A Comparison Between SAR Tomography and the Phase Histogram Technique for Remote Sensing of Forested Areas at L-Band

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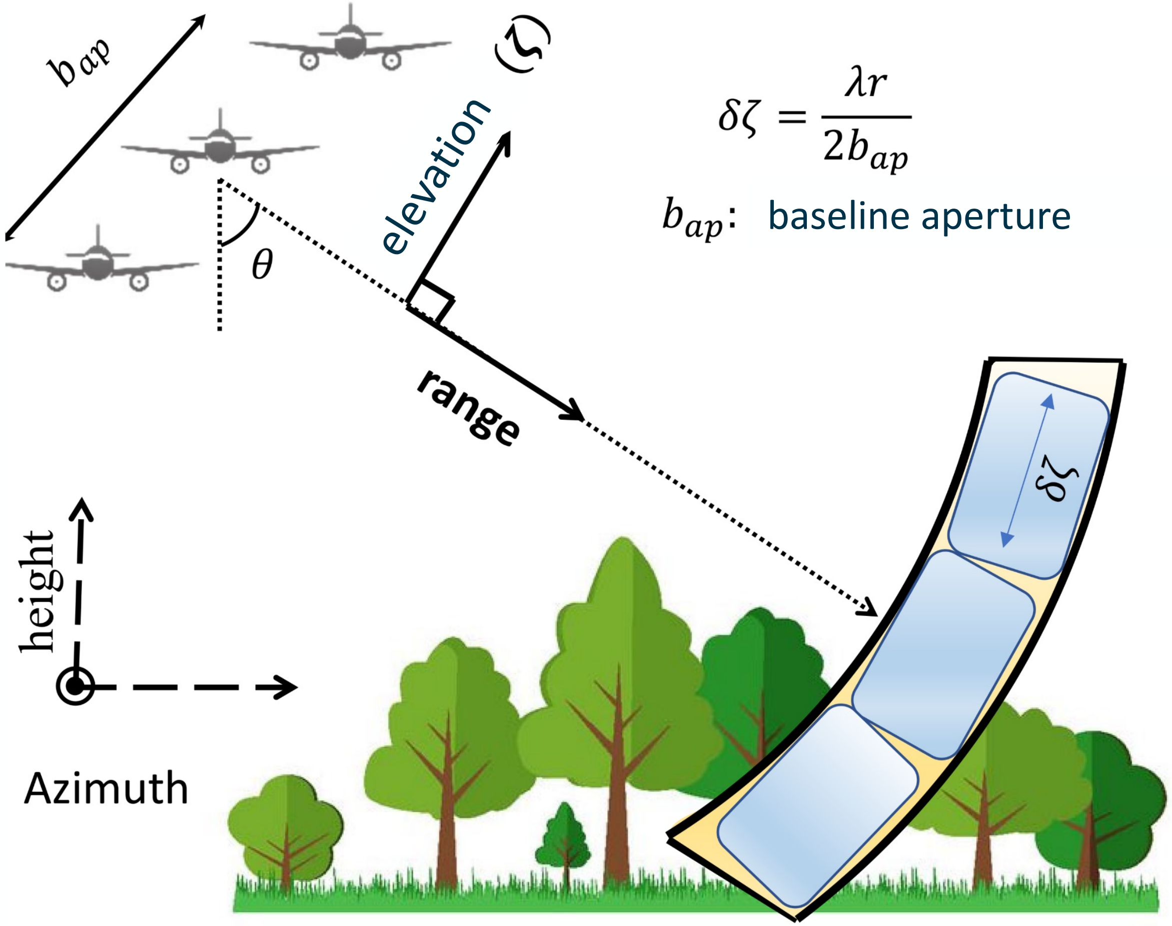
Model and algorithm

SAR tomography(TomoSAR):



$$\delta\zeta = \frac{\lambda r}{2b_{ap}}$$

b_{ap}: baseline aperture

◆ Assumptions:

① the acquired N trajectories along the azimuth axis of flights are approximately parallel;

② all images are properly coregistered.

Forming an additional synthetic aperture along cross-range direction

SAR pixel model: 1D integration along elevation

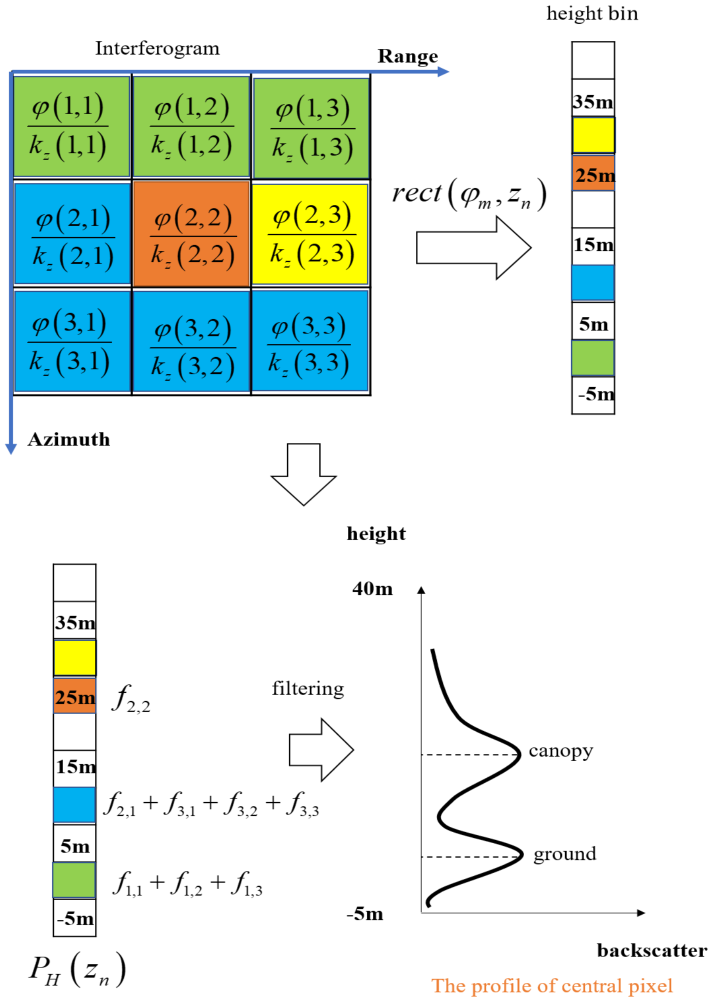
$$\mathrm{I_n} = \int \mathrm{p}(\zeta) \cdot \mathrm{xp}\left(\mathrm{j}\frac{4\pi \mathrm{b_n}}{\lambda \mathrm{R}} \cdot \zeta\right) d\zeta$$

Tomographic processing carried out by Capon beamforming

$$\mathrm{P_{capon}} = \frac{1}{\mathbf{ARA}^{\mathrm{H}}}$$

Model and algorithm

Phase Histogram(PH):



The Phase Histogram (PH) technique obtains a description of the forest structure from a single interferogram by analyzing the variation of the phase center height within a given estimation window(15 m*15 m)

- Implemented by accumulating the interferogram at specific height bin within a sliding window
- The height bin is selected based on the interferometric phase and phase-to-height conversion factor

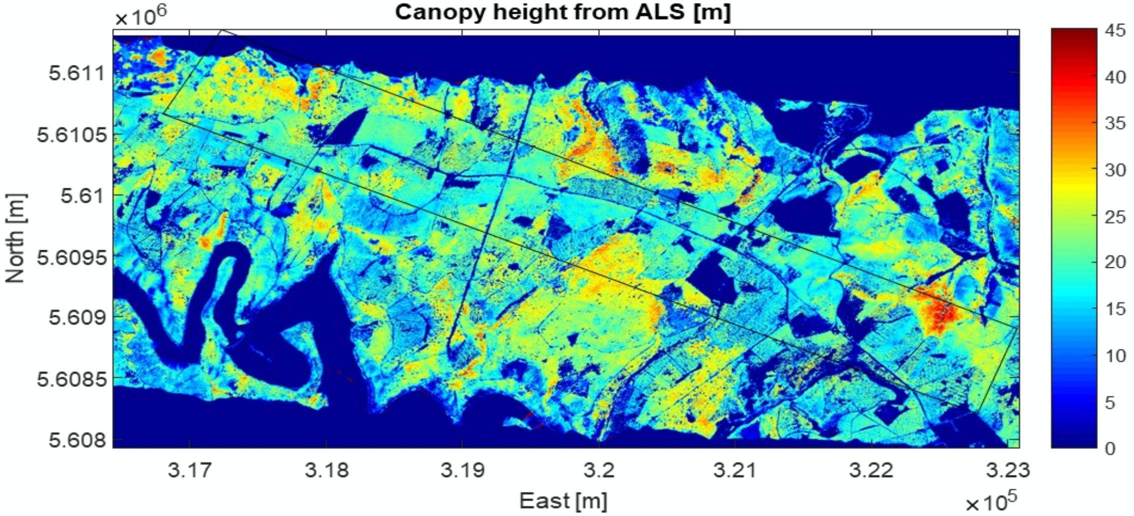
$$P_H(z_n)=\sum_{m=1}^{M}|I_1(m)\cdot I_2^*(m)|\cdot \mathrm{rect}(\varphi_m,z_n)$$

$$\mathrm{rect}(\varphi_m,z_n)=\begin{cases}1 & \text{if } \frac{\Delta h}{2}\ge\frac{\varphi_m}{k_z}-z_n\ge-\frac{\Delta h}{2}\\ 0 & \text{otherwise}\end{cases}$$

Reference: Shiroma G H X, Lavalle M. Digital terrain, surface, and canopy height models from InSAR backscatter-height histograms. TGRS.
Lei Y, Treuhaft R, Gonçalves F. Automated estimation of forest height and underlying topography over a Brazilian tropical forest with single-baseline single-polarization TanDEM-X SAR interferometry. RSE.

Study area and experimental dataset

The Kermeter area at the Eifel National Park,North-West Germany



The LiDAR-derived forest height

Real data from the TomoSense campaign

- Flown in 2021 at the Kermeter area, Eifel park
- Multi frequency (P-, L-, C-band), two headings
- Monostatic and bistatic data
- In-situ data from 80 plots
- Aerial Lidar data (DTM, forest height, AGB)
- High resolution Terrestrial Laser Scanning data

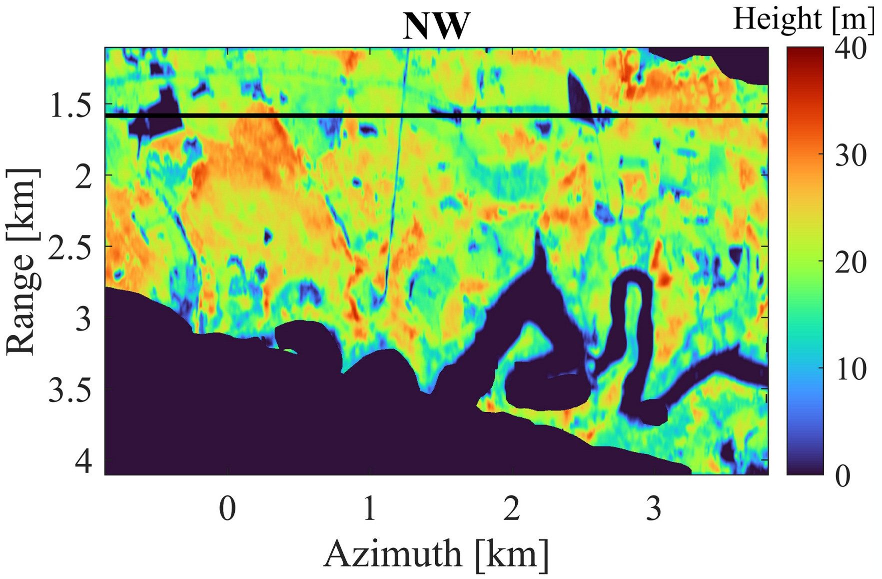
Data used in this work

- L-Band monostatic
- North-West and South-East headings
- 30 passes per heading
- Vertical resolution better than 5 m

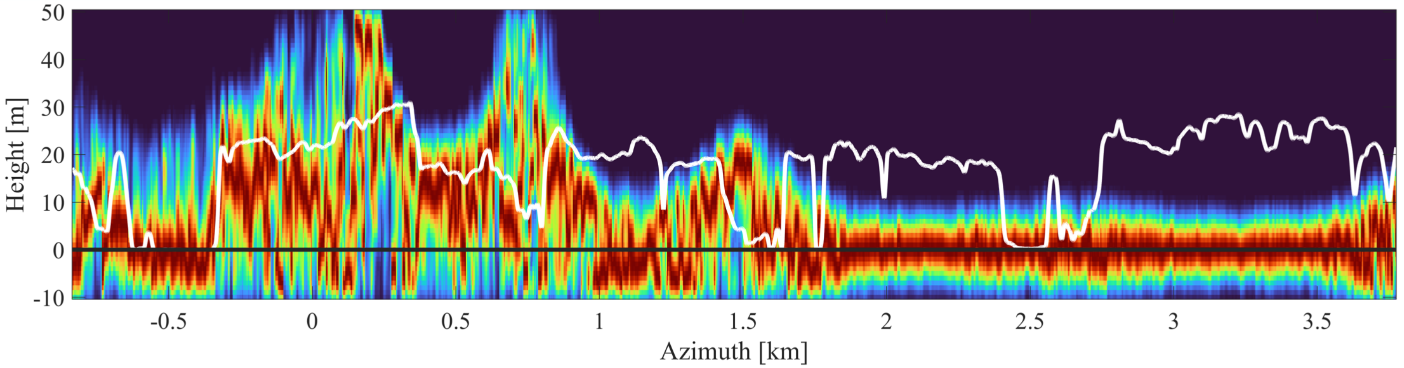
Reference: Tebaldini, Stefano, et al. "TomoSense: A unique 3D dataset over temperate forest combining multi-frequency mono-and bi-static tomographic SAR with terrestrial, UAV and airborne lidar, and in-situ forest census." *RSE.* .

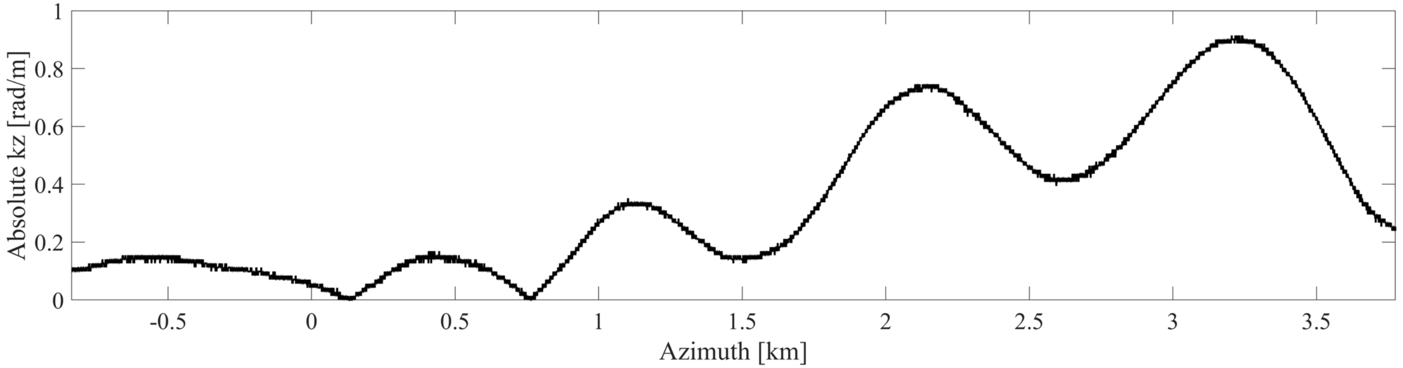
Results— PH from a single interferogram

Single interferogram PH



The LiDAR-derived forest height of NW flight heading





Some problems in single interferogram PH

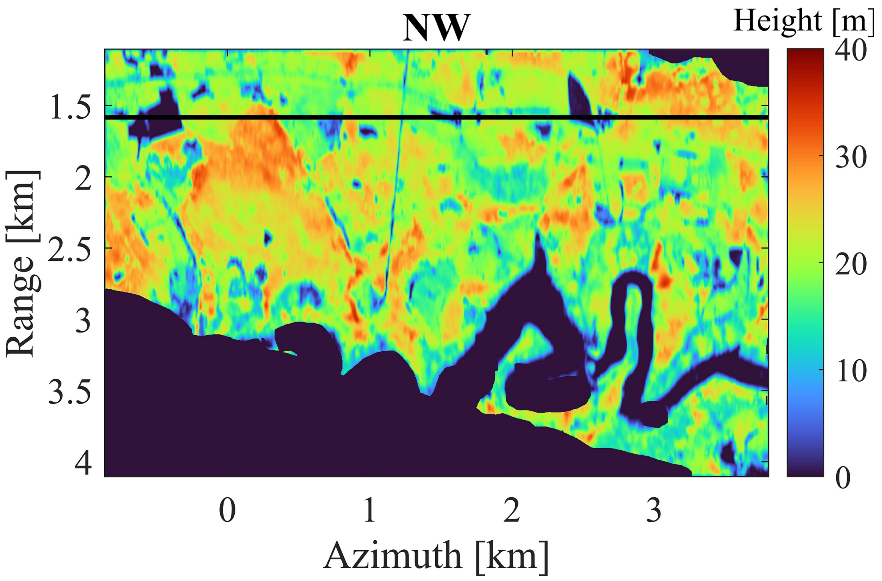
① Single observation

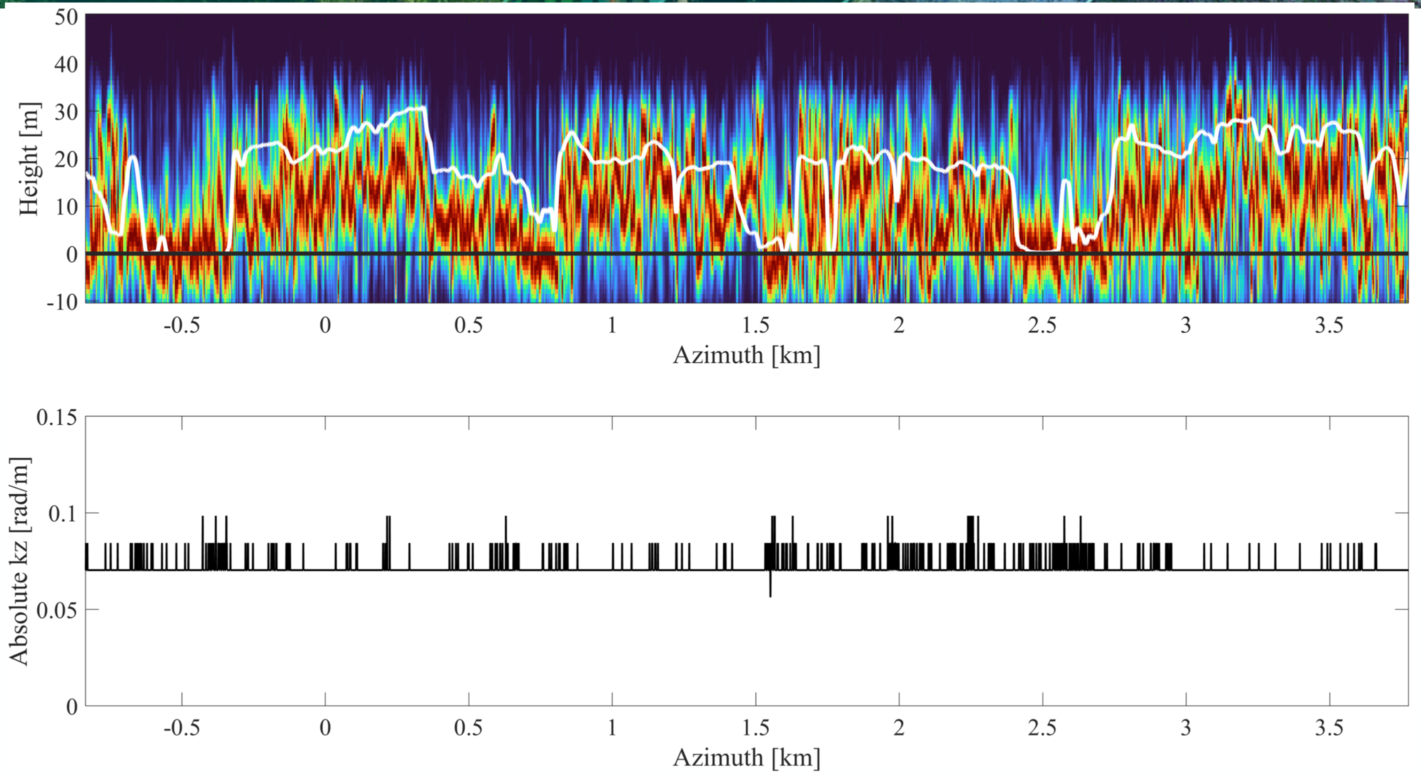
② Drastic changeable trajectory

③ Unexpected vertical wavenumber kz

Results—PH from a super-interferogram

Super interferogram PH





Full combination strategy with 30 passes:

① Form 435 pairs of interferograms;

② Set the minimum HoA close to 60m, perform the PH technique;

③ Repeat the procedure pixel by pixel.

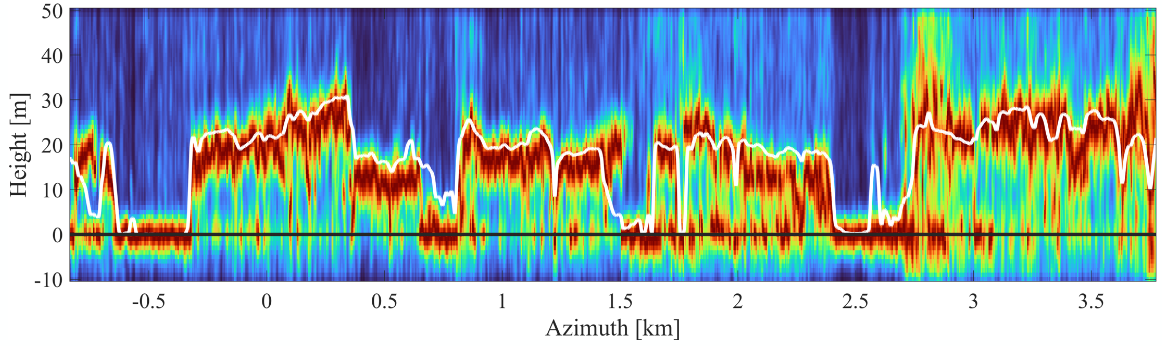
Optimization in super interferogram PH

① Use all the trajectories (rich observations)

② Form the super interferogram

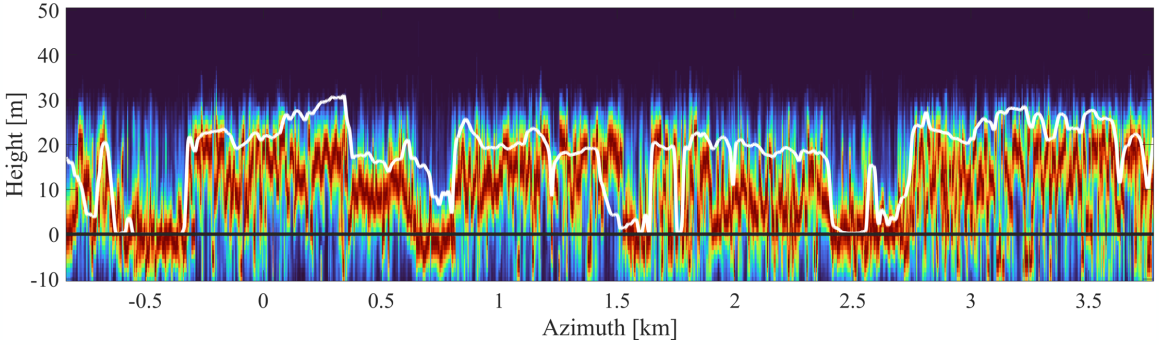
③ Approximately constant vertical wavenumber kz

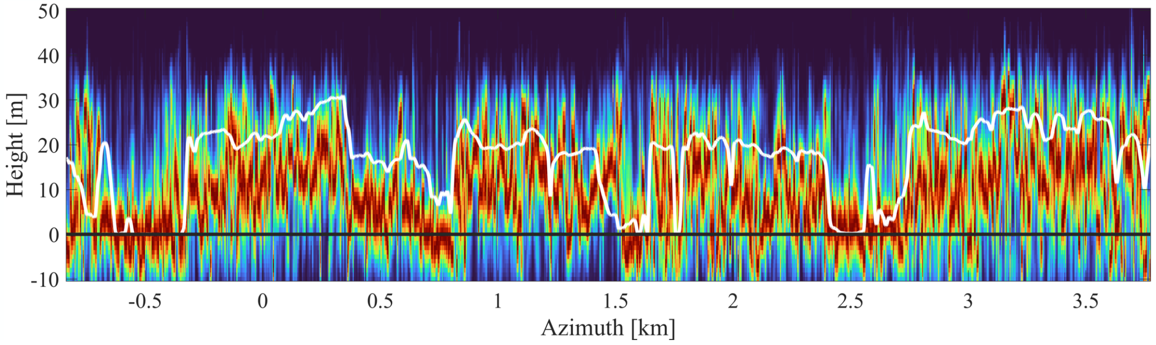
Results—super-interferogram PH vs TomoSAR

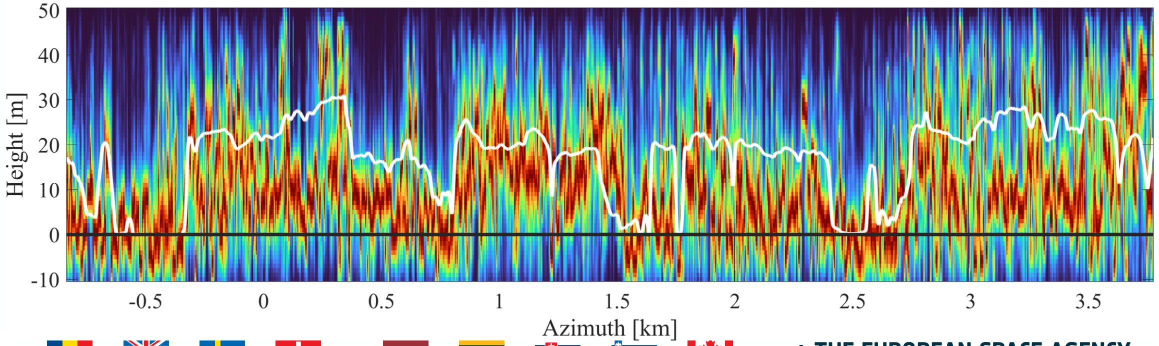

TomoSAR

With full resolution SLC data stacks:

- PH can only loosely approximate the vertical structure produced by SAR tomography;
- HoA must fit the proper range (roughly twice forest height).

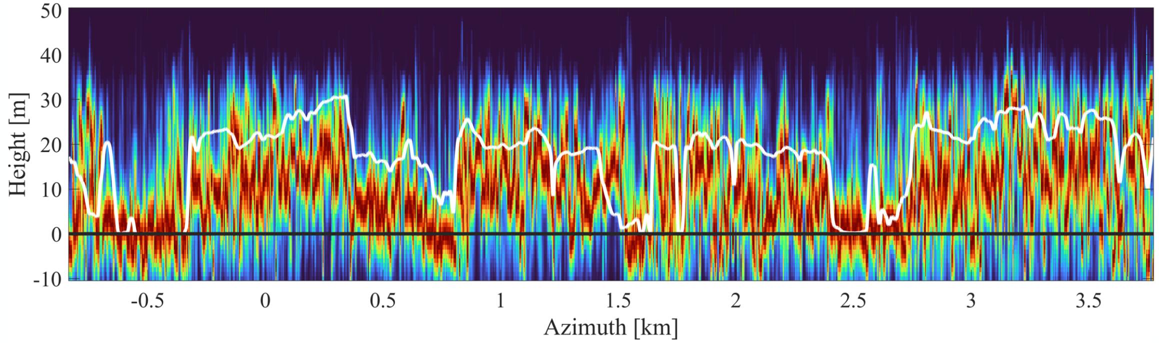

HoA =45m


HoA =60m


HoA =120m

Results—impact of multi-looking factor

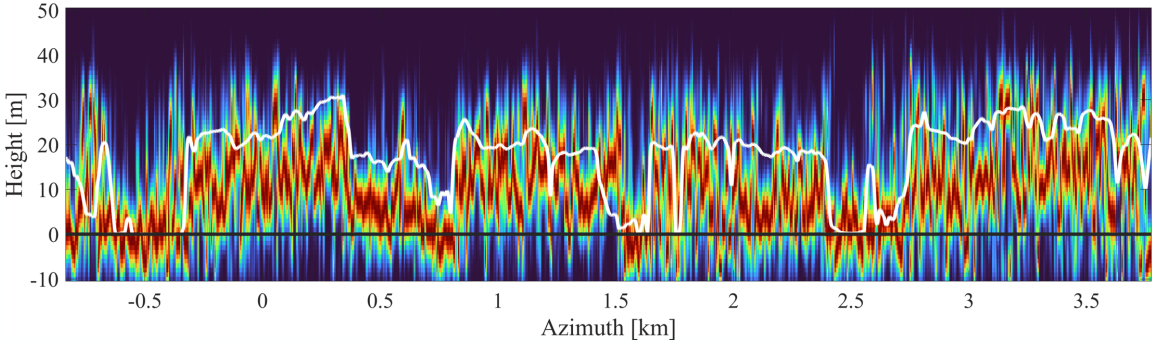
Single look InSAR phase



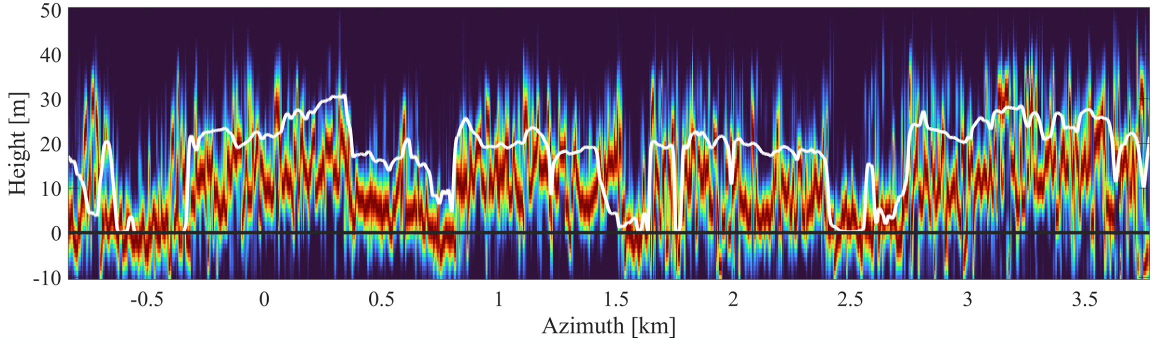
With HoA = 60 m:

- increasing the multi-looking factor leads to a more concentrated energy distribution in the backscatter profile

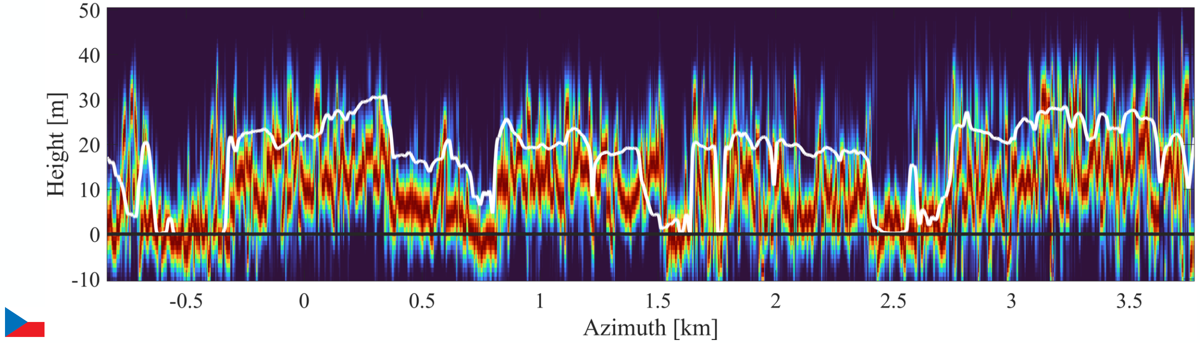
Multilook factor: (range, azimuth) - (1,10)



Multilook factor: (range, azimuth) - (1,20)



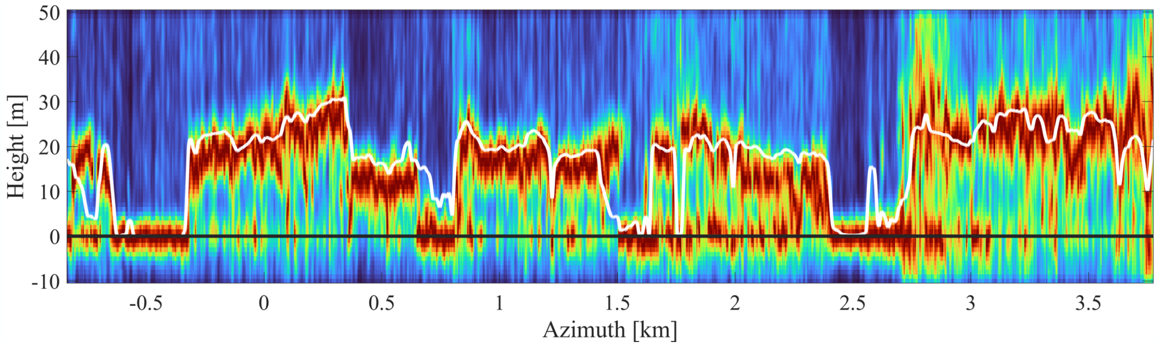
Multilook factor: (range, azimuth) - (5,20)



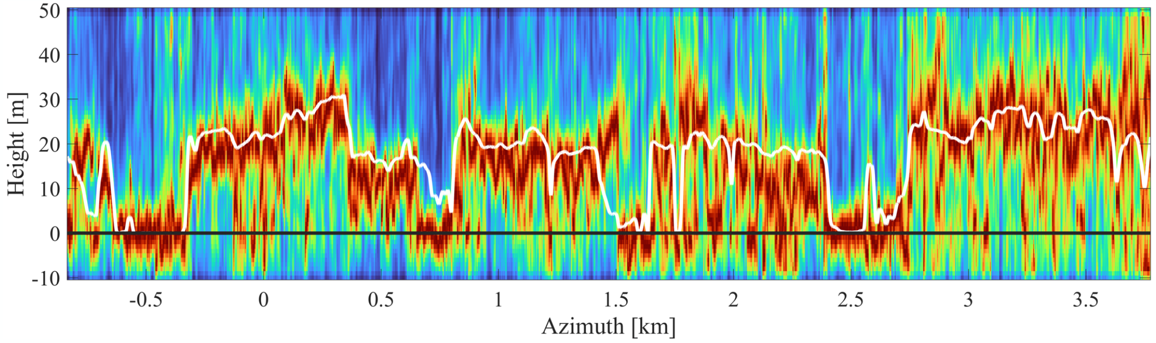
Results—impact of SLC resolution

TomoSAR

resolution: (range, azimuth) - (3,0.5)

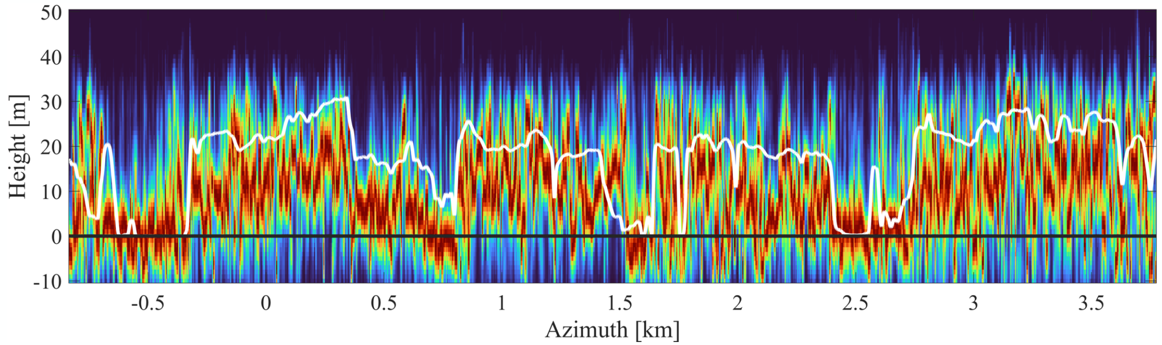


resolution : (range, azimuth) - (12, 8)

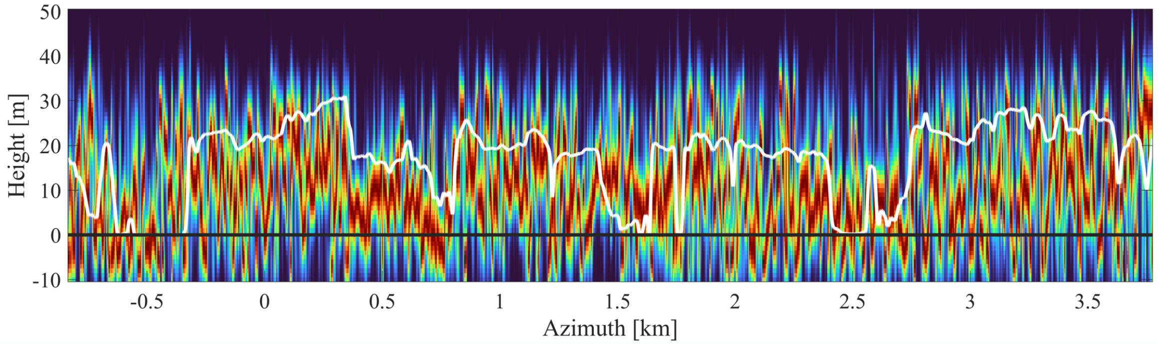


PH

resolution: (range, azimuth) - (3,0.5)



resolution : (range, azimuth) - (12, 8)



A simple physical model

Two dominant scatterer

$$SLC_m = A_g e^{j\varphi_g} + A_c e^{j\varphi_c}$$

$$SLC_s = A_g e^{j\varphi_g} e^{jk_z\cdot z_g} + A_c e^{j\varphi_c}\, e^{jk_z\cdot z_c}$$

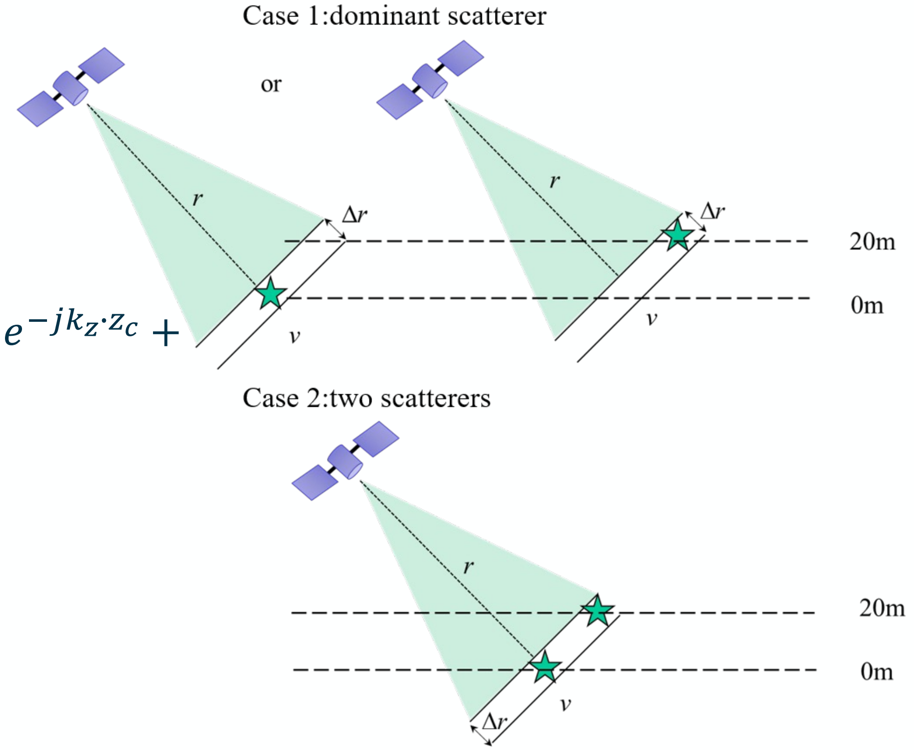
$$\varphi_{InSAR} = \angle\langle SLC_m \cdot SLC_s^H\rangle = \angle\left(\left|A_g\right|^2 e^{-jk_z\cdot z_g} + |A_c|^2 e^{-jk_z\cdot z_c} + A_g A_c e^{j(\varphi_g-\varphi_c)} e^{-jk_z\cdot z_c} + A_g A_c e^{j(\varphi_c-\varphi_g)} e^{-jk_z\cdot z_g}\right)$$

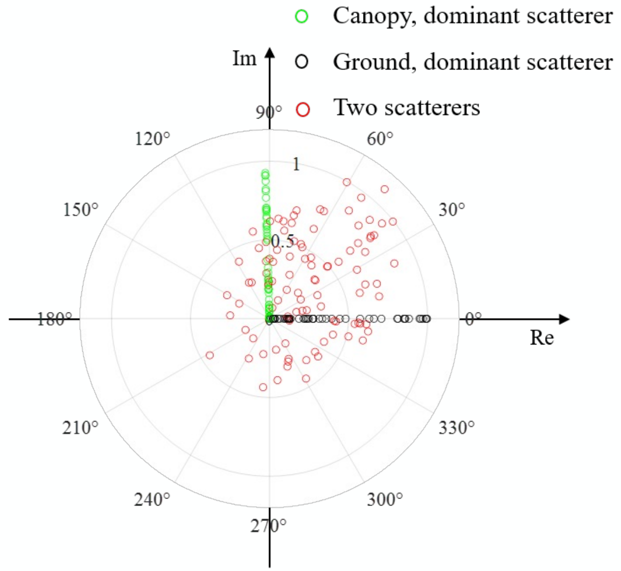
Single dominant scatterer

$$SLC_m = Ae^{j\varphi}$$

$$SLC_s = Ae^{j\varphi} e^{jk_z\cdot z}$$

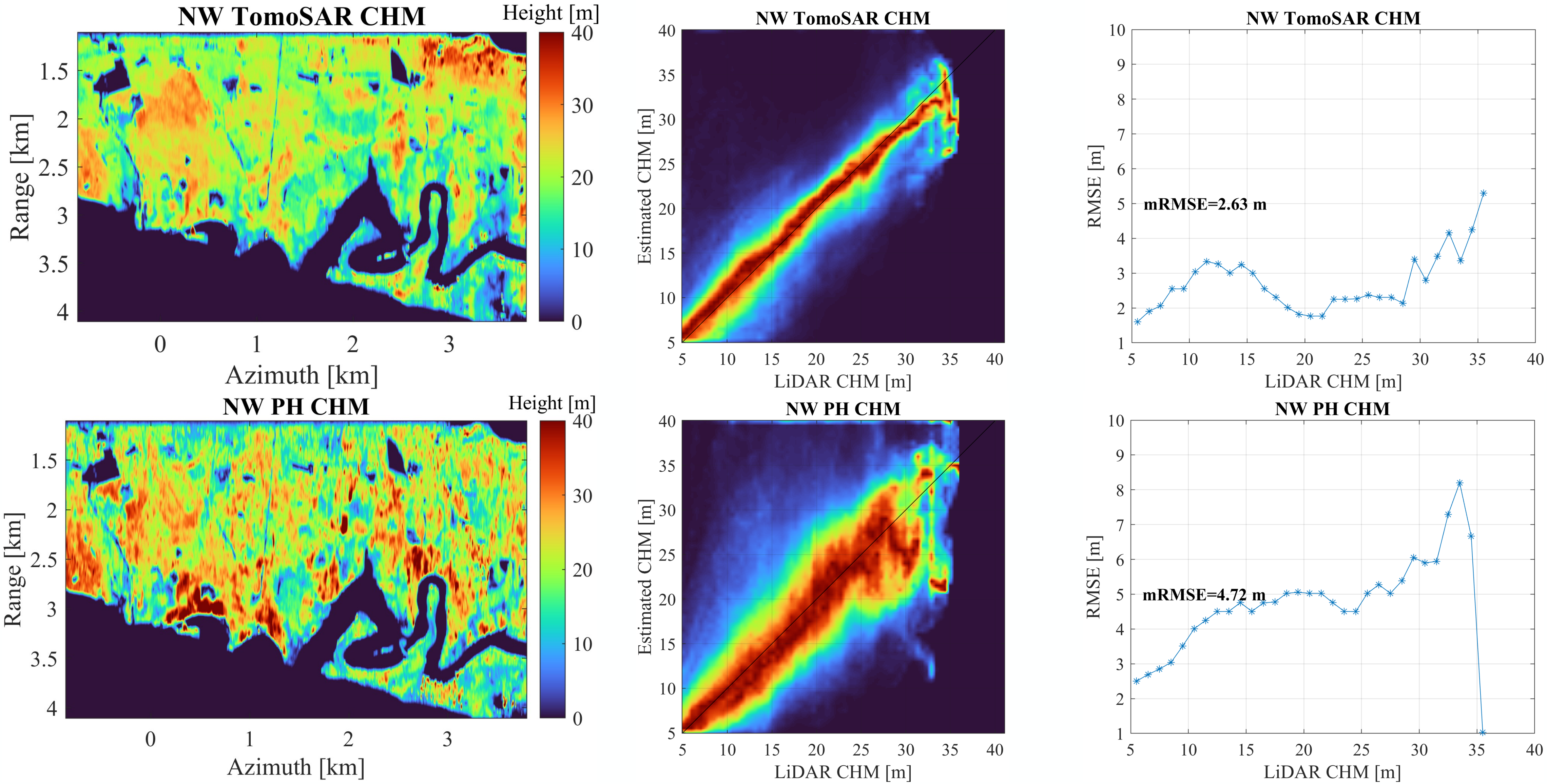
$$\varphi_{InSAR} = \angle\langle SLC_m \cdot SLC_s^H\rangle = \angle\left(|A|^2 e^{-jk_z\cdot z}\right) = k_z \cdot z$$



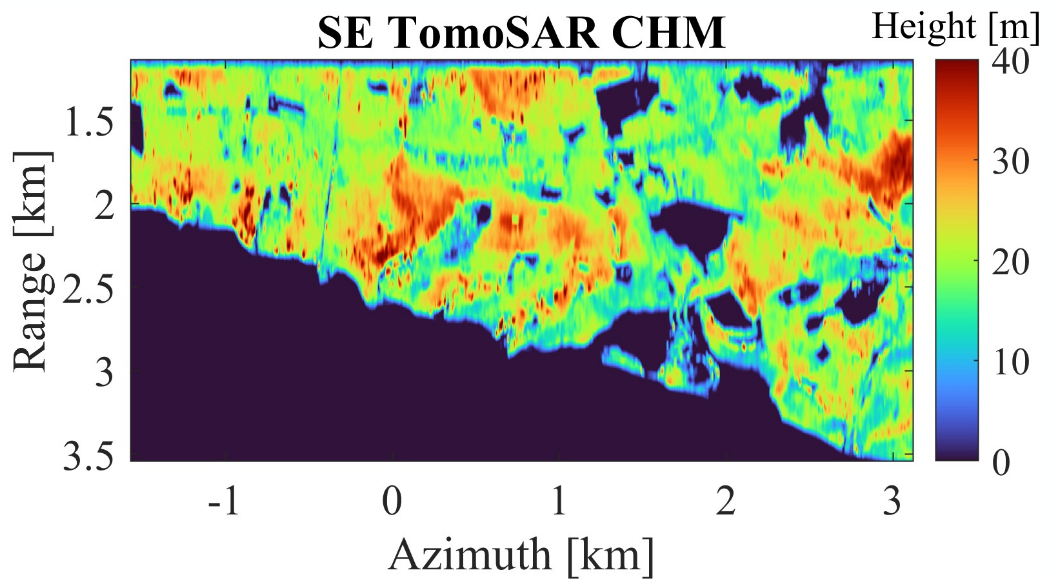


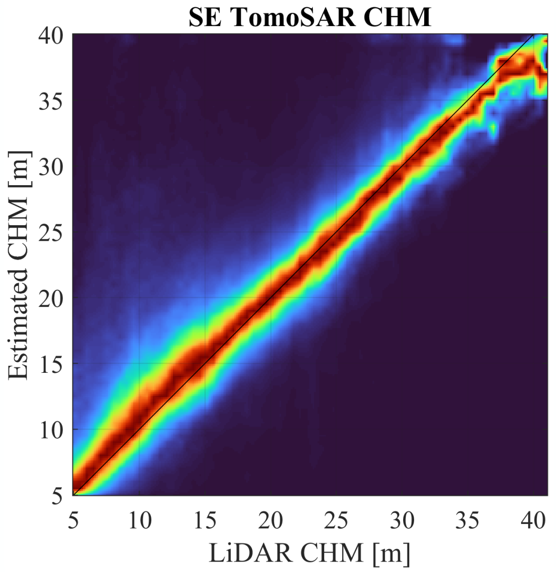
The left image depicts two simulated scenarios, while the right image illustrates the complex interferograms generated under these two scenarios, which are presented in the same polar coordinate system.

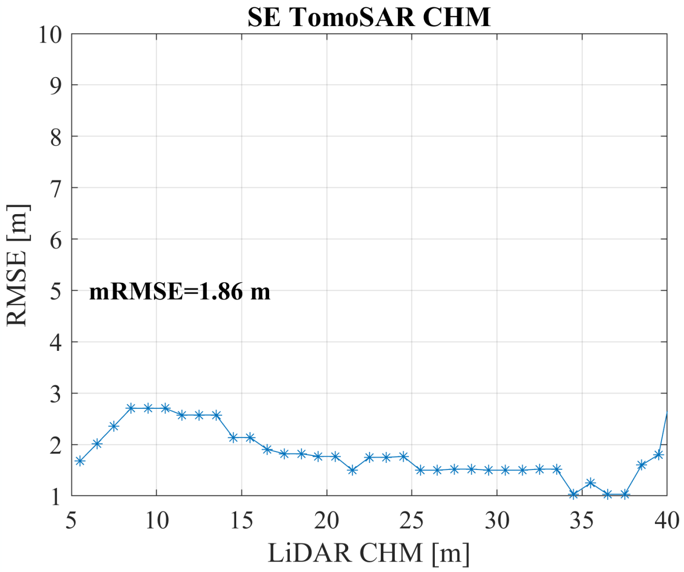
Forest height inversion — NW flight heading

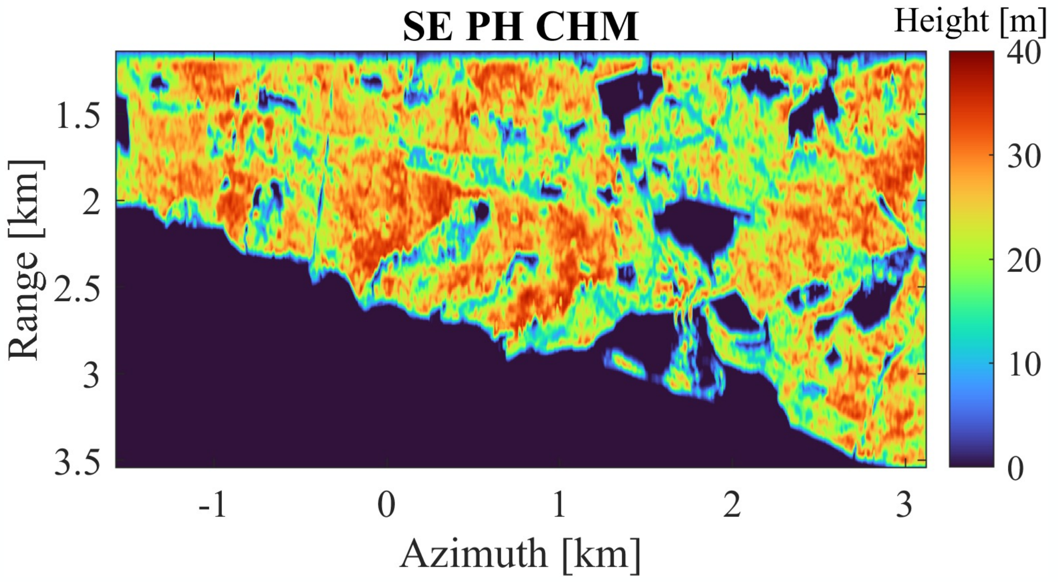


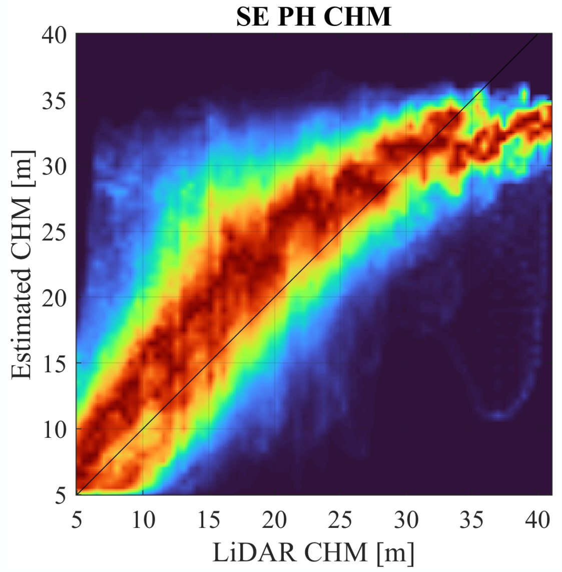
Forest height inversion — SE flight heading

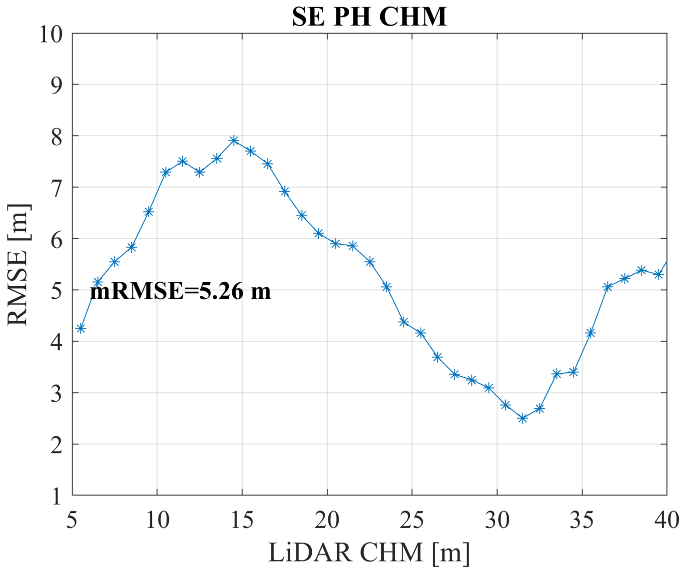

SE TomoSAR CHM


SE TomoSAR CHM


SE TomoSAR CHM


SE PH CHM


SE PH CHM


SE PH CHM

Conclusions

This paper presented an experimental comparison between TomoSAR and the PH technique based on the tomographic dataset from the TomoSense campaign.

The results within this paper confirm that the products generated by SAR Tomography are inherently more accurate. This is of course not surprising, as TomoSAR uses a much larger data volume that the PH technique.

Yet, the PH technique was observed to provide a fairly good estimate of forest height, resulting in an average RMSE w.r.t. Lidar height of 4.72 m (as compared to 2.63 m in the case of TomoSAR, NW flight heading).

The degraded performance of the PH technique on the low-resolution dataset indicates that this technique is best fit for scenarios where each SAR pixel is characterized by the presence of a dominant scatterer, whose height can be reliably assessed from the corresponding InSAR phase.

As a general conclusion, the results within this paper indicate that the PH technique is a valuable option in the context of high-resolution spaceborne missions such as TDX.

Thank you for your attention!