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

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Introduction

we compare two techniques for estimating forest height and vertical structure using airborne synthetic aperture radar (SAR) data, namely SAR tomography (TomoSAR) and the phase histogram (PH) technique. Results indicate that the PH technique can only loosely approximate the vertical structure produced by SAR tomography, but it can be used to produce a fairly good estimate of forest height. In particular, TomoSAR and the PH technique are observed to produce an average root mean square error (RMSE) of 2.63 m and 4.35 m in NW flight data, and 1.84m and 5.46m in SE flight data, respectively. The observed results are interpreted in light of a simple physical model to predict phase variations in the two cases where forest scattering is determined by the presence of a dominant scatterer at each resolution cell or by a multitude of elementary scatterers, leading to the conclusion that the PH technique is best fit for the case of high- or very high-resolution data at higher frequency bands. Overall, the analysis in this paper demonstrates, both theoretically and experimentally, that the PH technique cannot achieve the same performance as multi-baseline tomography when applied to lower frequency data at a resolution of few meters. Yet, even in these conditions we remark that the PH technique allows for the retrieval of forest height based on a single interferogram at a single polarization. This makes the PH technique extremely interesting in the context of spaceborne missions.

Methodology

TomoSAR algorithm

$$P_{capon} = \frac{1}{\mathbf{A}^{-1}\mathbf{R}\mathbf{A}}$$

Phase Histogram algorithm

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

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

Study area and experimental results

L-Band HV polarization tomographic data from the ESA airborne campaign TomoSense, flown in 2020 at the Kermeter area in the Eifel Park, North-West Germany were adopted to study the connection between TomoSAR and the PH technique. The data analyzed in this paper feature 30+30 overpasses acquired along two opposite flight headings, and provide a vertical resolution consistently better than 5 m on the whole area of interest.

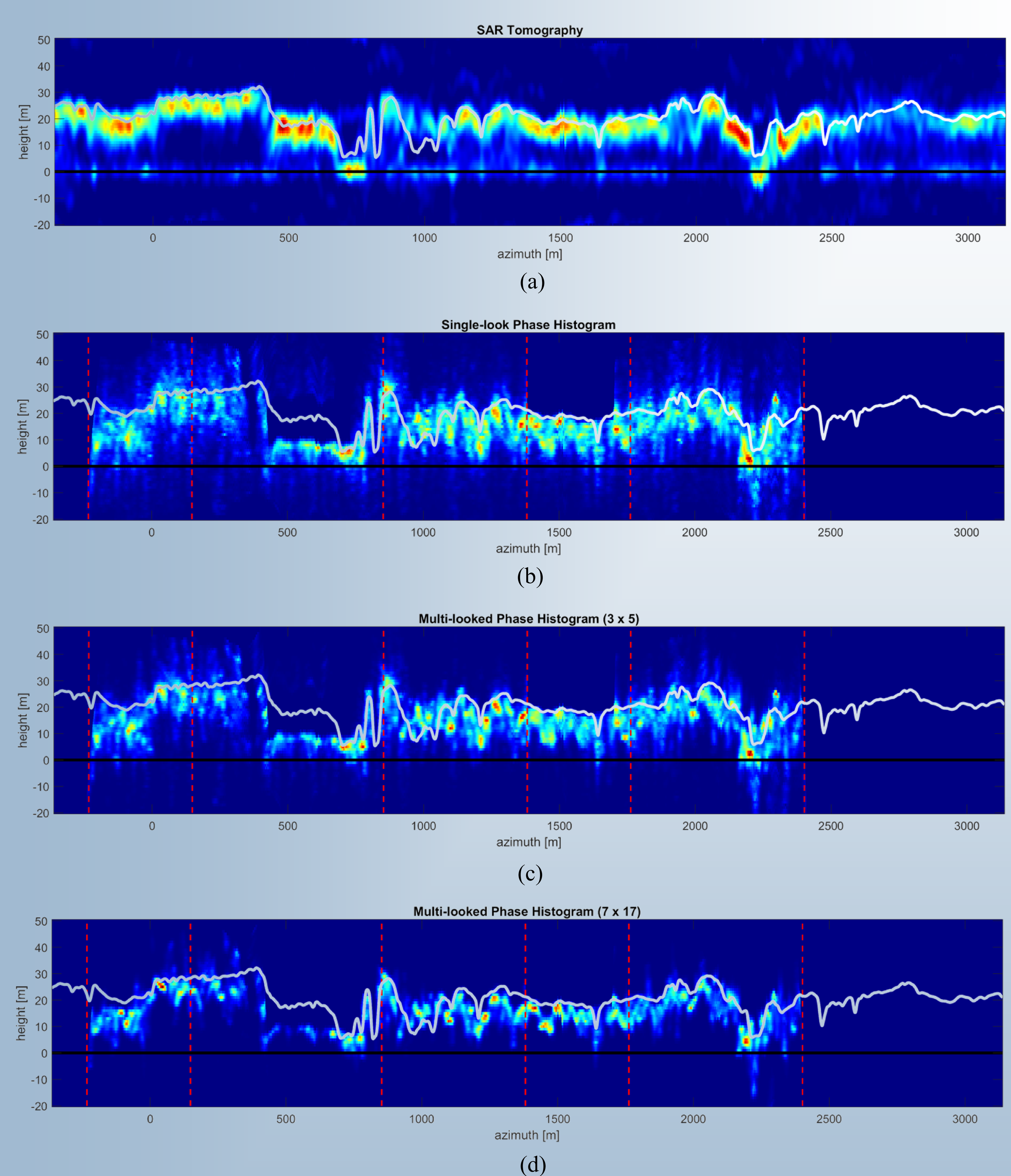

Figure 1. Vertical section from TomoSAR and the PH technique. First panel from top: SAR Tomography. Second panel from top: single-look phase histogram. Third panel from top: multi-looked phase histograms (3x5 looks). Fourth panel from top: multi-looked phase histograms (7x17 looks). In all panels, the white line denotes Lidar forest height. All panels are normalized such that the mean along each column is 1. The dashed red lines indicate the region covered by any single interferogram.

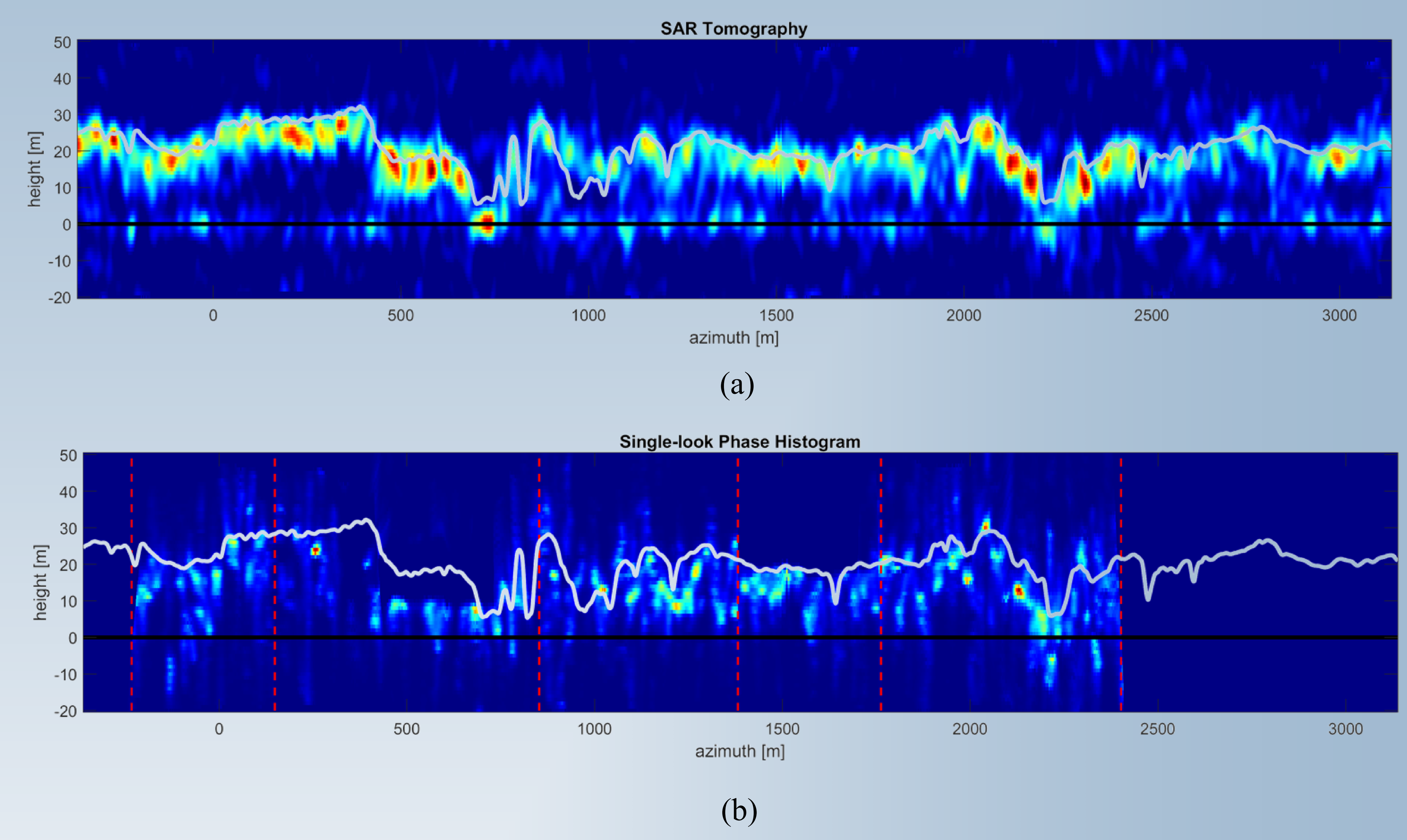

Figure 2. Vertical section from TomoSAR and the PH technique as obtained from degraded resolution data. First panel from top: SAR Tomography. Second panel from top: single-look phase histogram. In all panels, the white denotes Lidar forest height. All panels are normalized such that the mean along each column is 1. The dashed red lines indicate the region covered by any single interferogram.

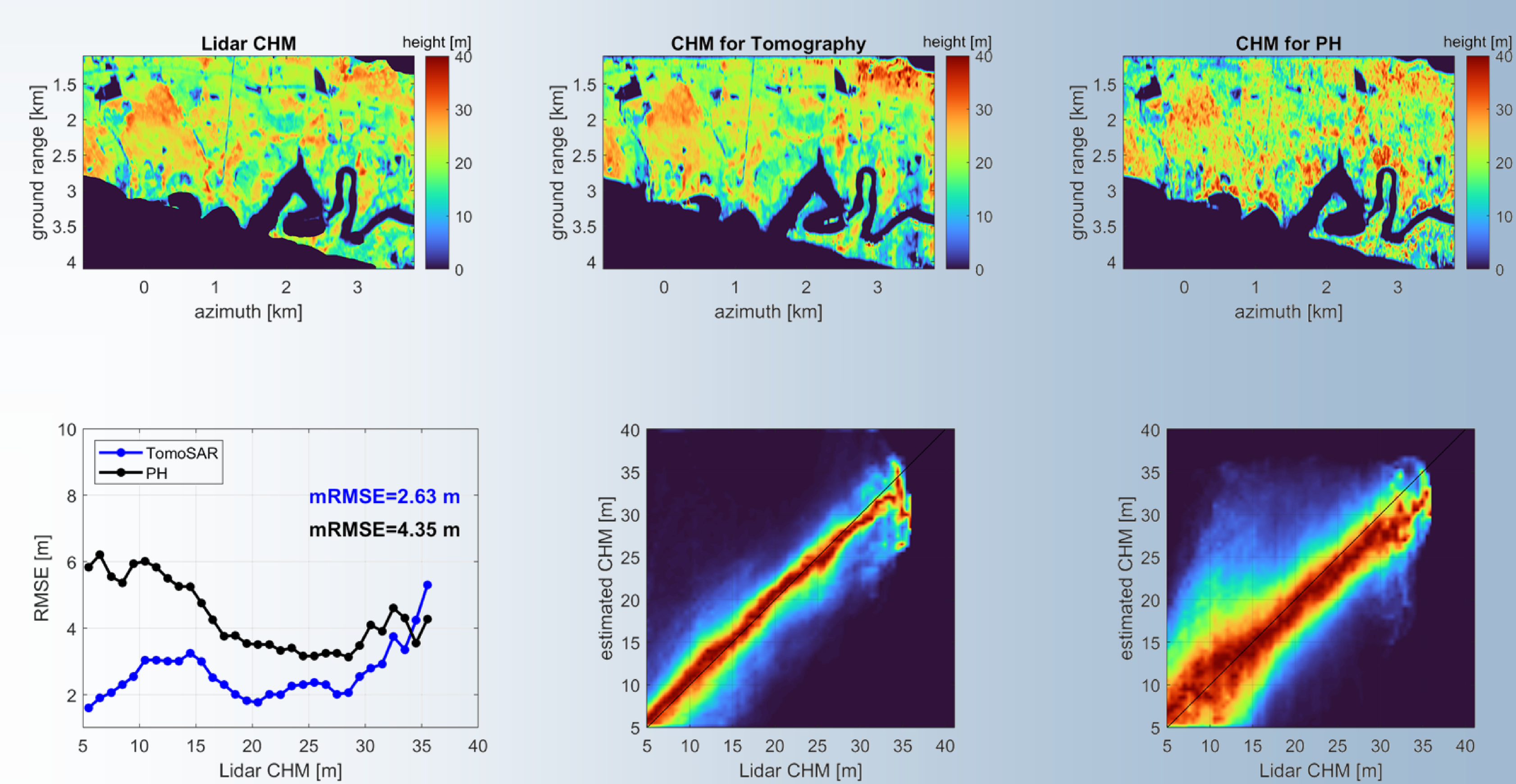

Figure 3. Forest height retrieval for NW acquisitions. Top row: canopy height model (CHM) from Lidar, TomoSAR, and the PH technique. Bottom row: resulting RMS error (left panel) and 2D histograms of Lidar CHM and the retrieved height from TomoSAR (mid panel) and the PH technique(right panel).

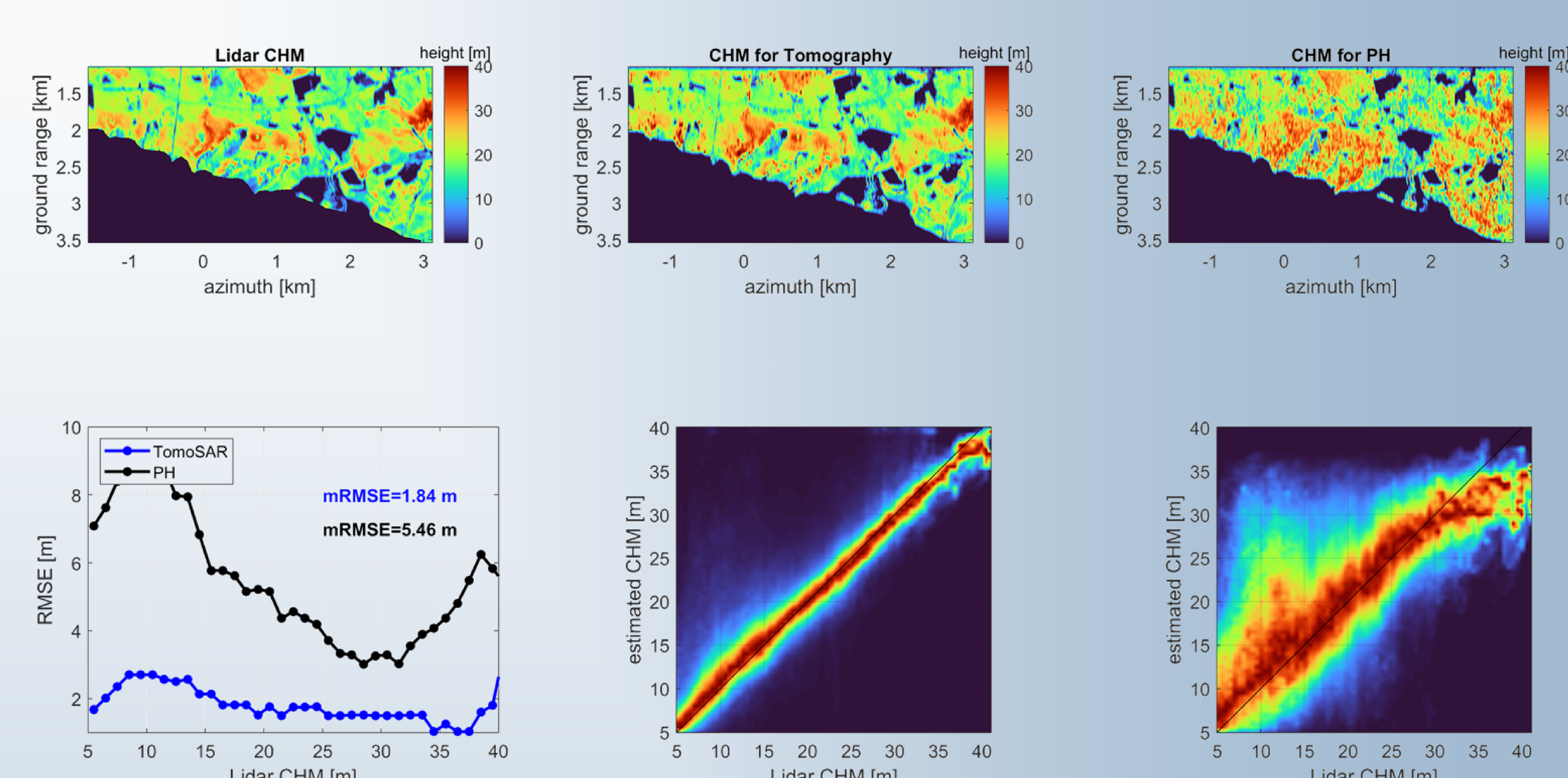

Figure 4. Forest height retrieval for SE acquisitions. Top row: canopy height model (CHM) from Lidar, TomoSAR, and the PH technique. Bottom row: resulting RMS error (left panel) and 2D histograms of Lidar CHM and the retrieved height from TomoSAR (mid panel) and the PH technique(right panel).

Conclusions

- PH technique is best fit for the case of high- or very high-resolution data at higher frequency.
- PH technique cannot achieve the same performance as multi-baseline tomography when applied to lower frequency data at a resolution of few meters. Yet, even in these conditions we remark that the PH technique allows for the retrieval of forest height based on a single interferogram at a single polarization.

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