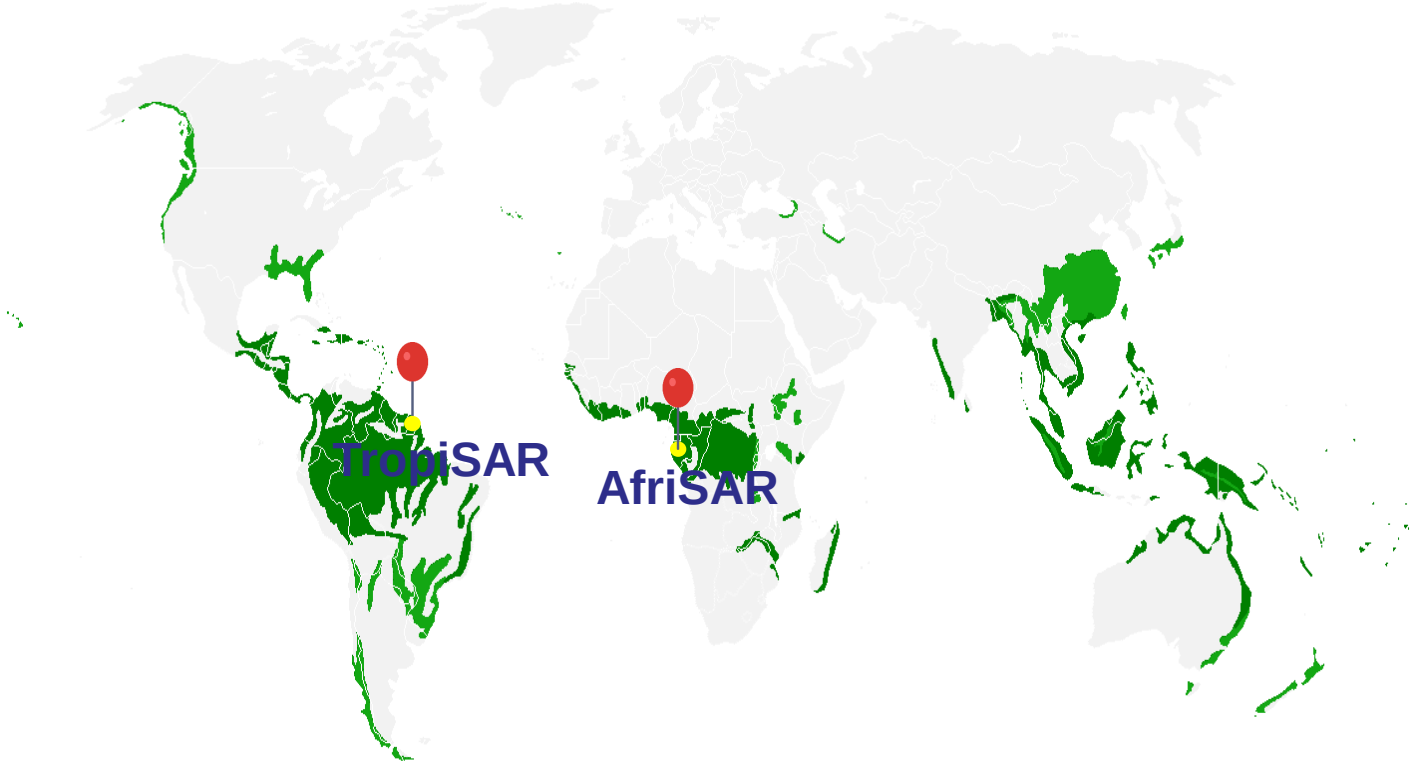
Estimation of Tropical Forest Vertical Structure with Spaceborne LiDAR and SAR Tomography



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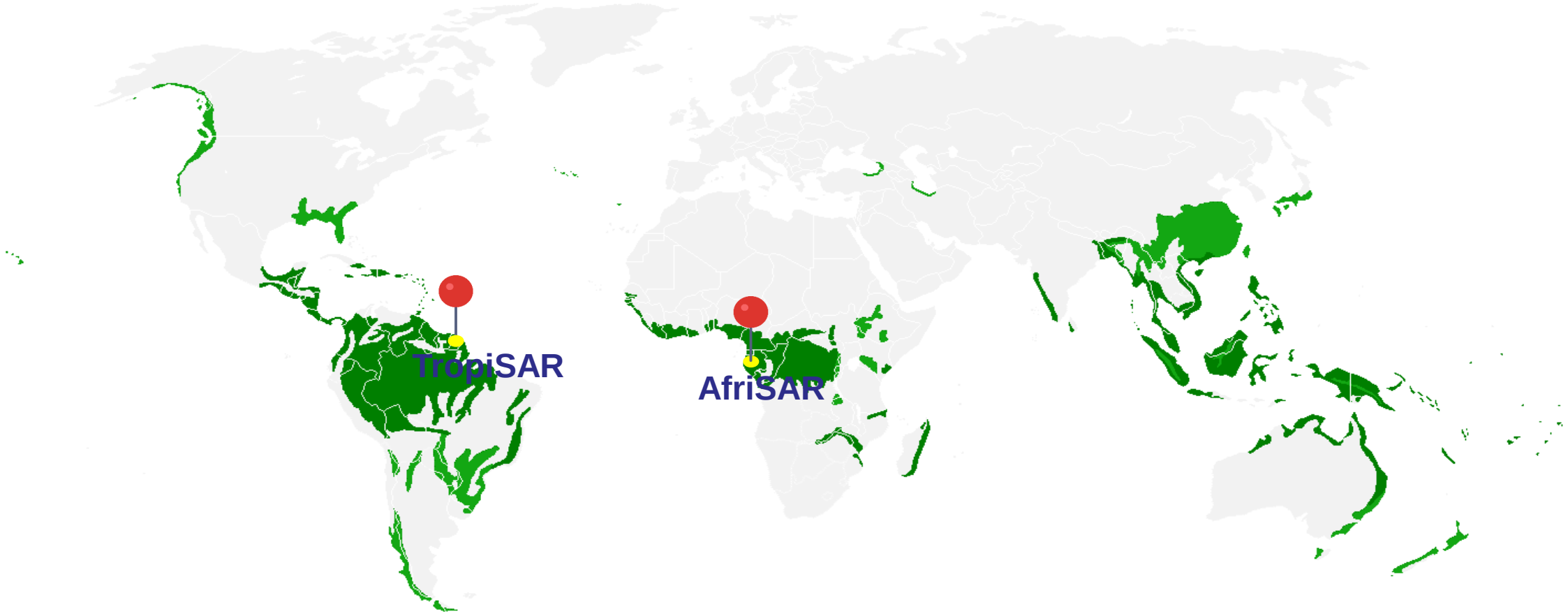
Context

- Active sensors like P-band SAR and LiDAR provide 3D information on forest structure by penetrating thick vegetation layers.
- NASA's GEDI mission and ESA's upcoming BIOMASS mission aim to offer spaceborne active data for studying global ecosystem dynamics.
- SAR tomography, also known as TomoSAR, utilizes multiple P-band SAR data acquisitions to generate three-dimensional images of the same areas.

Objective

- Investigate to better understand the performance of GEDI and TomoSAR acquisitions to estimate the vertical structures of tropical forests.

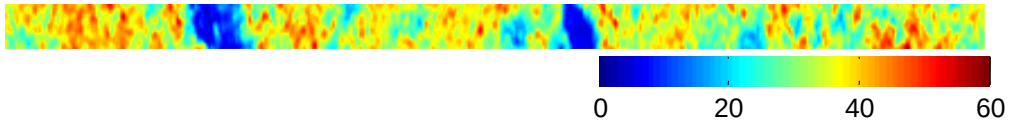
Study areas

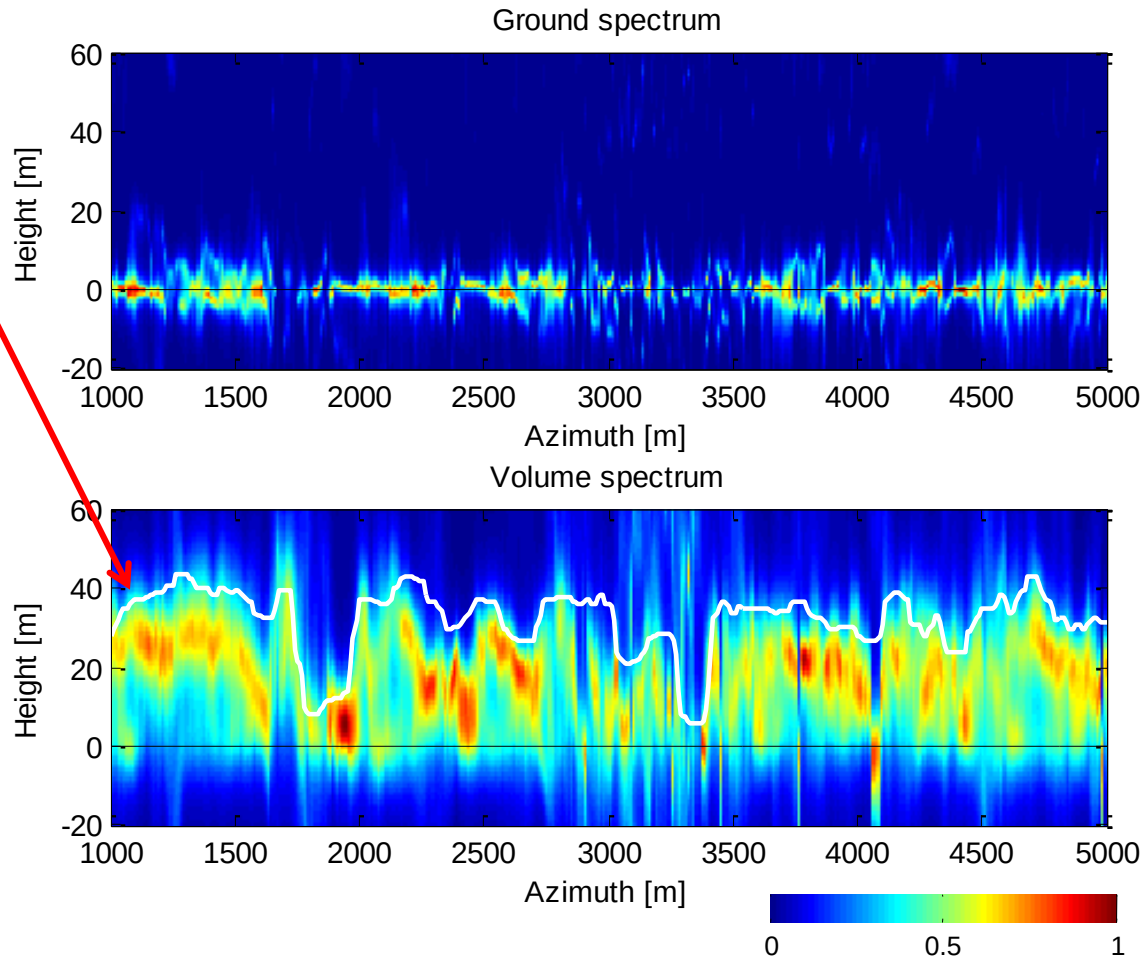


During the development of the BIOMASS mission, two campaigns were conducted in tropical forests to support the development of the forest biomass retrieval algorithm.

Tomography processing

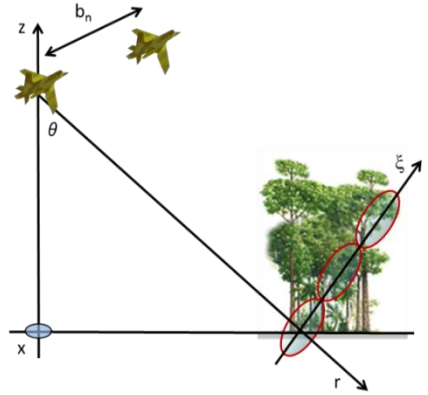
LiDAR top height

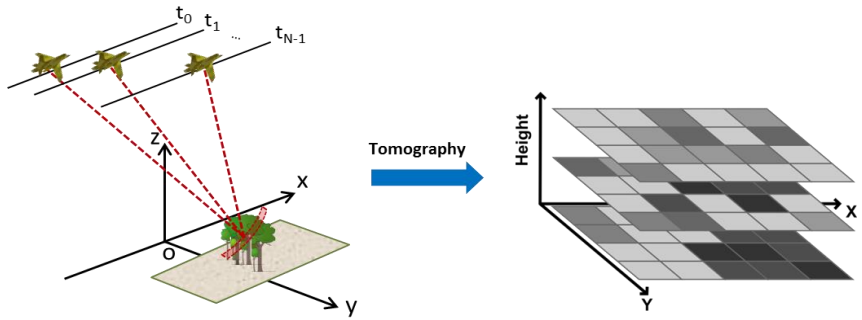




(Nouragues forest area)

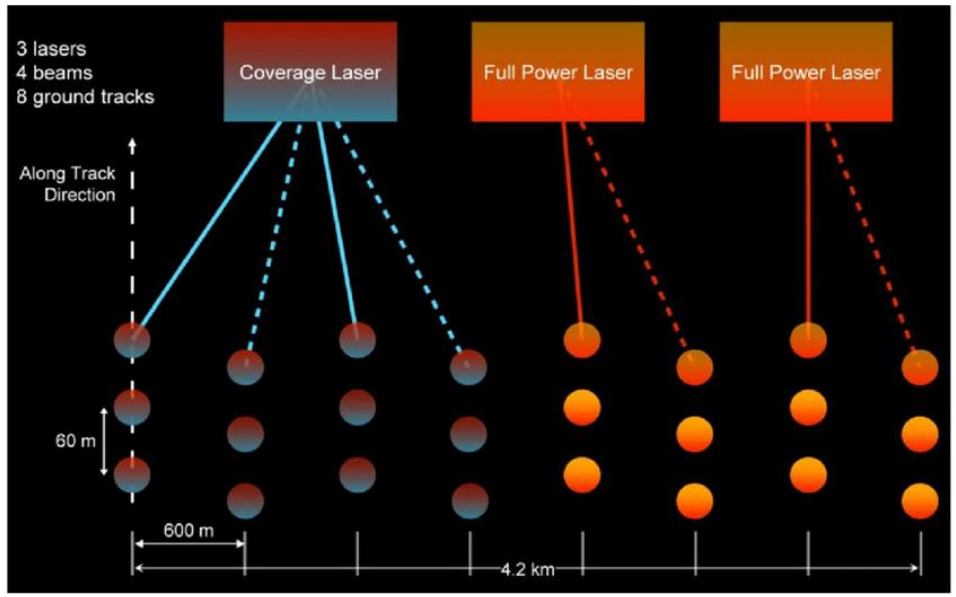
$$\hat{S}(\xi, r, x) = \sum_{n=1}^{N} y_n(r, x) \exp\left(-j\frac{4\pi}{\lambda r} b_n \xi\right)$$



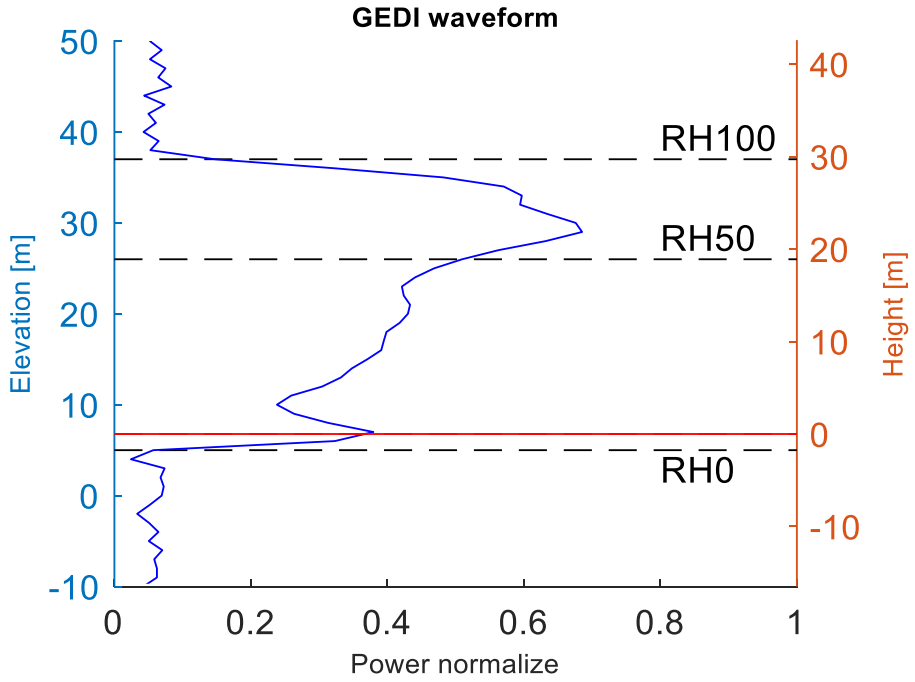


→ Coherent focusing: Aim to convert multi-baseline into multi-layer SAR data.

GEDI processing



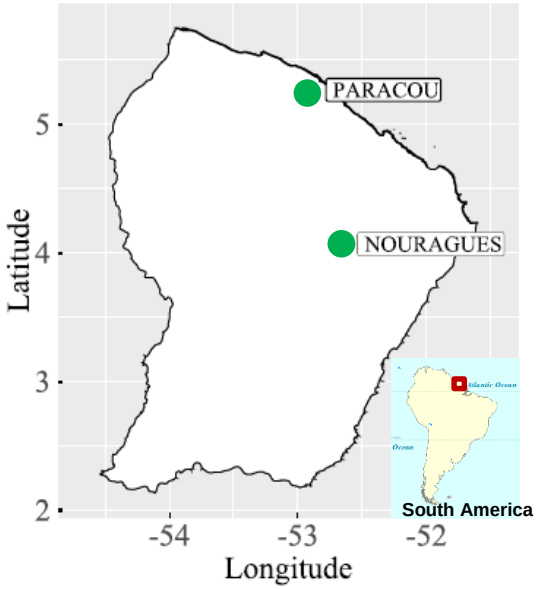
(Dubayah et al., 2020)

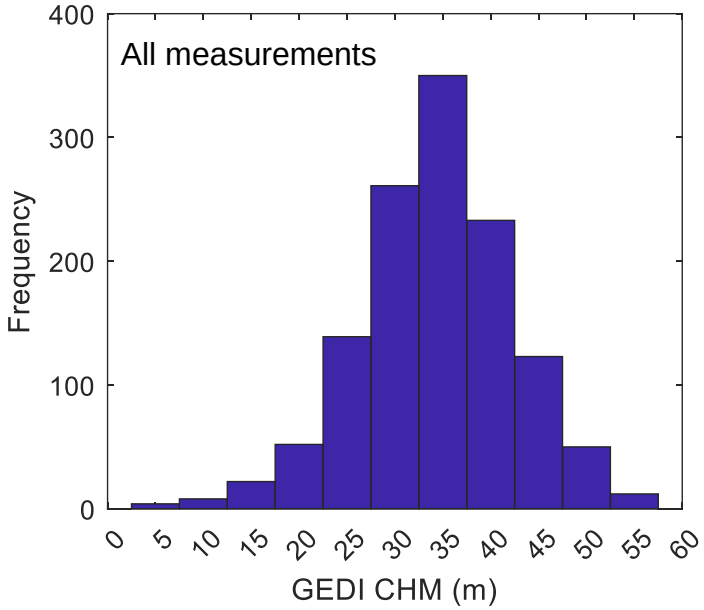


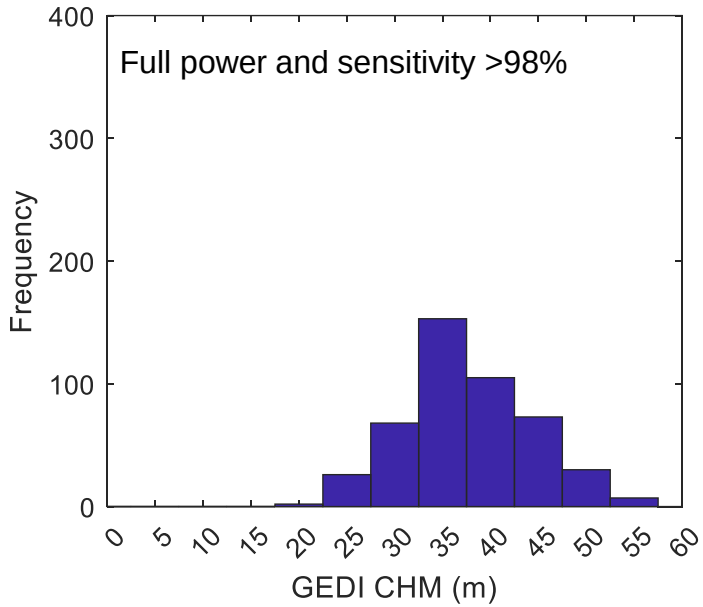
- The GEDI beam pattern produces scattered footprints that have a diameter of 25 meters. Along each track, these footprints are spaced at intervals of 60 meters, covering a distance of 600 meters across the tracks.

- 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.

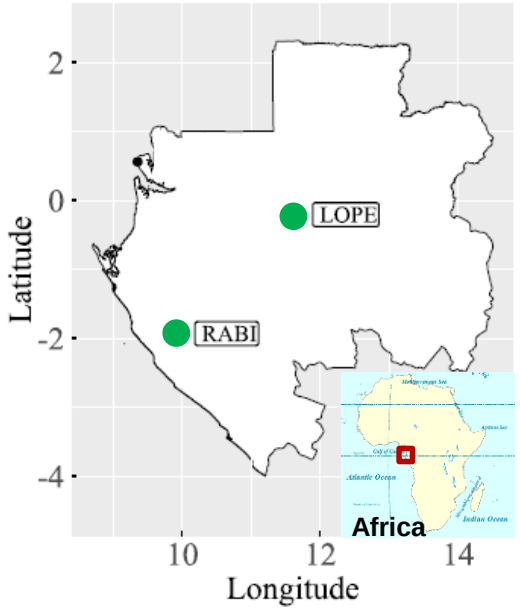
(a) South America: Paracou - Nouragues

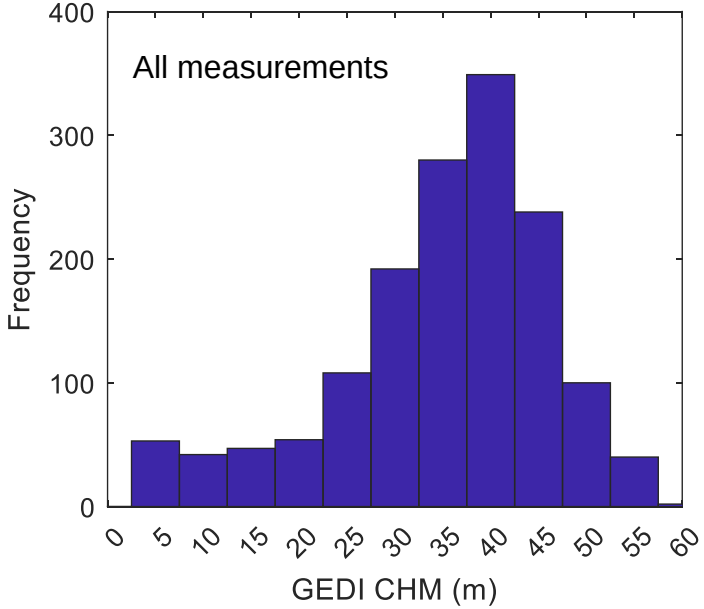


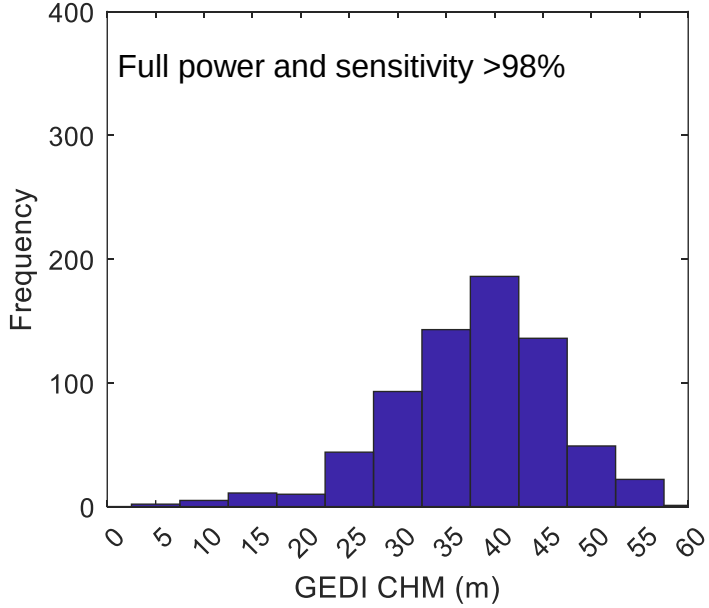




(b) Africa: Lopé - Rabi







GEDI CHM proxy

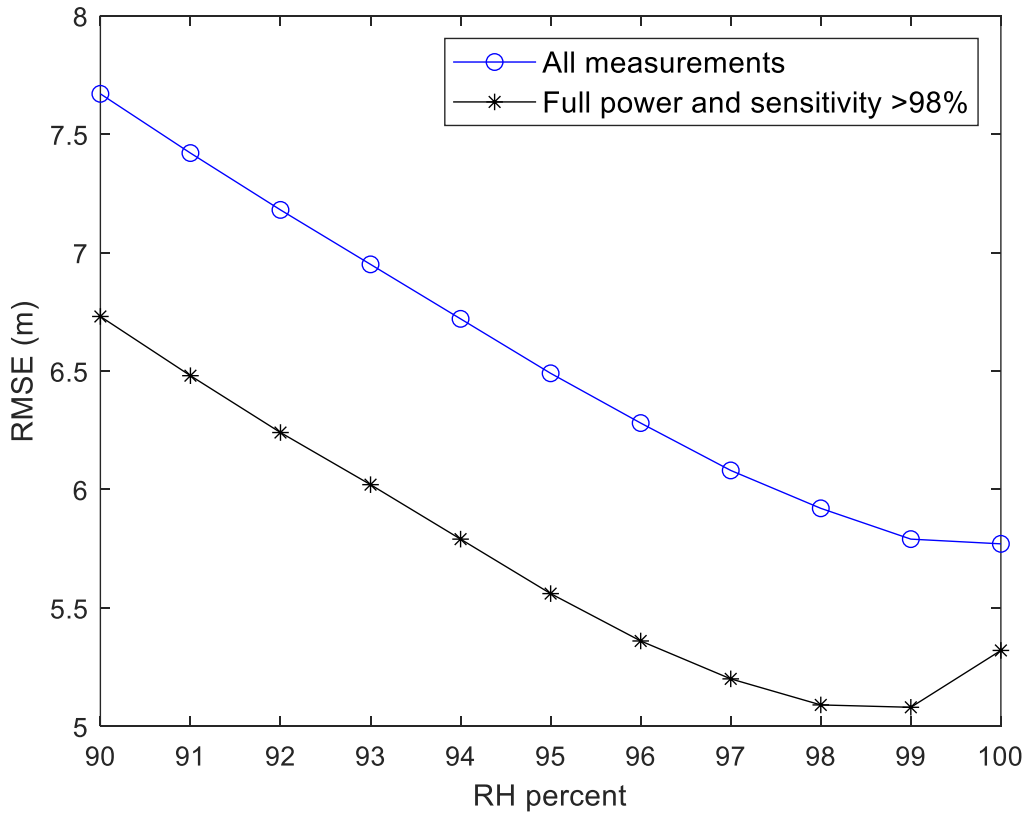
- The RH metrics provided by GEDI play a crucial role in providing height information, although it's important to note that these metrics may not always directly represent the height of the canopy top.

- Regarding the lasers used by GEDI, there are coverage lasers and full-power lasers. The shot sensitivity refers to the probability of a laser pulse reaching the ground through the canopy cover.

- In comparing the performance of GEDI RH metrics and airborne LiDAR in two scenarios, RH100 performs the best in terms of all measurements, with an error of 5.8 m.

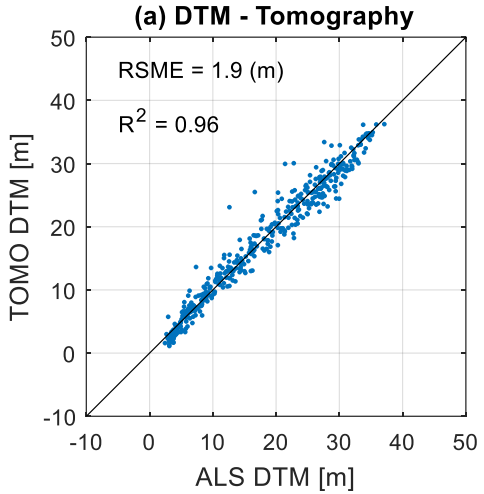
- However, in the case of the full-power laser with a sensitivity greater than 98%, RH98 outperforms RH100, resulting in a lower error of 5.1 m.

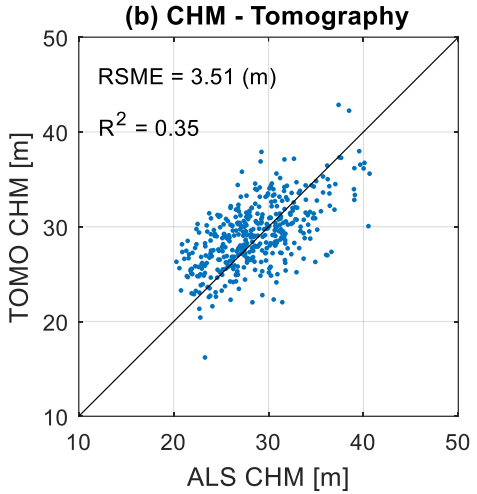
RMSE between GEDI CHM and Airborne LiDAR

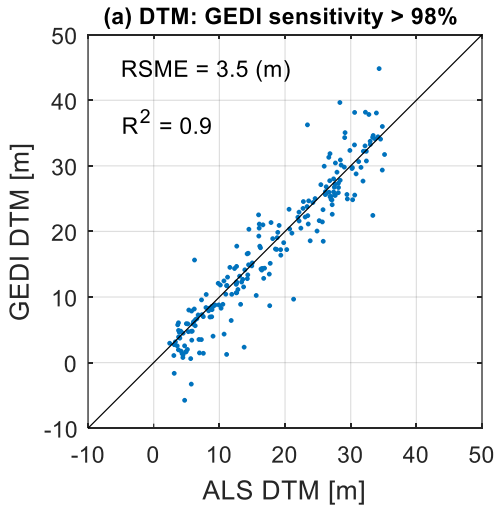


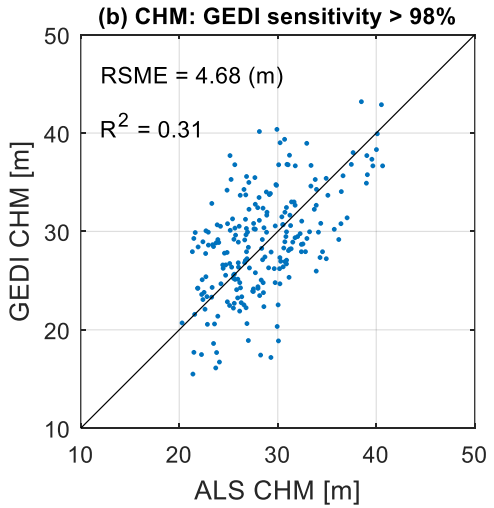
P-band tomography - GEDI performance

- Both GEDI and P-band TomoSAR have showcased their ability in estimating ground elevation and canopy height.
- However, when it comes to ground elevation parameters, they tend to outperform canopy height models.
- Additionally, airborne tomography exhibits superior performance compared to GEDI, primarily due to its heightened sensitivity to forest vertical structure.
- (The sensitivity of GEDI shots, influenced by the acquiring laser, determines the probability of a shot reaching the ground within a specific canopy cover.)



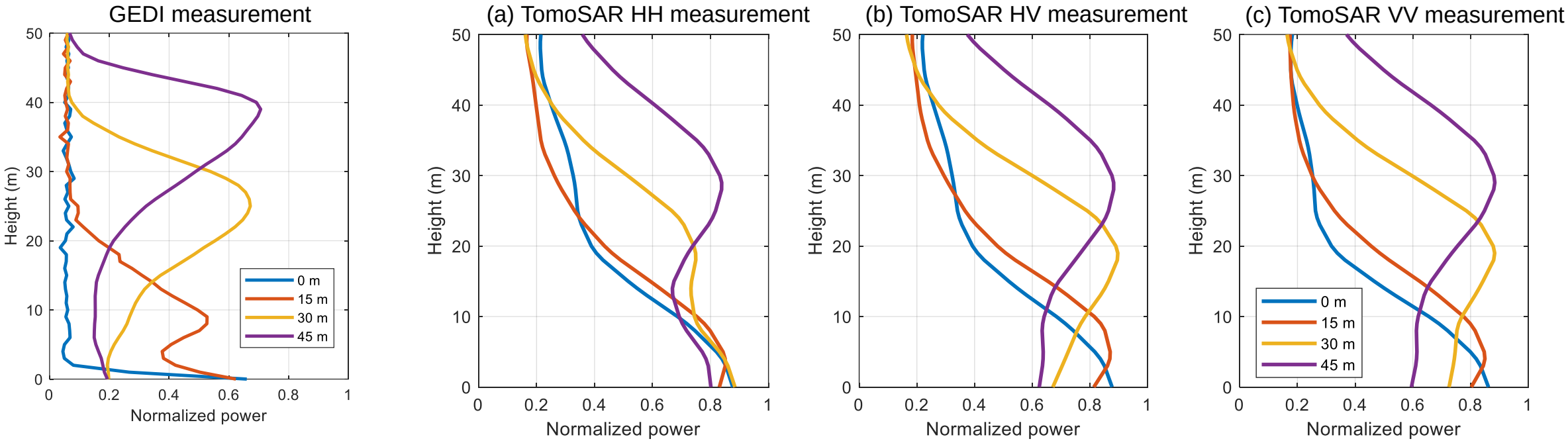






(Paracou forest area)

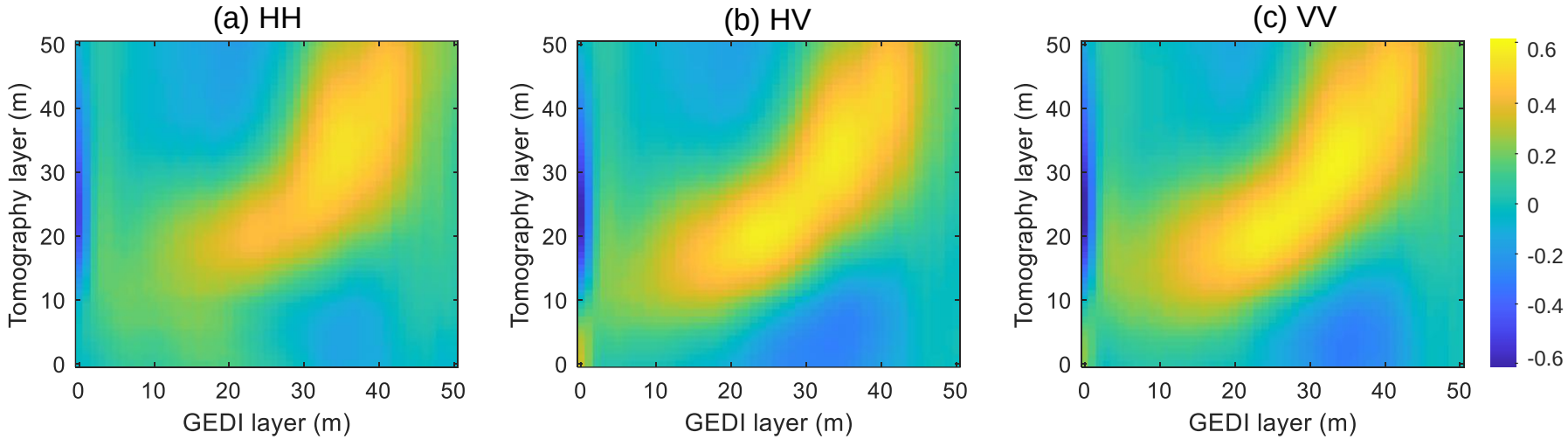
P-band tomography - GEDI performance



(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.
- Furthermore, P-band SAR exhibits better penetration of the ground layer compared to GEDI signals.

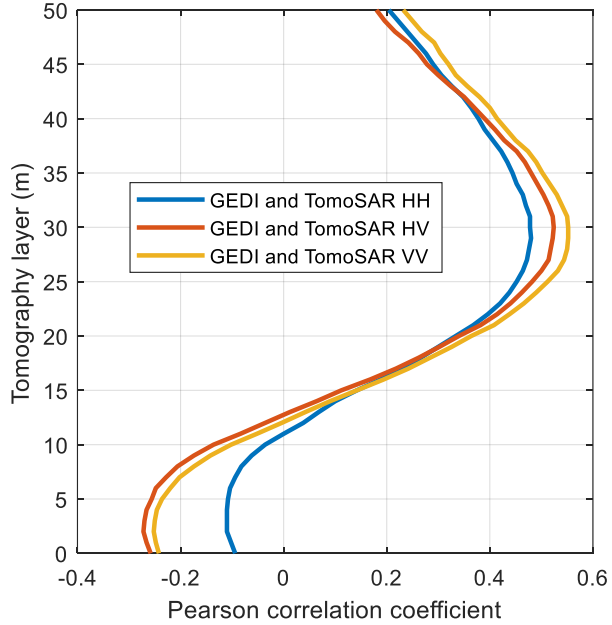
P-band tomography - GEDI performance



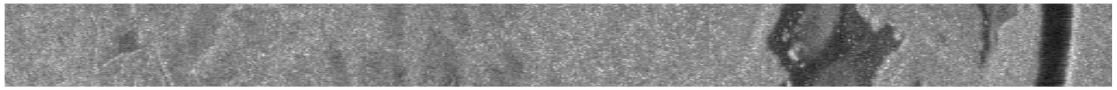
- GEDI and TomoSAR data have shown the capability to capture vertical information within the canopy levels, specifically in the range of 10 meters to 40 meters. There exists a strong correlation between GEDI and TomoSAR reflectivity in the canopy layers.

- The highest correlation was observed at approximately 30 meters above the ground, which aligns with previous research conducted in the development of algorithms for the BIOMASS mission, specifically for biomass retrieval.

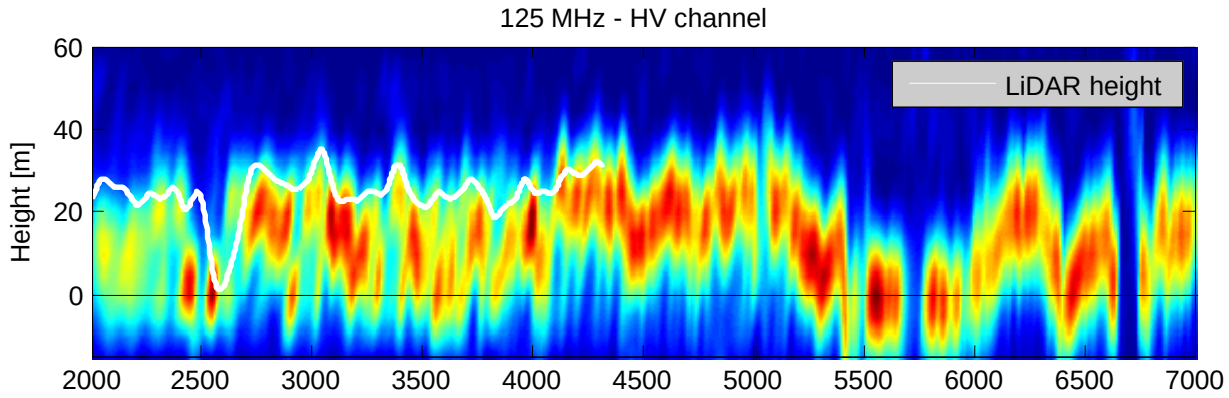
GEDI layer 20m – 40m to tomography



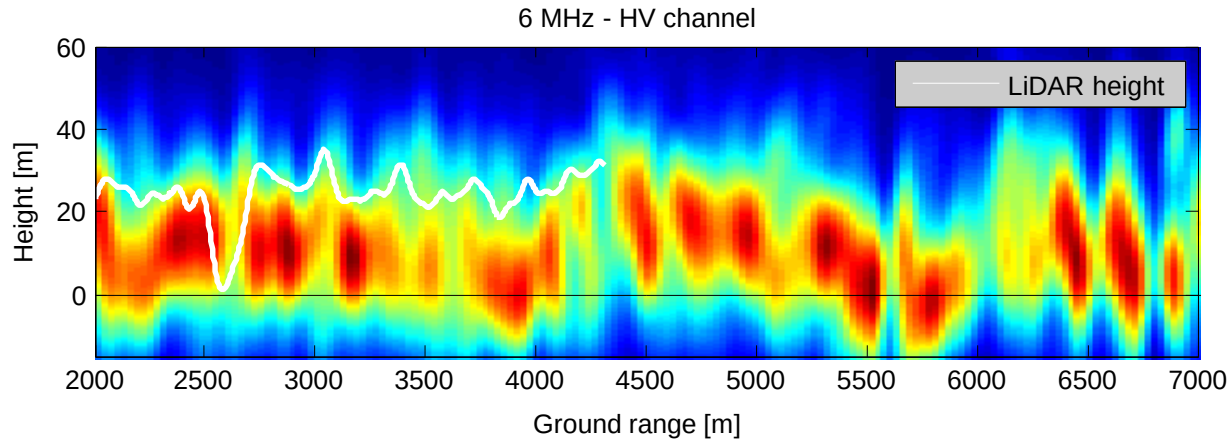
Spaceborne P-band tomography performance

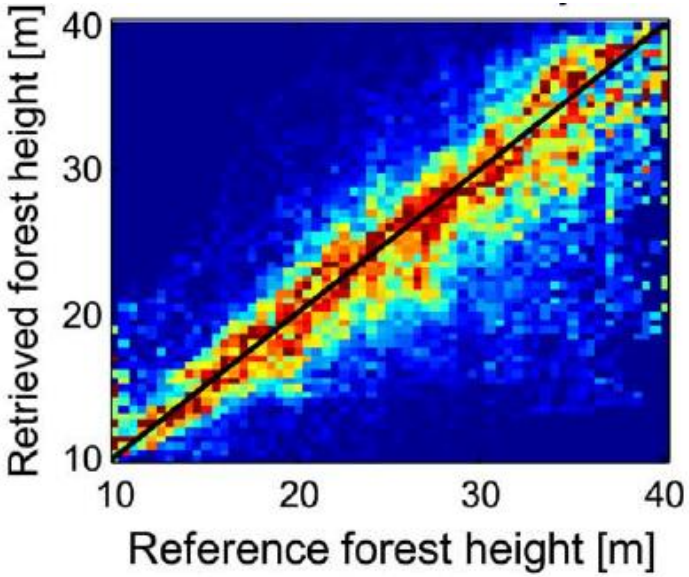


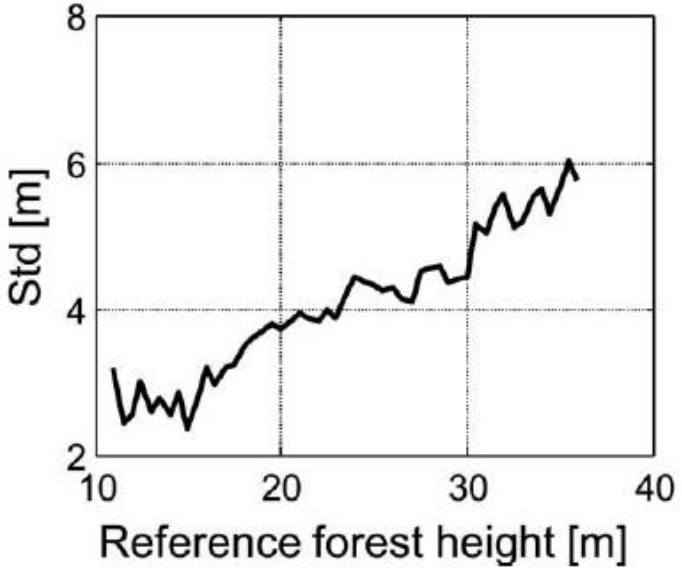
125 MHz **airborne**



6 MHz simulation **spaceborne**







Summarize

- GEDI's full power shots, with a sensitivity of 98%, can serve as a valuable reference for calibrating algorithms in the BIOMASS mission. In comparison to GEDI, TomoSAR exhibits a lower volume peak and has a penetration range of 2-4 meters, indicating its superior capability to penetrate the forest layers.

- Both GEDI and TomoSAR have demonstrated their ability to capture vertical information within the canopy levels, particularly between 10 meters and 40 meters. A strong correlation has been observed between the reflectivity measurements obtained from these technologies, with the highest correlation found at approximately 30 meters above the ground.

- In simulations conducted for the BIOMASS mission, the vertical resolution still falls significantly short of the actual forest height in tropical forests. However, reliable estimation of forest height has been achieved for vegetation layers ranging from 20 meters to 30-35 meters. The standard deviation, based on a pixel-to-pixel comparison at a 1-hectare resolution, has been assessed to be less than 5 meters.

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