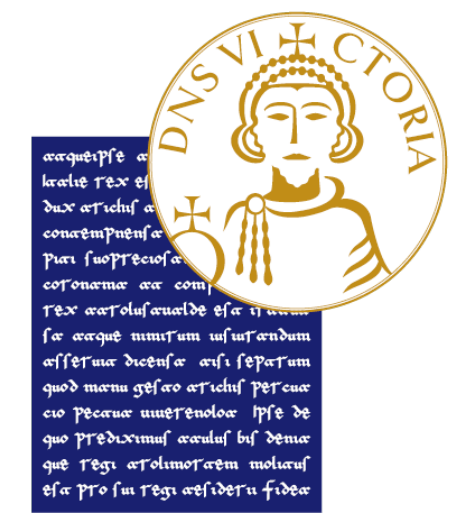




Retrieving 3D Forest Structure with P-band TomoSAR and Machine Learning for Disaster Risk Management

AfriSAR Mondah Test Site, Gabon

Francesco Buonavolontà, Francesco Mauro, Silvia Liberata Ullo

Department of Engineering, University of Sannio, Benevento, Italy

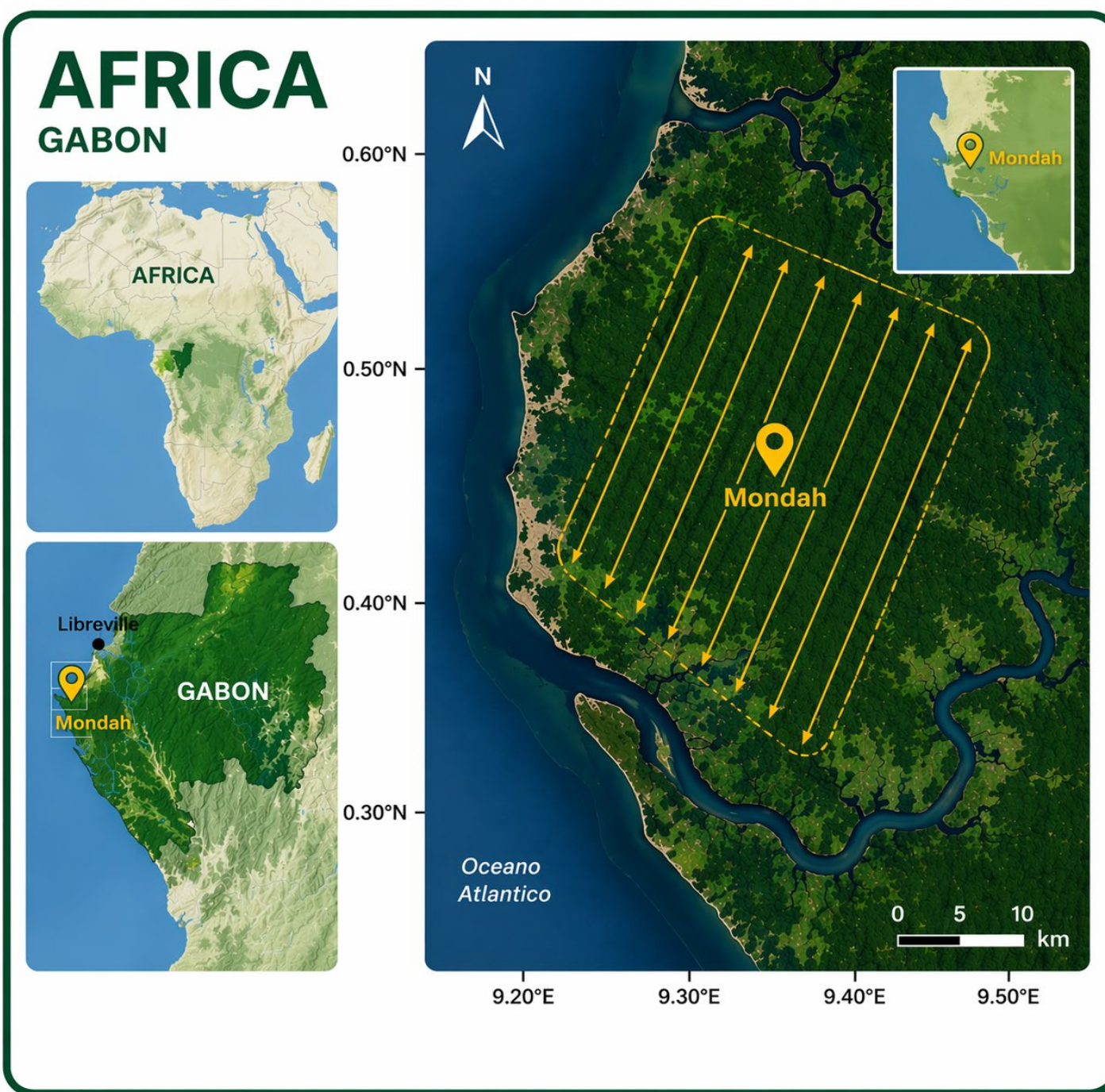
INTRODUCTION & STUDY AREA

WHY 3D FOREST STRUCTURE MATTERS

Forests act as protective infrastructure by storing carbon, intercepting rainfall, stabilizing soils, and reducing hydrological impacts. Therefore, after wildfires, severe storms, or landslides, damage is not limited to canopy removal. Limitations of two-dimensional forest maps are represented by misclassification: they may still classify an area as forested while losses in canopy height, woody volume, and vertical continuity have occurred. Moreover, structural changes can increase soil exposure, runoff, erosion, and cascading risk. Their correct evaluation is crucial.

Forest cover is not the same as forest structure.

P-band is especially valuable because its long wavelength penetrates the canopy and remains sensitive to woody layers.



STUDY AREA & DATA

Study area: Mondah forest, Gabon

Campaign: AfriSAR

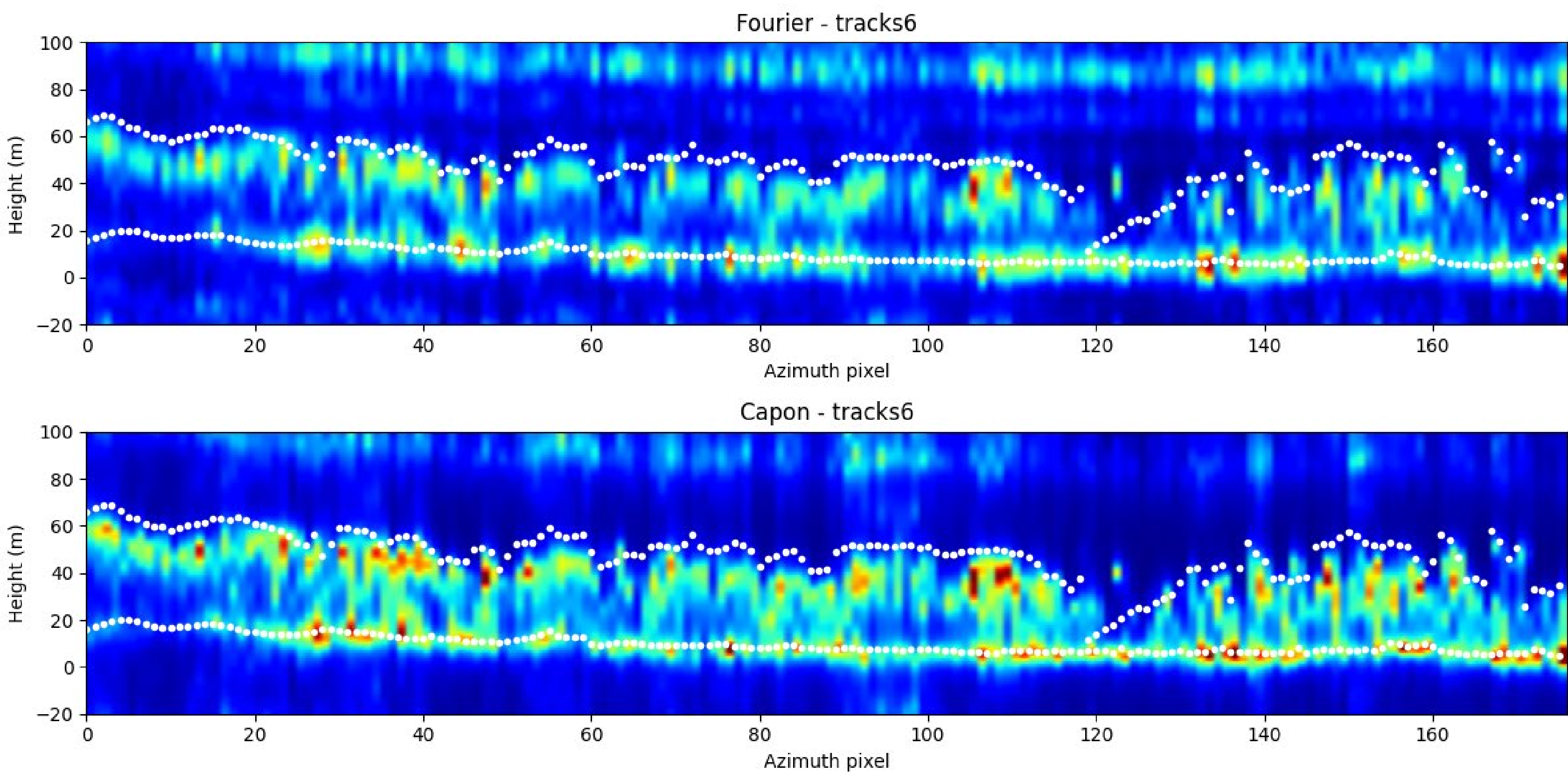
Data: 11 multi-baseline P-band SAR data from different flight tracks

Ground Truth: NASA LVIS terrain and canopy-height products – LiDAR data

Context: tropical-forest benchmark for structural retrieval and future pre-/post-event comparisons

TOMOGRAPHIC PRODUCTS & KEY RESULTS

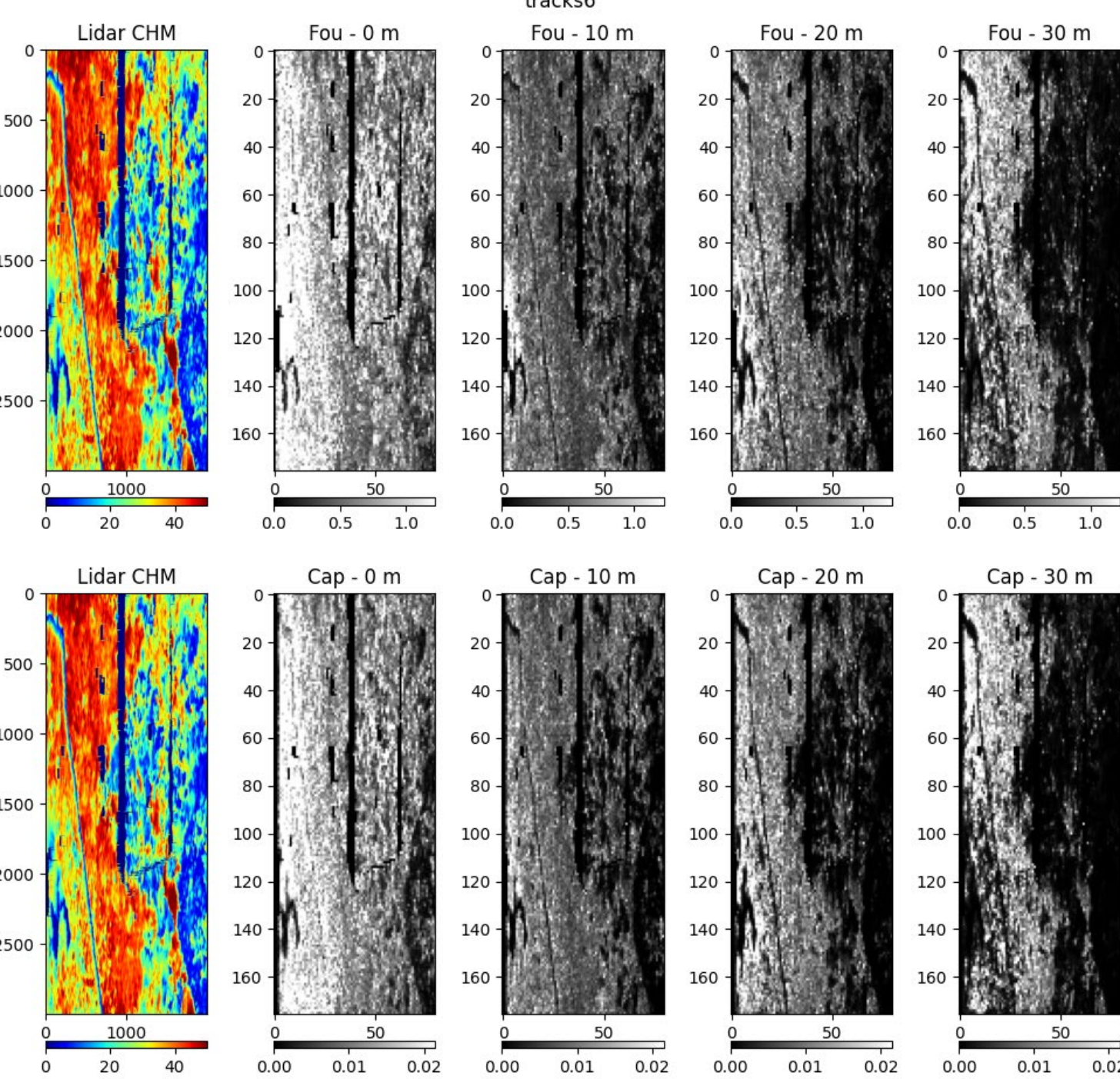
Azimuth-height tomographic profiles: Fourier and Capon



Six-track configuration; white markers show lidar-derived ground and canopy top.

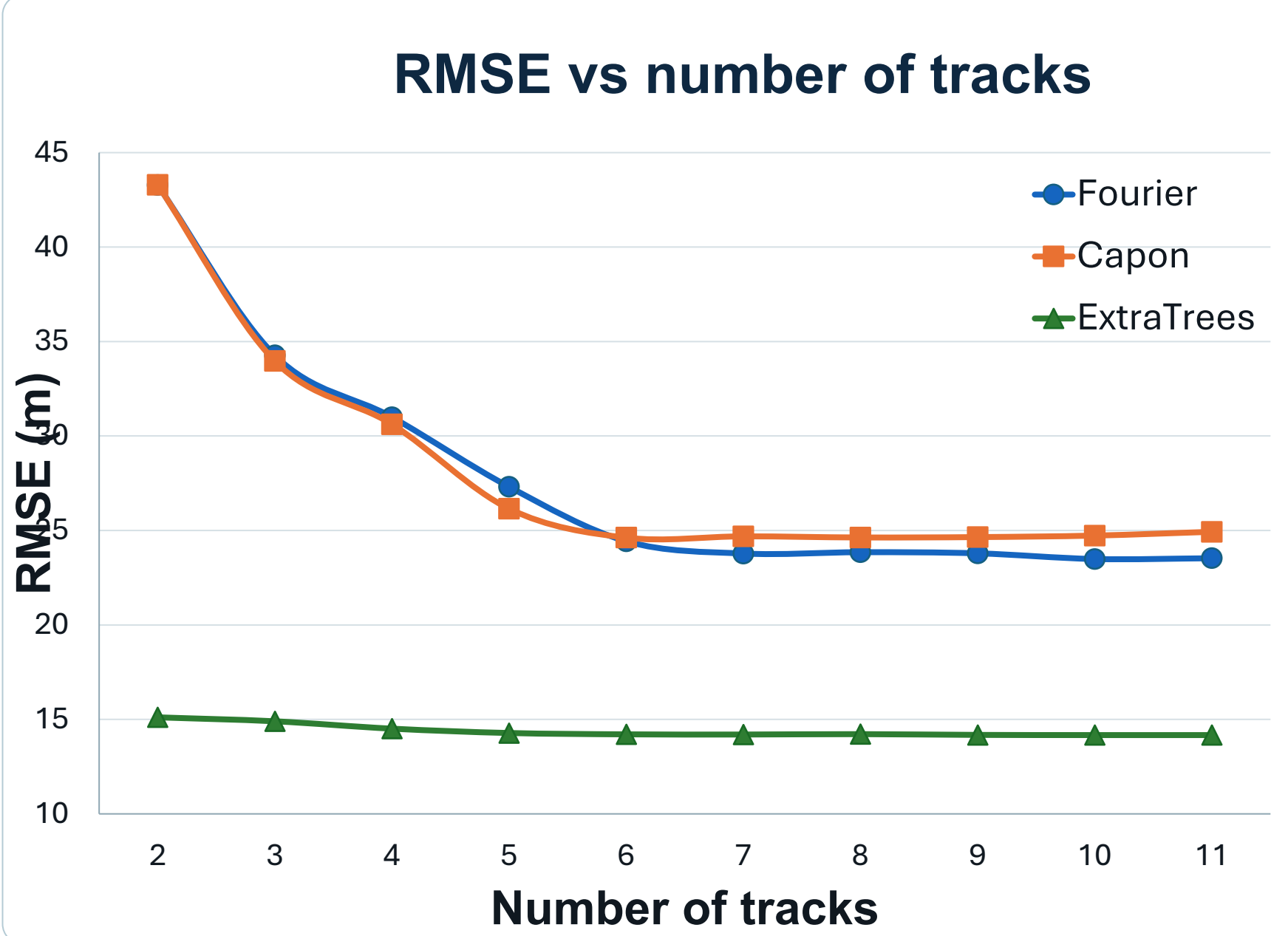
Tomography reveals the vertical separation of ground and canopy contributions.

Fixed-height reflectivity maps



Reflectivity layers at 0, 10, 20 and 30 m show how scattering changes from ground to canopy.

Canopy-height accuracy

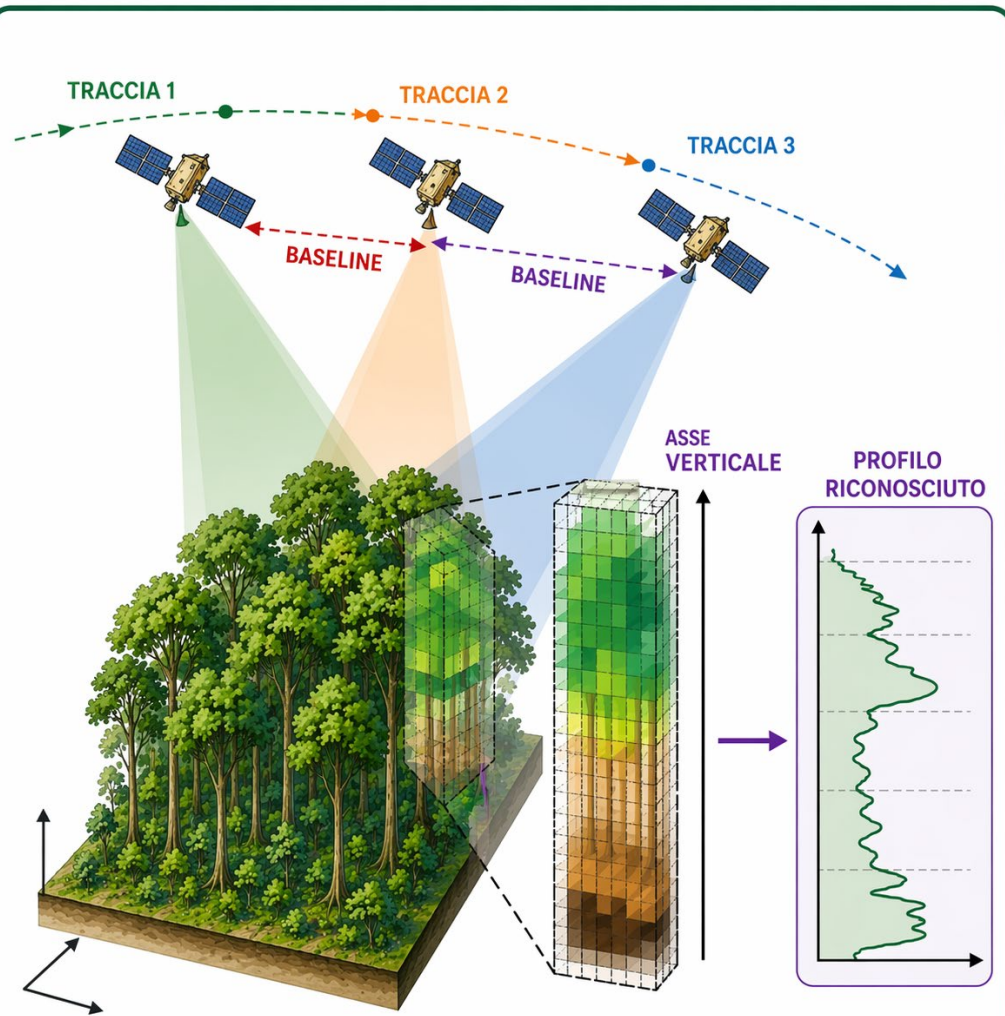


ExtraTrees remains near 14-15 m RMSE as the number of tracks changes; classical beamformers plateau near 23-25 m after six tracks.

Performance summary

Method	RMSE (m)	Bias (m)
ExtraTrees	14.17-15.11	0.42-0.91
Fourier	23.49-43.28	+9.43 to -14.17
Capon	24.62-43.29	+9.46 to -15.37

METHODOLOGY / WORKFLOW



1 Geometric preprocessing & flat-Earth compensation

- Coregistration of tracks
- DEM-assisted focusing
- Flat-Earth phase removal

2 Tomographic reconstruction (Fourier & Capon)

- 3D reflectivity estimation
- Coherence preservation
- Noise-robust Capon beamforming
- Capon: an adaptive method
- Fourier: a simple but robust method

3 Features from SAR covariance matrices

- Vertical statistics: mean, peak, variance, skewness, kurtosis
- Canopy and ground contributions
- Texture and entropy features

4 ExtraTrees height retrieval & track reduction

- Training against NASA LVIS canopy-height data
- Nonlinear relationships captured by an ensemble of randomized trees
- Robustness to fewer acquisition tracks
- RMSE and bias assessment versus Fourier and Capon

INPUTS
P-band SLC stack with multi-baseline geometry

Vertical wavenumber k_z and flat-Earth phase

LiDAR DTM and canopy-height model (CHM)

OUTPUTS
3D radar-reflectivity profiles

Canopy-height estimates

RMSE and bias versus number of tracks

DisasterRiskManagement RELEVANCE & CONCLUSIONS

DRM RELEVANCE: APPLICATIONS

Structural digital baseline for pre-/post-event comparisons
Detection of canopy collapse and exposed ground after disturbance
Wildfire impact and post-storm damage mapping
Support for landslide-susceptibility assessment
Cascading-risk analysis

3D forest-structure products can reveal damage that may be invisible in standard 2D land-cover maps.

TAKE-HOME MESSAGES

1. P-band TomoSAR effectively captures the vertical structure of tropical forests.
2. ExtraTrees substantially improves canopy-height estimation, with 14.17-15.11 m RMSE and near-zero bias.
3. Stable performance with fewer tracks supports future operational Earth Observation services for disaster risk management.

Future work: apply the workflow to real pre-/post-disturbance scenarios and integrate hazard and exposure layers.

REFERENCES :

[1] H. Aghababaei et al., Forest SAR Tomography: Principles and Applications, IEEE GRSM 8(2), 30-45, 2020.

[2] S. Tebaldini et al., State of the Art in SAR Tomography of Tropical Forests, Surveys in Geophysics 40(4), 779-801, 2019.

[3] T. Fatoyinbo et al., The NASA AfriSAR Campaign, Remote Sensing of Environment 264, 112533, 2021.

[4] F. Razzano et al., Comparison of ML and DL Methods for Forest Height Estimation Through Multi-Channel SAR Data, IGARSS 2025, 512-516.