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TAKING THE PULSE OF OUR PLANET FROM SPACE

Biomass Level-2 Algorithms And Processing Implementation

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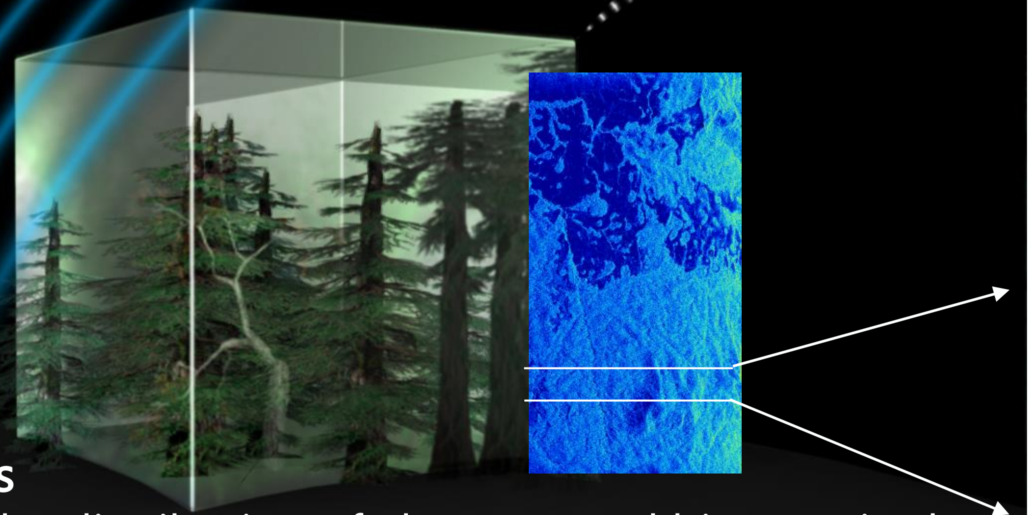
BIOMASS

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

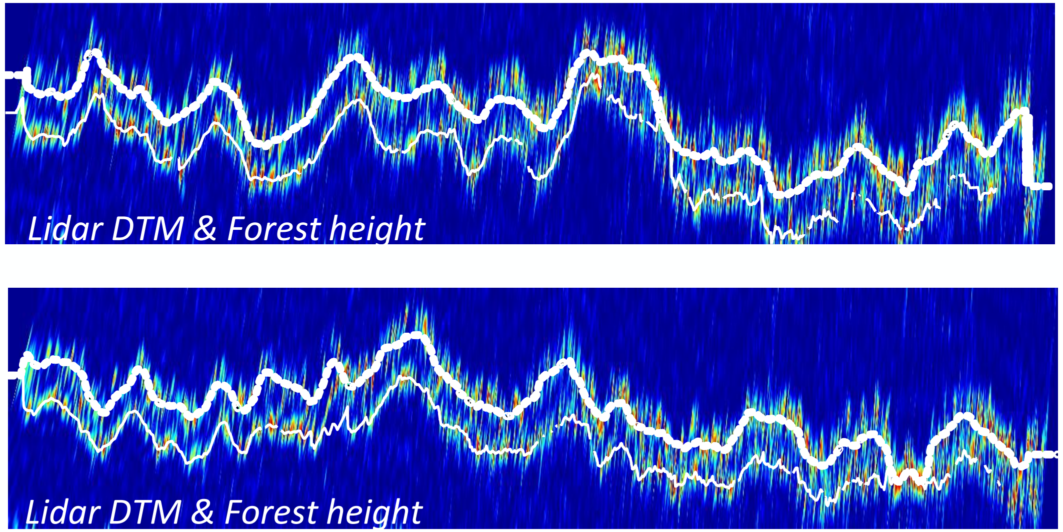


Mission Objectives

- 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

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

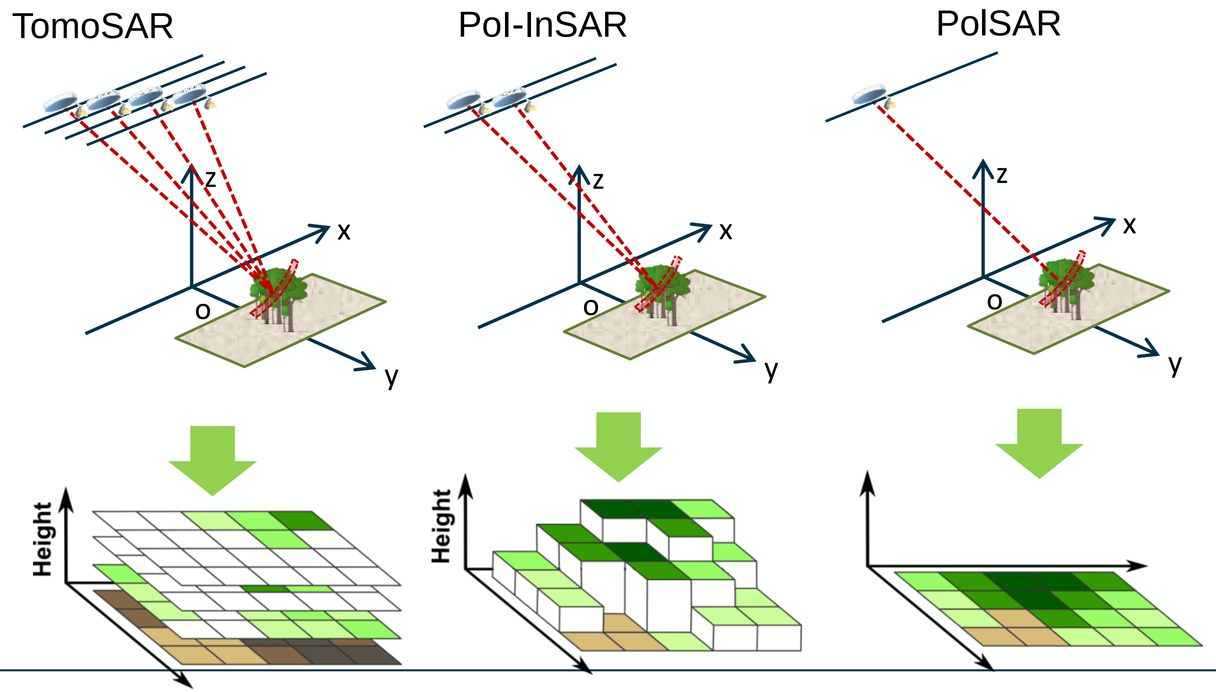


Vertical sections from AfriSAR (Gabon)

BIOMASS PHASES

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

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

Three primary biophysical products:

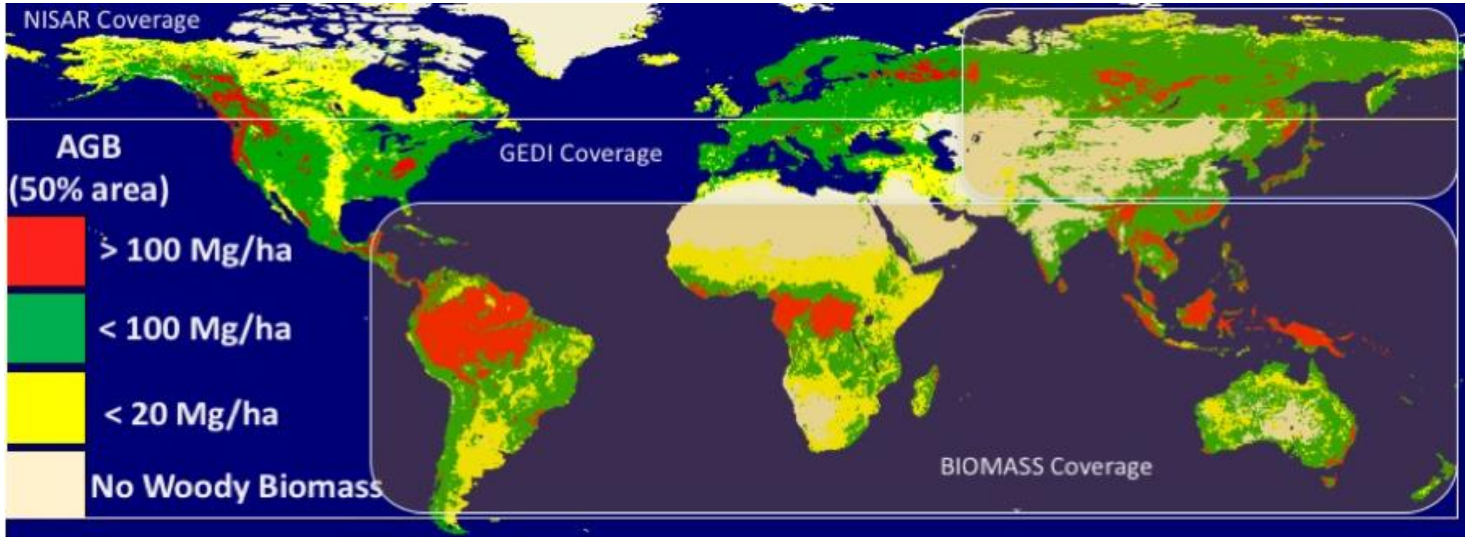
Above Ground Biomass (AGB) : dry weight of woody matter per unit area above the soil including stem, stump, branches, bark, seeds and foliage; it does not include dead mass, litter and below-ground biomass

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 and maps of deforestation from polarimetry and interferometry every 7 months for rest of 5-year mission

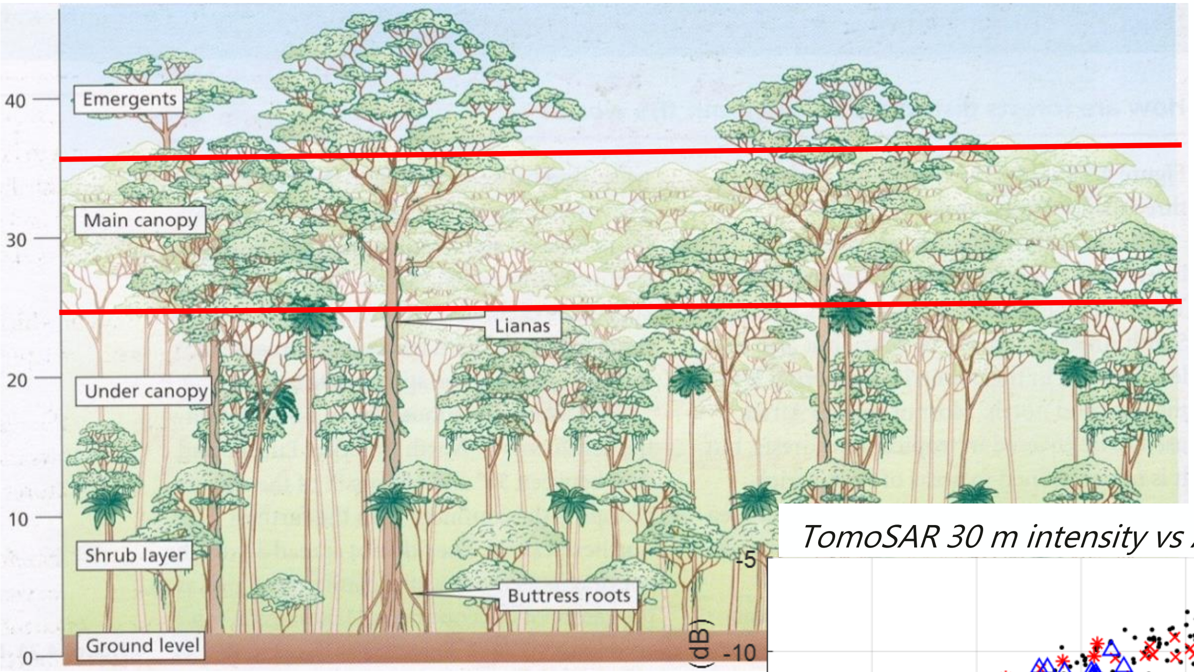


Correlation with AGB

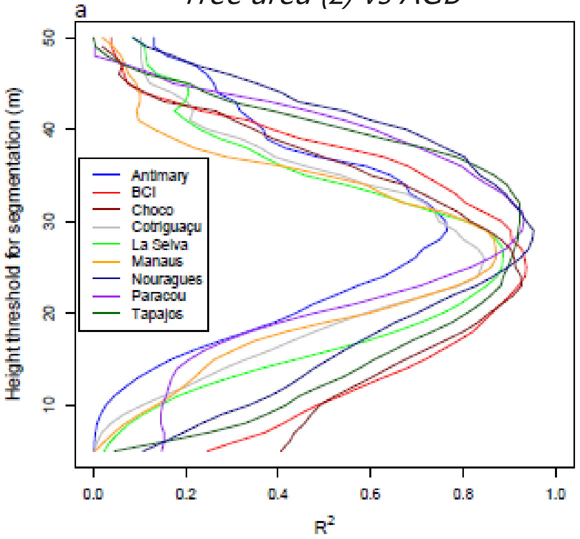
esa

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



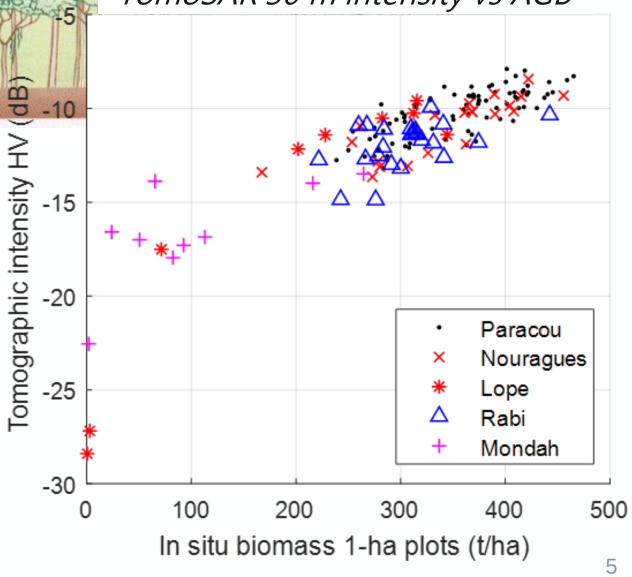
Tree area (z) vs AGB



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

TomoSAR 30 m intensity vs AGB



Tomography as a tool to remove ground echo

$$\sigma^0_{PQ} = A_{PQ} W^{\alpha_{PQ}} \cos\theta_i \left[1 - \exp\left(-\frac{B_{PQ} W^{\beta_{PQ}}}{\cos\theta_i}\right)\right] +$$

$$C_{PQ} W^{\delta_{PQ}} \Gamma_{PQ}(\theta_i, \varepsilon, k, s) \sin\theta_i \exp\left(-\frac{B_{PQ} W^{\beta_{PQ}}}{\cos\theta_i}\right) +$$

$$S_{PQ}(\theta_i, \varepsilon, k, s) \exp\left(-\frac{B_{PQ} W^{\beta_{PQ}}}{\cos\theta_i}\right)$$

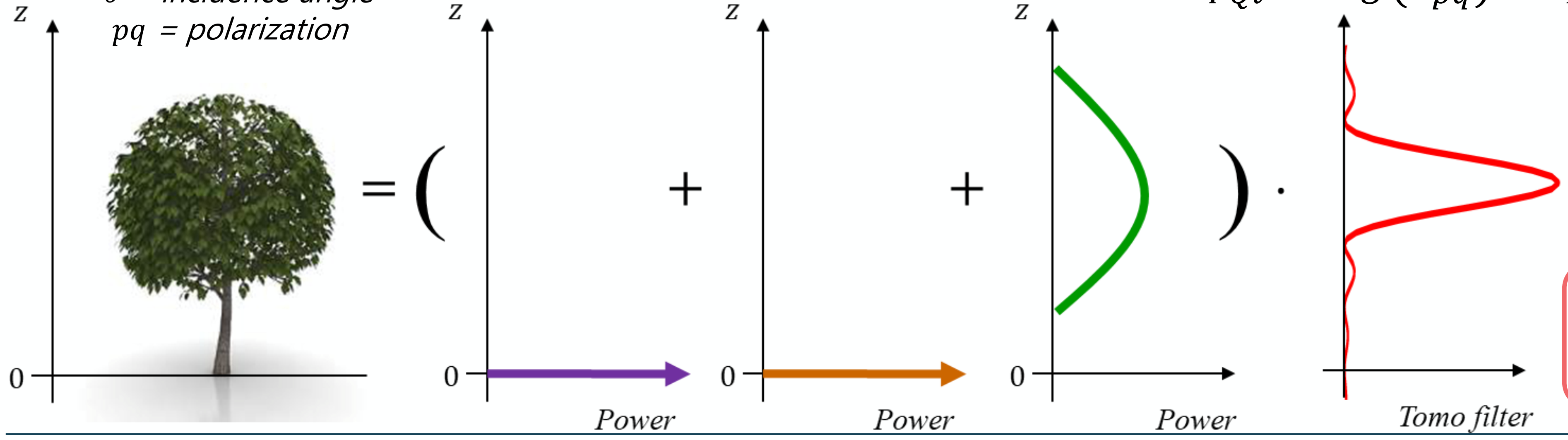
Retrieval algorithm

- 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 Tomography data

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

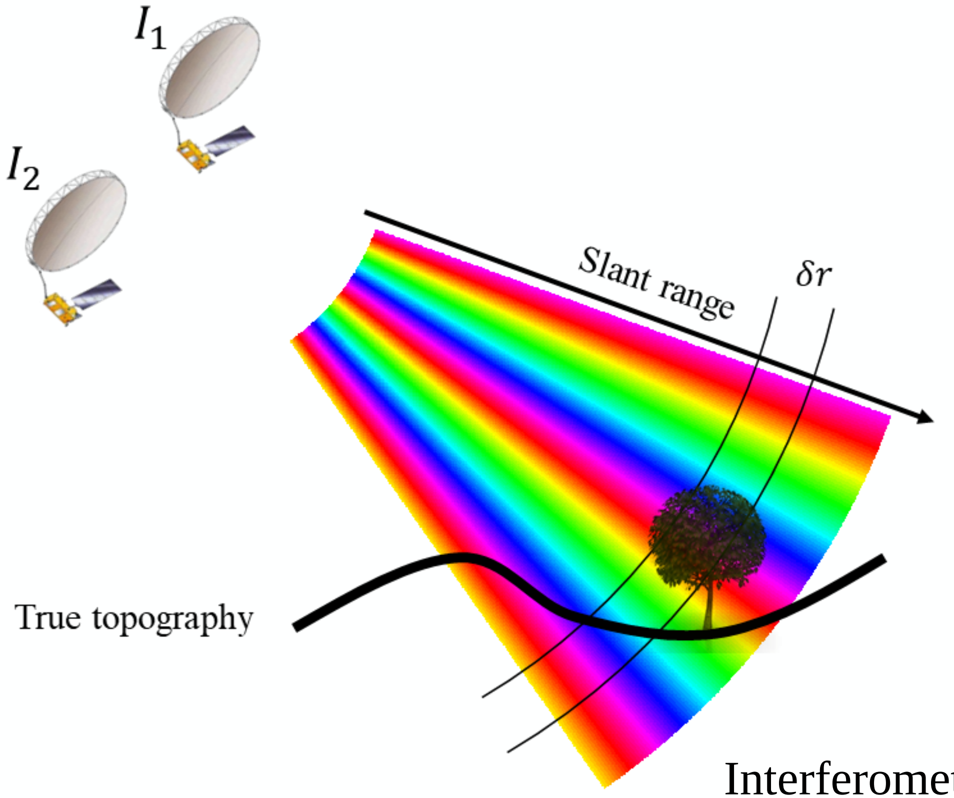
$$s_{PQi} = log\left(\sigma^v_{pq}\right) = l_{PQ} + \alpha_{PQ} w_i + n_{PQ} c_i$$

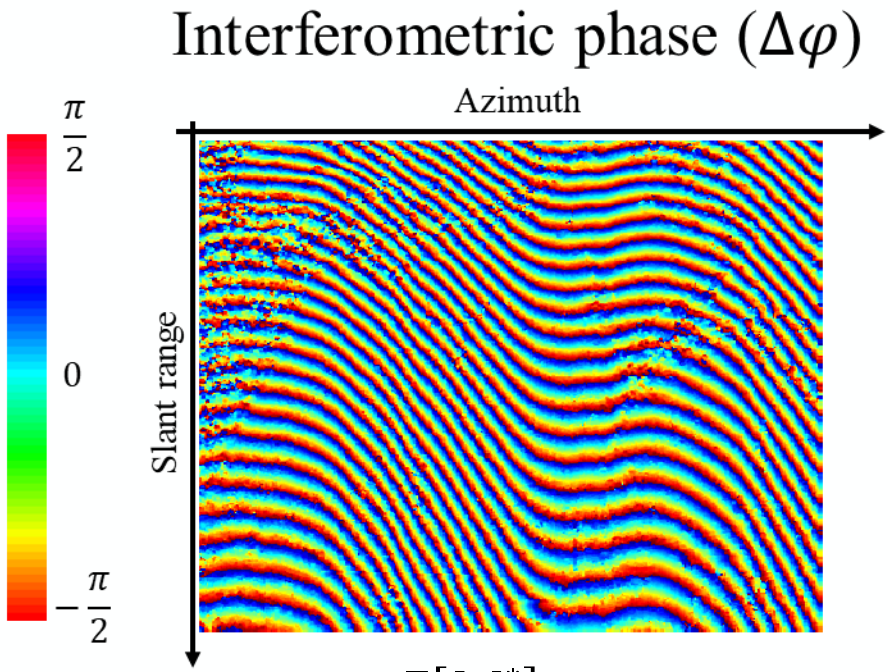
W = AGB
θ = incidence angle
pq = polarization



Interferometric phase: no Tomography

SAR interferometry





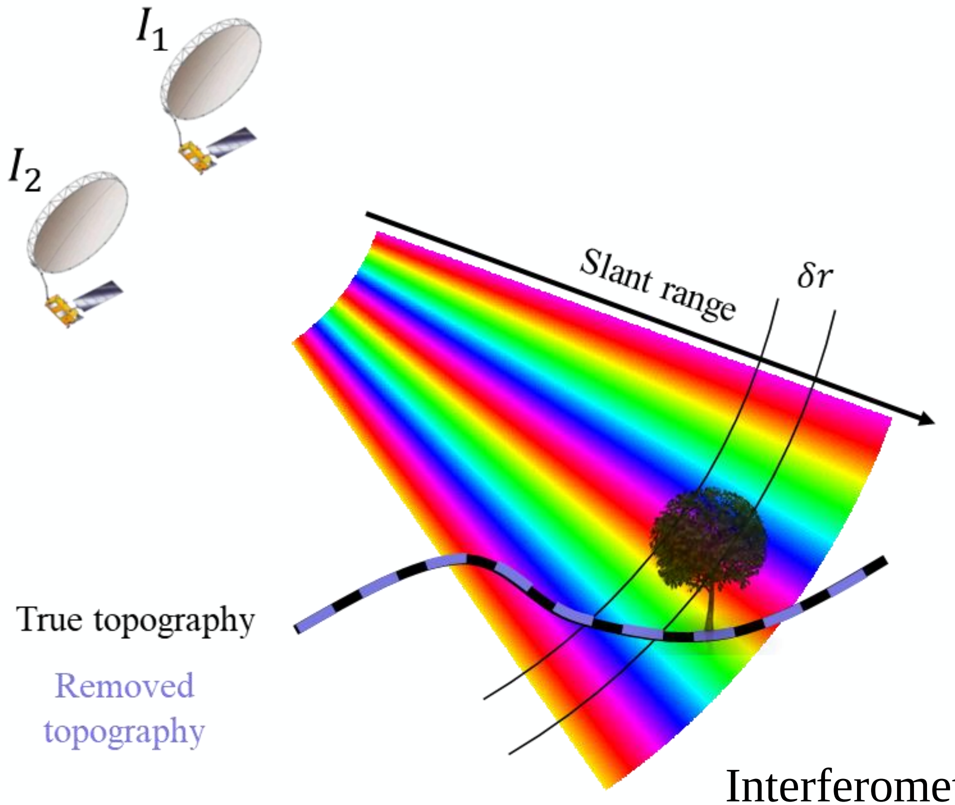
Interferometric coherence: $\frac{E[I_1 I_2^*]}{\sqrt{E[|I_1|^2]E[|I_2|^2]}} = \rho \cdot e^{j \cdot \Delta\varphi}$

$$\varphi_1 = \frac{4\pi}{\lambda} r_1 + \varphi_{sc}$$

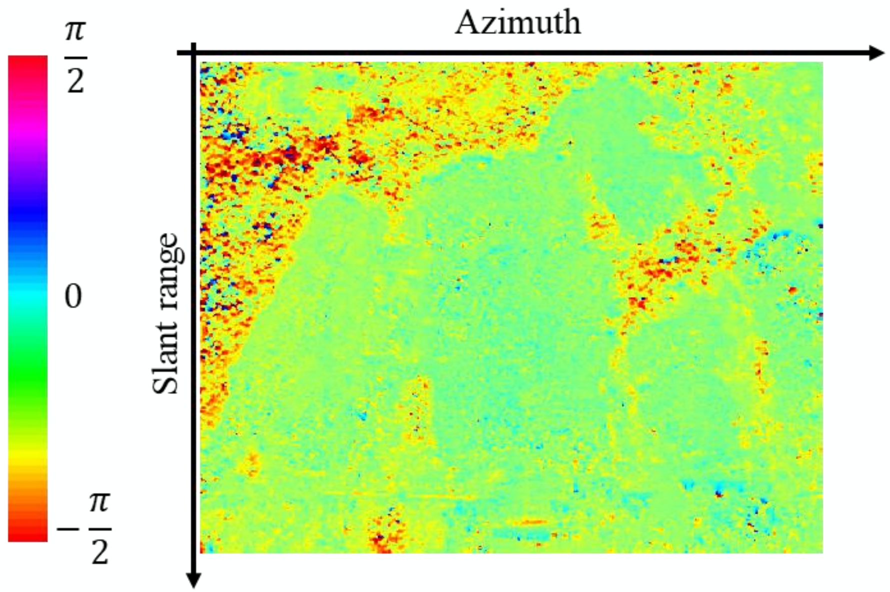
$$\varphi_2 = \frac{4\pi}{\lambda} r_2 + \varphi_{sc}$$

$$\Delta\varphi \triangleq \varphi_1 - \varphi_2 = \frac{4\pi}{\lambda}(r_1 - r_2)$$

SAR interferometry – DTM removal



Interferometric phase ($\Delta\varphi$)



Interferometric coherence: $$\frac{\mathrm{E}[I_1 I_2^*]}{\sqrt{\mathrm{E}[|I_1|^2]\mathrm{E}[|I_2|^2]}} = \rho \cdot e^{j\cdot\Delta\varphi}$$

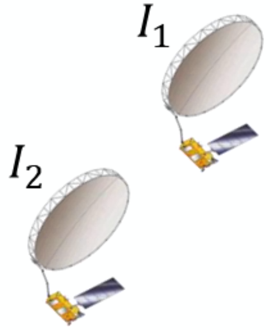
$$\varphi_1 = \frac{4\pi}{\lambda} r_1 + \varphi_{sc} - \frac{4\pi}{\lambda} r_{DTM,1}$$

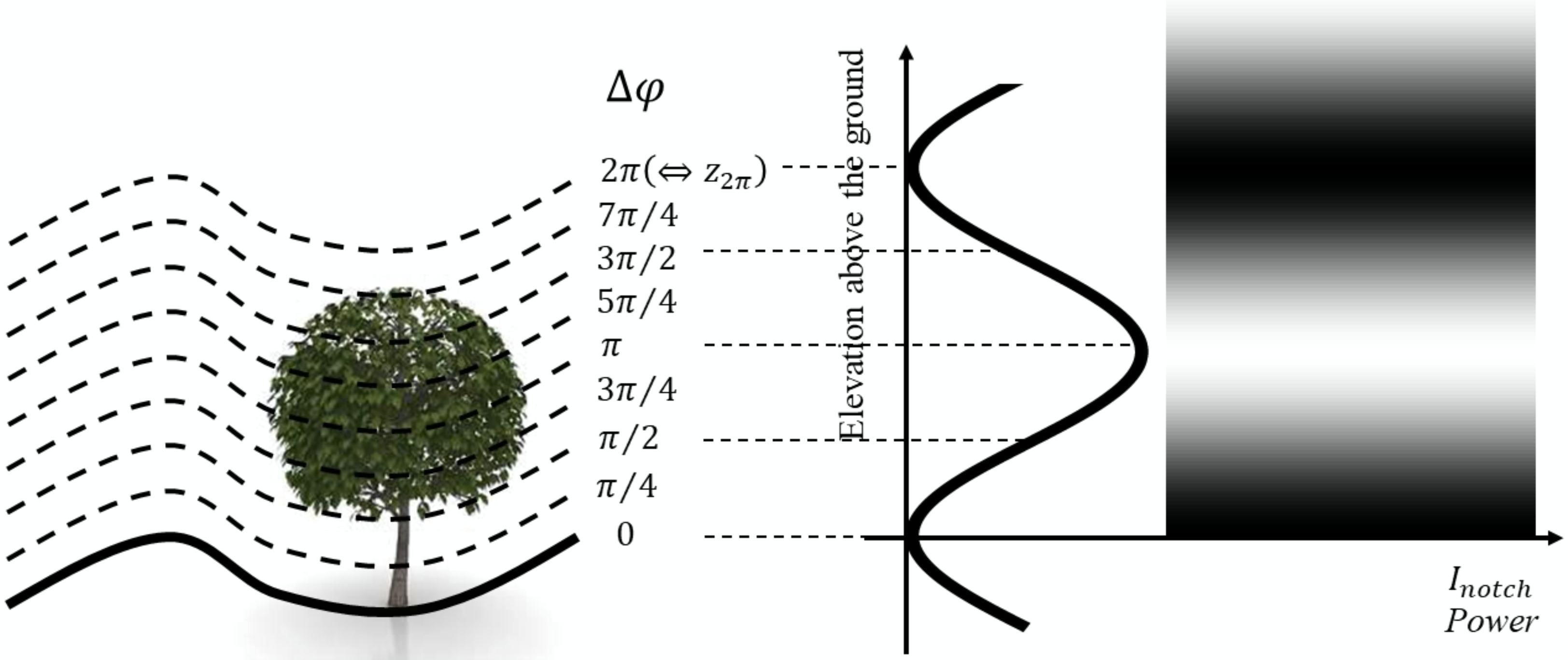
$$\varphi_2 = \frac{4\pi}{\lambda} r_2 + \varphi_{sc} - \frac{4\pi}{\lambda} r_{DTM,2}$$

$$\Delta\varphi \triangleq \varphi_1 - \varphi_2 = \frac{4\pi}{\lambda}(r_1 - r_2) - \frac{4\pi}{\lambda}\left(r_{DTM,1} - r_{DTM,2}\right)$$

"Ground steered" images
zero interferometric phase at the ground level

Ground cancellation





Zero interferometric phase means same phase for image 1 (I_1) and image 2 (I_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 baseline)

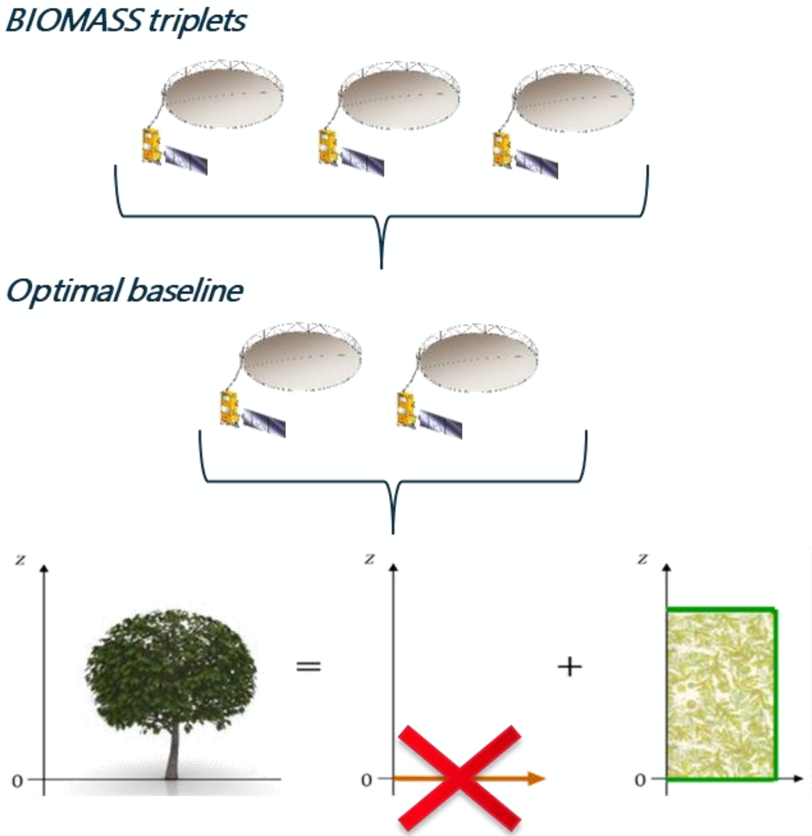
$$I_{notch} = I_1 - I_2$$

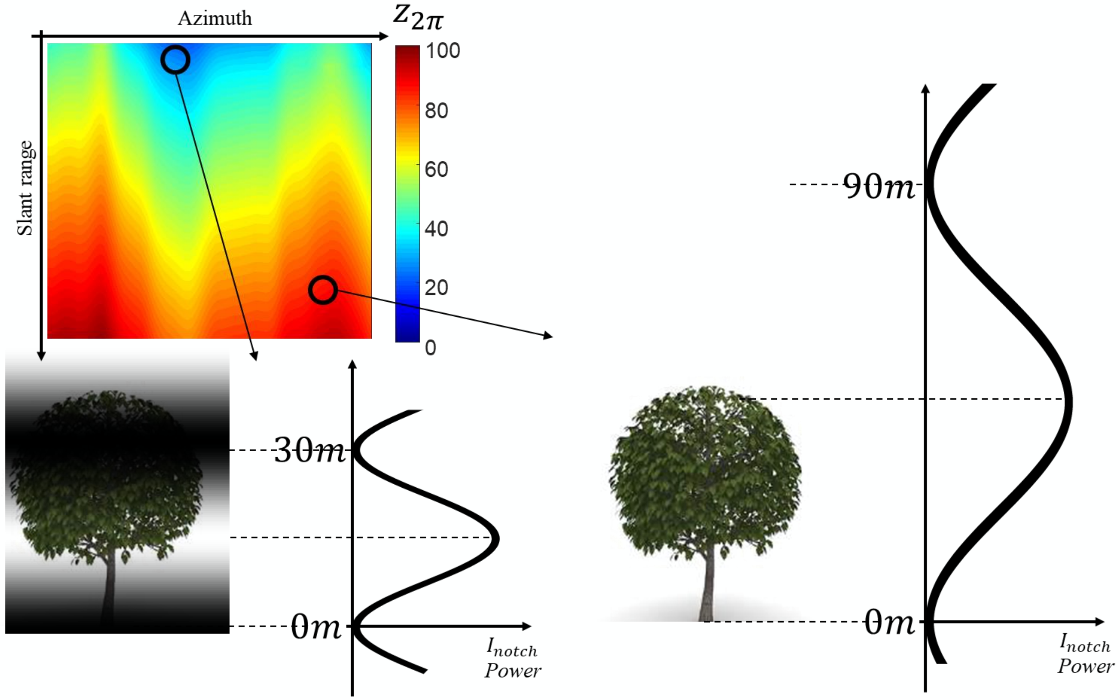
cancels out echoes coming from 0m ($\pm n \cdot z_{2\pi}$)
emphasizes echoes coming from $z_{2\pi}/2m$ ($\pm n \cdot z_{2\pi}$)

Multi-baseline Ground cancellation

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



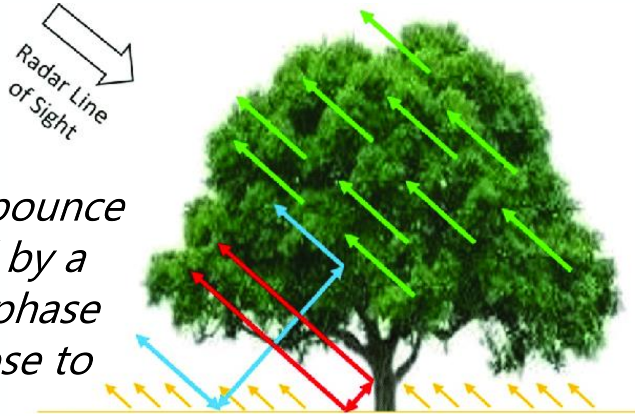


2. A ground-cancelled image is produced by coherent subtraction

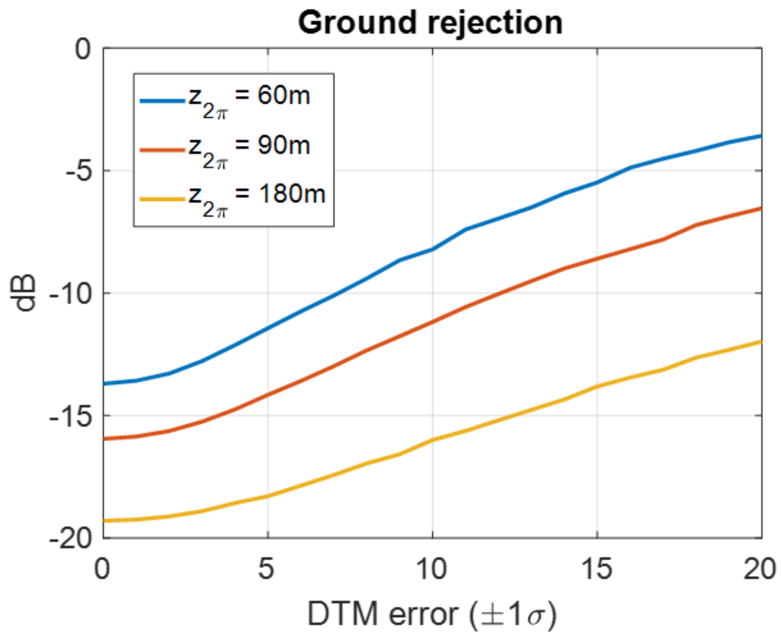
➢ Rejection of disturbing contributions from scattering from the ground layer

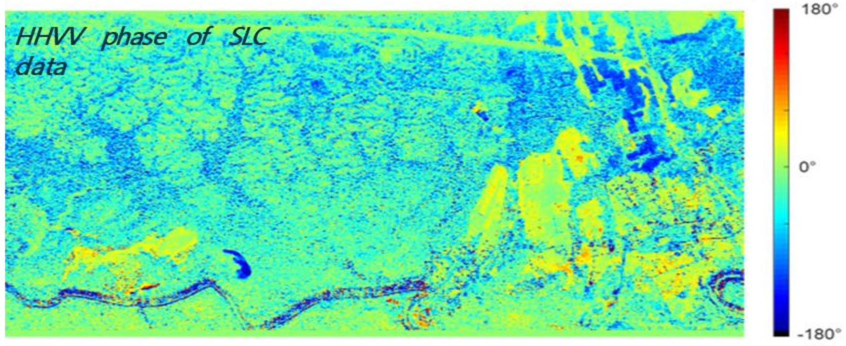
➢ Emphasis of volume scattering from the desired height (according to the **synthesized** baseline)

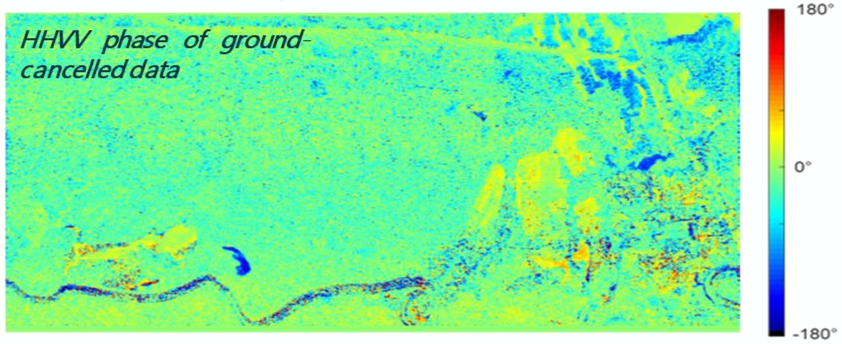
AGB – GROUND CANCELLATION

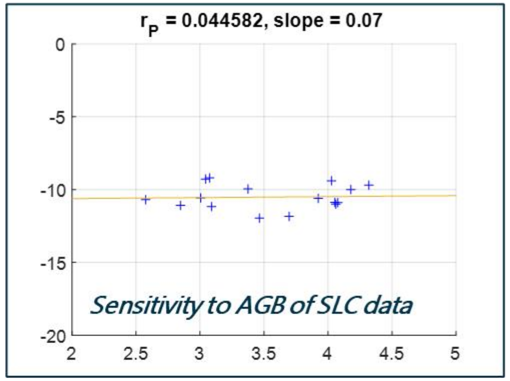


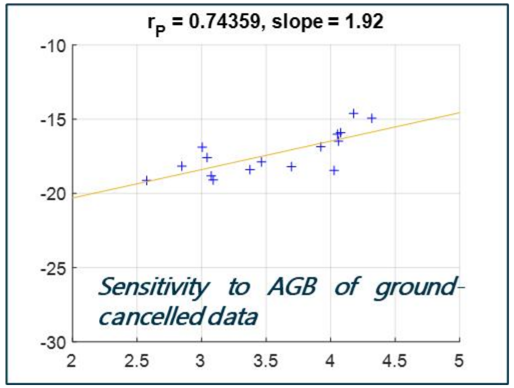
Double bounce revealed by a copolar phase value close to 180°









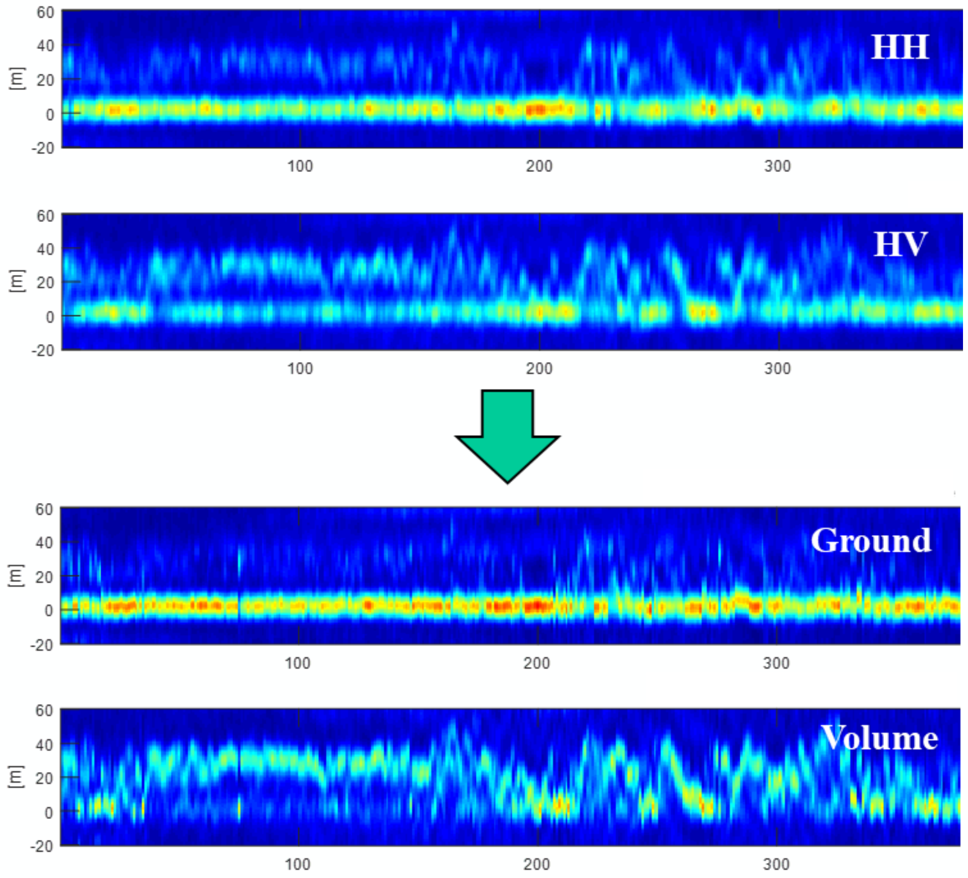


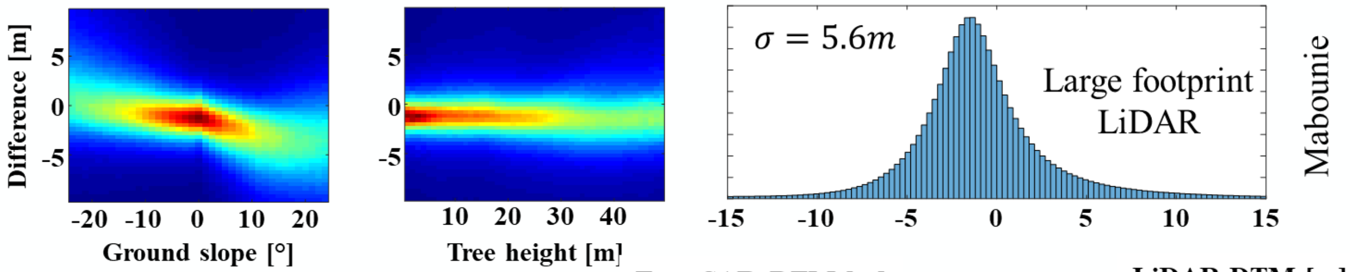
rely on accurate DTM

rely on accurate Phase calibration

Retrieval of DTM

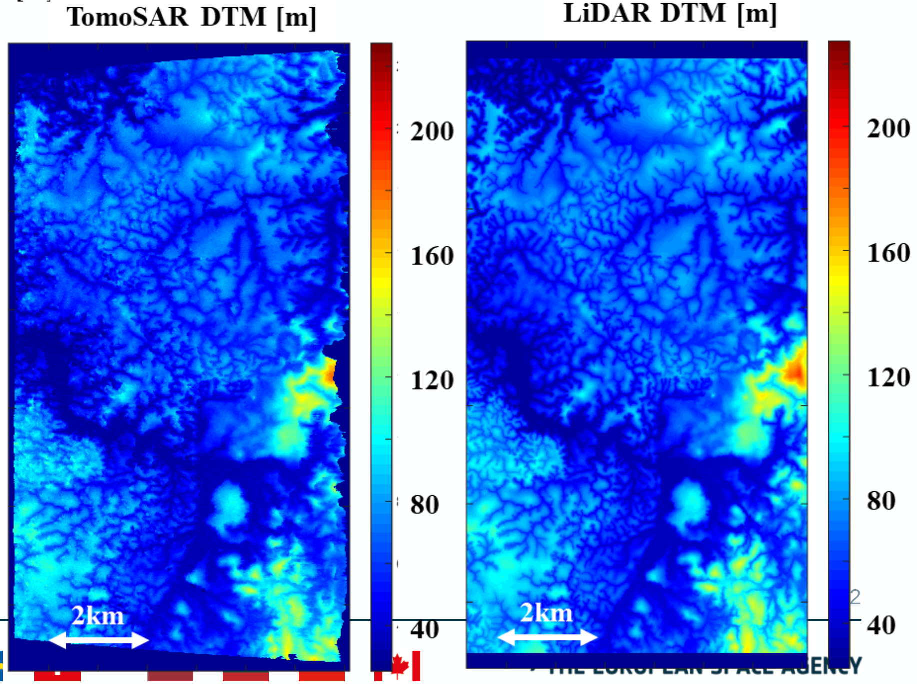
- The L2 processor is assumed to ingest phase-calibrated BIOMASS interferometric stacks and accurate information about sub-canopy terrain topography.
- Both these products will be derived through a close interconnection with the BIOMASS interferometric processor.





SKP tomography:

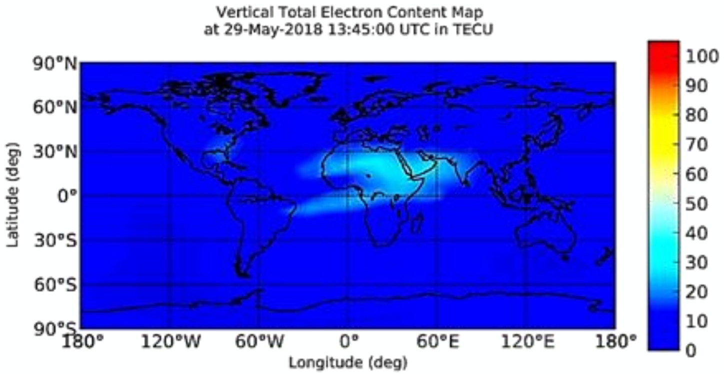
- Ground and volume are separated
- The elevation of the ground can be read in the tomographic profiles

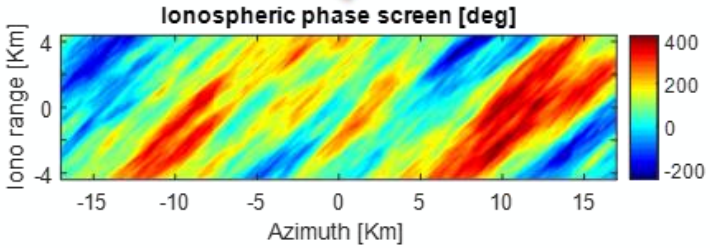


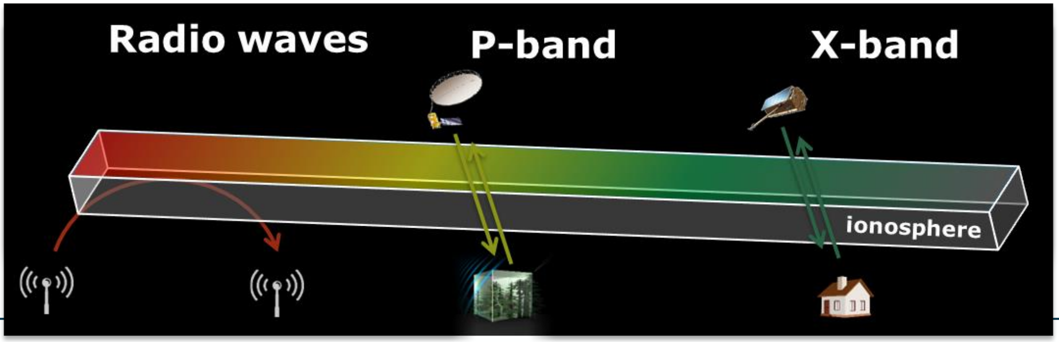
Phase calibration

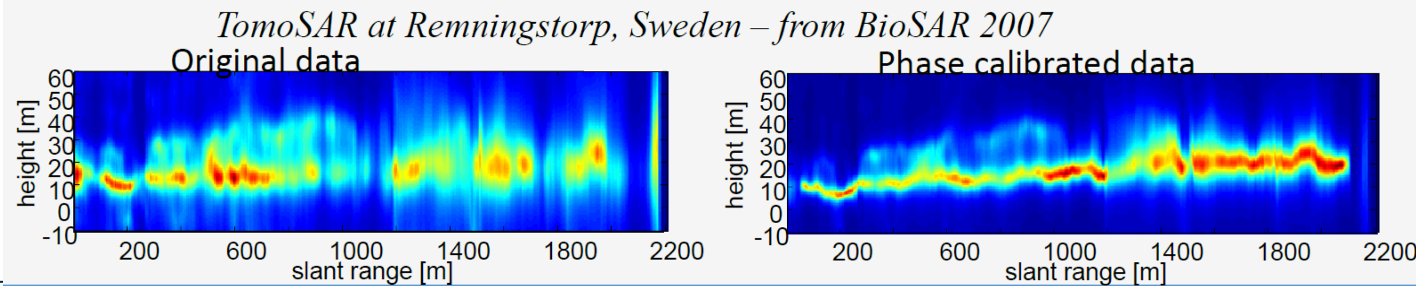
BIOMASS interferometric processor
exploit the whole stack to estimate residual ionospheric screens and baseline errors (relative to one reference image) using multi-squint techniques and SKP

Disturbance	Impact at L1	Impact at Tomo & InSAR level
Background ionosphere (**Corrected on L1**)	• Range shift • Faraday rotation	• Errors in Polarimetry
Linear ionosphere phase variations over the synthetic aperture	• Azimuth shift	• Coherence loss in interferometric pairs
Non-linear ionosphere phase variations	• Geolocation • Spatial resolution loss • Radiometric bias • PSLR & ISLR degradation	• Moderate coherence loss in interferometric pairs
baseline errors	• negligible	• phase disturbance and defocusing



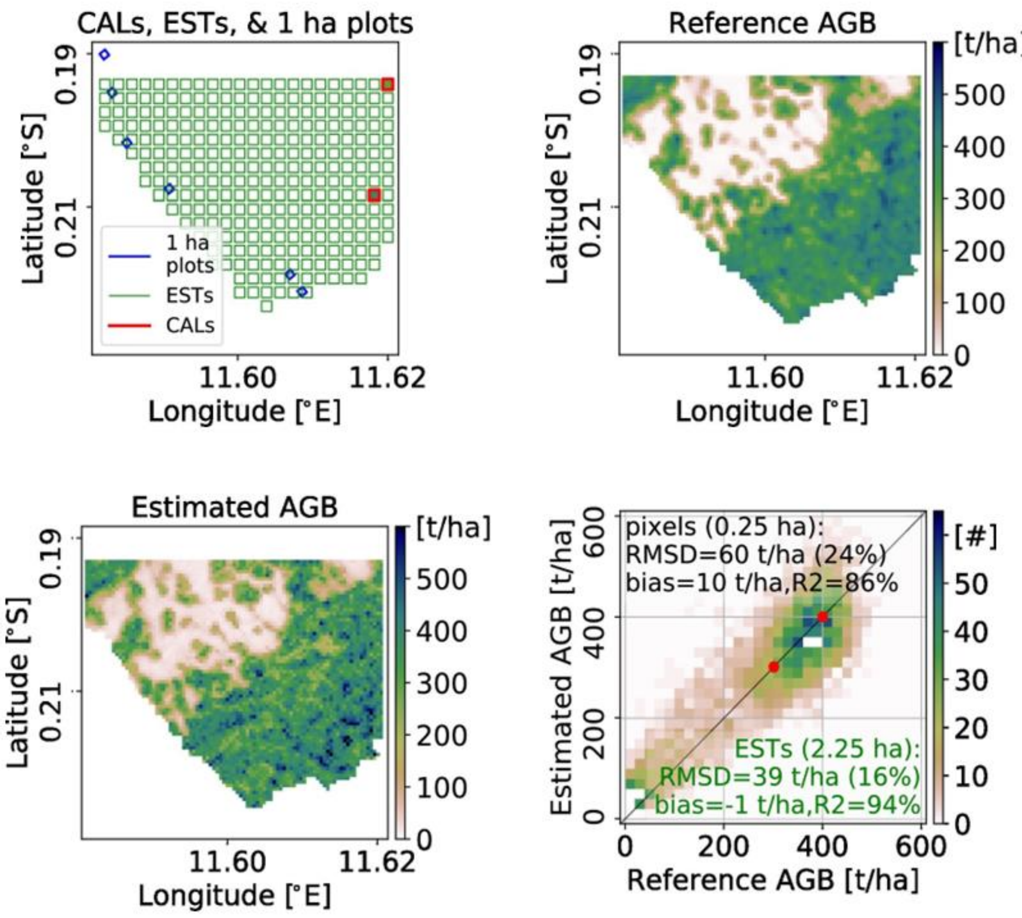






AGB – RESULTS FROM CAMPAIGN DATA

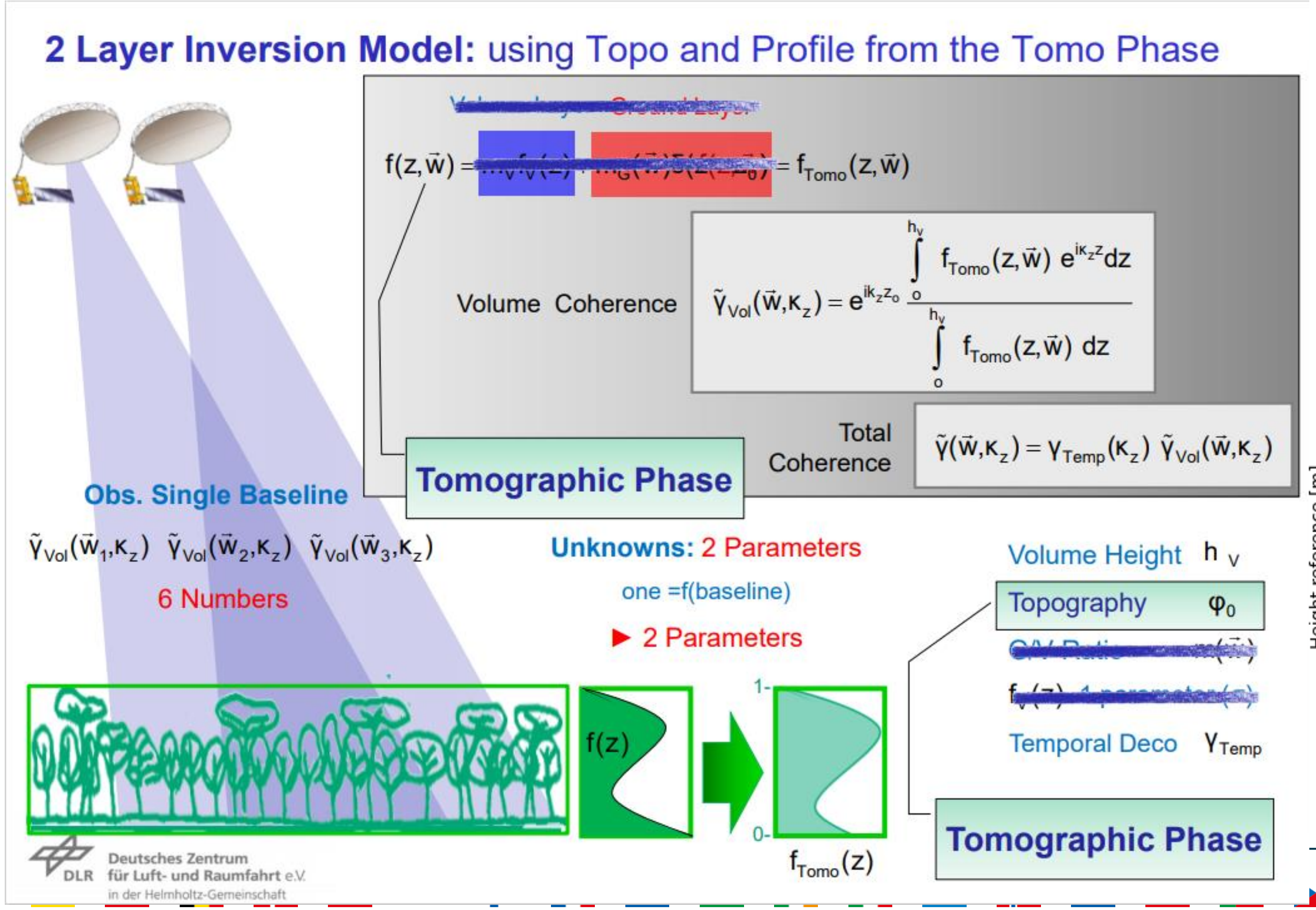
- To mimic BIOMASS spaceborne data, airborne SAR acquisitions from AfriSAR were filtered to 6 MHz and multi-looked to a resolution of 50 m in both ground range and azimuth directions
- Terrain topography was then estimated using tomographic processing, and the estimated DTM was used for the generation 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.
- Global AGB retrieval is intended to proceed using calibration data from GEDI
- Approach based on region-growing is currently under evaluation

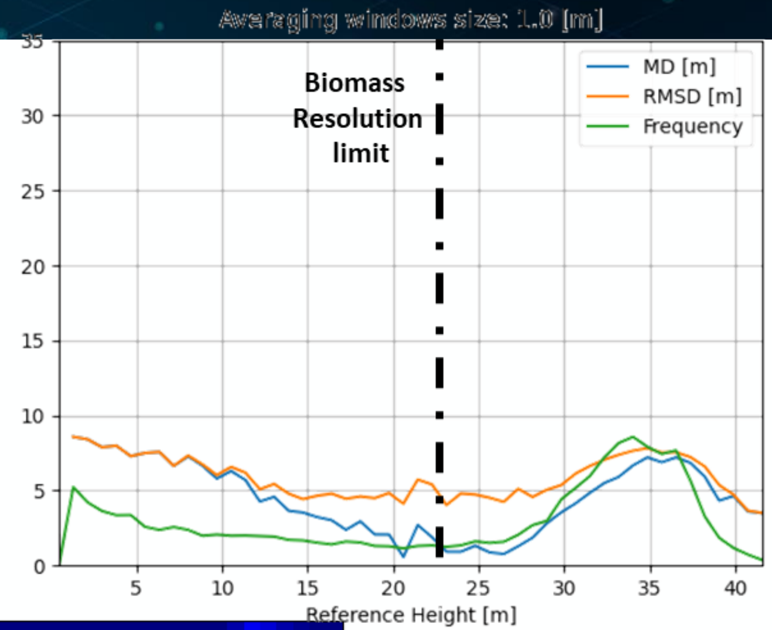


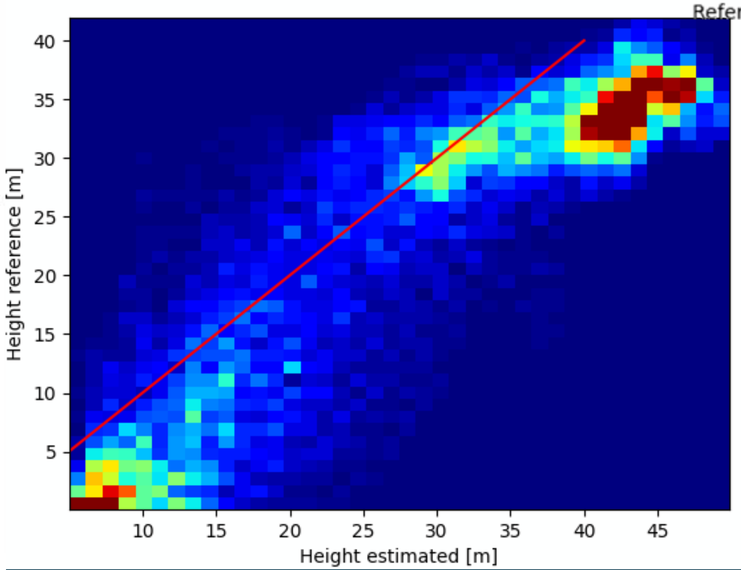
FOREST HEIGHT

Forest height retrieval leverages PolInSAR inversion

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







WHERE WE ARE NOW

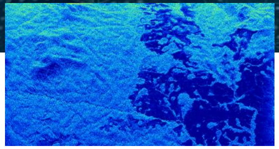
The BIOMASS level-2 processor implements state-of-the art SAR processing techniques that exploits polarimetric and baseline diversity

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



BioPAL

BIOMASS Product Algorithm Laboratory

biopal@esa.int

biopal.org

github.com/BioPAL

= Open Source Software Project

= official BIOMASS algorithms python

= first time that official algorithms are made publicly accessible

Banda, F.; Giudici, D.; Le Toan, T.; Mariotti d'Alessandro, M.; Papathanassiou, K.; Quegan, S.; Riembauer, G.; Scipal, K.; Soja, M.; Tebaldini, S.; Ulander, L.; Villard, L. "The BIOMASS Level 2 Prototype Processor: Design and Experimental Results of Above-Ground Biomass Estimation" Remote Sensing, 2020, 12, 985. doi.org/10.3390/rs12060985