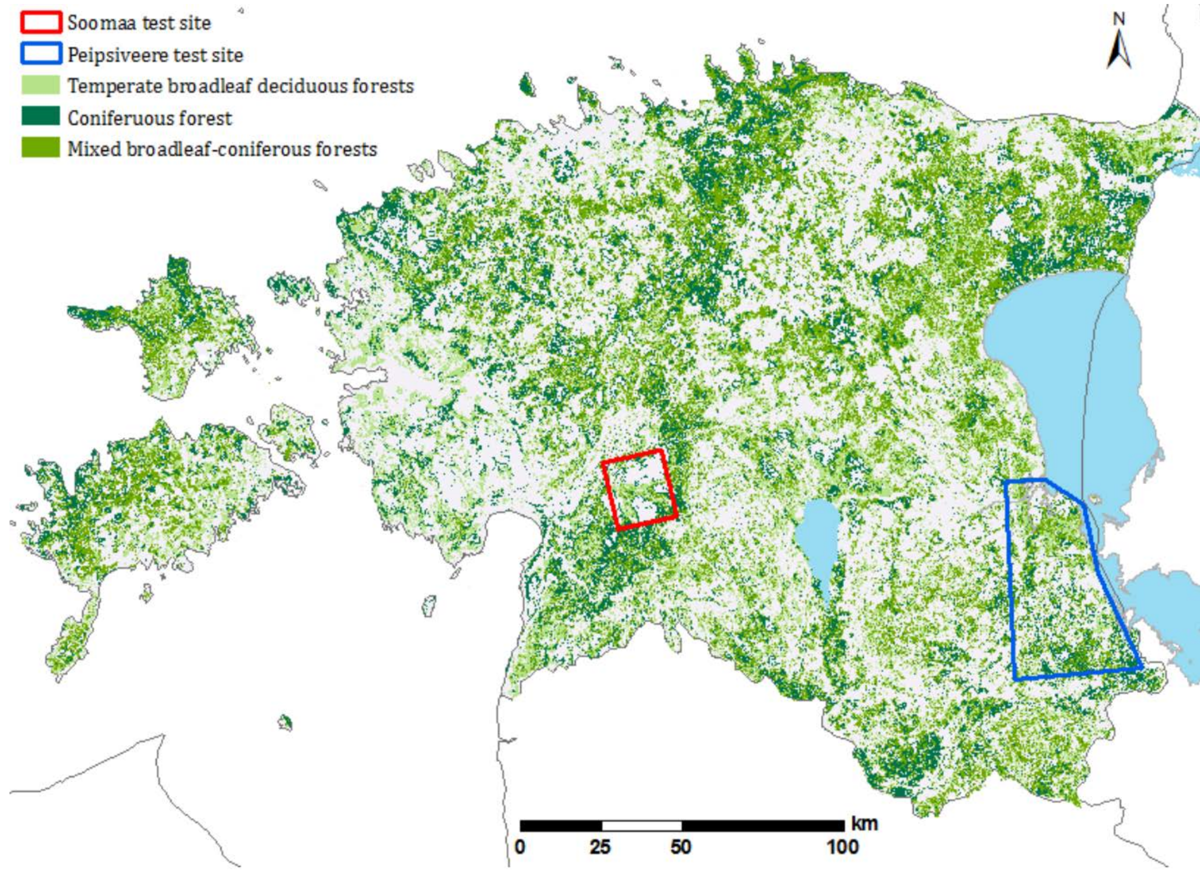
Multitemporal Data

19 TDX images from Estonia 2010-2012

&

ALS forest height



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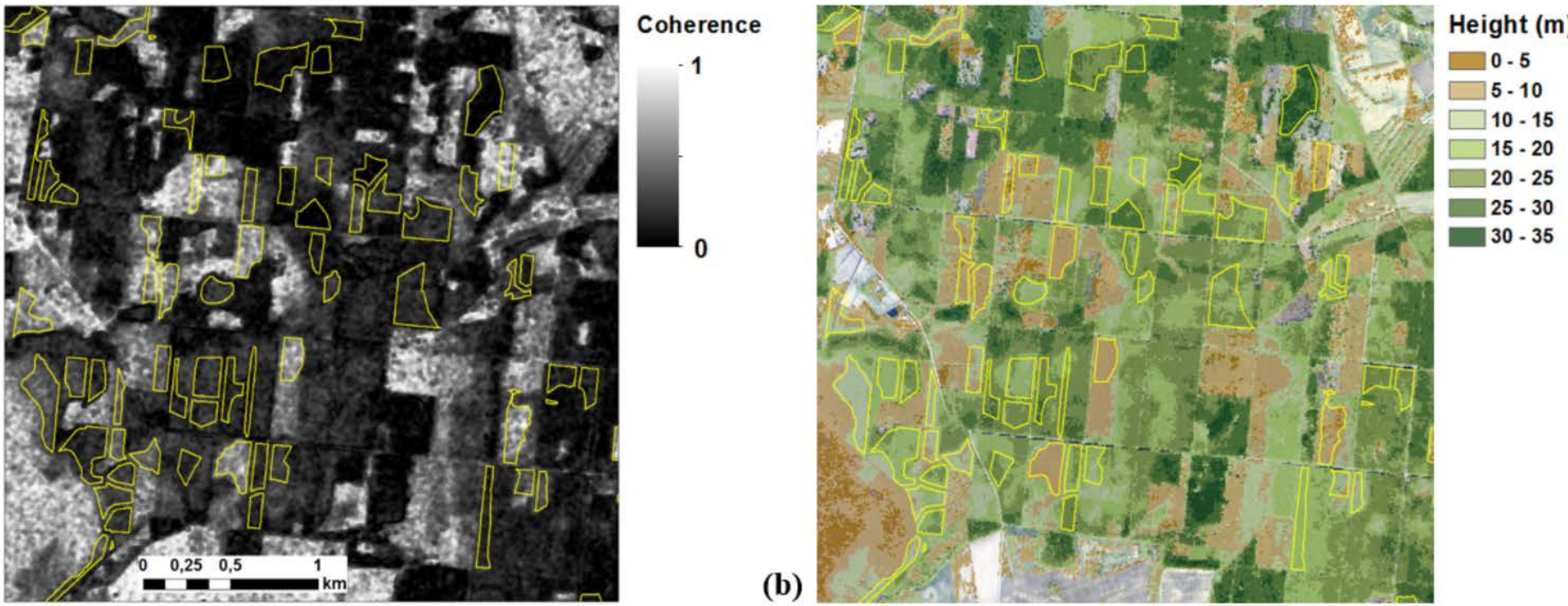
19 TDX InSAR pairs

2010-2012

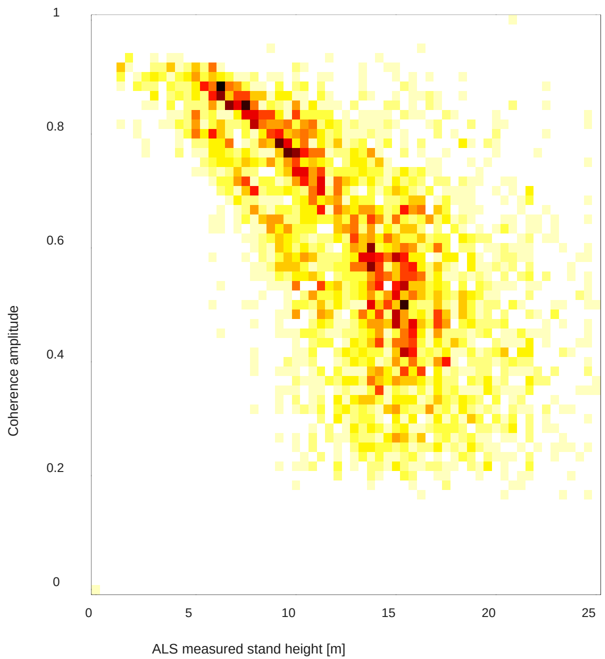
ID	Date	Incidence Angle (°)	HoA (m)	Minimum Ground Temperature (°C)
1	29 December 2010	44.6	41.4	−9.2
2	1 August 2011	36.2	45.9	12.0
3	3 March 2012	23.4	44.7	−5.3
4	8 March 2012	34.8	66.2	−22.9
5	14 March 2012	23.4	43.6	−5.5
6	25 March 2012	23.4	43.9	−3.5
7	5 April 2012	23.4	16.2	−8.4
8	5 April 2012	18.2	41.8	−8.4
9	15 April 2012	45.2	30.8	−2
10	02 May 2012	34.8	24.7	−2.2
11	18 May 2012	43.4	32.7	6.5
12	30 May 2012	23.4	18.5	6.6
13	3 October 2012	34.8	33.7	5.6
14	11 November 2012	23.3	19.7	−0.2
15	16 November 2012	34.8	31.8	0.6
16	4 January 2011	44.6	41.6	-13.4
17	9 September 2011	36.2	48.2	7.3
18	30 March 2012	45.2	30.1	0.0
19	5 November 2012	43.4	33.6	1.6

Stand averages for coherence and tree height



(a) (b)

Stand height vs coherence amplitude



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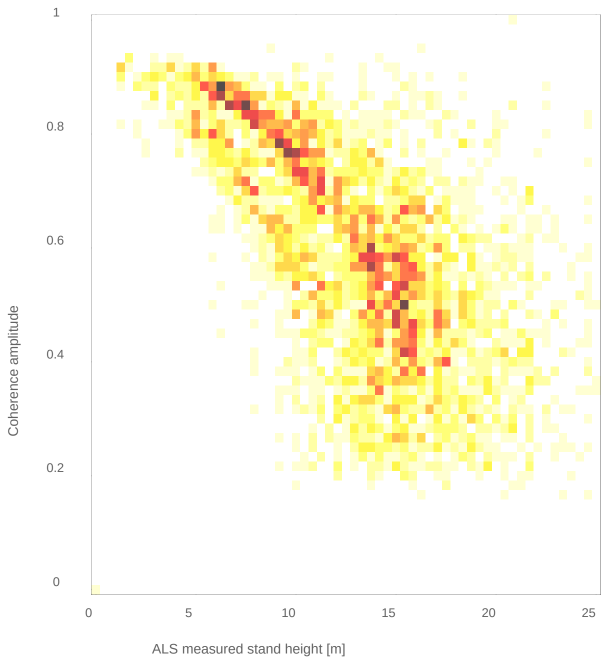
Stand height relative to HoA vs coherence



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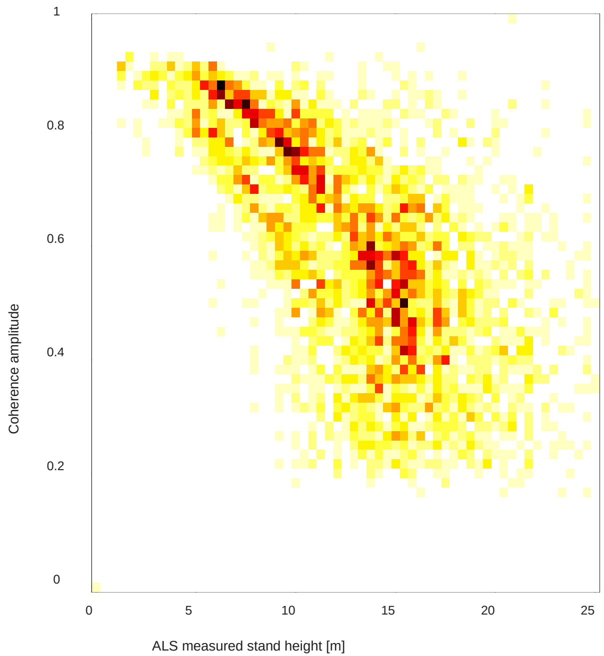
A. Olesk, J. Praks, O. Antropov, K. Zalite, T. Arumäe, and K. Voormansik. “Interferometric SAR Coherence Models for Characterization of Hemiboreal Forests Using TanDEM-X Data”. In: Remote Sensing 8.9 (2016), p. 700. issn: 2072-4292. doi: 10.3390/rs8090700. url: http://www.mdpi.com/2072-4292/8/9/700.

Inversion with simple linear model



Simplifications of RVoG model

Simplification and semi-empirical parametrization helps to make coherence models invertible with restricted amount of measurements

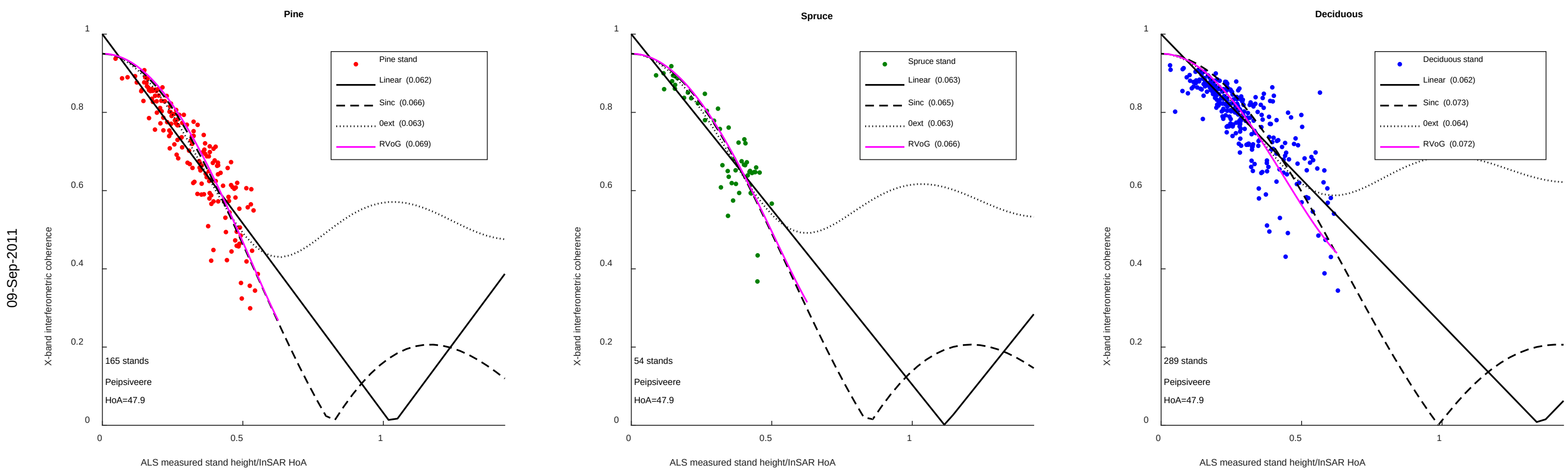
$$|\gamma_{linear}| = 1 - \frac{h}{HoA} C_{lin}$$

$$|\gamma_{sinc}| = 0.95 \cdot sinc\left(C_{sinc}\pi \frac{h}{HoA}\right)$$

$$\gamma_{0ext} = \left[\left(1 - e^{i2.4\pi\frac{h}{HoA}}\right)\frac{HoA}{h}\frac{i}{2.4\pi} - 1\right]\frac{1}{C_{0ext}} + 0.95$$

A. Olesk, J. Praks, O. Antropov, K. Zalite, T. Arumäe, and K. Voormansik. “Interferometric SAR Coherence Models for Characterization of Hemiboreal Forests Using TanDEM-X Data”. In: Remote Sensing 8.9 (2016), p. 700. issn: 2072-4292. doi: 10.3390/rs8090700. url: http://www.mdpi.com/2072-4292/8/9/700.

X-band coherence vs h/HoA September 2011



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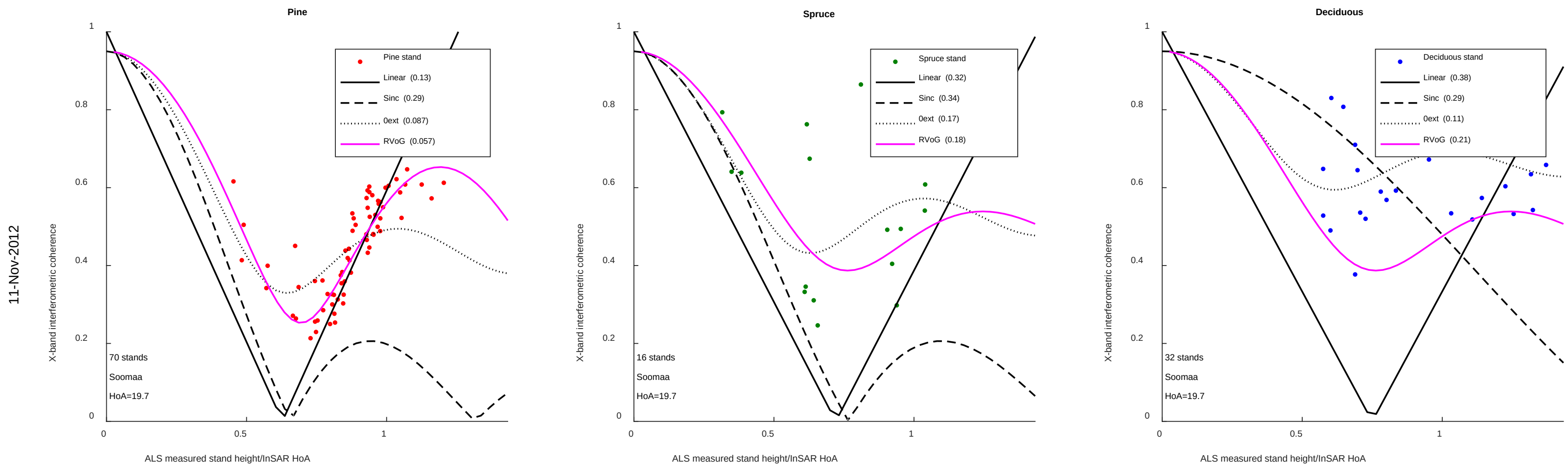
X-band coherence vs h/HoA November 2011



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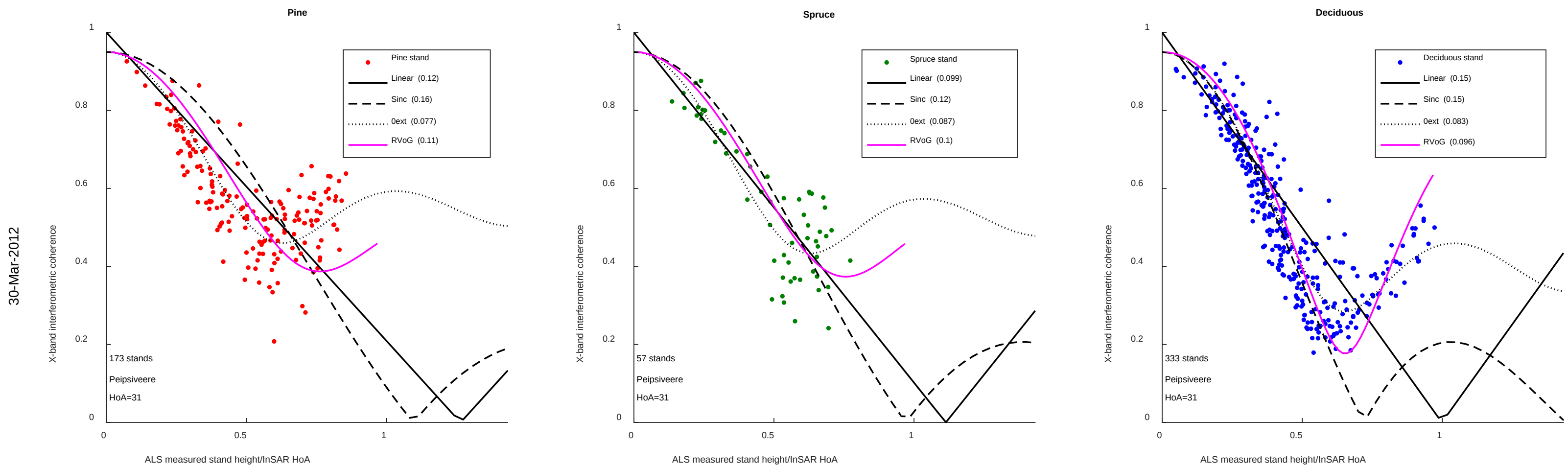
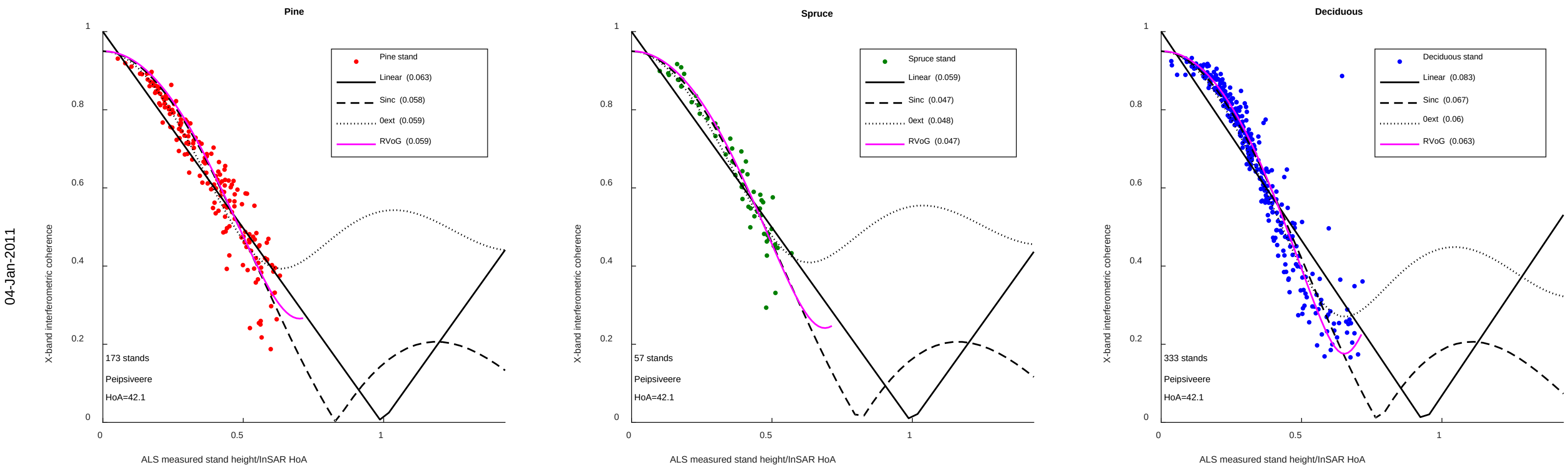
X-band coherence vs h/HoA March 2012



X-band coherence vs h/HoA January 2011



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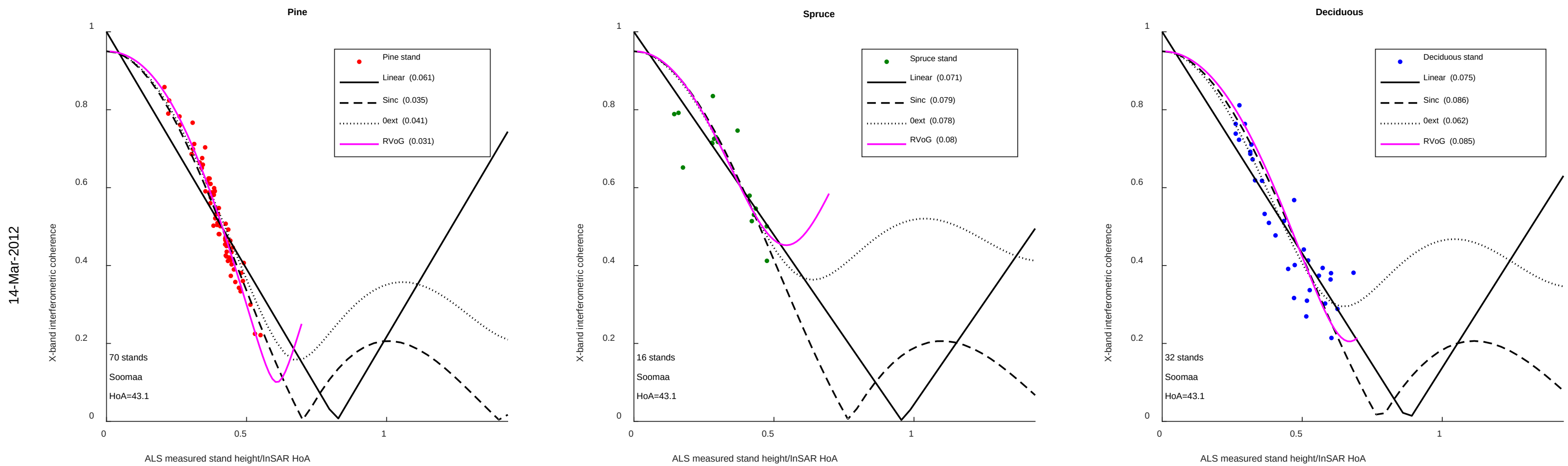
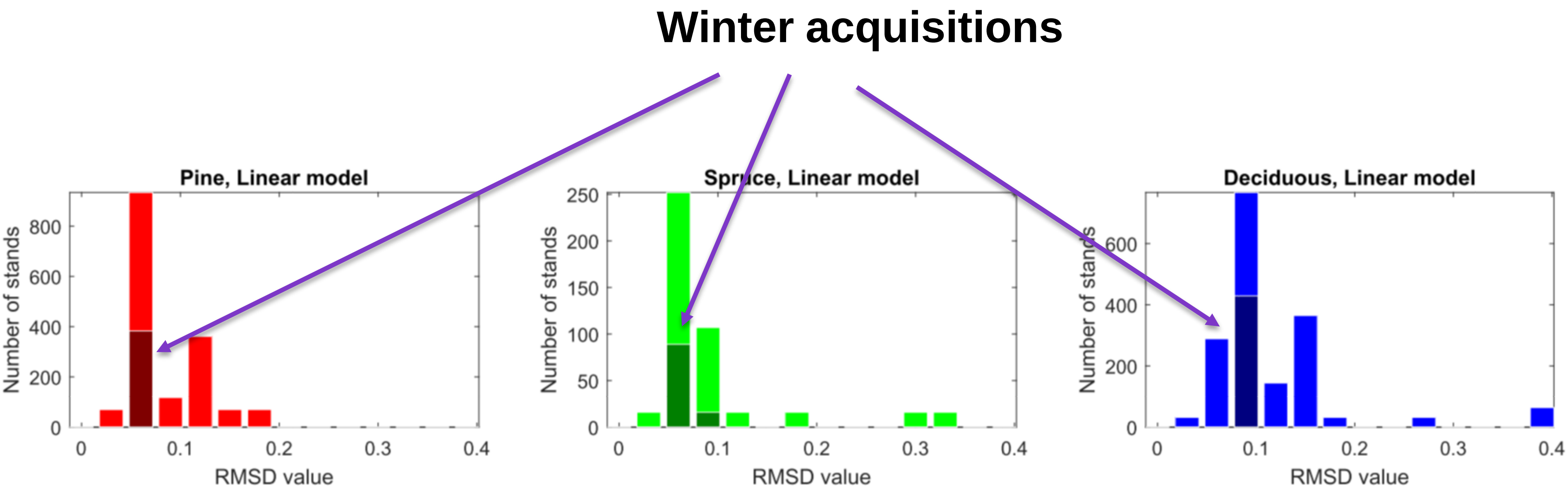
X-band coherence vs h/HoA March 2012



Model fit with data over 19 scenes



What happens in winter?

Forest scene properties during cold and dry weather at X-band

- *Extinction is low*
- *Ground reflection is low and even*
- *Missing leaves make decidious forest more homogeneous*
- *Coniferous forest is more even*

Simplifications of RVoG for easy inversion

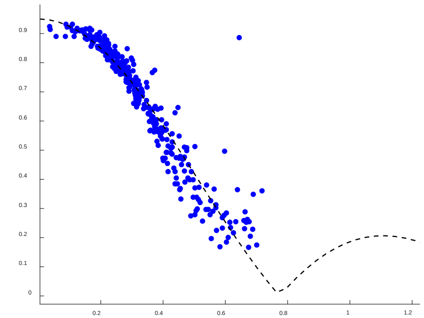
$$h_{lin} = \left(1 - \left|\gamma_{lin}\right|\right)\frac{HoA}{C_1} \qquad 0.9 \le C_1 \le 1.2$$

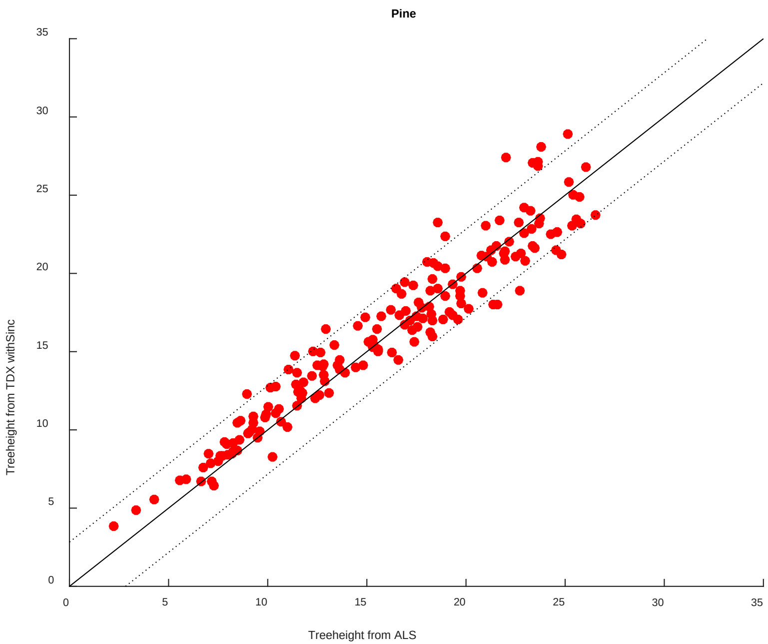
$$h_{\sin c} = \text{sinc}^{-1}\left(\frac{|\gamma|}{0.95}\right)\frac{HoA}{C_2} \qquad 1.1 \le C_2 \le 1.3$$

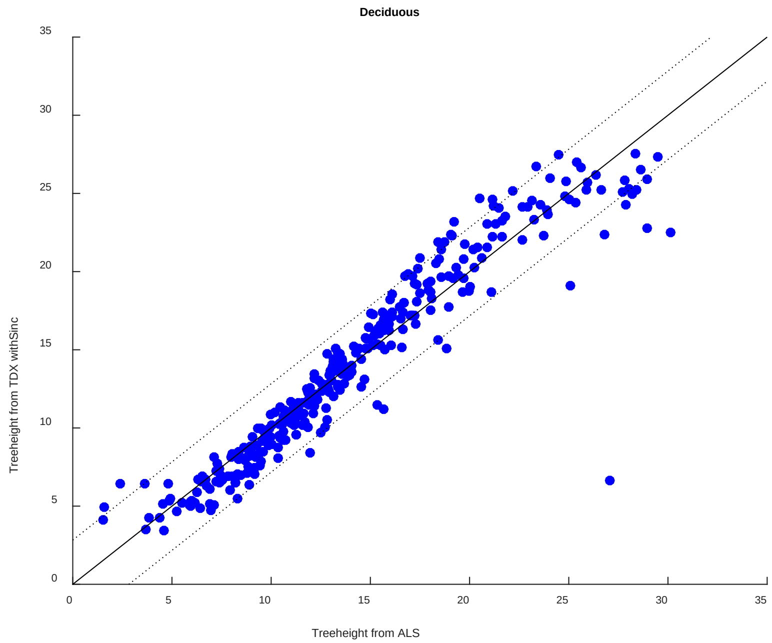
$$h_{\sin c} = \text{sinc}^{-1}\left(\frac{|\gamma| - 0.95}{C_3} + 1\right)HoA \qquad 0.4 \le C_3 \le 0.6$$

$$HoA = \frac{2\pi}{\kappa_z}$$

Simple sinc model







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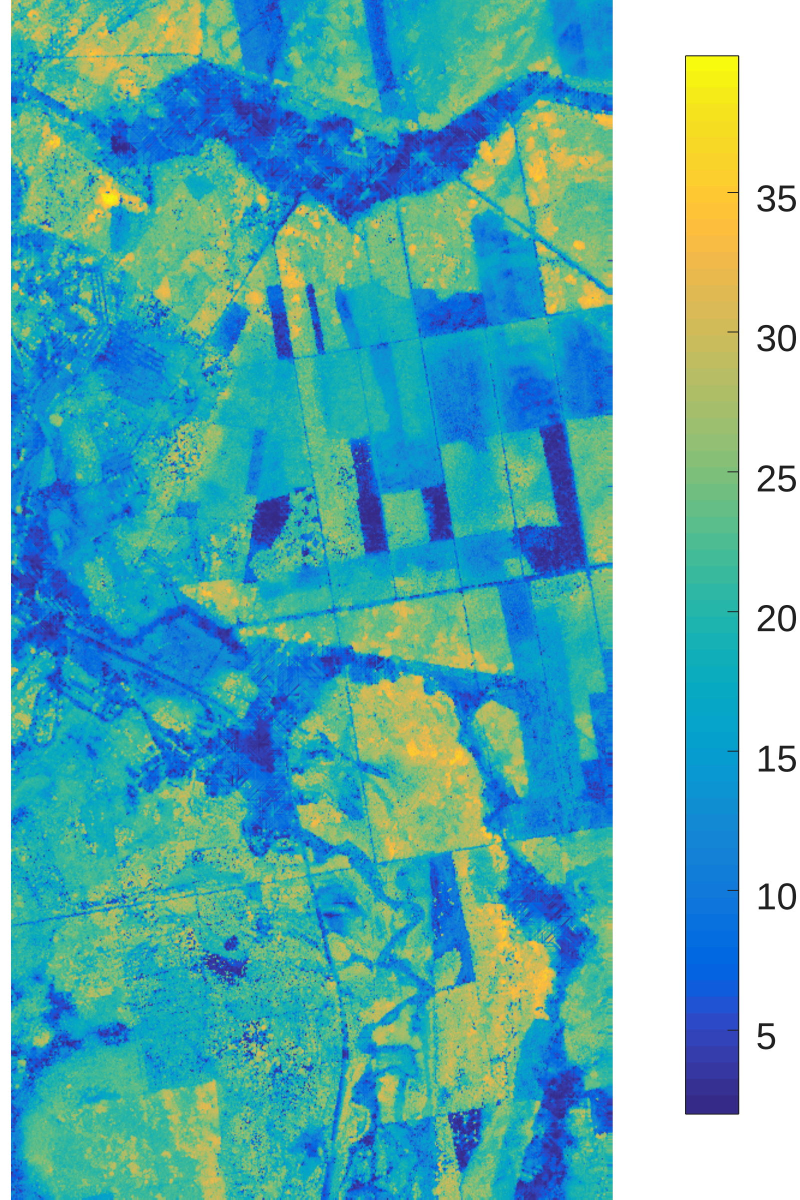
Tree height Map Lidar (m)



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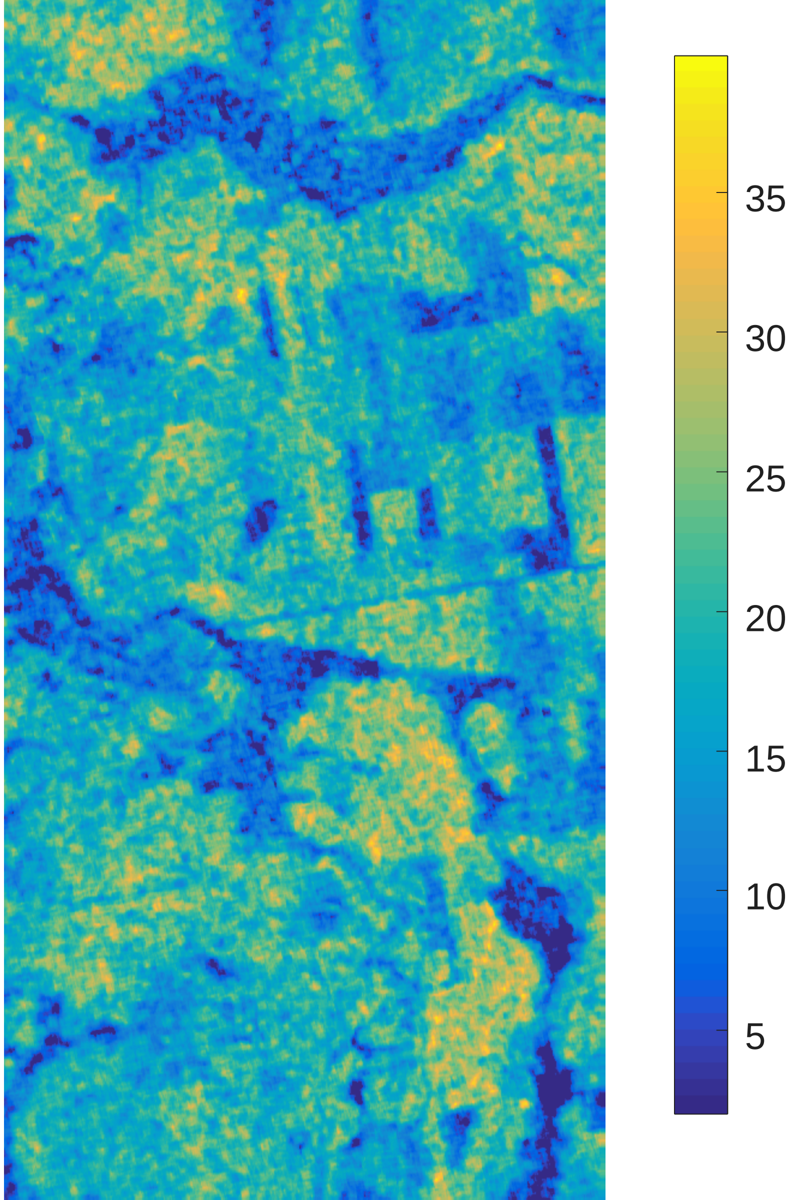
Tree height Map TanDEM-X (m)



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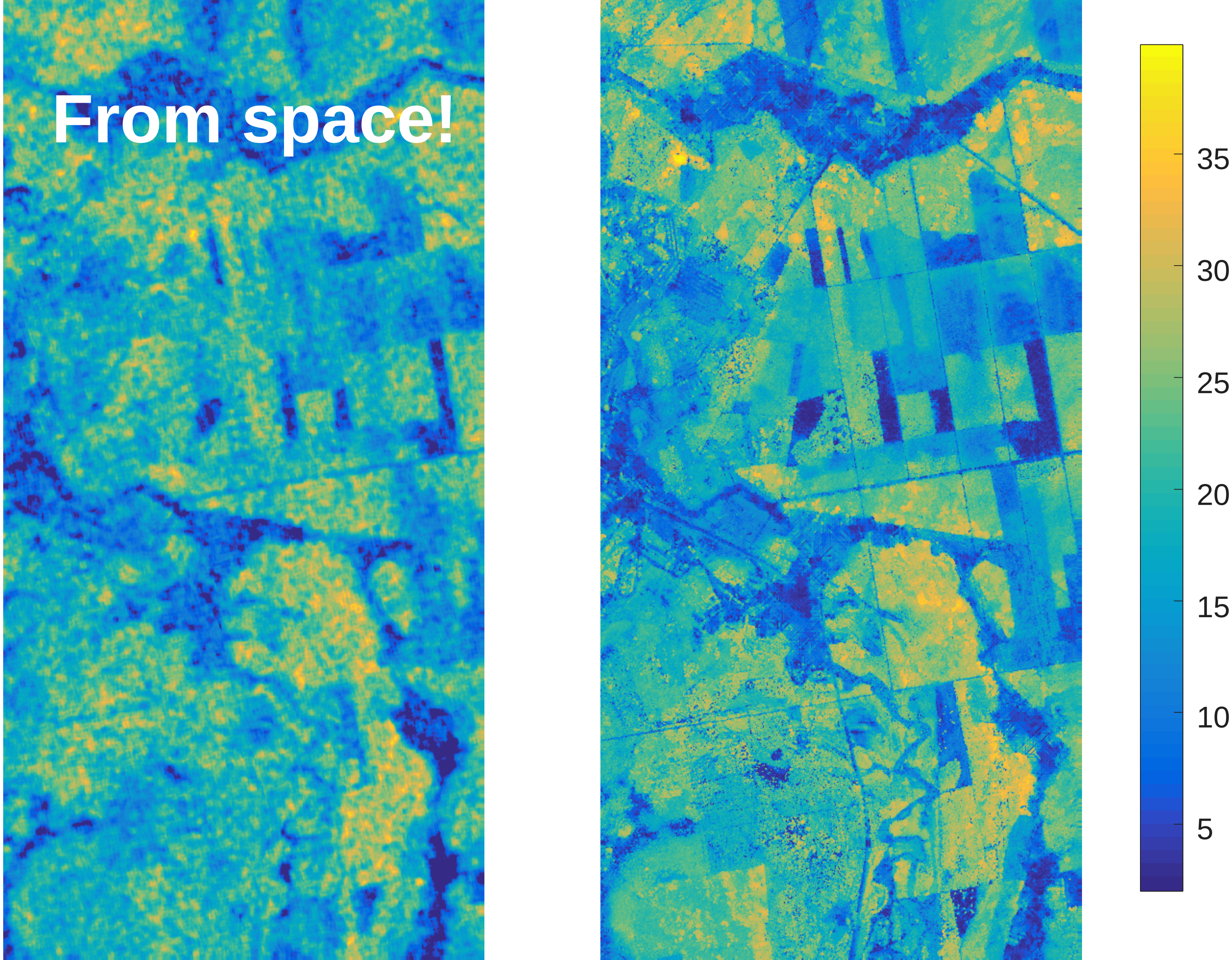
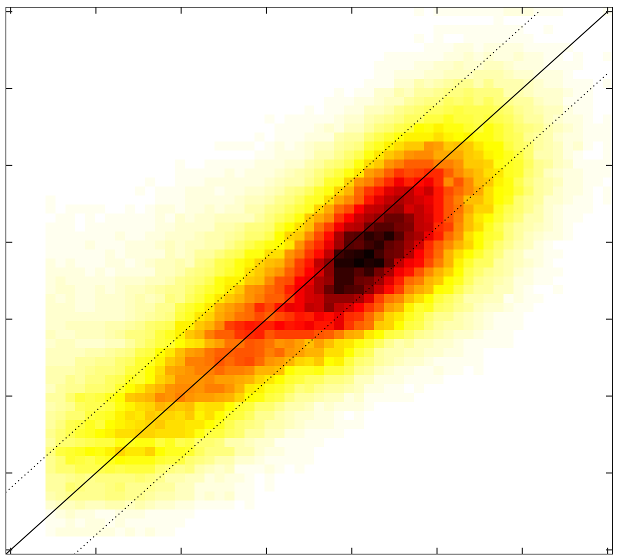
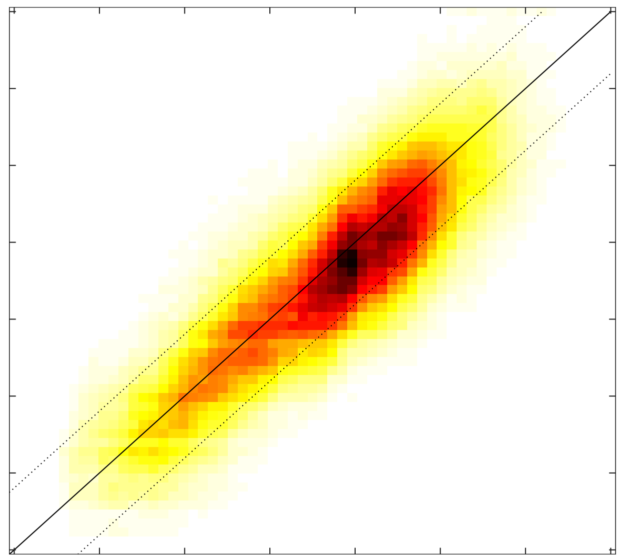

From space!
35
30
25
20
15
10
5

ALS height vs TDX height

Pixel by Pixel



Averaged ALS height map



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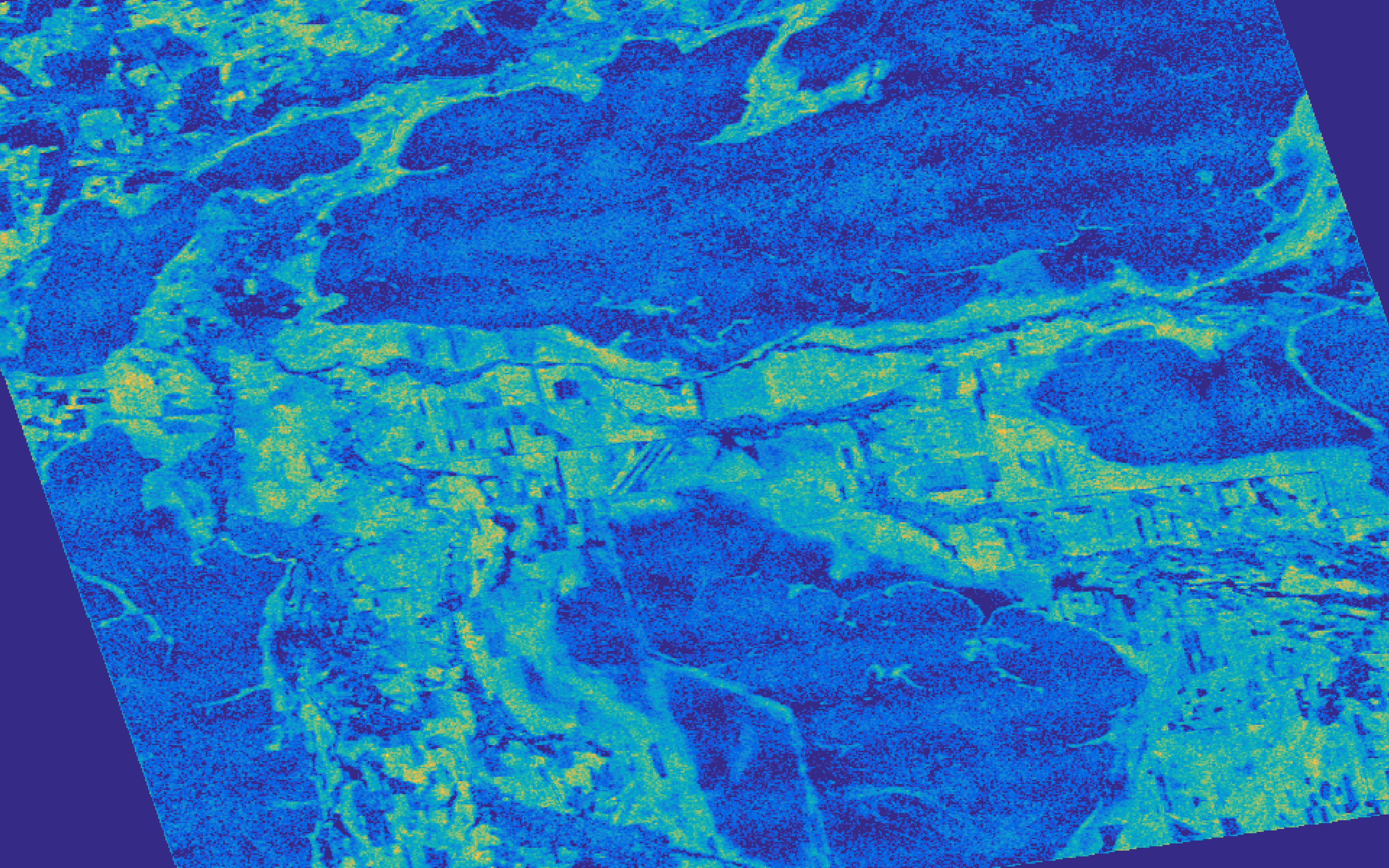
Conditions for deriving forest height from X-band interferometry

- **Single pass interferometry**
- **Winter or dry scenes**
- **Baseline should give Height of Ambiguity (HoA) two times bigger than max tree height**



Conclusions

X-band spaceborne Interferometric SAR has untapped potential in forest remote sensing

TandDEM-X should be able to deliver accurate tree height from space with rather high resolution

Several forest structure parameters could be derived from spaceborne Interferometric SAR images

- *Stand height*
- *Gap fraction*
- *Ground DEM*
- *Extinction*

Possibilities

Biomass mapping of arid areas

- Savannas
- Olive plantations

ALS alternative

- Large areas
- Poor countries

Thank you for your attention!

Freedom to succeed

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SAR interferometry

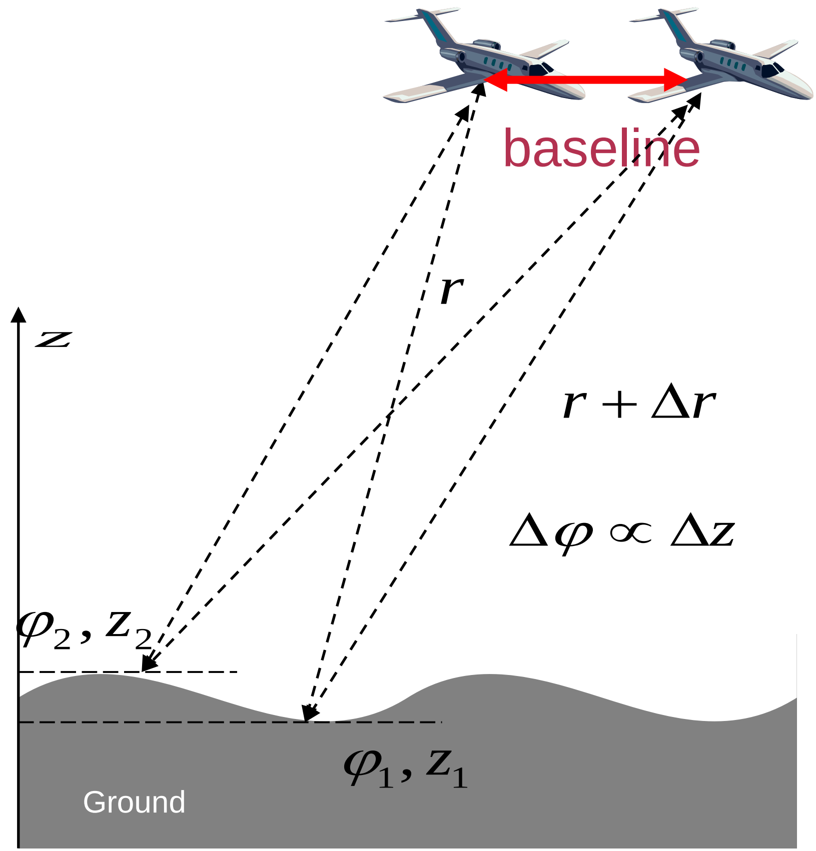
Interferometry uses two SAR images to calculate the complex coherence between the images

$$\hat{\gamma} = \frac{\langle s_1 s_2^* \rangle}{\sqrt{\langle |s_1^2| \rangle \langle |s_2^2| \rangle}}$$

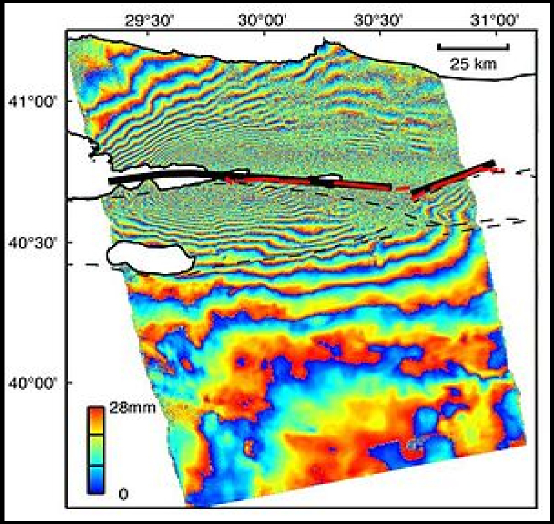
The phase of the coherence is proportional to spatial elevation differences

The magnitude of the coherence is proportional to scatterer randomness and/or change in placement

Measurement of coherence allows to calculate the thickness of the random scatterer, for example forest height



Interferometry



Polarimetry

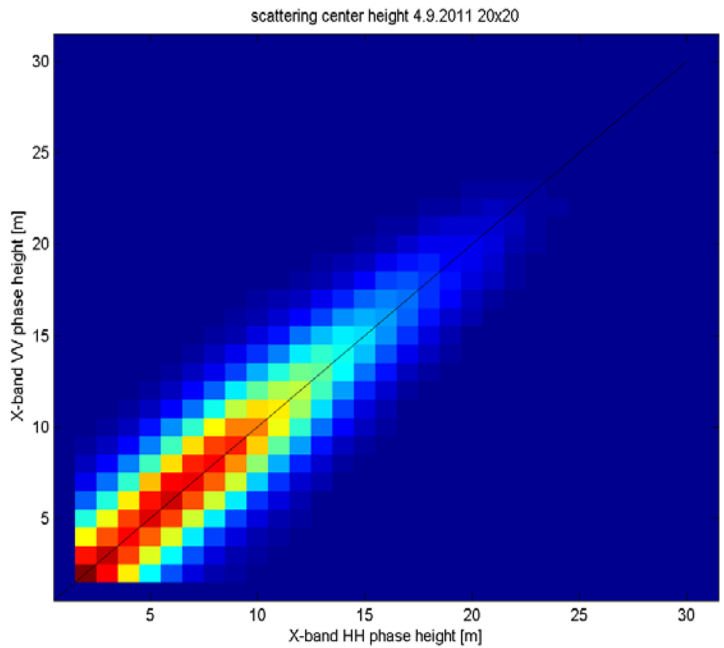
+

= Polarimetric Interferometry

Interferometric phase center location above ground, HH pol vs VV pol

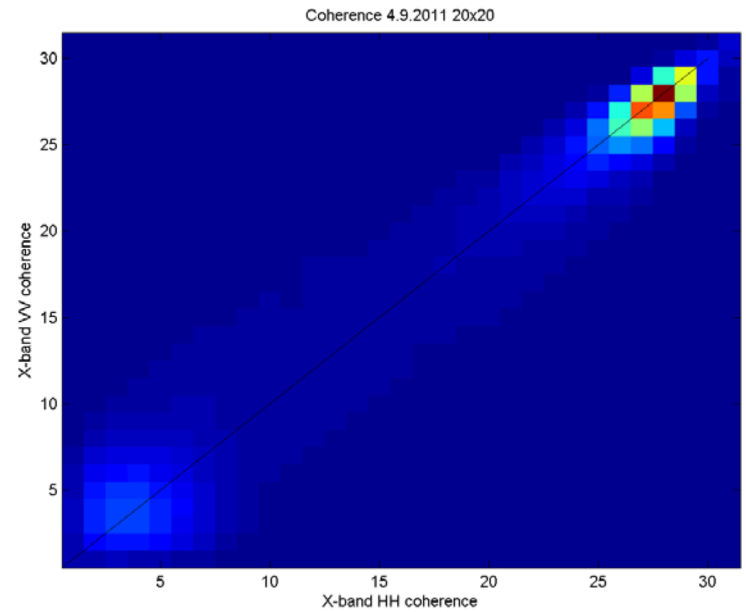
X-band penetration depth to forest does not depend on polarization.

This means that even fully polarimetric measurement would probably not allow to invert RVoG model for tree height.



X-band interferometric coherence HH pol vs VV pol

Coherence depends slightly on polarization. The dependance is probably too small for RVoG model inversion with fully polarimetric data.

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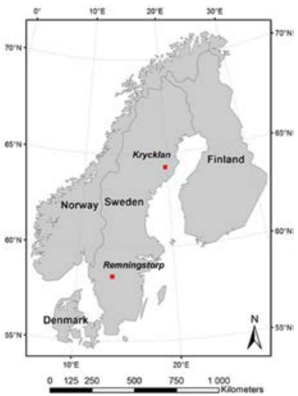
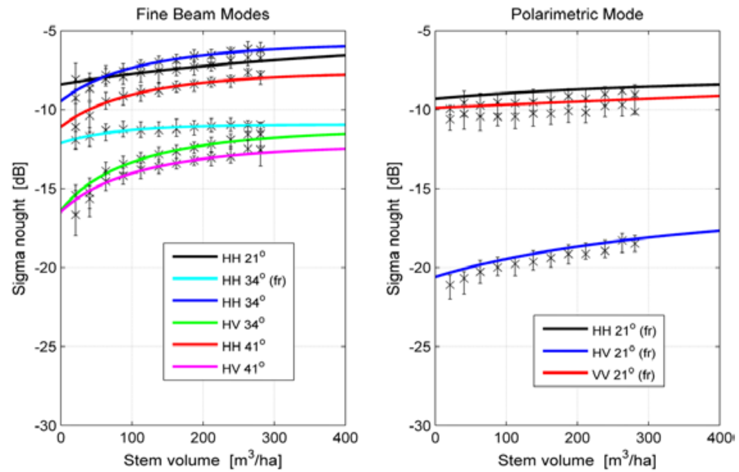
ALOS PALSAR in biomass estimation



Study area



Dependence of SAR backscatter on stem volume

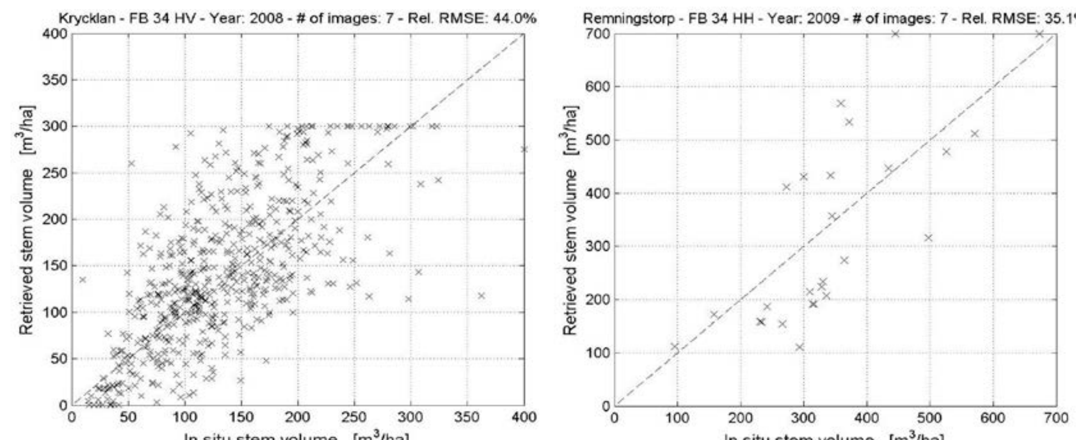
Semi-empirical model based inversion of L-band backscatter;

ALOS PALSAR data are used (several images) with stand-level forest inventory;

Final output estimate – "weighted" combination of stem volume retrived from several ALOS PALSAR scenes

$$\sigma^o_{for} = \sigma^o_{gr} e^{-\beta V} + \sigma^o_{veg}\left(1 - e^{-\beta V}\right)$$

$$V_{est} = -\frac{1}{\beta}\ln\left(\frac{\sigma^o_{veg} - \sigma^o_{for,meas}}{\sigma^o_{veg} - \sigma^o_{gr}}\right)$$



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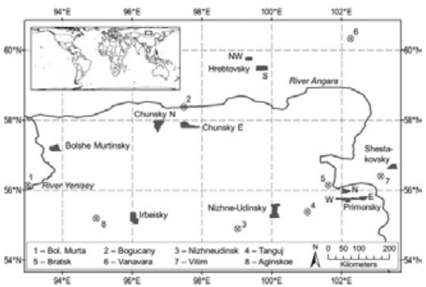
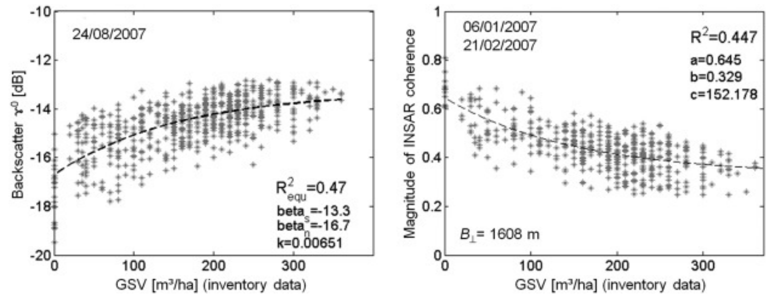
Santoro et al. " Reviewing ALOS PALSAR backscatter observations for stem volume retrieval in Swedish forest," Remote Sensing, 7(4), 2015.

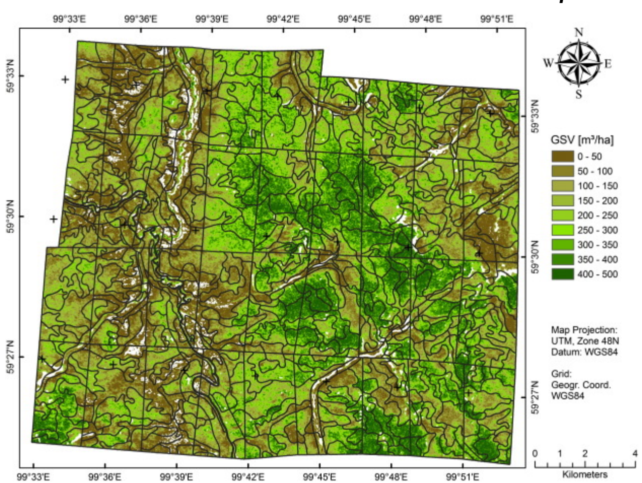
ALOS PALSAR in biomass estimation



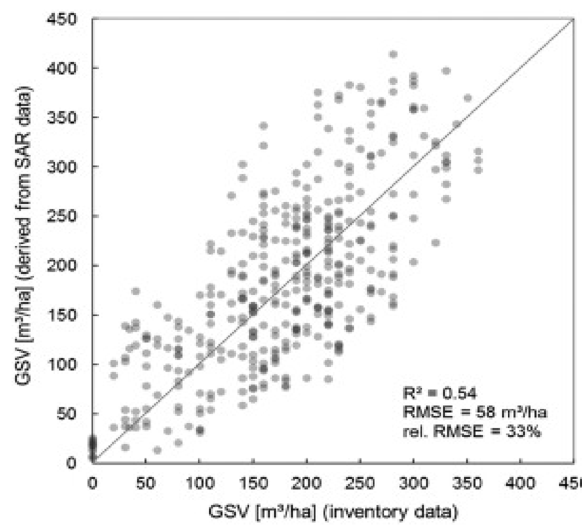
Study area in Central Siberia



Dependence of backscatter and coherence on GSV



Sample tree height map



Overall accuracies on stand-level

Combined use of backscatter and InSAR coherence for biomass (GSV) estimation;

ALOS PALSAR data – 87 frozen and unfrozen SLC images;

SAR backscatter and InSAR coherence are used in training; suitable semi-empirical models are employed.

Training using 20% of reference data, each scene individually and then combining outputs from backscatter and coherence images.

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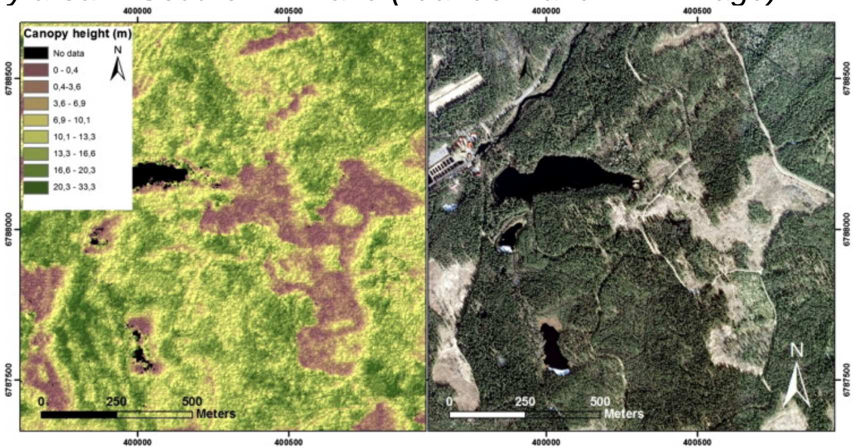
Thiel, Schmullius, " The potential of ALOS PALSAR backscatter and InSAR coherence for forest growing stock volume estimation in Central Siberia," Remote Sens. Env., 173, pp. 258-273, 2016.

TanDEM-X in biomass estimation

Study area in Southern Finland (lidar dem and VHR image)

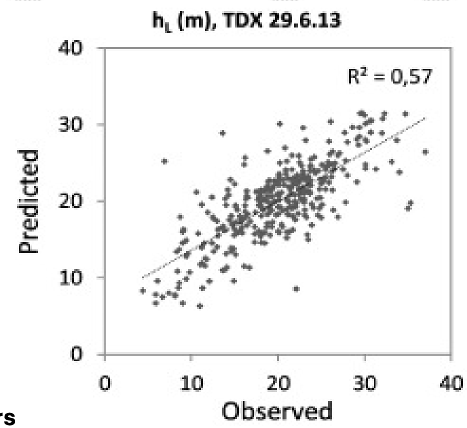


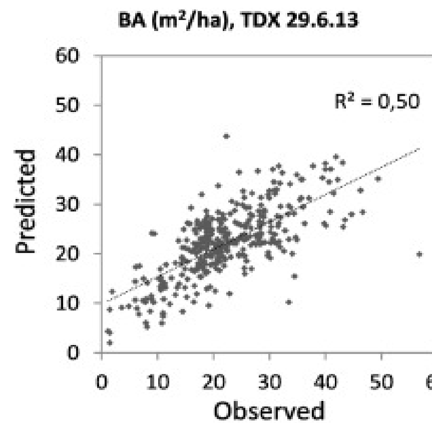
Forest parameter estimation directly from TanDEM-X scene features;

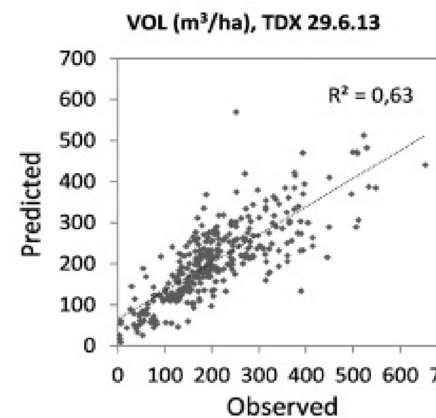
5 COSSC scenes, HoA=45-71 m;

Supervised plot-level approach, NN method with random-forest search was used.

InSAR CHM metrics used as predictors for several forest parameters: tree height, basal area and stem volume.







RMSE=32% (67 m^3/ha)

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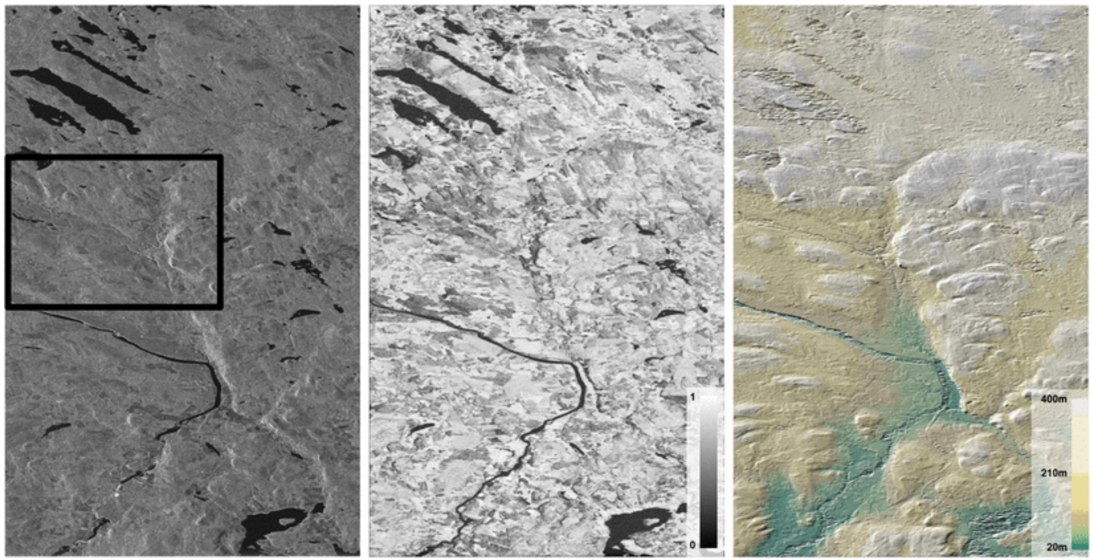
Karila et al. "Tandem-X interferometry in the prediction of forest inventory attributes in managed boreal forests," Remote Sens. Environ., 159, 259-268, 2015.

TanDEM-X for forest height



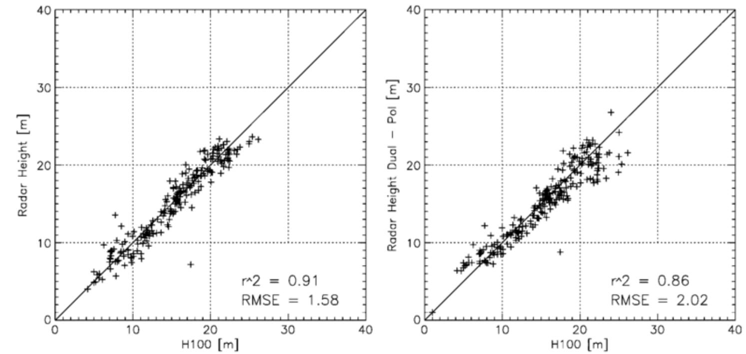
(a) (b) (c)

a) VV-pol amplitude image;
b) VV-pol interferometric coherence;
c) TDX DEM.

Forest height estimation using single- and dual-pol TanDEM-X pairs;

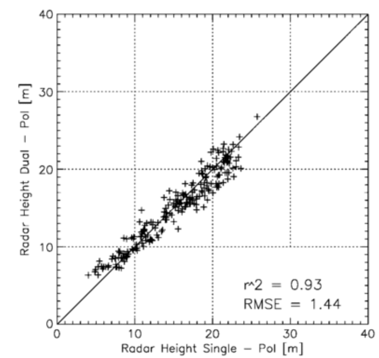
3 test sites (Krycklan, Traunstein, Mawas)

Model based approach (RVoG), for single-pol inversion fixing extinction.



(a) (b)

a) single-pol inversion vs. lidar height;
b) dual-pol inversion vs. lidar height;
c) single-pol vs. dual-pol inversion



(c)

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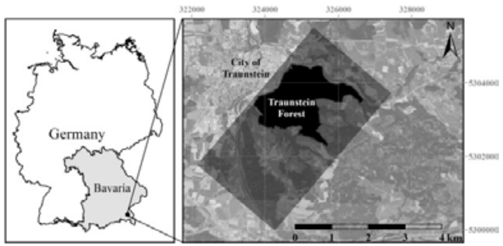
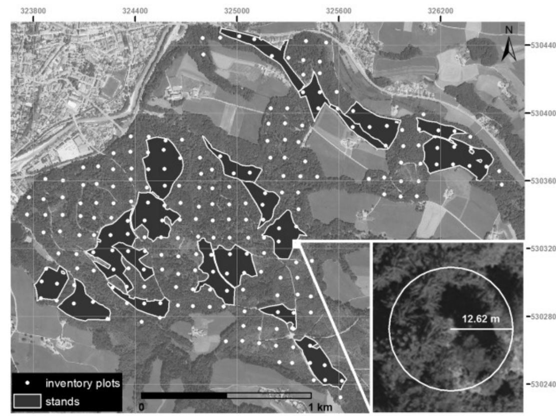
Kugler et al. " TanDEM-X Pol-InSAR performance for forest height estimation," IEEE Trans. Geosci. Remote Sens., vol. 52, no.10, pp. 6404-6422, 2014.

TanDEM-X in biomass estimation



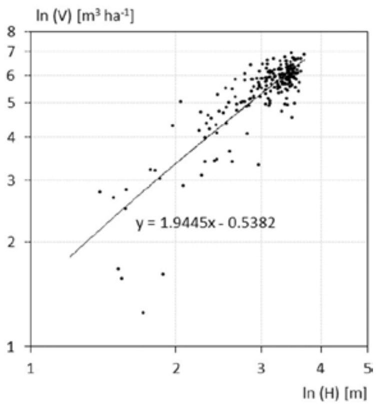
Study area and reference data



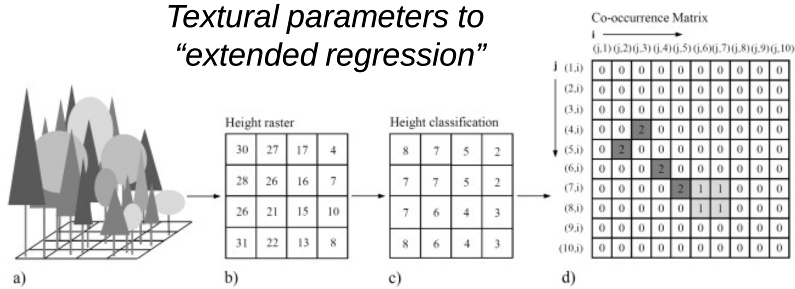
Tree height retrieved from TanDEM-X, later converted to stem volume using regression allometric relationship. Supervised stand-level (plot-level) approach.

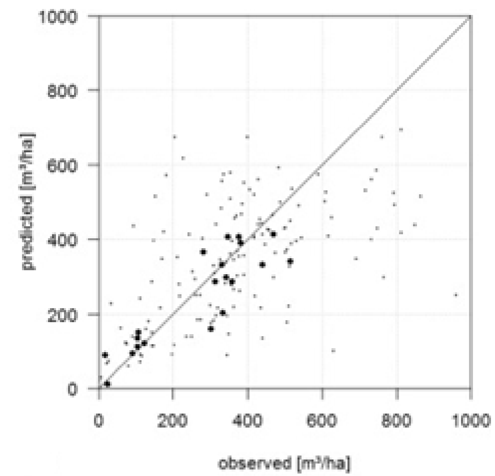
Regression is done on tree height and textural parameters of tree height (as proxy to basal area).

Stem volume to height dependence



Textural parameters to “extended regression”





Plots: R2=0.66, RMSE=155 m3/ha
Stands: R2=0.94, RMSE=44 m3/ha.

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Abdullahi, Kugler, Pretzsch ”Prediction of stem volume in complex temperate forest stands using TanDEM-X SAR data,” Remote Sens. Environ., 174(1), 197-211, 2016.