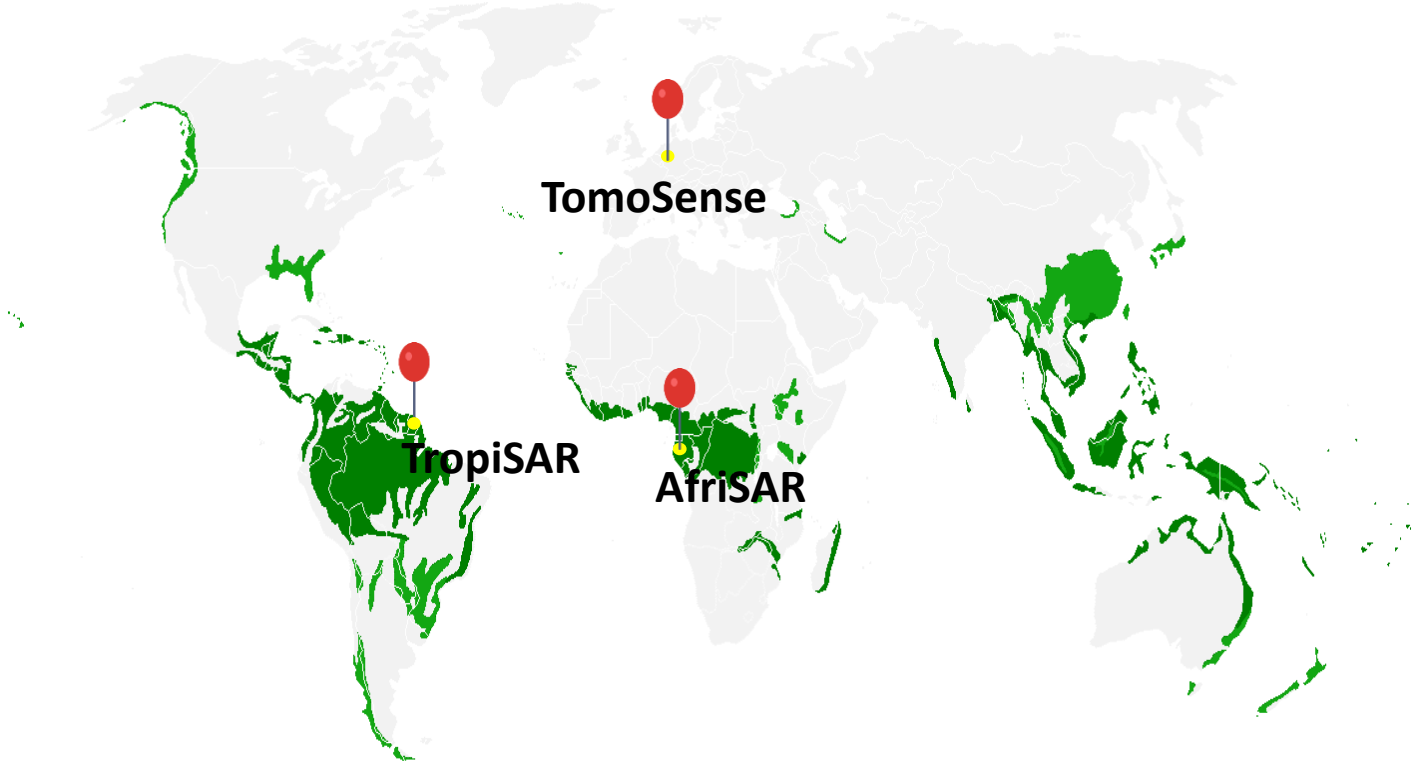
Advancing High-Biomass Tropical Forest Estimation with BIOMASS SAR Tomography and GEDI LiDAR



Dinh HO TONG MINH

with contributions:

Yen-Nhi Ngo - INRAE
Thuy Le Toan - CESBIO - GlobEO

Paris, IPGP, December 06th , 2024

I am a recognized expert with over 10 years of pioneering work in SAR Tomography.

dinhhotongminh.github.io

Current position

Since 2015: Research Scientist, INRAE, Montpellier, France

Previous positions

- 2013 –2015: Post-doc, CESBIO, Toulouse, France
- 2006 – 2009: Lecturer, Bach Khoa University Ho Chi Minh City, Vietnam

Education

- 2019: Doctor Habilitation, the highest French academic degree, University of Montpellier, France
- 2010-2013: PhD Information Technology, Politecnico di Milano, Italy

Scientific Leadership

- **High Citation Metrics**: With +3000 citations, an h-index of 25, and 47 i10-index publications, my work has become a benchmark in the SAR community.
- **IEEE Senior Member** (since 2023): Recognition of technical excellence and professional contributions in SAR Tomography and Interferometry
- **Invited Lecturer**: 7 tutorials at the world-class IEEE conferences

OUTLINE

1. **The structure and biomass of forests are vital components of the global carbon cycle and climate system.**

2. We lack accurate global measurements of forest structure and biomass, hindering management and climate strategies.

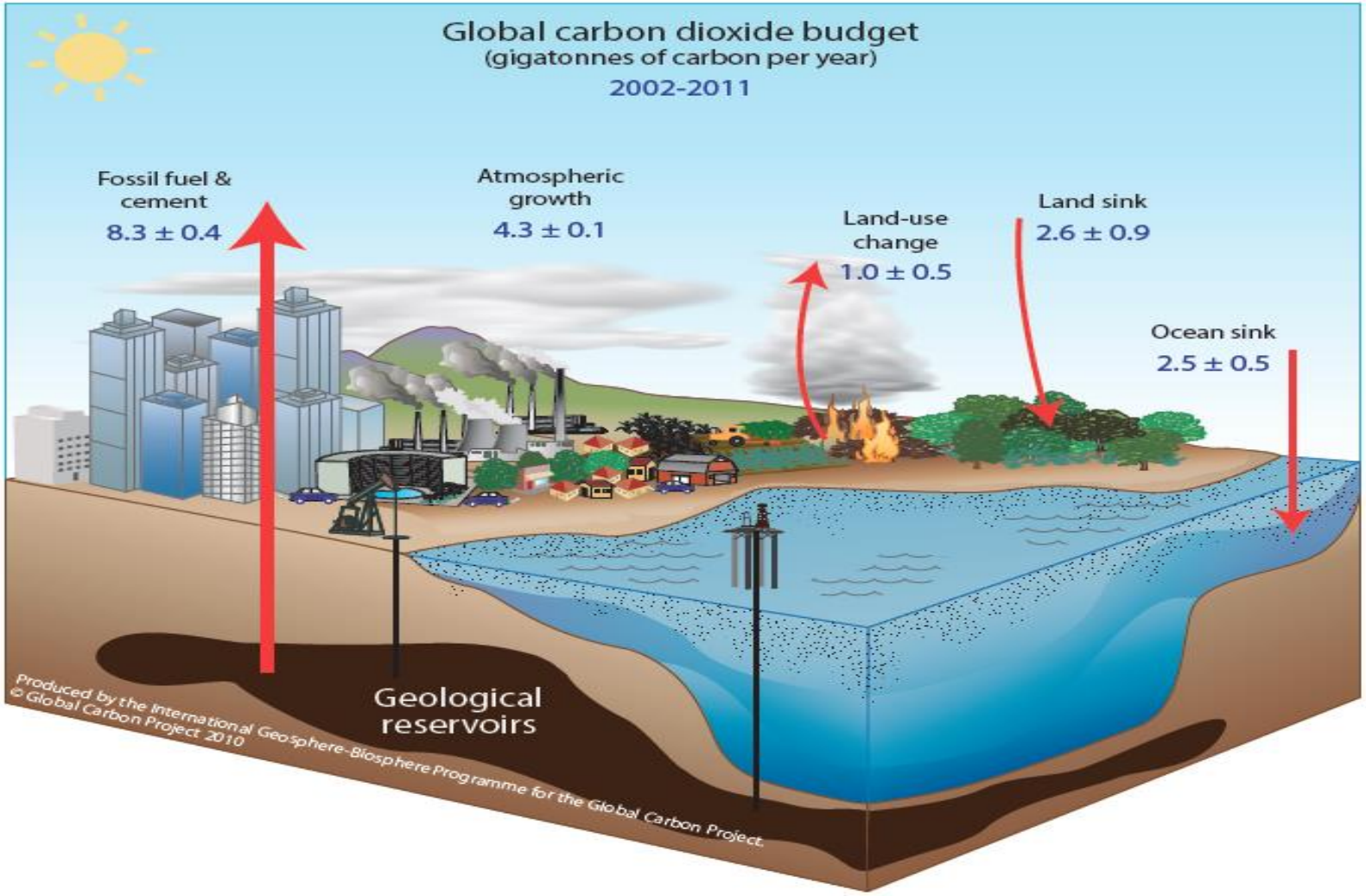
3. Existing methods face several limitations, including: 1) an inability to penetrate dense canopies, 2) insufficient global coverage, and 3) biomass saturation.

4. We hypothesize that P-band BIOMASS SAR Tomography can deliver accurate, high-resolution global measurements of forest structure and biomass.

5. We demonstrated results through 1) deep canopy penetration, 2) global mapping, and 3) no biomass saturation with airborne P-band TomoSAR and spaceborne GEDI LiDAR.

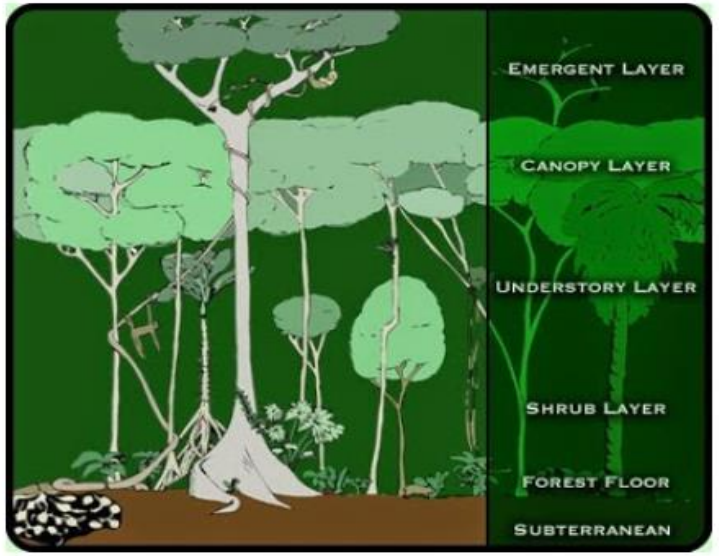
The structure and biomass of forests are vital components of the global carbon cycle and climate system.

- Forest biomass stores nearly 80% of all plant biomass on Earth.



The structure and biomass of forests are vital components of the global carbon cycle and climate system.

- 100 Mg Biomass = 50 Mg Carbon stock
- The high range of biomass (> 200 Mg/ha - 50%) in tropical forests represents a challenge for most remote sensing systems (optical, high frequency SAR data, spaceborne Lidar),
- Estimates of biomass in this range are necessary to reduce uncertainties in Carbon stocks and losses due to deforestation and degradation.



Multi-layer structure with dense canopy and few emerging trees which store a great part of biomass

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We lack accurate global measurements of forest structure and biomass, hindering management and climate strategies.

- The forest biomass is poorly quantified, particularly in regions with low forest inventory capacity.

- Several above ground biomass (AGB) maps of tropical forests have been realized, by combining multiple satellite observations, in-situ inventory measurements and airborne Lidar data.

- Spatial patterns and magnitude of AGB are found well captured, but large uncertainties in AGB estimates are significant, particularly in high-carbon-stock forests with AGB > 250 Mg/ha.

Discrepancies in AGB maps in Brazilian Amazon

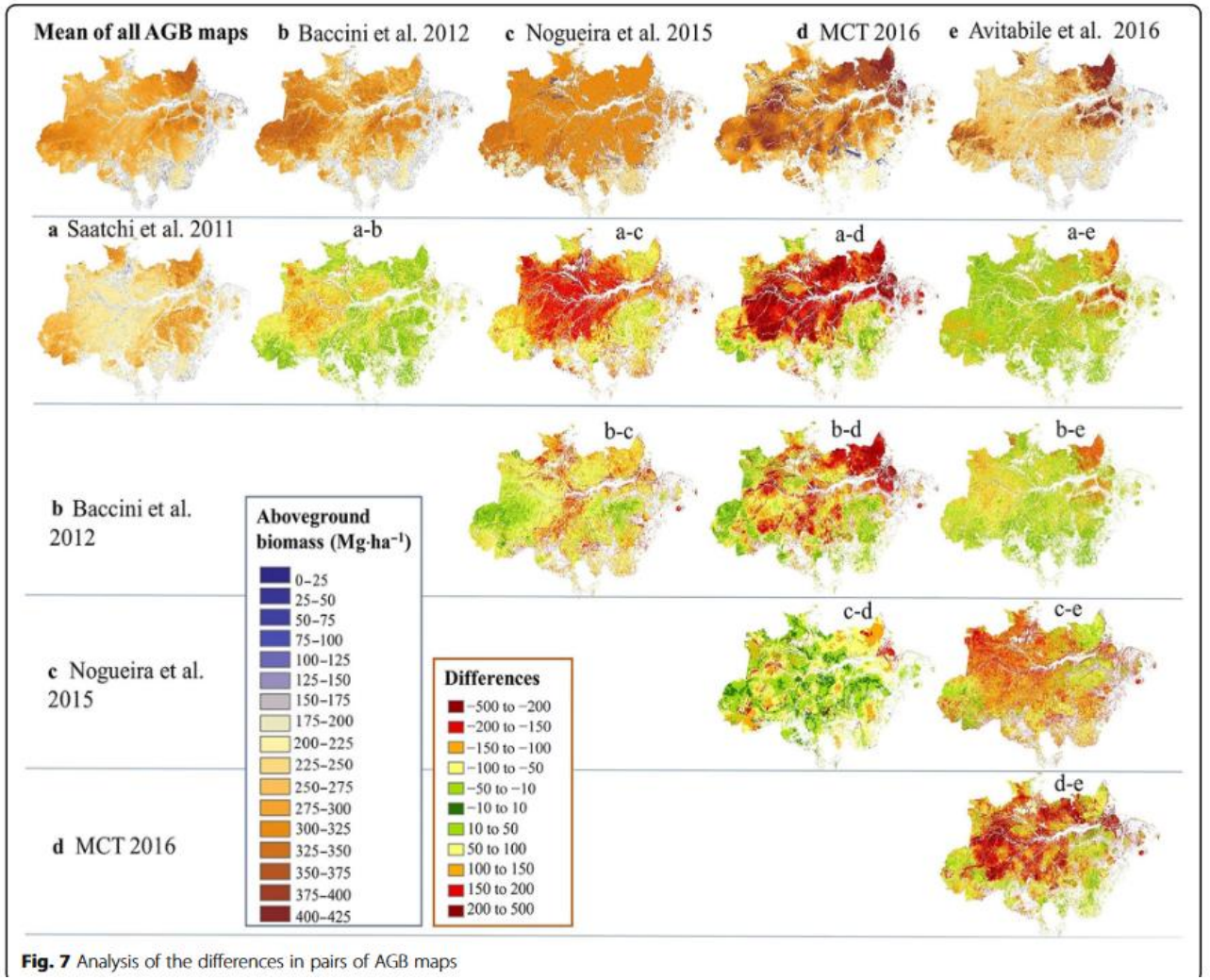

Fig. 7 Analysis of the differences in pairs of AGB maps

Tejada et al. (2020). Mapping data gaps to estimate biomass across Brazilian Amazon forests. *Forest Ecosystems*, *7*, 1-15.

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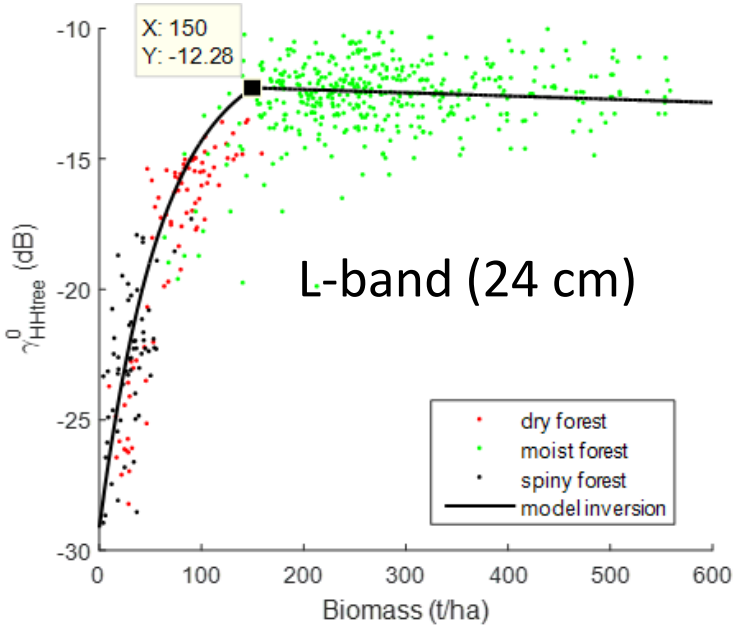
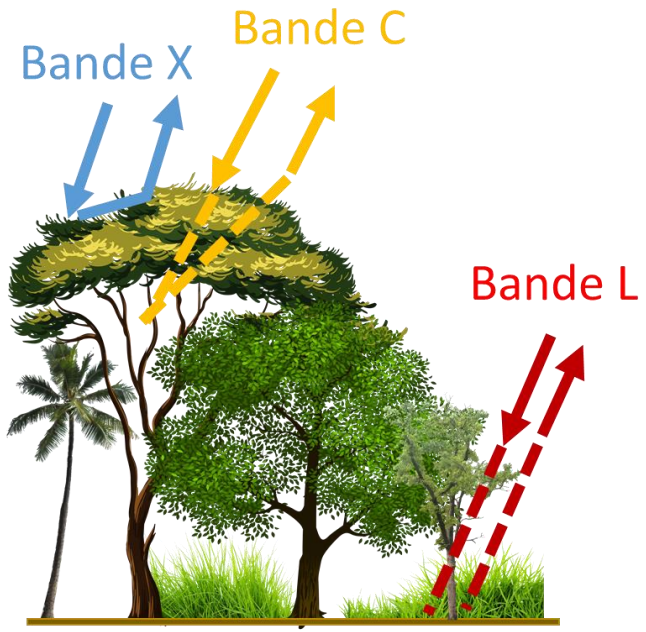
Remote sensing observations do not directly measure forest above-ground biomass (AGB), leading to inaccurate estimates at the pixel level.

1) **an inability to penetrate dense canopies:** short wavelength (< 25 cm)
2) **insufficient global coverage:** no satellite for biomass measurements
3) **biomass saturation:** limited sensitivity to forest biomass beyond their saturation level (common to optical and radar at X, C, L frequency band)





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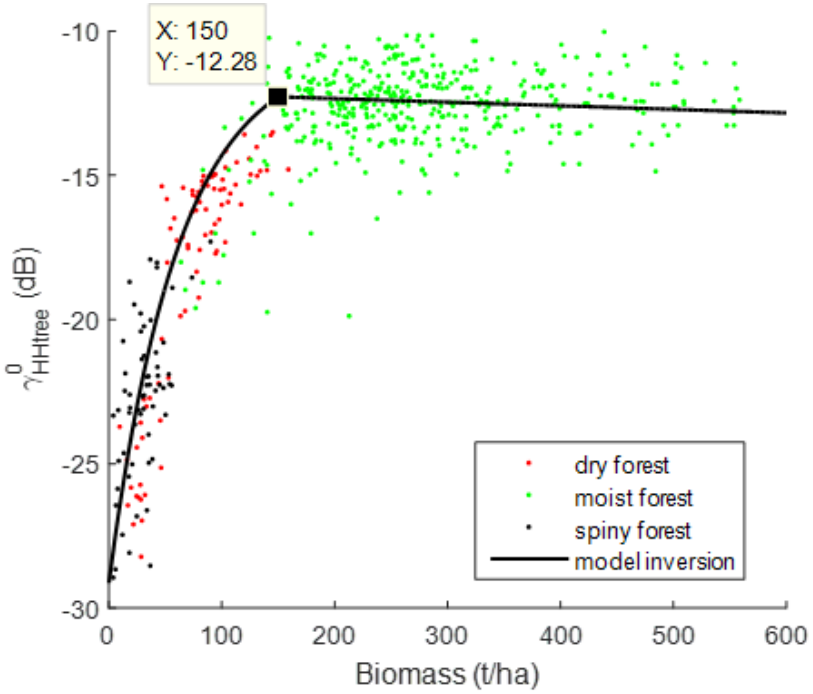
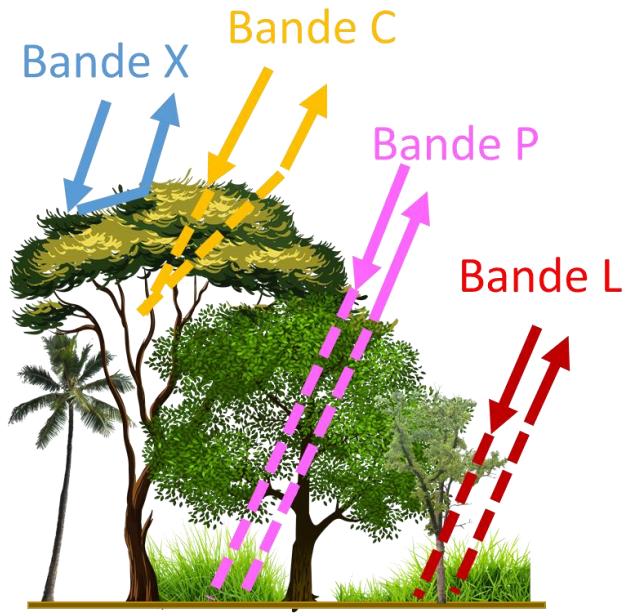
1) **an inability to penetrate dense canopies: ->** need radar longer wavelength (70 cm)

2) **insufficient global coverage: ->** need radar satellite for biomass measurements

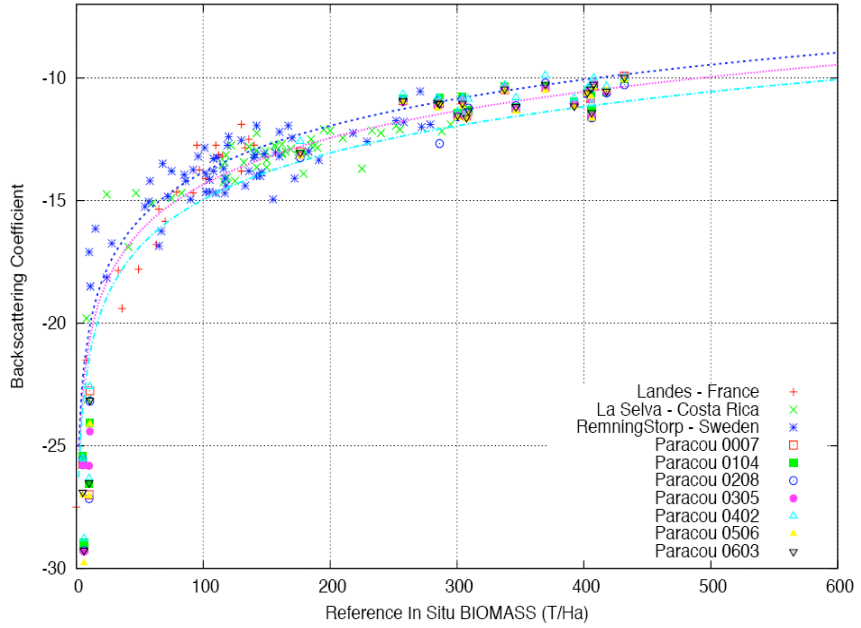
3) **biomass saturation: ->** need vertical structure from radar tomography

L-band (24 cm)





P-band (70 cm)



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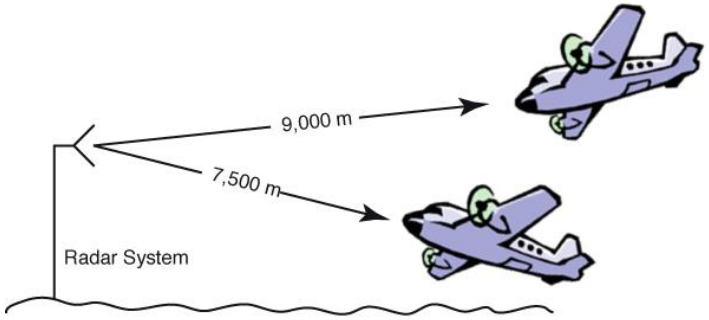
RADAR: Radio Detection and Ranging

Radar is an ancient technique.
It's where the beam swipes around measuring time and you can find things far away.



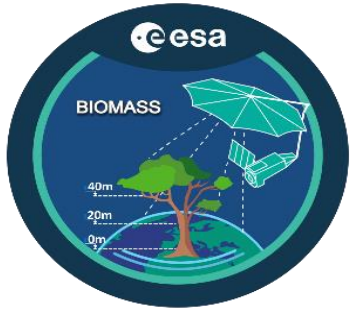
Sentinel-1 constellation

SAR: Synthetic Aperture Radar

We stick a radar on a satellite and we can do exactly same thing.

European Space Agency SAR satellites: ERS-1/2 (1992-2010), Envisat ASAR (2003-2010), Sentinel-1 (from 2014). They are about 680km above us.

BIOMASS satellite: ESA P-band with tomography (2025)



Expected Launch: April 2025

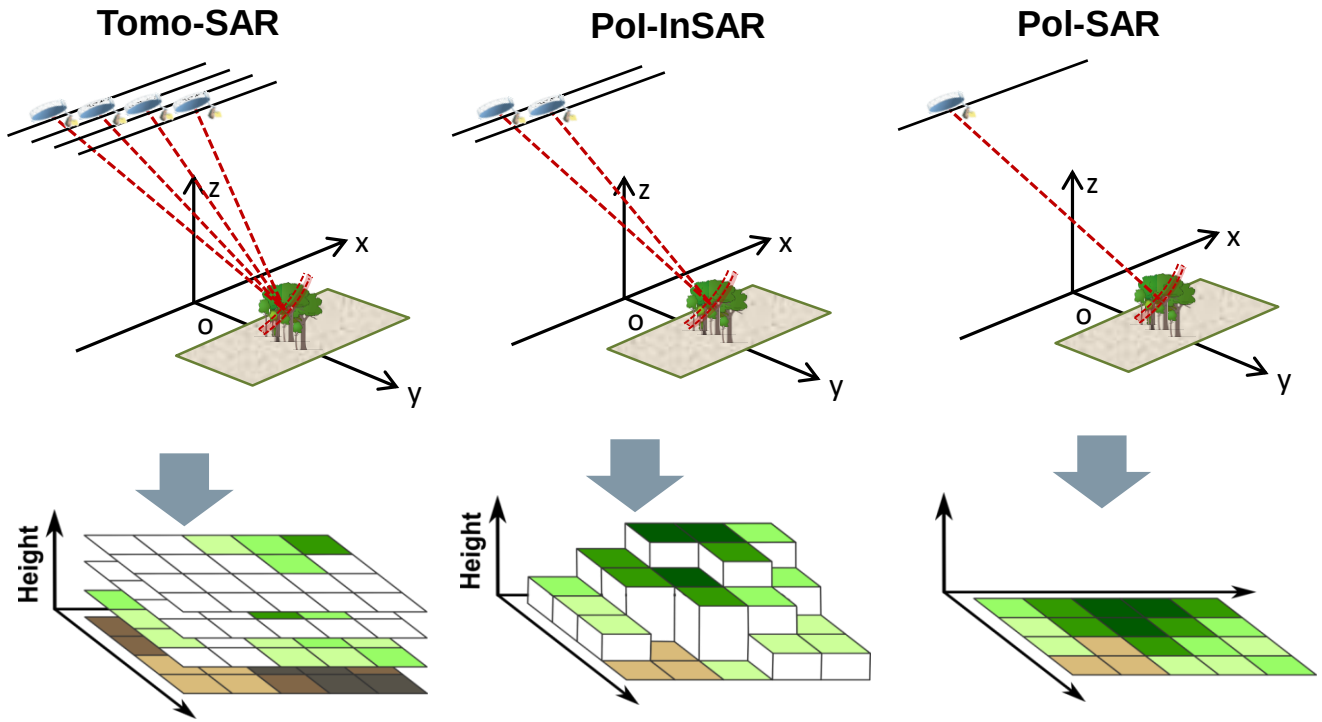
We hypothesize that P-band BIOMASS SAR Tomography can deliver accurate, high-resolution global measurements of forest structure and biomass.

BIOMASS objective:

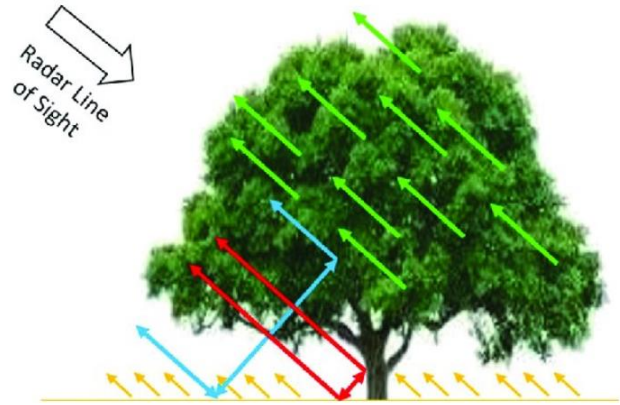
mapping of forest biomass in the high biomass of tropical forests, not accessible from current missions.

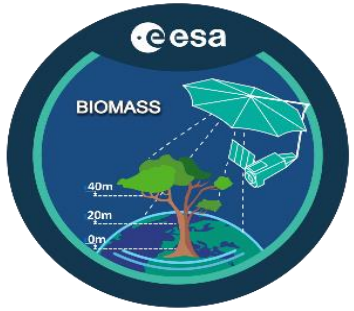
Tomographic Phase
7 x 3-day repeat
16 months for global coverage

Interferometric Phase
3 x 3-day repeat;
8 months for global coverage



P-band - 69 cm





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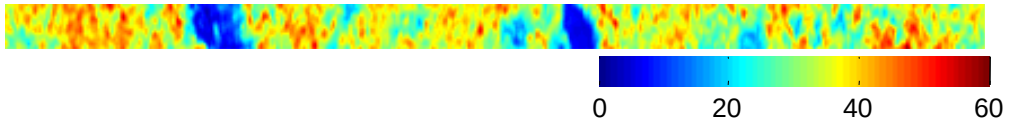
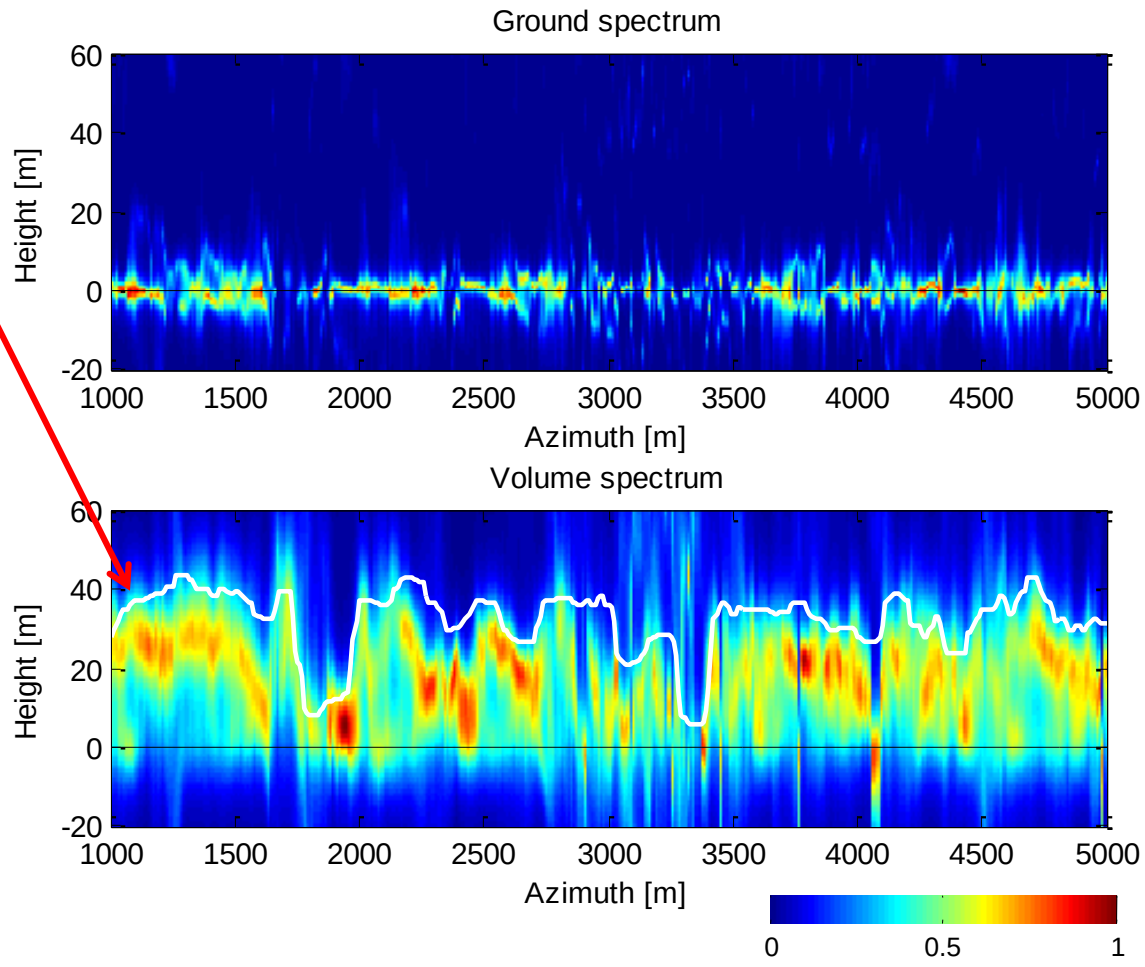
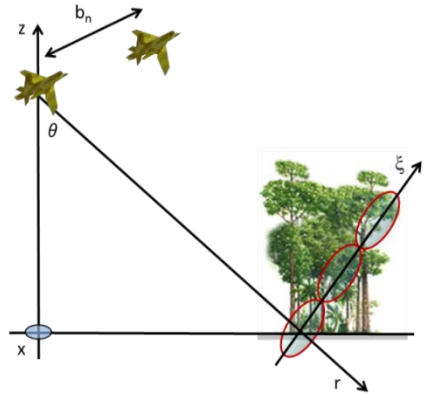
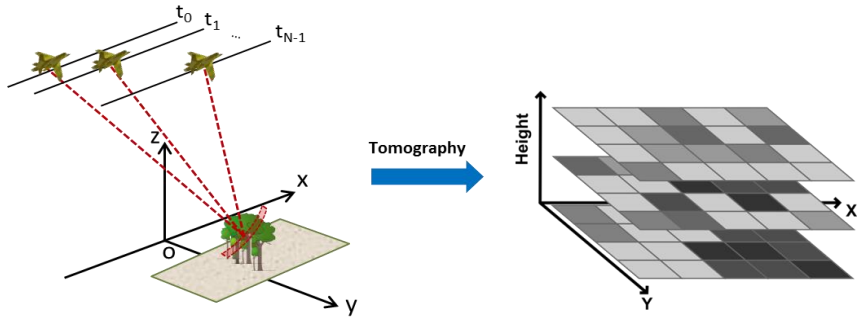
LiDAR top height





$$\hat{S}(\xi, r, x) = \sum_{n=1}^{N} y_n(r, x) \exp\left(-j\frac{4\pi}{\lambda r} b_n \xi\right)$$





→ Coherent focusing: Aim to convert multi-baseline into multi-layer SAR data.

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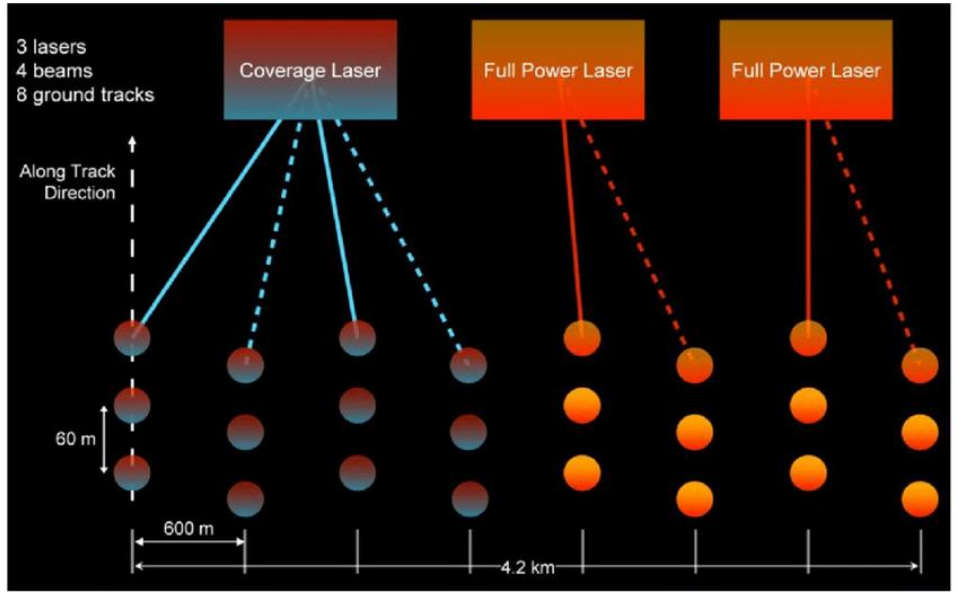
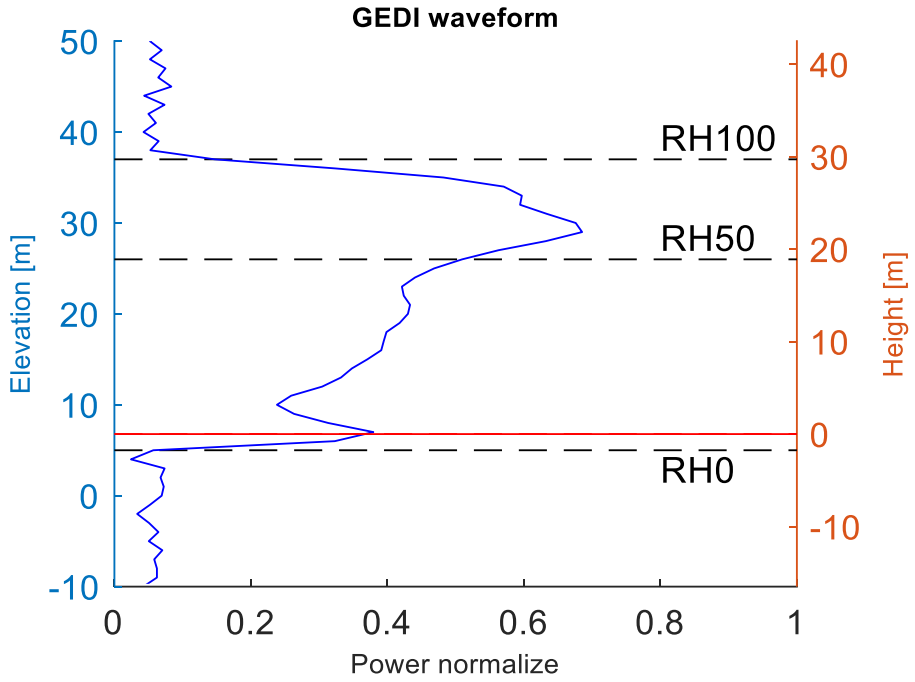


(Dubayah et al., 2020)



- The GEDI beam pattern produces scattered footprints that have a diameter of 25 meters. Along each track, these footprints are spaced at intervals of 60 meters, covering a distance of 600 meters across the tracks.

- GEDI employs relative height metrics (RHn) that range from 0 to 100%. These metrics provide valuable information about the vertical distribution within a forest, enabling us to understand the different layers and their heights relative to the ground.

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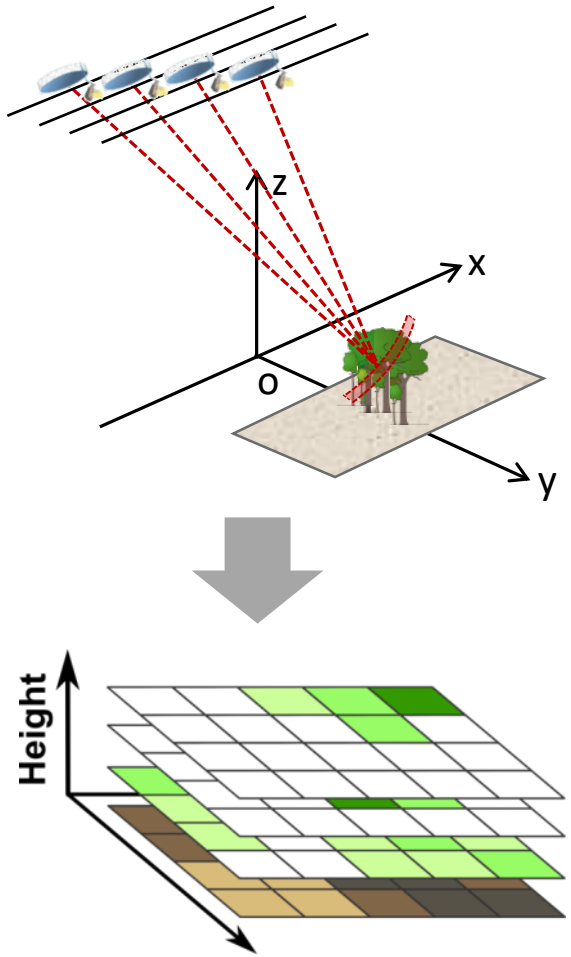
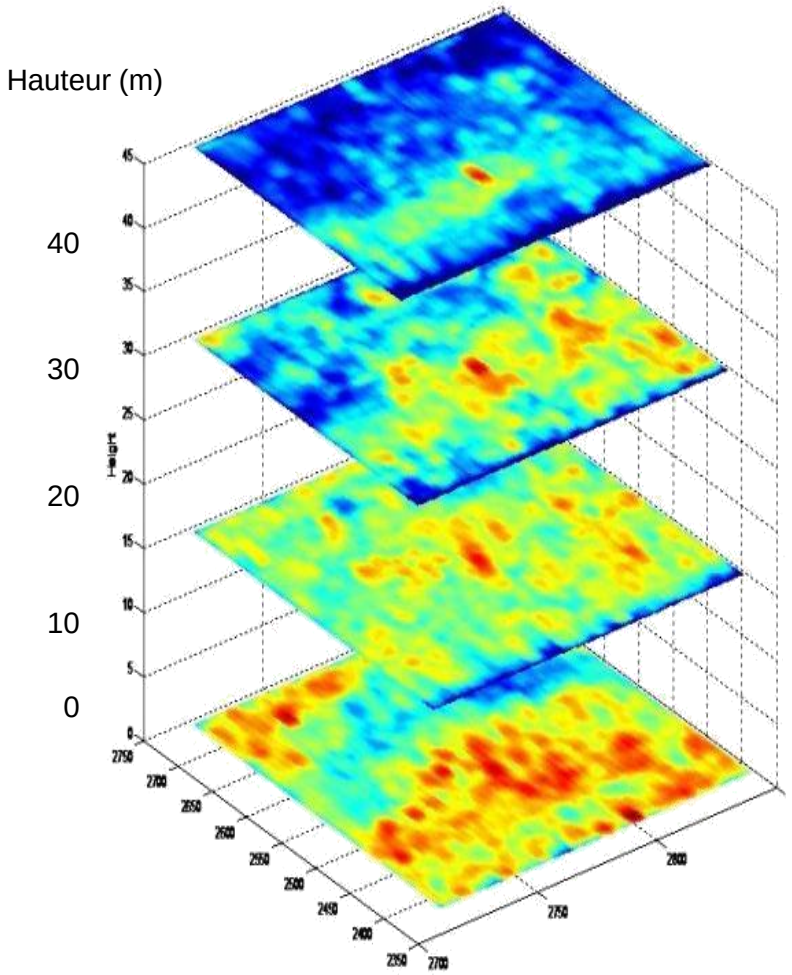
1) deep canopy penetration





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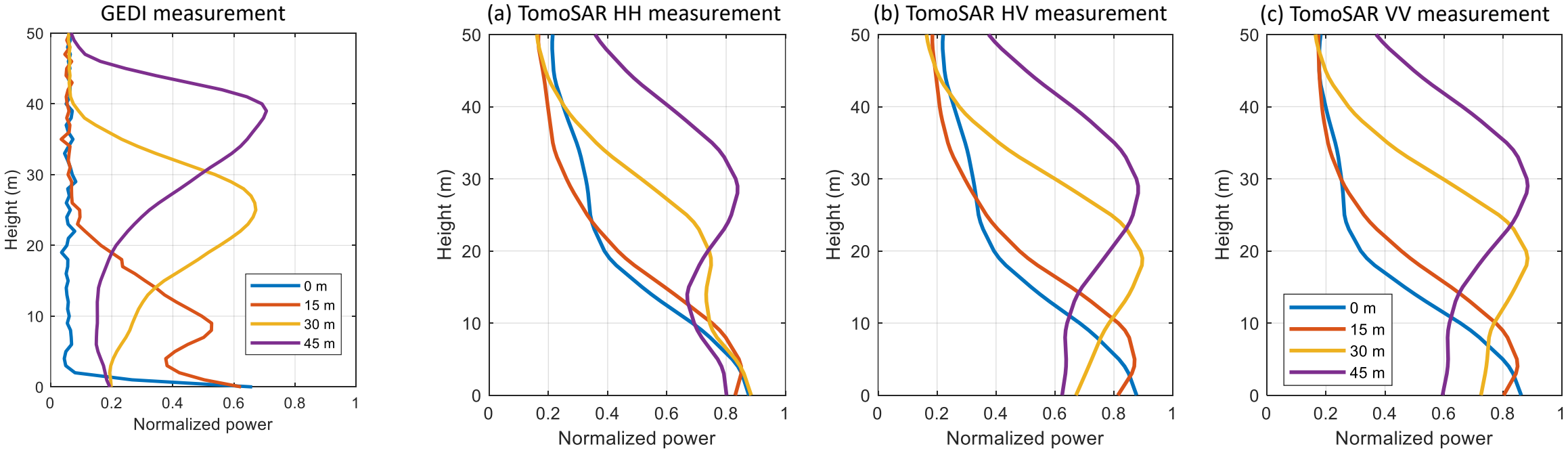
1) deep canopy penetration

(Lopé and Paracou forest areas)



- Significant contributions in terms of data acquisition and analysis can be made at the canopy levels ranging from 10 to 40 meters.

- In TomoSAR, the location of the phase center is consistently lower compared to GEDI, typically by 2-4 meters, depending on the height and polarization of the forest layers.

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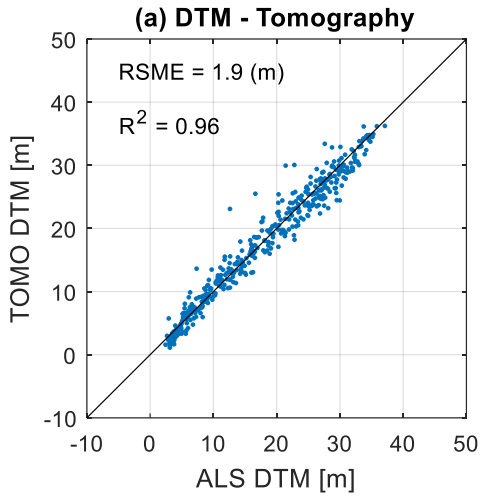
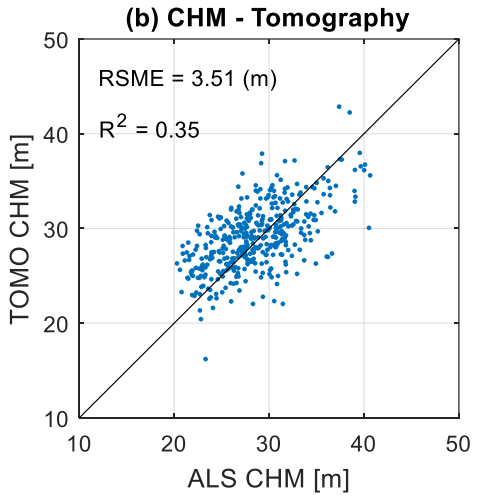
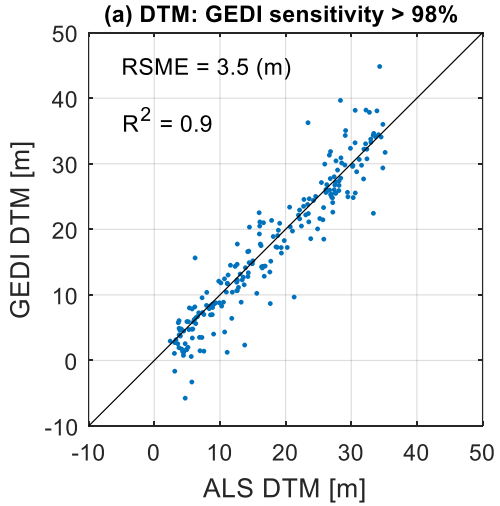
1) deep canopy penetration

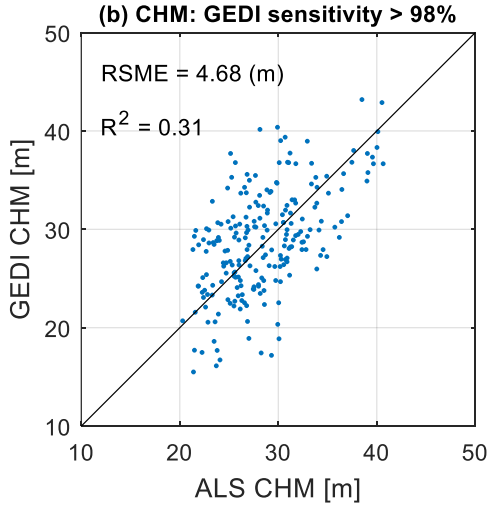
- Both GEDI and P-band TomoSAR have showcased their ability in estimating ground elevation and canopy height.

- Airborne TomoSAR exhibits superior performance compared to GEDI, primarily due to its heightened sensitivity to forest vertical structure.









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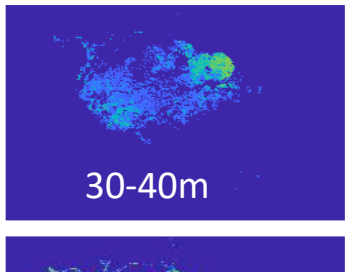
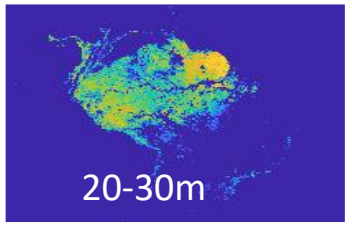
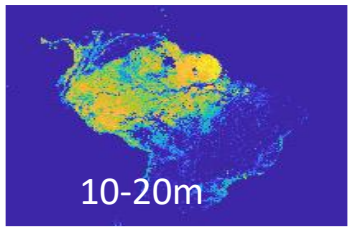
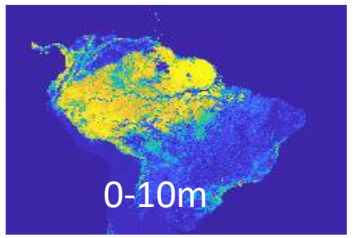
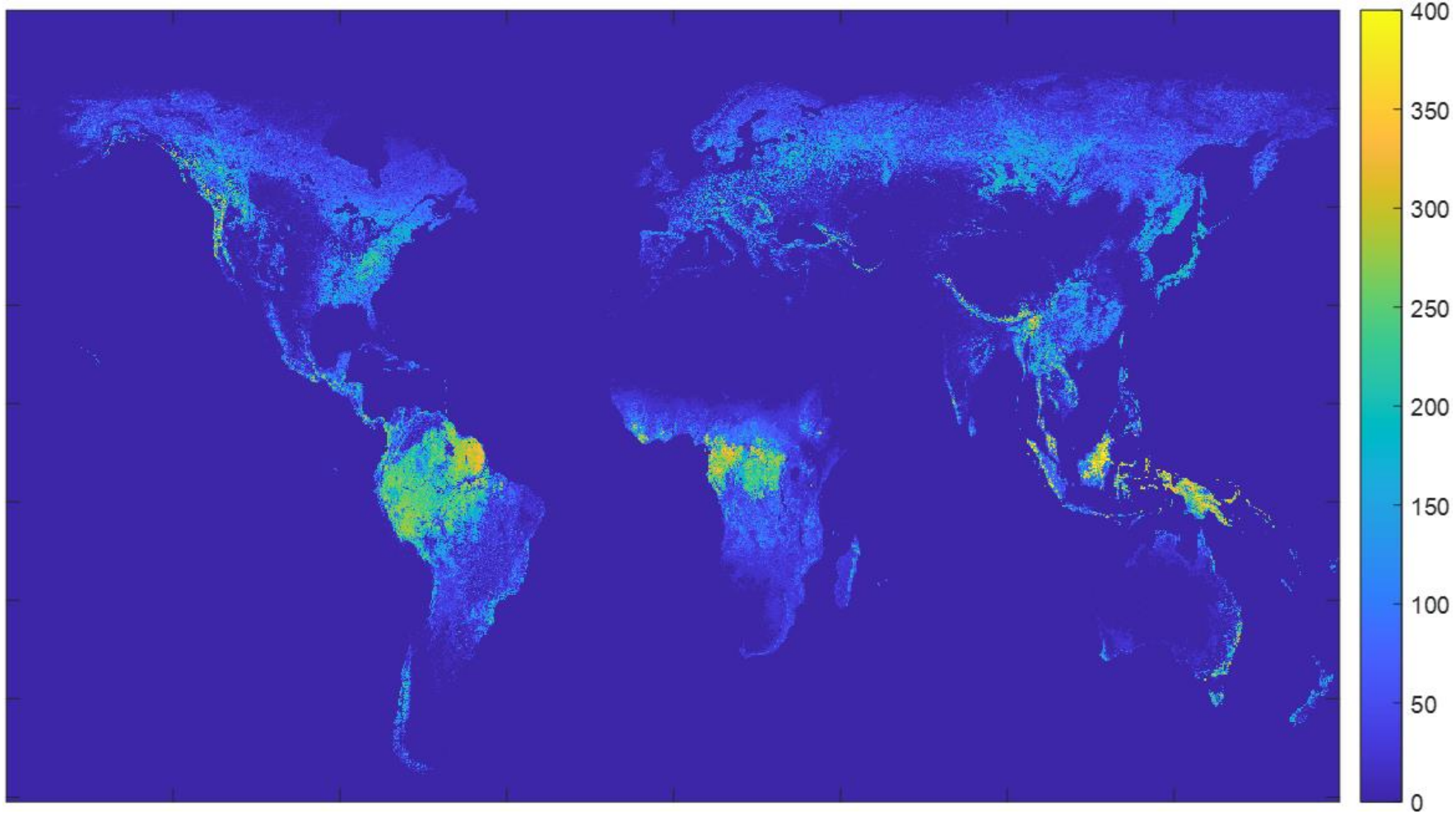
2) Global mapping: a simulation











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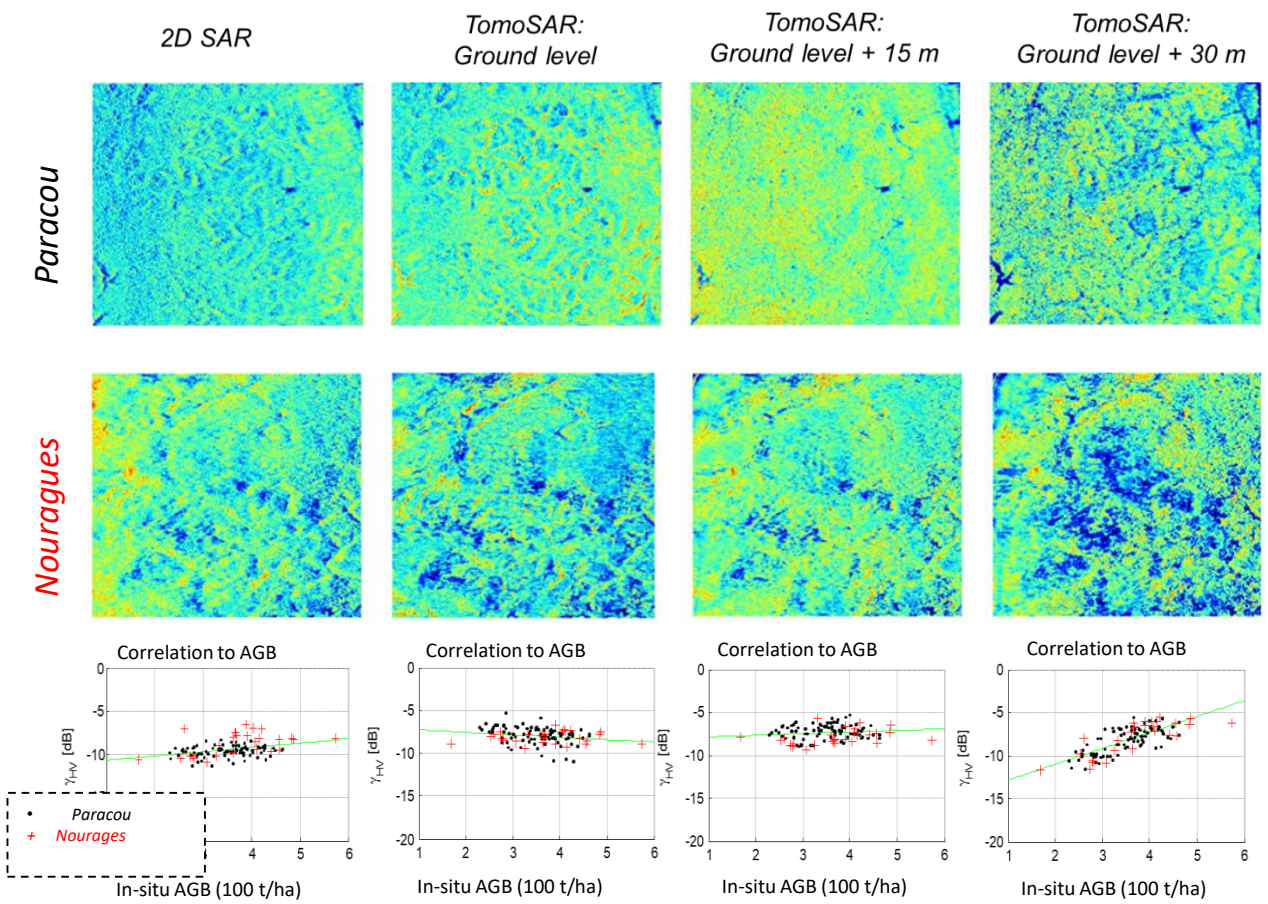
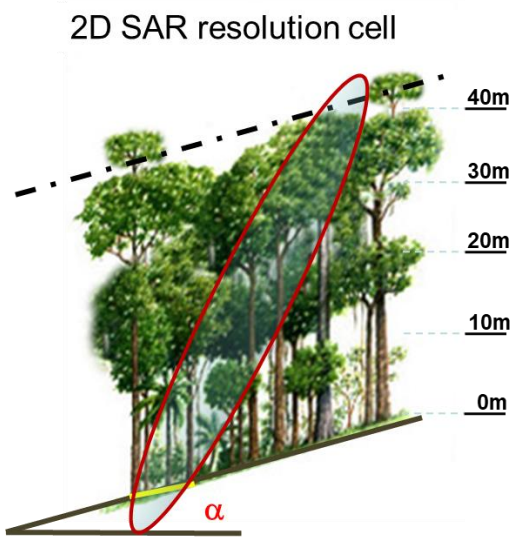
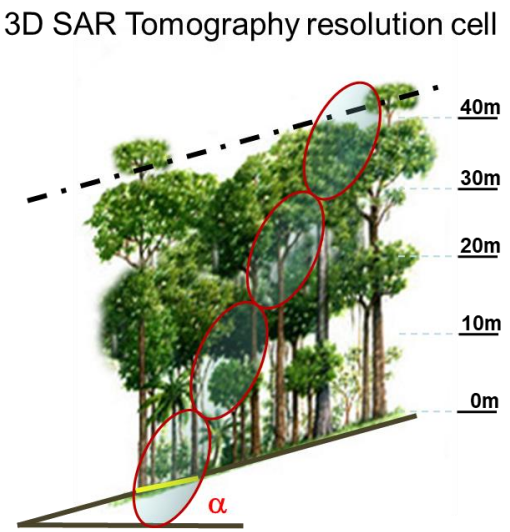
3) No biomass saturation







TomoSAR maximises relationship beween backscatter and AGB.

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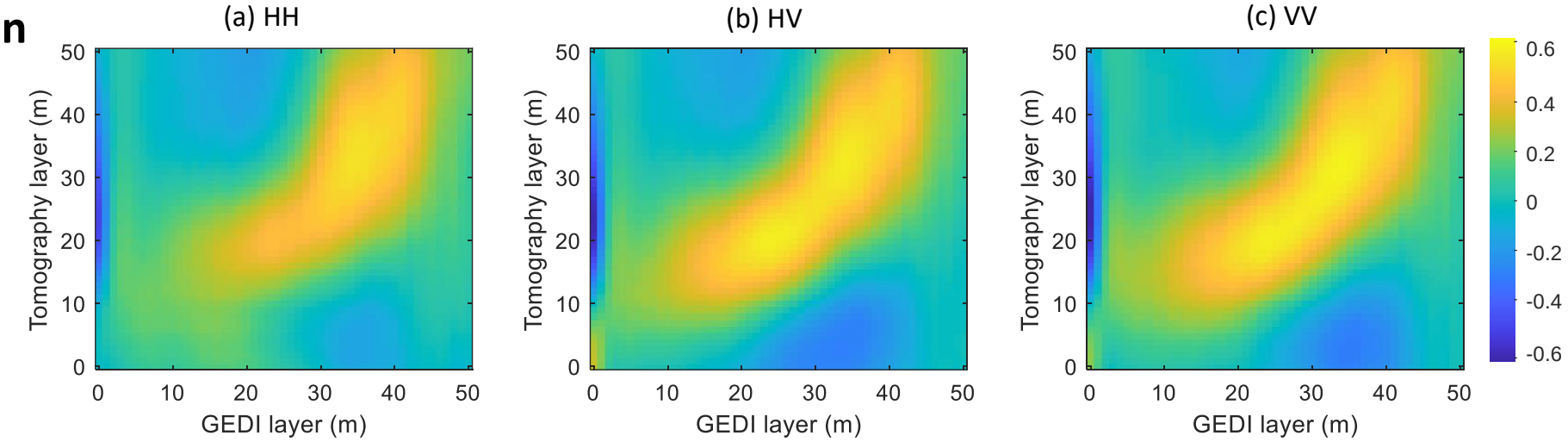
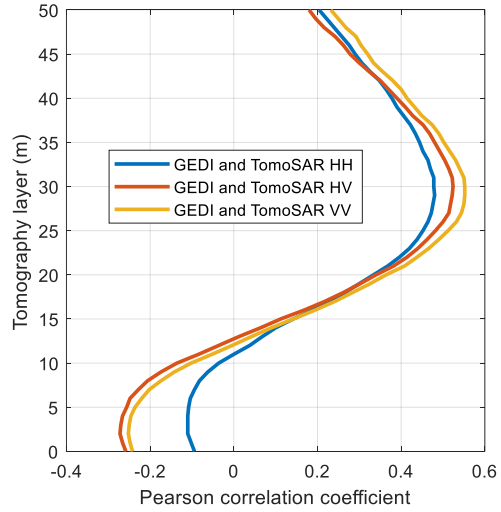
3) No biomass saturation



- GEDI and TomoSAR data : capture vertical information within the canopy levels, specifically in the range of 10 meters to 40 meters, showing a strong correlation.

- The highest correlation was observed at 30 meters above the ground, which aligns with previous research in biomass retrieval.

GEDI layer 20m – 40m to tomography



More reading

1. S. Quegan et al., “The European Space Agency BIOMASS mission: measuring forest above–ground biomass from space”. Remote Sensing of Environment, 2019. ***We introduced the P-band BIOMASS mission, which aims to map global above-ground biomass and reduce uncertainties in carbon stock and flux calculations.***
2. D. Ho Tong Minh et al., “SAR tomography for the retrieval of forest biomass and height: Cross-validation at two tropical forest sites in French Guiana”, Remote Sensing of Environment, 2016. ***I developed SAR Tomography methods to estimate tropical forest biomass with errors as low as 15% in high-biomass and estimated top-of-canopy height within a 2.5m deviation.***
3. J.M.B. Carreiras et al., “Coverage of high biomass forests by the ESA BIOMASS mission under defense restrictions”. Remote Sensing of Environment, 2017. *We showed the tropical forest biome will experience minimal data loss under Space Objects Tracking Radar restrictions.*
4. D. Ho Tong Minh et al., “Relating P-band synthetic aperture radar tomography to tropical forest biomass”. IEEE Transaction on Geoscience and Remote Sensing. 2013. ***I found that the radar signal from about 30 meters above the ground has the best correlation and sensitivity to forest biomass from 250 to 450 Mg/ha as per a forest model.***
5. Y-N Ngo et al., "Tropical forest vertical structure characterization: From GEDI to P-band SAR tomography," in *IEEE Geoscience and Remote Sensing Letters*, 2022. ***We highlight the potential of GEDI LiDAR to calibrate future BIOMASS mission algorithms for forest structure assessment.***
6. D. Ho Tong Minh et al., "Interferometric Phase Linking: Algorithm, application, and perspective," in IEEE Geoscience and Remote Sensing Magazine, 2023. ***My efforts explore using Deep Learning to enhance tomographic phase linking techniques, improving performance in complex signal environments.***

Take home messages

1. Radar Tomography for high-biomass measurement

Radar tomography is a crucial technique for accurately measuring high-biomass forests from space. By combining multiple radar observations from different angles, radar tomography can reconstruct 3D images of the forest structure, allowing for precise estimates of forest biomass.

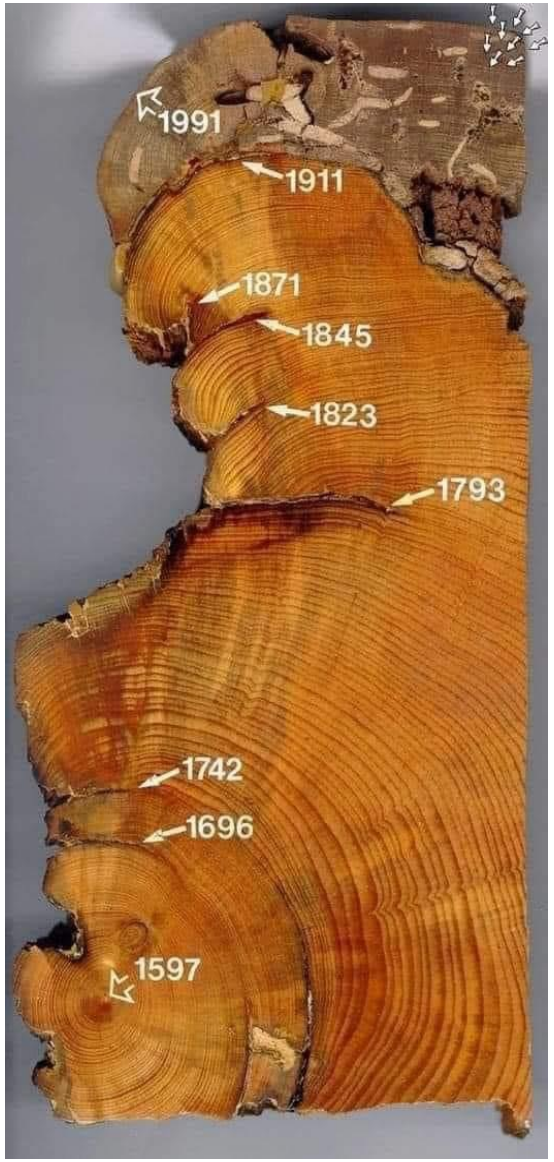
2. BIOMASS mission

The BIOMASS mission will be the first satellite to use P-band radar with tomography capabilities. It penetrates deeper into the forest canopy, capturing information from lower layers that may be hidden from shorter wavelength sensors.

3. Complementary roles of SAR Tomography and GEDI

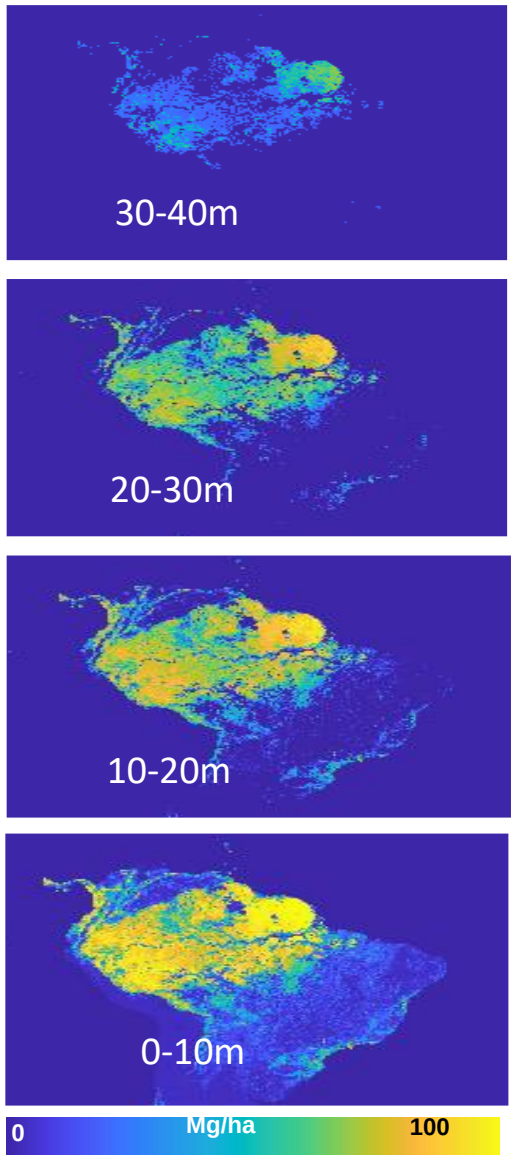
SAR tomography provides detailed information about the forest's vertical structure, while GEDI LiDAR offers high-resolution canopy height and structure measurements. By combining these two technologies, we can obtain a more comprehensive understanding of forest ecosystems.

This work was supported by CNES, focused on BIOMASS-valorisation and TomoSAR-valorization projects.



Thank you very much!

youtube.com/DinhHoTongMinh



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