TomoSAR Sensitivity to Temperate Forest Above-Ground Biomass at P- and L-band in the TomoSense ESA Campaign

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Overview of the TomoSense experiment

- Funded by ESA to support remote sensing of forested areas by means of SAR data, with special focus on TomoSAR
- The site is a temperate forest at the Eifel National Park in North-West Germany
- Dominant species are beech and spruce trees, typically of 10 to 30 m height
- Above-ground biomass (AGB) ranges from 20 to 300 t/ha, with peaks up to 400 t/ha
- The SAR dataset is complemented by TLS, UAV-L, ALS and in-situ forest sensus

Fig. 1. The Urft Valley in front / south of the Kermeter area at the Eifel National park, North-West Germany.

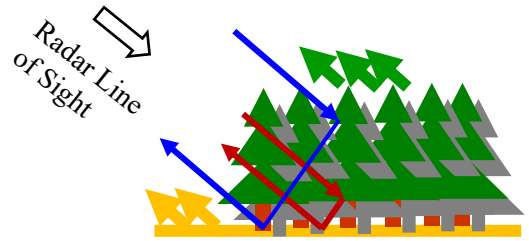
Flight plan – P-Band

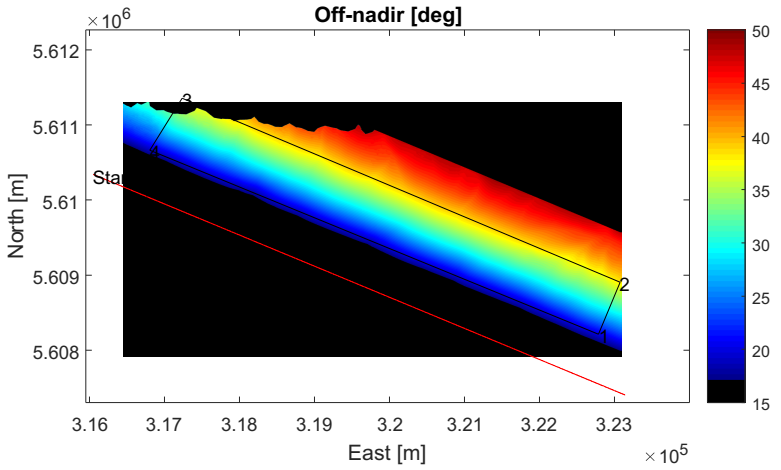
Flight height variation in 20 passes (meters w.r.t. 2200 m)

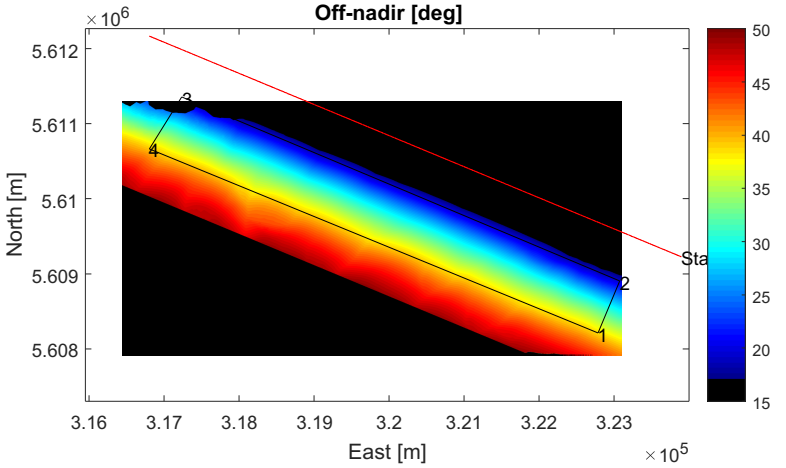
0 0 0 0 0 0 0 0 0 0 -4 -8 -12 -16 -20 -24 -28 -32 -36 -40

Fly 10 passes at the same height,

then decrease flight height by 4 m every pass



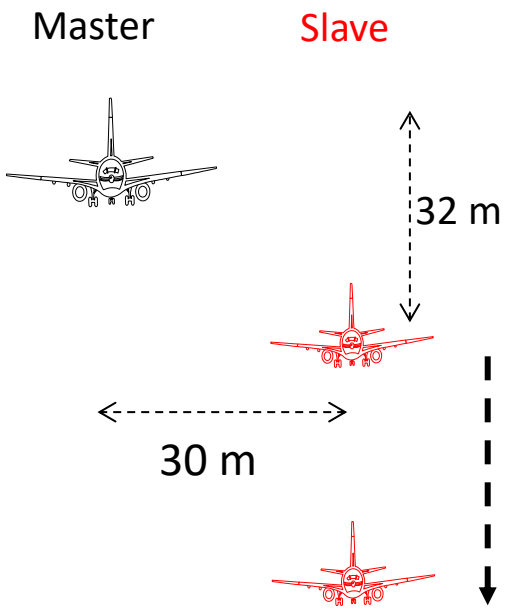


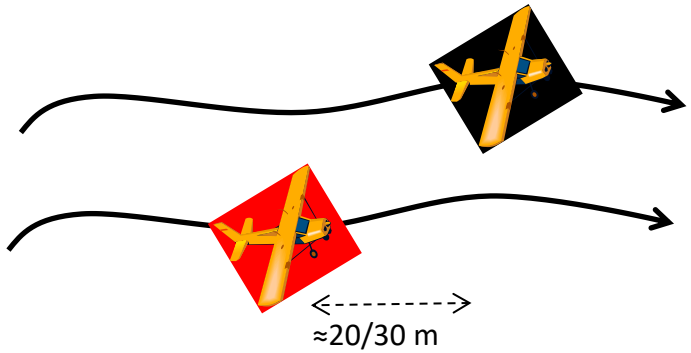


Flight plan – L-Band

Slave flights 30 m to the left w.r.t. Master (if Radar is left-looking)

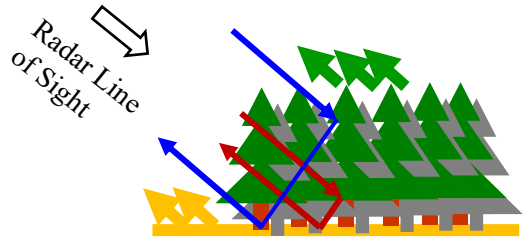
Master flights ahead by 20/30 m (preferably 30 m)

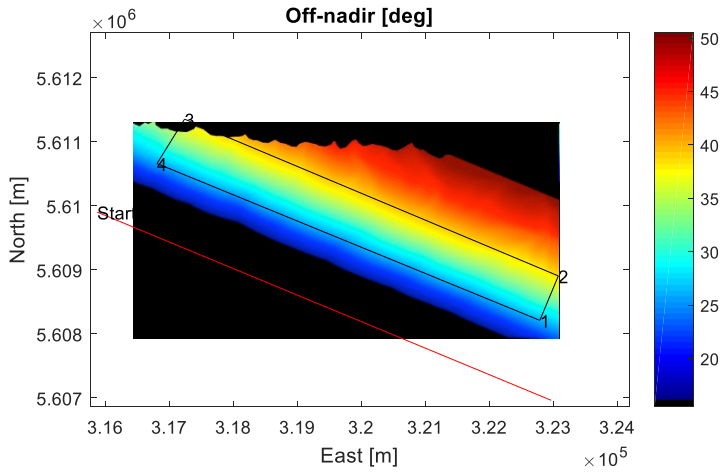


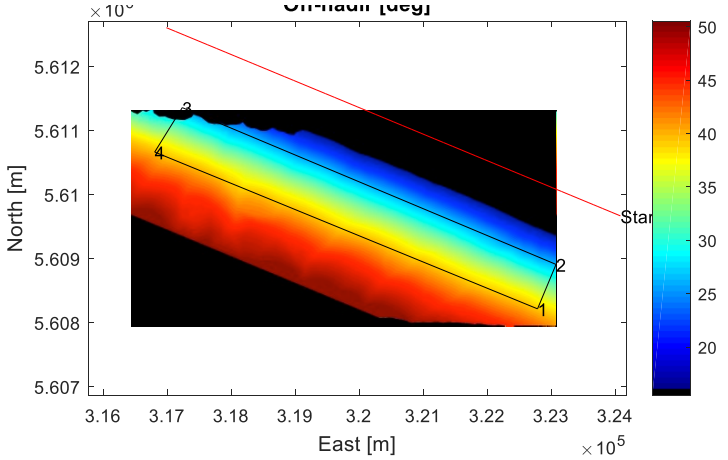


Slave starts 32 m lower than Master in the first flight

Then decreases flight height by 3 m every pass

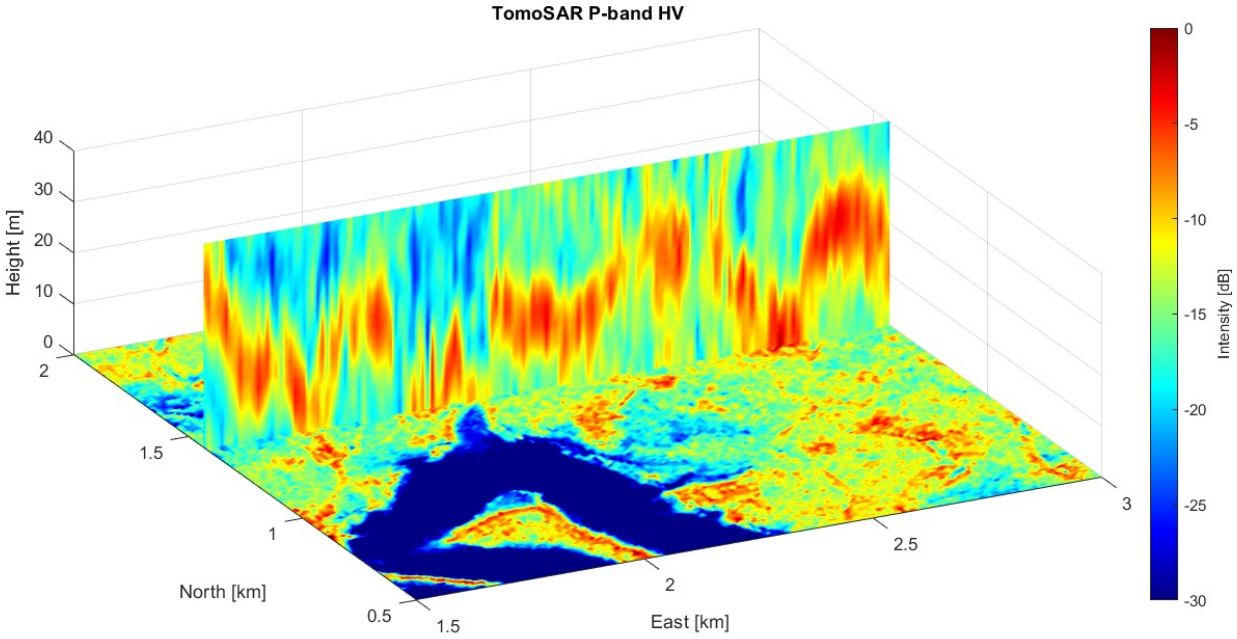






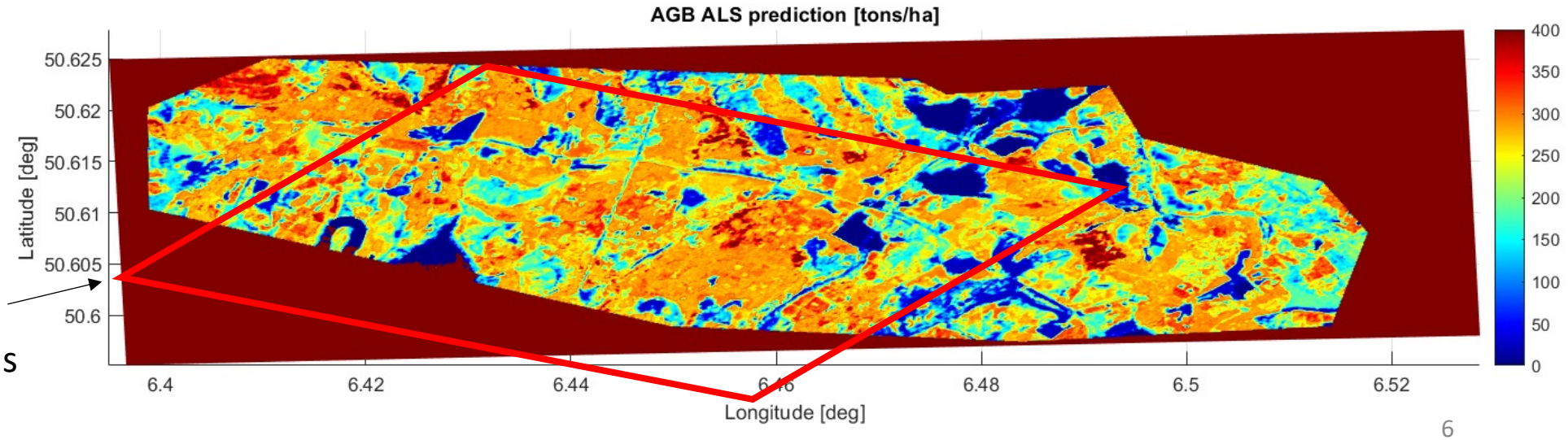
The TomoSAR data product

- Data from 20/30 (P-band/L-band) airborne radar acquisitions is combined to construct a 3D image of the scene reflectivity
- The reflectivity is resolved in height layers
- P- and L-band are important for forest applications since the signal penetrates the canopy and scatters off tree stems and larger branches, containing a majority of the tree biomass



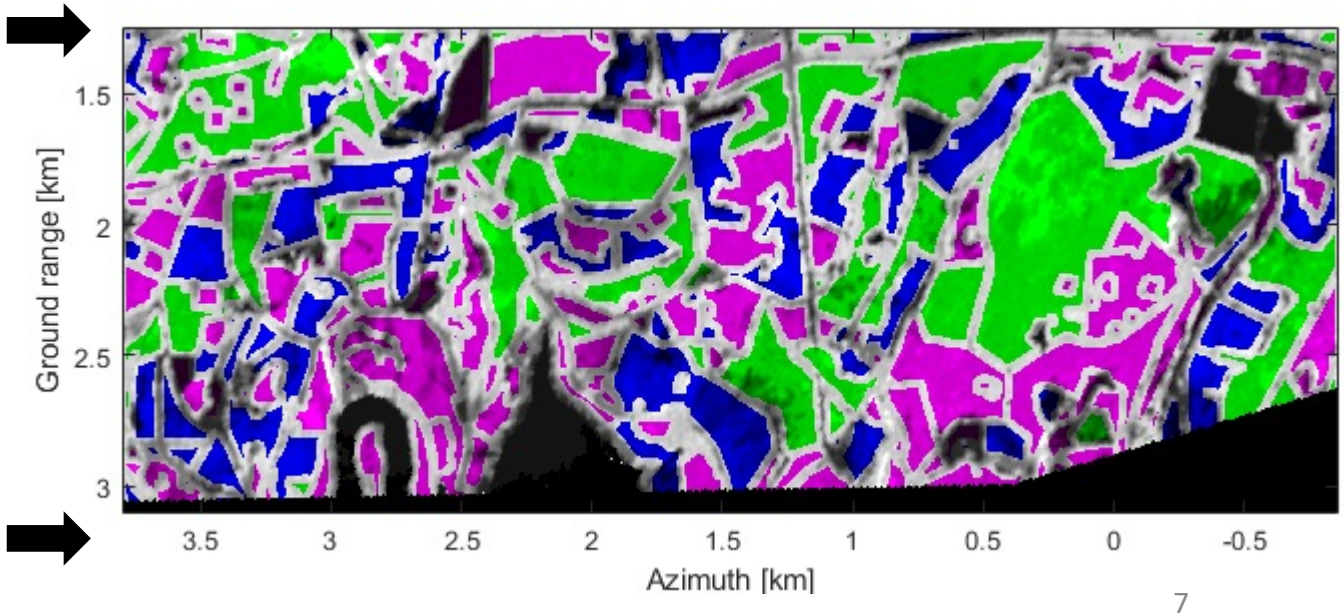
Reference AGB map estimated from ALS

- Airborne Lidar Scan (ALS) by CzechGlobe in June 2021
- Model training done using 80 in-situ forest plots and assisted by 100 additional plots from a study site in Silesian Beskids (2019 & 2020)
- Final ALS AGB map showing an R^2 of 0.95 and an RMSE of 27 t/ha (about 10 %) when compared to all Kermeter plots (75 % for model training)



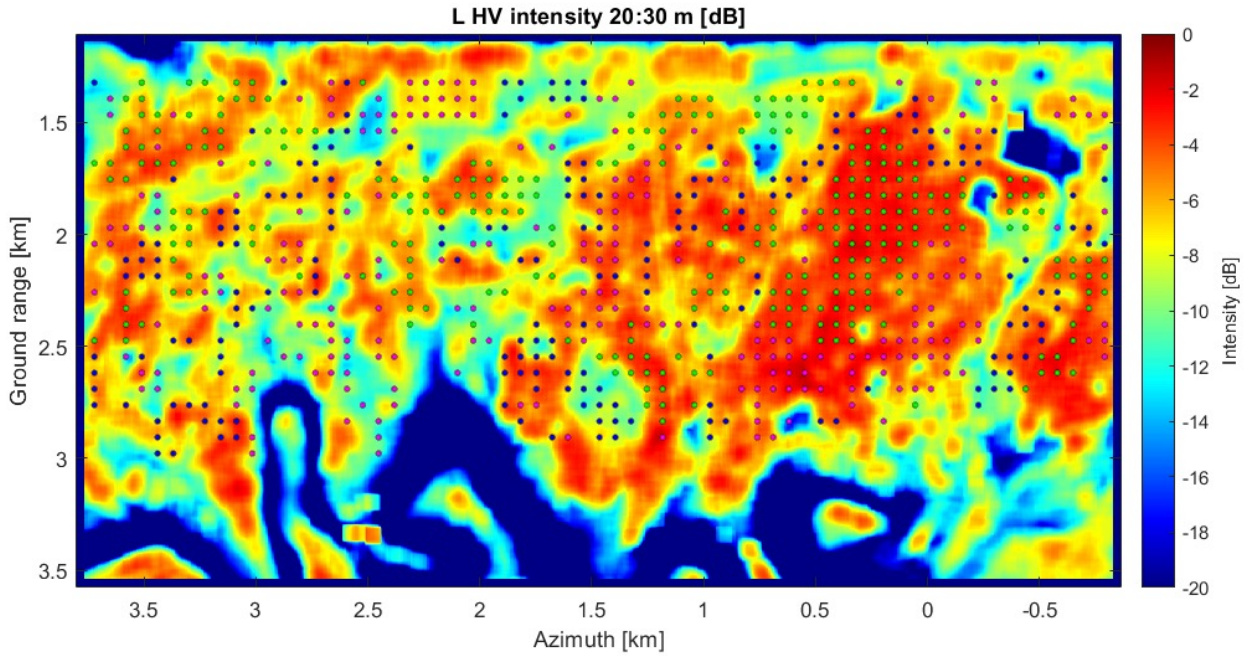
Forest type segmentation

- Left figure - Forest type inventory map from 2013 (Wald und Holz): Brown: beech, blue: spruce
- Right figure – L-band TomoSAR coverage: Green: beech, blue: spruce, magenta: other temperate forest



Main results of this study

- Presented vertical reflectivity profiles (VRPs) as a function of AGB for three forest types
- TomoSAR AGB retrieval performance for three methods and forest types
- Ground slope is a significant nuisance factor for AGB retrieval at P-band

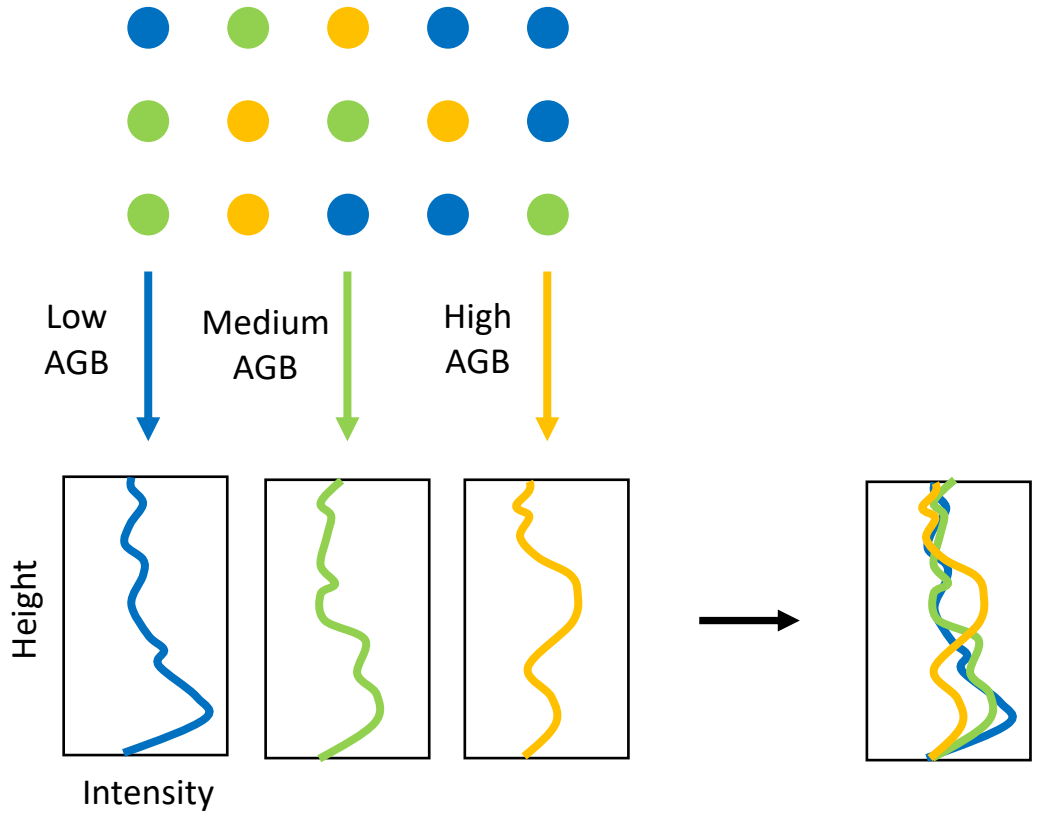


Location of data points on top of the L-band HV TomoSAR map (20 m to 30 m intensity integral), averaged over 0.5 ha. Color of points indicate forest type; green: beech, blue: spruce and magenta: other temperate forest.

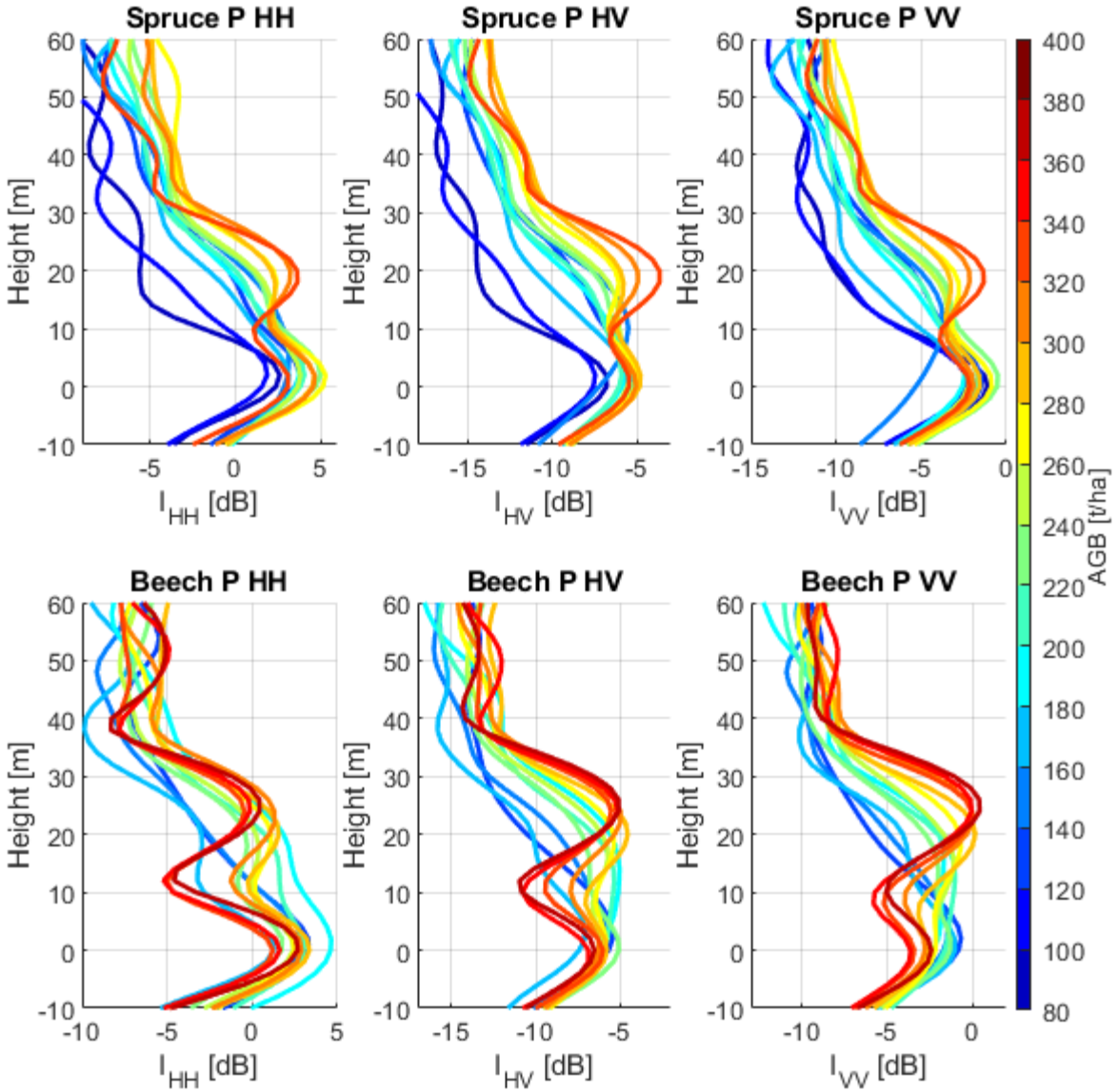
Vertical reflectivity profiles

Method

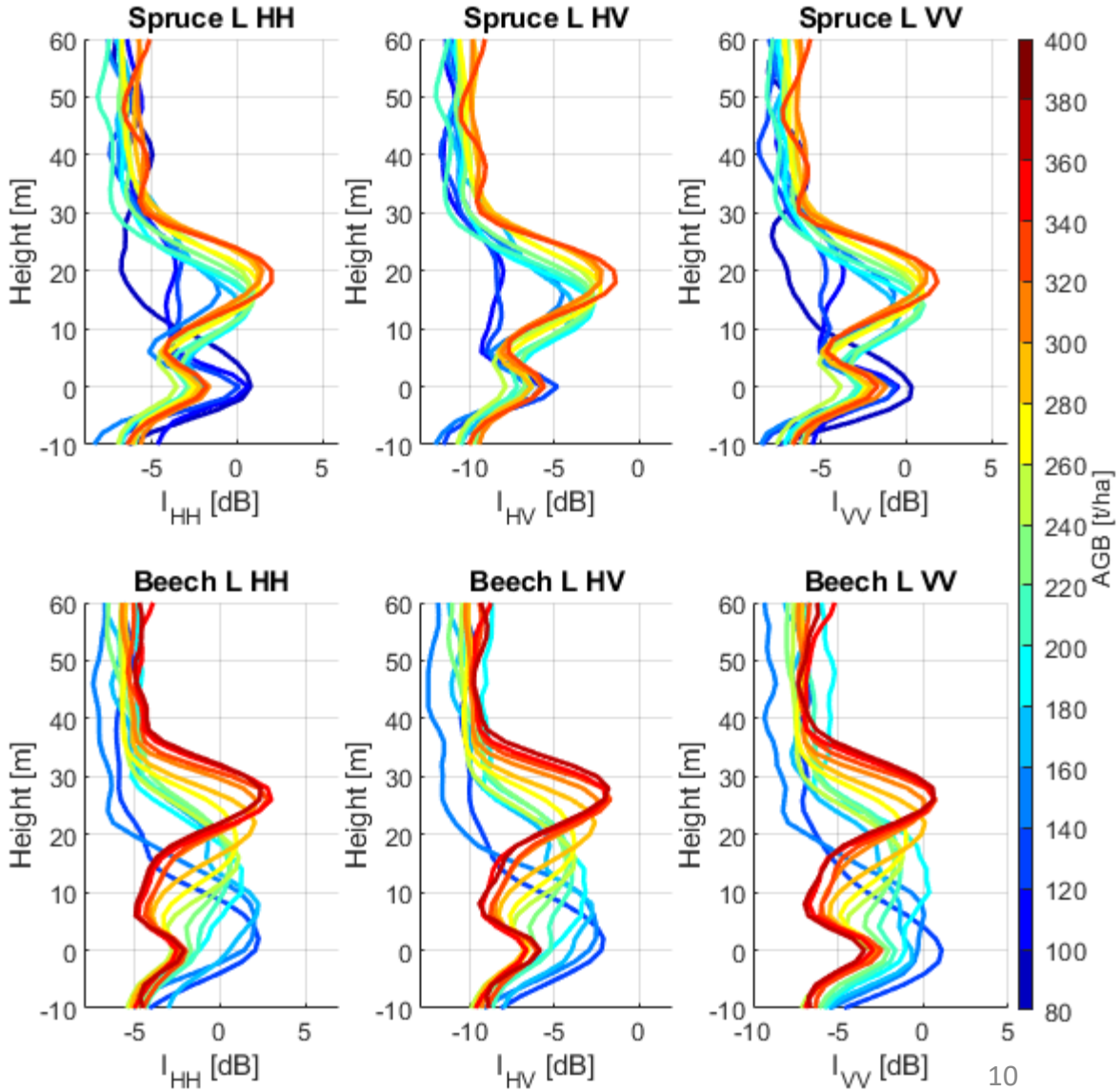
- Extract data points (0.5 ha cells)
- Sort according to AGB (20 t/ha intervals)
- Compute average VRP (height reflectivity function) for each AGB set
- Color indicate AGB value for each profile



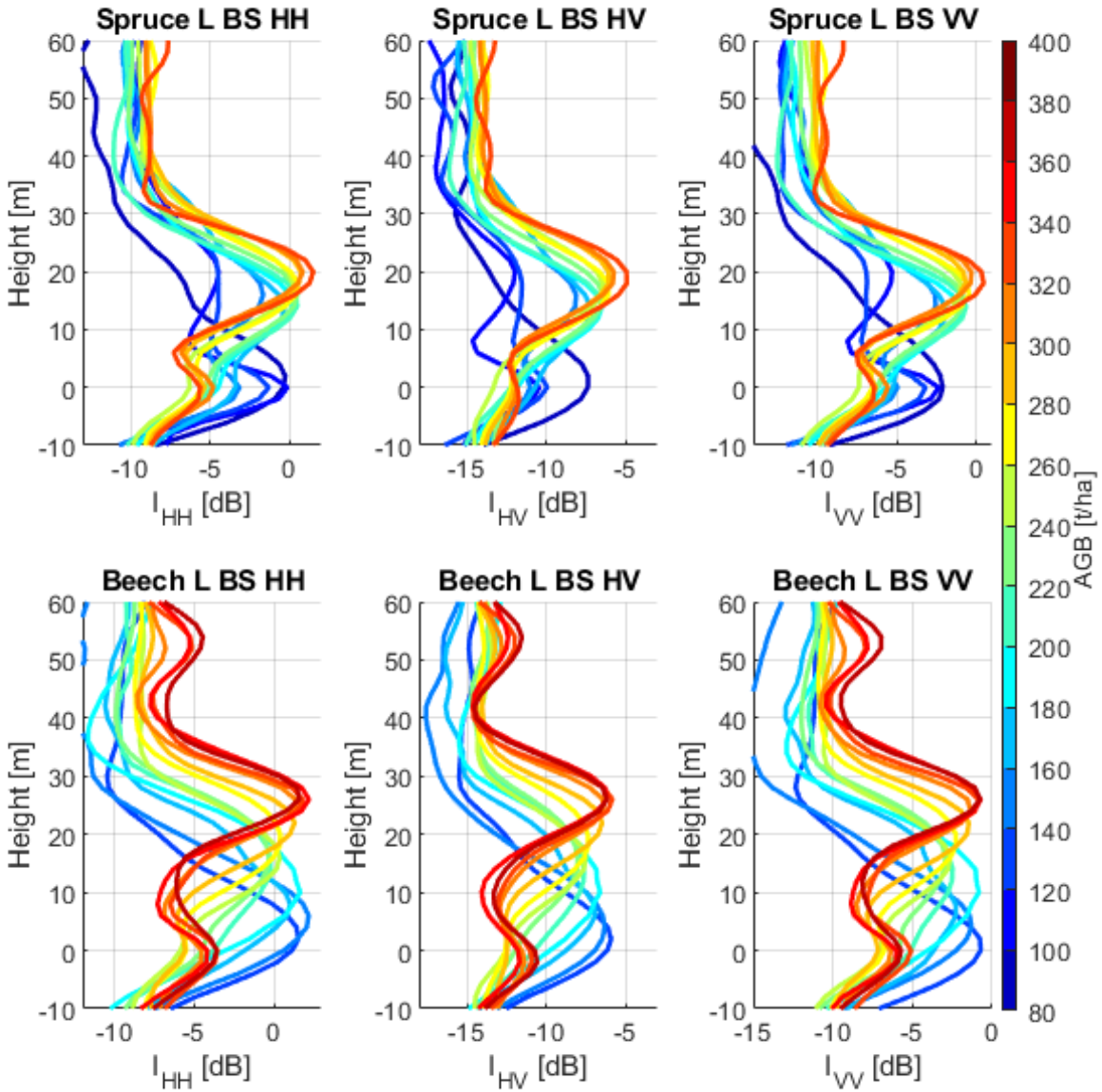
P-band VRPs



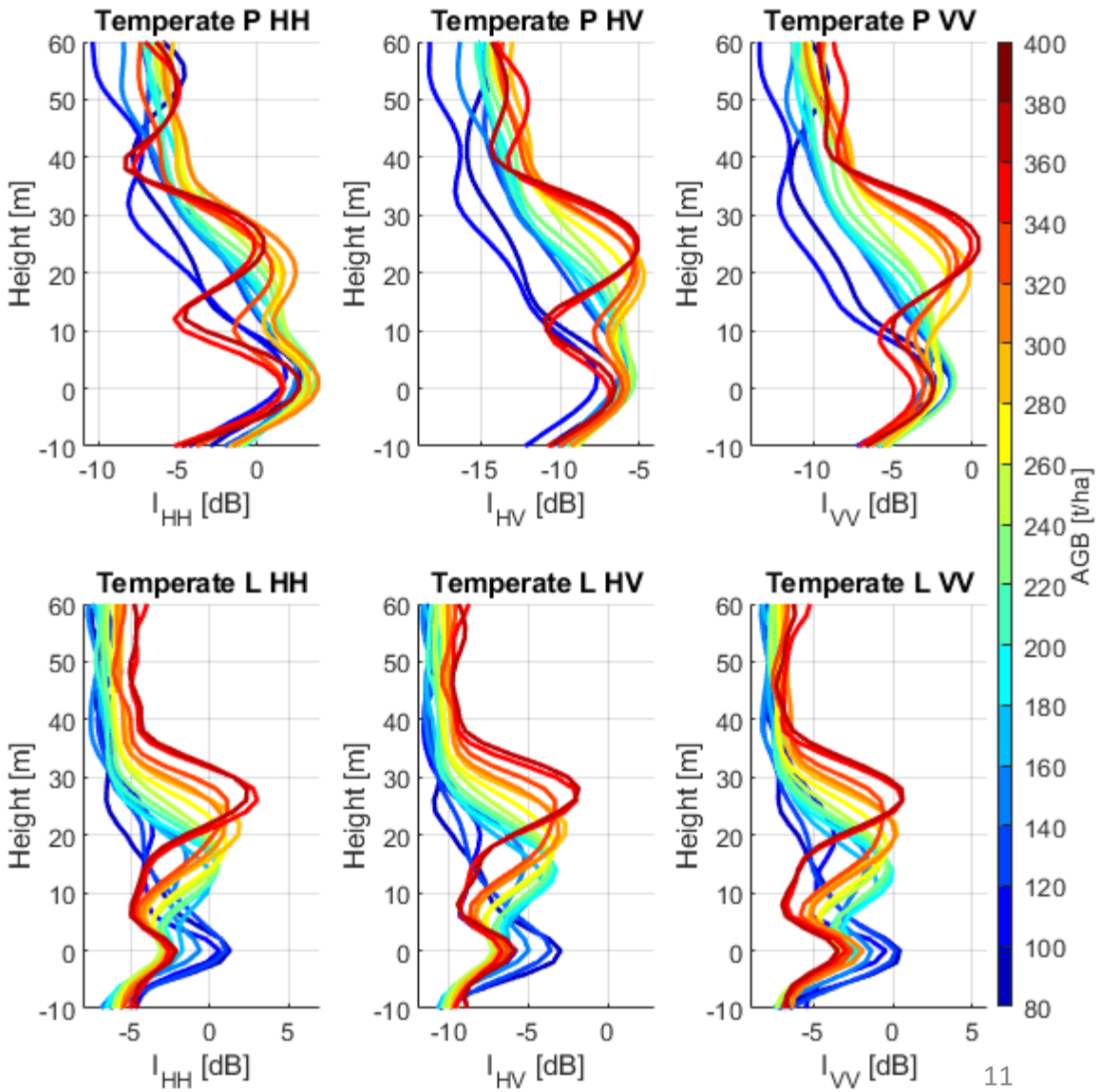
L-band VRPs



L-band bistatic VRPs

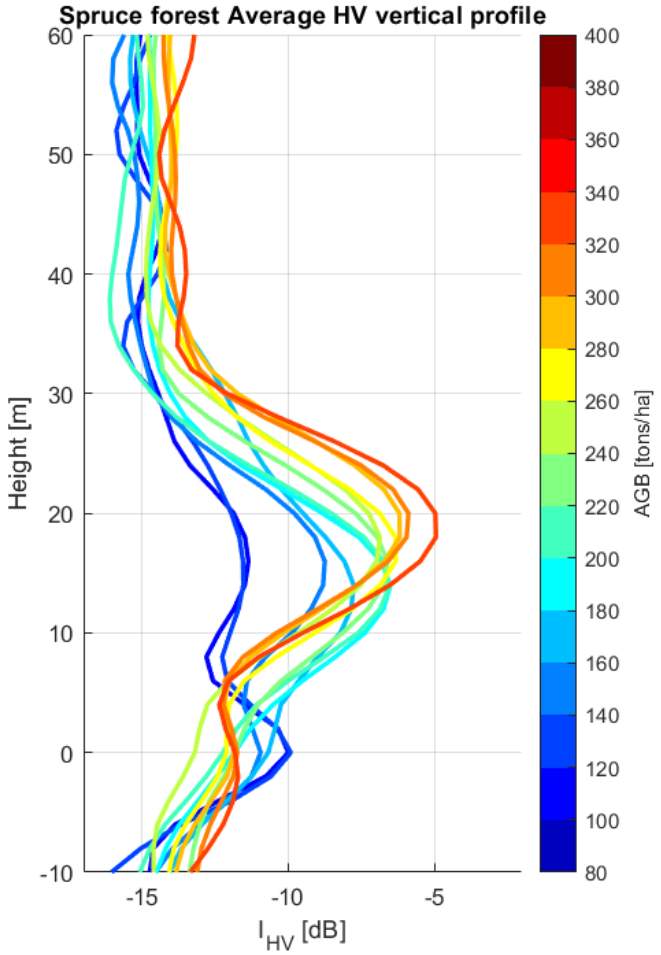


Temperate forest VRPs

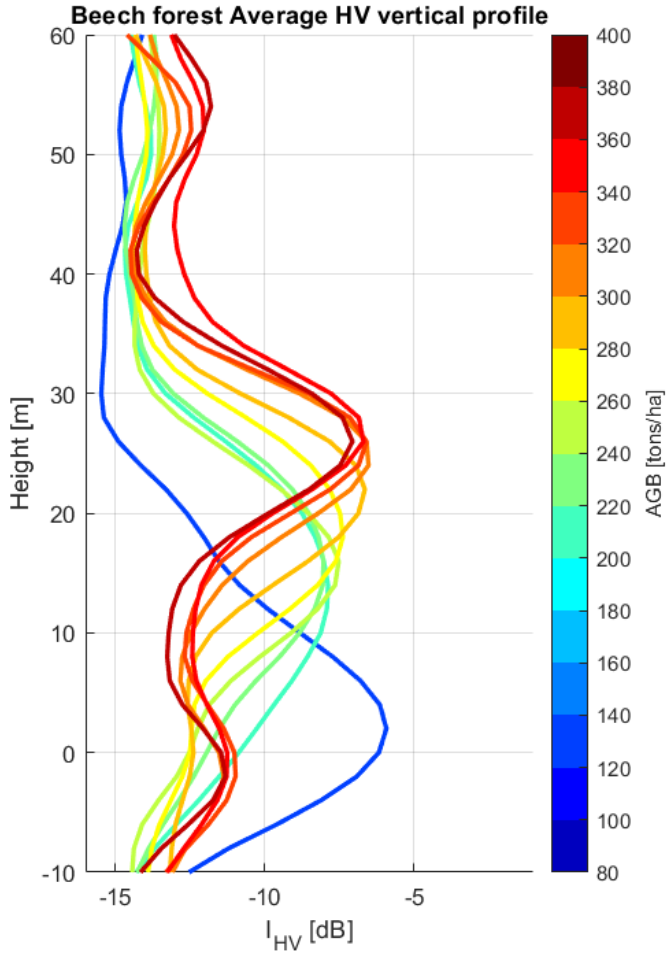


VRP differences and forest type structure

Spruce (L-band)



Beech (L-band)



TomoSAR AGB retrieval

Method

- Fit exponential model to data points

$$\hat{B}_{TomoSAR} = \exp(a_0 + a_1 I_{dB})$$

- Use 50 % of data points for **training** (**green color**) and the remaining 50 % for **validation** (**black color**)

Performance metrics

- R^2
- RMSE: $\sqrt{\frac{1}{N}\sum(\hat{B}_{TomoSAR} - B_{ALS})^2}$
- % RMSE of mean AGB

Retrieval methods

Method 1 (M1): Total intensity

Method 2 (M2): Canopy intensity (20 m to 30 m height integral)

Method 3 (M3): Canopy ratio to total intensity (M2 / M1, normalized)

Method 1: Total intensity

P-band

Spruce

- R^2 = 0.32, RMSE = 53 t/ha (23 %)

Beech

- Not sensitive to AGB

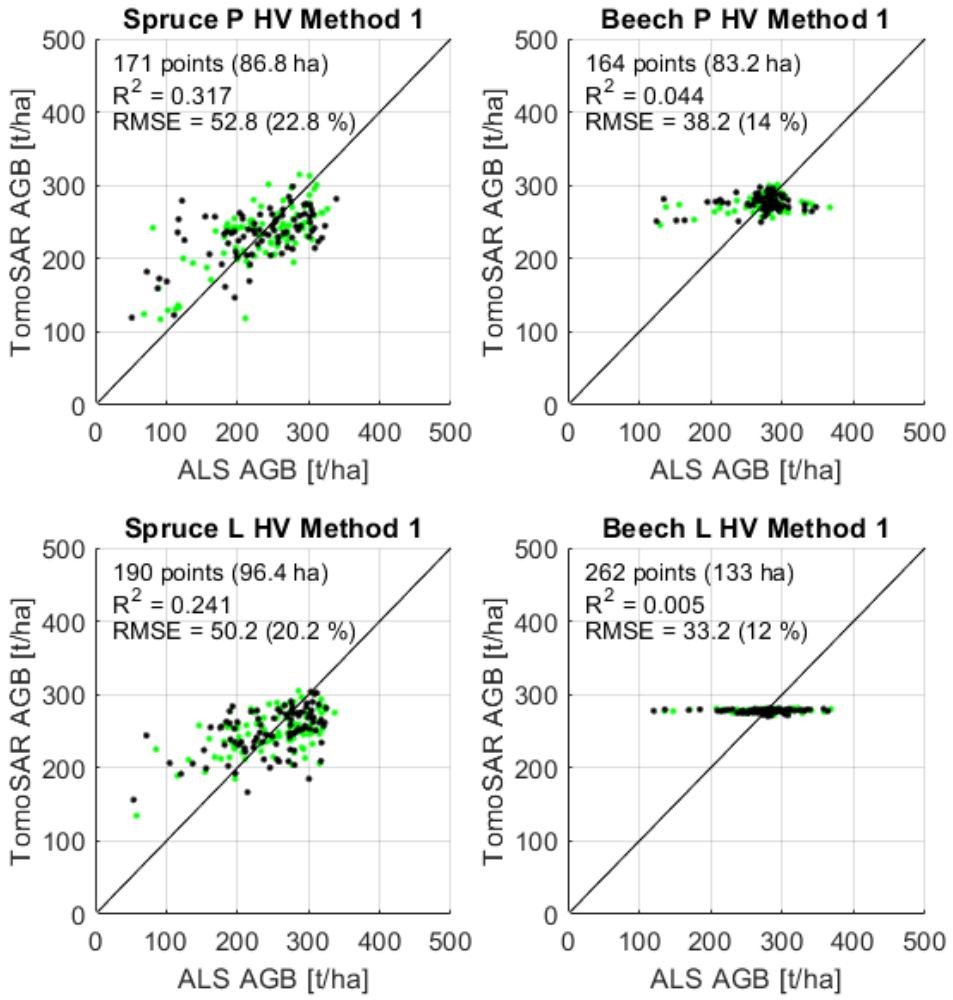
L-band

Spruce

- R^2 = 0.24, RMSE = 50 t/ha (20 %)

Beech

- Not sensitive to AGB



Method 2: Canopy intensity

P-band

Spruce

- R^2 = 0.47, RMSE = 47 t/ha (20 %)

Beech

- R^2 = 0.32, RMSE = 32 t/ha (12 %)

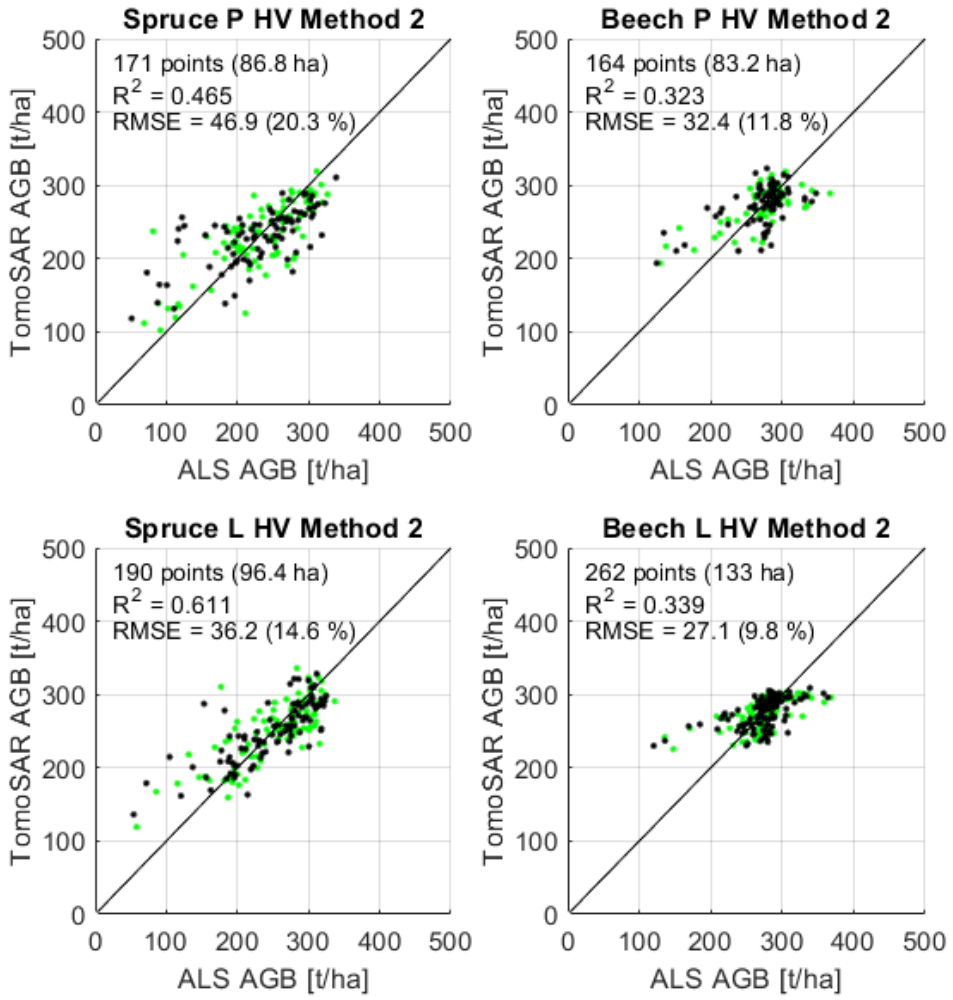
L-band

Spruce

- R^2 = 0.61, RMSE = 36 t/ha (15 %)

Beech

- R^2 = 0.34, RMSE = 27 t/ha (10 %)



Method 3: Canopy ratio to total intensity

P-band

Spruce

- R^2 = 0.37, RMSE = 51 t/ha (22 %)

Beech

- R^2 = 0.36, RMSE = 31 t/ha (12 %)

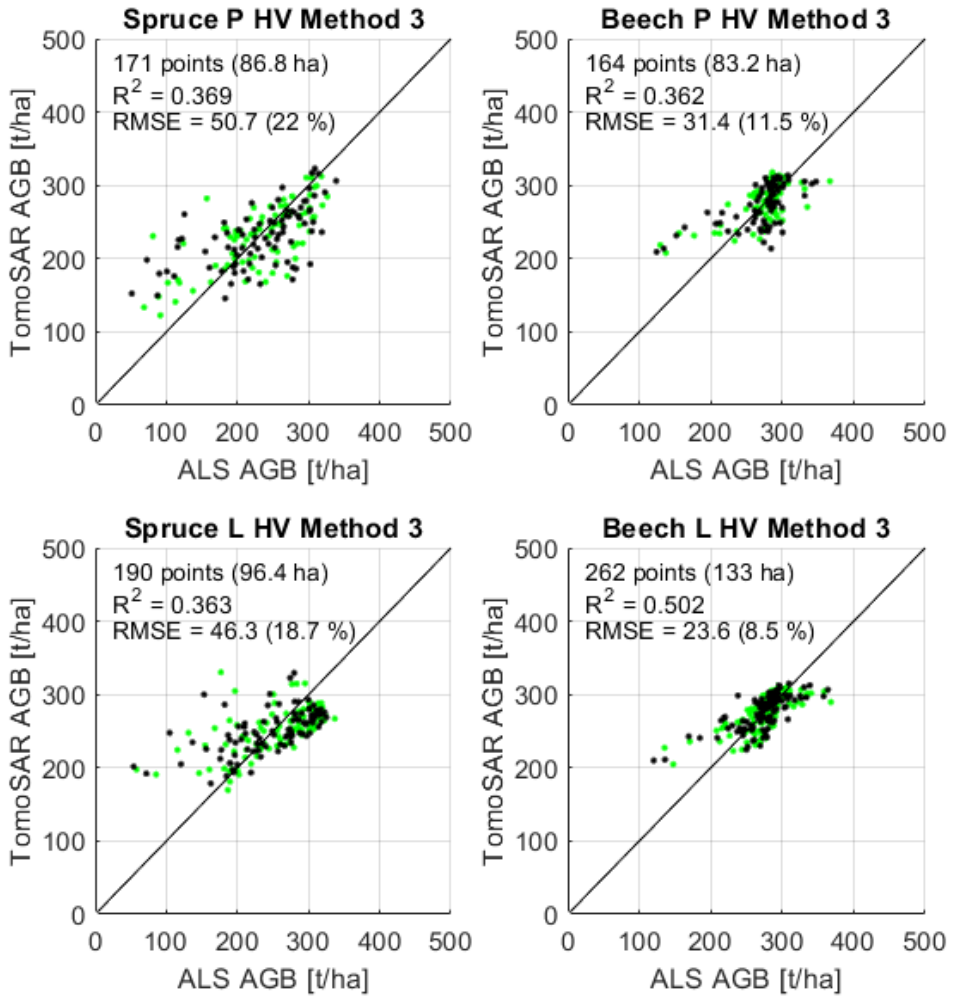
L-band

Spruce

- R^2 = 0.36, RMSE = 46 t/ha (19 %)

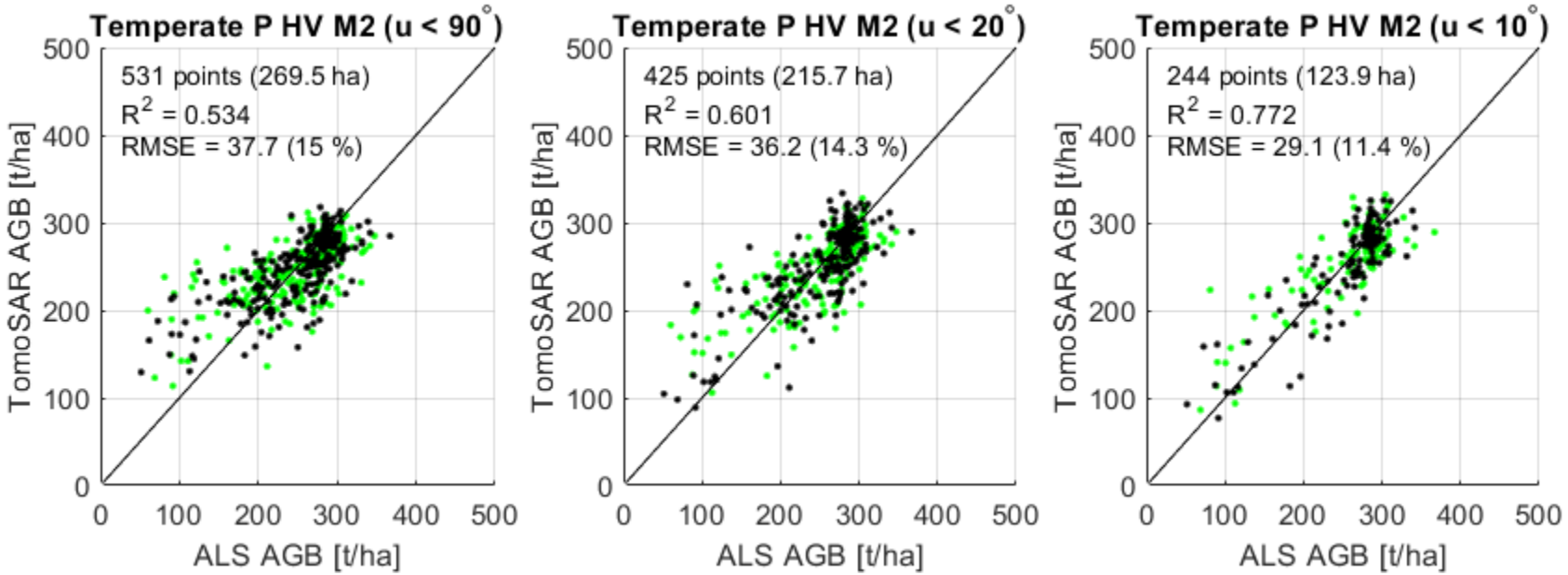
Beech

- R^2 = 0.50, RMSE = 24 t/ha (9 %)



Ground slope nuisance factor (P-band)

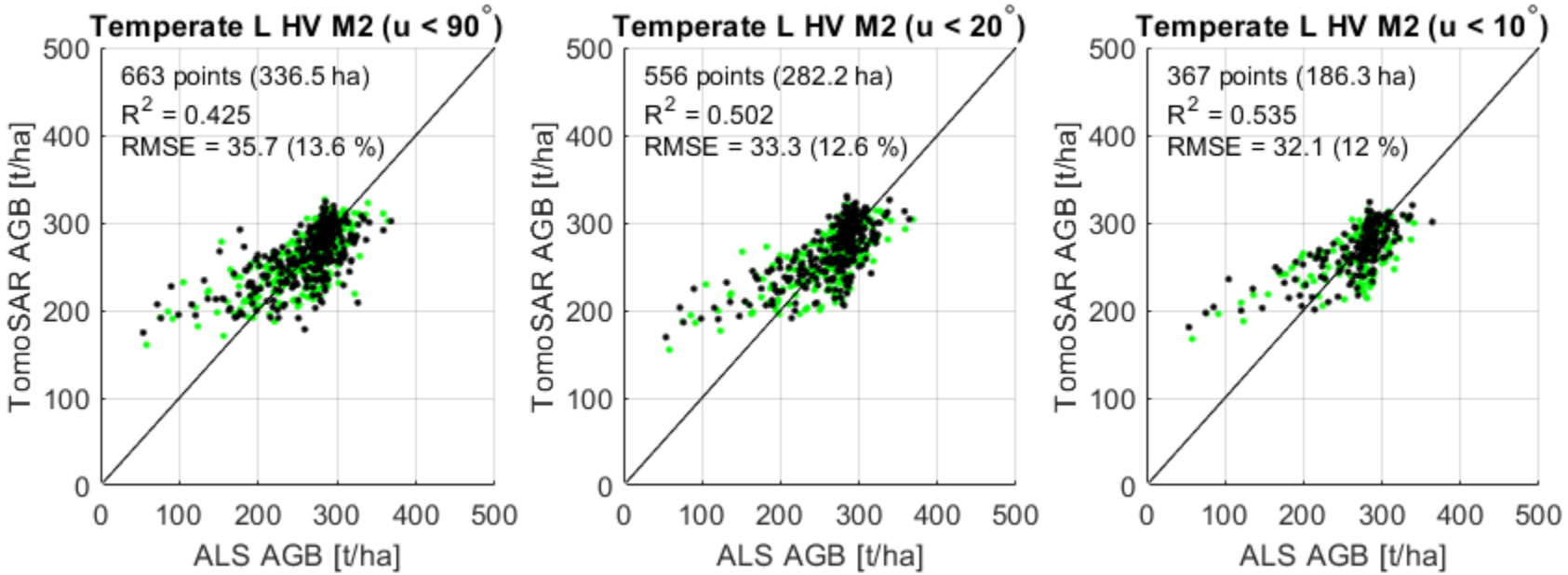
$u < 90°$	$u < 20°$	$u < 10°$
R^2 = 0.53	R^2 = 0.60	R^2 = 0.77
RMSE = 38 t/ha (15 %)	RMSE = 36 t/ha (14 %)	RMSE = 29 t/ha (11 %)



P-band HV TomoSAR AGB retrieval using method 2 (canopy intensity) and data points conditioned on the average ground slope u.

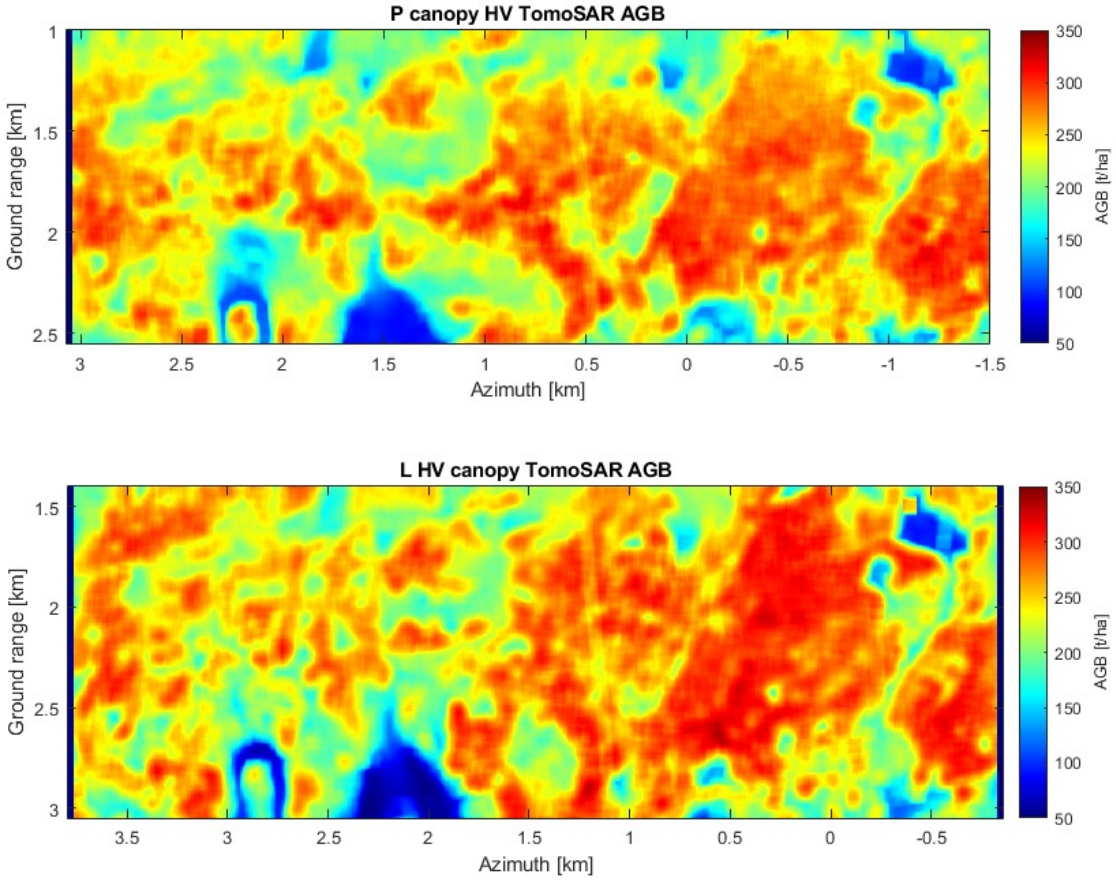
Ground slope nuisance factor (L-band)

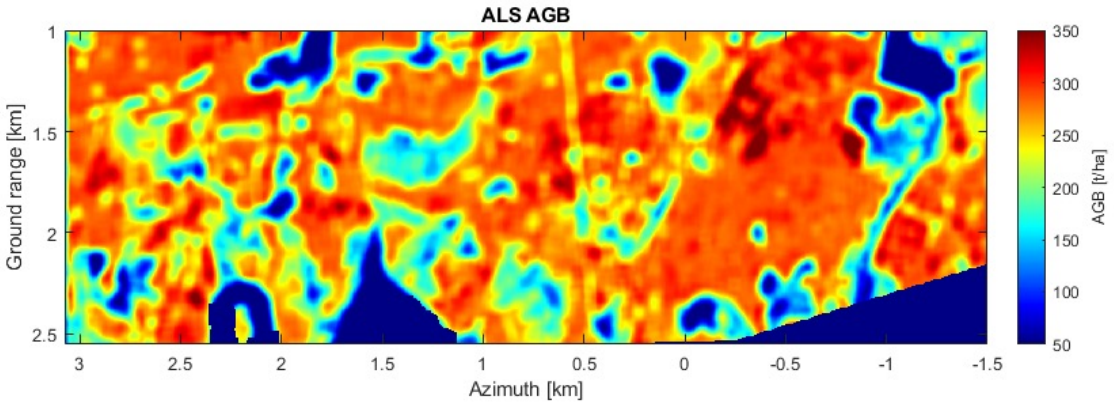
$u < 90°$	$u < 20°$	$u < 10°$
R^2 = 0.43	R^2 = 0.50	R^2 = 0.54
RMSE = 36 t/ha (14 %)	RMSE = 33 t/ha (13 %)	RMSE = 32 t/ha (12 %)



L-band HV TomoSAR AGB retrieval using method 2 (canopy intensity) and data points conditioned on the average ground slope u.

TomoSAR AGB maps





Conclusions

Vertical reflectivity profiles

Show a clear AGB dependence

- **Spruce** VRPs grow strongly in intensity and slightly in height for increasing AGB
- **Beech** VRPs grow strongly in height and not in intensity for increasing AGB

This is speculated to originate from forest structure

- **Spruce**: Increased number of scatterers (branches) for larger trees
- **Beech**: Canopy mainly elevated in height for larger trees

Conclusions

TomoSAR AGB retrieval performance

Total intensity: Sensitivity to spruce AGB at both P- and L-band, especially for HV. No significant sensitivity for beech.

Canopy intensity: Temperate P/L: R^2 0.53/0.43, RMSE 38/36 t/ha (15/14 %)

Canopy ratio: Comparable to previous, but spruce AGB sensitivity is reduced at both bands while that of beech is increased

Note: TomoSAR AGB error is close to ALS AGB error! (27 t/ha, around 10 %)

Ground slope nuisance factor

Shown to be significant, especially for P-band

Limiting ground slope below 10°

- R^2 improves from 0.53 to 0.77
- RMSE from 38 t/ha (15 %) to 29 t/ha (11 %)

Most significant for spruce, where R^2 changes from 0.47 to 0.86