

Forest Above Ground Biomass Inversion Based on Baseline-Optimized Phase Histogram Technique

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Introduction

The interferometric phase histogram (PH) technique typically requires only single-polarization and single-baseline data (or a limited number of interferograms) to retrieve low-resolution vertical forest structures and estimate forest physical parameters, such as sub-canopy terrain and forest height. However, unstable airborne trajectories can lead to significant variations in the interferometric vertical wavenumber, potentially degrading inversion performance. To mitigate this issue, this study proposes an interferometric baseline optimization strategy. By constraining the phase height of ambiguity range, suitable baselines for PH-based inversion are selected, ensuring continuous vertical backscattering intensity distributions across the test site. Based on forest scattering mechanisms, three-dimensional parameters including forest height, intensity at specific height bin, and the volume-to-ground intensity ratio (VGR)—can be derived from the backscattering intensity distribution. By incorporating these vertical structure-related parameters and integrating them with regression models, the estimation accuracy of above-ground biomass (AGB) is significantly improved.

Methodology

Baseline-Optimized Phase Histogram model:

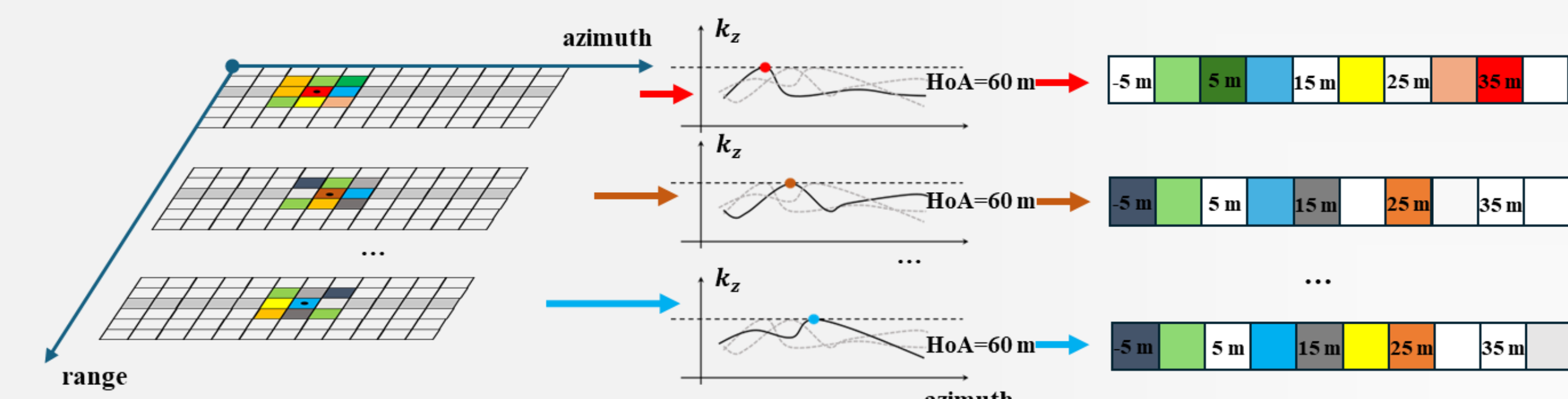


Figure 1. Schematic diagram illustrating the optimization using full combination of interferometric baseline of PH technique

① baseline optimization strategy:

$$[i, j] = \underset{i, j \in [1, \dots, N], j > i}{\operatorname{argmin}} \left| k_z^{i, j}(m) - \frac{2\pi}{HoA} \right|$$

② Phase Histogram inversion:

$$P_H^{i, j}(z_n) = \sum_{m=1}^M f_m^{i, j} \cdot \operatorname{rect}(\varphi_m^{i, j}, z_n) \quad \text{with} \quad \operatorname{rect}(\varphi_m, z_n) = \begin{cases} 1, & \text{if } \frac{\Delta h}{2} \geq \frac{\varphi_m}{k_z} - z_n \geq -\frac{\Delta h}{2} \\ 0, & \text{otherwise} \end{cases}$$

Study area and experimental results

1. Test Site

The proposed method is validated using tomographic SAR data from ESA's airborne TomoSense campaign, which includes both P-band and L-band acquisitions. The TomoSense experiment flown in 2020 at the Kermeter area in Eifel National Park, North-West Germany. The analyzed dataset includes 28 P-band and 30 L-band overpasses in South-East flight directions.

2. Comparison of 3D imaging between single-baseline PH and multi-baseline PH

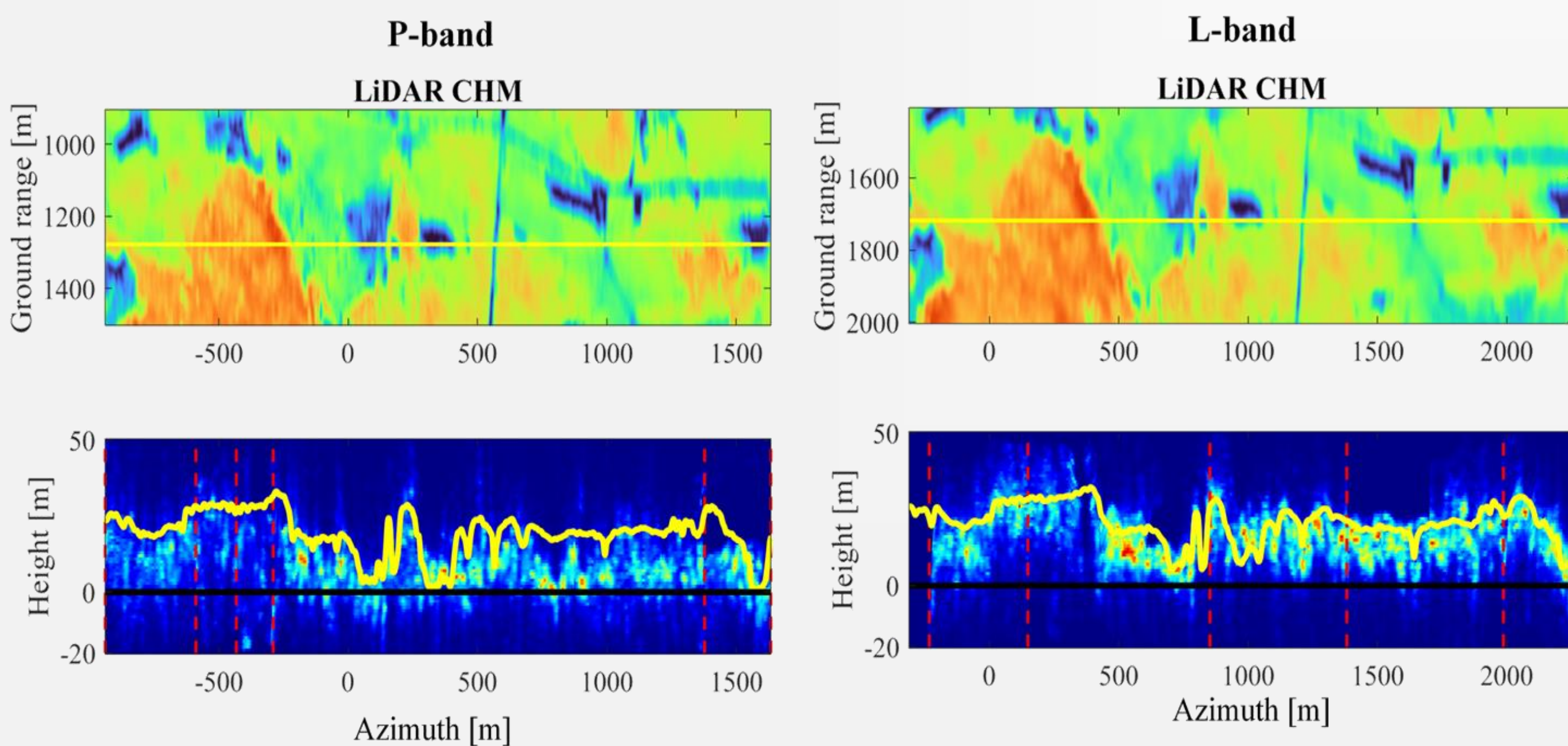


Figure 2. Vertical backscattering intensity profiles obtained by baseline-optimized PH technique.

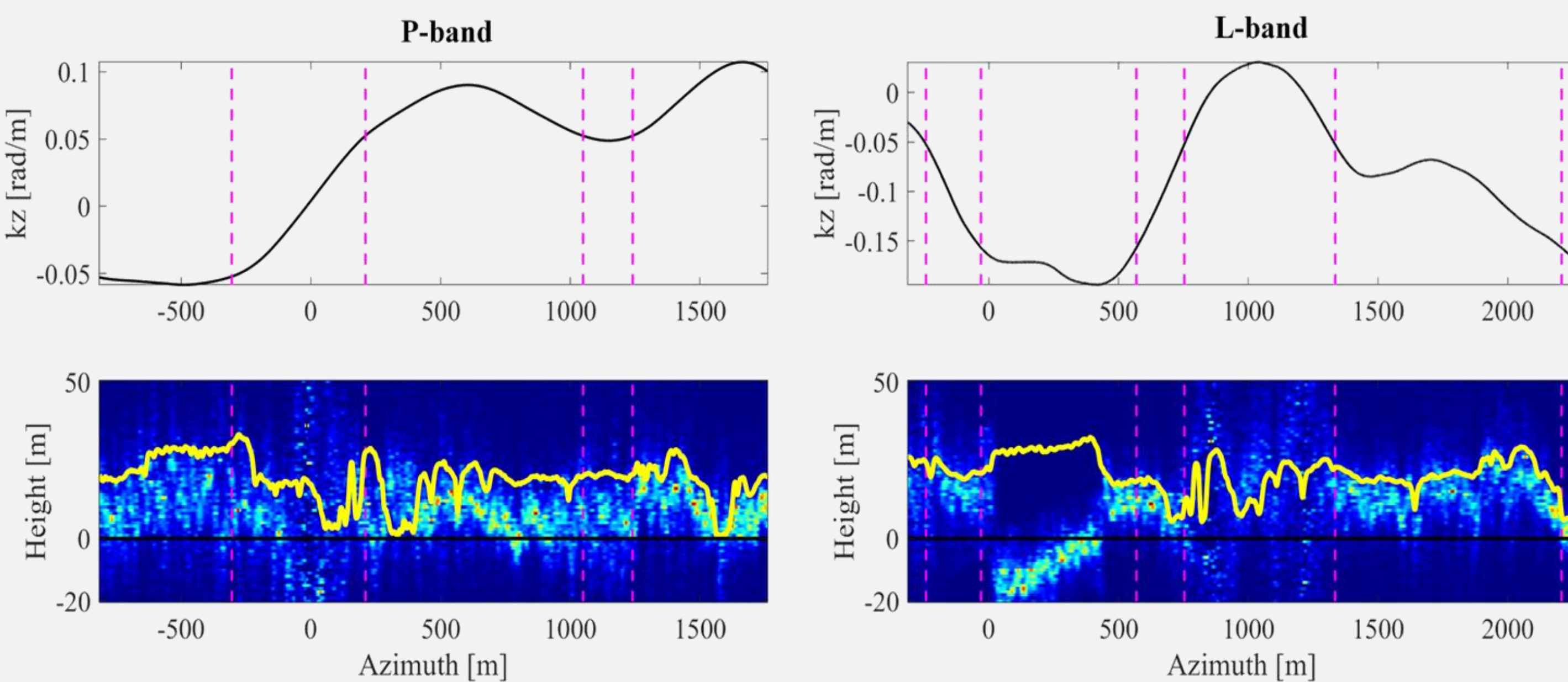


Figure 3. Vertical backscattering intensity profiles obtained by single-baseline PH technique.

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3. Sensitivity between parameters of different dimensions and AGB

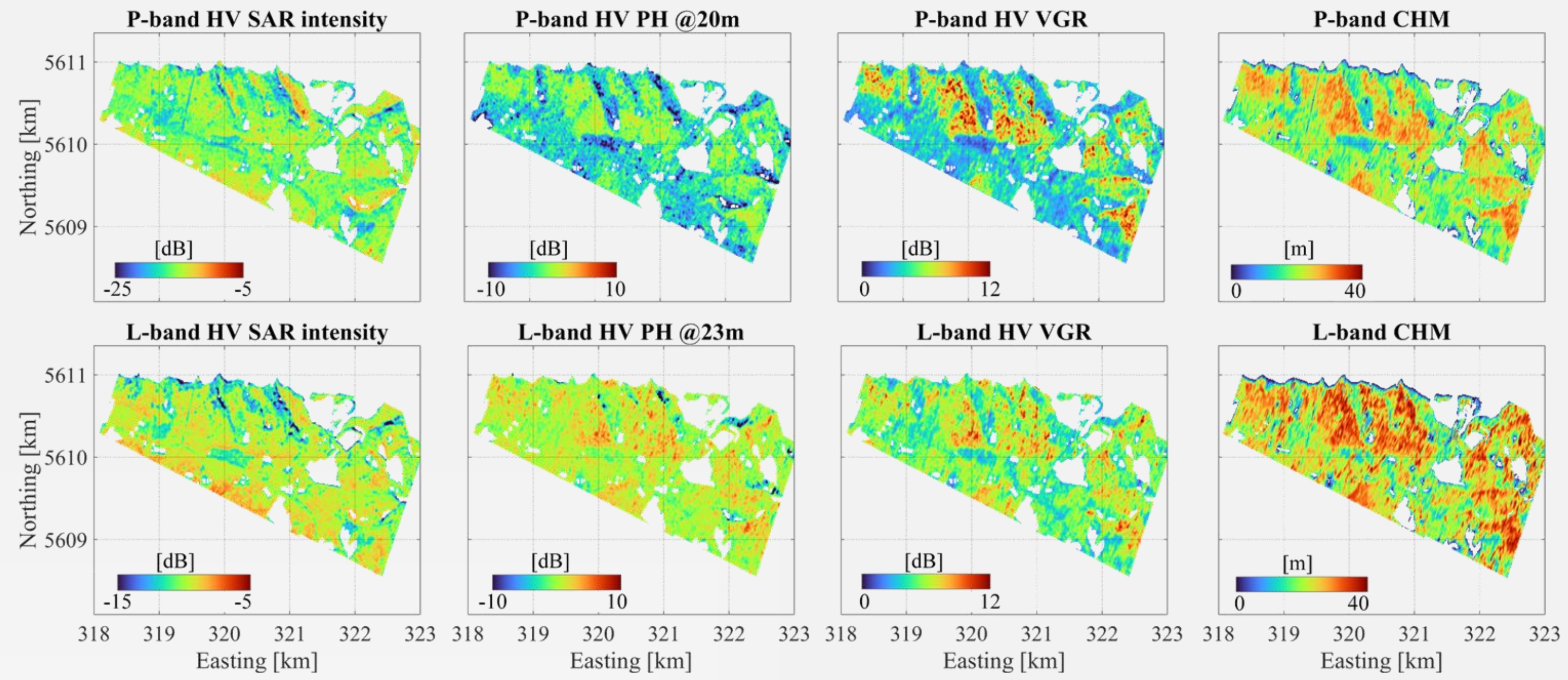


Figure 4. Single SAR intensity and the PH-derived 3D observables. (PH@20 m and PH@23 m represents the PH-derived backscatter intensity fixed at a height of 20 m and 23 m)

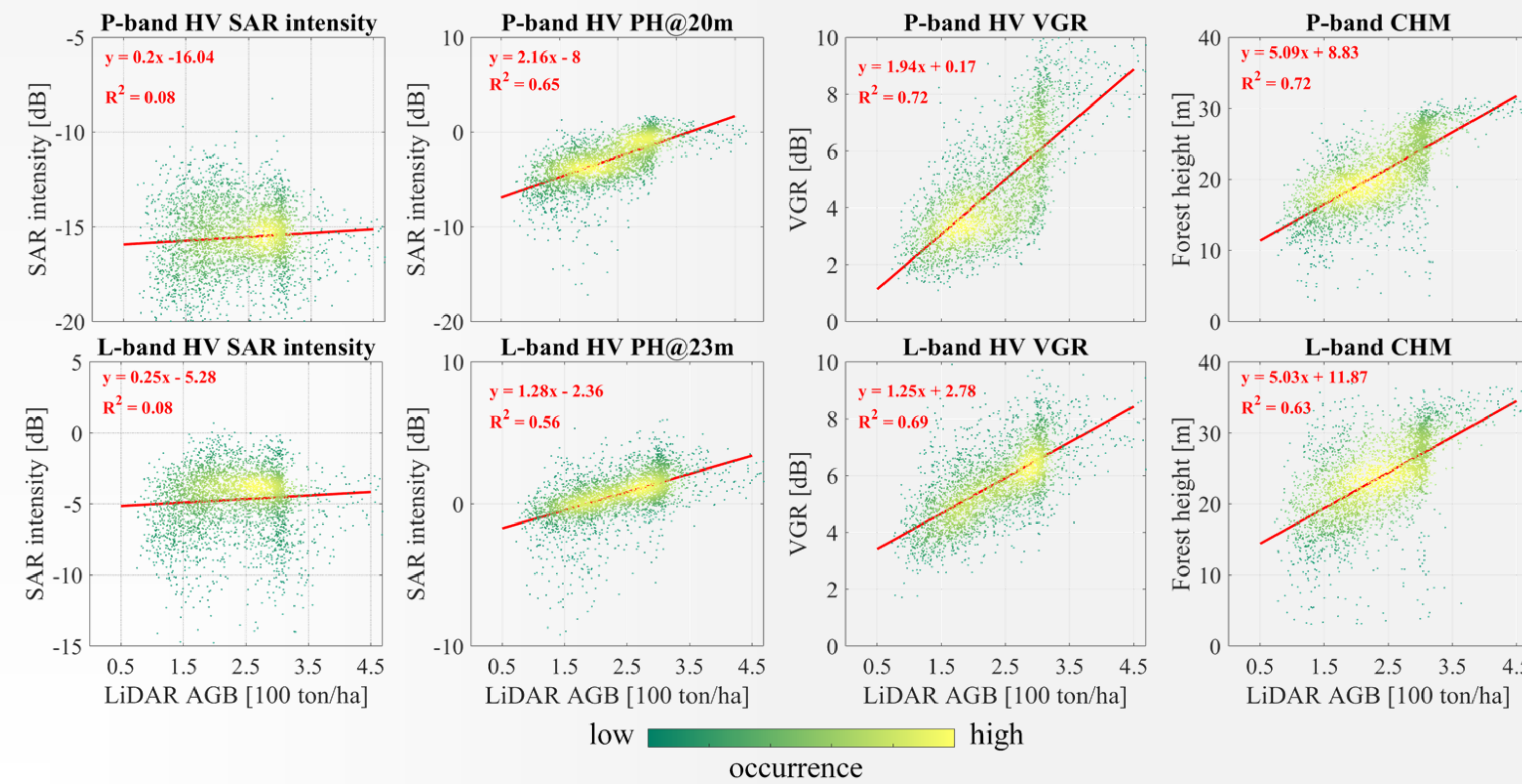


Figure 5. Sensitivity of the single SAR intensity and the PH-derived 3D observables to forest AGB. (PH@20 m and PH@23 m represents the PH-derived backscatter intensity fixed at a height of 20 m and 23 m)

4. AGB regression prediction results considering multi-band and multi-dimensional parameters

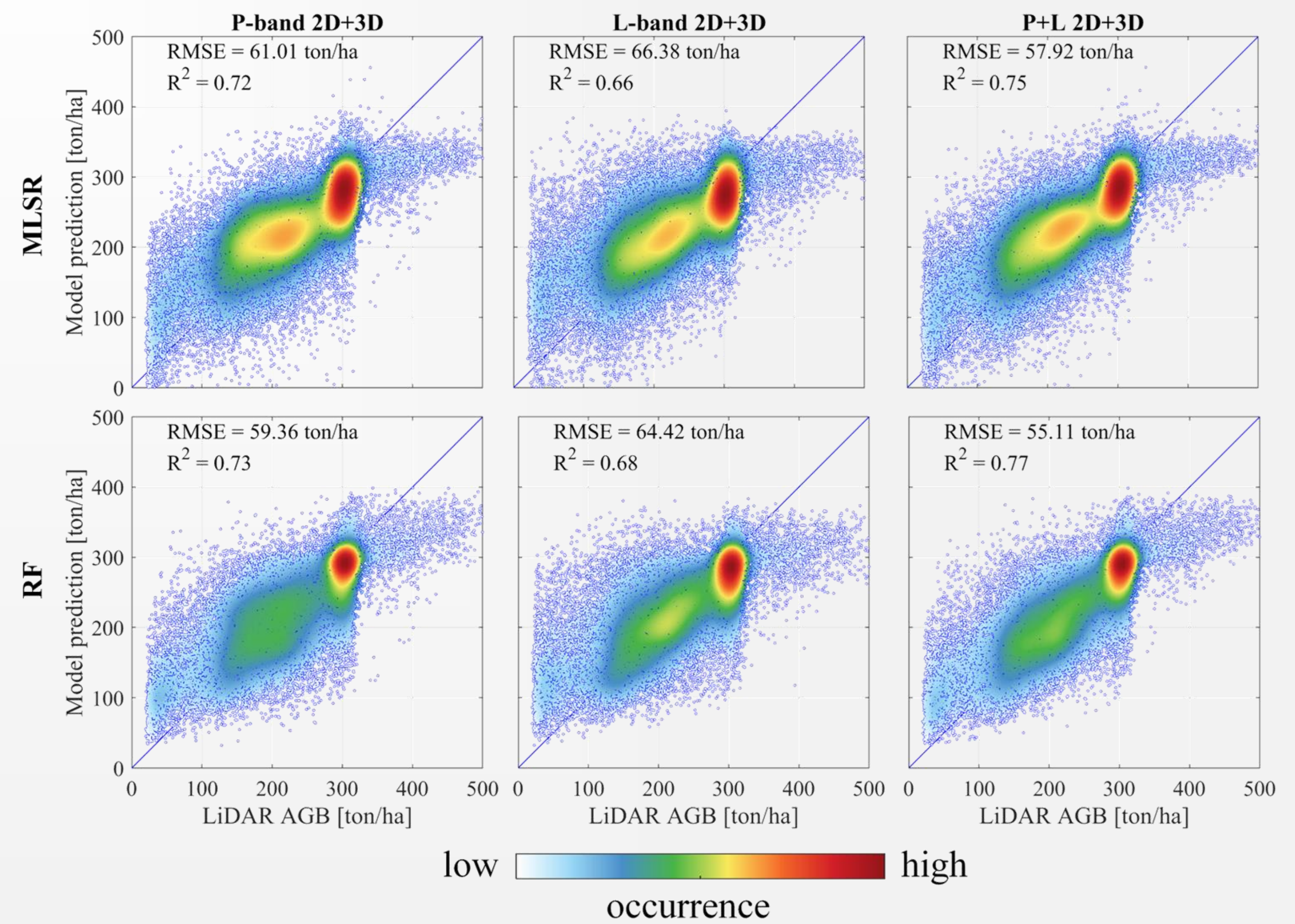


Figure 6. Verification results between the P-band and L-band 2D + 3D observables and the forest AGB using the MLSR and RF models

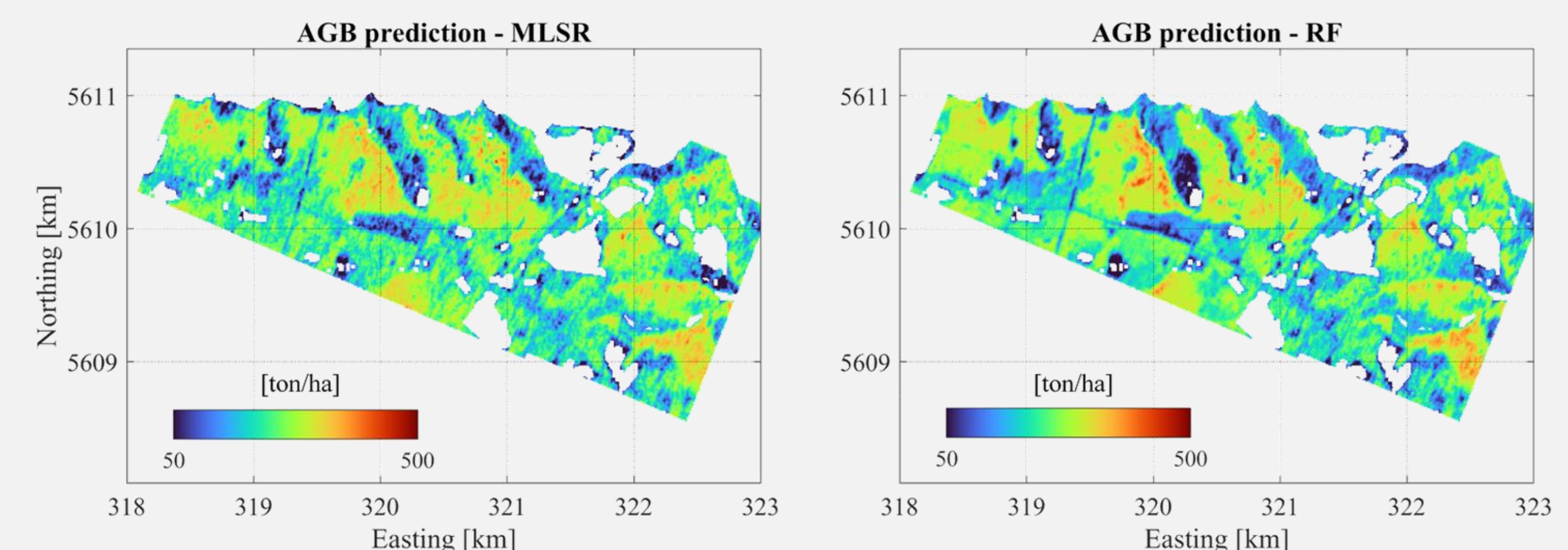


Figure 7. Forest AGB maps are based on P-band and L-band combination predicted by MLSR and RF models

Conclusions

- PH technique can provide low-resolution forest vertical structure indicators and obtain forest height products with considerable accuracy.
- The forest AGB method based on vertical structural features extracted by PH technique can improve the accuracy of forest AGB estimation and provide new opportunities for the inversion of forest AGB.