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TAKING THE PULSE
OF OUR PLANET FROM SPACE

Biomass Level-2 Products: Methods, Processing Schemes And Results From Campaign Data

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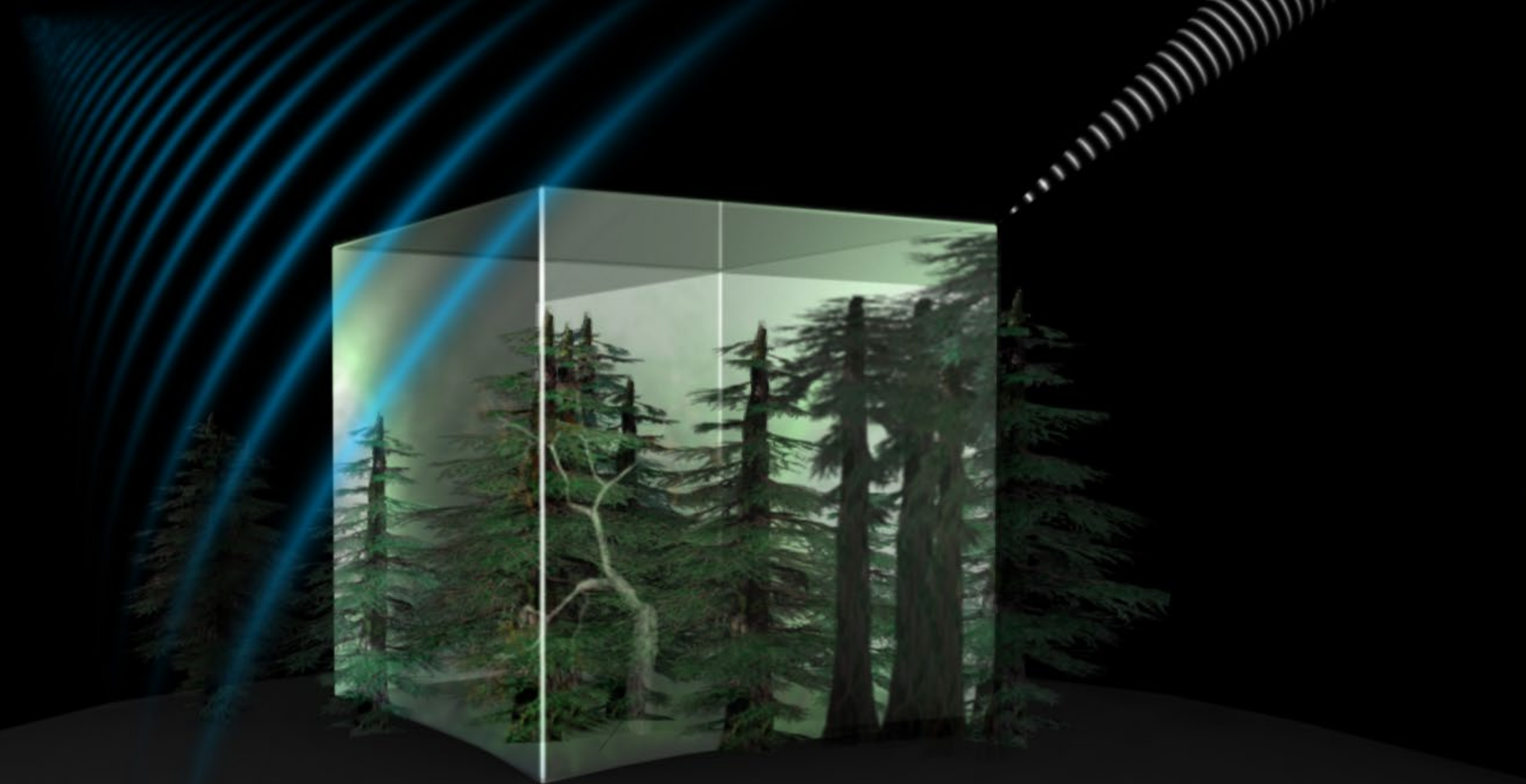
BIOMASS

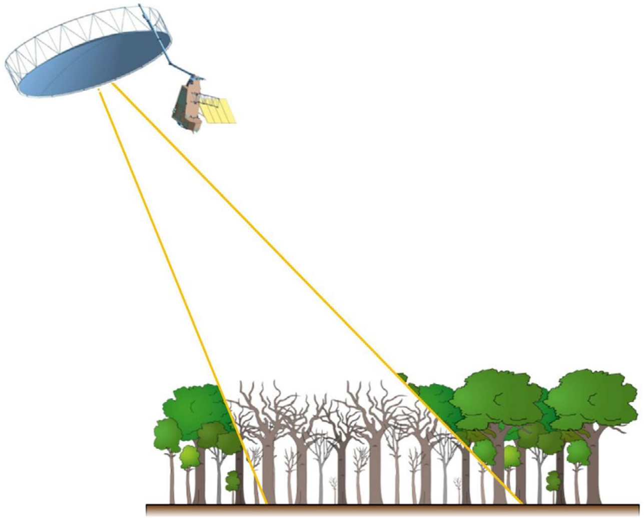
Scheduled for launch in 2023, ESA's seventh Earth Explorer Mission, ***BIOMASS***, will carry the first P-band SAR to be flown in space, to gather fully polarimetric acquisitions over forested areas worldwide in interferometric and tomographic modes



Mission Objectives

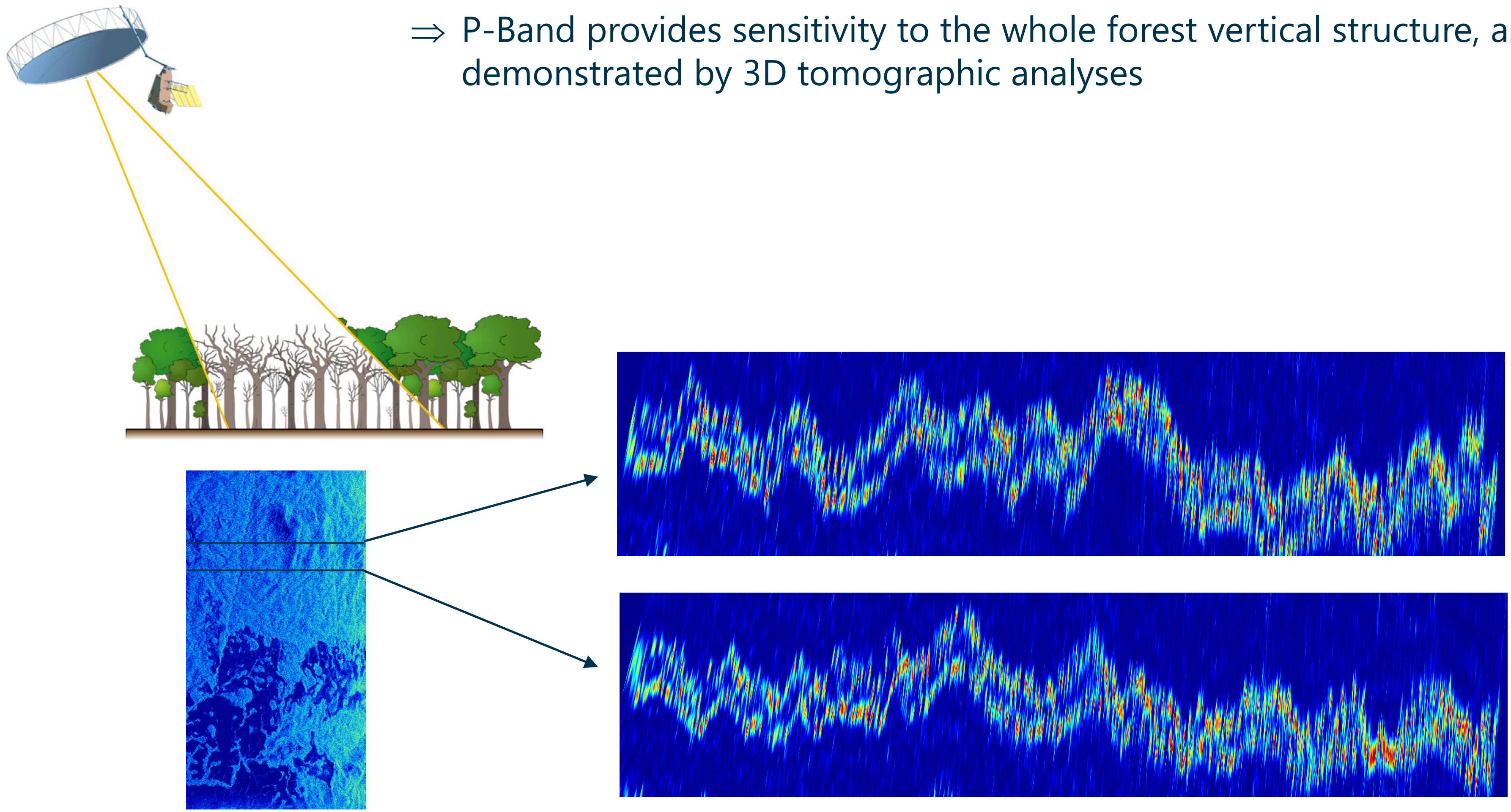
- to determine the distribution of aboveground biomass in the world's forests
- to measure annual changes in this stock over the period of the mission.

P-Band waves ($\lambda = 70\ cm$) penetrate the vegetation layer down to the underlying terrain, while giving rise to backscattering from trunks and branches



P-Band waves ($\lambda = 70\ cm$) penetrate the vegetation layer down to the underlying terrain, while giving rise to backscattering from trunks and branches

$\Rightarrow$ P-Band provides sensitivity to the whole forest vertical structure, as demonstrated by 3D tomographic analyses



Vertical sections from AfriSAR (Gabon)

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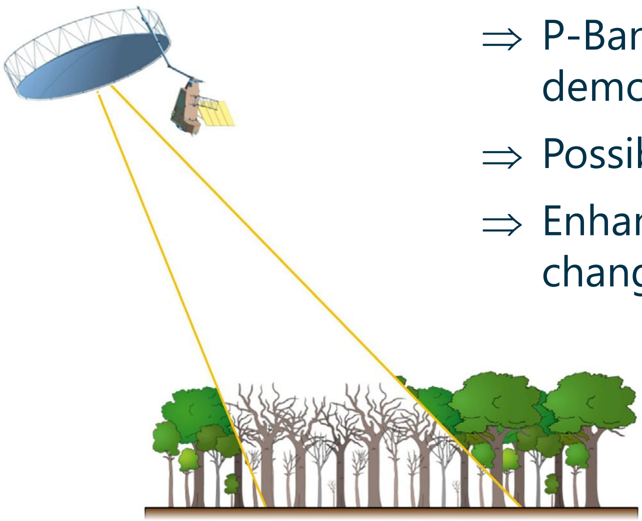
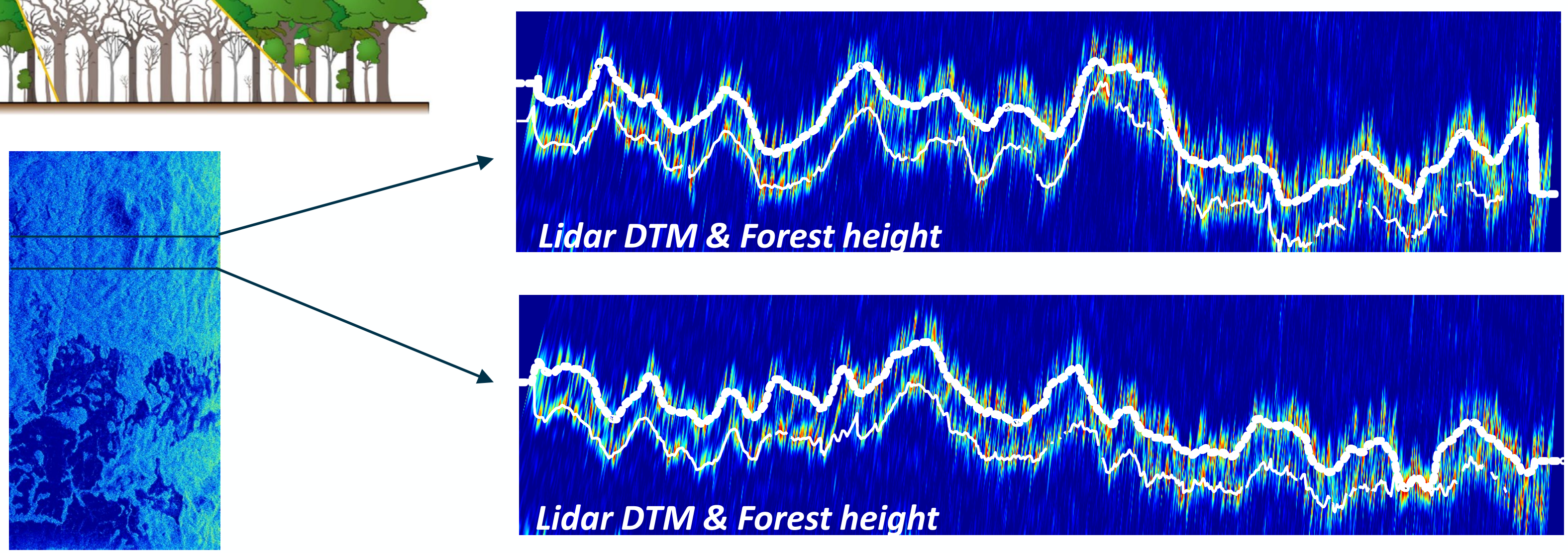


$\Rightarrow$ P-Band provides sensitivity to the whole forest vertical structure, as demonstrated by 3D tomographic analyses

$\Rightarrow$ Possibility for retrieving forest height and terrain topography

$\Rightarrow$ Enhanced sensitivity to forest Above Ground Biomass (AGB) and changes over time

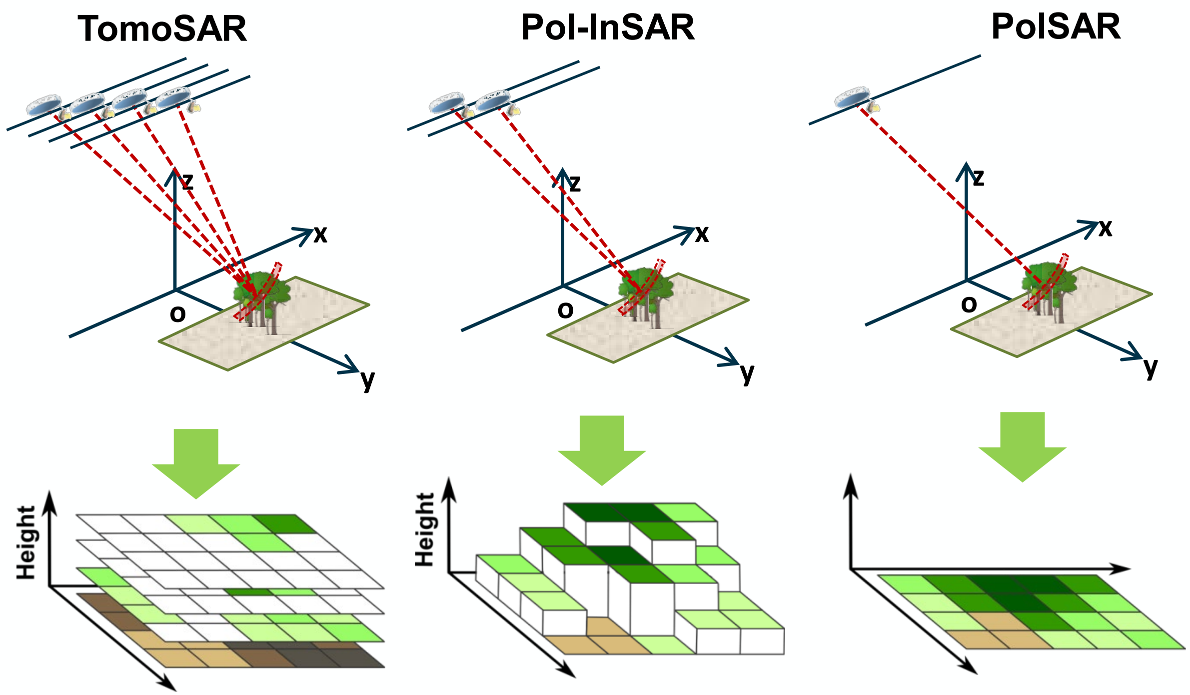


Vertical sections from AfriSAR (Gabon)

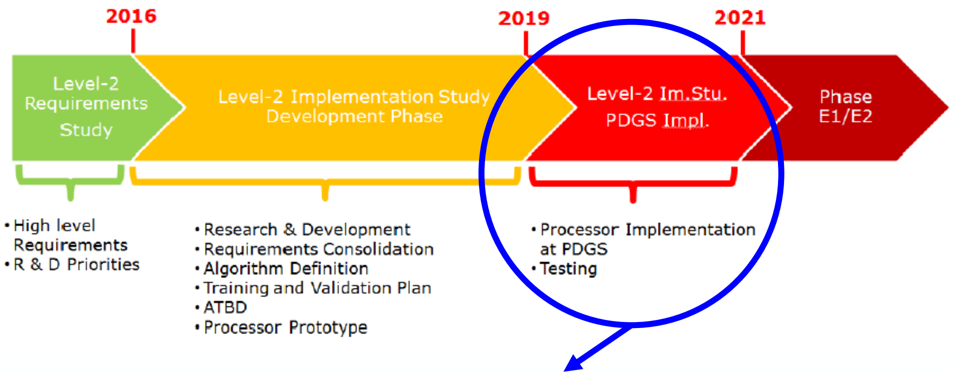
BIOMASS will implement two acquisition phases:

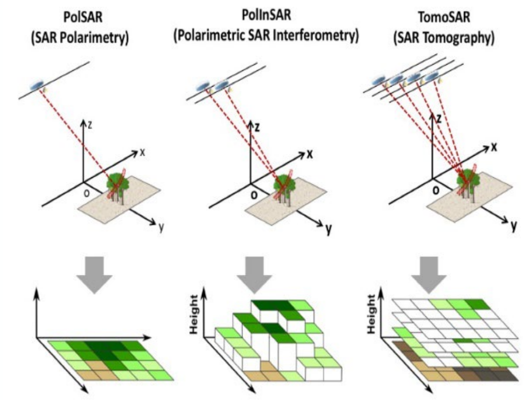
- *Tomographic phase (first 14 – 16 months):* stacks of seven consecutive passes with a revisit time of 3 days, to provide 3D imaging capabilities with a vertical resolution of about 23 m at the equator
- *Interferometric phase* (rest of mission lifetime): stacks of three consecutive acquisitions (or triplets) with a revisit time of 3 days, ensuring interferometric global coverage every seven to nine months

all acquisitions are full-pol 😎



BIOMASS LEVEL-2 PRODUCTS





- **BIOMASS L2 Implementation Study**: Currently extended to 2023 to refine algorithms for forest disturbance, height, biomass retrieval.

- **BIOMASS Processing Suite**: Recently started, in synergy with Implementation Study, to develop the Operational Processor for the Mission until the launch in 2023.

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Three primary biophysical products:

- ***Above Ground Biomass (AGB) :*** dry weight of woody matter per unit area above the soil including stem, stump, branches, bark, seeds and foliage; it does not include dead mass, litter and below-ground biomass
- ***Forest Height (FH)*** : defined as upper canopy height according to the H100 standard.
- ***Forest Disturbance (FD)*** : defined as an area where an intact patch of forest has been cleared, expressed as a binary classification.

Frequency and coverage:

- 1 near-global map of biomass and height from tomography in first 14 months
- Updated biomass and height maps from polarimetry and interferometry every 7 months for rest of 5-year mission
- Annual maps of deforestation

Product	Resolution	Accuracy
AGB	200 m	< 20% (or < 10 t/ha for AGB < 50 t/ha)
FH	200 m	Biome-dependent, < 30% for trees higher than 10 m
FD	50 m	Detection at a specified level of significance

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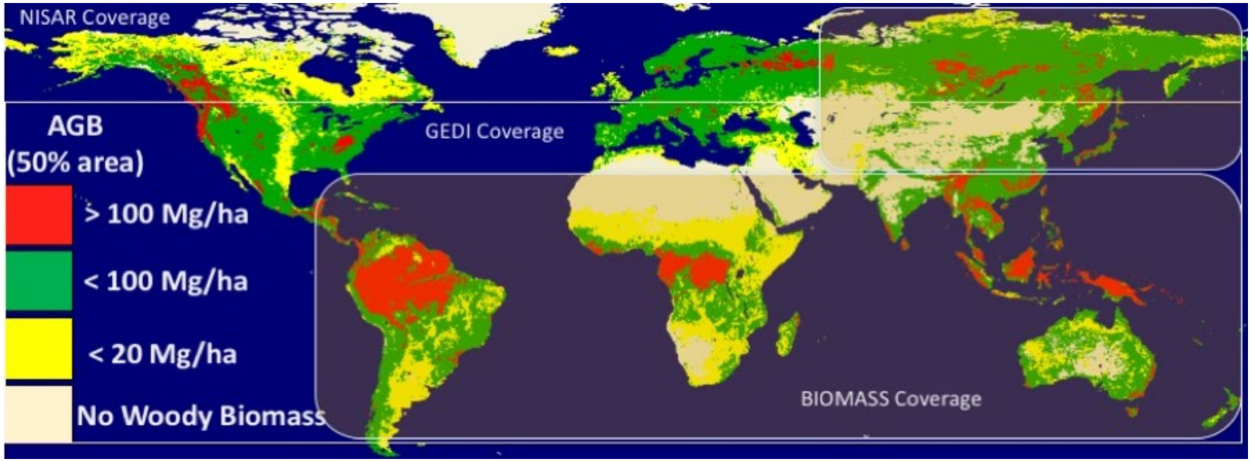

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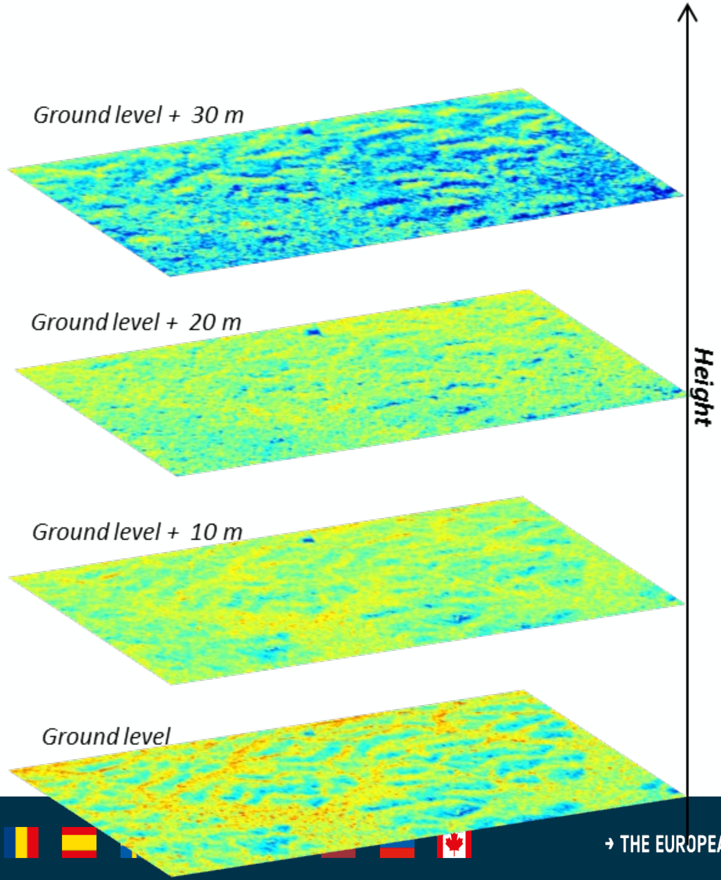
In addition:

- *Tomographic voxels :* a processing module is also devised for the generation of tomographic voxels from the tomographic phase
- *Sub-canopy DTM :* the L2 processor will be inter-linked with the **BIOMASS interferometric processor** to produce the first spaceborne digital terrain model (DTM) of ground topography below dense vegetation.



The initial phase of the L2 study was dedicated to deepening our understanding of how AGB can be best retrieved from P-Band data

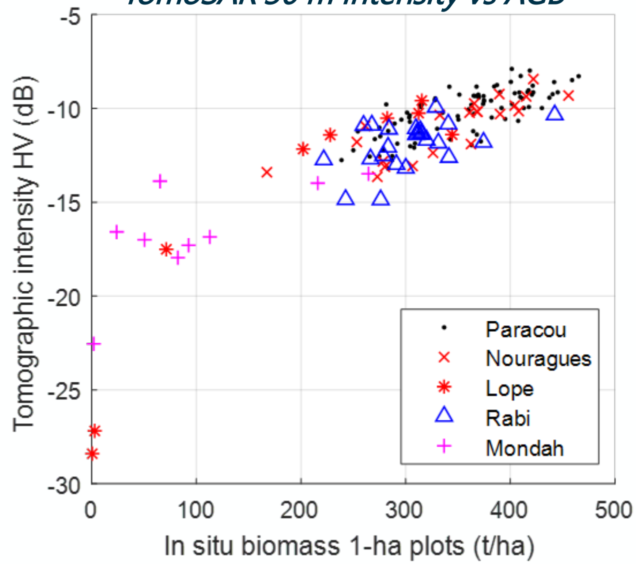
- Critical analysis of findings from Tomography and Ground/Volume decomposition.
- Development of an optimisation approach to solve for AGB based on a physical model while minimizing the need for reference data.

esa

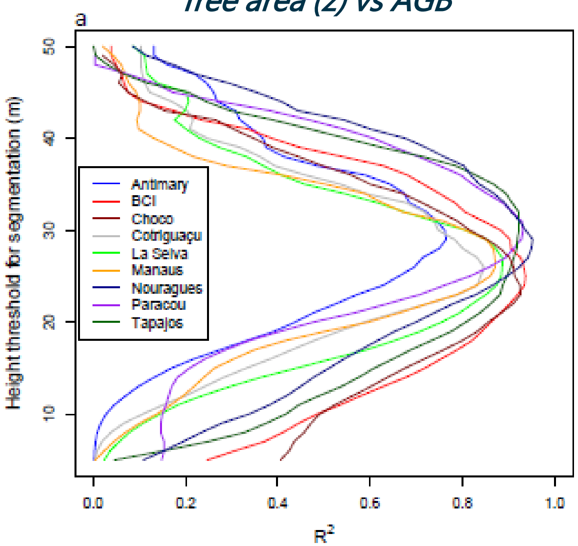
Observations

- Correlation of Radar intensity to AGB in tropical forest improves dramatically by using Tomographic intensity at 30 m
- Observed in South American and African sites (Paracou, Nourages, Lope, Rabi, Mondah)
- Relation between AGB and TomoSAR intensity is consistent across all sites

TomoSAR 30 m intensity vs AGB



Tree area (z) vs AGB



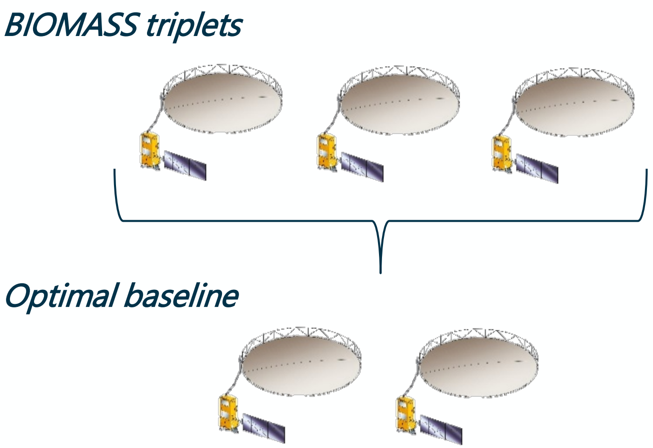
Our conclusions

- Scattering from the ground layer acts as a disturbance factor, as it is strongly determined by multiple reflections, hence soil moisture, terrain slope, understory, …
- For mature tropical forests, the 20-40 m layer is a good proxy for AGB – Supported by ecological modelling and Lidar based analysis

Ground cancellation

Inspired by this new understanding, the ground cancellation technique was developed to preserve the advantages of SAR Tomography during Mission lifetime.

Conceptually implemented in two steps:



1. Use of BIOMASS triplets to synthesize a virtual InSAR pair with optimal baseline across the swath

➢ Robustness against spatial/temporal variation of the InSAR wavenumber k_z

AGB – GROUND CANCELLATION

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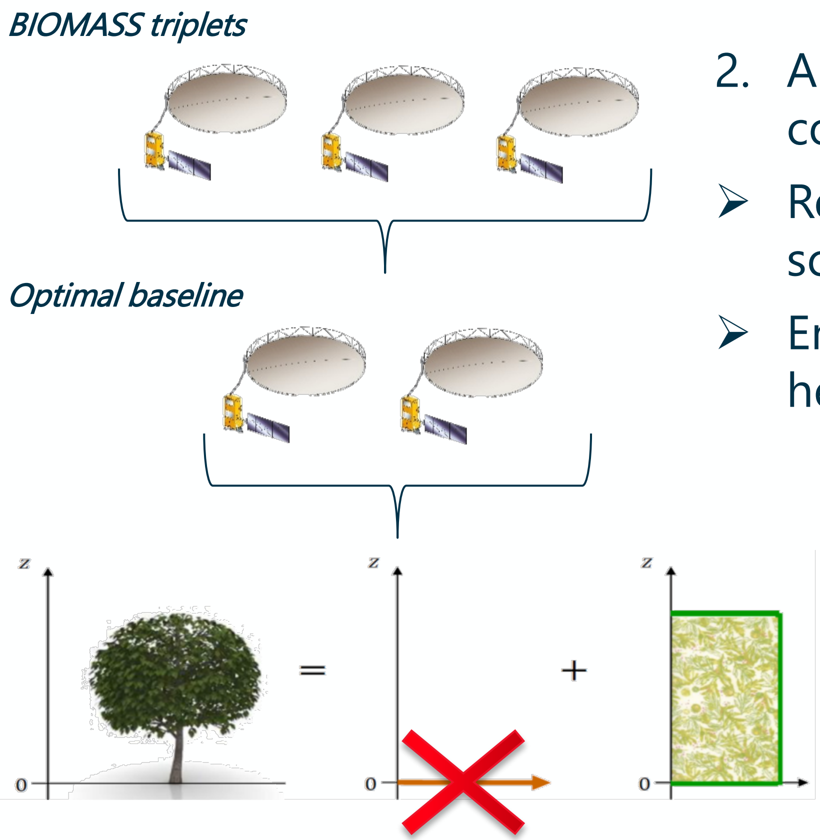

2. A ground-cancelled image is produced by coherent subtraction
   - ➢ Rejection of disturbing contributions from scattering from the ground layer
   - ➢ Emphasis of volume scattering from the desired height (according to the synthesized baseline)

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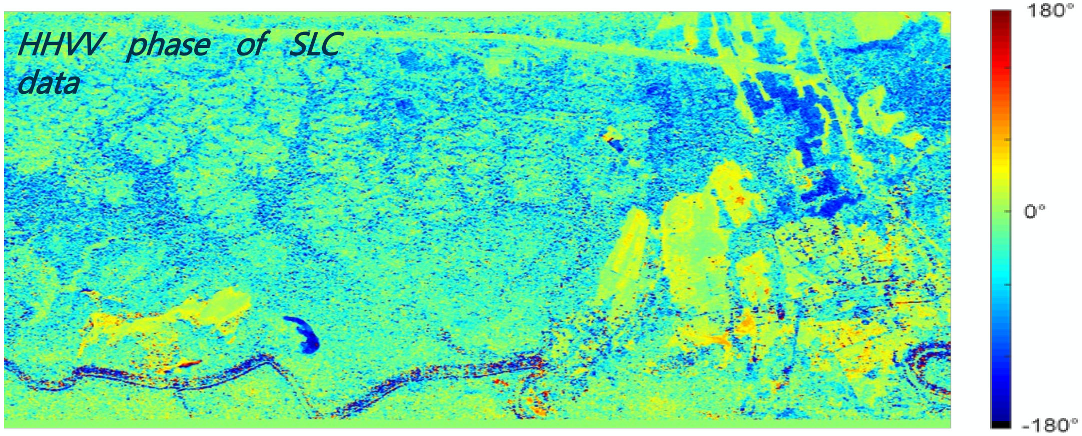
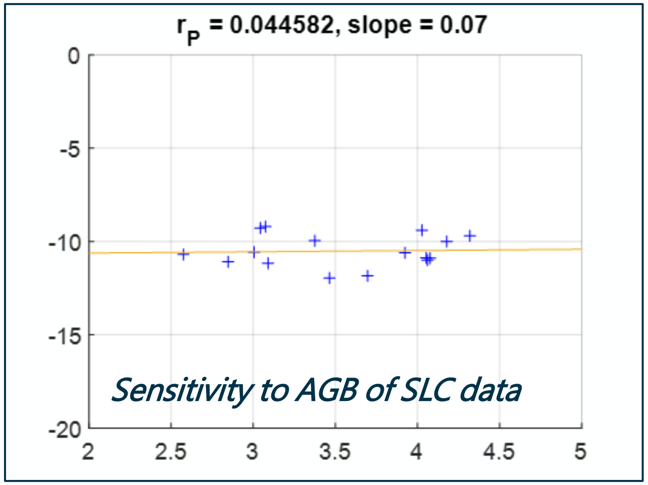
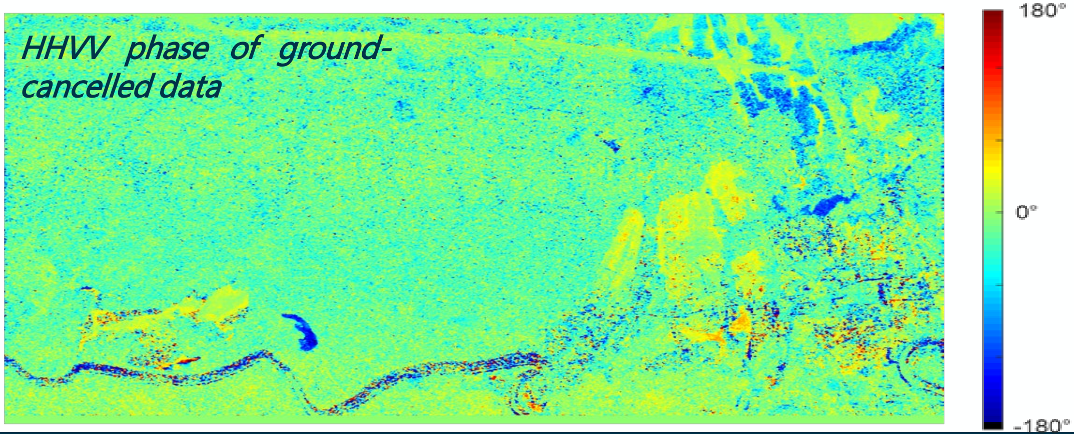
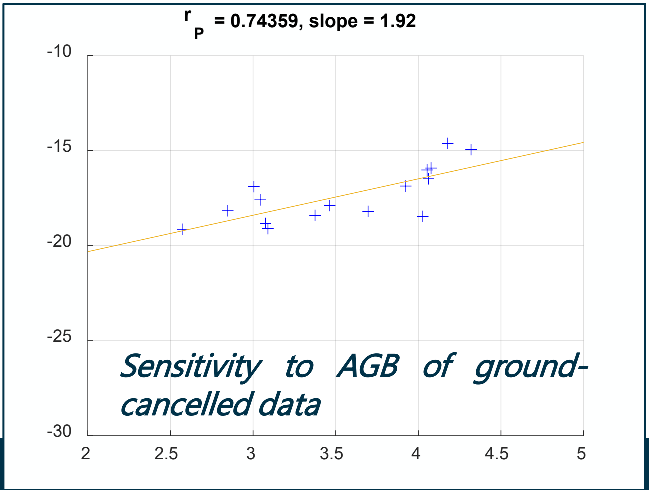








Retrieval algorithm

- The starting point of the inversion algorithm is the *volume+db+soil* formalized by the ***Truong-Loi model***

$$\sigma_{pq} = \text{volume} + \text{double} - \text{bounce} + \text{soil}$$

$$= A_{pq} W^{\alpha_{pq}} \cos\theta \left(1 - \exp\left(-\frac{B_{pq} W^{\beta_{pq}}}{\cos\theta}\right)\right) + C_{pq} \Gamma_{pq} W^{\delta_{pq}} \sin\theta \exp\left(-\frac{B_{pq} W^{\beta_{pq}}}{\cos\theta}\right)$$

$$+ S_{pq} \exp\left(-\frac{B_{pq} W^{\beta_{pq}}}{\cos\theta}\right)$$

W = AGB
θ = incidence angle
pq = polarization

AGB – RETRIEVAL ALGORITHM

Retrieval algorithm

- The starting point of the inversion algorithm is the *volume+db+soil* formalized by the *Truong-Loi model*

☺ This model is considerably simplified when applied to ground cancelled data

$$\sigma_{pq} = \text{volume} + \text{double-bounce} + \text{soil}$$

$$= A_{pq}W^{\alpha_{pq}}\cos\theta\left(1-\exp\left(-\frac{B_{pq}W^{\beta_{pq}}}{\cos\theta}\right)\right) + C_{pq}\Gamma_{pq}W^{\delta_{pq}}\sin\theta\exp\left(-\frac{B_{pq}W^{\beta_{pq}}}{\cos\theta}\right)$$

$$+ S_{pq}\exp\left(-\frac{B_{pq}W^{\beta_{pq}}}{\cos\theta}\right)$$

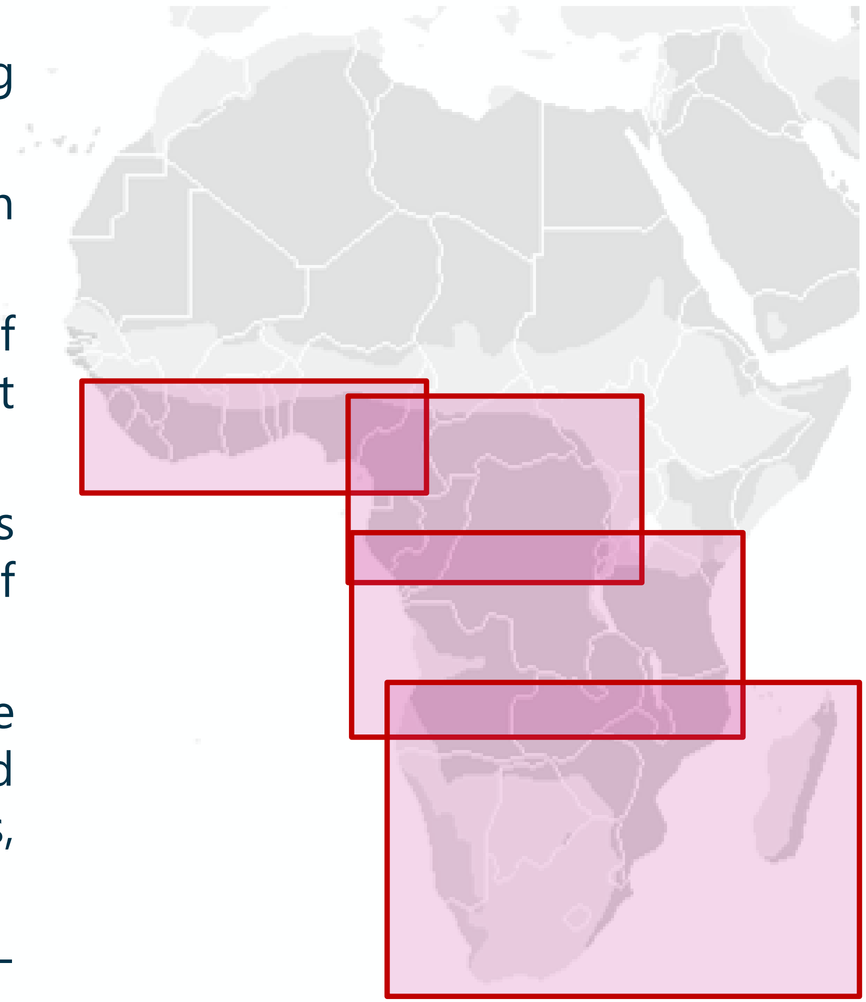
W = AGB
θ = incidence angle
pq = polarization

For both low and high attenuation this reduces to a power law whose parameters can be estimated from the data using limited ground data:

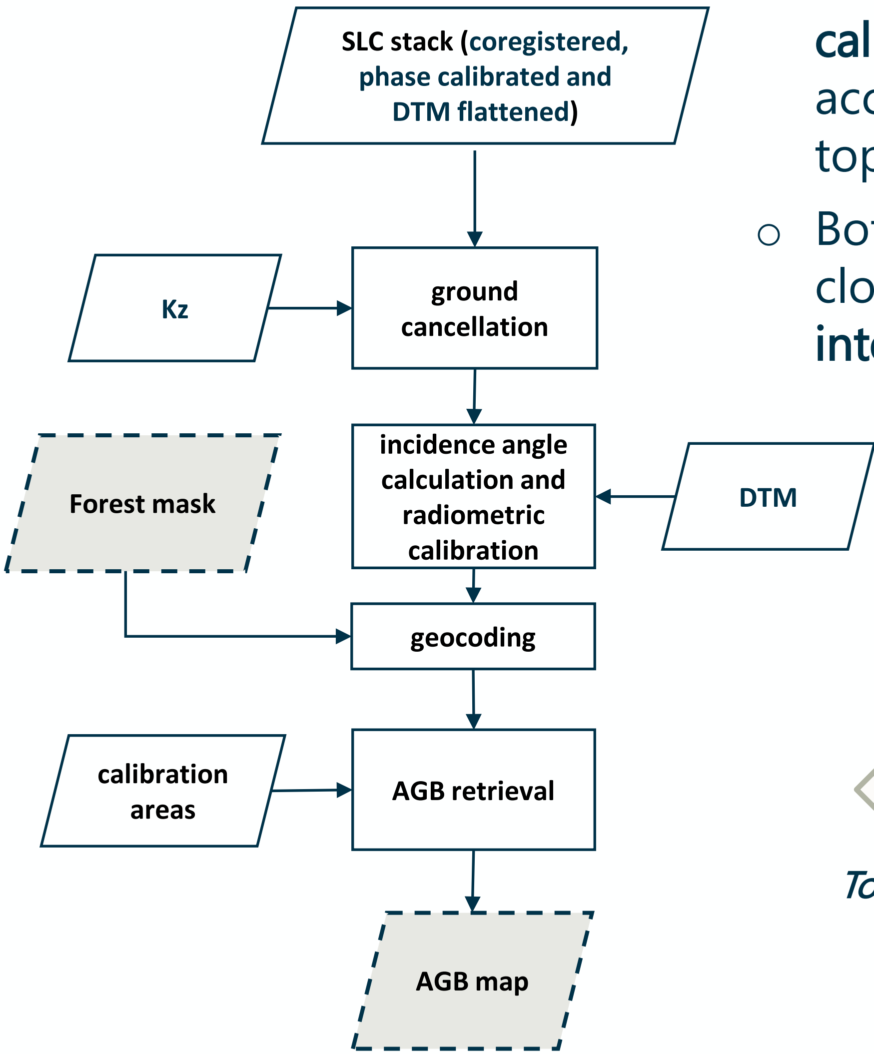
$$s_{PQi} = log(\sigma_{pq}^{v}) = l_{PQ} + \alpha_{PQ}w_i + n_{PQ}c_i$$

Global mapping approach

- AGB retrieval is intended to proceed using calibration data from GEDI
- The global forests are covered with overlapping blocks
  - Blocks allow large-scale variability of the (nominally) space-invariant parameters
  - Overlaps ascertain smooth transitions of AGB across blocks in case of missing/low quality calibration data
  - Block sizes chiefly determined by the forward model accuracy, the expected spatial variability of model parameters, and the available calibration data
- Alternative approach based on region-growing is currently under evaluation

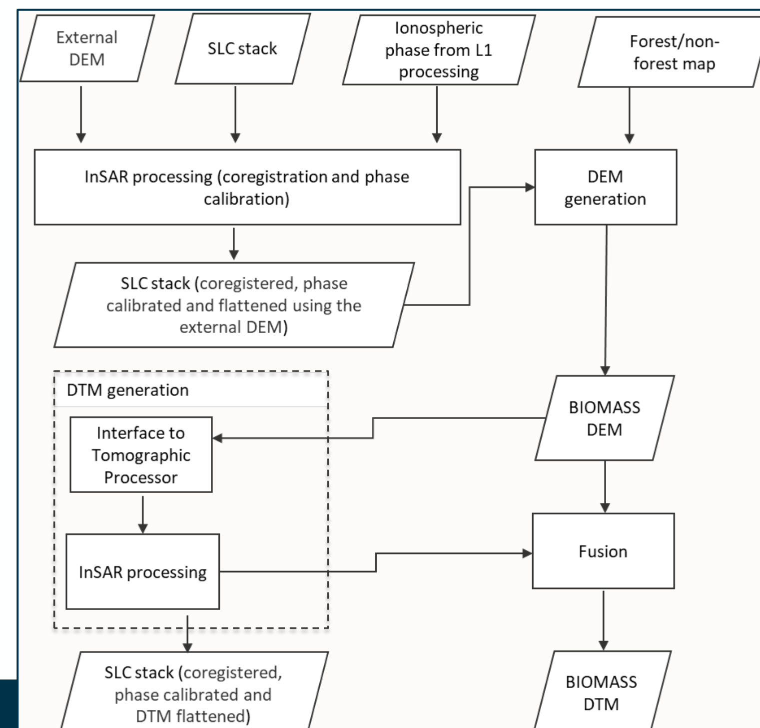


AGB – PROCESSING SCHEME



- The L2 processor is assumed to ingest **phase-calibrated** BIOMASS interferometric stacks and accurate information about sub-canopy terrain topography.
- Both these products will be derived through a close interconnection with the **BIOMASS interferometric processor**.

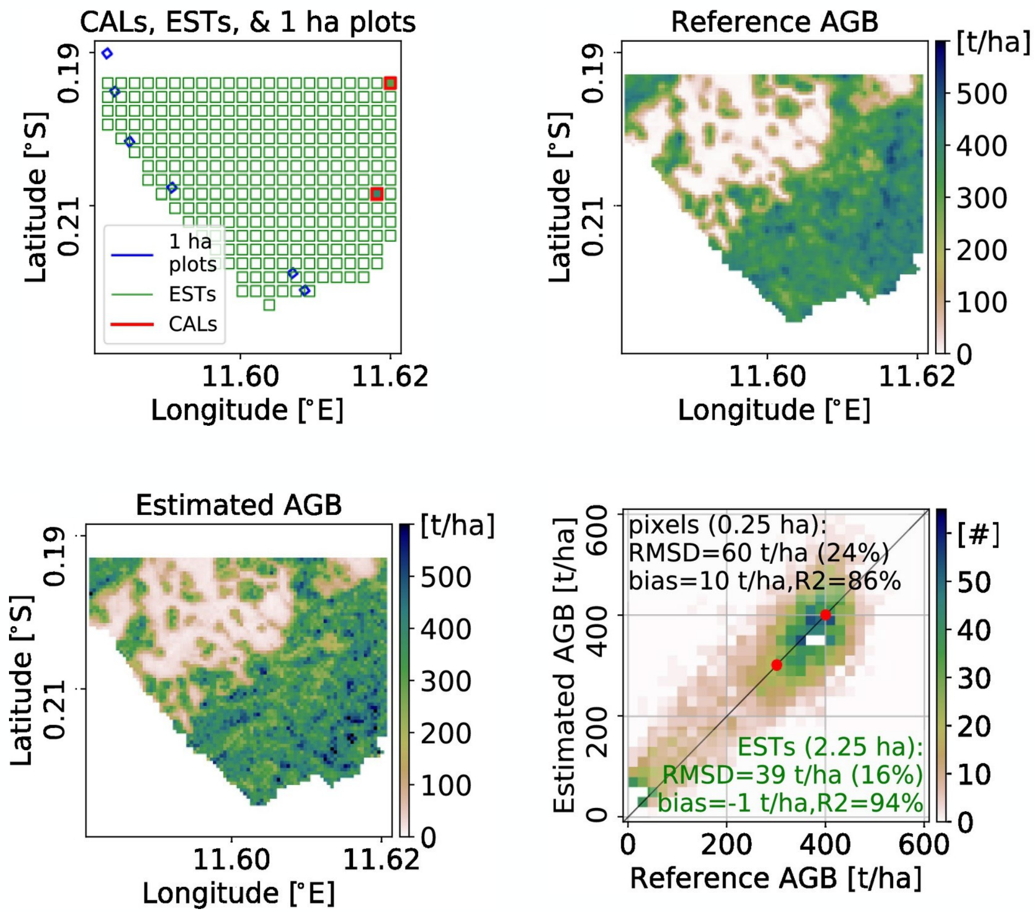
To L2 processor



AGB – RESULTS FROM CAMPAIGN DATA

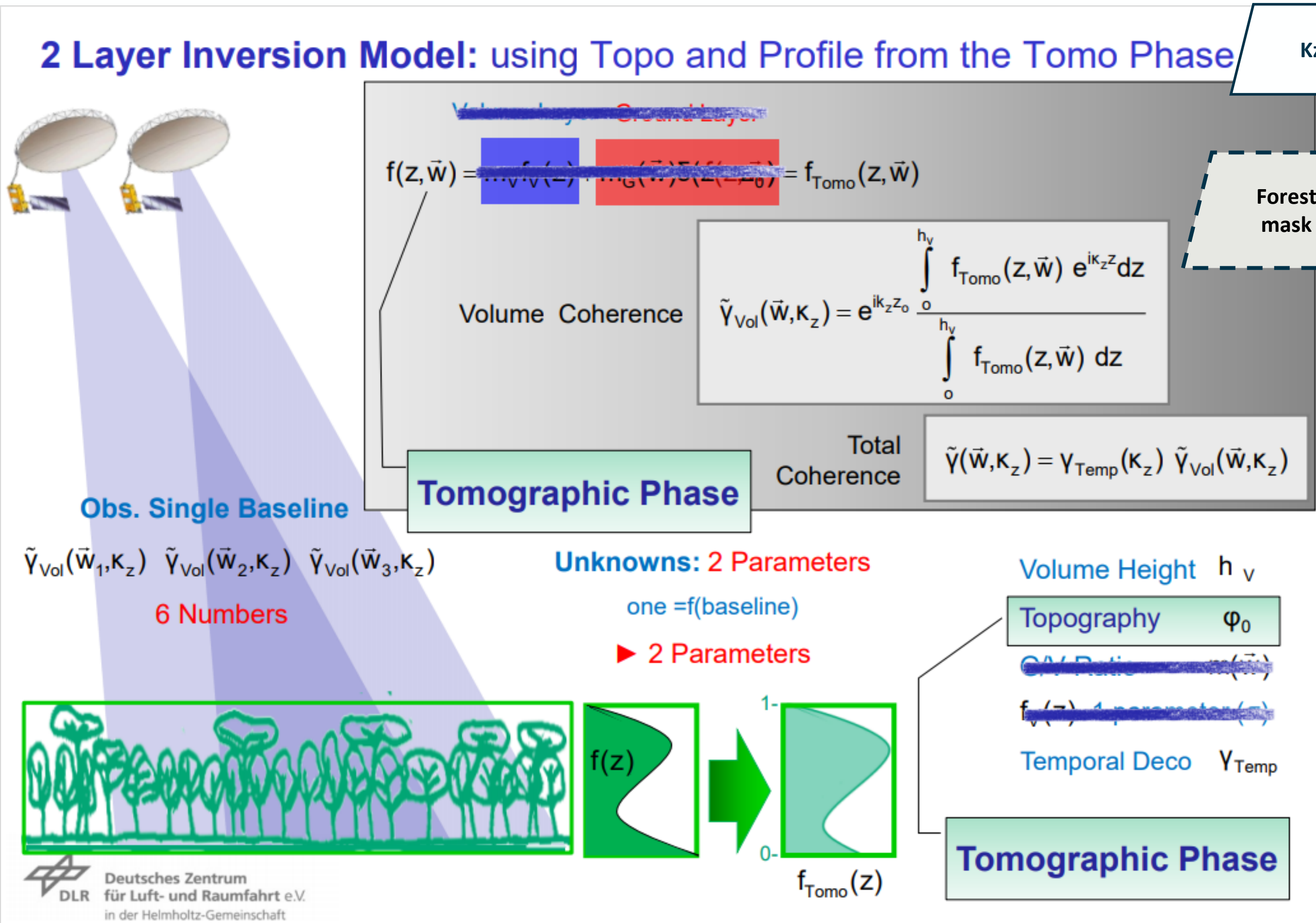
- To mimic BIOMASS spaceborne data, airborne SAR acquisitions from AfriSAR were filtered to 6 MHz and multi-looked to a resolution of 50 m in both ground range and azimuth directions
- Terrain topography was then estimated using tomographic processing, and the estimated DTM was used for the generation of ground-cancelled SAR images

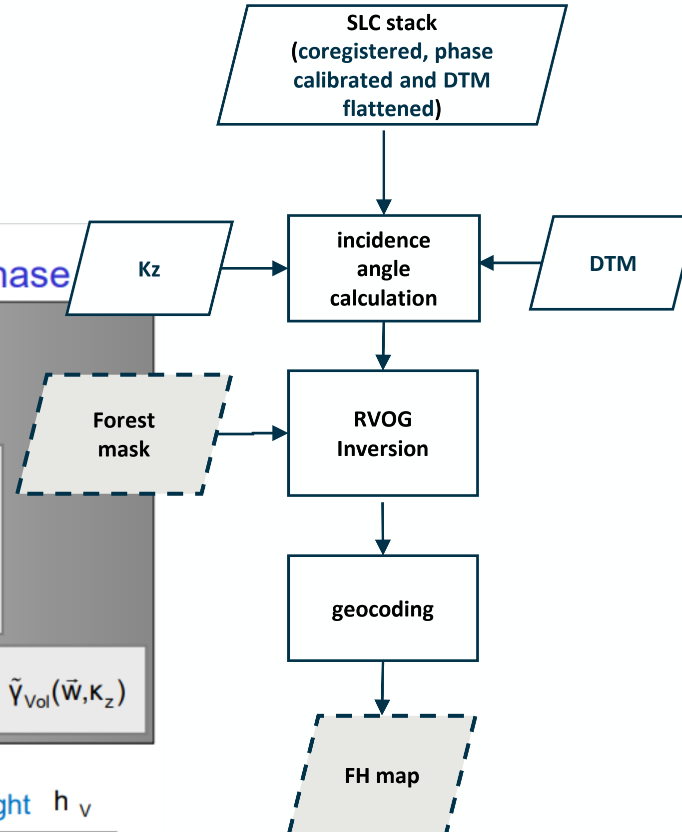
- > 500 independent tests carried out with different sets of calibration and estimation areas.
- In each test, **two** sampling areas (AGB > 100 t/ha) were chosen at random and treated as calibration areas
- The relative RMSD with respect to the reference ALS data turned out to be between 18% and 33% at 2.25 ha resolution for all six test sites for areas with AGB > 200 t/ha, with the best performance being achieved in the presence of large AGB variability and an average AGB around 200–250 t/ha.



Forest height retrieval leverages PolInSAR inversion

- Based on triplets to mitigate temporal decorrelation
- Exploits previous info from the Tomographic phase





WHERE WE ARE NOW

The BIOMASS level-2 processor implements state-of-the art SAR processing techniques that exploits polarimetric and baseline diversity

A prototype L2 processor has been completed but the algorithms are still under development.

A significant challenge is to develop and test algorithms with only a limited set of P-band SAR data with good *in situ* data available.

This means that only a small set of environmental conditions are represented. The algorithms therefore need to be developed with flexibility in mind, so they can be adjusted as BIOMASS data become available.

As of today, the AGB retrieval algorithm was demonstrated capable of a 20% accuracy with respect to in situ data using only two "good" calibration points, although retrieval accuracy was observed to depend significantly on the quality of the available calibration points