Assessment of tropical forest height retrieval based on multi-baseline P-Band SAR data… *and more*

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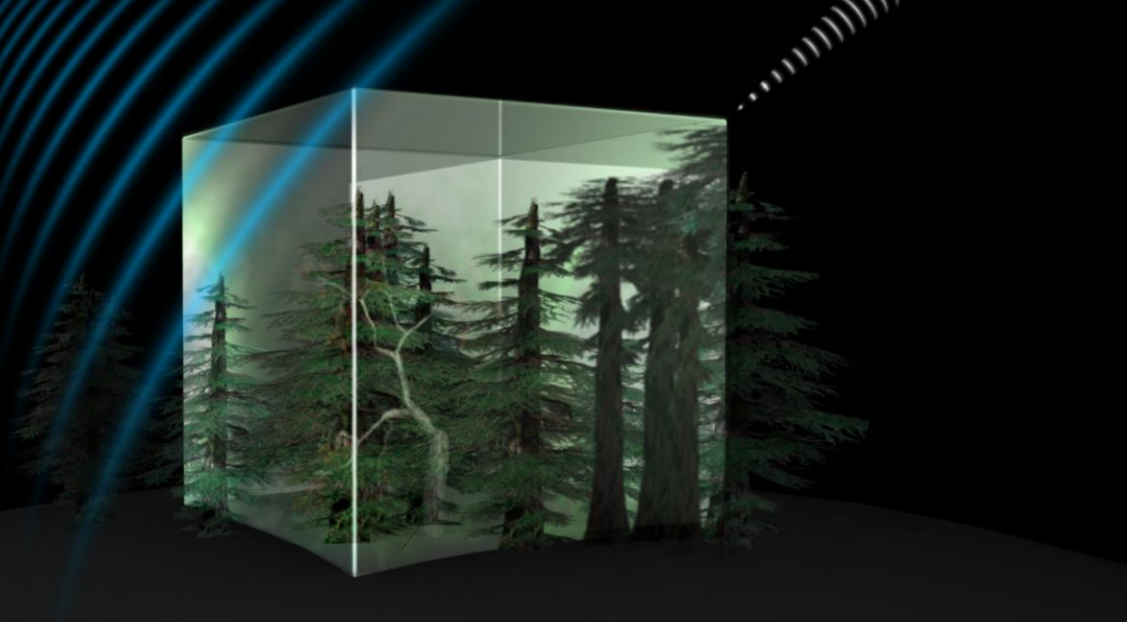
BIOMASS (ESA)

P-Band SAR

Selected as next ESA Earth Explorer Core Mission

Currently in Phase-B

Launch expected in 2021-22



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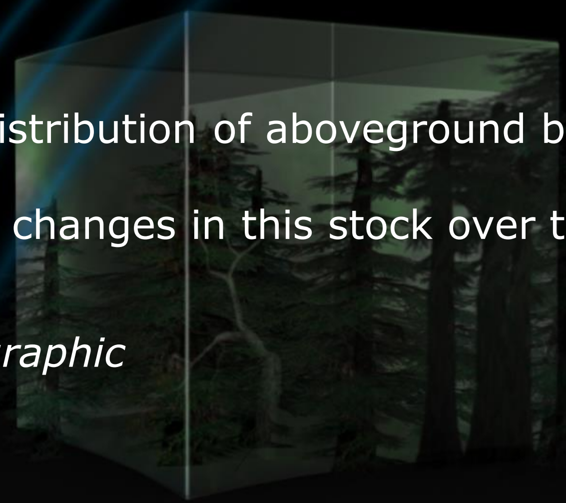


Mission Objectives

- to determine the distribution of aboveground biomass in the world's forests
- to measure annual changes in this stock over the period of the mission.

The BIOMASS Tomographic phase

- One year duration
- Global coverage
- 7 passes per illuminated sites
- 3 day repeat pass time
- Vertical resolution ≈ 23 m

TomoSAR & Forested areas

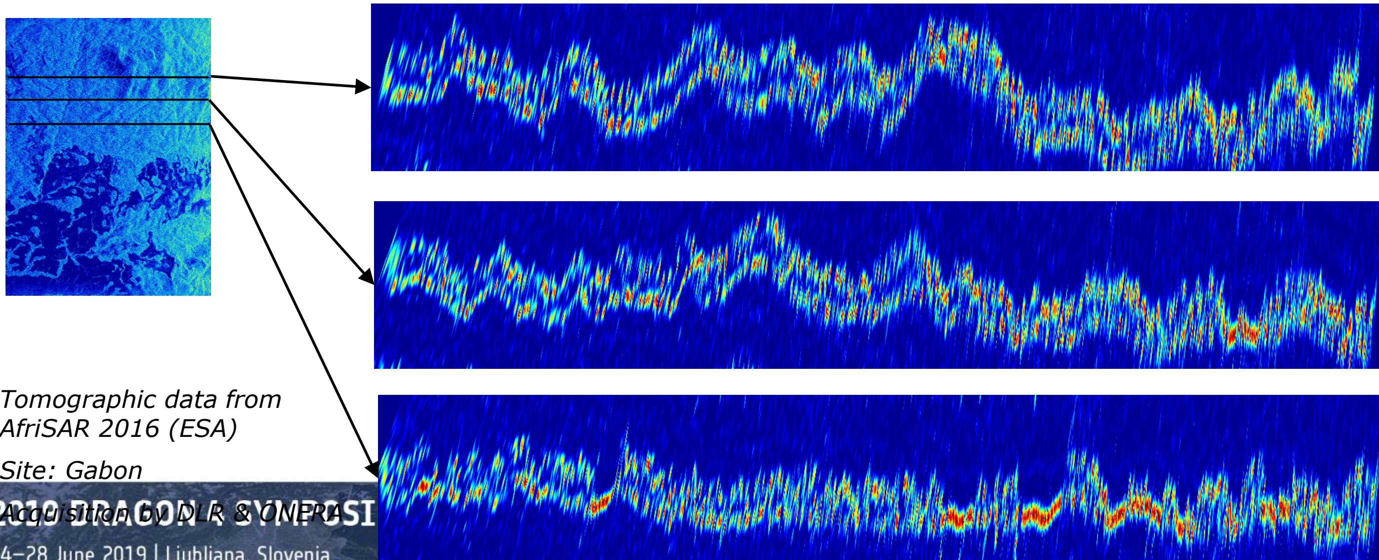
Forest scenarios: separation of backscatter from different heights within the vegetation

⇒ *Forest height*

⇒ *Sub-canopy terrain topography*

⇒ *Classification of forest structure*

⇒ *Improved forest biomass retrieval*



Tomographic data from AfriSAR 2016 (ESA)

Site: Gabon

Acquisition by DLR & ONERA

TomoSAR & Forested areas

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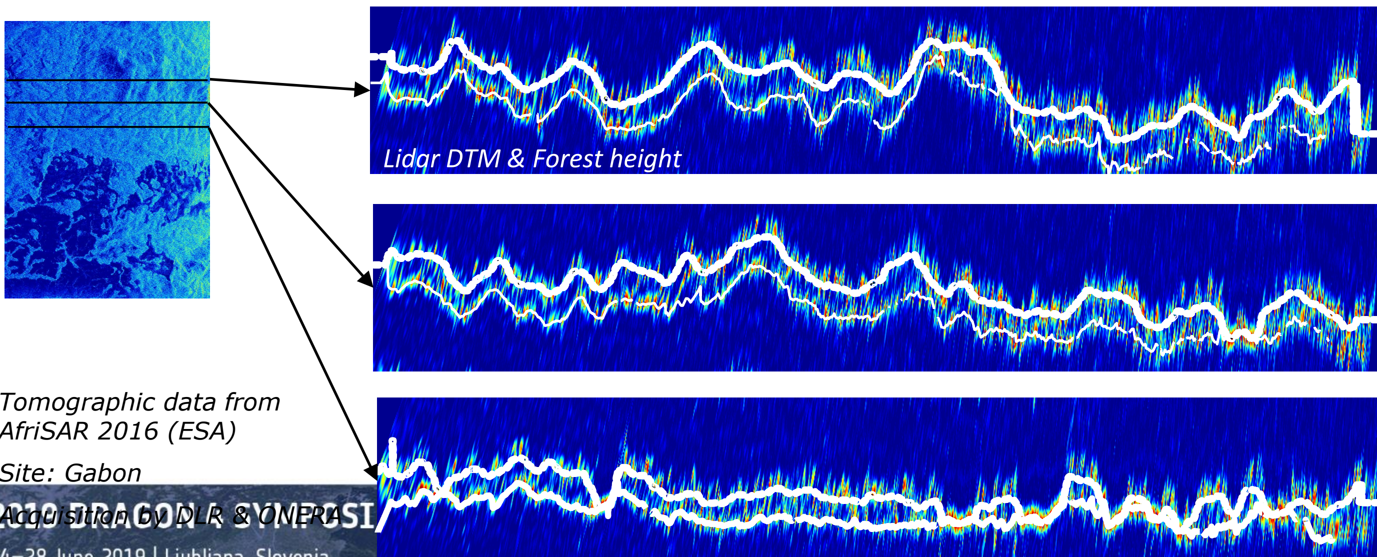


Tomographic data from AfriSAR 2016 (ESA)

Site: Gabon

Acquisition by DLR & ONERA

Goals of this work

Q1): what is the best approach to forest height estimation using multi-baseline P-Band data?

Q2): what is the role of wave attenuation on AGB retrieval from tomographic data?

Forest height from P-Band data

Q1): what is the best approach to forest height estimation using multi-baseline P-Band data?

⇒ Comparison of two alternative methods:

- Parametric estimation under the assumption of the Random Volume over Ground (RVoG) model
  - ✓ Established methodology, repeatedly validated in PolInSAR literature
  - ✓ Physically based
  - ✓ Computational burden may be high

- Direct retrieval from focused tomographic sections
  - ✓ Retrieval is straightforward as it is based on intensity thresholding
  - ✓ Very low computational burden
  - ✓ Requires user to specify the optimal threshold

Forest height by parametric estimation

Under assumption of the RVoG model, the coherence in any given InSAR pair is modeled as:

$$\boldsymbol{\gamma} = \boldsymbol{\gamma}(\boldsymbol{z_g}, \boldsymbol{\sigma}, \boldsymbol{h}, \boldsymbol{\mu}; \boldsymbol{\theta}, \boldsymbol{k_z})$$

- $\boldsymbol{z_g}$ is terrain elevation
- $\boldsymbol{\sigma}$ is wave extinction
- $\boldsymbol{h}$ is forest height
- $\boldsymbol{\mu}$ is the ground-to-volume backscattering ratio
- $\boldsymbol{\theta}$ is the local incidence angle (known)
- $\boldsymbol{k_z}$ is the height-to phase conversion factor (known).

Estimation of the unknown parameters ($\boldsymbol{zg}$,$\boldsymbol{\sigma}$,$\boldsymbol{h}$,$\boldsymbol{\mu}$) by minimizing the l2-norm of the residuals with respect to InSAR coherences in all available InSAR pairs:

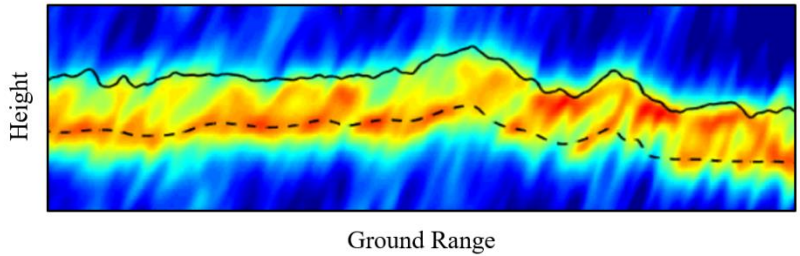
$$\left\| \Gamma - \Gamma(z_g, \sigma, h, \mu; \theta, k_z) \right\|^2$$

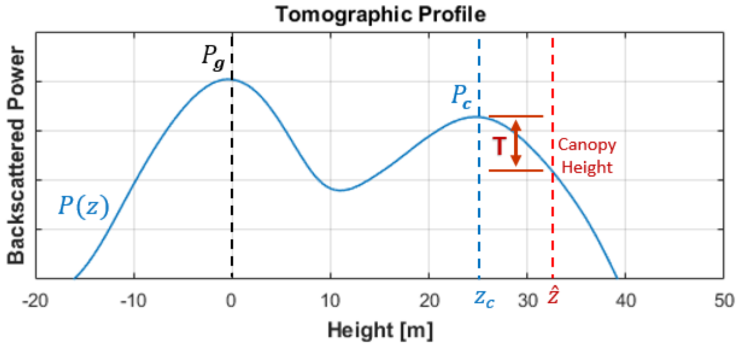
As the minimization is linear in the parameter $\boldsymbol{\mu}$, it can be solved through a three-dimensional research in the parameters ($\boldsymbol{zg}$,$\boldsymbol{\sigma}$,$\boldsymbol{h}$).

Forest height by tomography

Height retrieval from SAR Tomography is based on the ***simple*** idea that wave scattering from forested areas is bound to occur between the terrain and the top of the canopy.

Multi-looked tomographic section





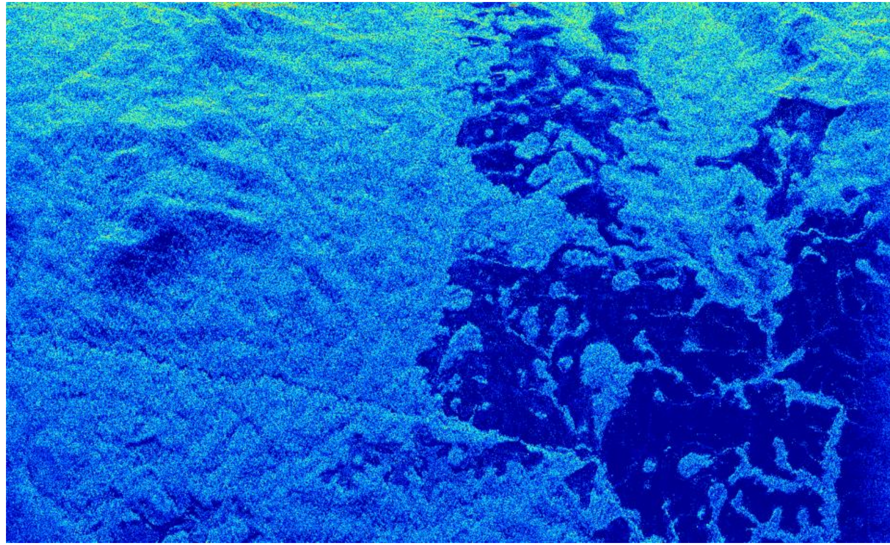
Based on this observation, forest height is here retrieved by taking the point at which scattering intensity decays by a fixed threshold **T** w.r.t. the upper phase center.

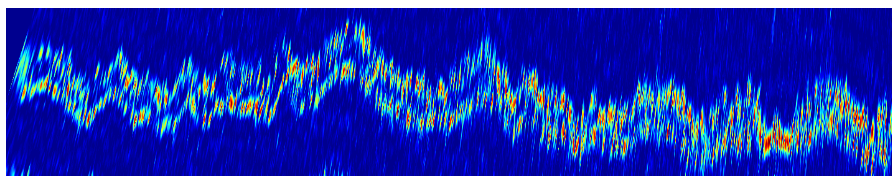
Data-set: La Lopé – AfriSAR

Dataset: ESA AfriSAR

carried out by DLR in February 2016 at La Lopé, Gabon.

Parameters	Value
Frequency	435 [MHz]
Wavelength	0.6897 [m]
Bandwidth	50 [MHz]
Range Resolution	3 [m]
Vertical Resolution	15-25 [m]
Flight Tracks	10 (FP)
Baseline	Vertical
Incidence Angle	20°- 60°





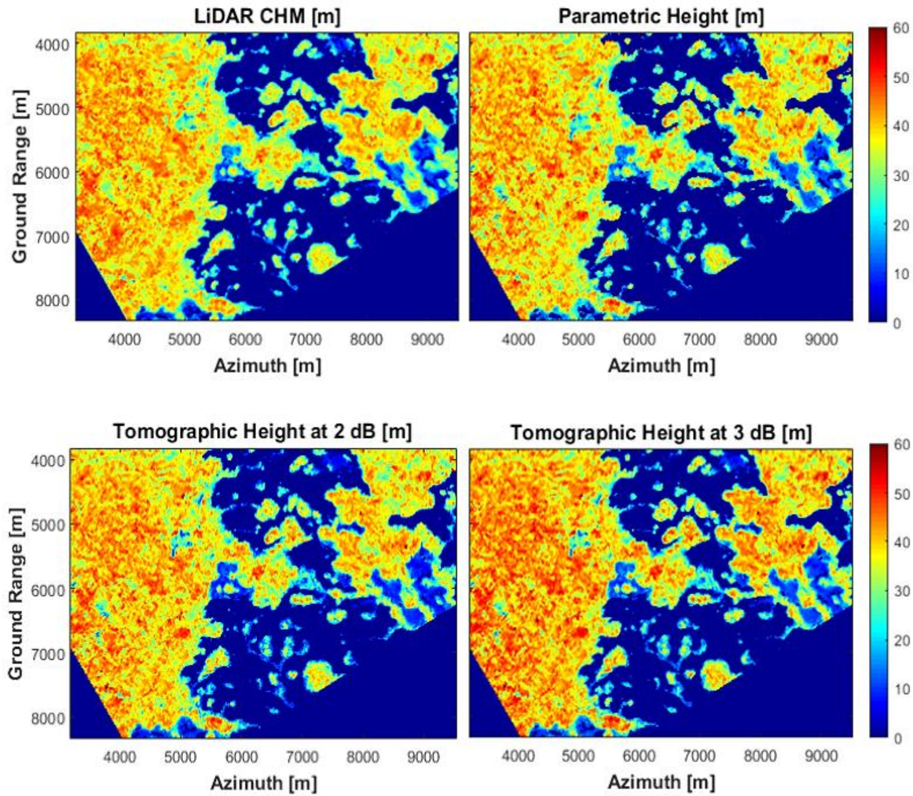
Forest height retrieval results

Both algorithms were implemented at a spatial scale of 25 m x 25 m, using data from HV polarization.

A reference Canopy Height Model (CHM) was derived from airborne LiDAR measurements by:

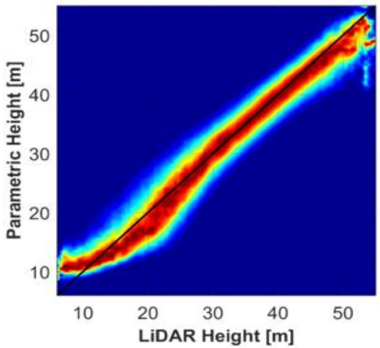
i. taking top height within a 10 m x 10 m window, and

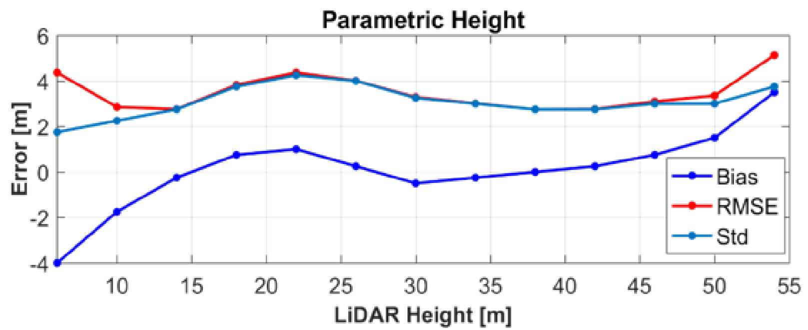
ii. averaging the result at 25 m x 25 m.

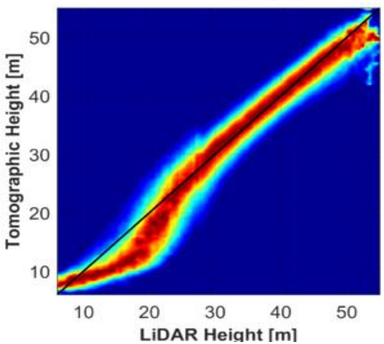


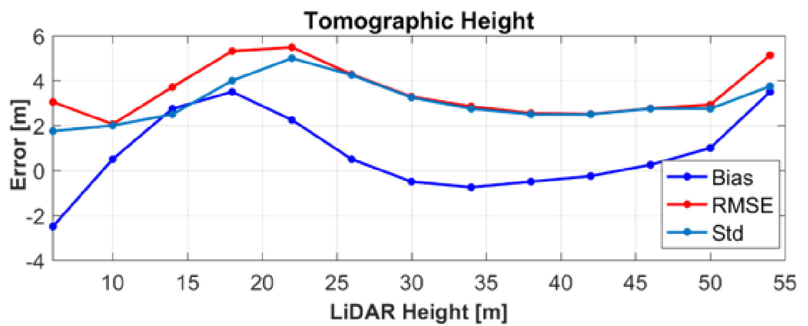
Forest height retrieval results

Validation is carried out in a pixel-by-pixel fashion, i.e.: with no further aggregation of results at stand level.









Forest biomass from P-Band data

Q2): what is the role of wave attenuation on AGB retrieval from tomographic data?

Forest biomass from P-Band data

Correlation between Radar intensity and Above Ground Biomass (AGB)

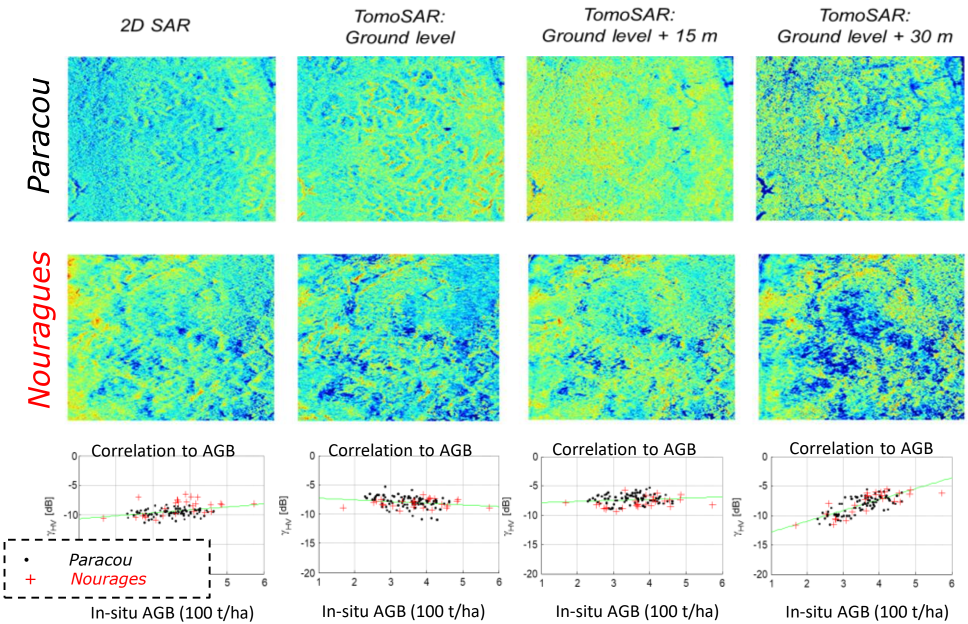
- 2D SAR intensity is poorly correlated to AGB
- TomoSAR intensity at 0 m is poorly and negatively correlated to AGB
- TomoSAR intensity at main canopy height is highly correlated to AGB (≈ 50 Mg/ha per dB)

Sites: Paracou, Nourages (French Guiana)

Frequency: P-Band

Data-set: TropiSAR (ESA)

Data-set by ONERA

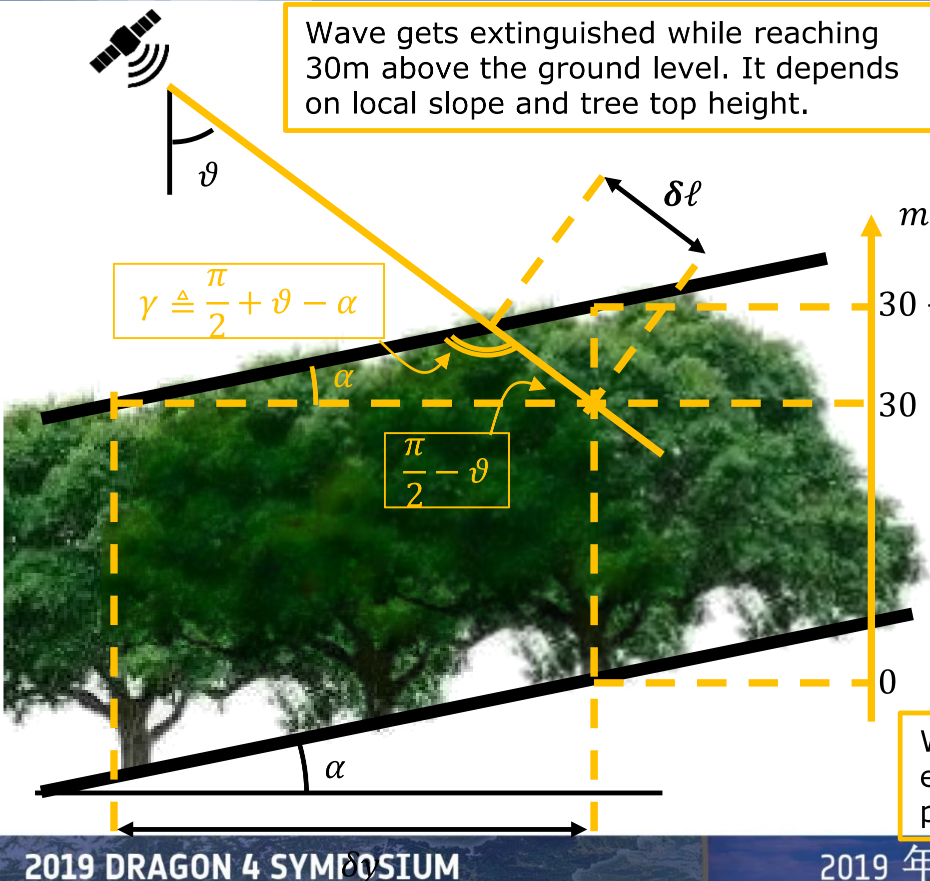


Ho Tong Minh et al., TGRS, 2014

Ho Tong Minh et al., Remote Sensing of Environment, 2016

The rolw of wave extinction

Wave gets extinguished while reaching 30m above the ground level. It depends on local slope and tree top height.



$\delta\ell$: path length
δz: tree top height minus 30m
α: ground slope
ϑ: look angle

Law of sines:

$$\frac{\delta\ell}{\sin\alpha} = \frac{\delta y}{\sin\gamma}$$

Substituting:

$$\sin\gamma = \cos(\vartheta - \alpha)$$

$$dy = \frac{\delta z}{\tan\alpha}$$

$$\delta\ell = \frac{\cos\alpha}{\cos(\vartheta - \alpha)} \cdot \delta z$$

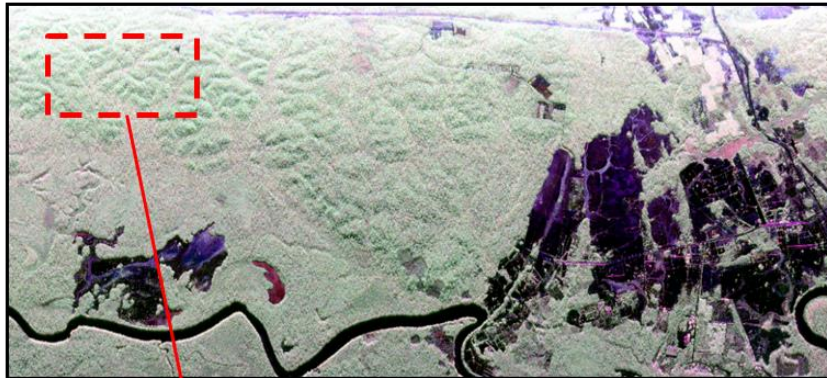
We need tree top height and extinction to compensate this power loss

Data-set: Paracou – TropiSAR

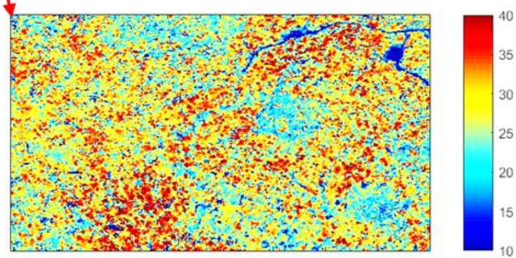
Dataset: ESA TropiSAR:

carried out by ONERA in August 2009 at Paracou, French Guiana.

Parameters	Value
Frequency	397.5 [MHz]
Wavelength	0.7547 [m]
Bandwidth	125 [MHz]
Range Resolution	1 [m]
Vertical Resolution	15-25 [m]
Flight Tracks	6 (FP)
Baseline	Vertical
Incidence Angle	20°- 60°

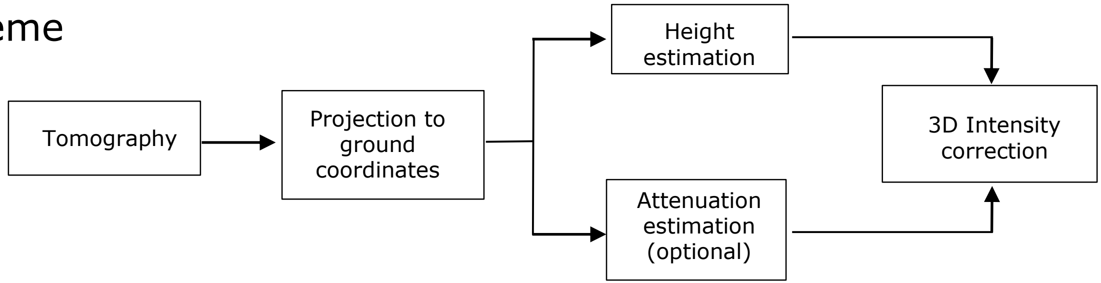


LiDAR Canopy Height Model (CHM)

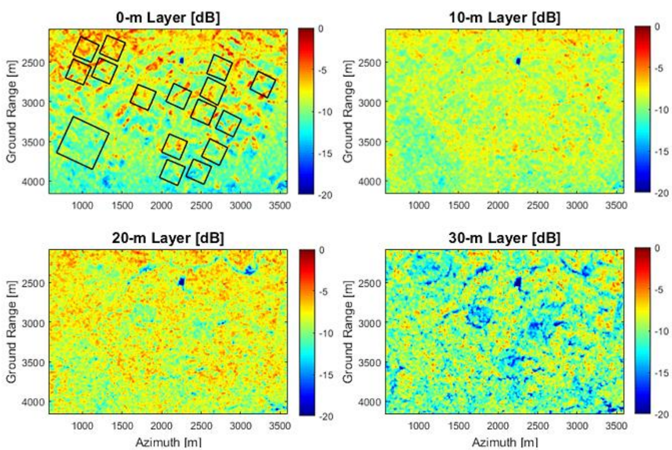


Results

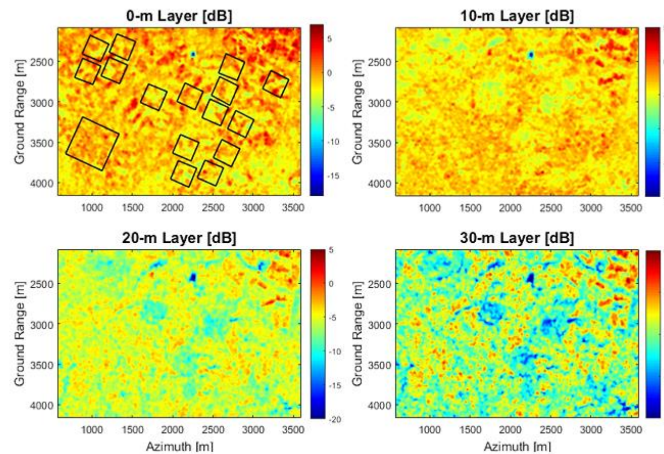
Correction scheme



Tomographic sections



Corrected Tomographic sections



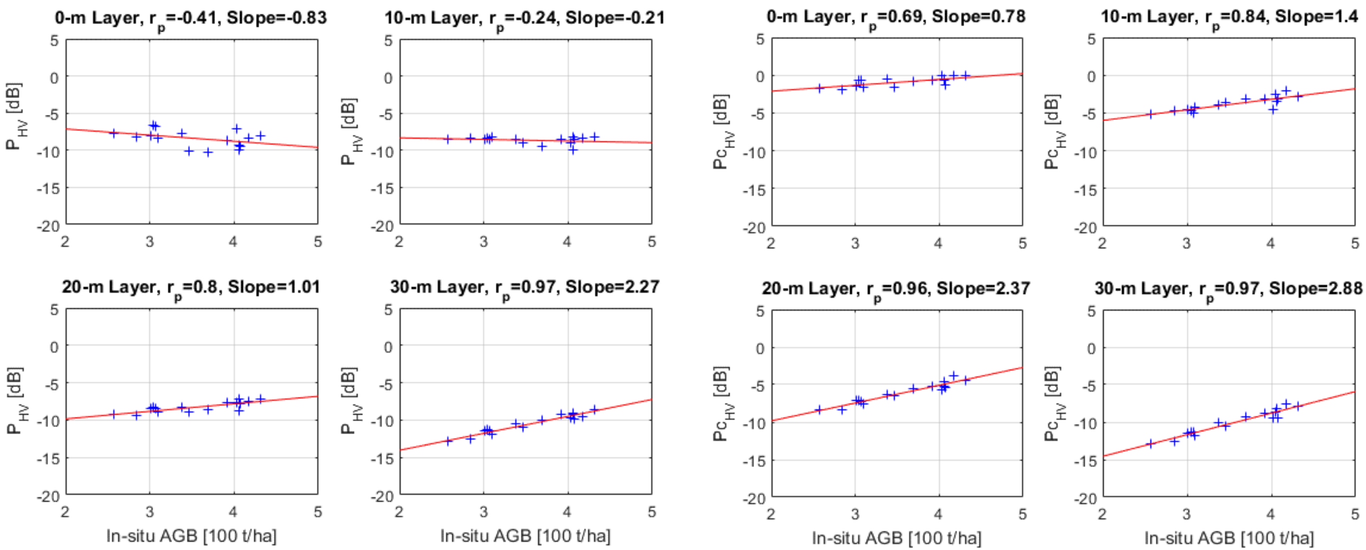
Forest biomass from P-Band data

Regression against in-situ AGB data

- 16 aggregated plots ≈ 6 h.

Tomographic sections

Corrected Tomographic sections



Conclusions

Forest height:

Both parametric and tomographic height retrieval produced reliable results for forest height values ranging from 30 m to 50 m. Dispersion ≈ 3 m or better.

Height retrieval by tomography turned out to be slightly less dispersed, although at the expense of a larger bias whenever forest height is lower than about 20 m.

⇒ development of hybrid algorithms that preserve the advantages of both methods, namely the capability of model-based retrieval to work without requiring parameter tuning, and the computational efficiency and accuracy of SAR tomography.

Wave attenuation:

AGB was observed to improve significantly by accounting for wave extinction and forest height, even though tomographic intensity at 30 m is still observed to provide the best correlation correlation.

⇒ both wave extinction and forest height take part in the connection between total volume backscatter and AGB

⇒ new hints for the implementation of AGB retrieval schemes during the interferometric phase of BIOMASS.

Papers

X. Yang, M. M. d'Alessandro, S. Tebaldini and M. Liao, "Tropical Forest Height Retrieval Based on P-band Multibaseline SAR Data ", IEEE Geoscience and Remote Sensing Letters, accepted

Y. Bai, X, Yang, et al. , “Progresses on SAR remote sensing of tropical forests: forest biomass retrieval and analysis of changing weather conditions”, prepared for Dragon 2018

X. Yang, M. M. d'Alessandro, S. Tebaldini and M. Liao, "Relating Sar Tomography to Tropical Forest Biomass Via Lidar Data," *IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium*, Valencia, 2018, pp. 9034-9037.

X. Yang, M. M. d'Alessandro, S. Tebaldini and M. Liao, "Retrieval of forest height in tropical areas based on P-Band multi-baseline data" *Living Planet Symposium 2019, Milan*.

X. Yang, M. M. d'Alessandro, S. Tebaldini and M. Liao, " The Impact of Wave Extinction on Relating SAR Tomography to Tropical Forest Biomass”, submitted to JSTARS