P-band Tomography imaging of tropical forest at 6 MHz bandwidth: capabilities for forest biomass and height estimation

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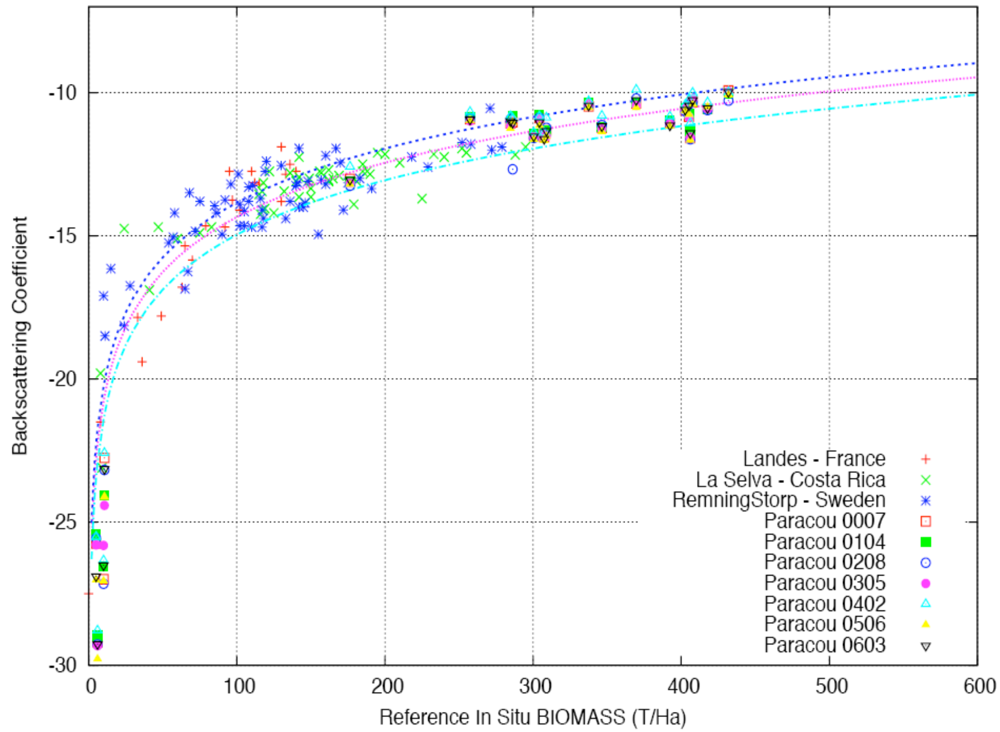
Introduction

• Even at P-Band, Radar intensity tends to saturate for very high biomass density (> 300 t/ha) ⇒ Information about forest structure becomes crucial

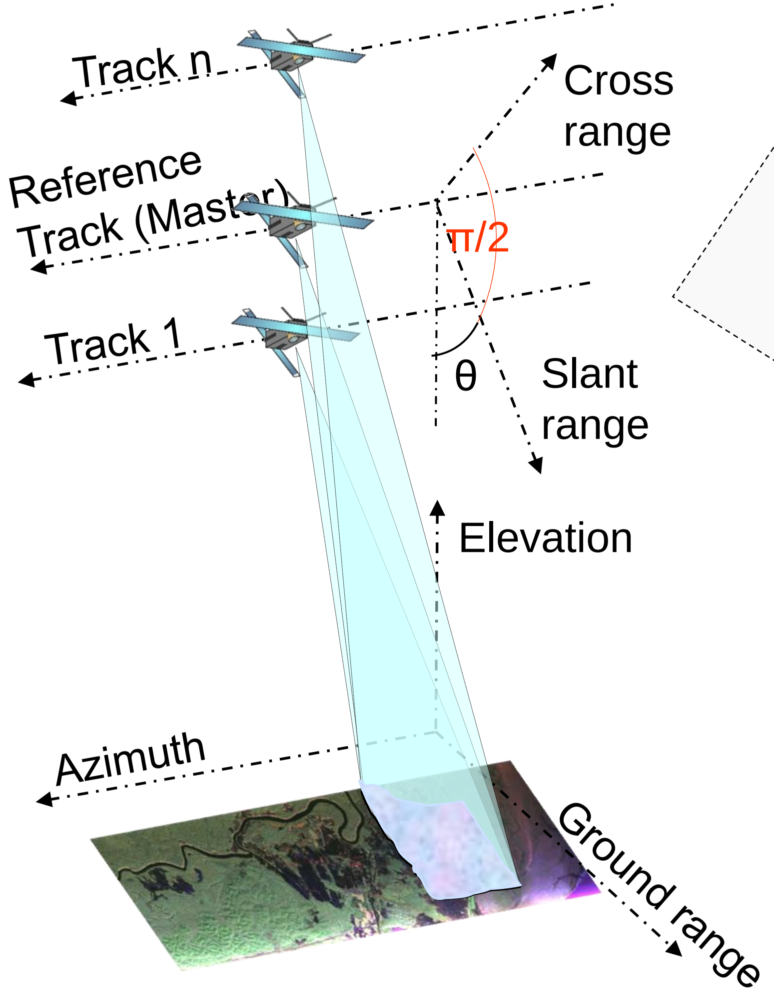


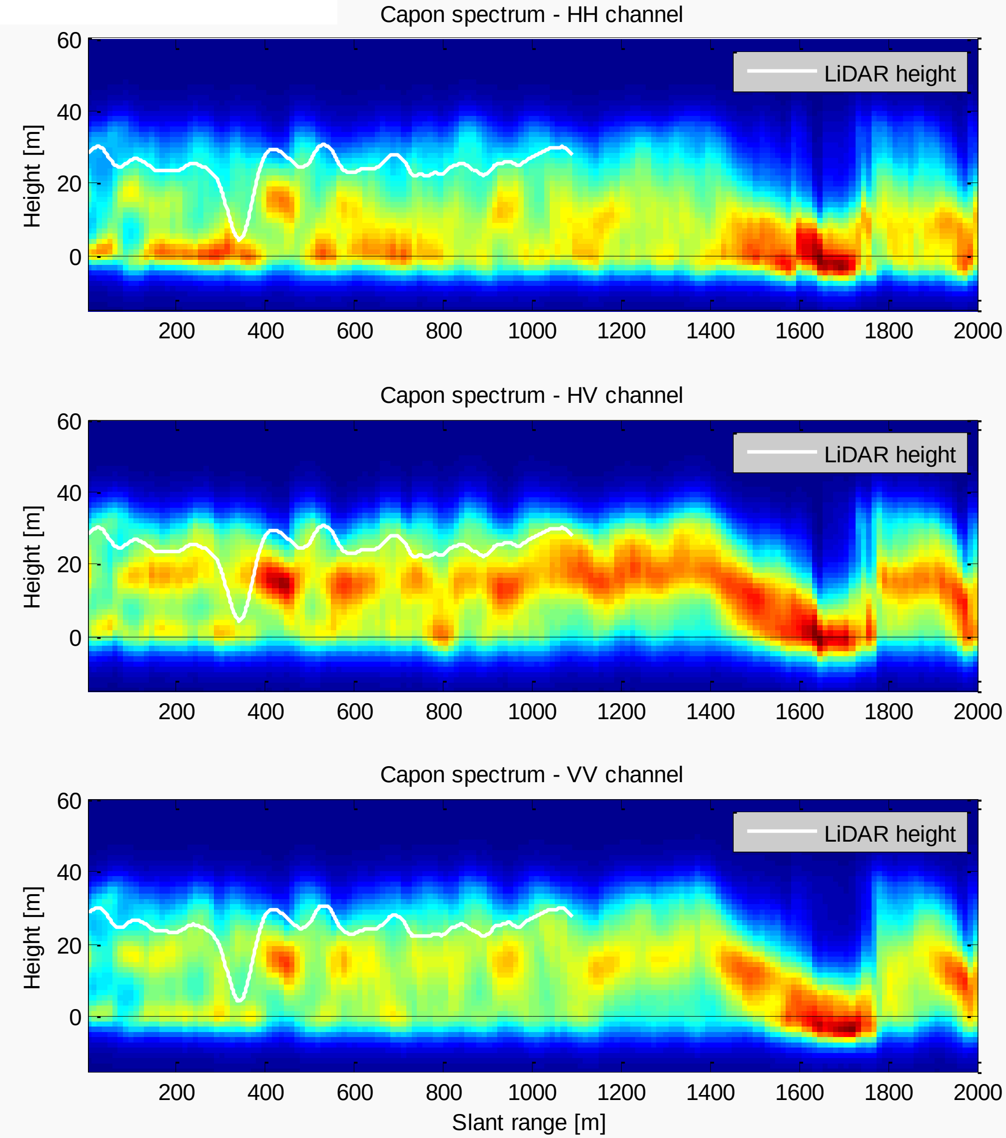
By Airborne TropiSAR data, **3D P-band SAR Tomography shows :**

Scattering contributions from about *30 m* above ground exhibit high sensitivity to forest biomass value ranging *from 250 t/ha to 450 t/ha*.

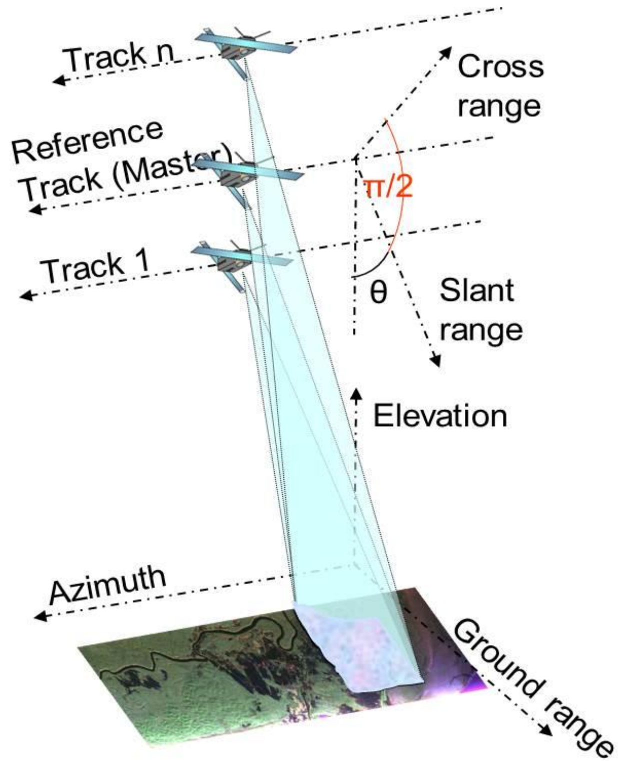
Introduction

BIOMASS Tomographic Phase





Introduction



P-band SAR tomography

key tool to *SEE* through the forest

suitable long wavelength to penetrate the dense forest layer

key indicator to tropical forest biomass

Bandwidth constraint: 6 MHz

A significant reduction of the number of looks

A significant vertical and horizontal resolution loss

GOAL: Study the 6 MHz performance of radar signal scattering mechanisms which relate to the tropical forest biomass and height

Vertical resolution and look angle

$$\Delta r = \frac{c}{2B} \qquad \Delta\xi = \frac{\lambda r}{2A_\xi} \qquad \Delta x = \frac{\lambda r}{2A_x}$$

B : pulse bandwidth

A_ξ : baseline aperture

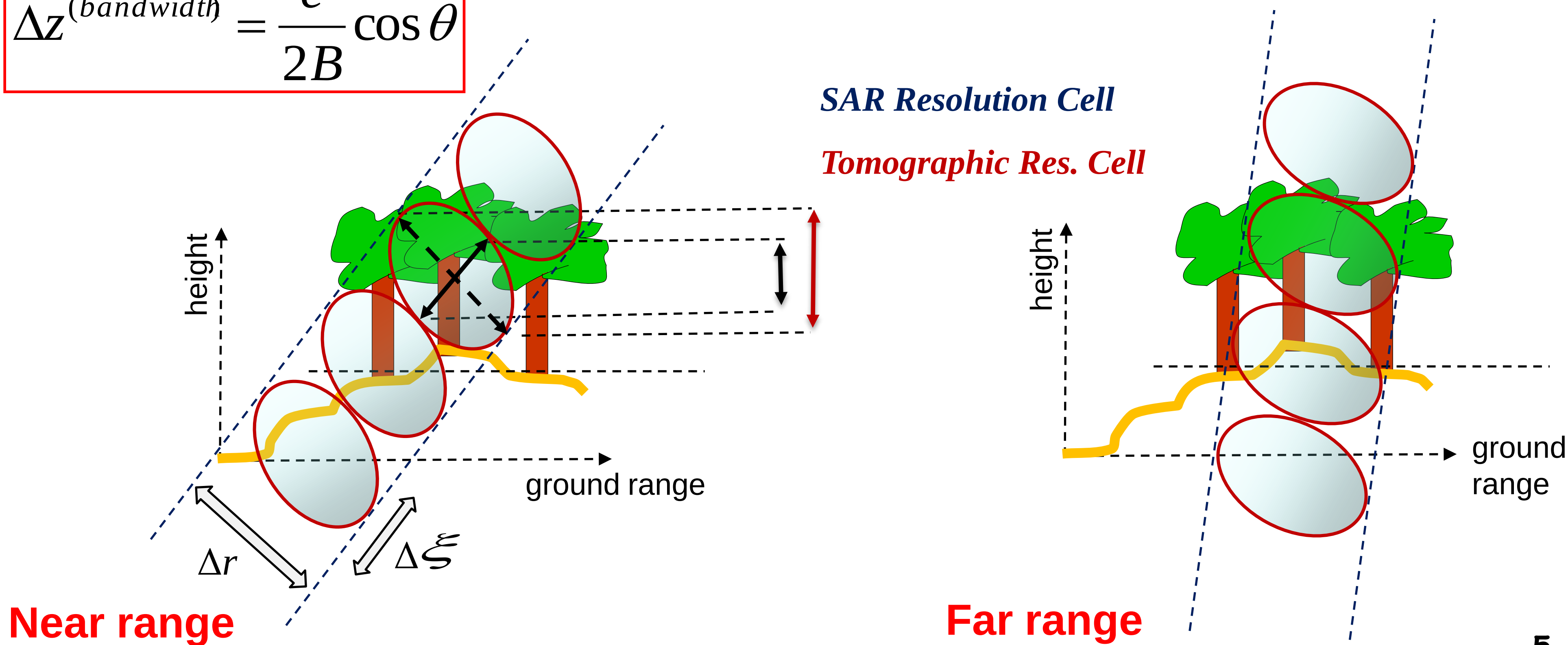
A_x: azimuth aperture

λ: carrier wavelength

$$\Delta z^{(baseline)} = \frac{\lambda r}{2A_\xi}\sin\theta$$

$$\Delta z^{(bandwidth)} = \frac{c}{2B}\cos\theta$$

BIOMASS: B = 6 MHz, θ = 25° => Δz > 20 m



Reducing bandwidth

6 MHz bandwidth: two different processing approaches have been considered

1. Degrading the resolution of 125 MHz airborne data through linear filtering. (ONERA)

Advantage: fast

Disadvantage: incident angle varying

2. Back projection of airborne tomographic data onto BIOMASS geometry. (Polimi)

Advantage:

incident angle almost constant

Investigated site : *Paracou, French Guyana*

Tropical forest area	
Period	August 2009
Bandwidth	**125 MHz**
Carrier frequency	P-Band
Vertical resolution	≈20 m
Data from TROPISAR by ONERA	

Reducing bandwidth

6 MHz bandwidth: two different processing approaches have been considered

1. Degrading the resolution of 125 MHz airborne data through linear filtering. (ONERA)

Parameter	Value
Aircraft height	**≈ 0.4 km**
Look angle	**20° - 60°**
Central frequency	0.435 GHz
Maximum allowed bandwidth	6 MHz
Height ambiguity	> 100 m
Range resolution	25 m
Azimuth resolution	12.5 m
Range sampling	18 m
Azimuth sampling	5 m
Number of track	6
Baseline aperture	75 m

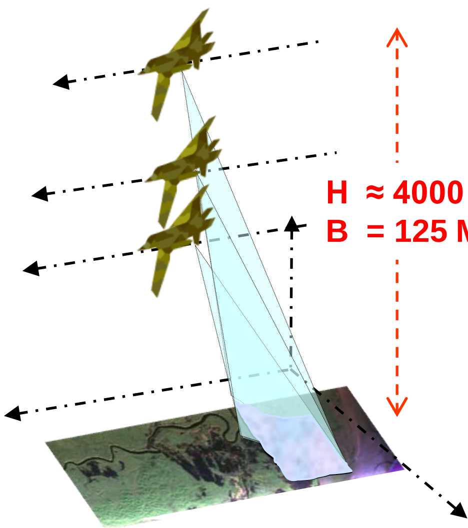
2. Back projection of airborne tomographic data onto BIOMASS geometry. (Polimi)

Parameter	Value
Satellite height	**650 km**
Look angle	**25°**
Central frequency	0.435 GHz
Maximum allowed bandwidth	6 MHz (<-50 dB at +-3 MHz)
Height ambiguity	160 m
Range resolution	25 m
Azimuth resolution	12.5 m
Range sampling	4 m
Azimuth sampling	5 m
Number of track	8
Baseline aperture	4610 m (critical)

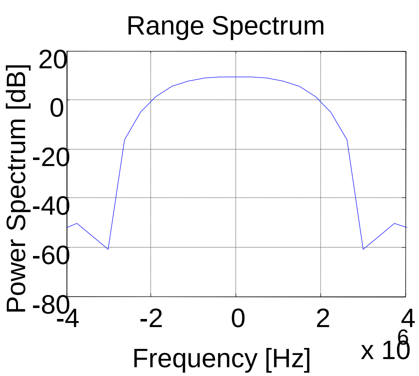
Implementation approach 2

Simulated scenario : backprojection of airborne tomographic data onto BIOMASS geometry

TropiSAR data

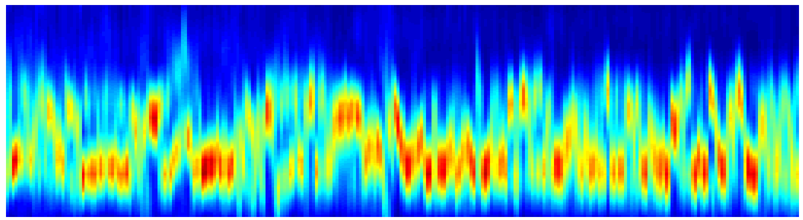


H ≈ 4000 m
B = 125 MHz



1

3D Tomographic reconstruction



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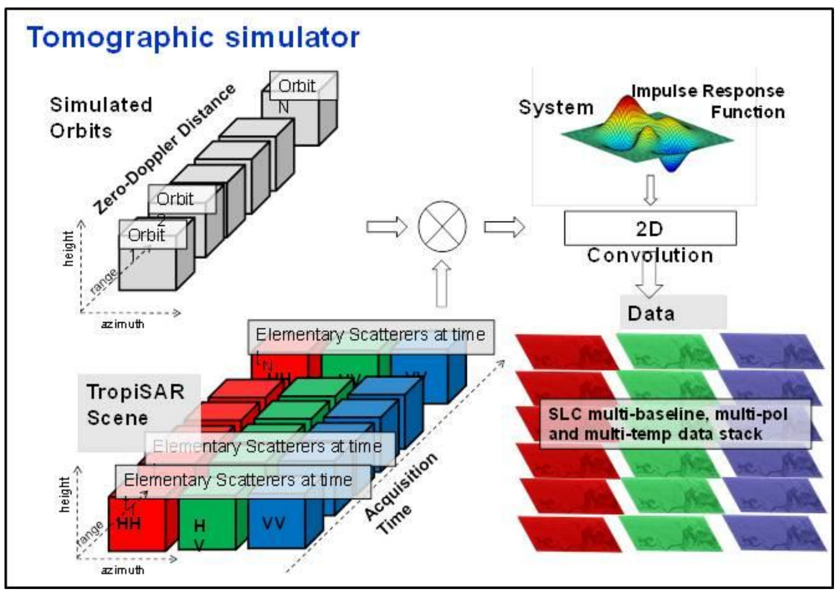
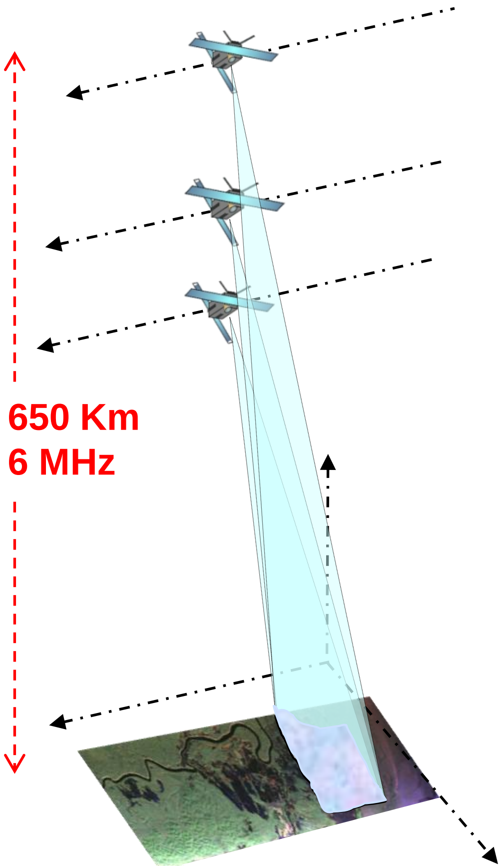


3

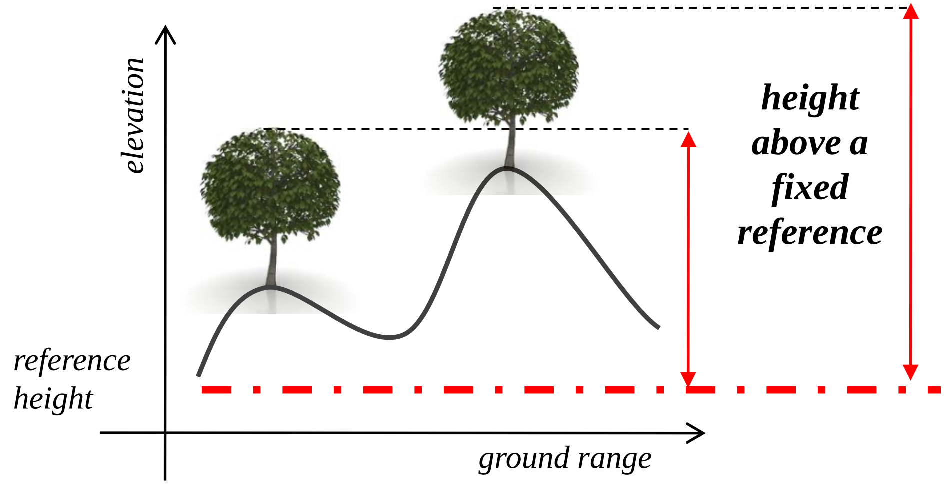
BIOMASS data

H = 650 Km
B = 6 MHz



Preliminary issue with approach 1

Terrain topography

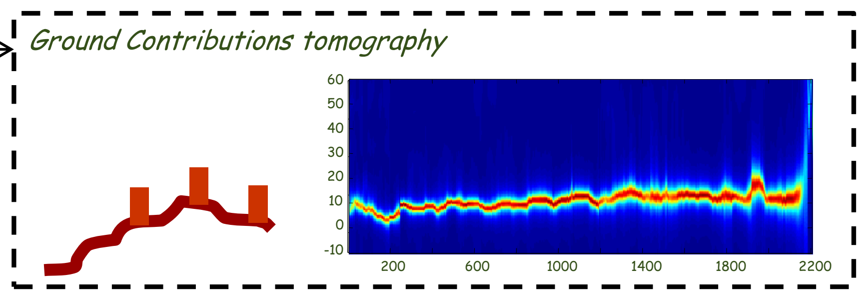


Standard interferometric processing removes the phases associated with a constant elevation along the images. The local topography is not taken into account so that height measurements are not referred to the ground level.

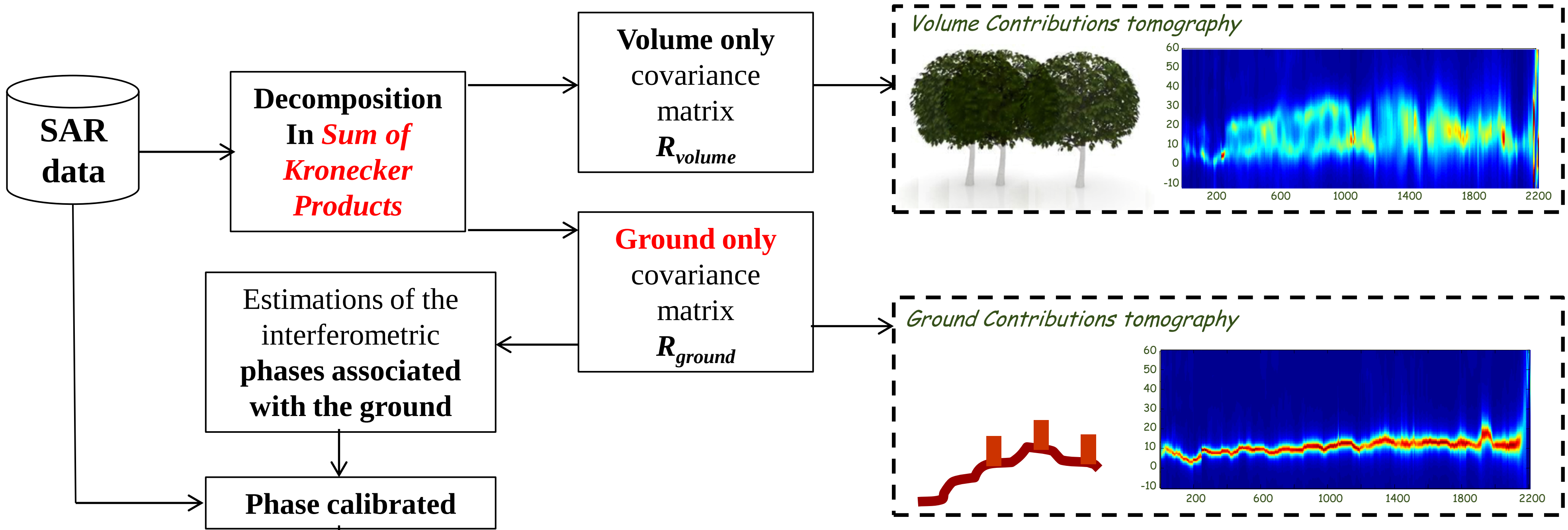
Being the goal the exploration of the forest layer, *the topographic contribution shall be removed*.

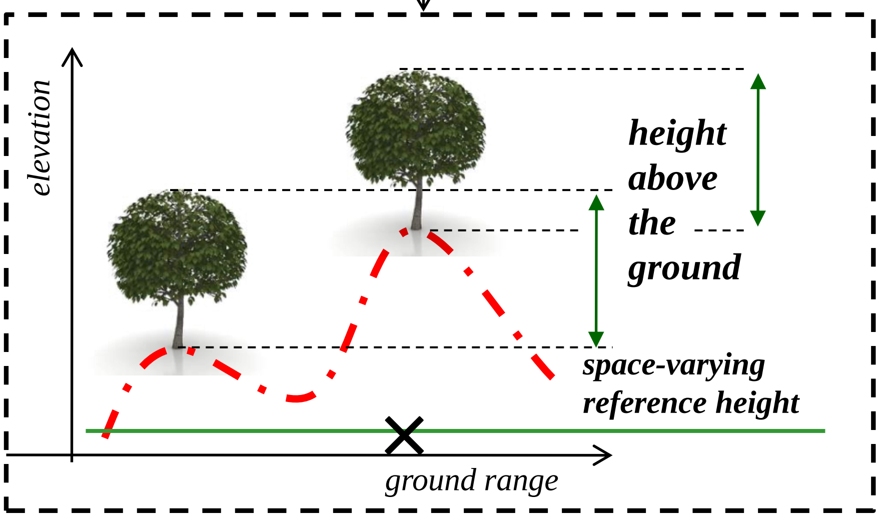
How to remove terrain

Ground only →



Phase calibration





The removal of the interferometric phases associated with the ground level makes the local elevation of the terrain the reference height.
The phases are determined by the optical wavepath so that the effects due to uncompensated platform motion are removed as well

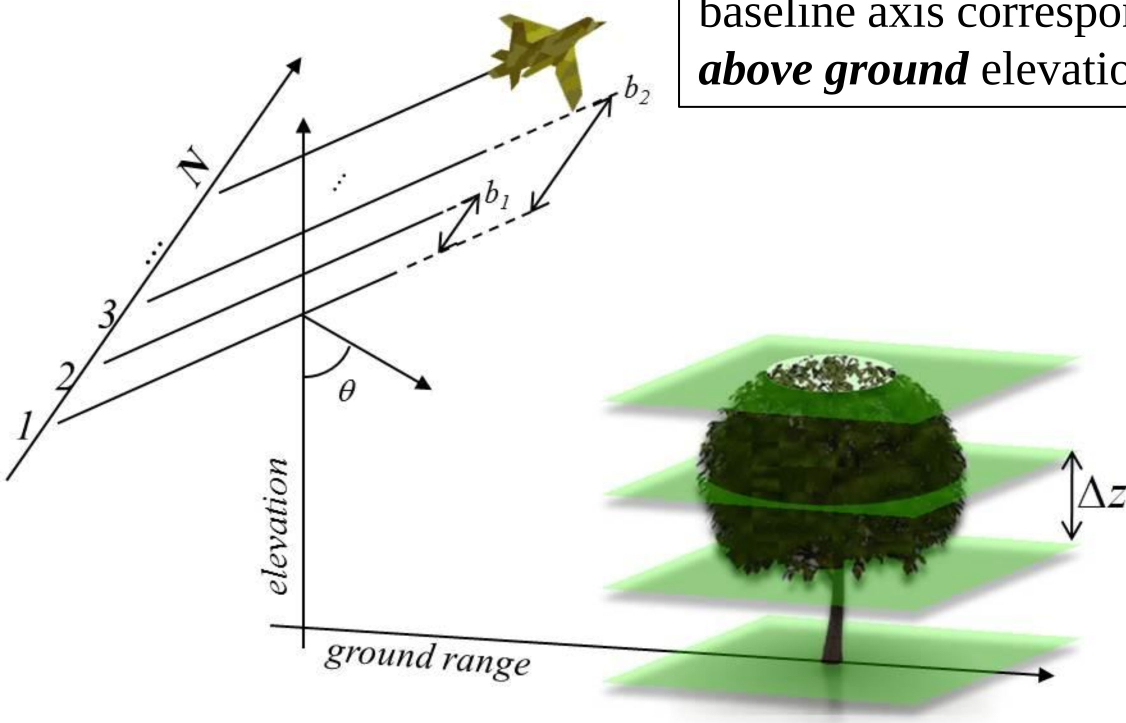
Hereinafter, *0m* always refers to the ground level regardless of the actual topography.

From multi-baseline to multi-layer

Complex reflectivity along cross-range (ξ) direction and signal along image index are related by a ***Fourier Transform***.

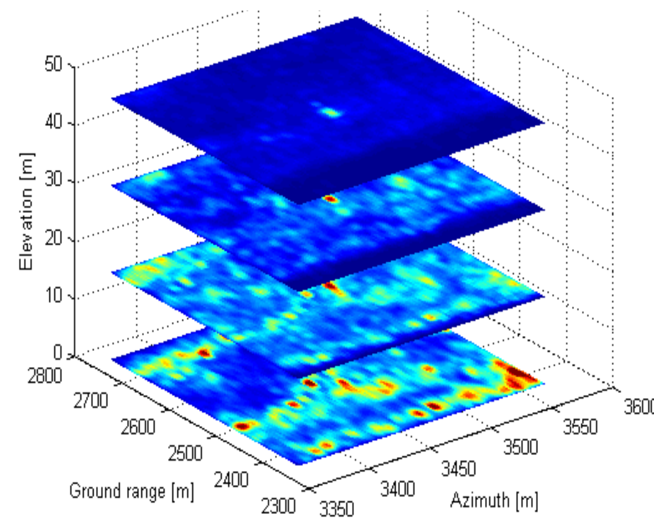
$$y_n(r,x) = \int P(\xi, r, x) \exp\left(j \frac{4\pi}{\lambda r} b_n \xi \right) d\xi$$

Spatial frequencies along the baseline axis correspond to ***above ground*** elevations.



The Guyaflux tower (camera)

SAR Tomography

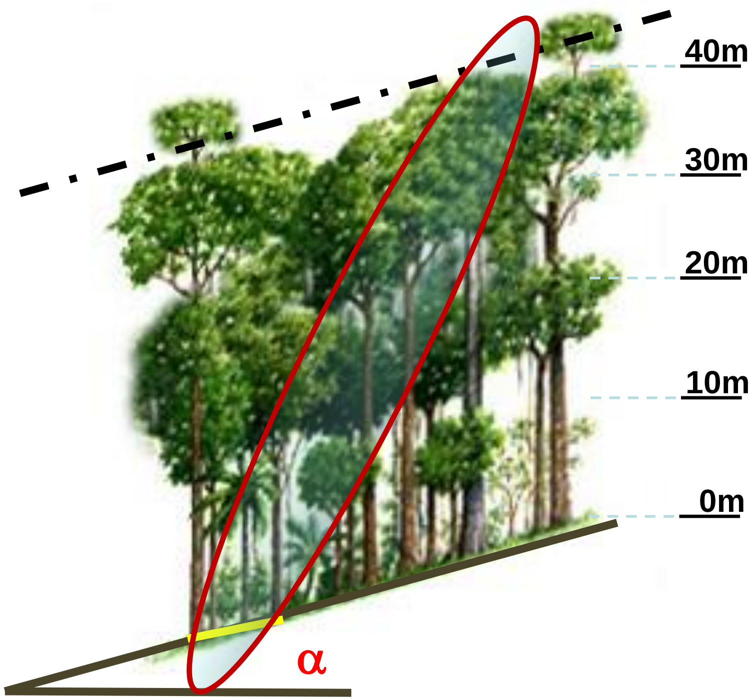


Vertical backscatter distribution of 55 m tower

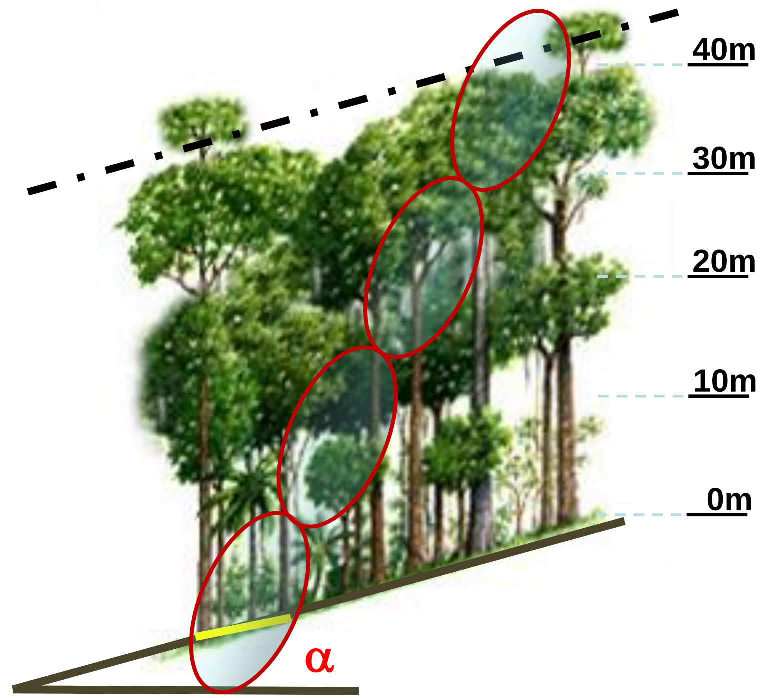
Multi-layer

Note:
Height is always measured with respect to terrain elevation

SAR resolution cell



SAR Tomography resolution cell



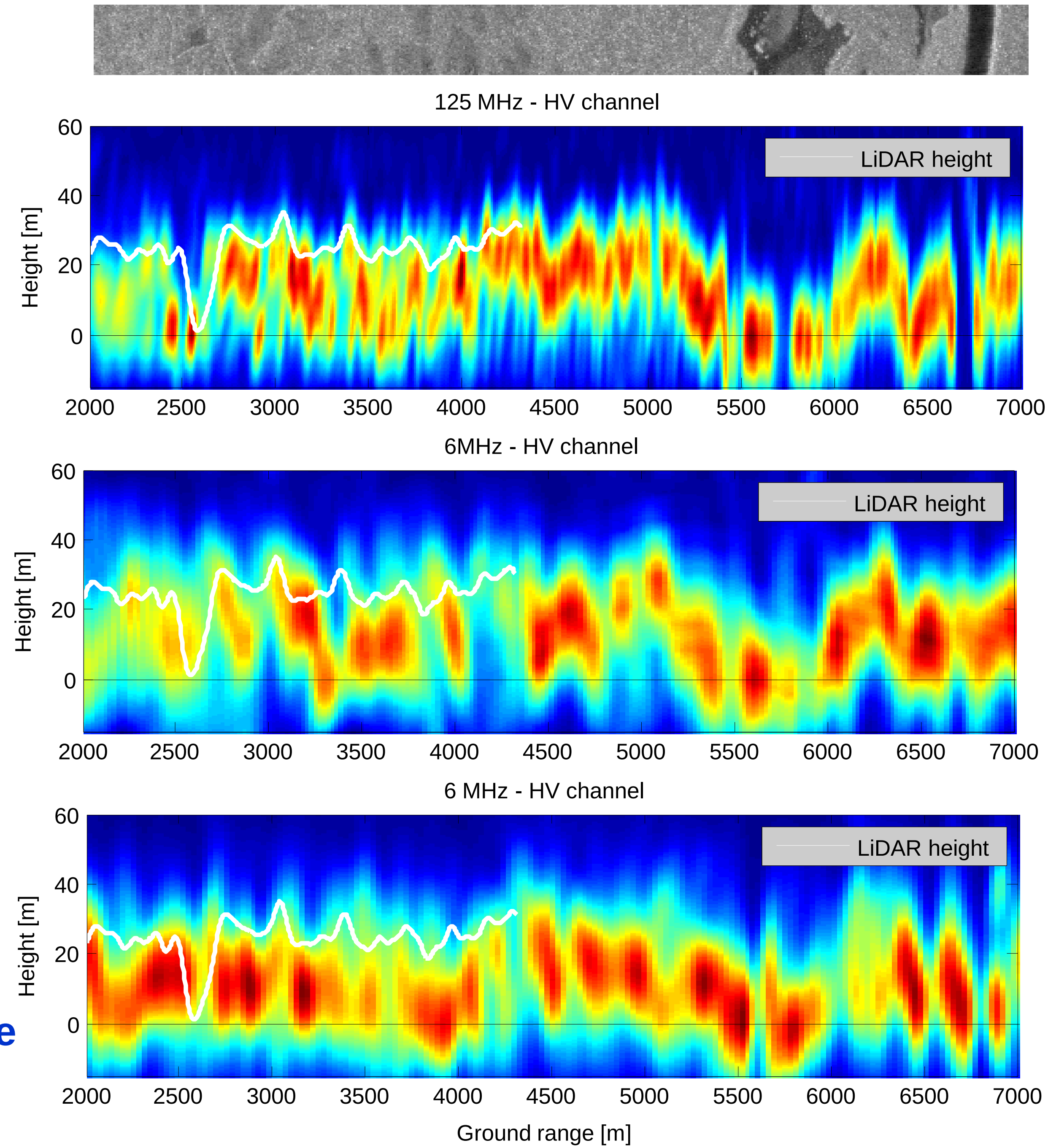
Profile

125 MHz
airborne geometry

6 MHz filtering
airborne geometry

6 MHz simulation
spaceborne geometry

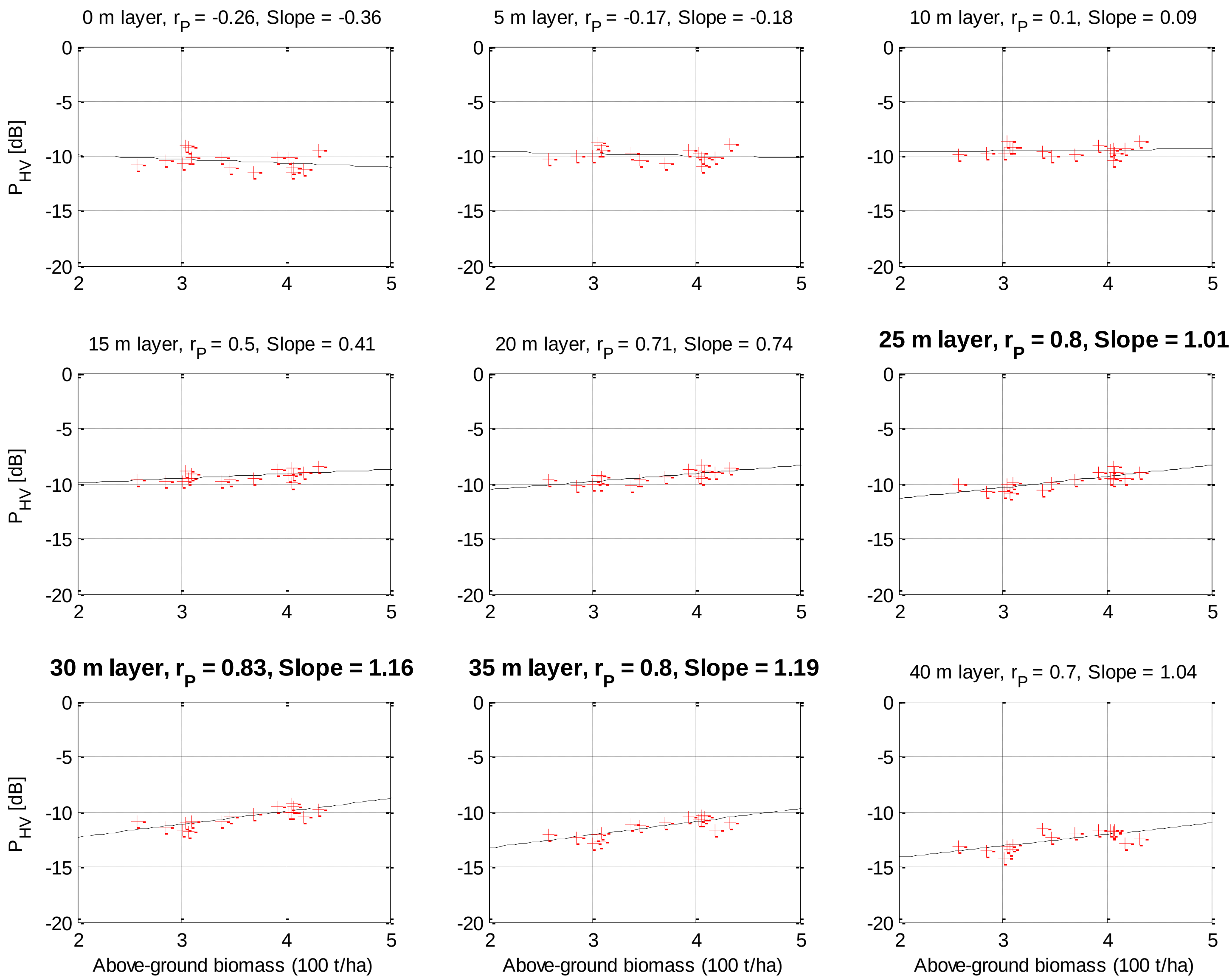
The contributions from the canopy is important



Relation to forest biomass

Airborne geometry

The backscattered power associated with the volume layer (about 30 m above the ground) is observed to exhibit the highest sensitivity to forest biomass, even for high biomass values (250-450 t/ha).



Relation to forest biomass

Spaceborne geometry

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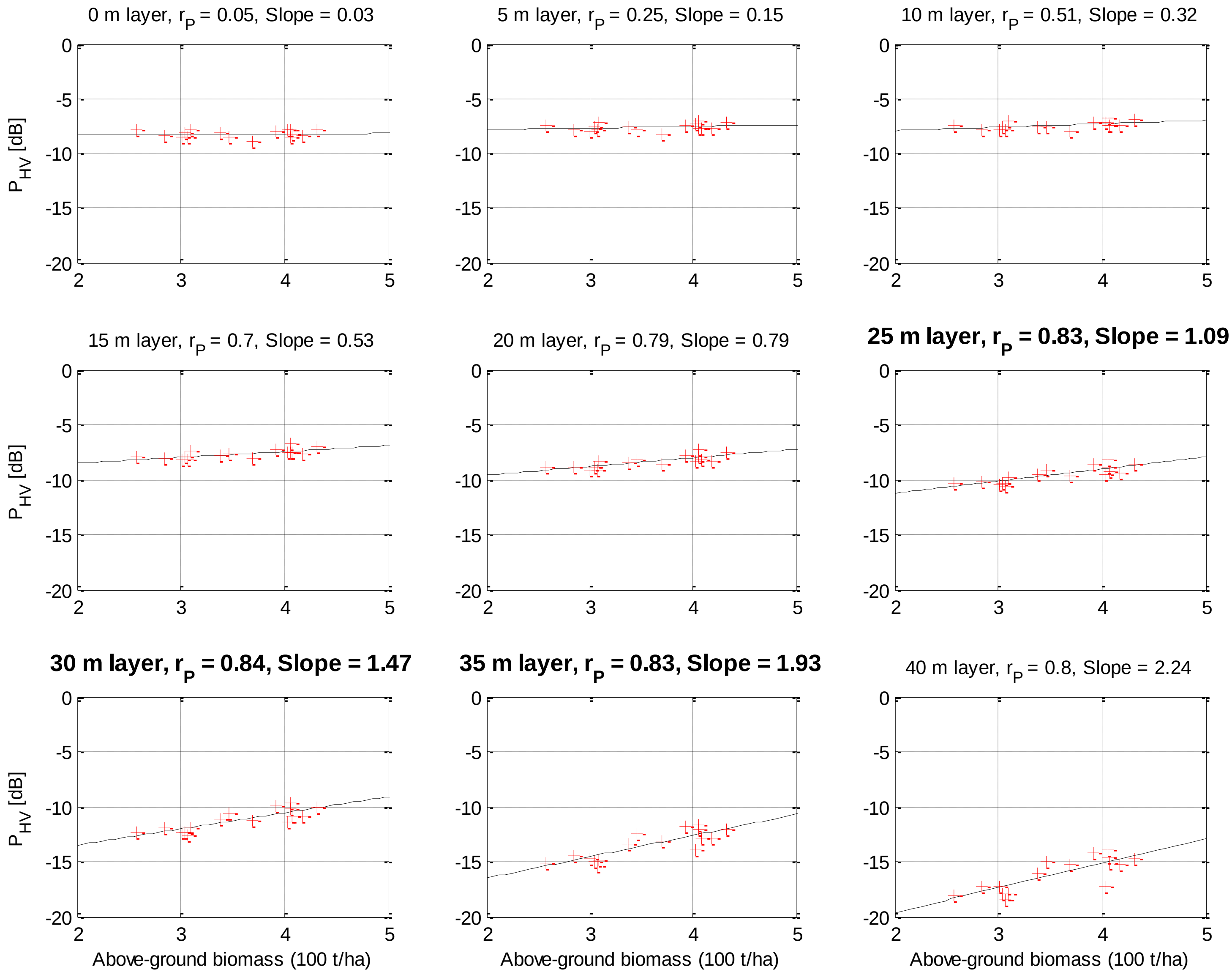


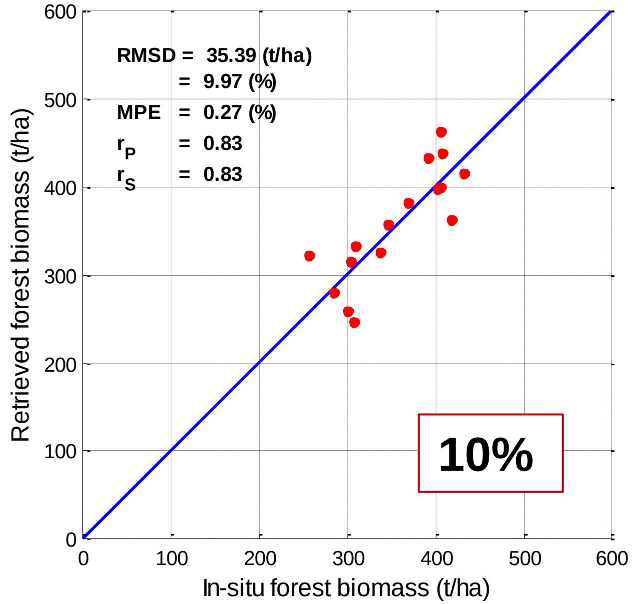
Tomography biomass inversion

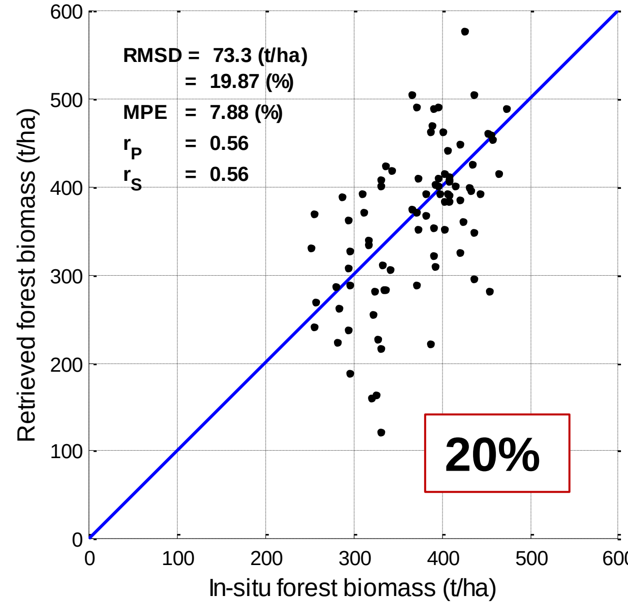
HV 30 m layer

6 ha : 250m x 250m

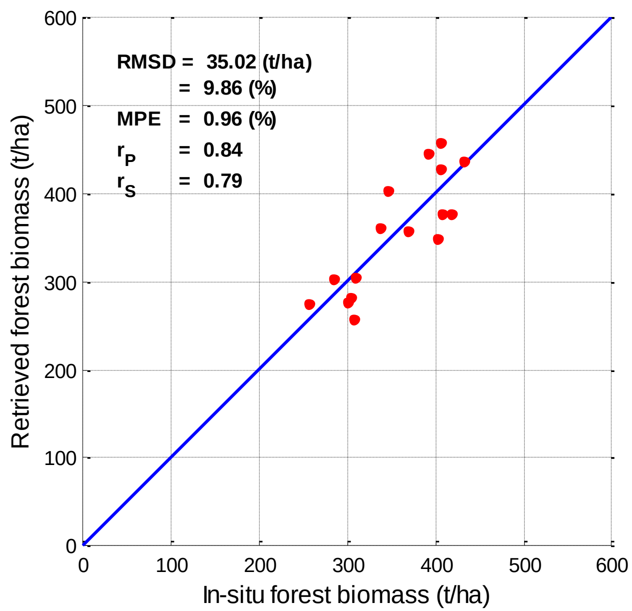
1.5ha : 125m x 125m

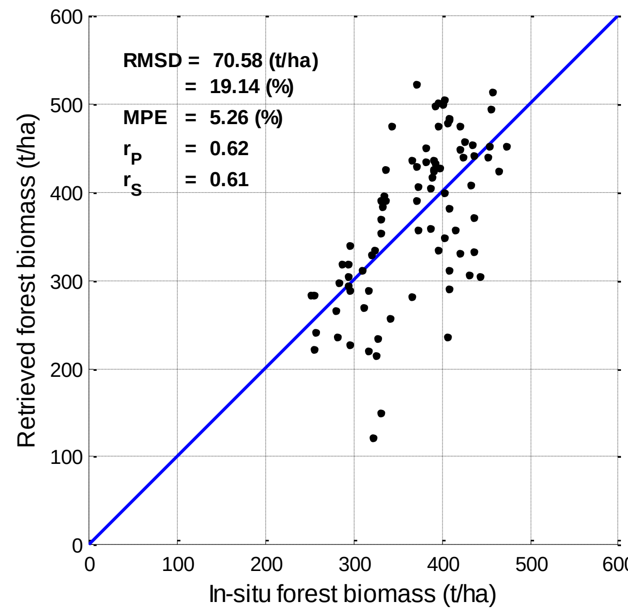
Airborne geometry





Spaceborne geometry





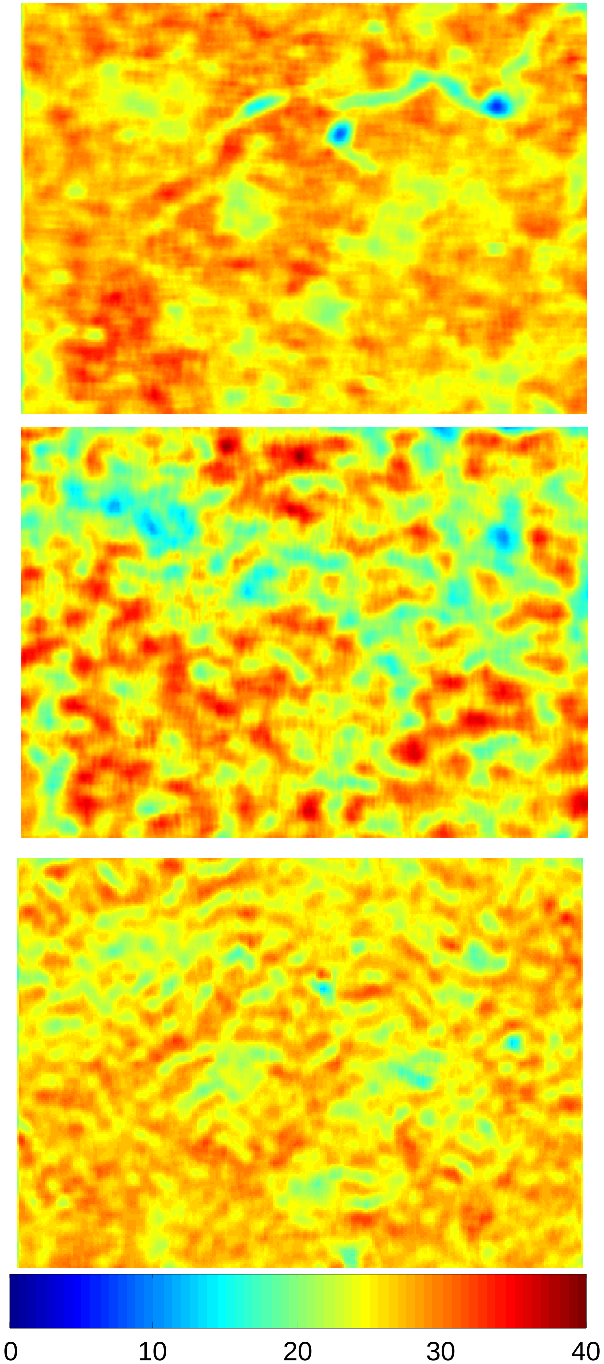
Forest height

Algorithm : slc verical focusing

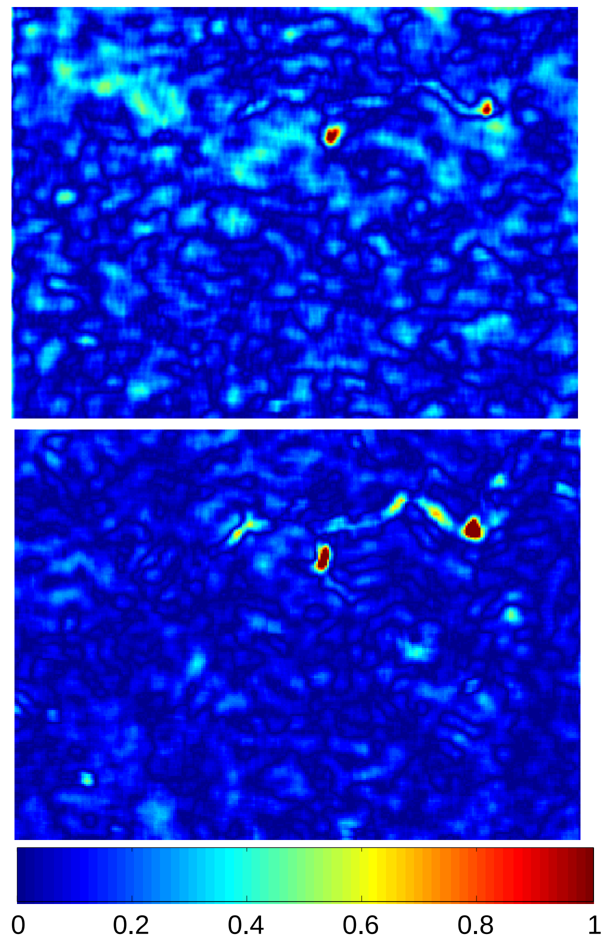
LiDAR

Tomography **airborne**

Tomography **spaceborne**



Relative error
$|H_{tomogaphy} - H_{LiDAR}|/H_{LiDAR}$



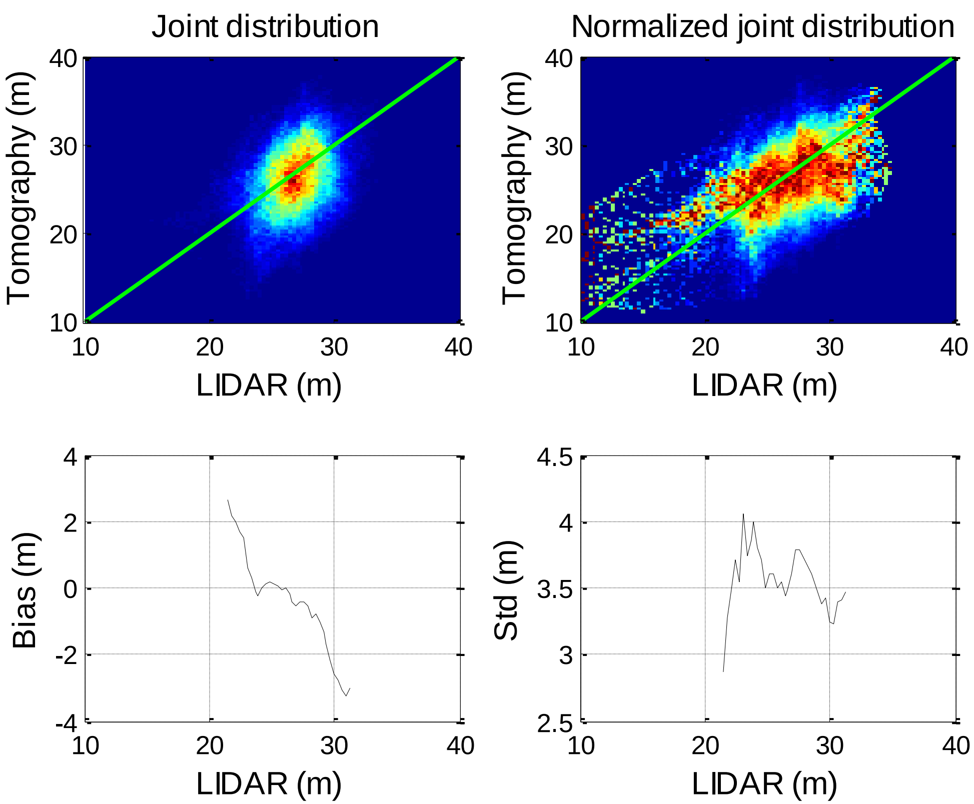
The average value is 0.13 (13%)

The average value is 0.10 (10%)

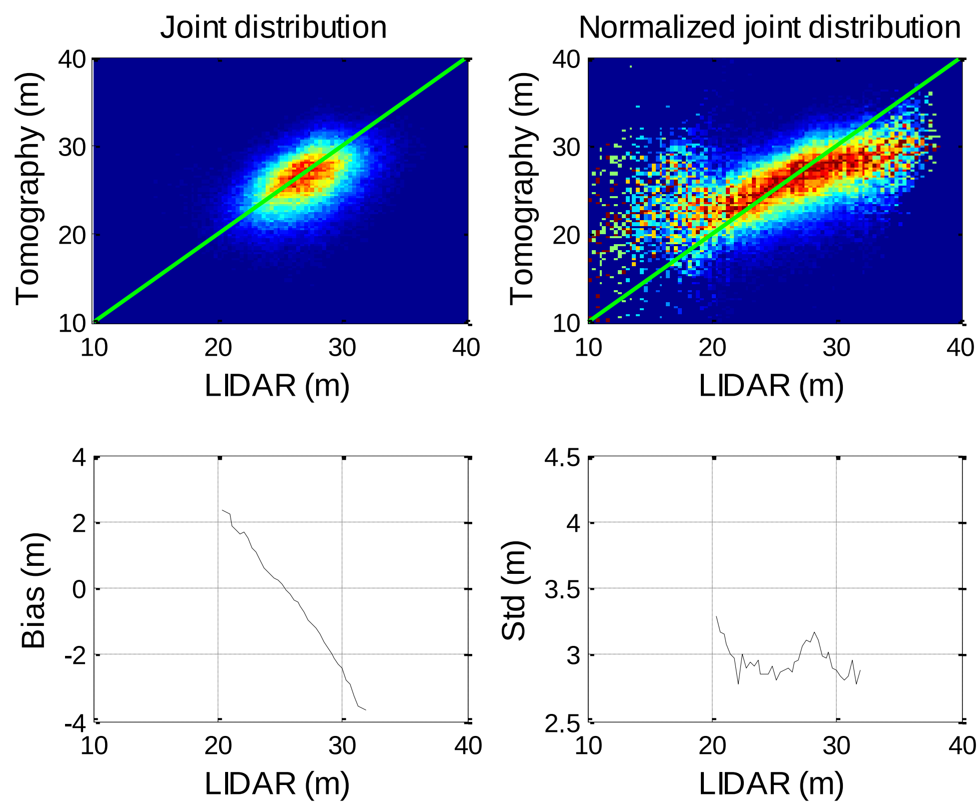
Forest height

Algorithm : Fourier Transform

Airborne geometry



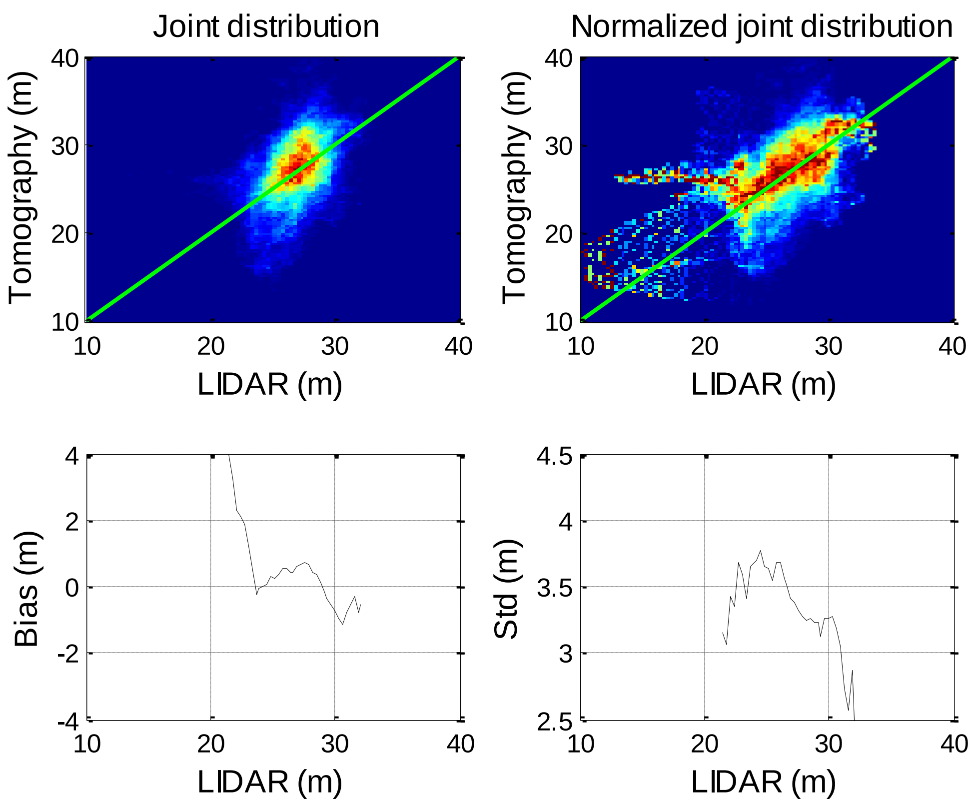
Spaceborne geometry



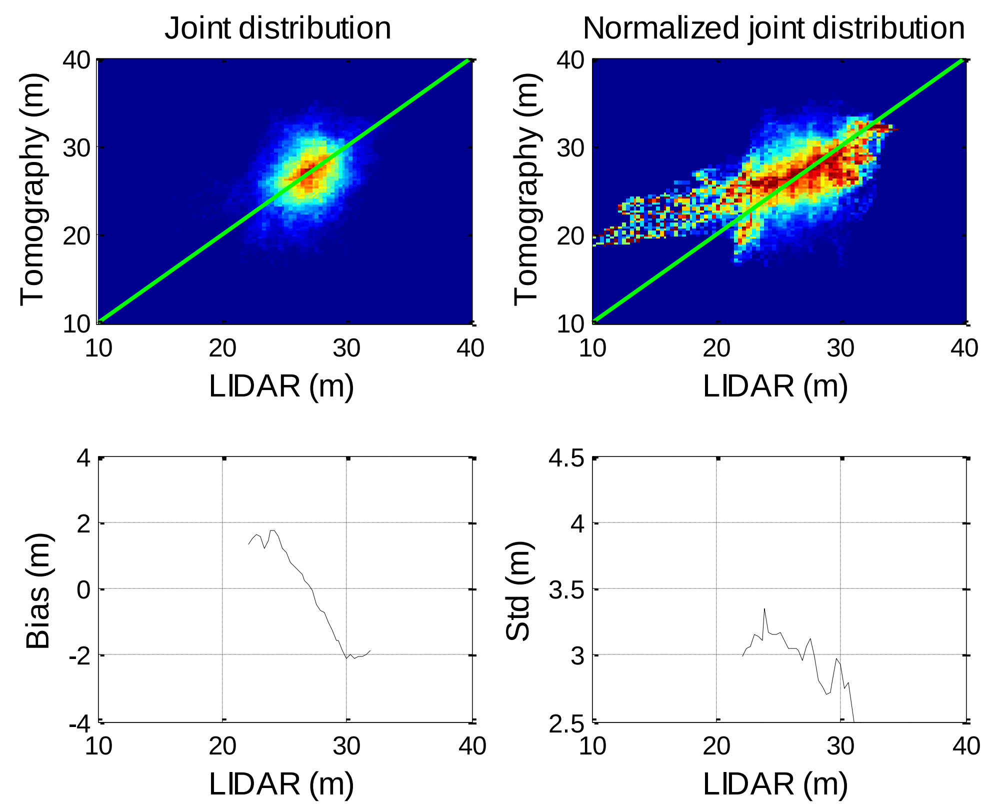
Forest height

Algorithm : Capon spectrum

Airborne geometry



Spaceborne geometry



Conclusions

1. Two approaches are presented for reducing 6 MHz bandwidth data-set. The backprojection SAR data on *spaceborne geometry* approach is so far *the most faithful simulation* for BIOMASS system in a tropical forest, at least to our knowledge.

2. The loss of vertical resolution from both approaches due to reducing bandwidth is evident but it is not critical.

    - Resolution is still significantly lower than forest height in tropical forests

3. Tomography-biomass relation: SAR Tomography was used to derive a 3D reconstruction of the Paracou forest site at 6 MHz. The 30 m layer was found to exhibit a correlation value with respect to ABG higher than 0.8 at 6 ha resolution for AGB values ranging from 250 t/ha to 450 t/ha.

4. The forest height estimation appears to be reliable for vegetation layers ranging from 20 m to 30-35 m. Standard deviation has been assessed in less than 4 m based on a pixel-to pixel comparison at 1 ha resolution.

Particular acknowledgement goes to Dr. Pascale Dubois-Fernandez, for the radar data-sets; and to Dr. Lilian Blanc for providing in-situ data.

Thanks for your attention!