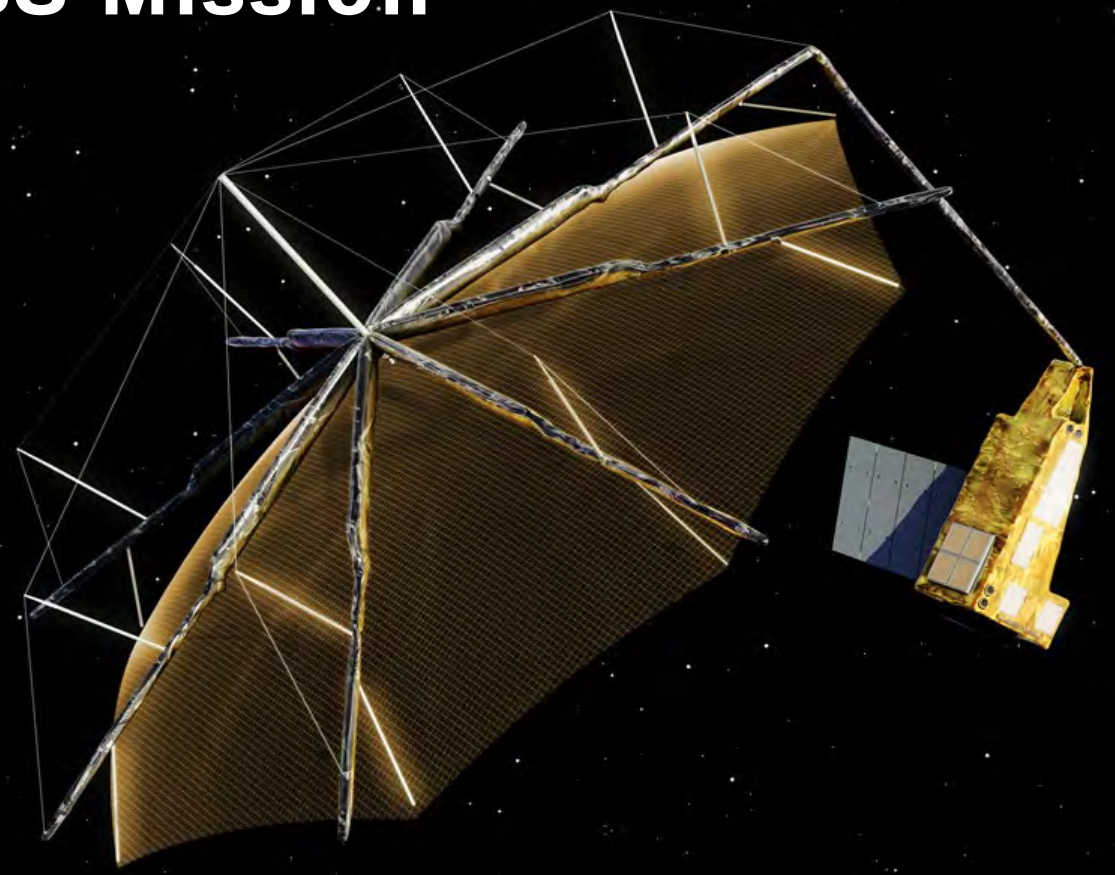
The BIOMASS Mission – ESA's PolInSAR mission

PolInSAR training course

10/05/2021

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

2010

Proba-1
SMOS
GOCE
CryoSat

2015

Meteosat 10 (MSG)
MetOp-B
Meteosat 11 (MSG)
Sentinel-1A
Sentinel-2A
Proba-V
Swarm
Sentinel-1B
Sentinel-2B
Sentinel-3A
Sentinel-3B
Sentinel-5p
Seosat
Aeolus
EarthCARE
Biomass
FLEX
Sentinel-1C
Sentinel-6A
Sentinel-2C
Sentinel-1D
Sentinel-2D
Sentinel-6B
Sentinel-3C
Sentinel-3D

2020

MetOp-C
MetOp-SG-B1
Sentinel-5A
MetOp-SG-A1
MTG-I
Sentinel-4A
MTG-S1

2025

MTG-I2
Sentinel-5B
MetOp-SG-A2
MTG-I3
Sentinel-4B
MTG-S2
MetOp-SG-B2

2030

Science

Copernicus

Meteorology

EUMETSAT

www.esa.int

European Space Agency

Fate of Anthropogenic CO_2 Emissions (2005-2015)

SOURCES

34.1±1.7 $GtCO_2$/yr 91%

3.5±1.8 $GtCO_2$/yr 9%

PARTITIONING

16.4±0.4 $GtCO_2$/yr
44%

11.5±3.1 $GtCO_2$/yr
31%

9.7±1.8 $GtCO_2$/yr
26%

What information do we need?

1. We need estimates of **forest biomass, 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**
5. A biomass accuracy of 20% at 4 hectares, **comparable to ground-based observations**
6. Detection of **deforestation at 0.25 ha**
7. **Repeated measurements** over multiple years to identify deforestation and regrowth

How to measure biomass?

Tree allometry links biomass to

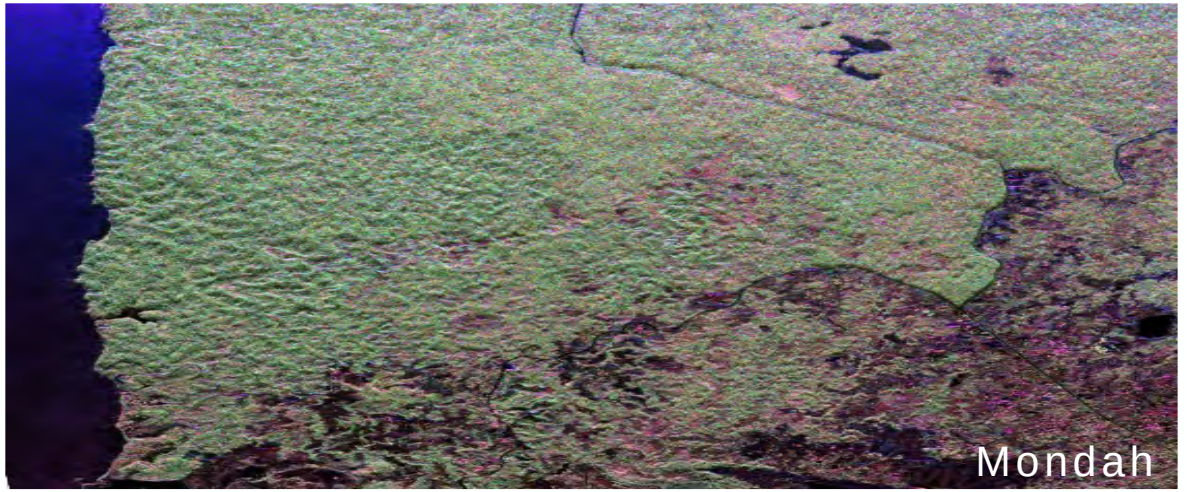
$$AGB = \rho \cdot D^2 \cdot H$$

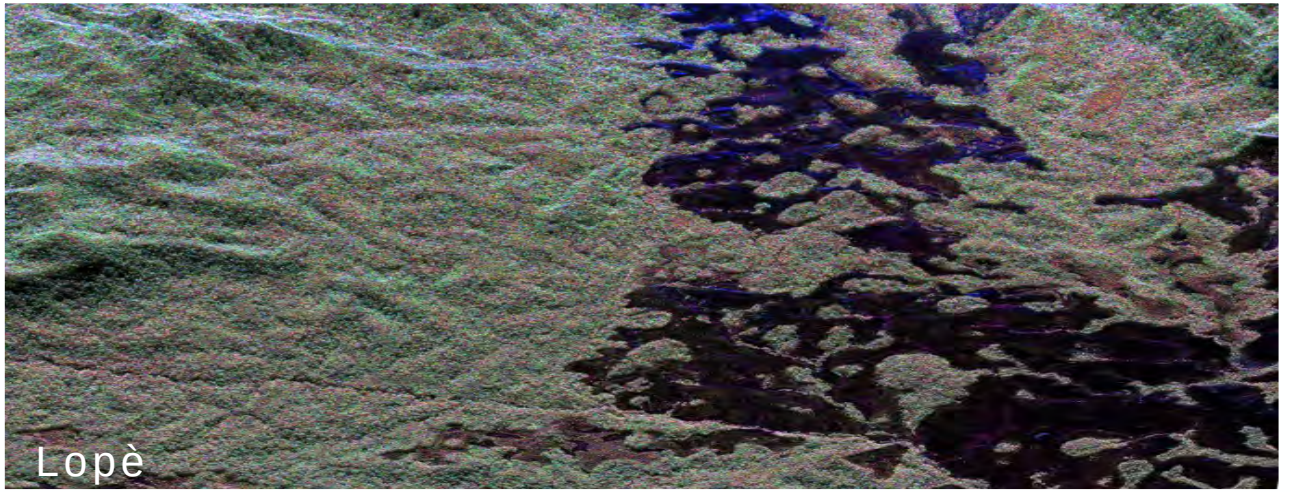
Wood density

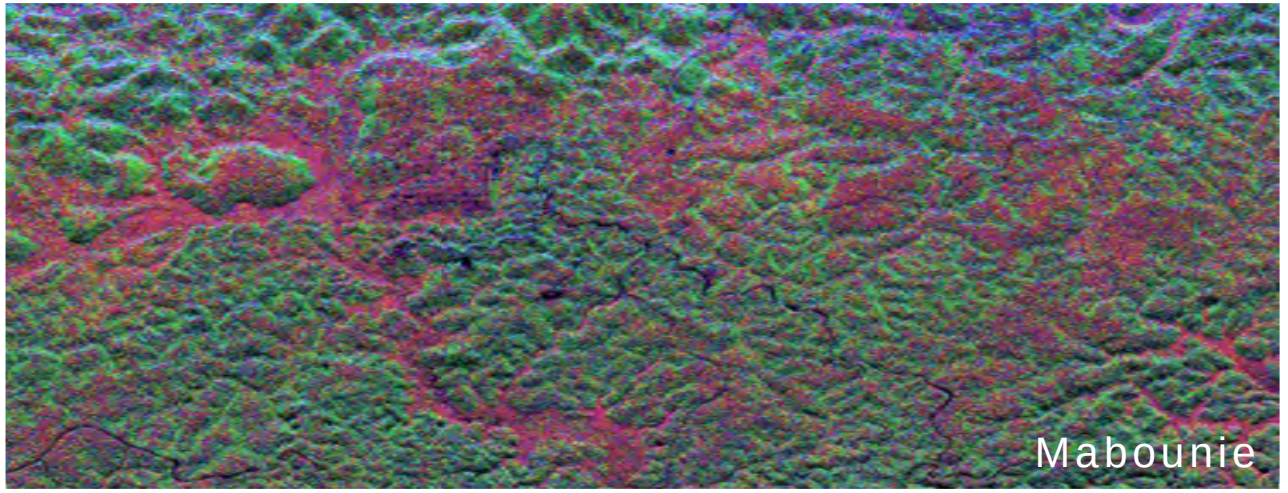
Diameter

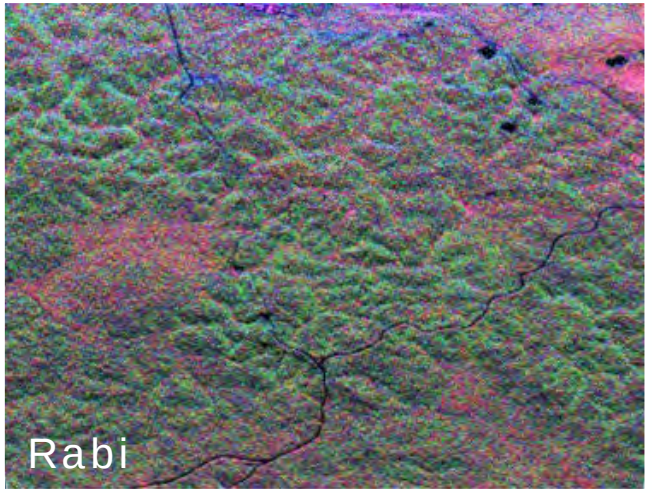
Height

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



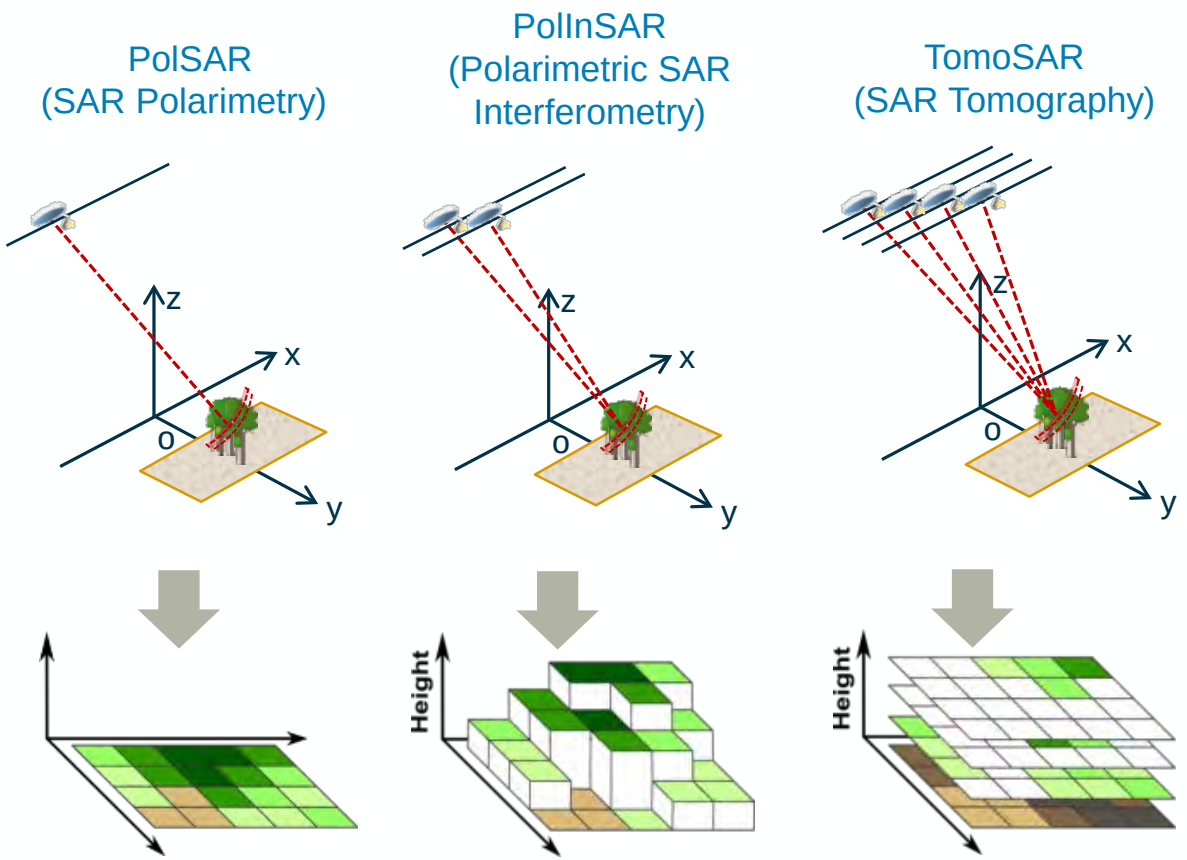






HH+VV HV HH-VV

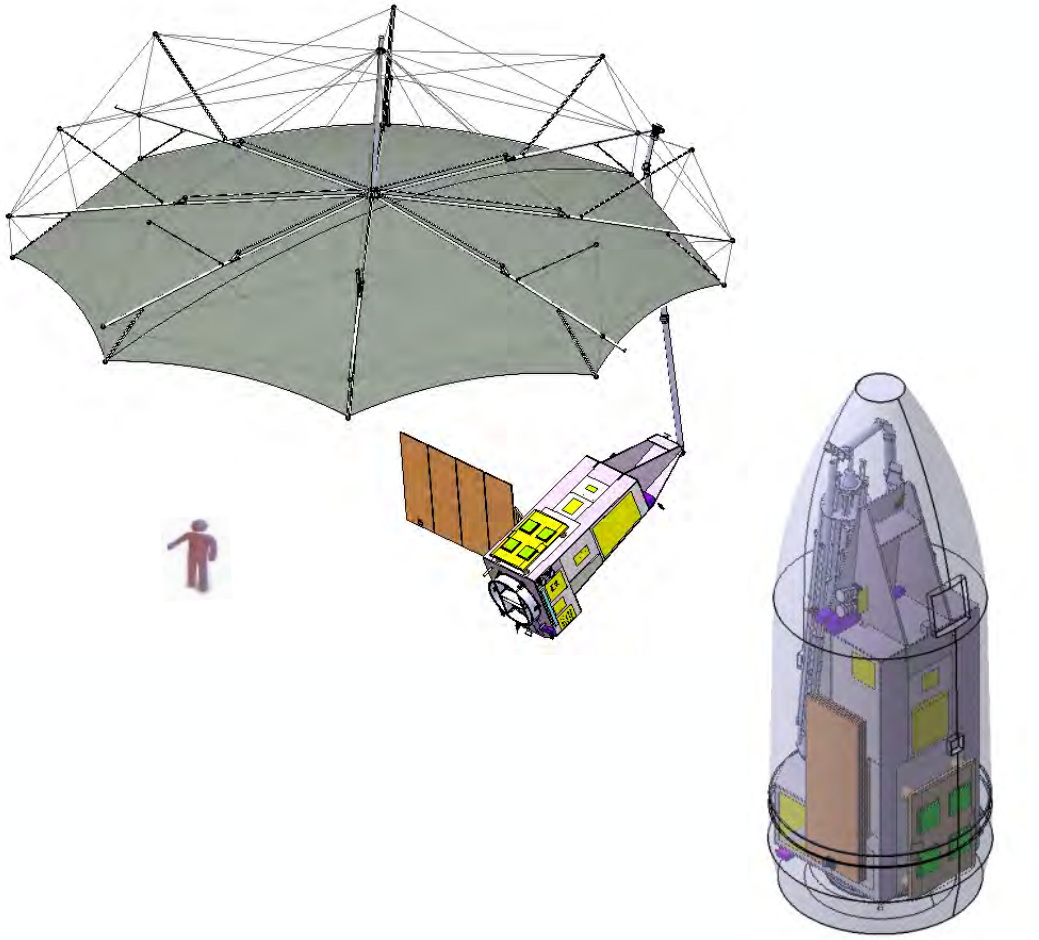
BIOMASS Mission Concept



- ✓ 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 (year 1), Interferometry (year 2-5)
- ✓ Multi-repeat pass interferometry (3 passes in nominal operations) with a 3 days repeat cycle
- ✓ Global coverage in ~7 months (228 days) on ascending and descending passes
- ✓ 5 years lifetime

BIOMASS Mission Requirements

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 ✓

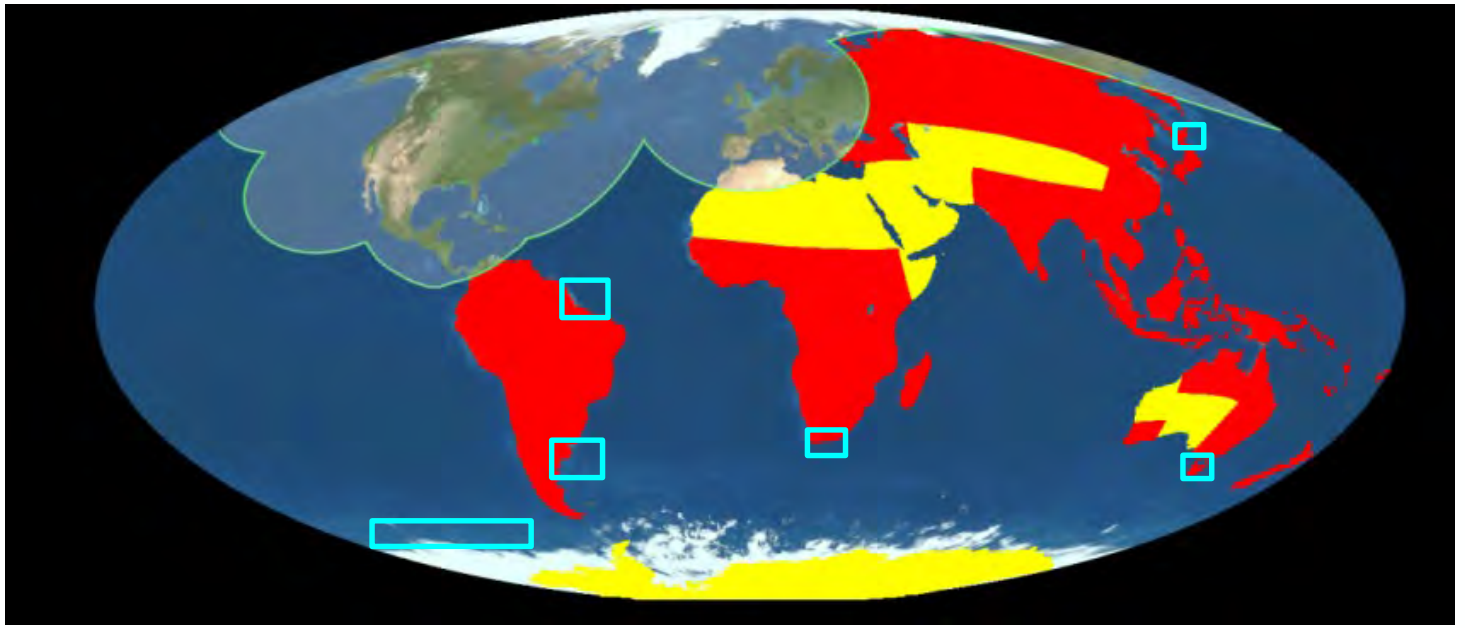


BIOMASS spacecraft

Courtesy Airbus

Coverage

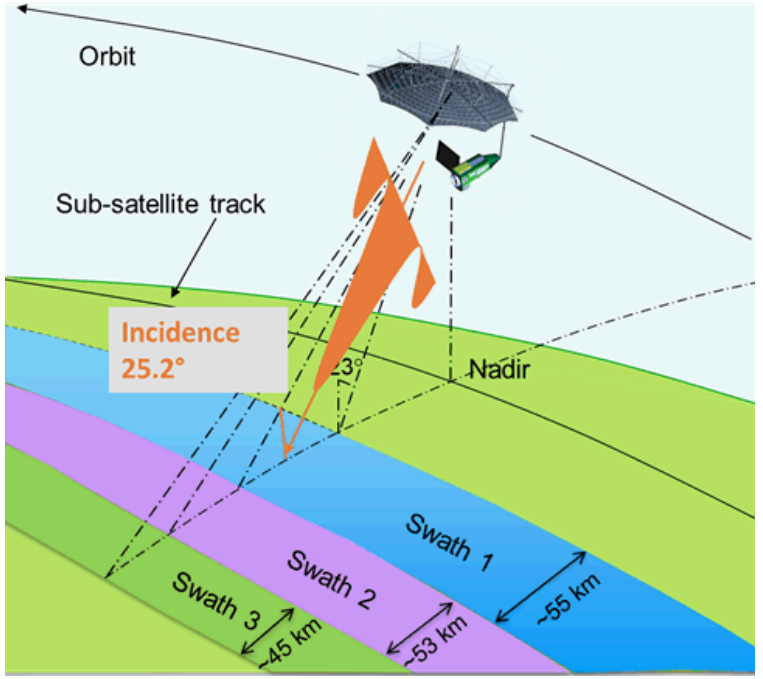
1. Systematic Acquisitions for forested land (red area)
2. Global coverage in 7.5 months (INT phase) and 14 months (TOM phase).
3. Best effort acquisitions for non forested areas (yellow + ocean/sea ice ROIs)
4. Acquisition mask restricted by US Space Objects Tracking Radar (SOTR)

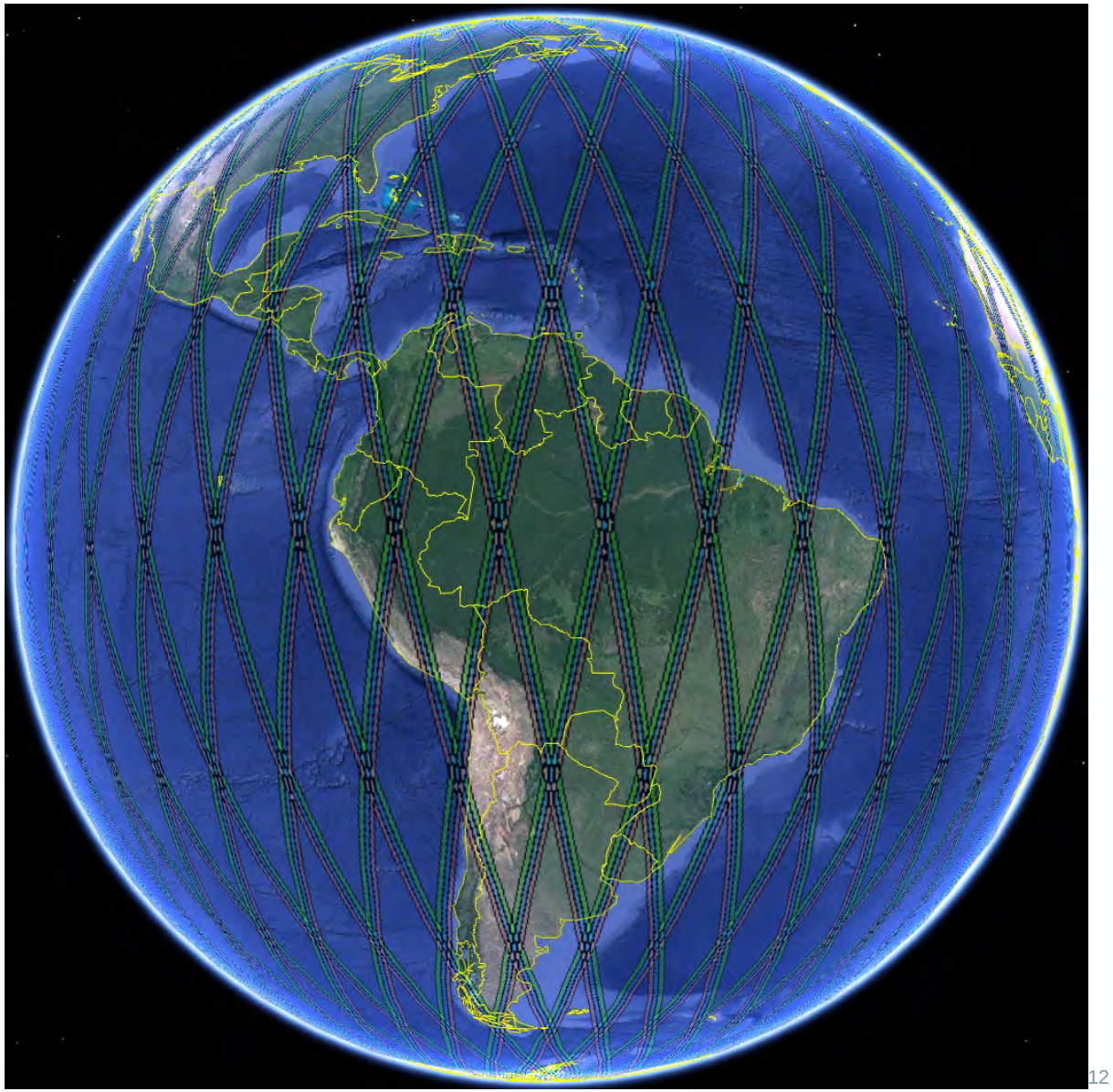


(Red = Primary objective coverage mask, Yellow = Secondary objective coverage mask)

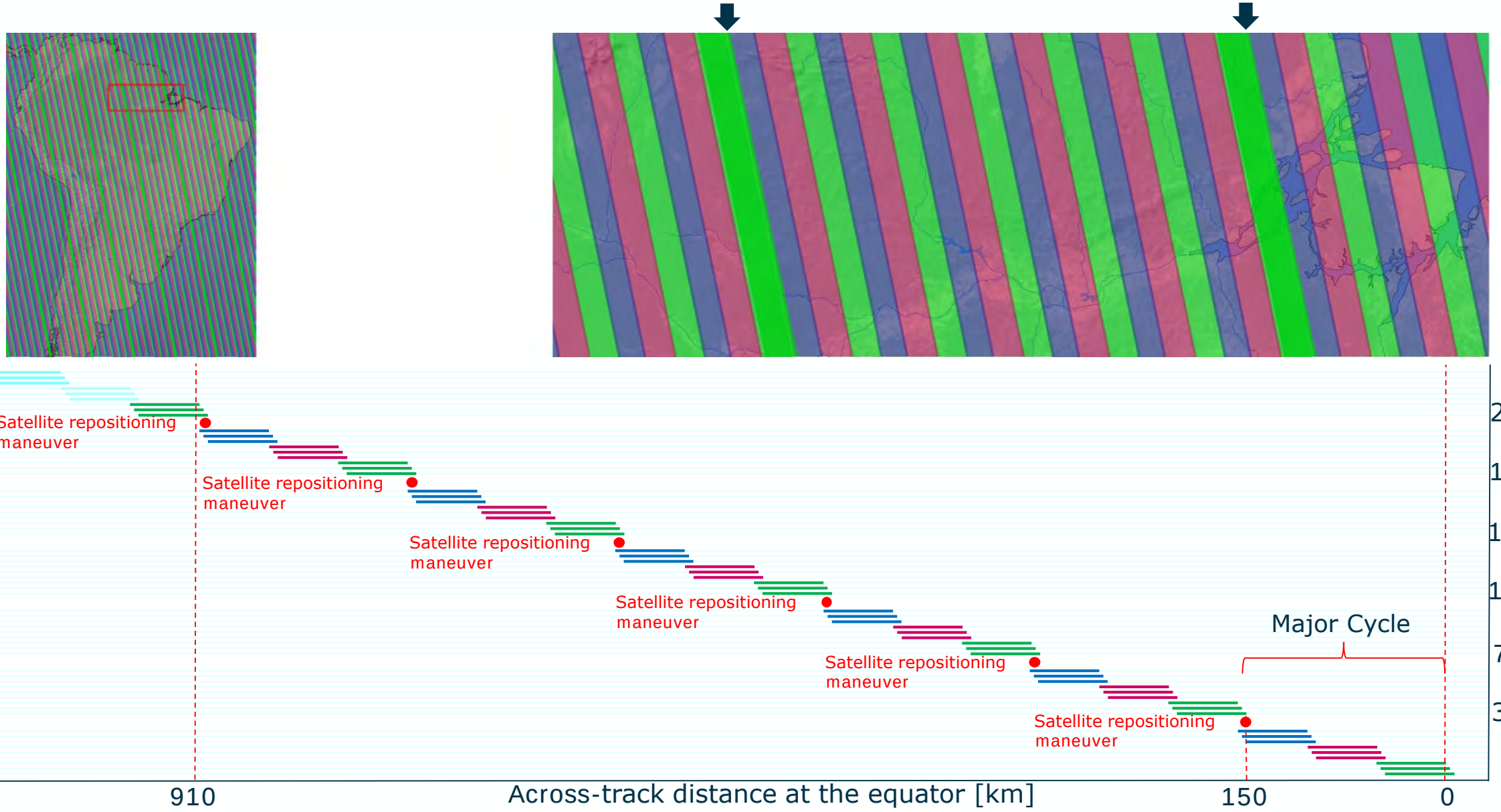
BIOMASS orbit & swath considerations

- Sun-synchronous 666 km dawn-dusk orbit
- 3-day repeat / 44 orbits
- 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



Key challenge - how to estimate biomass

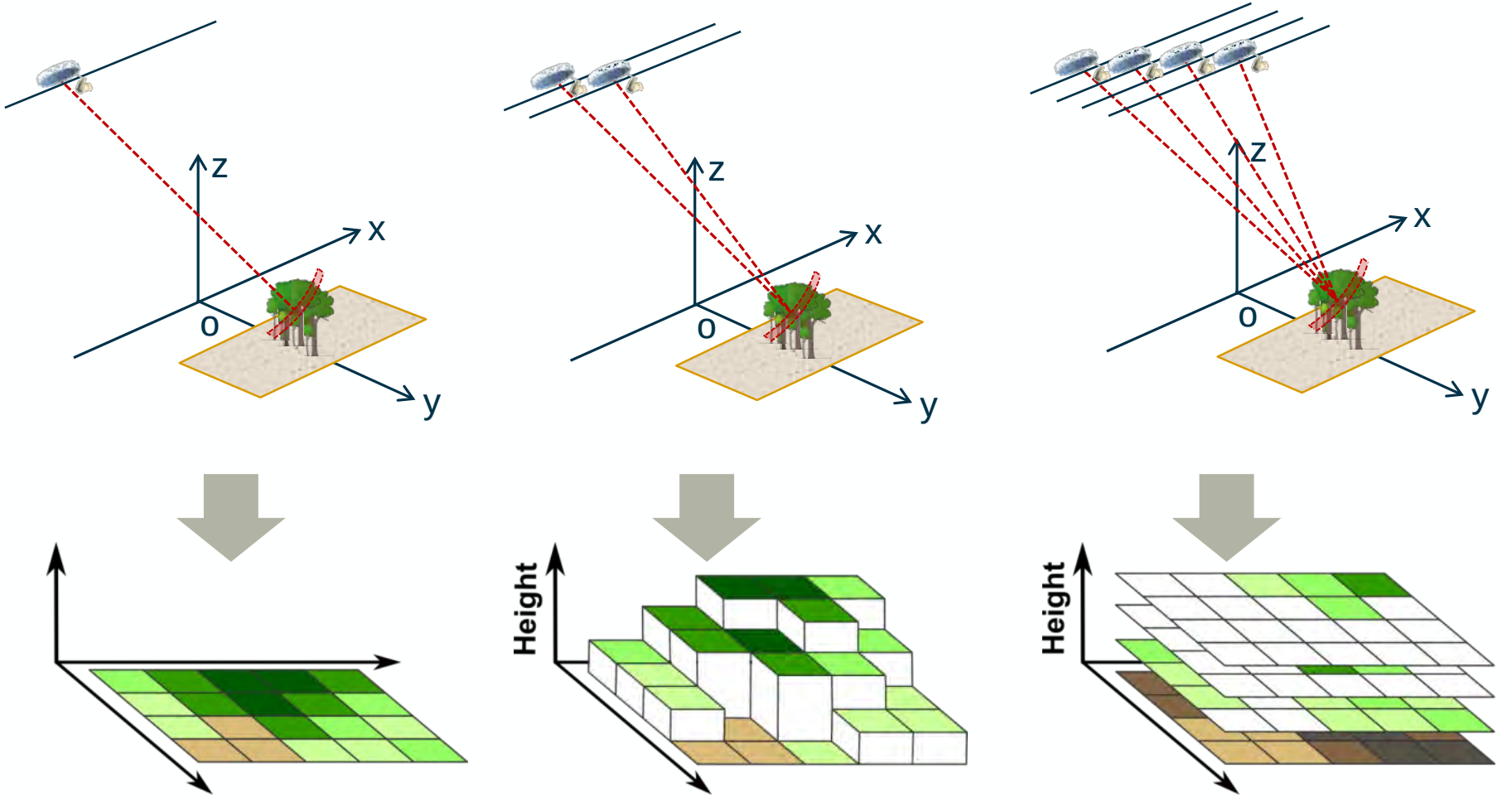
1. Loss of sensitivity in the high biomass range even at P-band.
2. Environmental nuisance factors (vegetation and soil water changes, freeze/thaw, wind, …).

SAR can deliver 3 independent types of information related to biomass

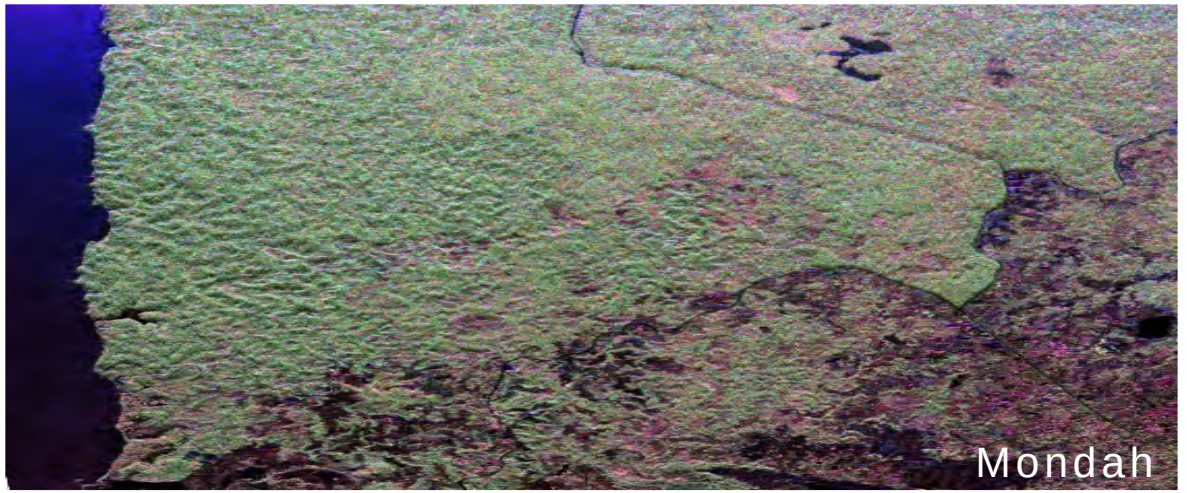
PolSAR
(SAR Polarimetry)

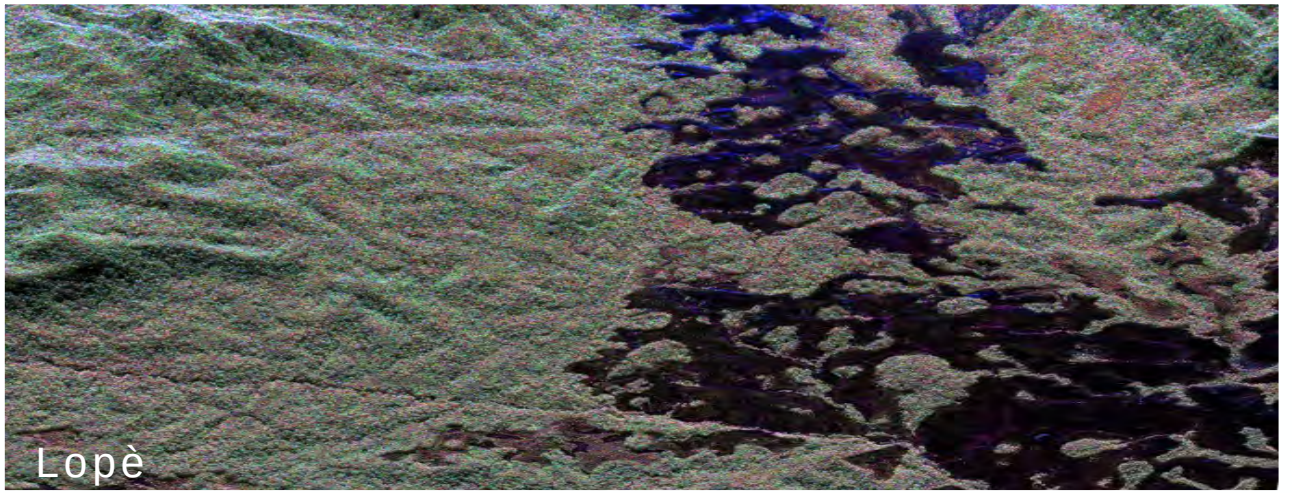
PolInSAR
(Polarimetric SAR Interferometry)

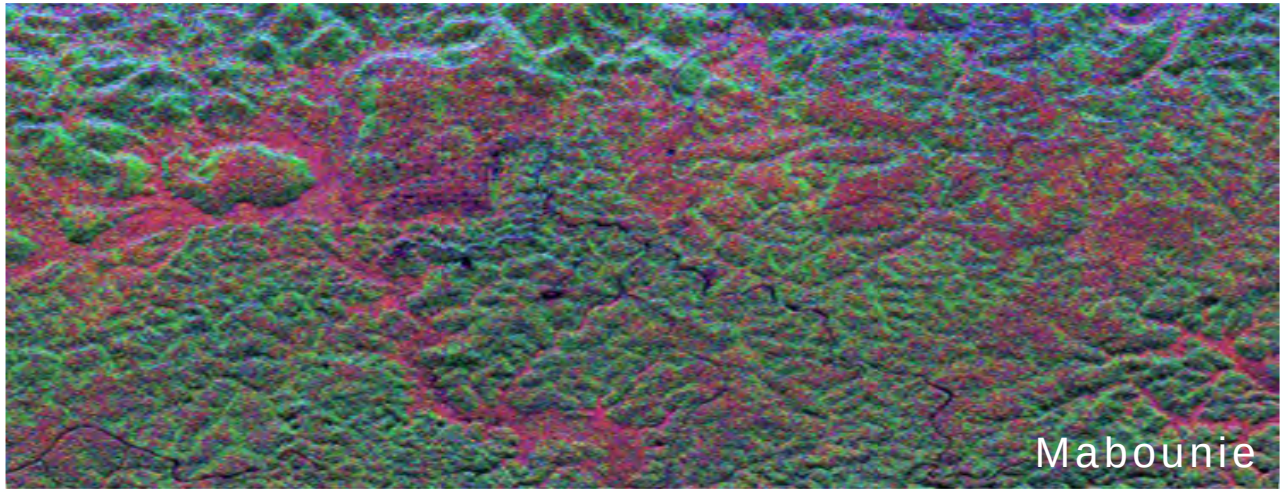
TomoSAR
(SAR Tomography)

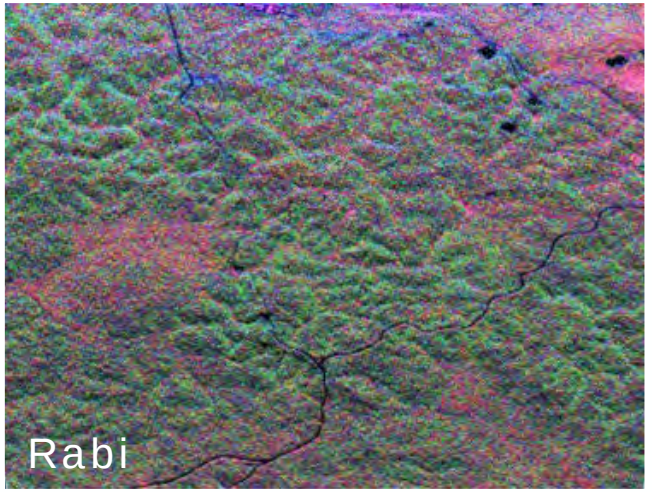


Tropical Forest as seen by DLR‘s P-band F-SAR





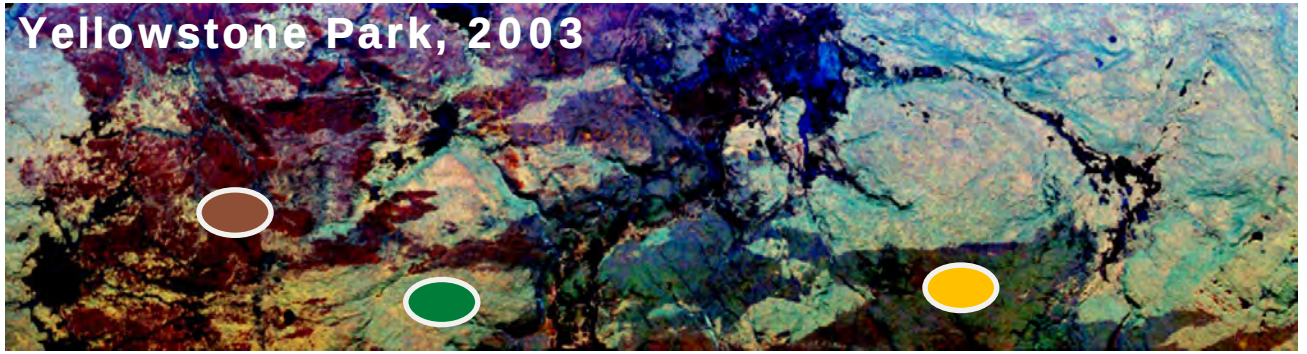


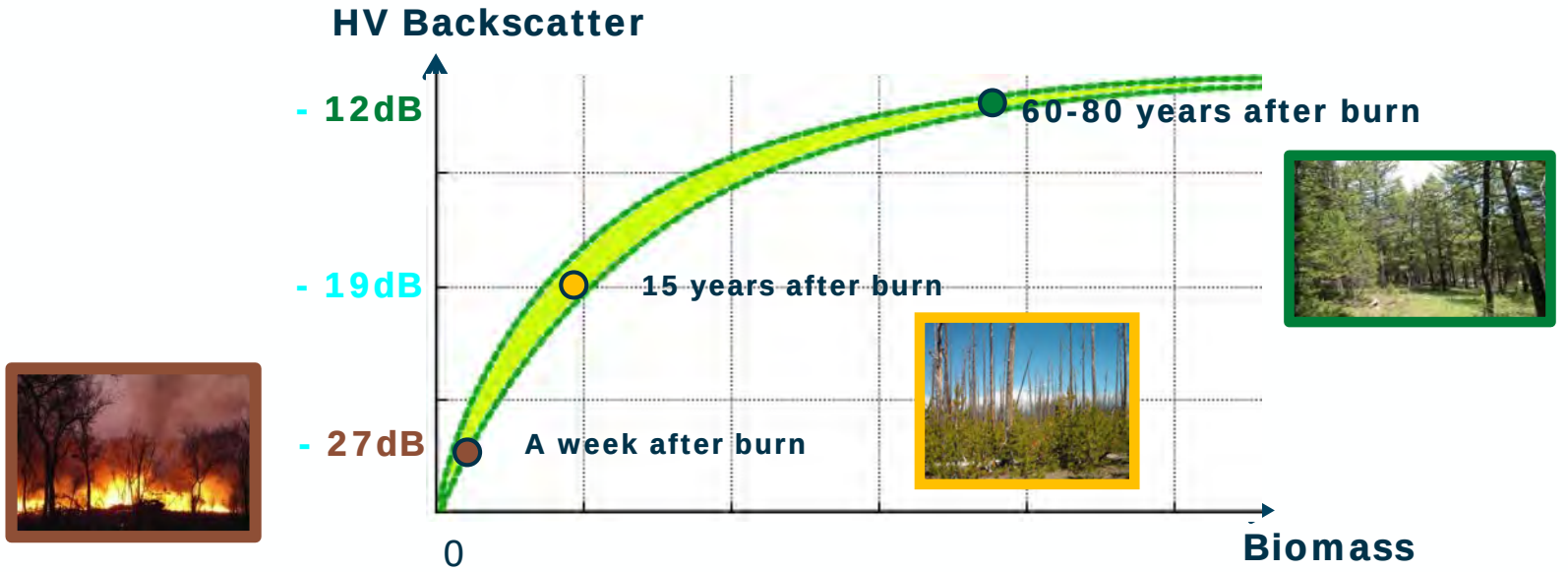


HH+VV HV HH-VV

P-band SAR measures biomass and quantifies landscape dynamics

P-band SAR image (HH, VV, HV)

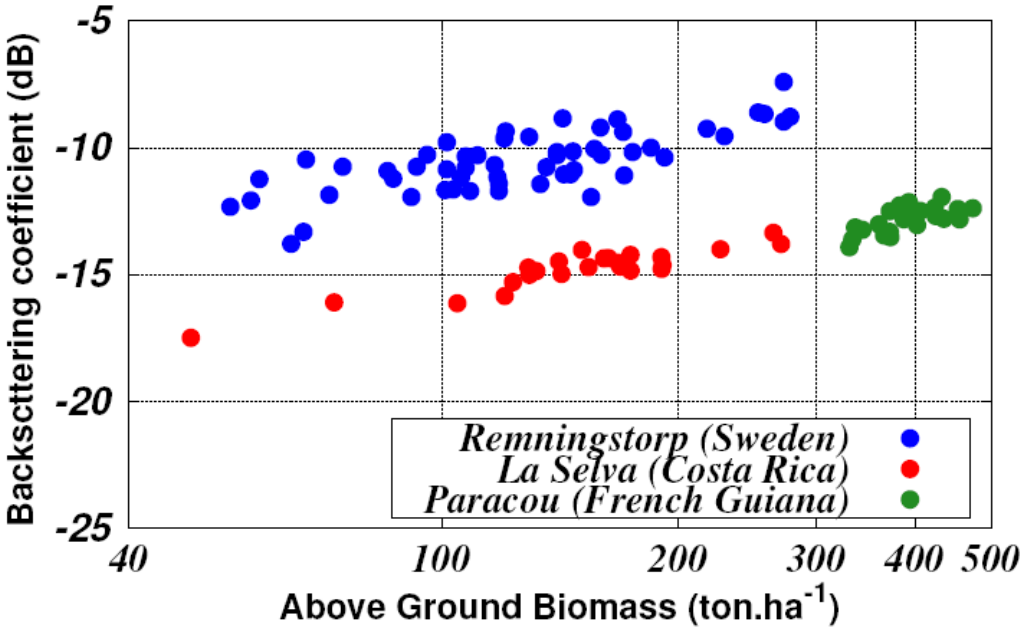




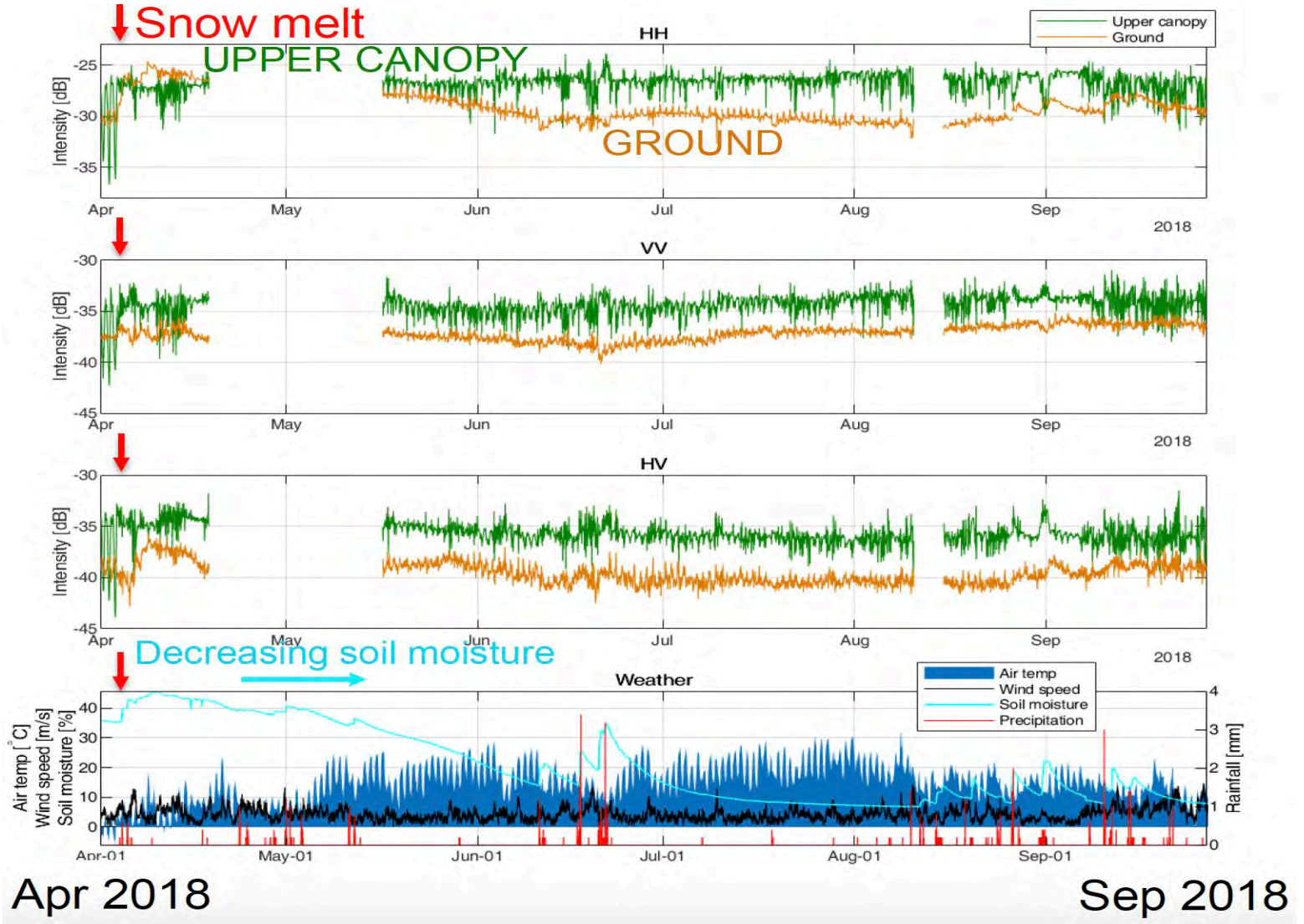
Global consistency in the biomass – P-band backscatter relationship

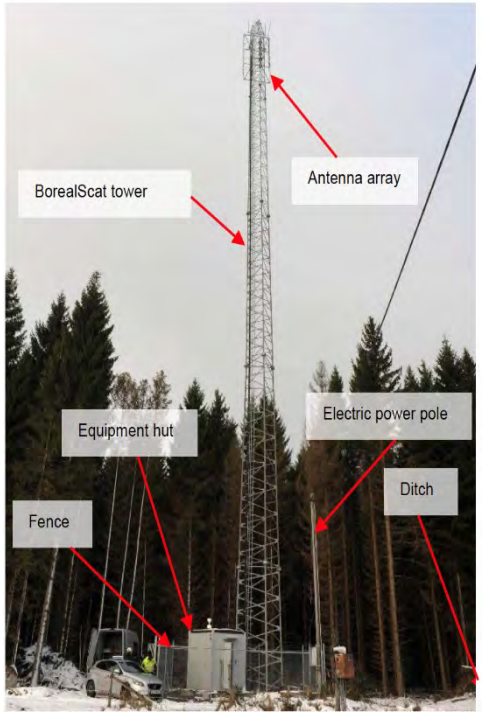
The simplest inversion: Similar power-law relationships between backscatter and biomass are found for all forests where we have data

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



Strong variations in backscatter signal





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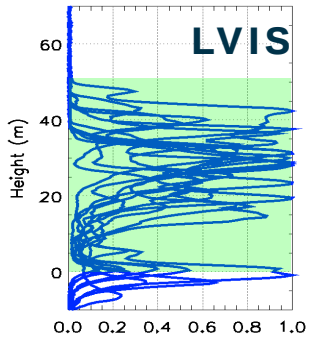
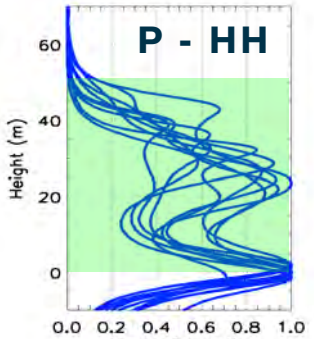
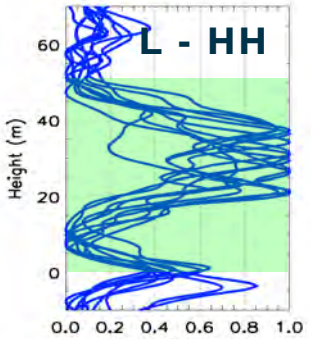
CHALMERS UNIVERSITY OF TECHNOLOGY

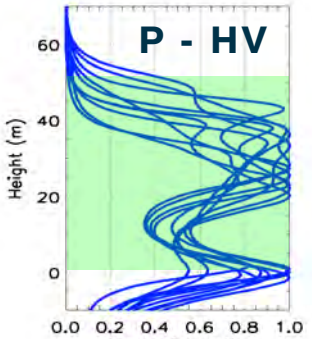
Information content of P-, L- band SAR and lidar

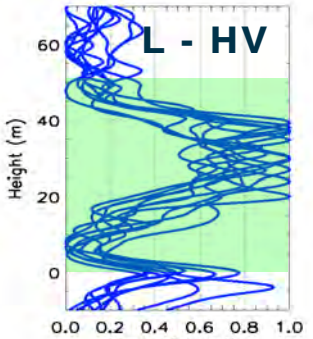
LNL-10 (MAR1)



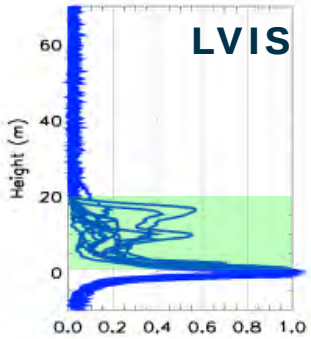


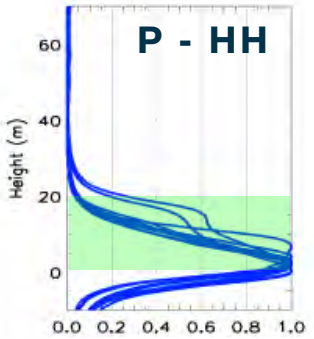


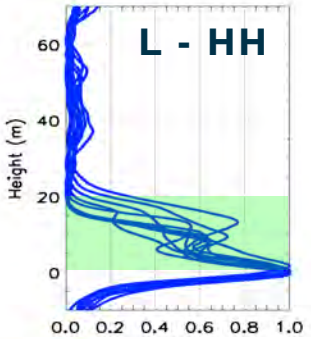


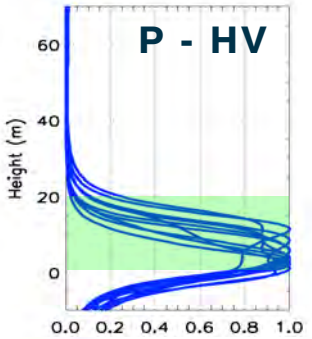


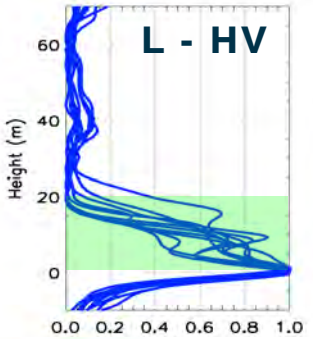
LNL-05 (COL2)



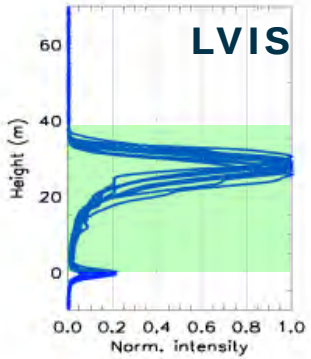


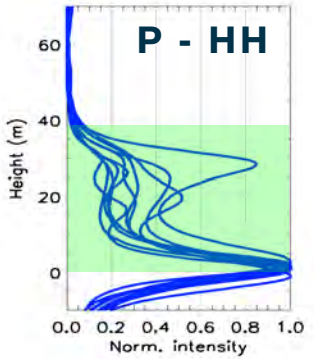


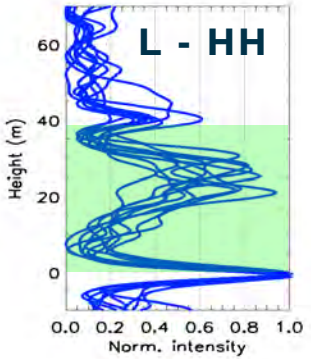


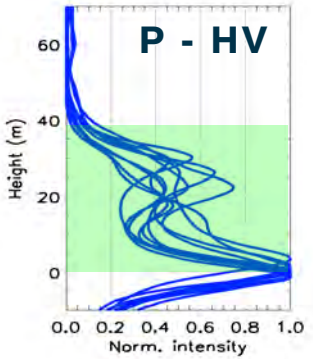


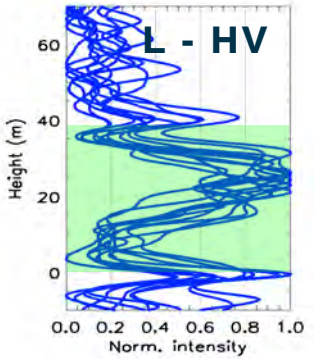
LNL-08 (OKO2)









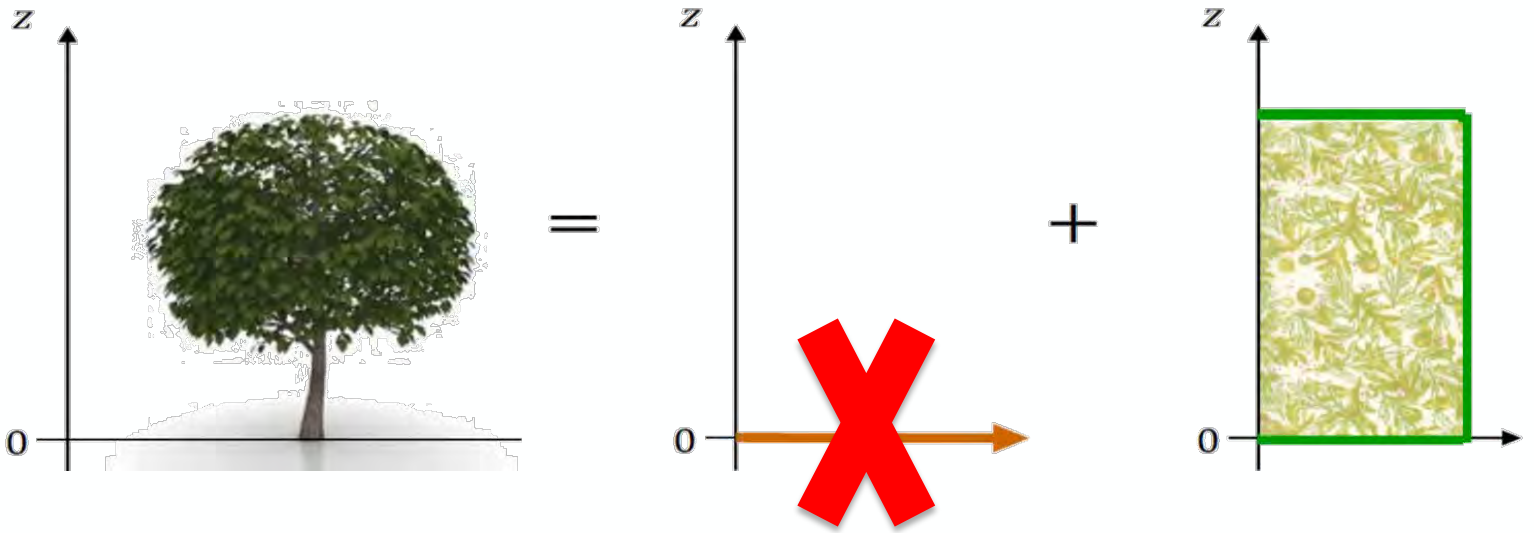


Courtesy: M. Pardini - DLR

Key challenge - how to estimate biomass

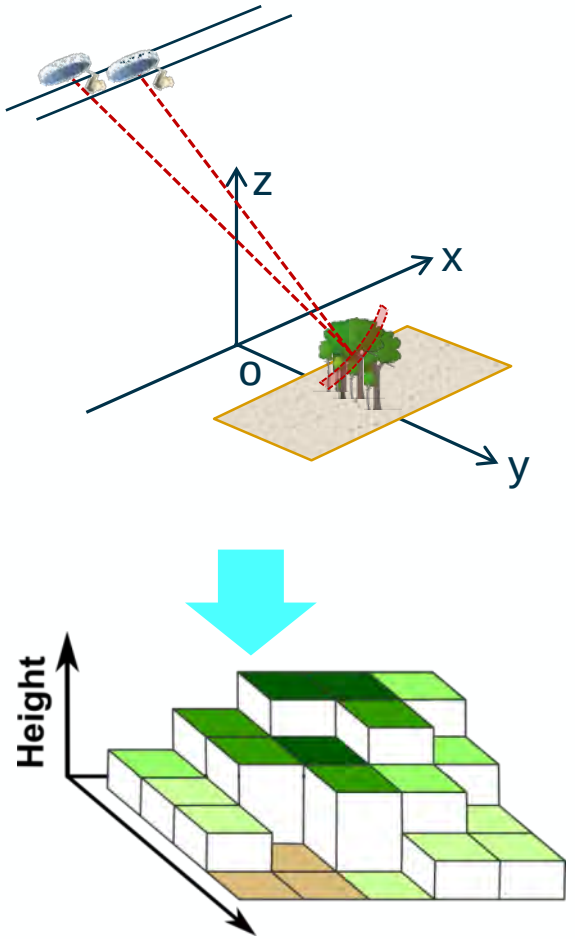
1. Loss of sensitivity in the high biomass range even at P-band.
2. Environmental nuisance factors (vegetation and soil water changes, freeze/thaw, wind, …).

Biomass enables a new approach to tackle these problems: notch out the ground



SAR can deliver 3 independent types of information related to biomass

PolInSAR
(Polarimetric SAR Interferometry)



Interferometric ground notching

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

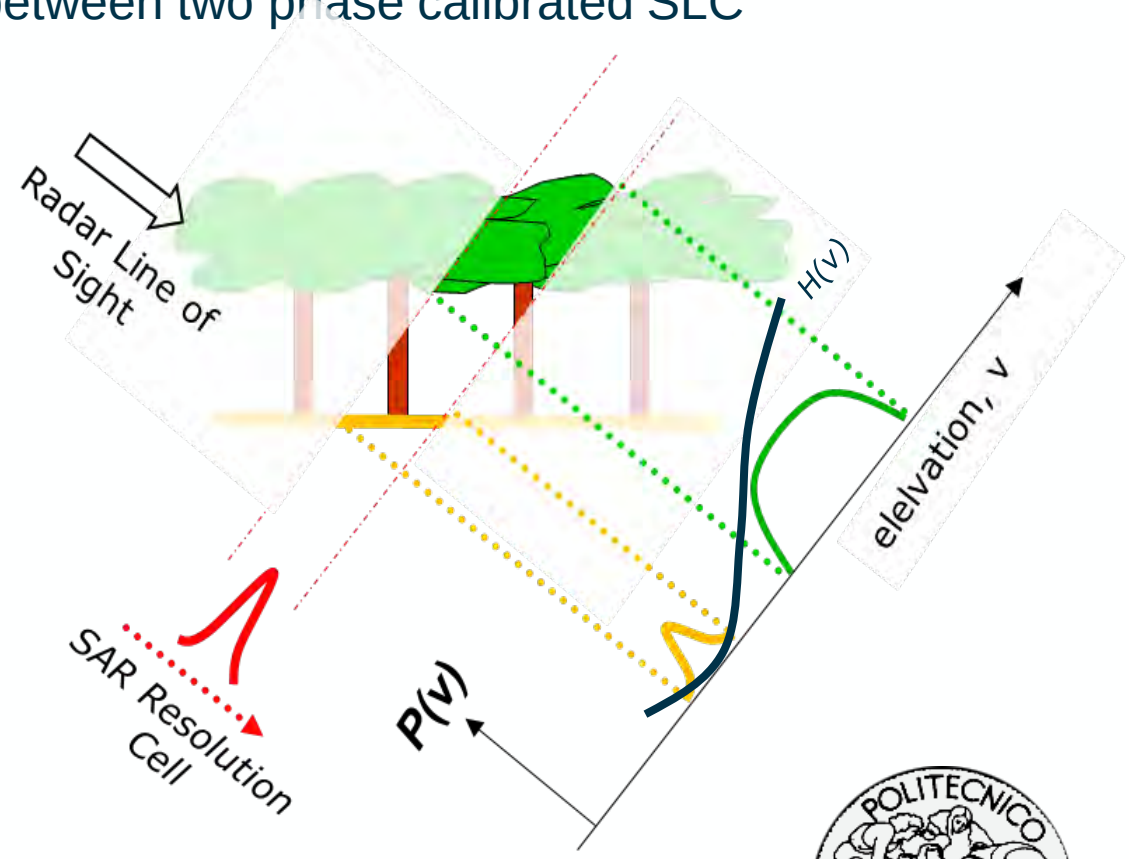
Master: $s_1 = \int P(z) \cdot dz$

Slave: $s_2 = \int P(z) \cdot exp(jk_z z) \cdot dz$

Ground notched image = Slave – Master

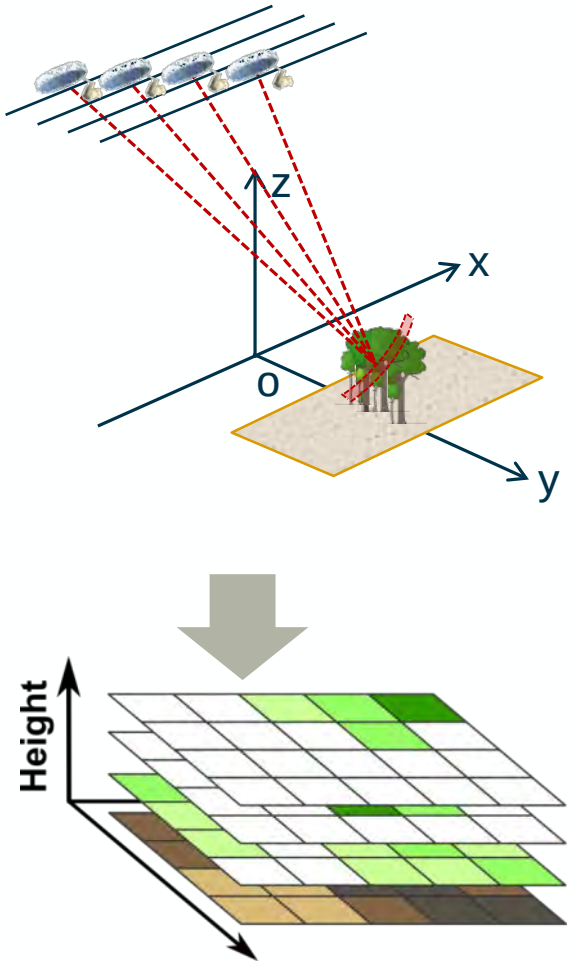
$$d = s_2 - s_1 = \int P(z) \cdot H(z) \cdot dz$$

H(z) = Vertical Impulse Response Function (IRF)



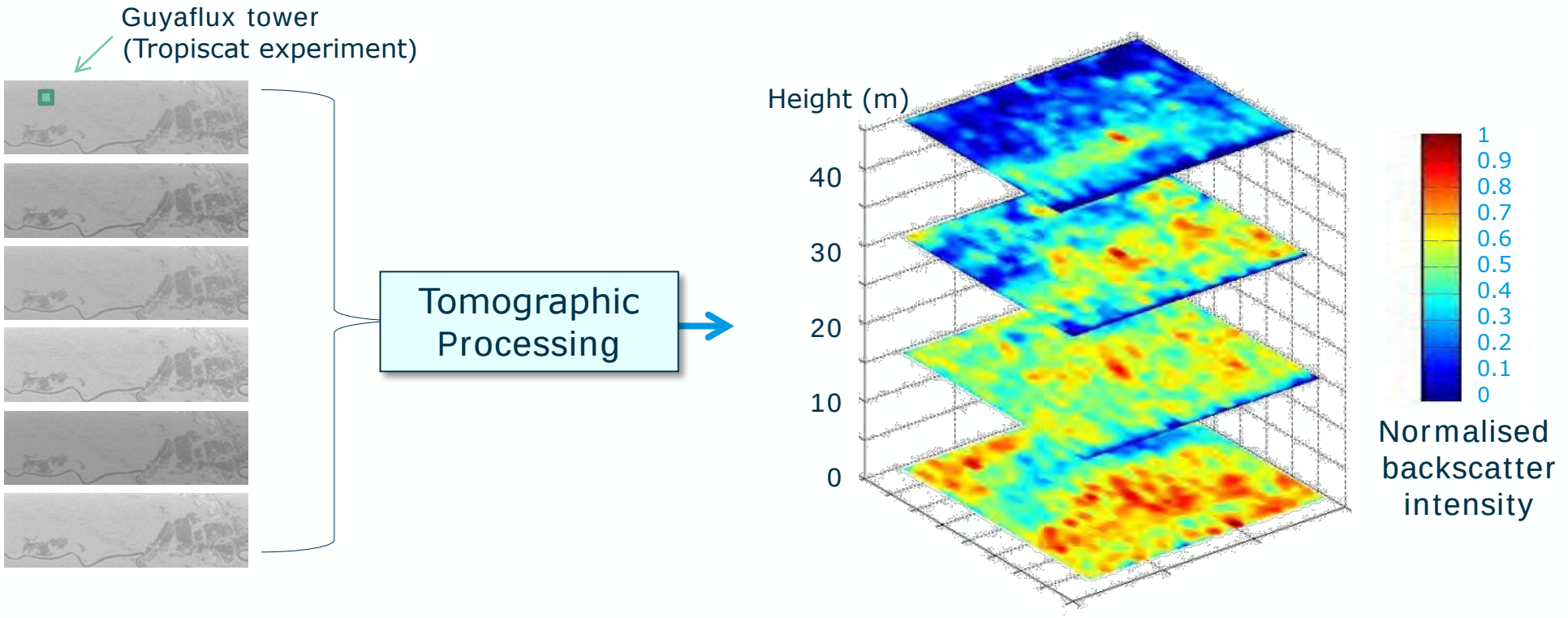
SAR can deliver 3 independent types of information related to biomass

TomoSAR
(SAR Tomography)

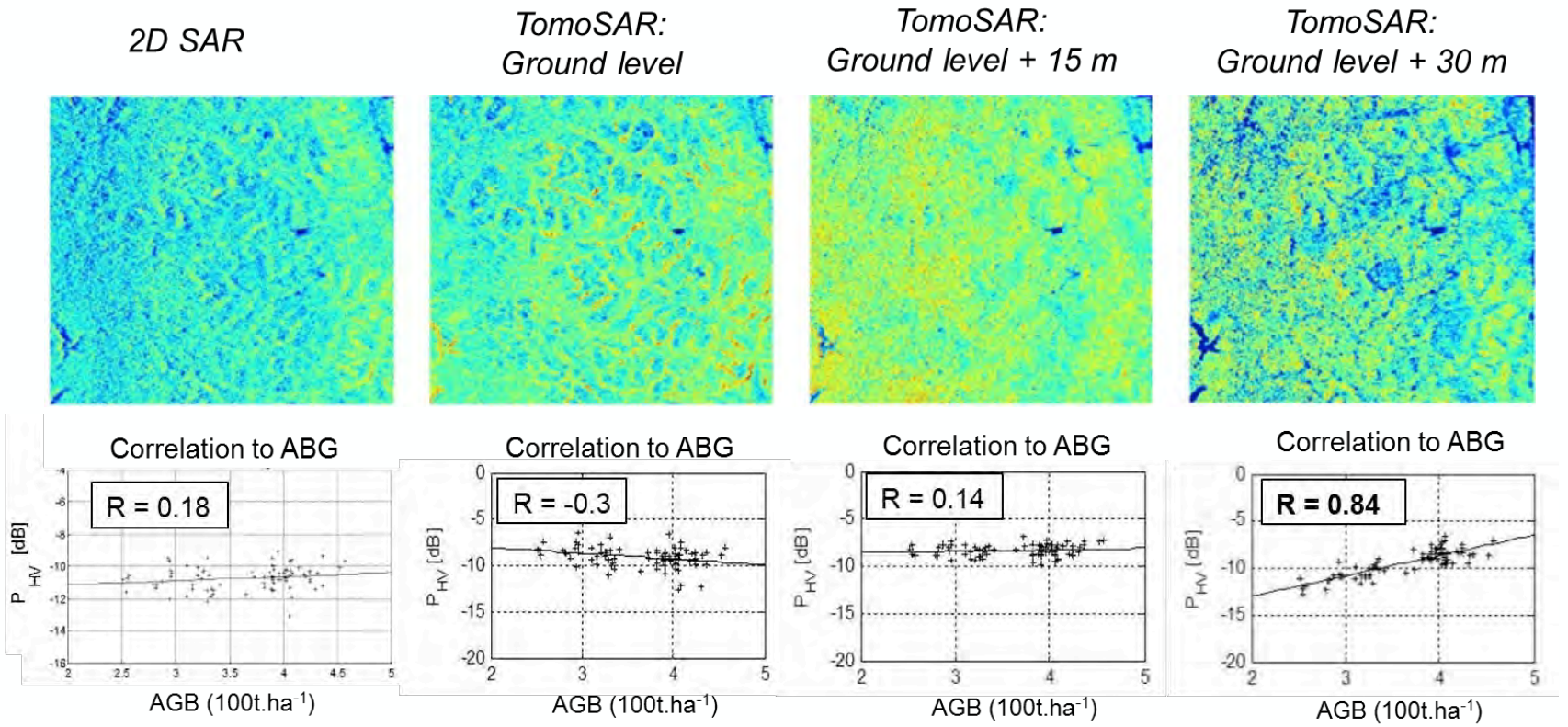


SAR tomography, a new concept to explore 3D forest structure

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

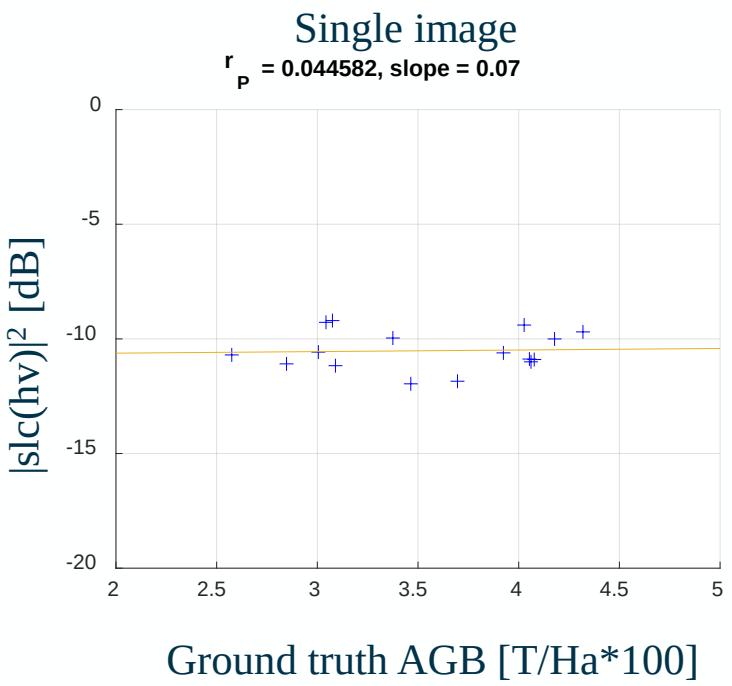


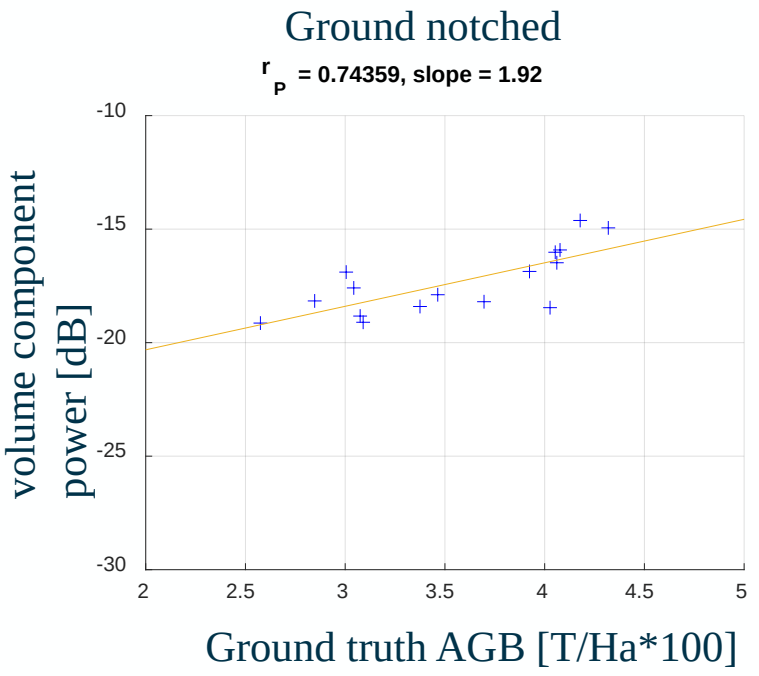
Tomographic imaging in Paracou

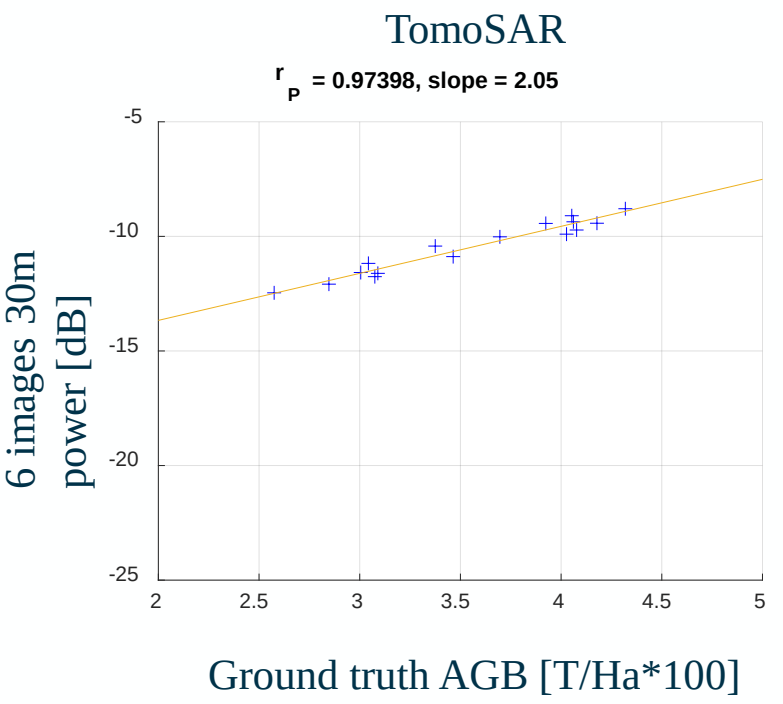


D. Ho Tong Minh et al., "Relating P-band SAR tomography to tropical forest biomass", TGRS, Feb. 2014.

AGB vs TropiSAR backscatter





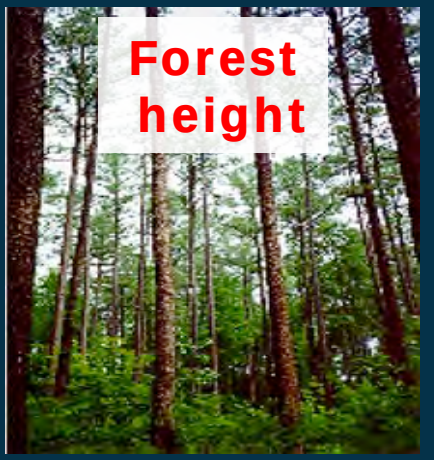


Ground rejection greatly improves correlation and sensitivity

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

Biomass will allow DEM production under dense tropical canopies

Paracou

TropiSAR data

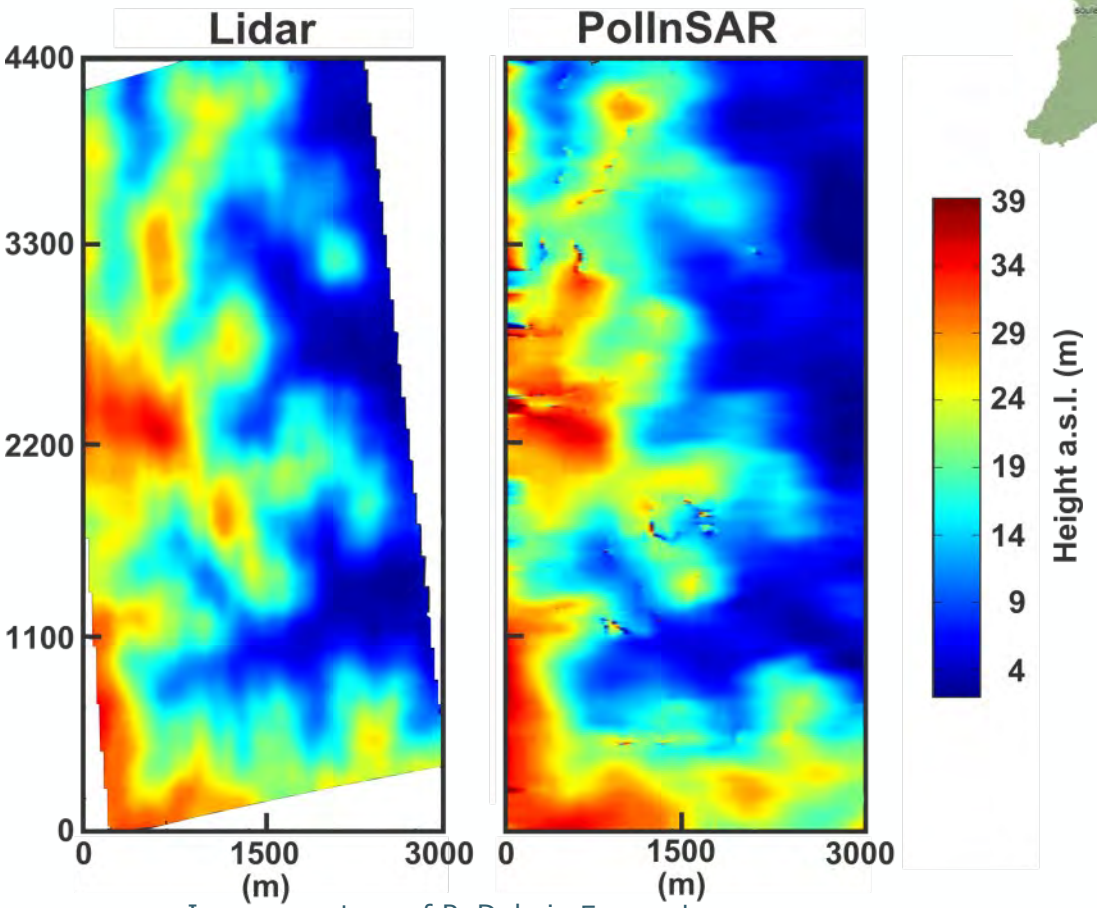
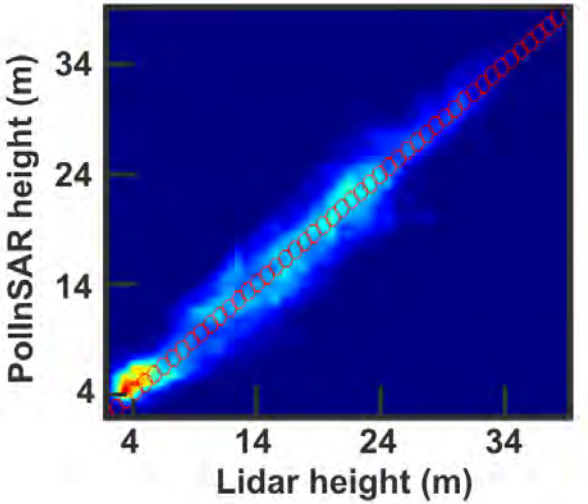


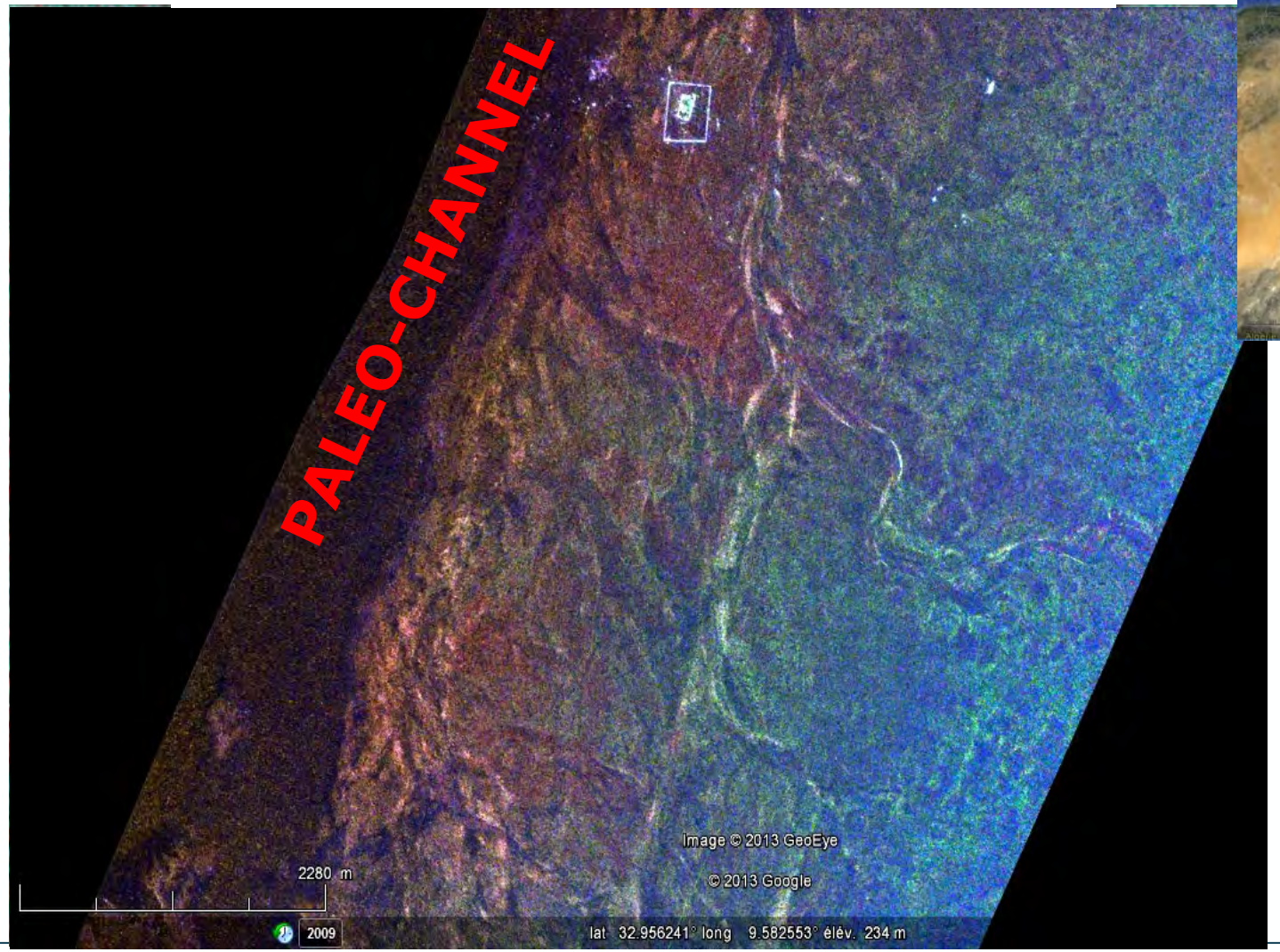
Image courtesy of P. Dubois-Fernandez



90m x 90m DEM feasible with **~ 2 m height accuracy** from Biomass

P-band enhances subsurface imaging in arid zones

P-band SAR (ONERA's SETHI sensor)



BioPAL

BIOMASS Product Algorithm Laboratory

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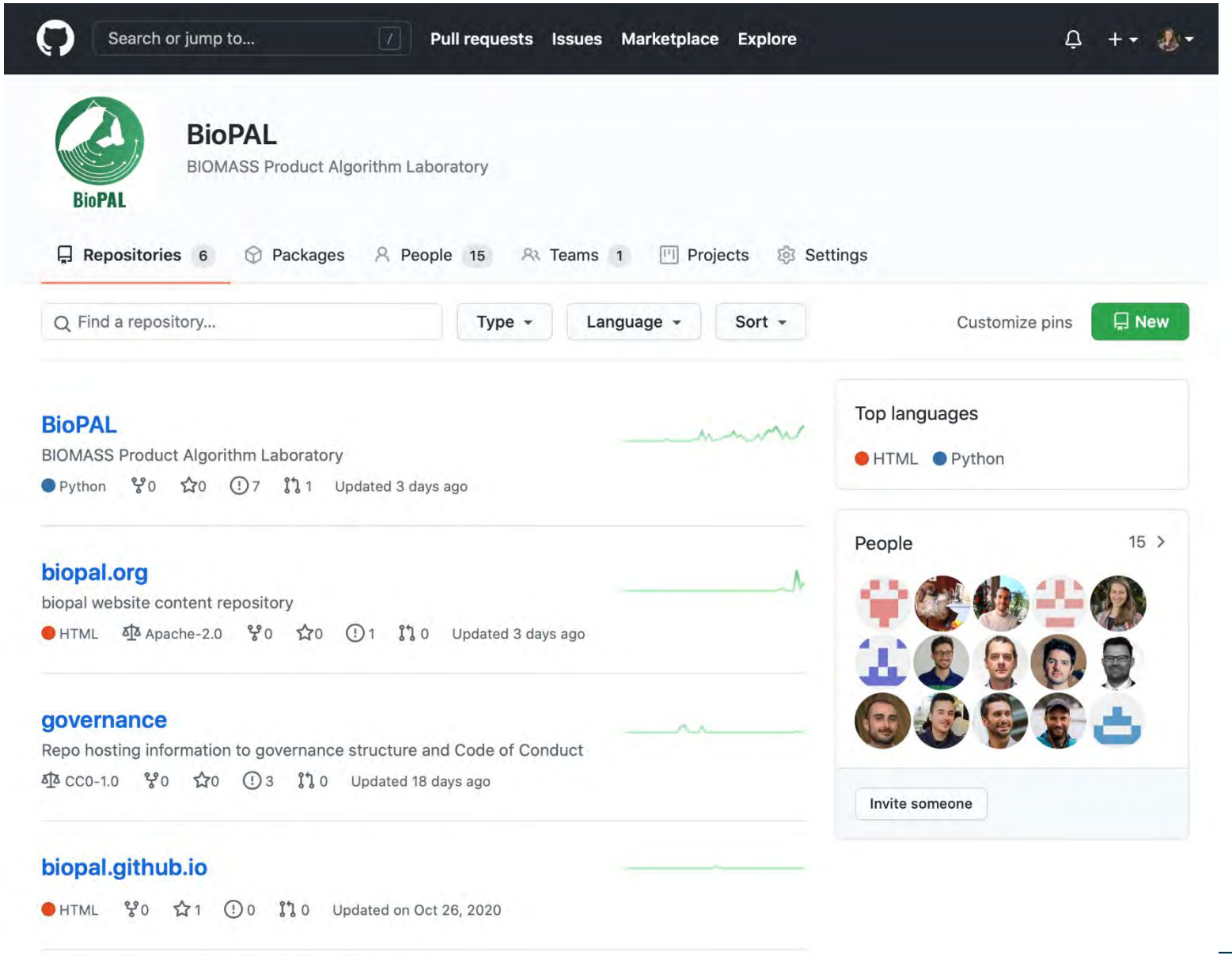
biopal.org
github.com/BioPAL

= 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

Join the adventure!



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Summary – BIOMASS a true Earth Explorer

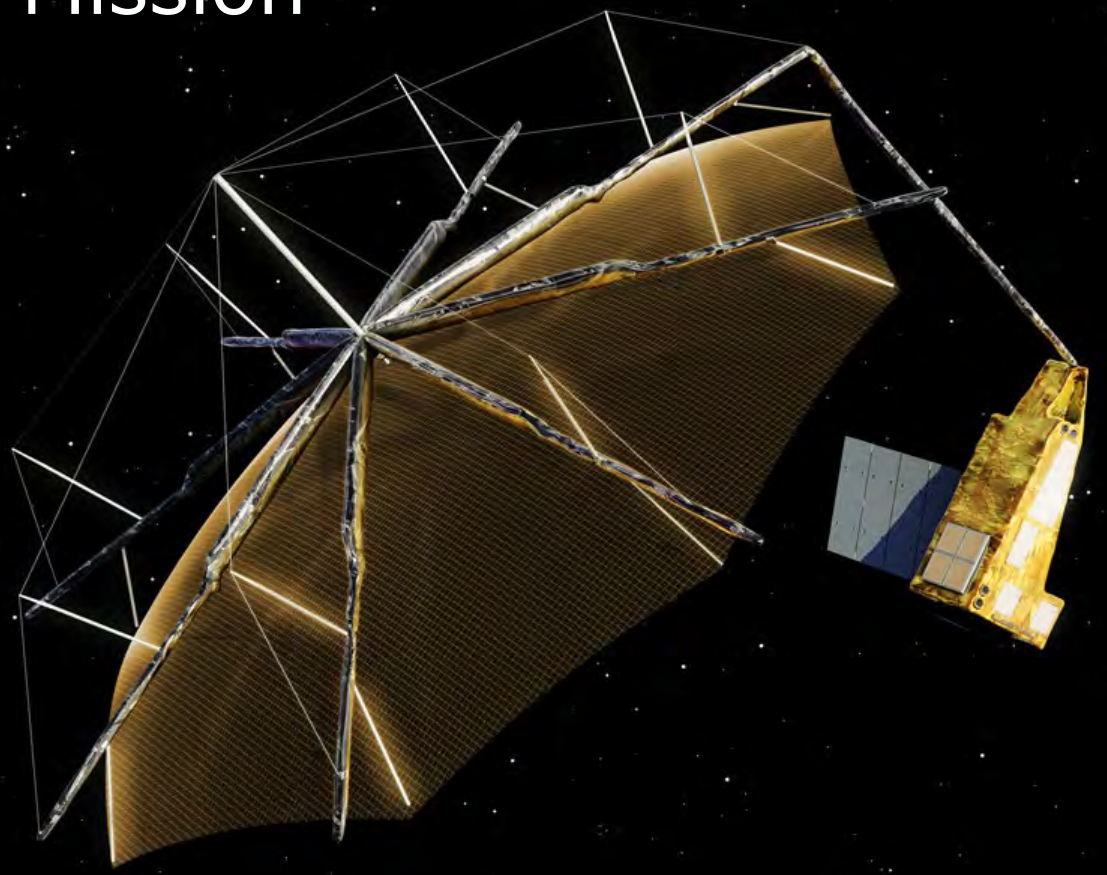
1. BIOMASS implementation started in Nov. 2013. We just closing Phase-C (the Critical Design Review is ongoing). We are working towards a launch in 2023.

2. BIOMASS is the first P-band SAR and first 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 ESA Earth Explorer mission that will follow an Open Source approach in the algorithm developement

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 ...

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