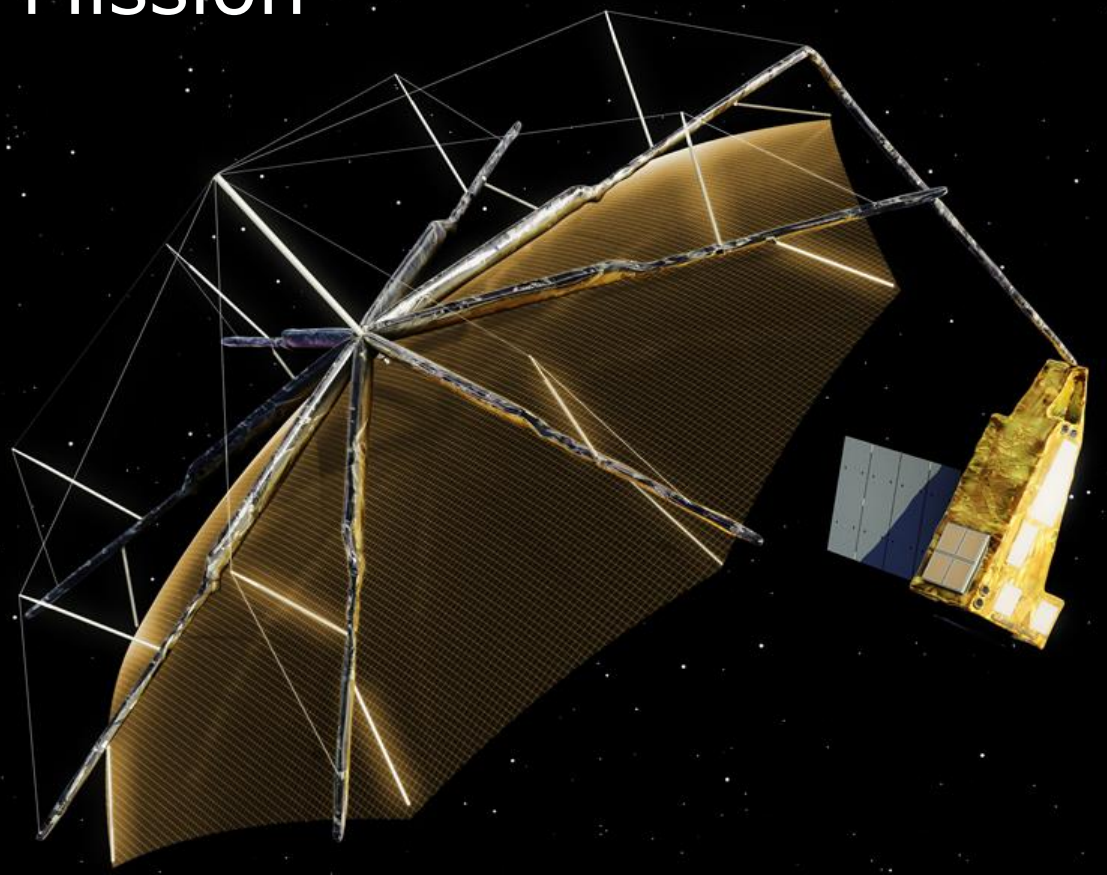
The Biomass Mission – ESA's Forest mission

ESA LAND TRAINING 2021
KLAUS SCIPAL

The BIOMASS Mission

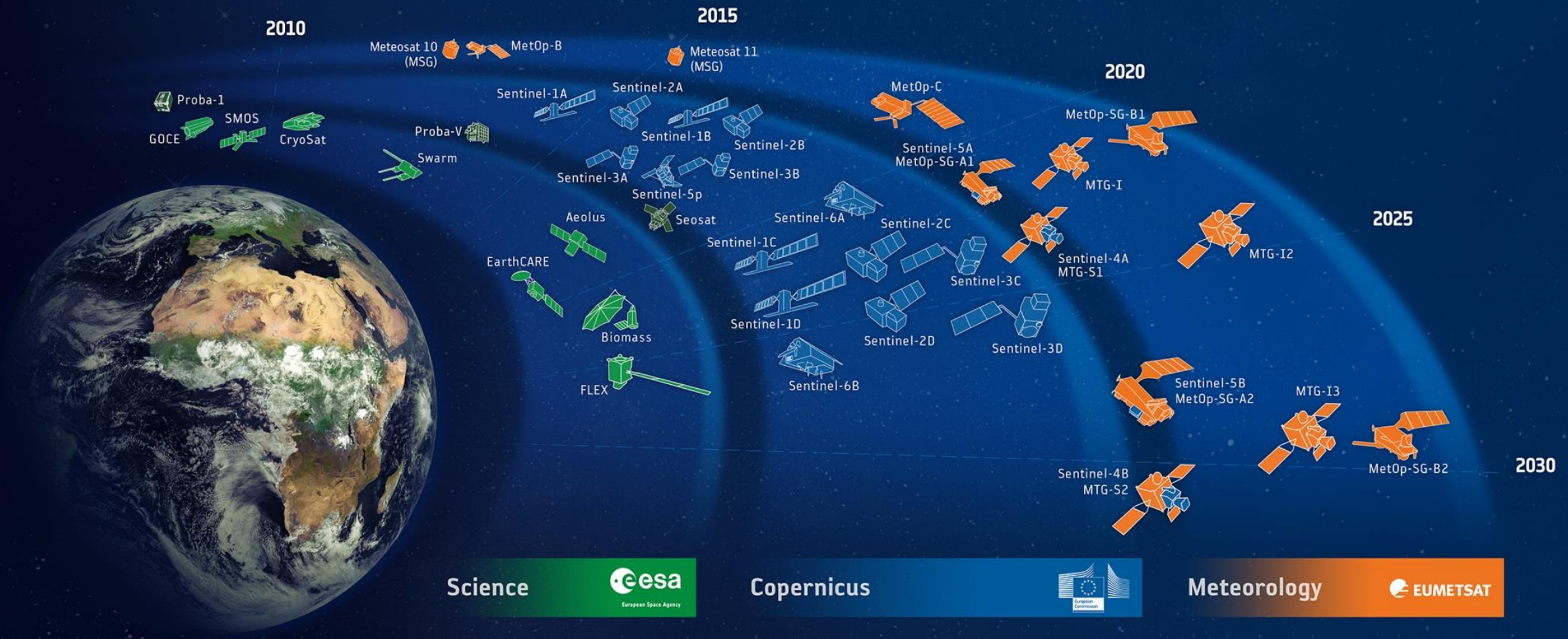


ESA’s 7th Earth Explorer to be deployed in 2023

An interferometric, polarimetric P-band SAR

Designed to observe forest height and biomass

ESA–DEVELOPED EARTH OBSERVATION MISSIONS



www.esa.int

European Space Agency

Fate of Anthropogenic CO_2 Emissions (2010-2019)

SOURCES

35.2±1.8 $GtCO_2/yr$

5.9±2.6 $GtCO_2/yr$

SINKS

18.7±0.1 $GtCO_2/yr$

12.5±3.3 $GtCO_2/yr$

9.2±2.2 $GtCO_2/yr$

Global Carbon Project, 2020

What information do we need?

1. We need estimates of **forest biomass (AGB),** height and disturbances.
2. The **crucial information need is in the tropics**:

   deforestation (~95% of the Land Use Change flux)

   regrowth (~50% of the global biomass sink)
3. Biomass measurements are needed where the changes occur and at the **effective scale of change**: 4 hectares.
4. Measurements are needed **wall-to-wall** with **repeated measurements** over multiple years to identify deforestation and regrowth.
5. A biomass accuracy of 20% at 4 hectares, **comparable to ground-based observations.**

How to measure biomass from space?

Tree allometry links biomass to

$$AGB = \rho \cdot D^2 \cdot H$$

Wood density

Diameter

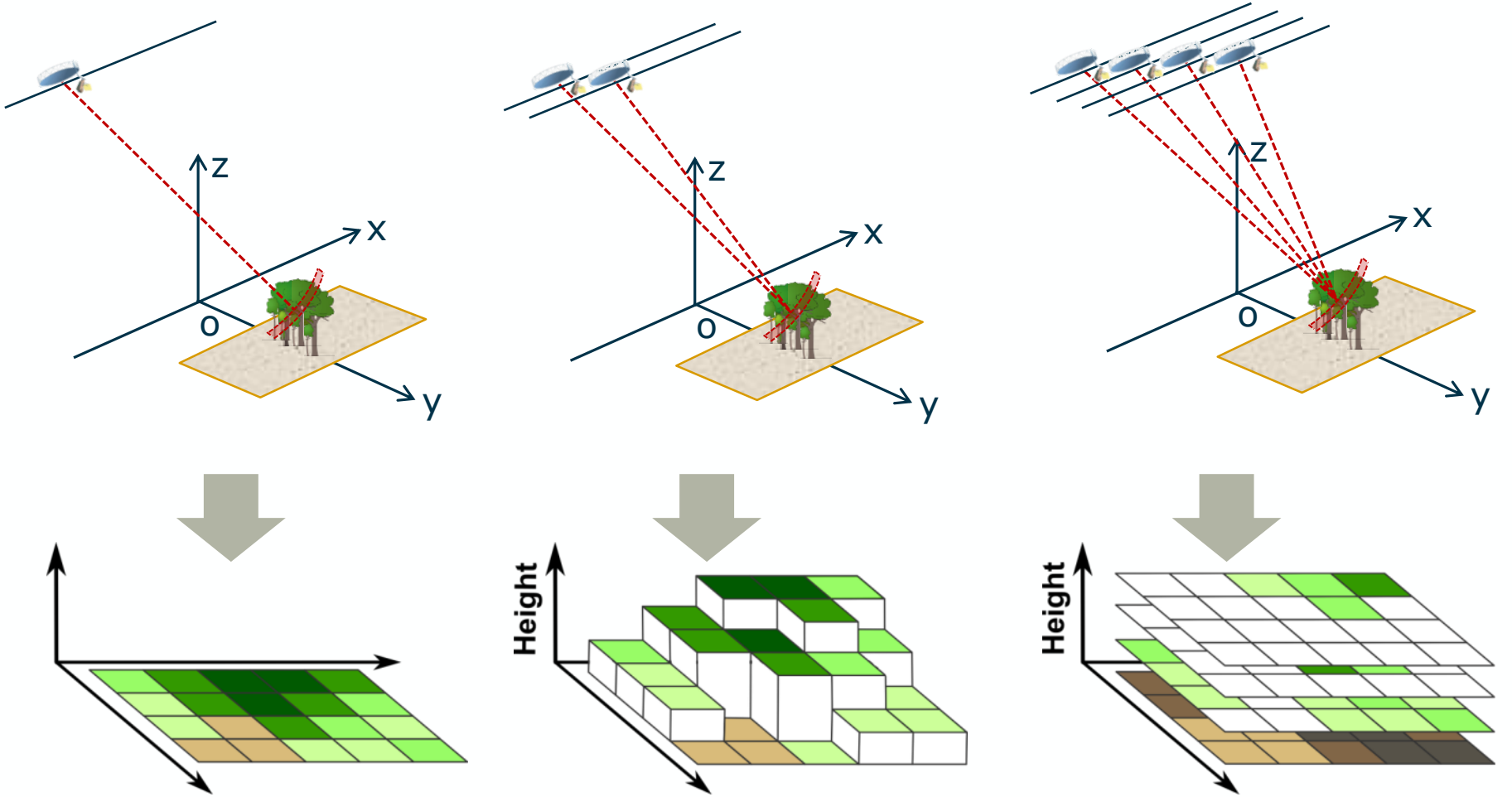
Height

SAR can deliver 3 independent types of information related to biomass

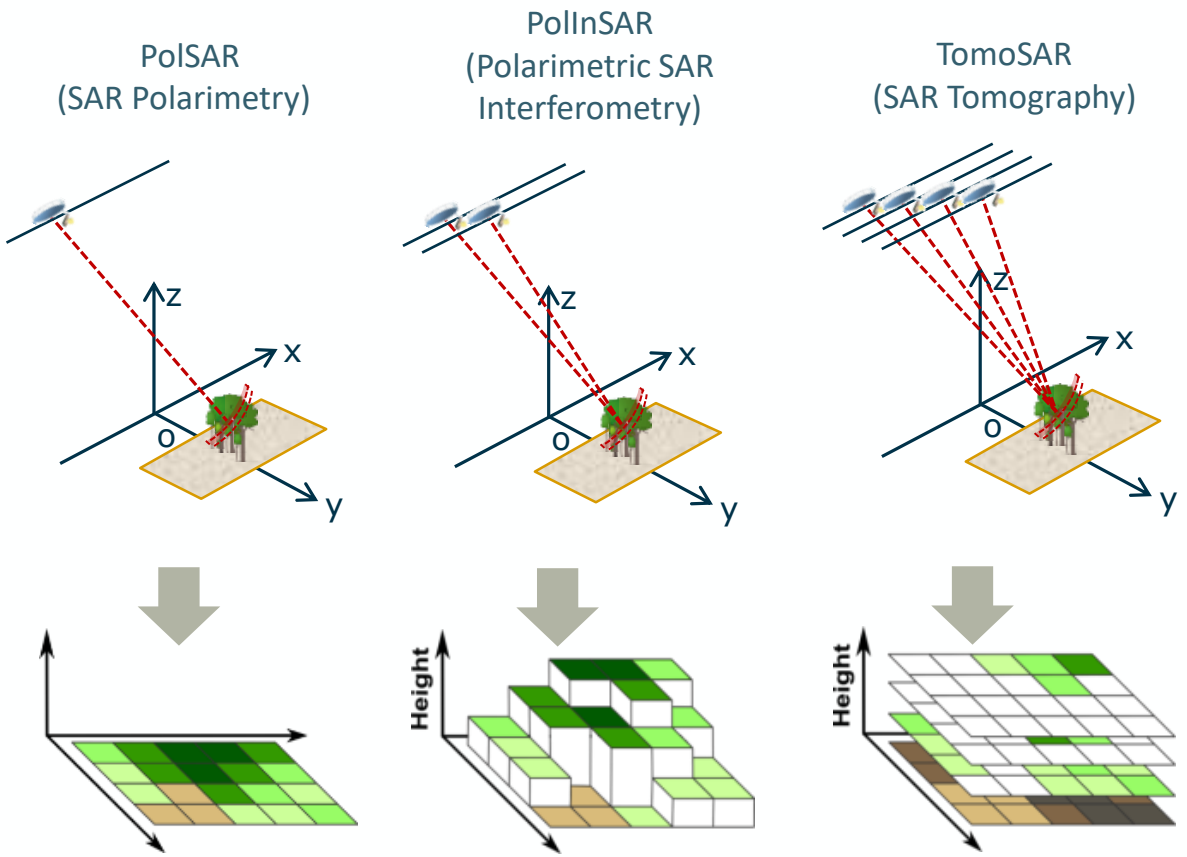
PolSAR
(SAR Polarimetry)

PolInSAR
(Polarimetric SAR Interferometry)

TomoSAR
(SAR Tomography)



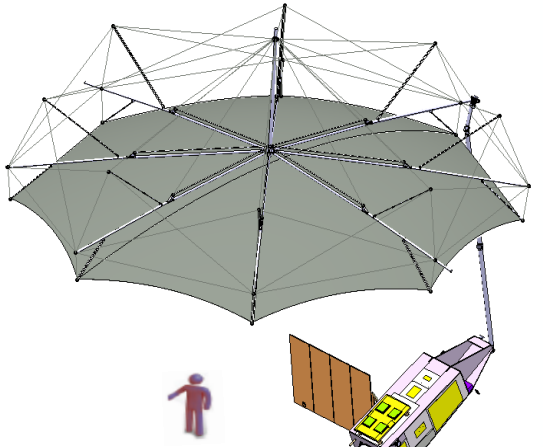
Biomass Mission Concept

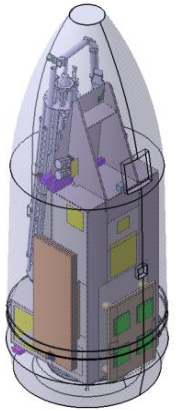


- ✓ Single satellite, operated in a polar sun-synchronous orbit
- ✓ Full polarimetric P-band (435 MHz) Synthetic Aperture Radar with 6 MHz bandwidth
- ✓ Two mission phases: Tomography (first 18 months), Interferometry (rest of the mission lifetime)
- ✓ Multi-repeat pass interferometry (3 passes in nominal operations) with a 3 days repeat cycle
- ✓ Global coverage in ~9 months on asc. and des. passes
- ✓ 5 years lifetime

The Biomass Spacecraft

Key Parameters	
Sensitivity (NESZ)	≤ -27 dB
Total Ambiguity Ratio	≤ -18 dB
SLC resolution	≤ 60m x 8m
Dynamic Range	35 dB
Radiometric Stability	≤ 0.5 dB
Radiometric Bias	≤ 0.3 dB
Crosstalk	≤ -30 dB





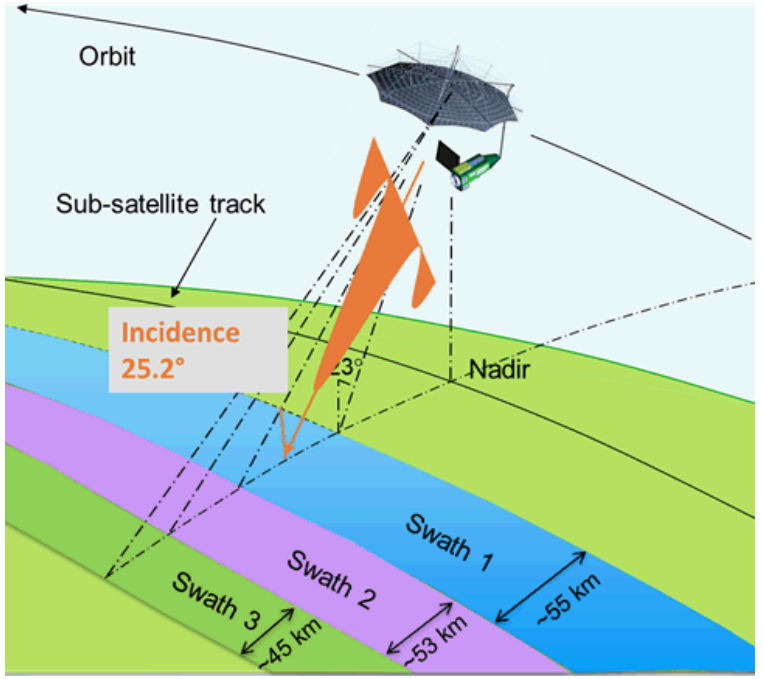
AIRBUS

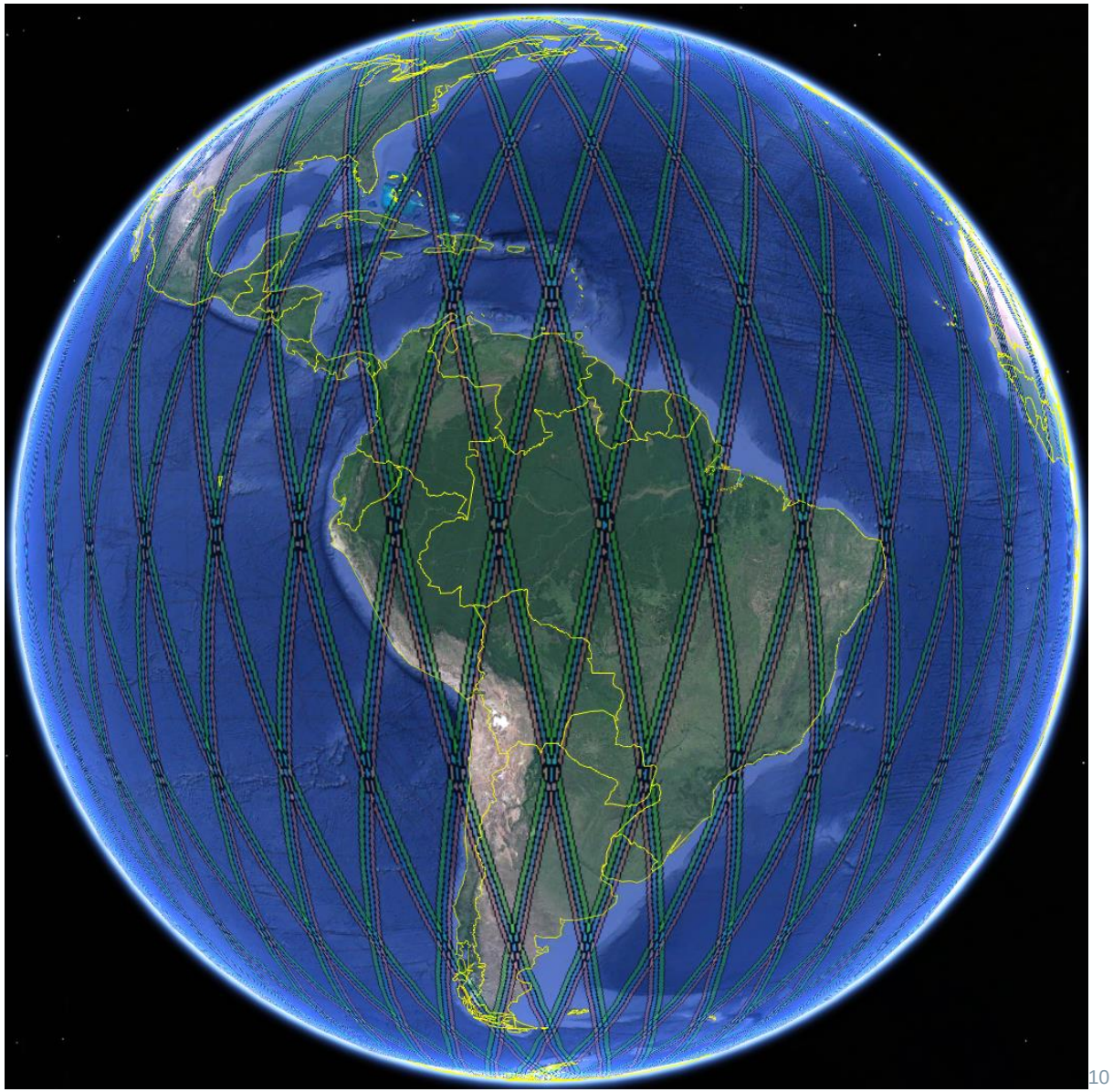
ThalesAlenia Space

L3HARRIS™

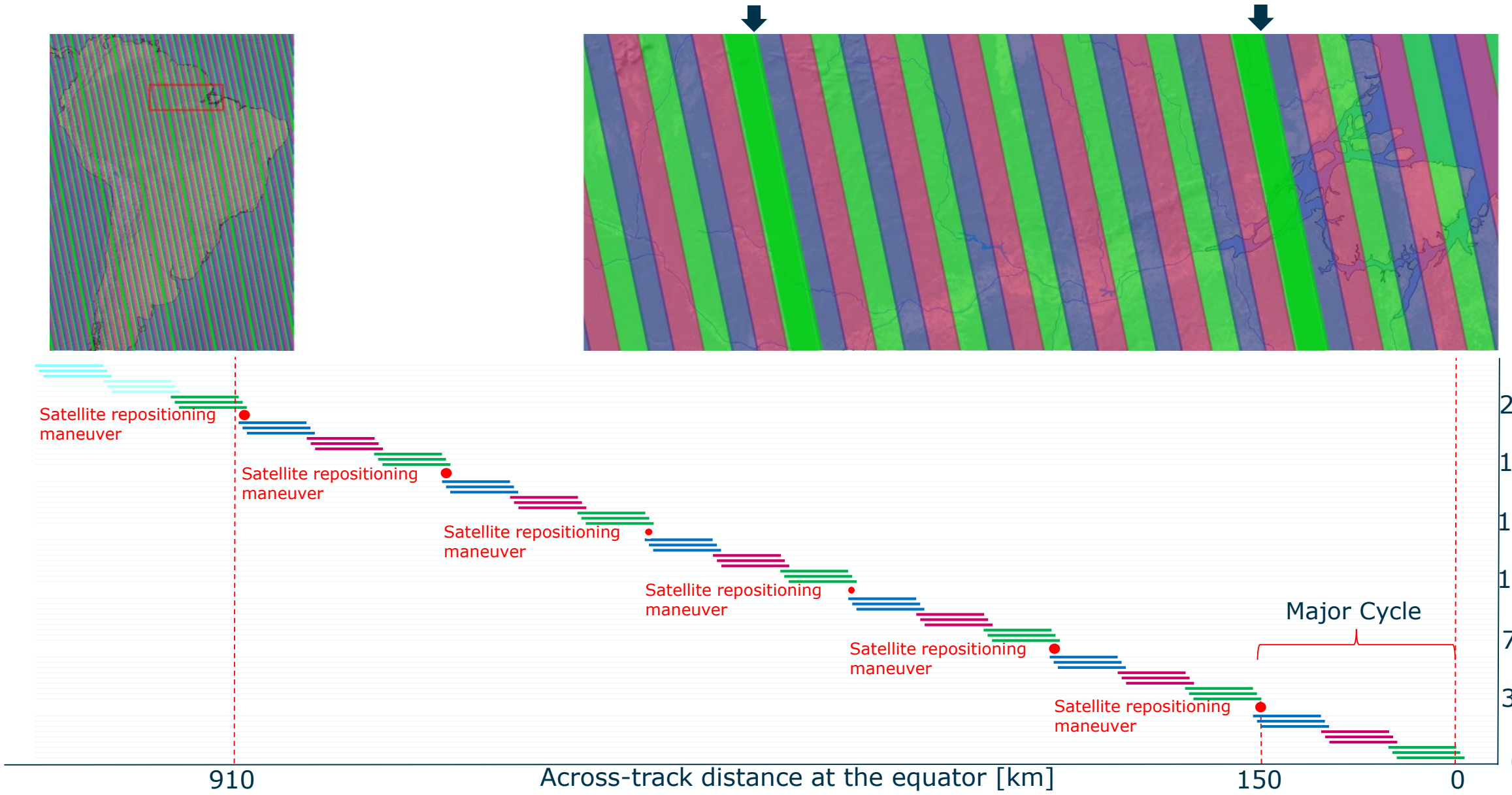
Biomass orbit & swath considerations

- Sun-synchronous 666 km dawn-dusk orbit
- 3-day repeat
- small East-West drift to implement baselines
- Stripmap mode operation
- Satellite roll for swath access (left-looking)
- Satellite repositioning manoeuvre after each “major cycle”



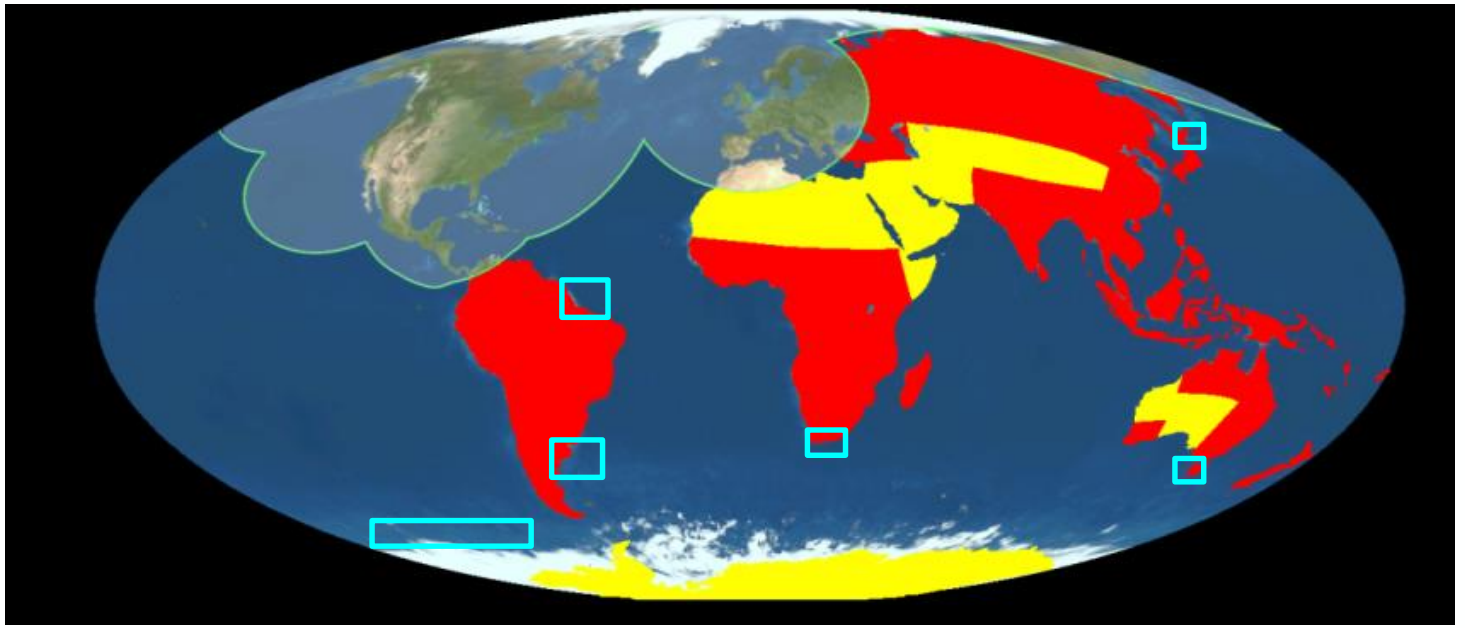


Global Coverage Strategy



Coverage

1. Systematic Acquisitions for forested land (red area)
2. Global coverage in 9 months (INT phase) and 18 months (TOM phase).
3. Best effort acquisitions for non forested areas (yellow + ocean/sea ice ROIs)
4. Acquisition mask restricted by US Space Objects Tracking Radar (SOTR)



(Red = Primary objective coverage mask, Yellow = Secondary objective coverage mask)

What information will we get from Biomass

Above-ground biomass (tons/hectare)

- 200 m resolution
- 1 map every 6 months
- global coverage of forested areas
- accuracy of 20%, or 10 t ha^{-1} for biomass < 50 t ha^{-1}

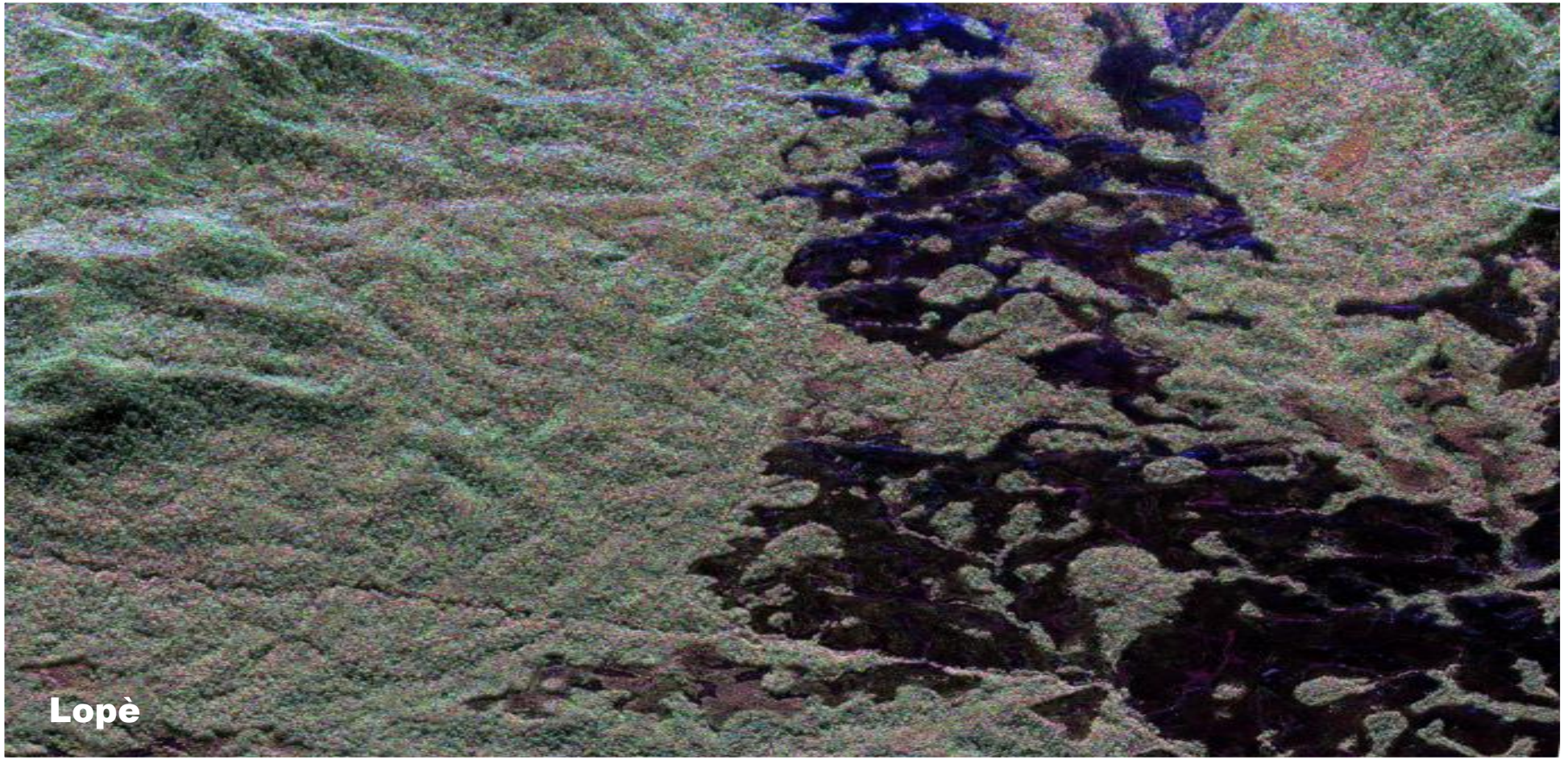
Upper canopy height (meter)

- 200 m resolution
- 1 map every 6 months
- global coverage of forested areas
- accuracy of 20-30%

Areas of forest clearing (hectare)

- 50 m resolution
- 1 map every 6 months
- global coverage of forested areas
- 90% classification accuracy

Tropical Forest as seen by DLR‘s P-band F-SAR

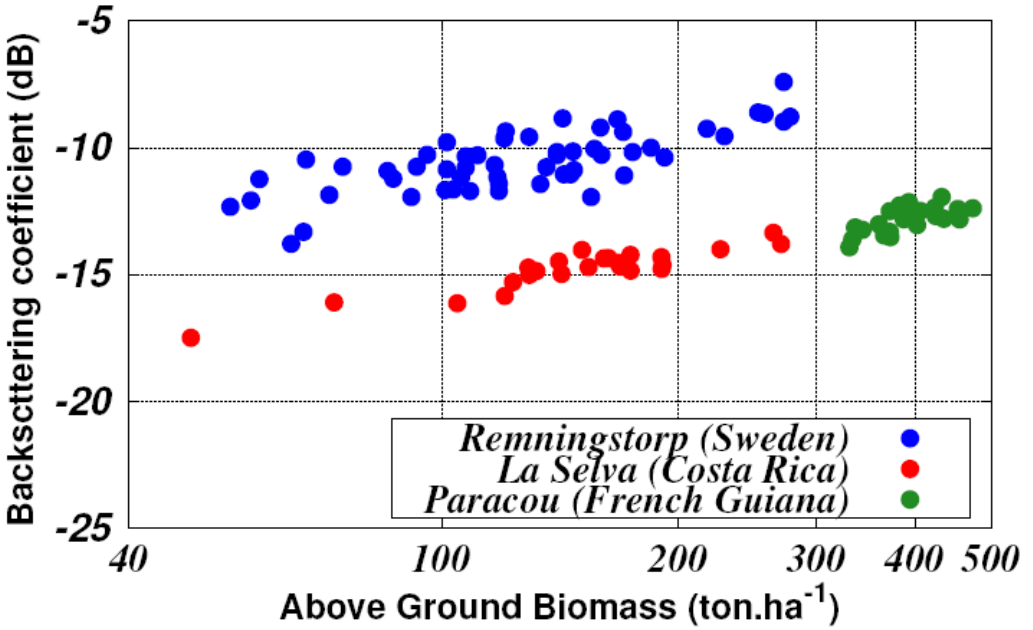


HH+VV HV HH-VV

How to we use the observations

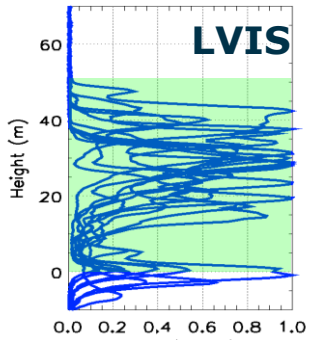
The simplest inversion: Similar power-law relationships between backscatter and biomass are found for all forests where we have data

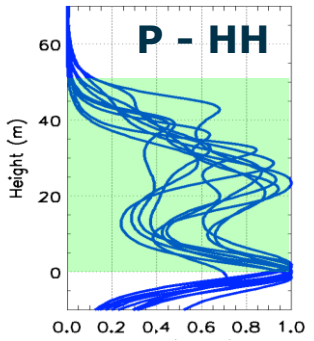
$$\log(AGB) = a + b \cdot \gamma^{0}{}_{HV}$$

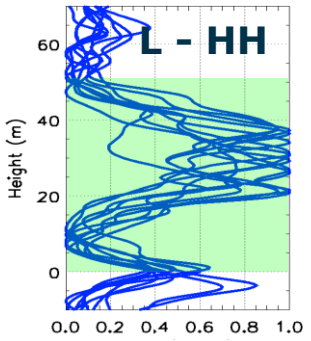


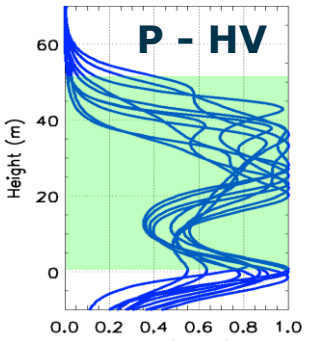
Information content of P-, L- band SAR and lidar

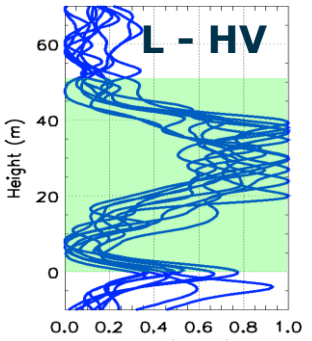
LNL-10 (MAR1)



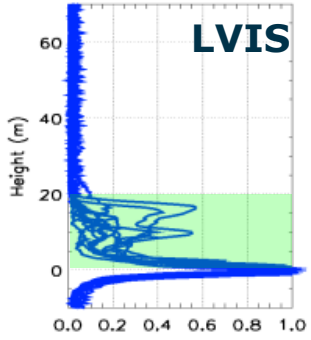


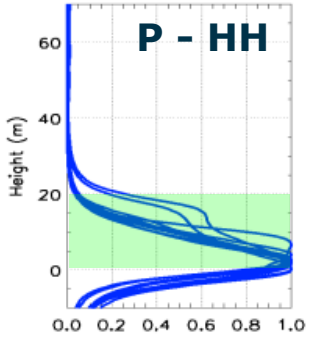


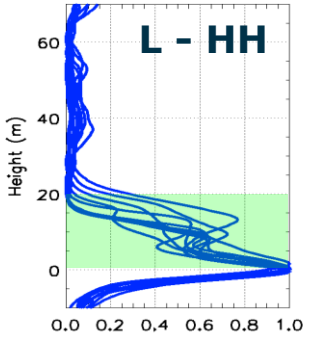


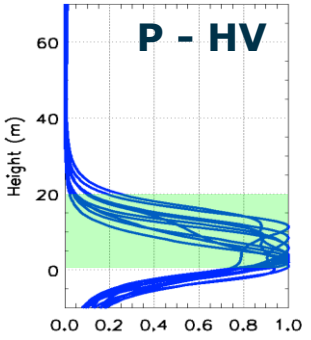


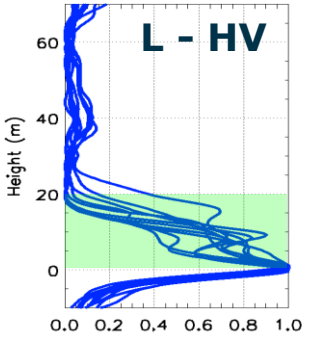
LNL-05 (COL2)



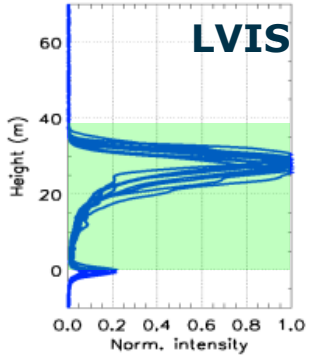


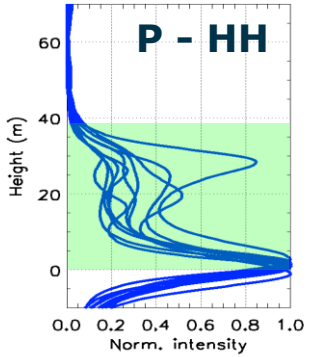


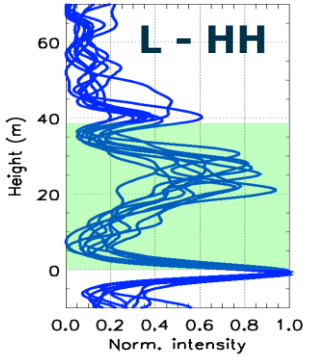


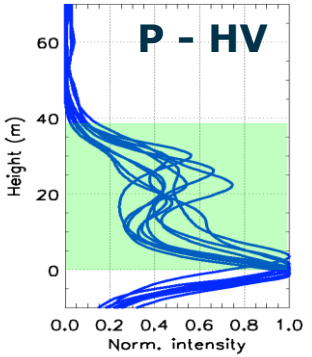


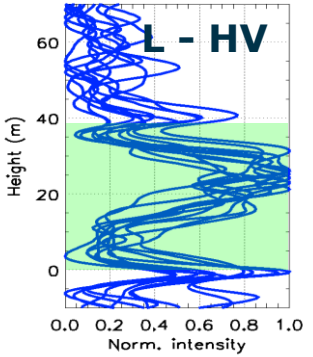
LNL-08 (OKO2)







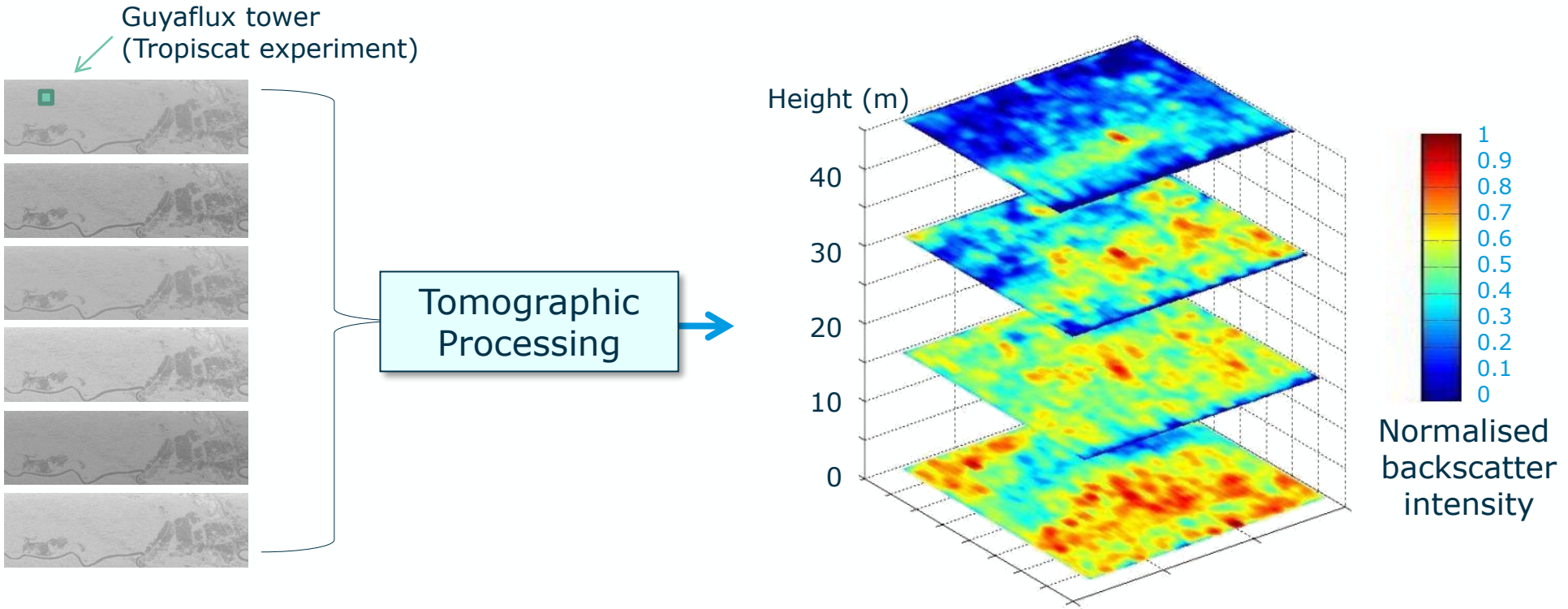




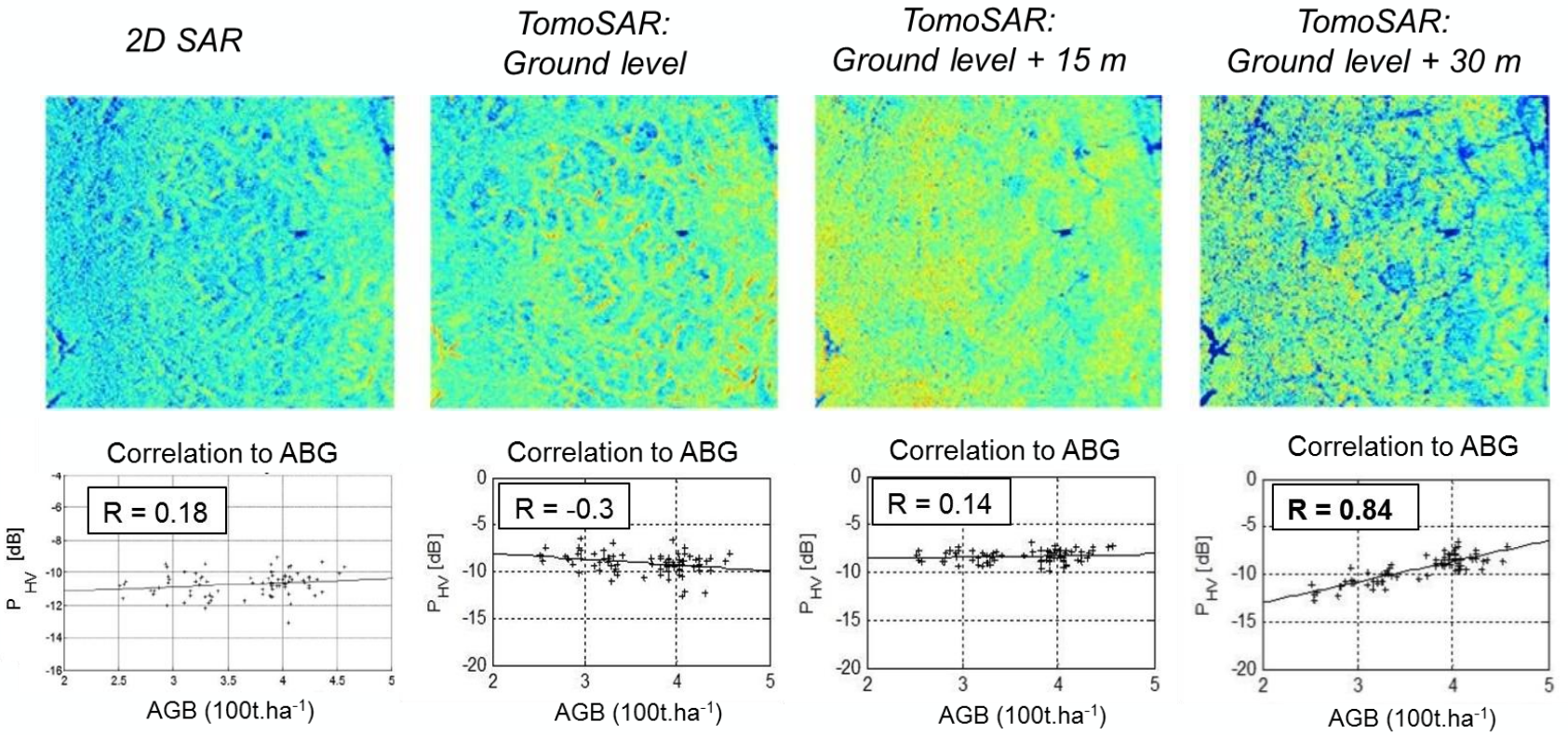
Courtesy: M. Pardini - DLR

SAR tomography, a new concept to explore 3D forest structure

Generates images of different forest layers from multi-orbit SAR images



Tomographic imaging in Paracou



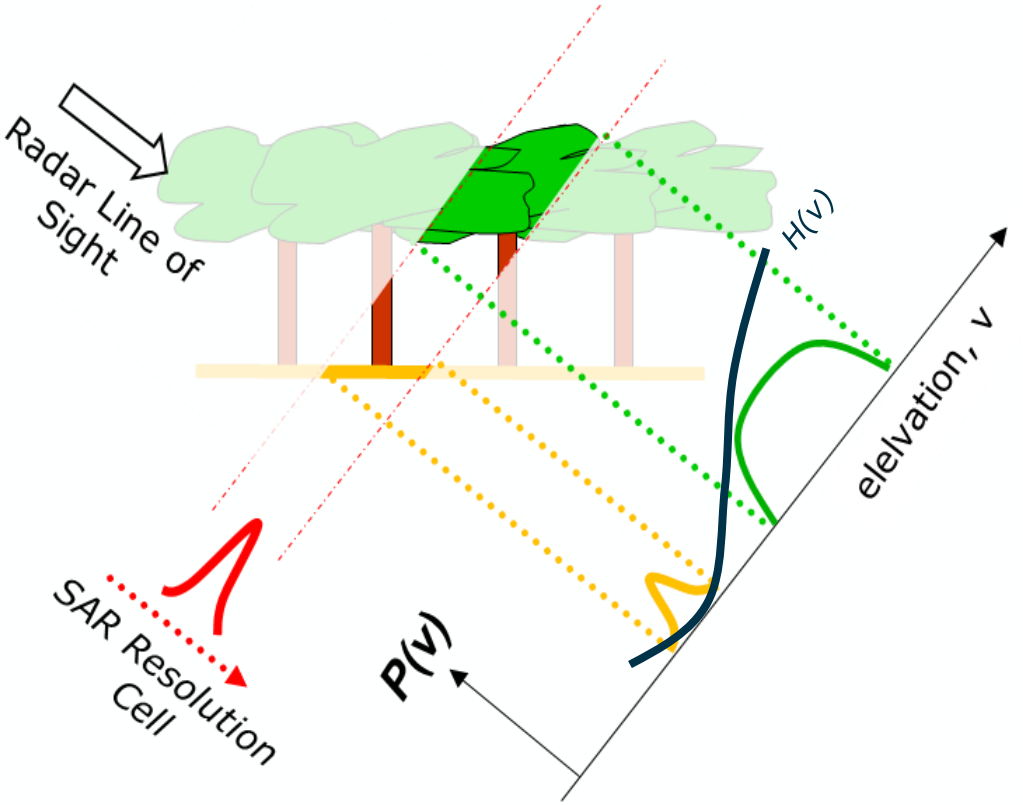
D. Ho Tong Minh et al., "Relating P-band SAR tomography to tropical forest biomass", TGRS, Feb. 2014.

Interferometric ground notching

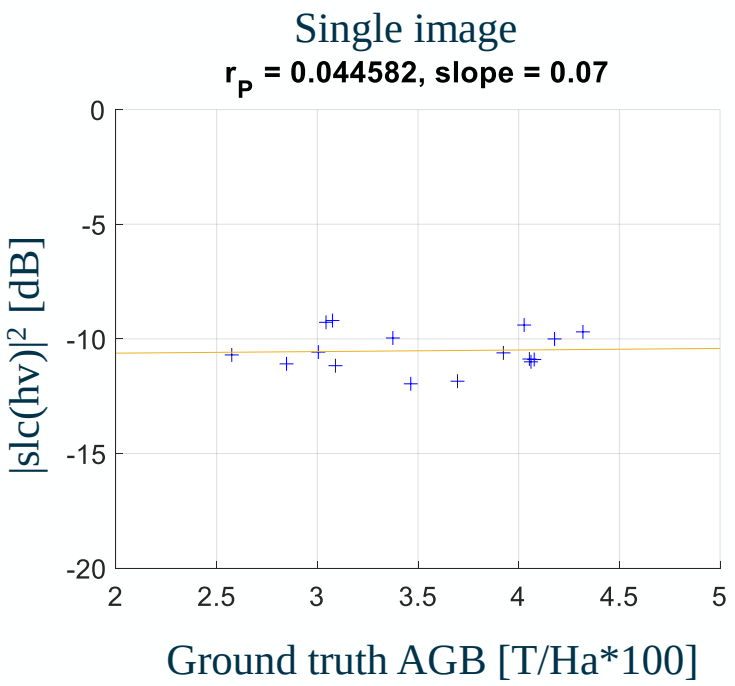
Ground cancellation: Inspired by this new understanding, the ground cancellation technique was developed to preserve the advantages of SAR Tomography during Mission lifetime.

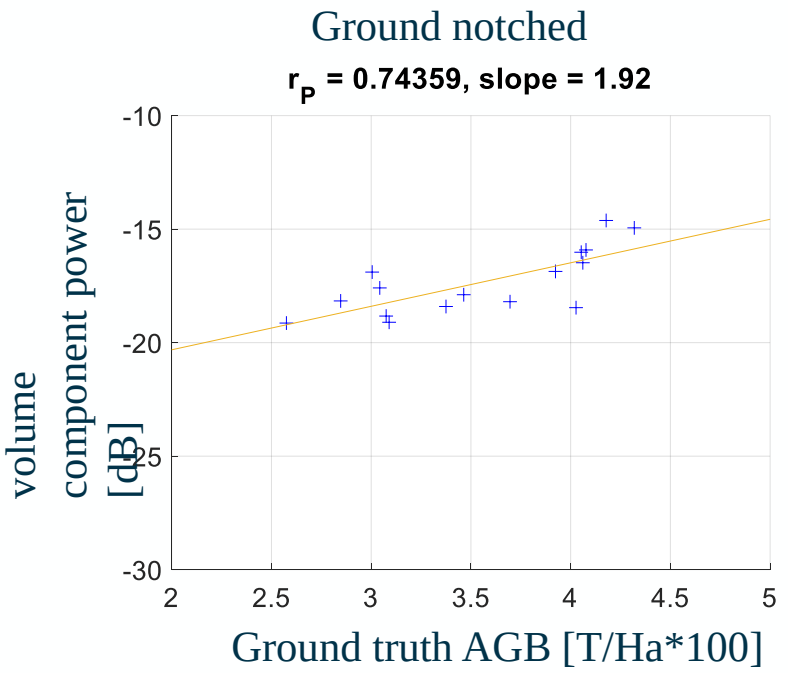
Idea: cancel out ground scattering by taking the difference between two phase calibrated SLC BIOMASS images.

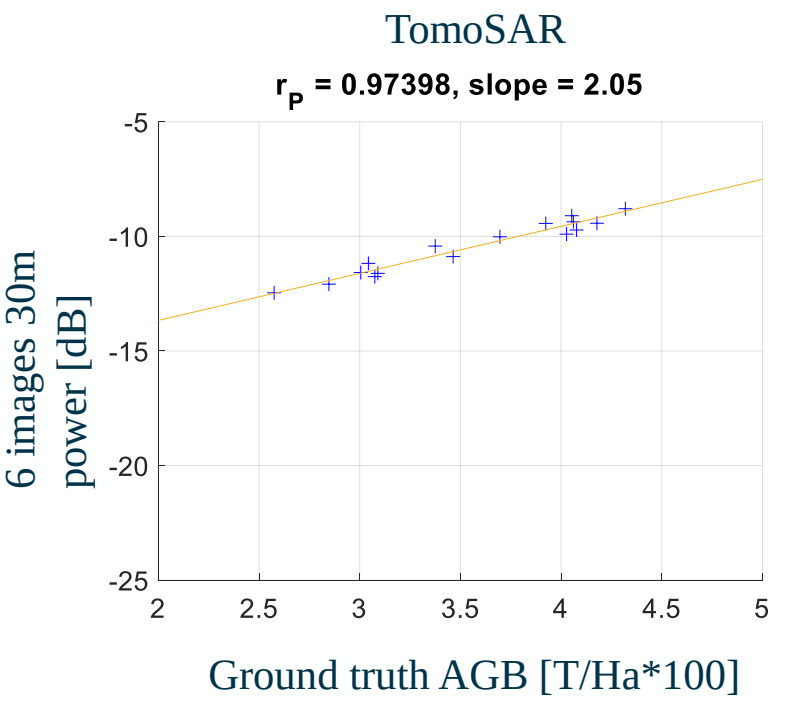
Principle: SLC = projection of modulated target reflectivity along elevation.



AGB vs TropiSAR backscatter







Ground rejection greatly improves the sensitivity and correlation

Using physical models to estimate AGB

Retrieval algorithm

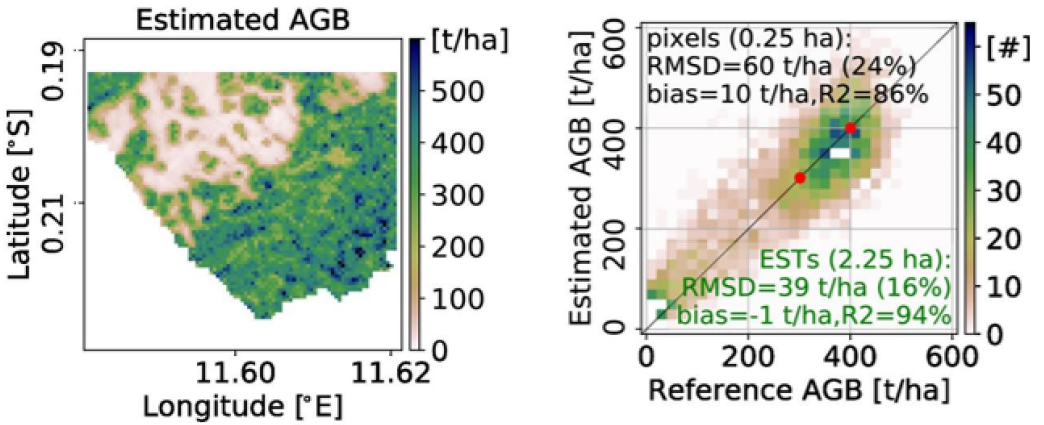
- The starting point of the inversion algorithm is the *volume+db+soil* formalized by the *Truong-Loi model*
- ☺ This model is considerably simplified when applied to ground cancelled data

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

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

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

W = AGB
θ = incidence angle
pq = polarization



Join the adventure!

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

Summary – BIOMASS a true Earth Explorer

1. BIOMASS implementation started in Nov. 2013. We just closed Phase C and start with the assembly of the whole system. We are working towards a launch in 2023.

2. BIOMASS is the first P-band SAR and first systematic radar tomographic space mission; it is a true Earth Explorer with a lot of unknowns and exciting science for global biomass mapping.

3. It is the first Open Source Earth Explorer.

4. The new unique vision of Earth from Biomass will extend beyond forests and into measurements of ice, sub-surface geomorphology in deserts, topography, the ionosphere, ocean ...