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BIOMASS Level-2 Algorithms: Current Status

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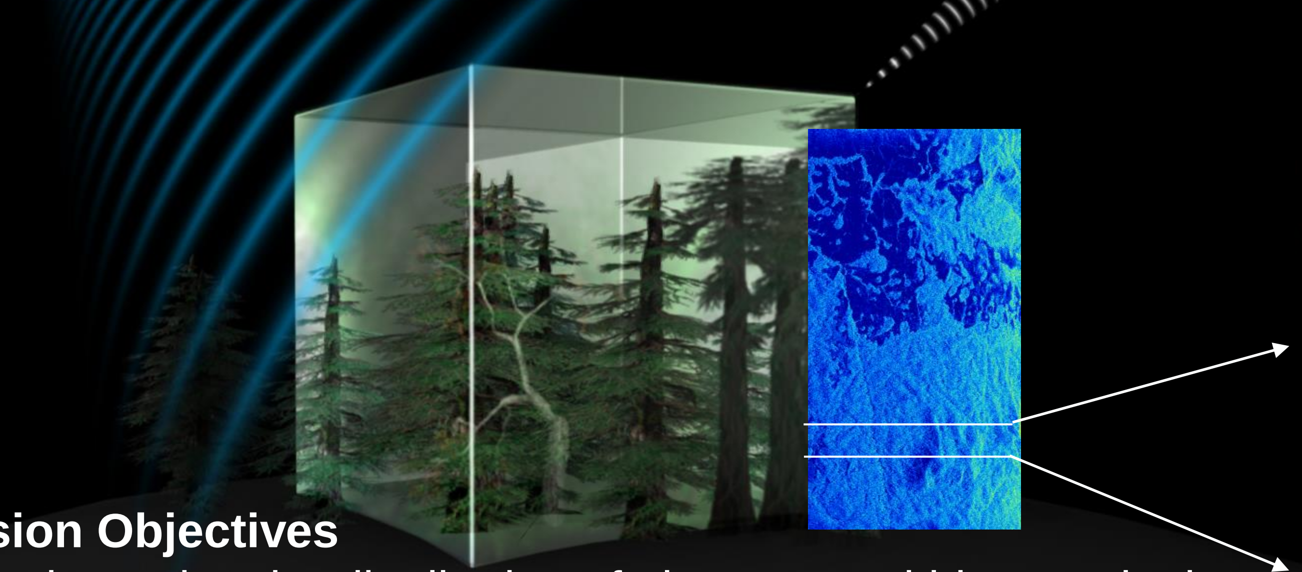
BIOMASS

Scheduled for launch in 2024, 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

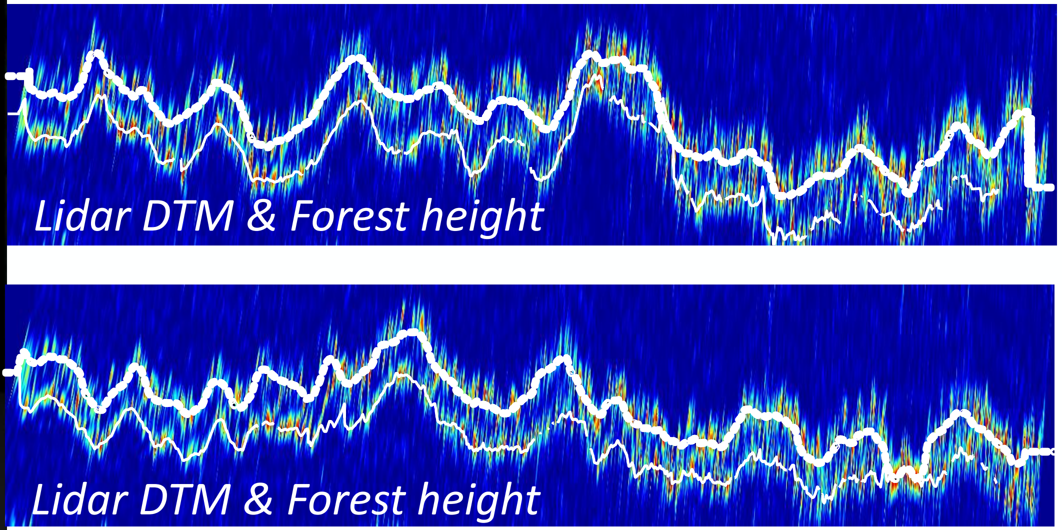


Mission Objectives

- 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



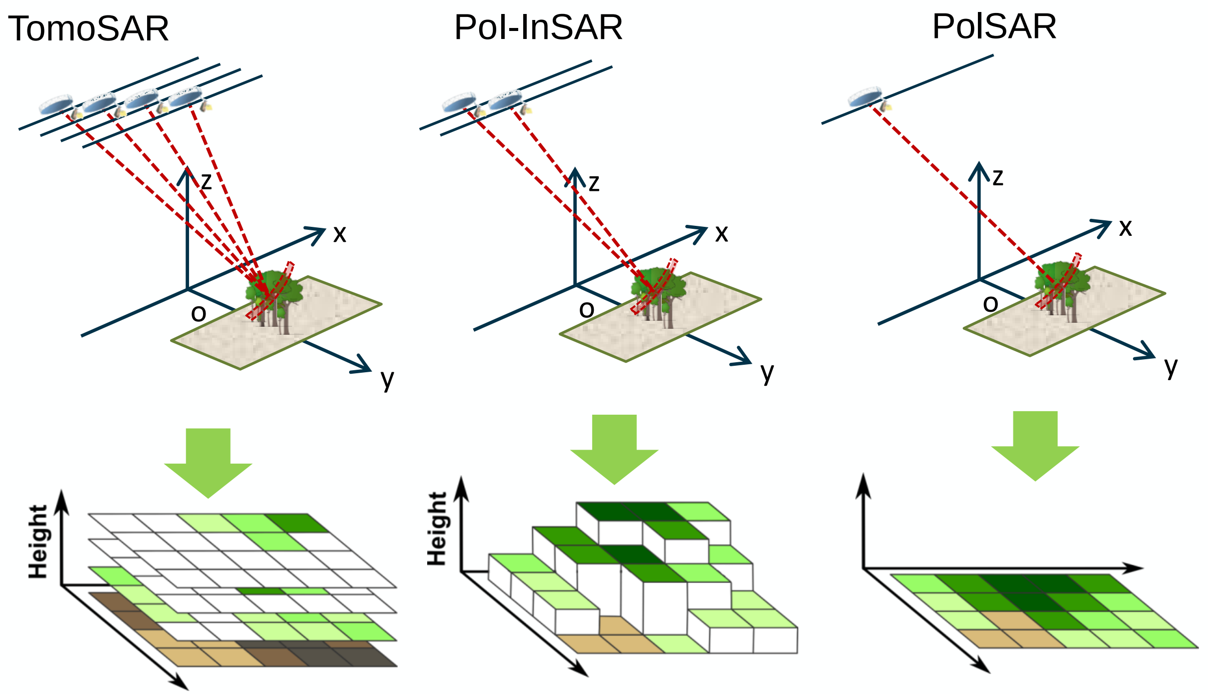
Vertical sections from AfriSAR (Gabon)

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:

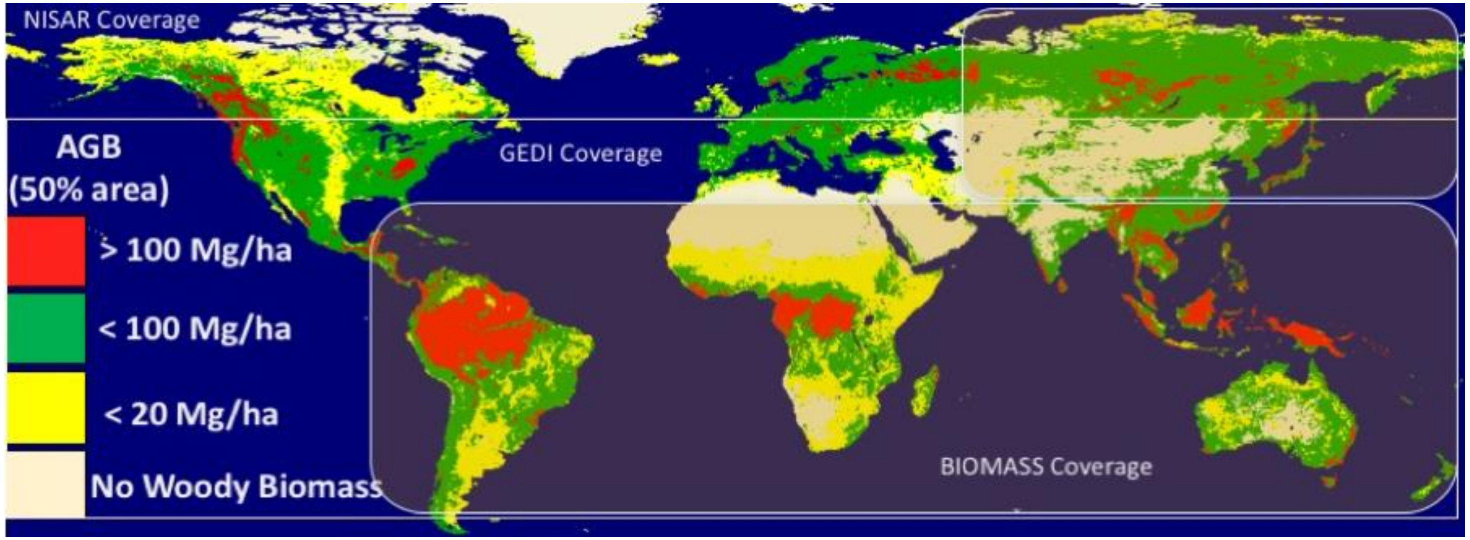
Above Ground Biomass (AGB) *:* dry weight of woody matter per unit area above the soil including stem, stump, branches, bark, seeds and foliage; it does not include dead mass, litter and below-ground biomass

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

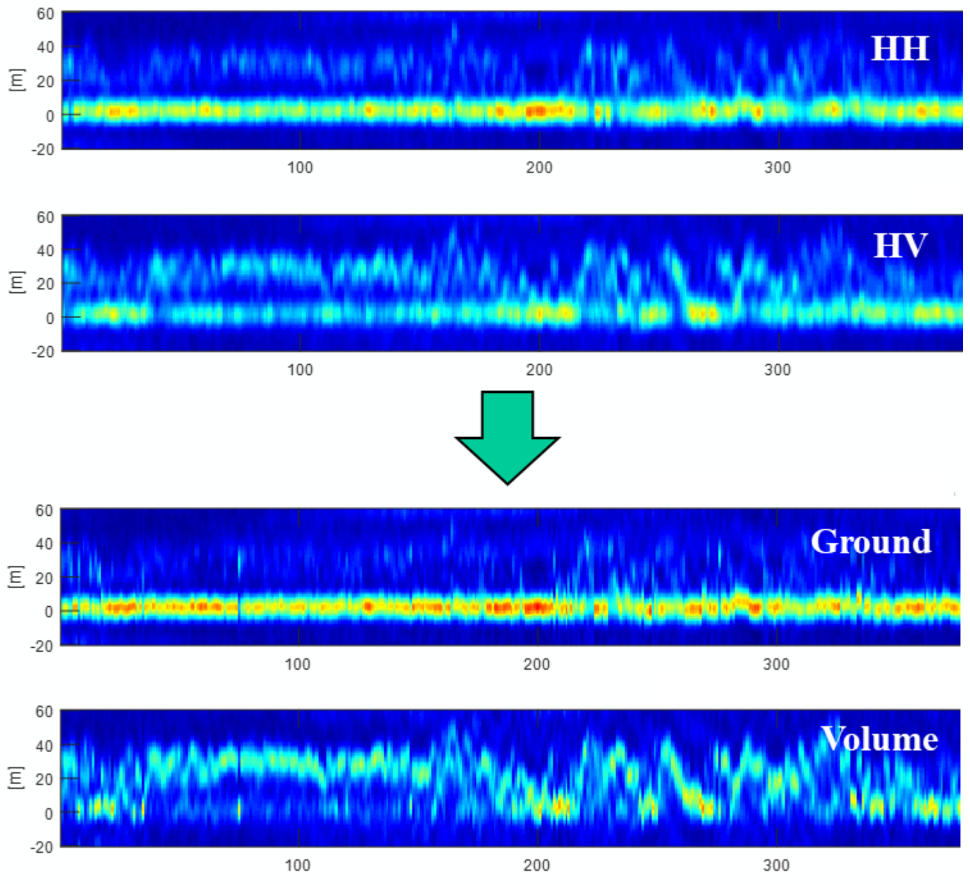
Frequency and coverage:

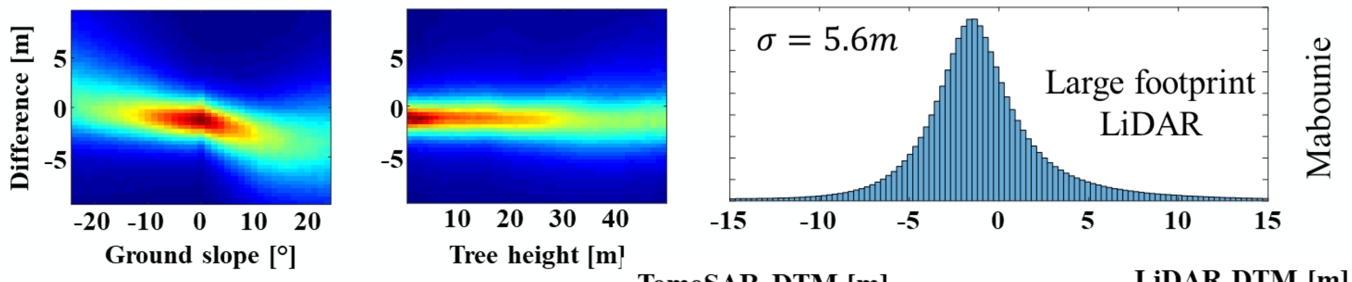
- 1 near-global map of biomass and height from tomography in first 14 months
- Updated biomass and height maps and maps of deforestation from polarimetry and interferometry every 7 months for rest of 5-year mission



RETRIEVAL OF DTM

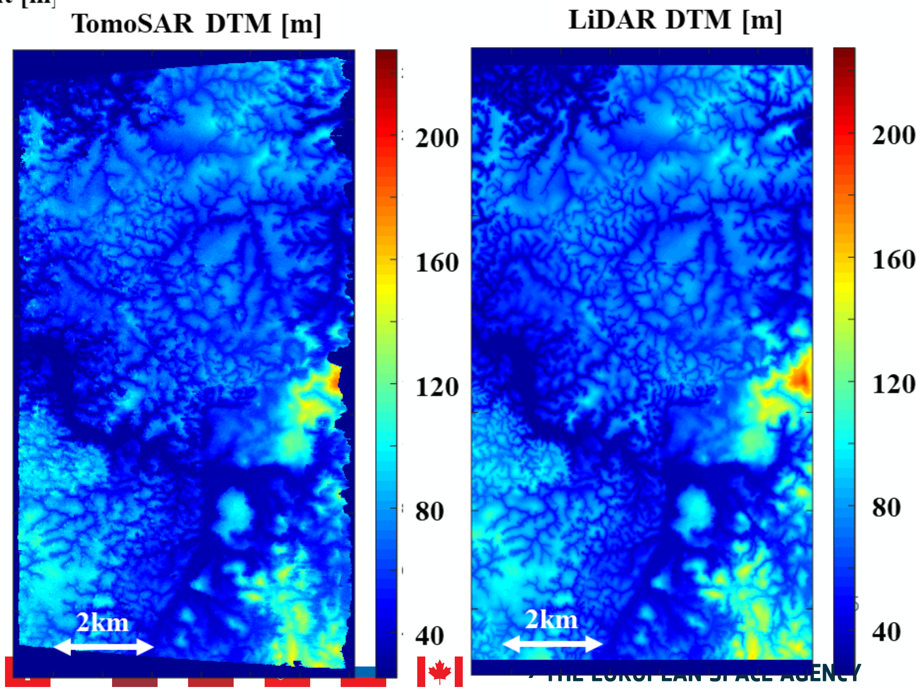
- The L2 processor is assumed to ingest phase-calibrated BIOMASS interferometric stacks and accurate information about sub-canopy terrain topography
- Both these products will be derived through a close interconnection with the BIOMASS interferometric processor





SKP tomography:

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

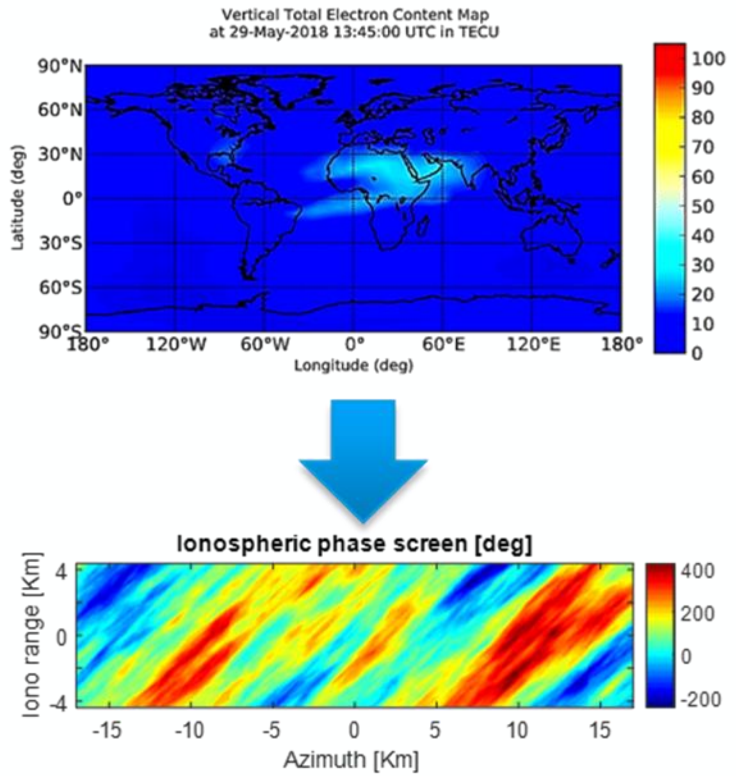


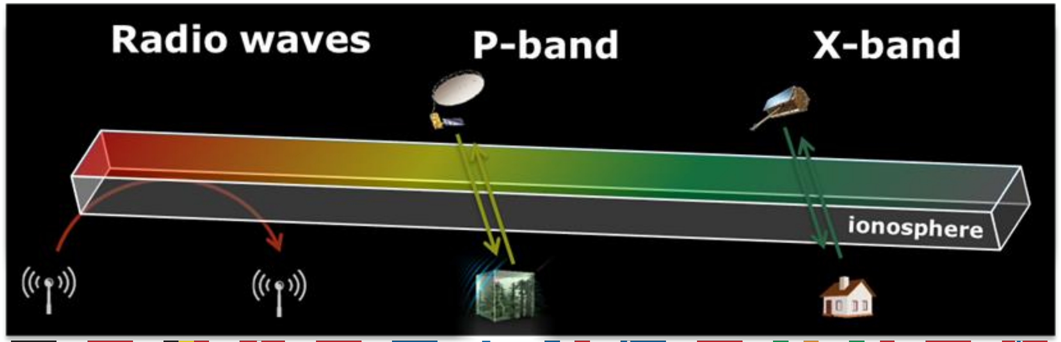
PHASE CALIBRATION

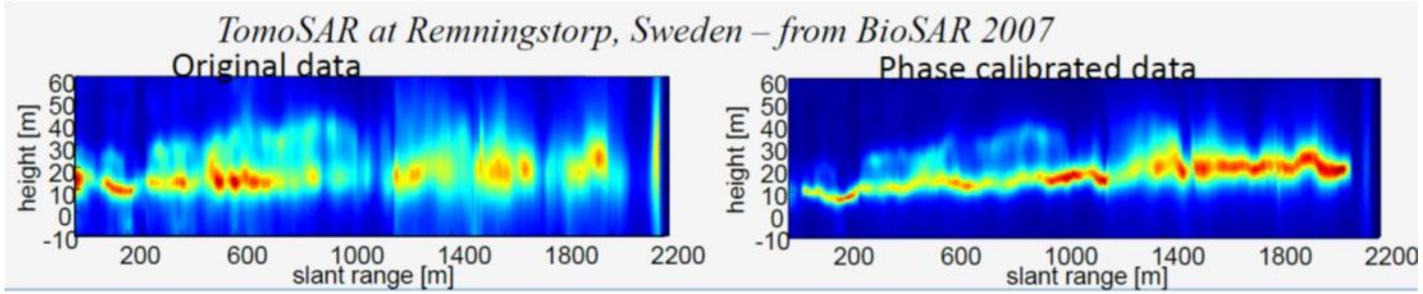
BIOMASS interferometric processor

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



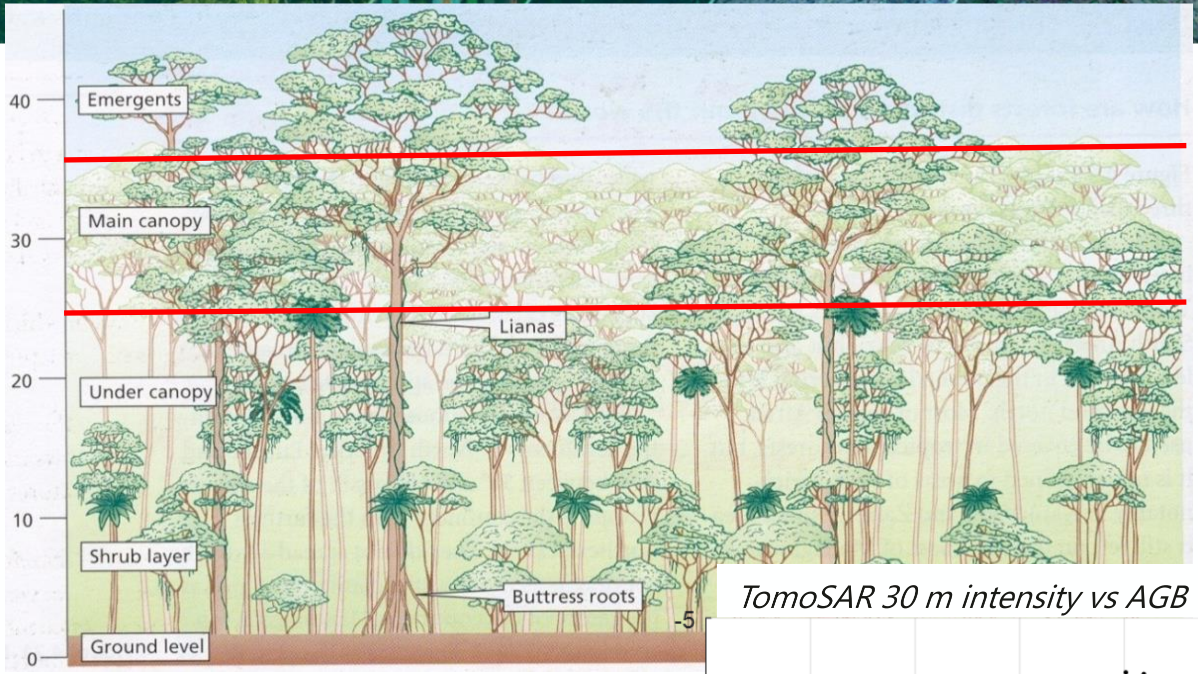




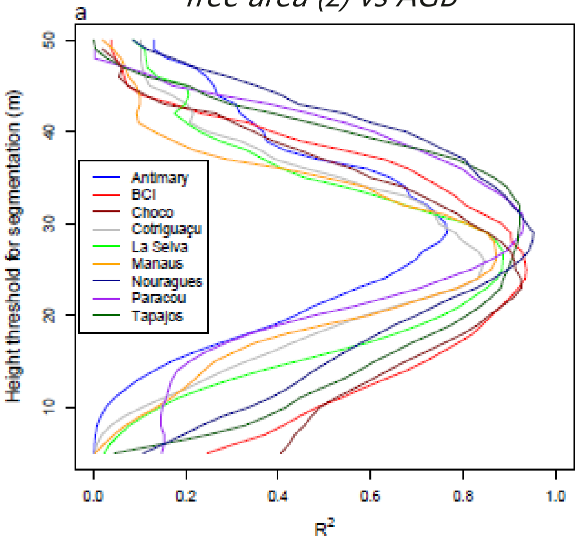
CORRELATION WITH AGB

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



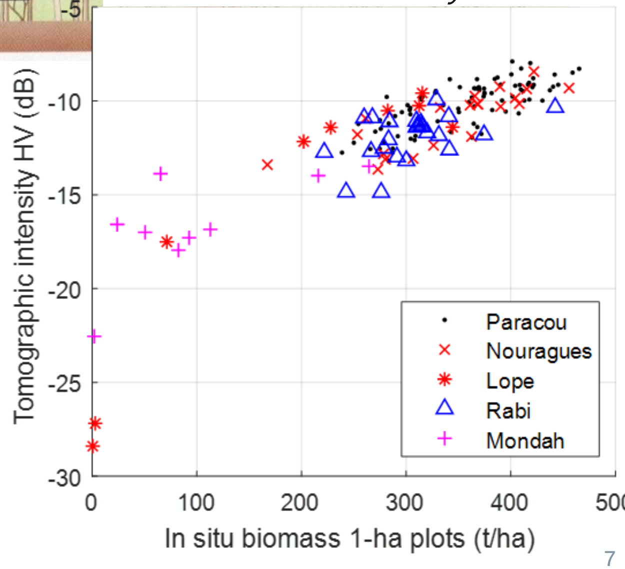
Tree area (z) vs AGB



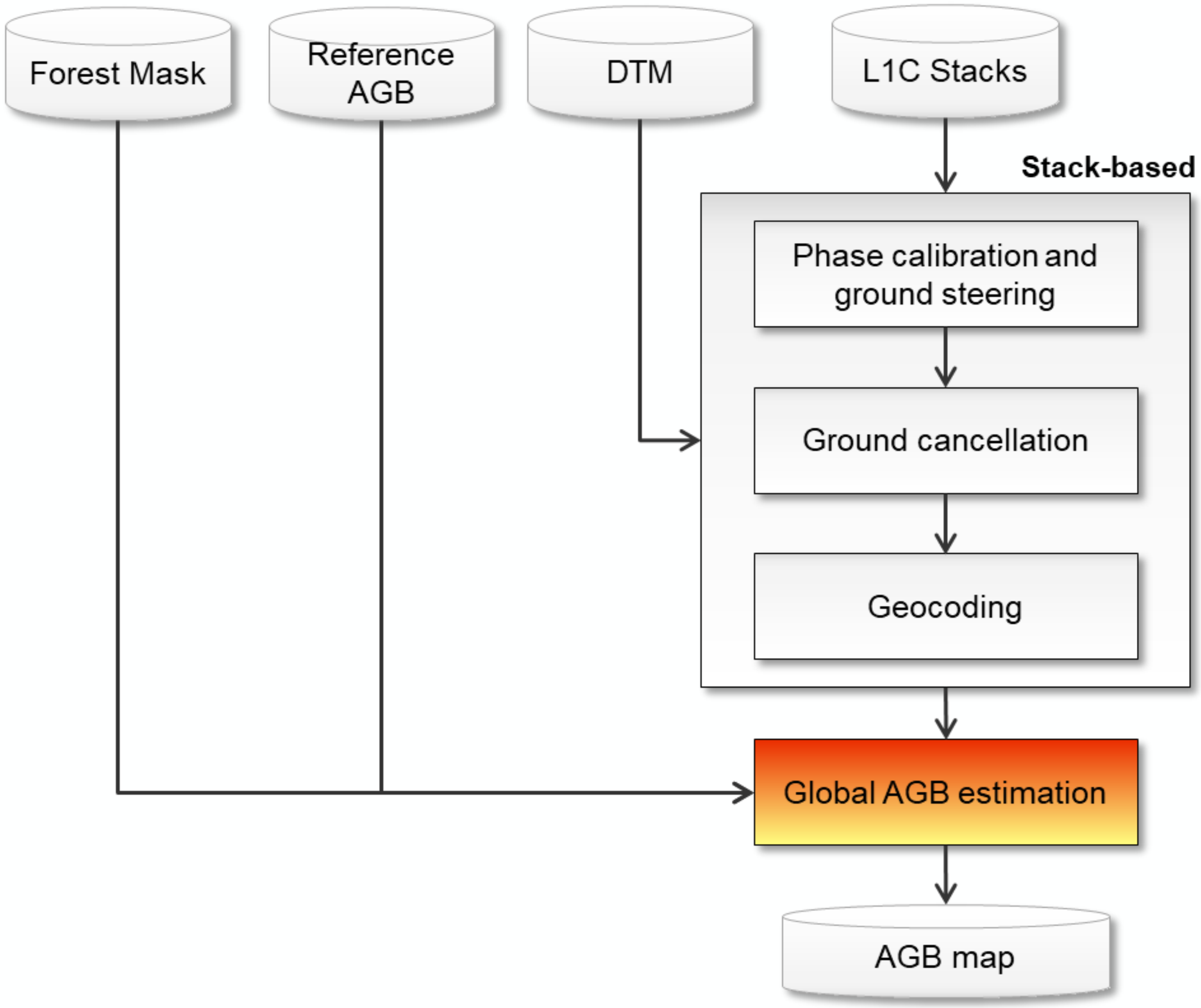
Our conclusions

- 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



AGB ESTIMATION SCHEME

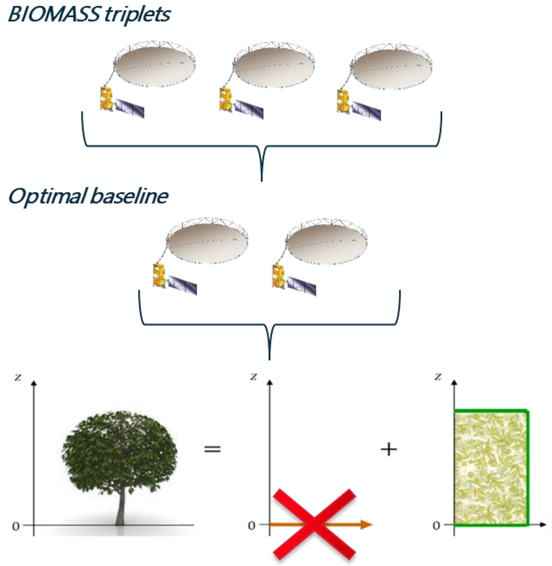


Stack based processing:

interferometric *ground cancellation* applied to each L1 stack to attenuate ground contribution in the data

Global AGB estimation on map (Work In Progress):

inverts a power-law function relating AGB to ground cancelled backscatter data trained with external reference data



AGB ESTIMATION CONCEPT

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

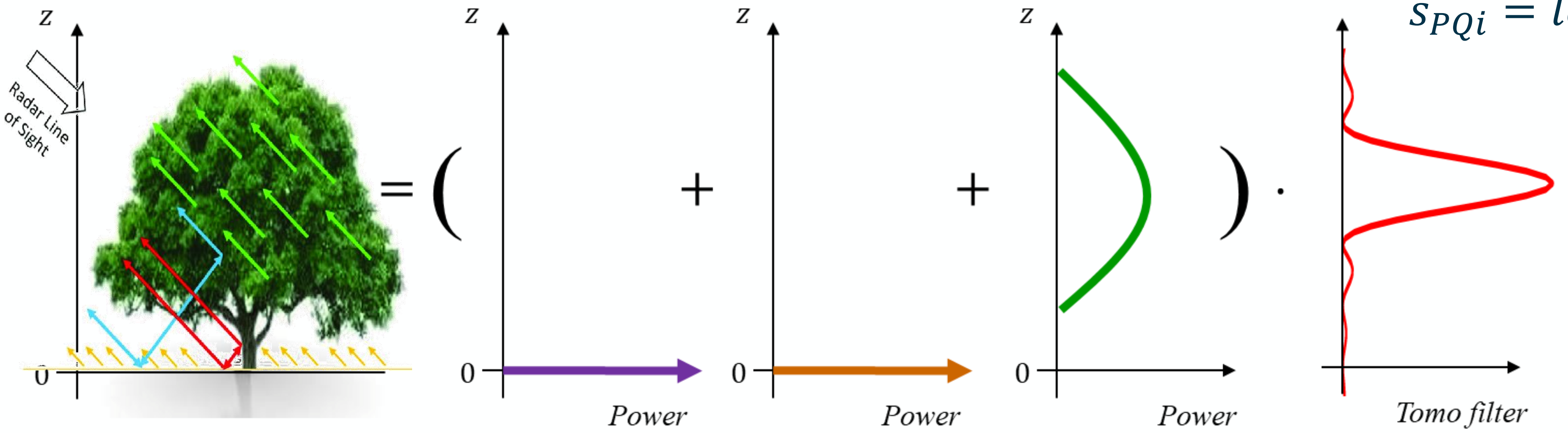
$$C_{PQ} W^{\delta_{PQ}} \Gamma_{PQ}(\theta_i, \varepsilon, k, s) \sin\theta_i \exp\left(-\frac{B_{PQ} W^{\beta_{PQ}}}{\cos\theta_i}\right) +$$

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

- 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:

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

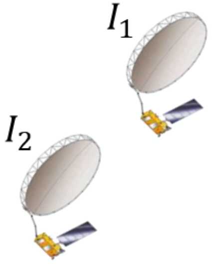


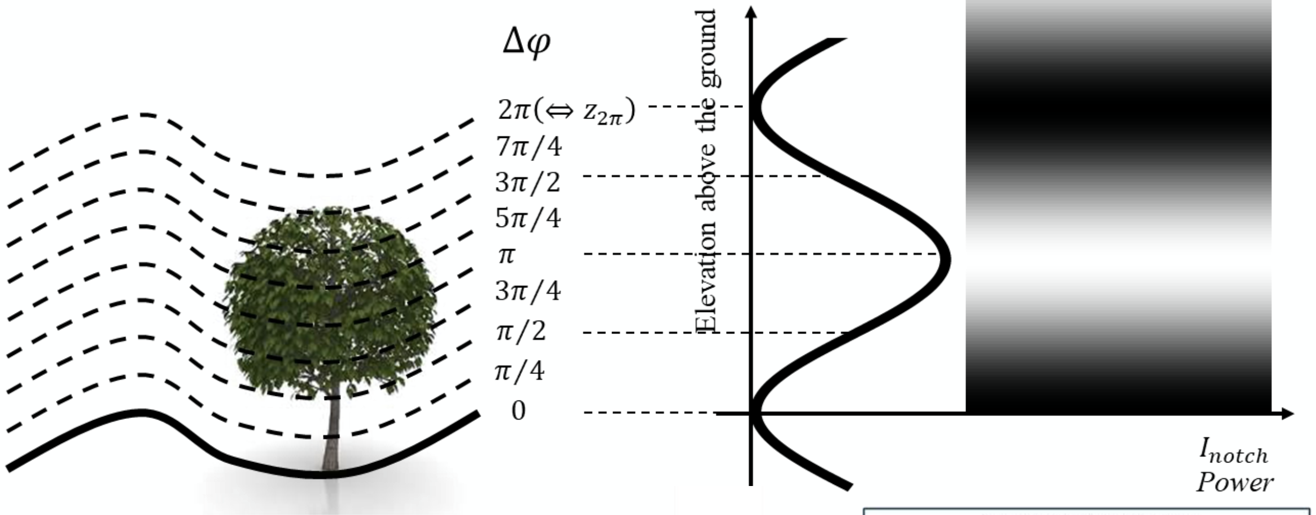
W = AGB
θ = incidence angle
pq = polarization

INTERFEROMETRIC GROUND CANCELLATION

Coherent subtraction *after phase calibration and terrain phase compensation*

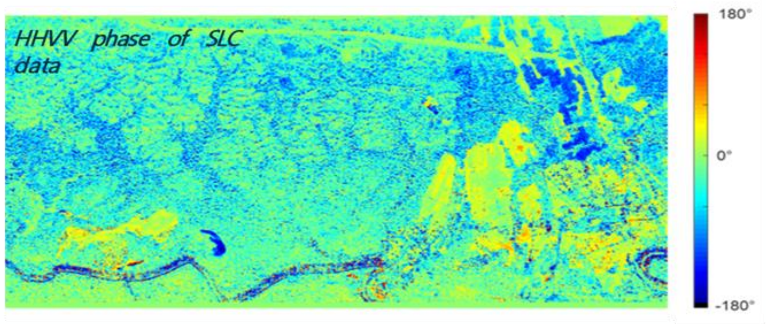
- rejection of disturbing contributions from the ground layer
- <u>emphasis of volume scattering</u> from the desired height (according to the baseline)
- with BIOMASS stack: synthesize optimal baseline across the swath

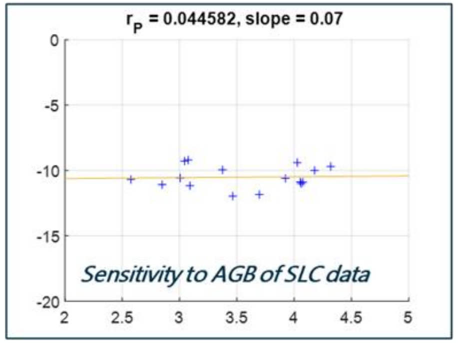


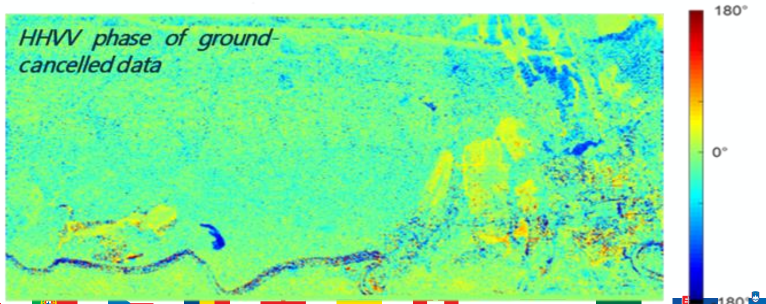


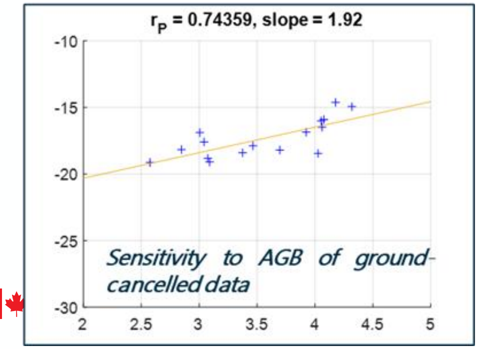
$$I_{notch} = I_1 - I_2$$

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

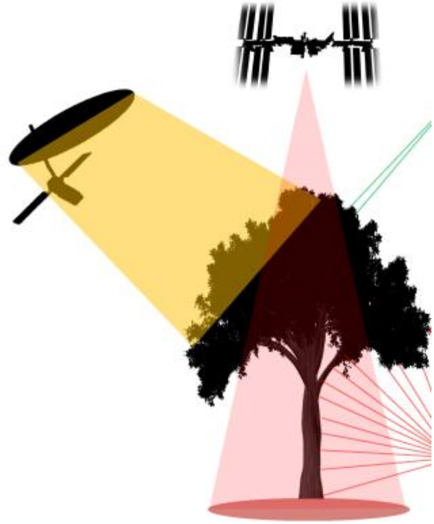




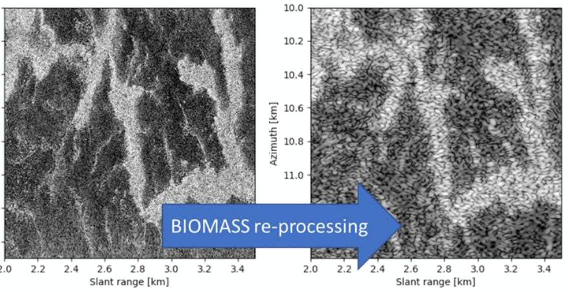


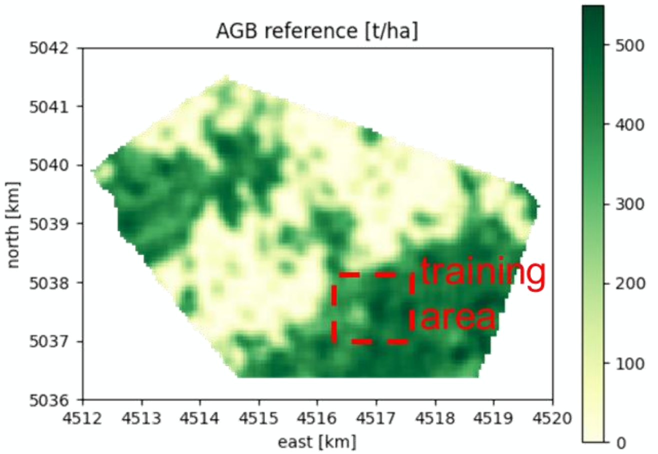


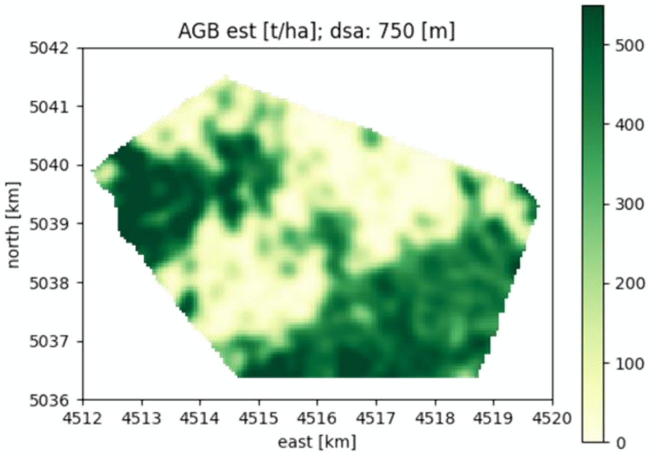
AGB RESULTS FROM CAMPAIGN DATA

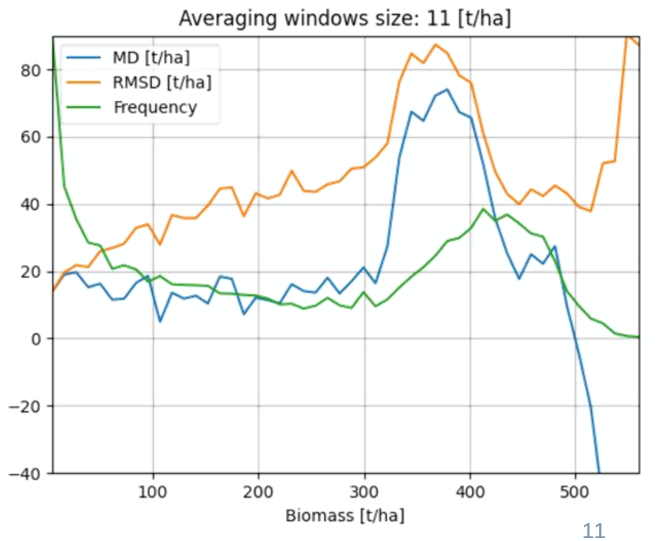


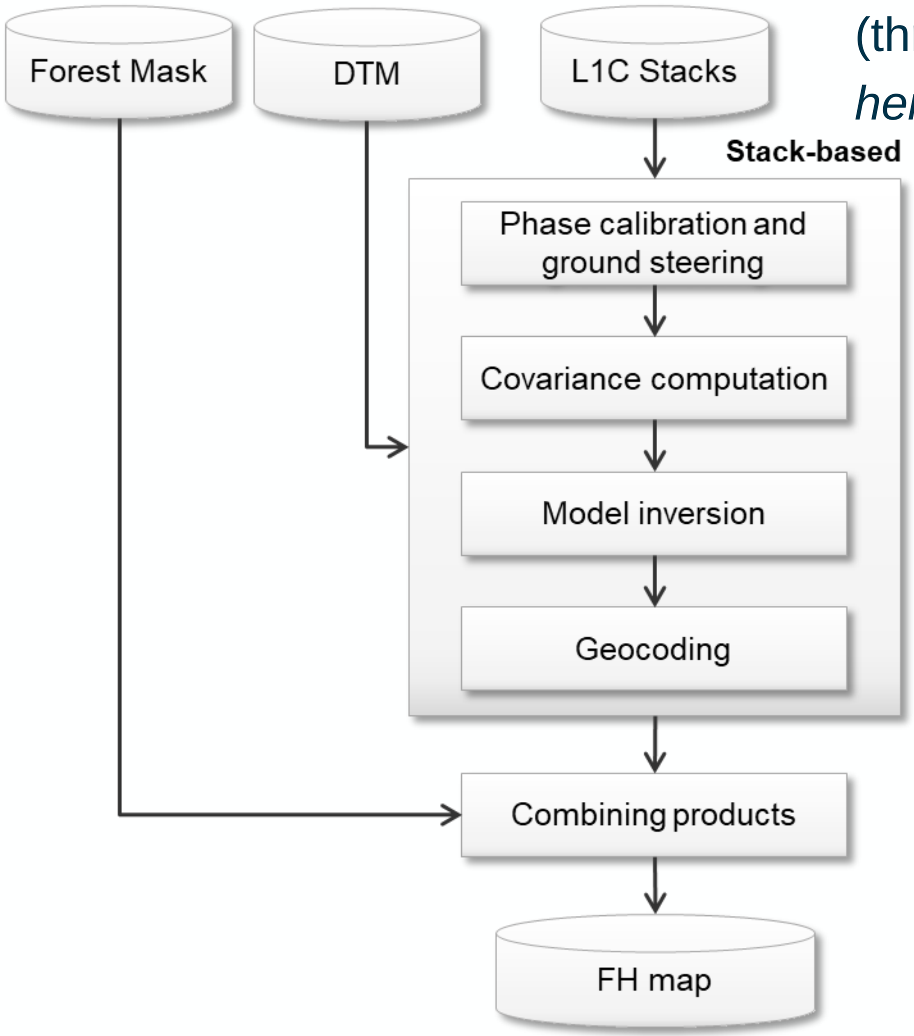
- airborne SAR acquisitions from AfriSAR filtered to 6 MHz and multi-looked to mimic BIOMASS
- topography estimated using tomographic processing, estimated DTM used for the generation of ground-cancelled SAR images
- > 500 independent tests with different sets of >100 t/ha training areas chosen at random
- relative RMSD wrt reference ALS data between 18% and 33% at 2.25 ha resolution in areas with large AGB variability and an average AGB around 200–250 t/ha
- global AGB retrieval is intended to proceed using GEDI as reference
- approach based on region block processing is currently under evaluation









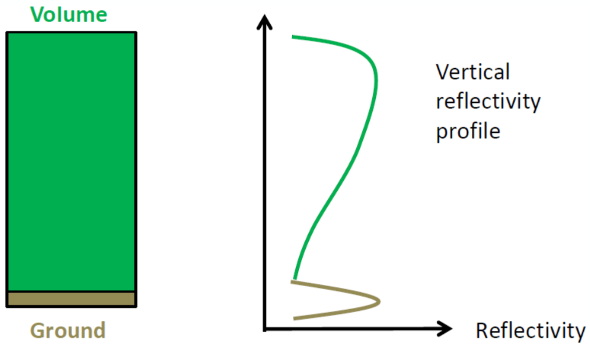


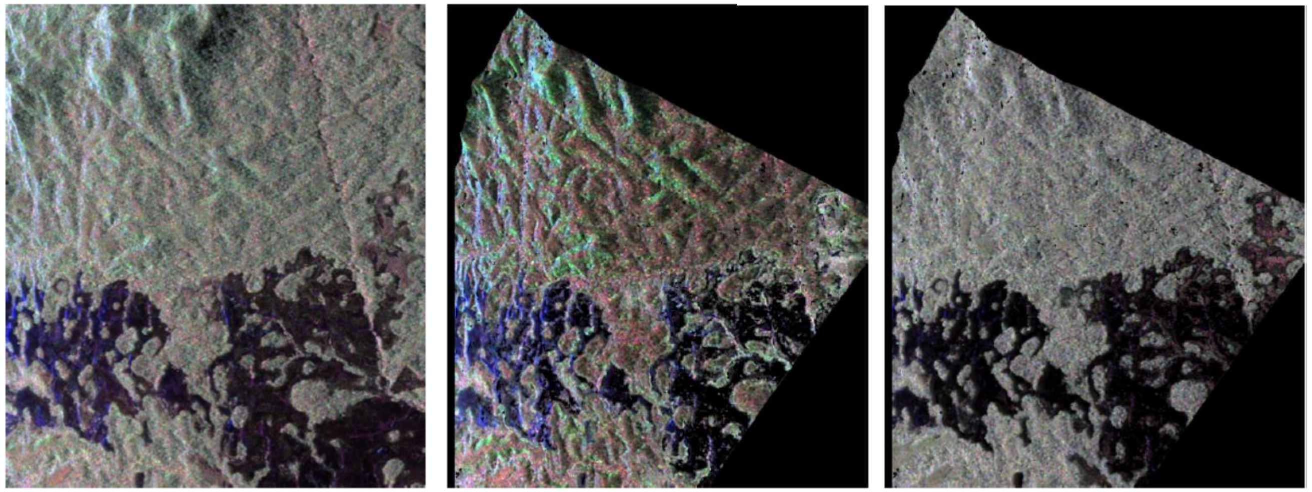
PolInSAR inversion: polarimetric-interferometric correlations are linked (through RVoG model) to forest structural parameters such as *forest height, ground-to-volume ratio, temporal decorrelation*

ground & volume are uncorrelated

Dirac-delta ground reflectivity

Polarimetry & Interferometry are independent

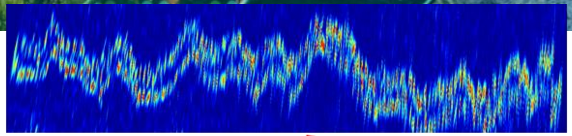




Original Ground Volume

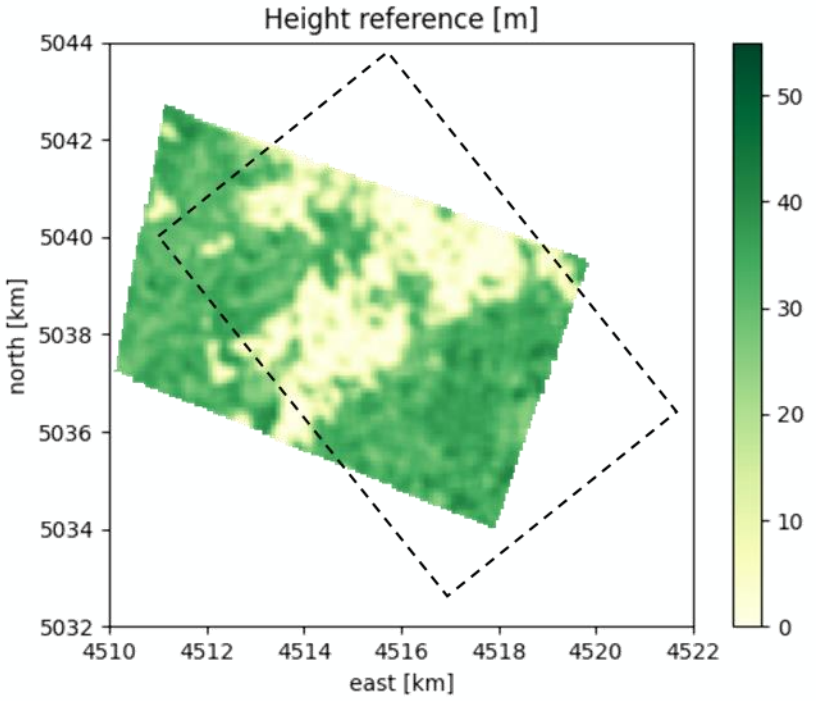
FOREST HEIGHT RESULTS FROM CAMPAIGN DATA

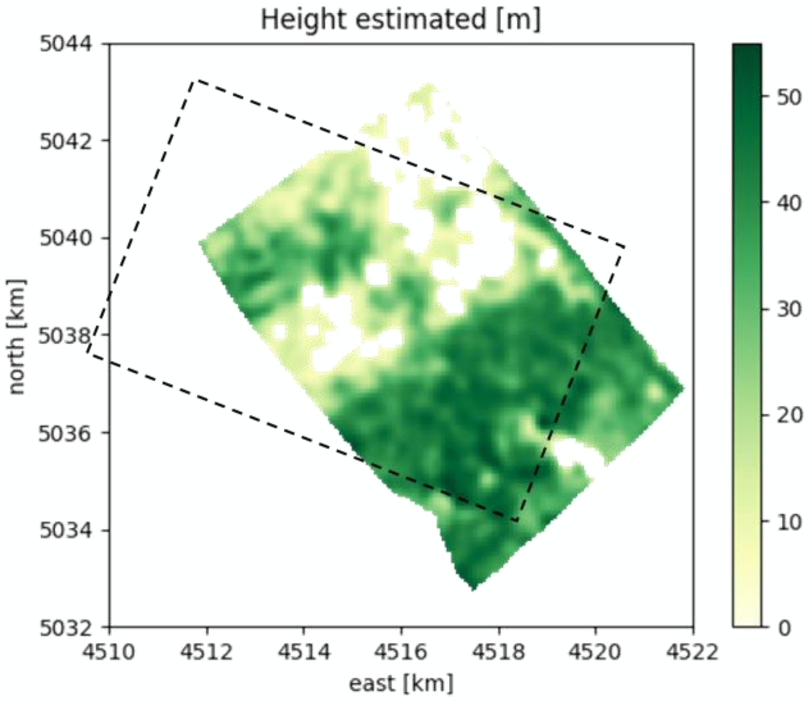
- Based on triplets to mitigate temporal decorrelation
- Exploits previous info from the Tomographic phase
- RMSD values of 20%-30% on higher trees

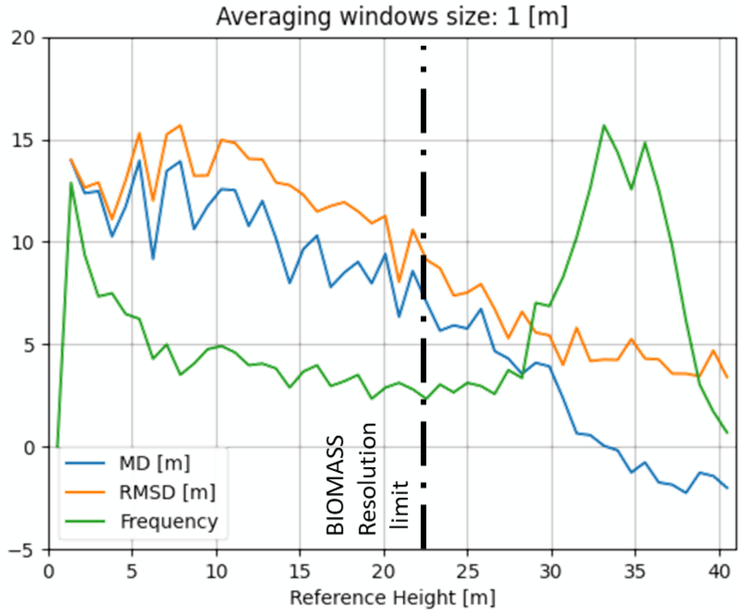


$$\tilde{\gamma}_{Obs}(\kappa_z, \vec{w}) = \exp(i\varphi_0)\,\frac{\gamma_{TempV}\,\tilde{\gamma}_{V0}(\kappa_z) + m(\vec{w})}{1 + m(\vec{w})}$$

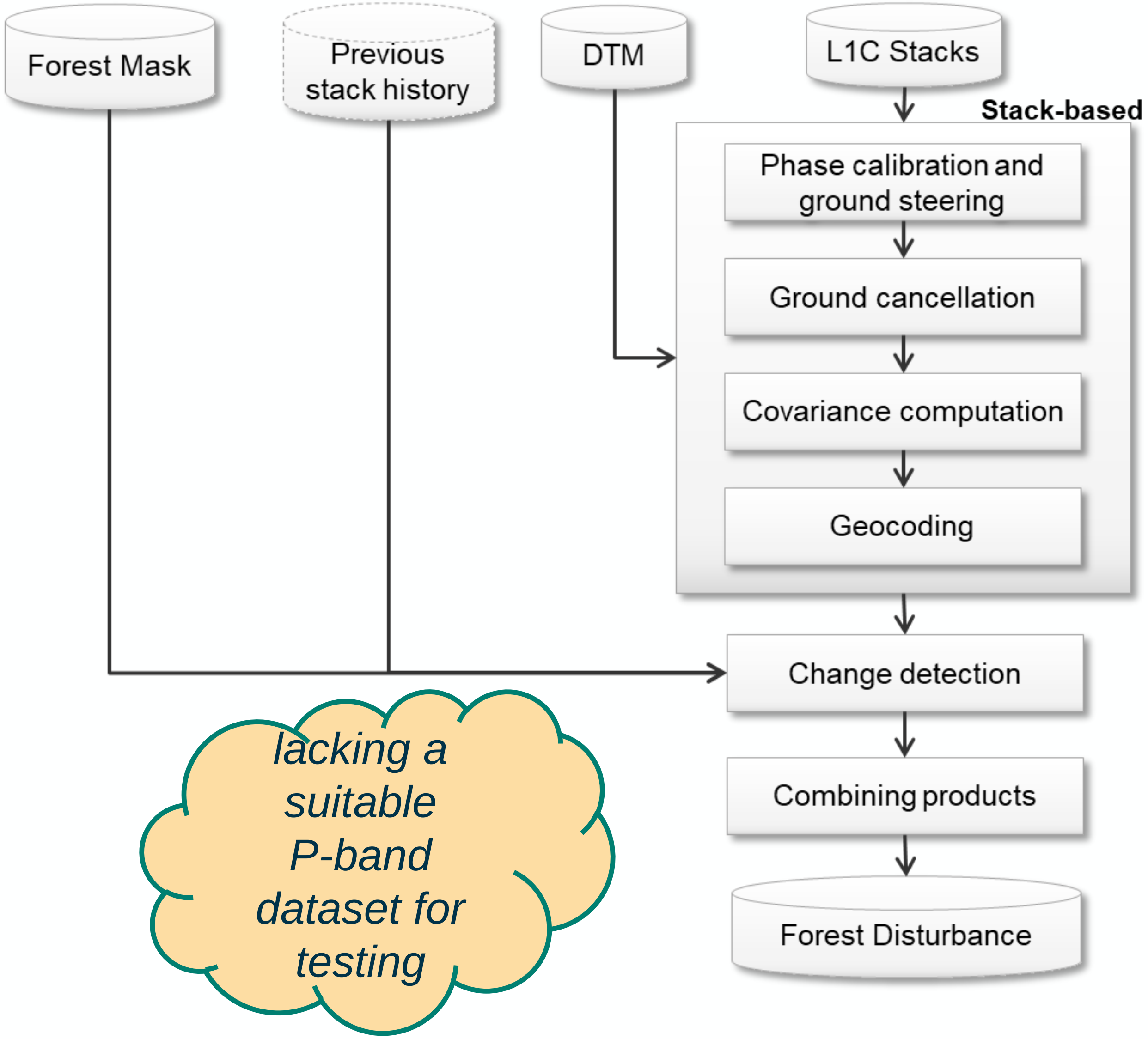
$$\tilde{\gamma}_{V0}(\kappa_z) = \frac{\int_{z_0}^{z_0+h_V} P_V(z)\exp(i\kappa_z z)dz}{\int_{z_0}^{z_0+h_V} P_V(z)(z, \vec{w})\, dz}$$





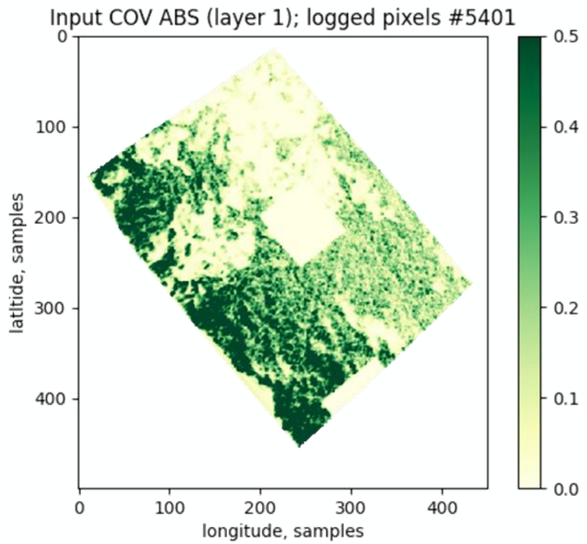


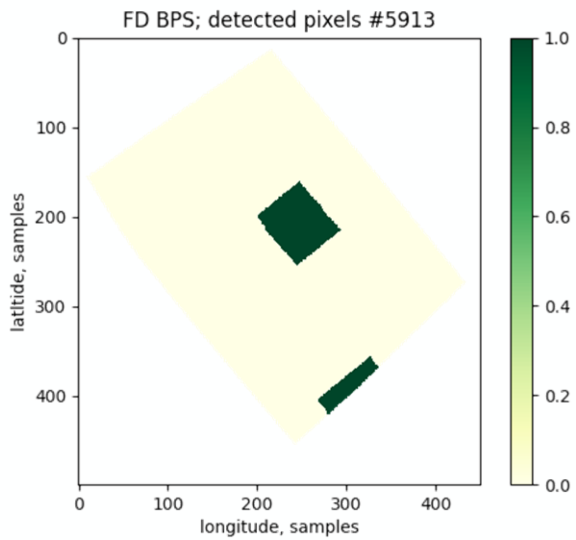
FOREST DISTURBANCE ESTIMATION SCHEME



Change detection:

- null hypothesis: no change has occurred in a time series of polarimetric data
- If this hypothesis fails at a given level of significance, then we assume a change has occurred
- only deforestation is targeted





SUMMARY AND CONCLUSIONS

BIOMASS L2 processor implements state-of-the art SAR processing techniques that exploit polarimetric and baseline diversity

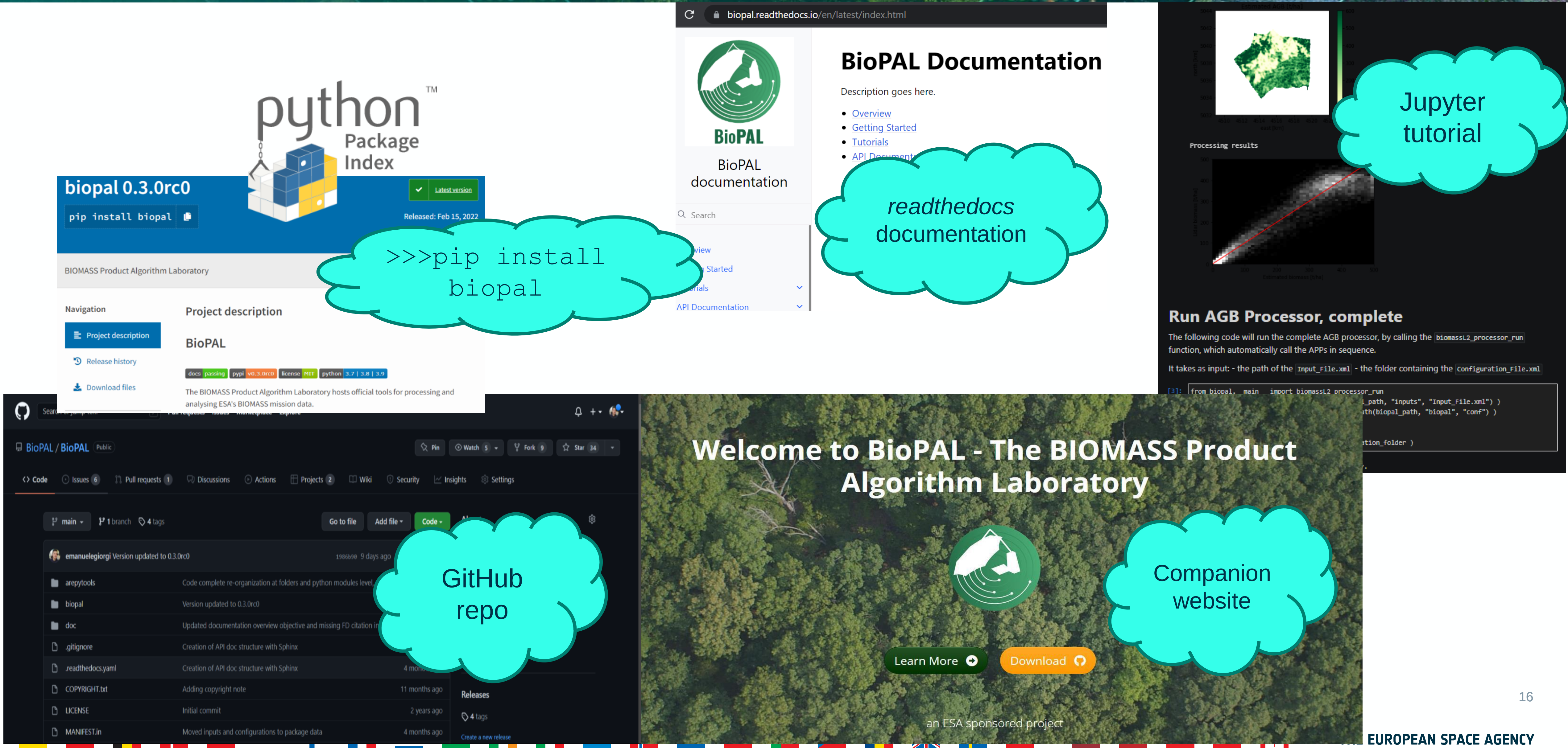
BIOMASS prototype L2 processor has been completed but the algorithms are still under development in synergy with operational BIOMASS Processing Suite

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 few “good” reference points, although retrieval accuracy was observed to depend significantly on the quality of the available reference points

BioPAL
BIOMASS Product Algorithm Laboratory



= Open Source Software Project

= official BIOMASS algorithms

= first time that official algorithms are made publicly accessible

biopal@esa.int

biopal.org

github.com/BioPAL

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