The Biomass Mission

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What is Biomass about

Forest biomass | **Forest height** | **Disturbances**

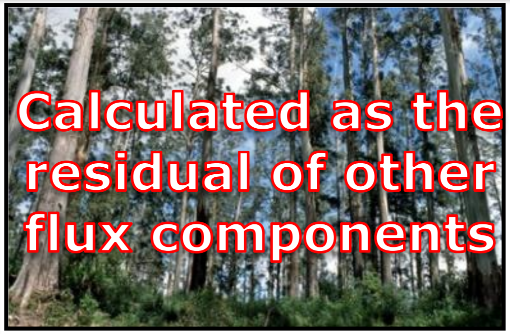
Fate of Anthropogenic CO_2 Emissions (2002-2011)

8.3±0.4 GtC/yr

1.0±0.5 GtC/yr net flux

4.3±0.1 GtC/yr

2.6±0.9 GtC/yr



2.5±0.5 GtC/yr

Global Carbon Project, 2012

What do we want to achieve – Primary Mission Objectives

1. Reduce the major uncertainties in carbon fluxes linked to Land Use Change, forest degradation and regrowth
2. Providing support for International Agreements (UNFCCC and REDD+)
3. Inferring landscape carbon dynamics and supporting predictions
4. Initialising and testing the land component of Earth System models
5. Providing key information on forest resources, ecosystem services, biodiversity and conservation

Required measurement properties

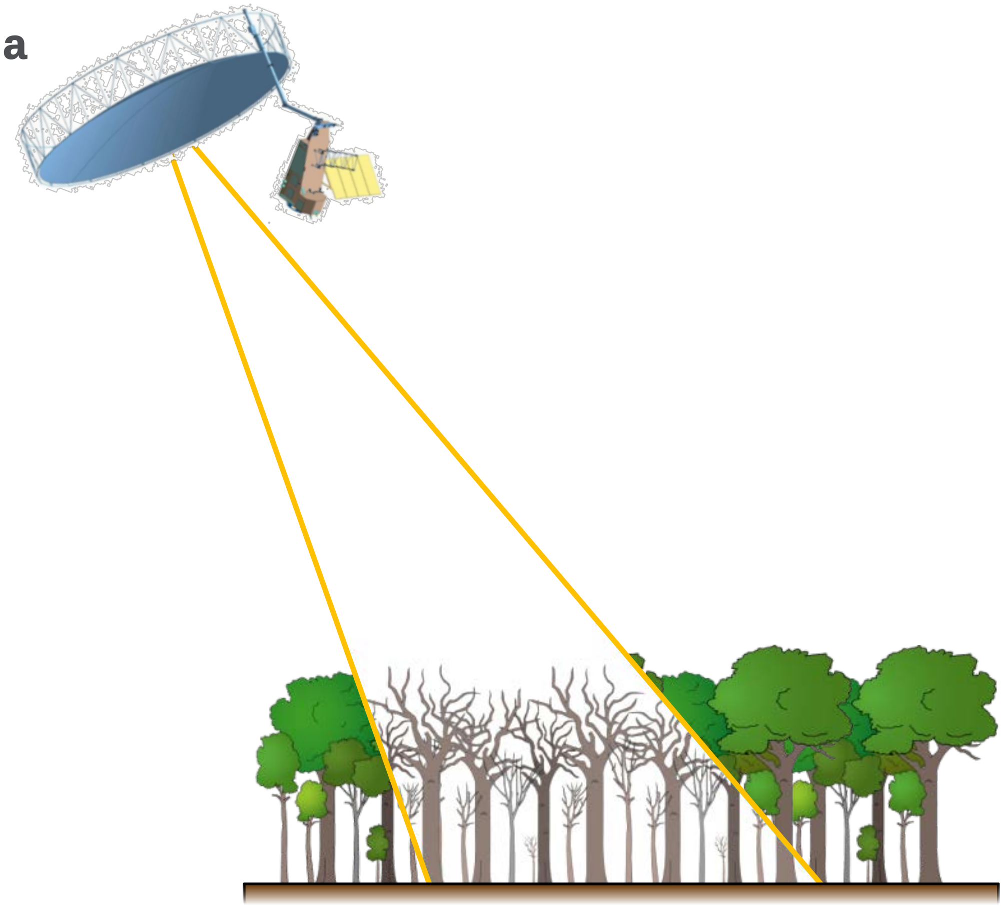
1. The **crucial information need** is in the tropics:
   a. deforestation (~95% of the Land Use Change flux)
   b. regrowth (~50% of the global biomass sink)
2. Biomass measurements are needed where the changes occur and at the **effective scale of change**: 4 hectares
3. A biomass accuracy of 20% at 4 hectares, **comparable to ground-based observations**
4. Forest height to provide **a further constraint** on biomass estimates
5. **Detection** of deforestation at 0.25 ha
6. **Repeated measurements** over multiple years to identify deforestation and growth

How can biomass be measured from space?

Mapping forest biomass requires a radar sensor with long wavelength:

1. to penetrate the canopy in all forest biomes
2. to interact with woody vegetation elements
3. so that forest height can be estimated with a single satellite

This implies a radar at P-band, of wavelength ~70 cm, the longest possible from space

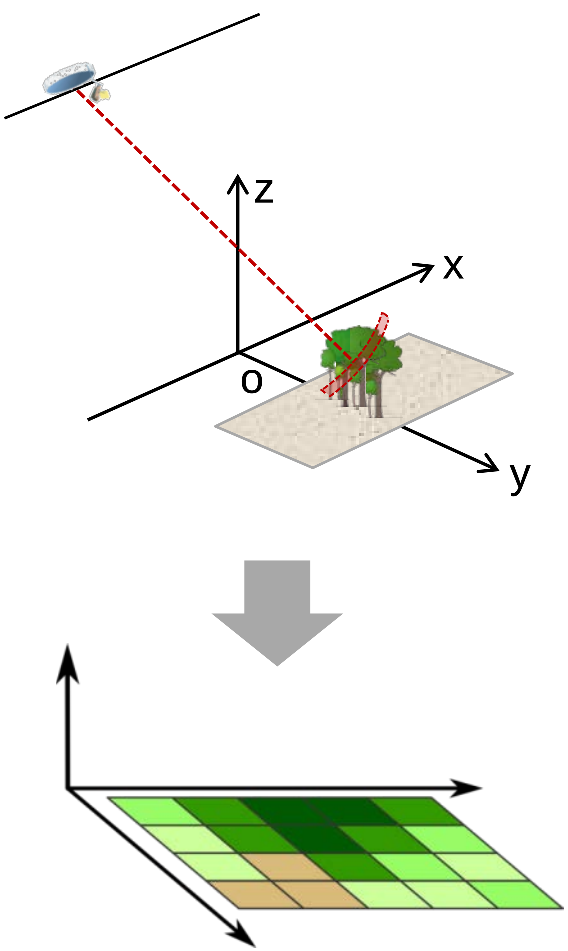


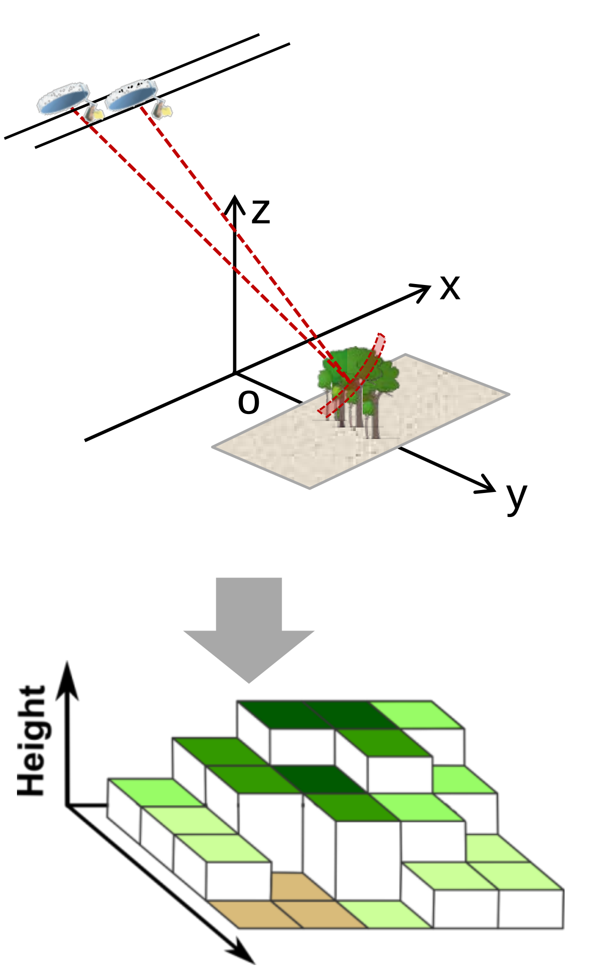
SAR can deliver 3 independent types of information related to biomass

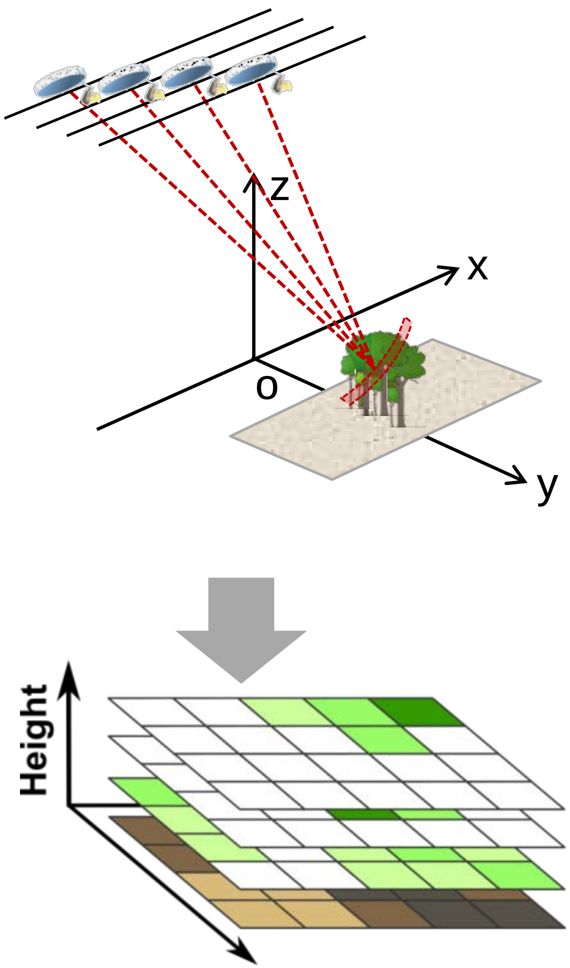
PolSAR
(SAR Polarimetry)

PolInSAR
(Polarimetric SAR Interferometry)

TomoSAR
(SAR Tomography)

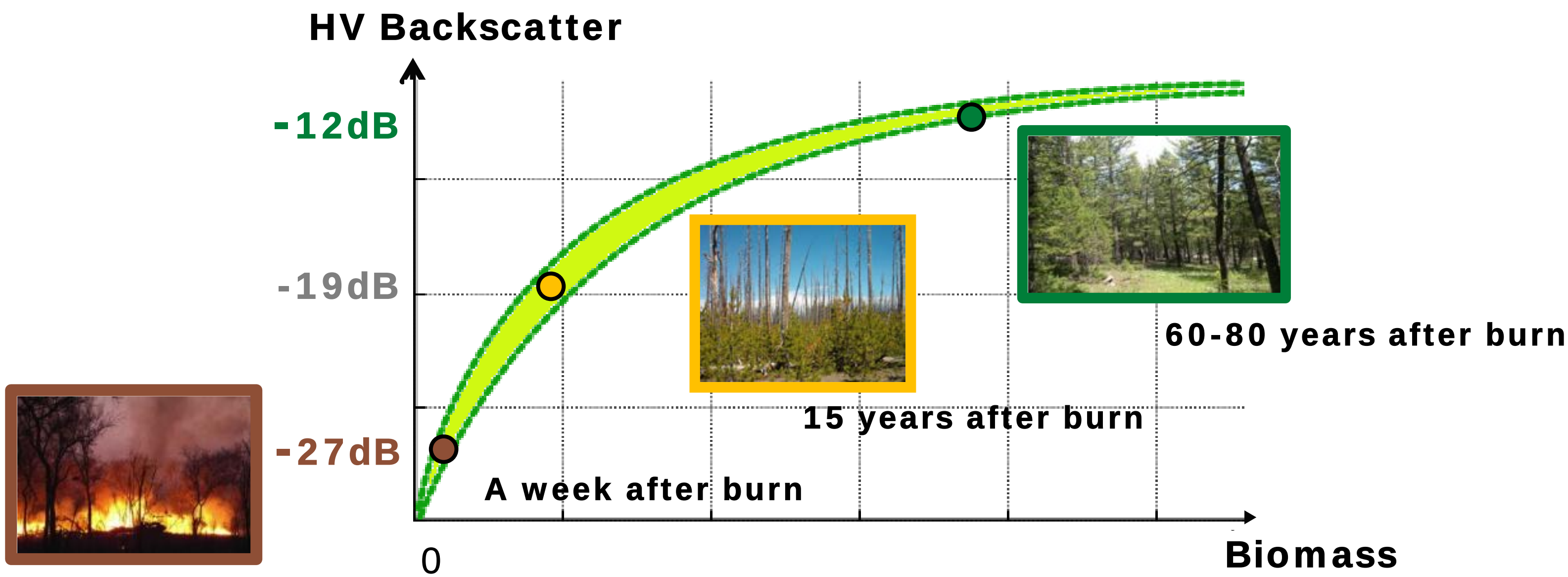






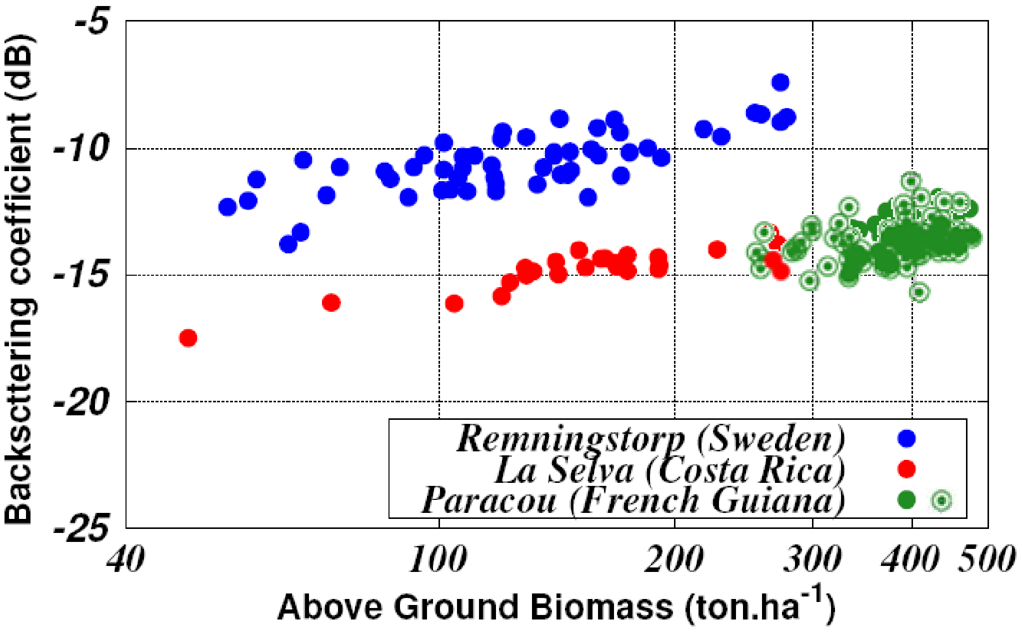
P-band SAR measures biomass and quantifies landscape dynamics

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



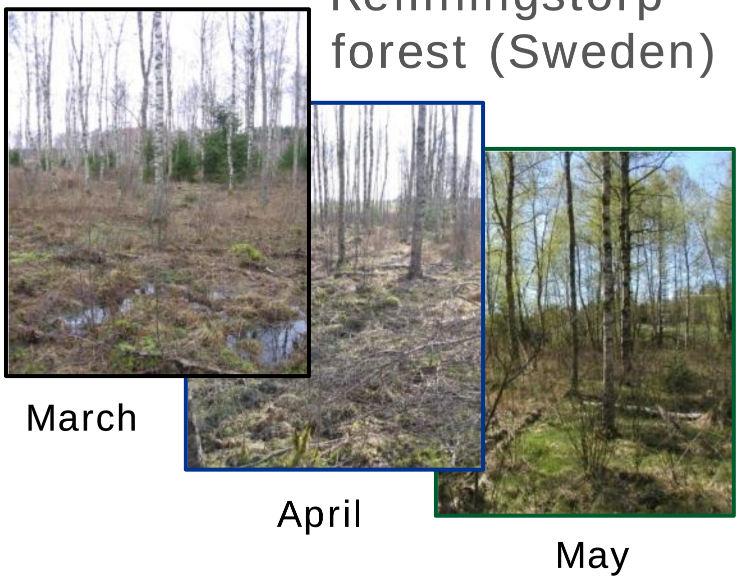
Global consistency in the biomass – P-band backscatter relationship

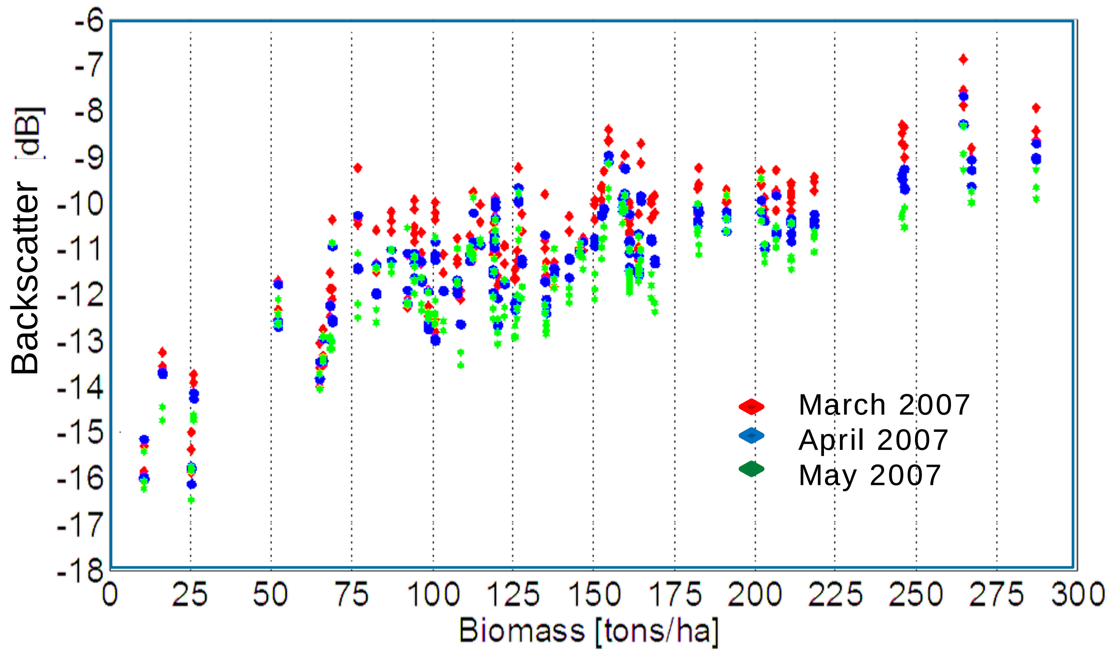
1. Similar power-law relationships between backscatter and biomass are found for all forests where we have data
2. Inversion techniques need to deal with data dispersion and differences between different types of forest



In boreal forest, soil moisture and topography affect the backscatter-biomass relationship

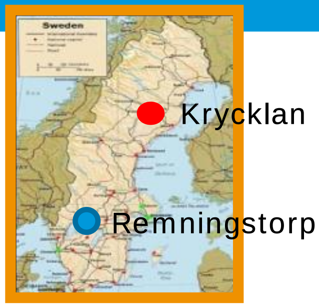
Remningstorp forest (Sweden)





Because the disturbing effects differ among polarisations, all polarisations and a DEM are used to account for environmental and topographic effects.

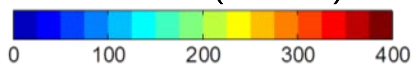
Consistent biomass estimates are obtained after correcting environmental effects



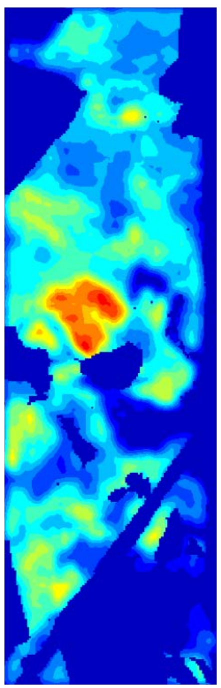
Biomass map, Remningstorp, Sweden

Training at Krycklan

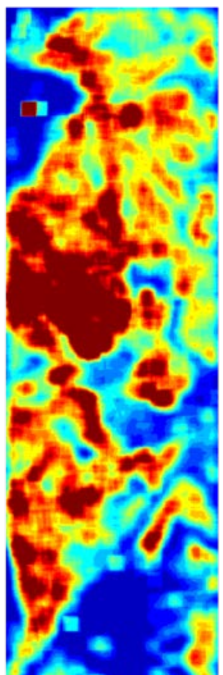
Biomass (ton/ha)



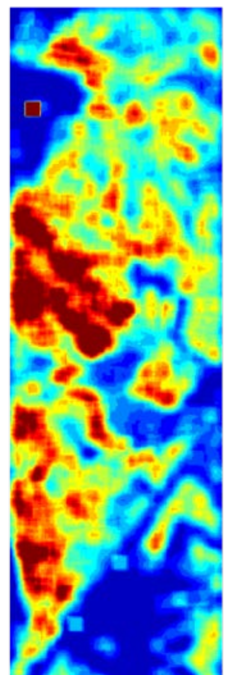
Lidar biomass estimate



Inversion using single polarisation (HV)

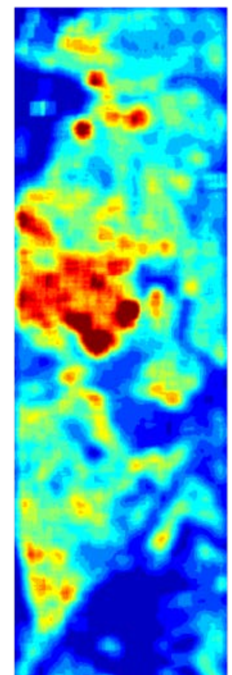


March

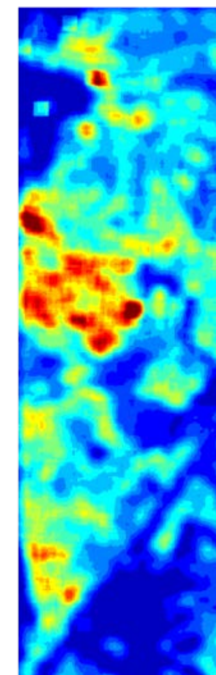


May

Inversion using multiple polarisations and DEM

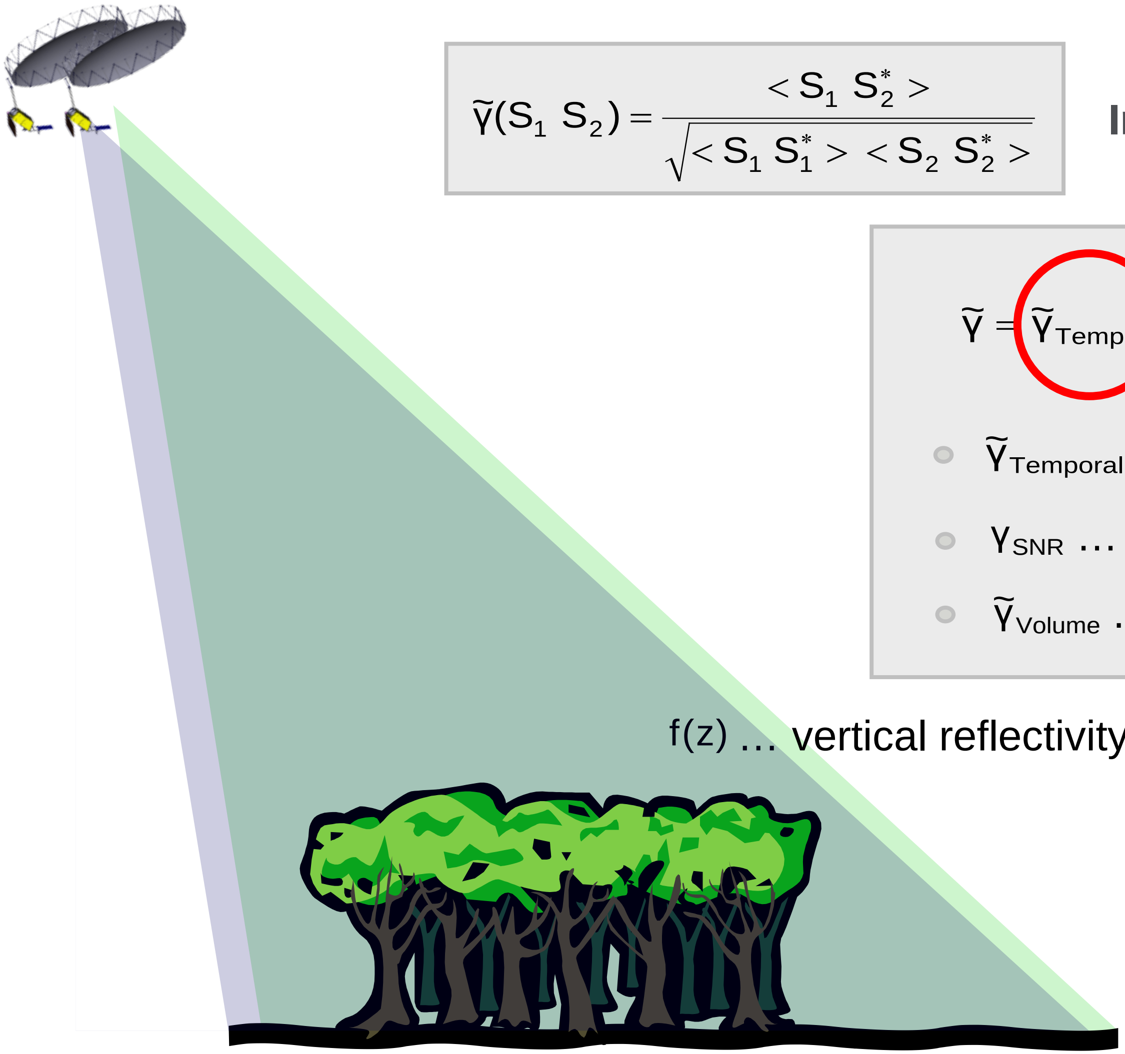


March



May

PolInSAR provides a second estimate of biomass using height …



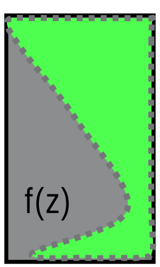
$$\tilde{\gamma}(S_1\ S_2) = \frac{\langle S_1\ S_2^* \rangle}{\sqrt{\langle S_1\ S_1^* \rangle \langle S_2\ S_2^* \rangle}}$$

Interferometric Coherence

$$\tilde{\gamma} = \tilde{\gamma}_{Temporal}\ \gamma_{SNR}\ \tilde{\gamma}_{Volume}$$

- $\tilde{\gamma}_{Temporal}$ … temporal decorrelation
- γ_{SNR} … additive noise decorrelation
- $\tilde{\gamma}_{Volume}$ … geometric decorrelation

$f(z)$ … vertical reflectivity function



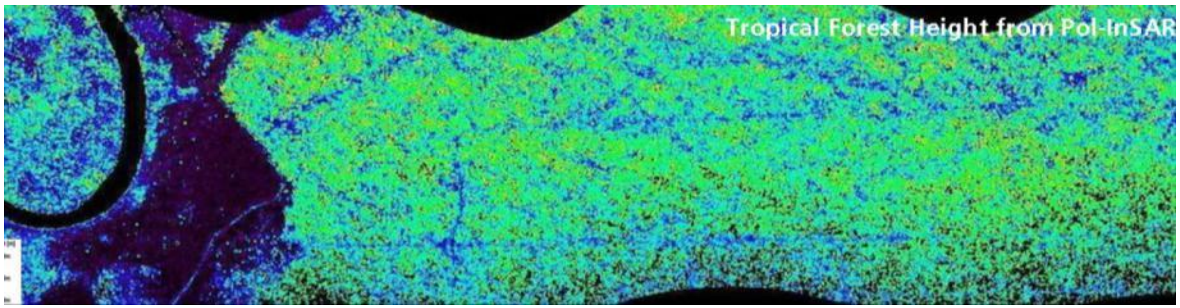
$$\tilde{\gamma}_{Vol}(f(z)) = e^{ik_z z_o} \frac{\int_o^{h_v} f(z)\, e^{ik_z z} dz}{\int_o^{h_v} f(z)\ dz}$$

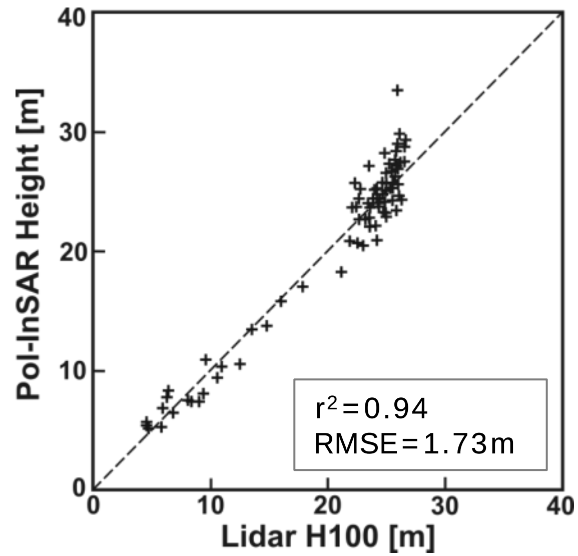
PolInSAR has mapped height over tropical and boreal sites

Height maps from PolInSAR

Tropical forest

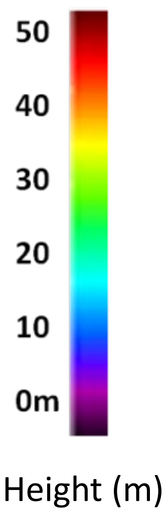
Kalimantan, Indonesia

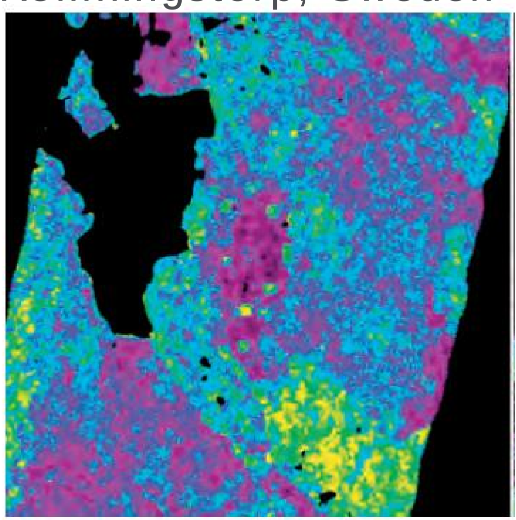


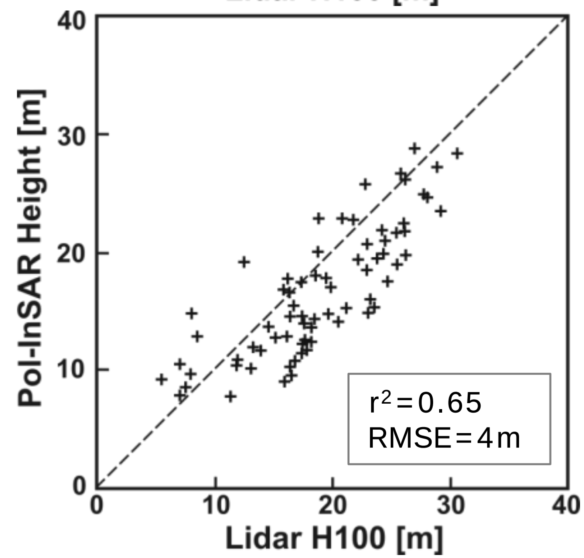


Boreal forest

Remningstorp, Sweden



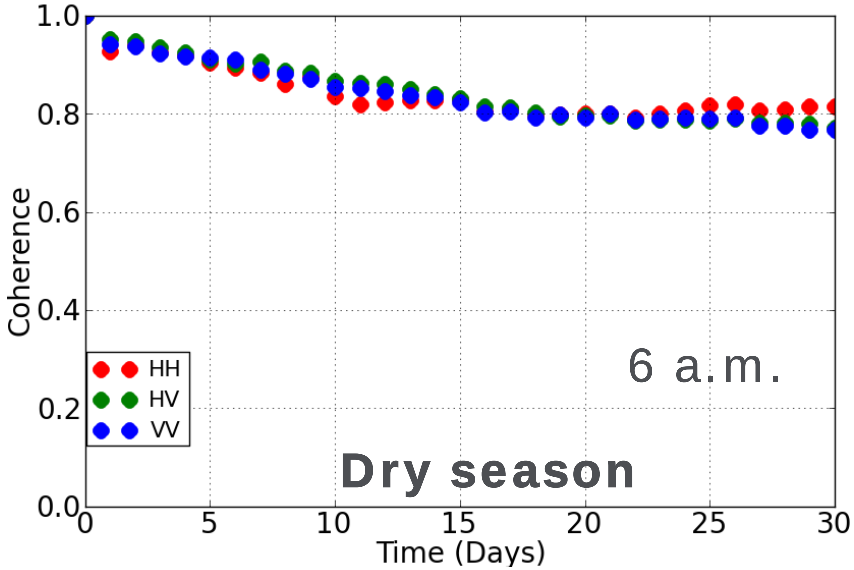


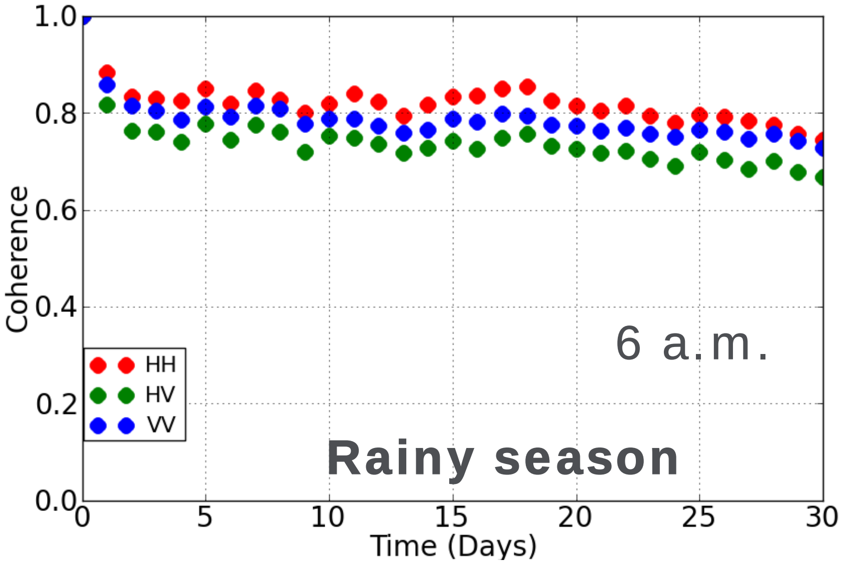


Seasonal variation: coherence is higher in the dry season, giving better height estimates

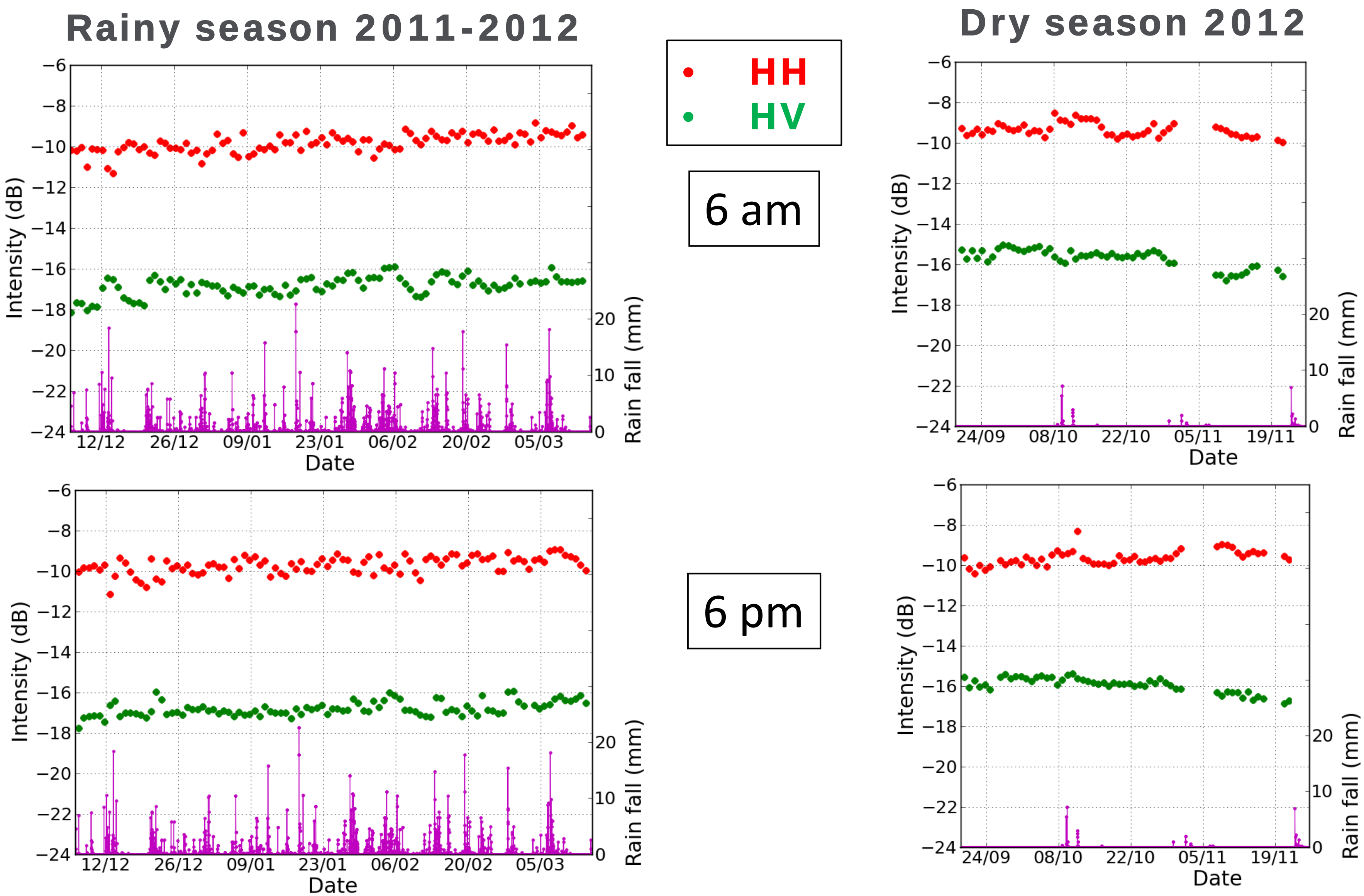
TropiScatt experiment:

- Tower-based P-band tomographic measurements.
- Measurements every 15 minutes.
- Started December 2011, still running.



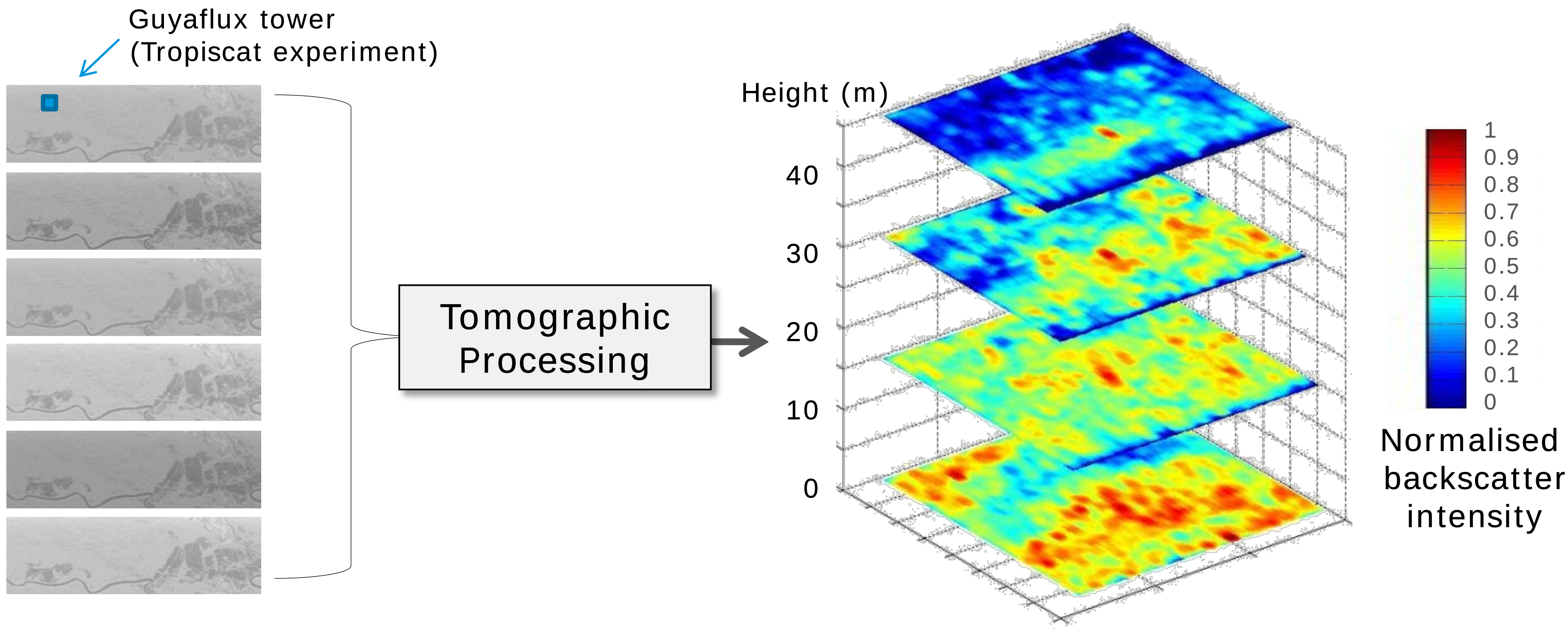


Slow variation in backscatter → PolSAR retrieval must adapt to moisture changes

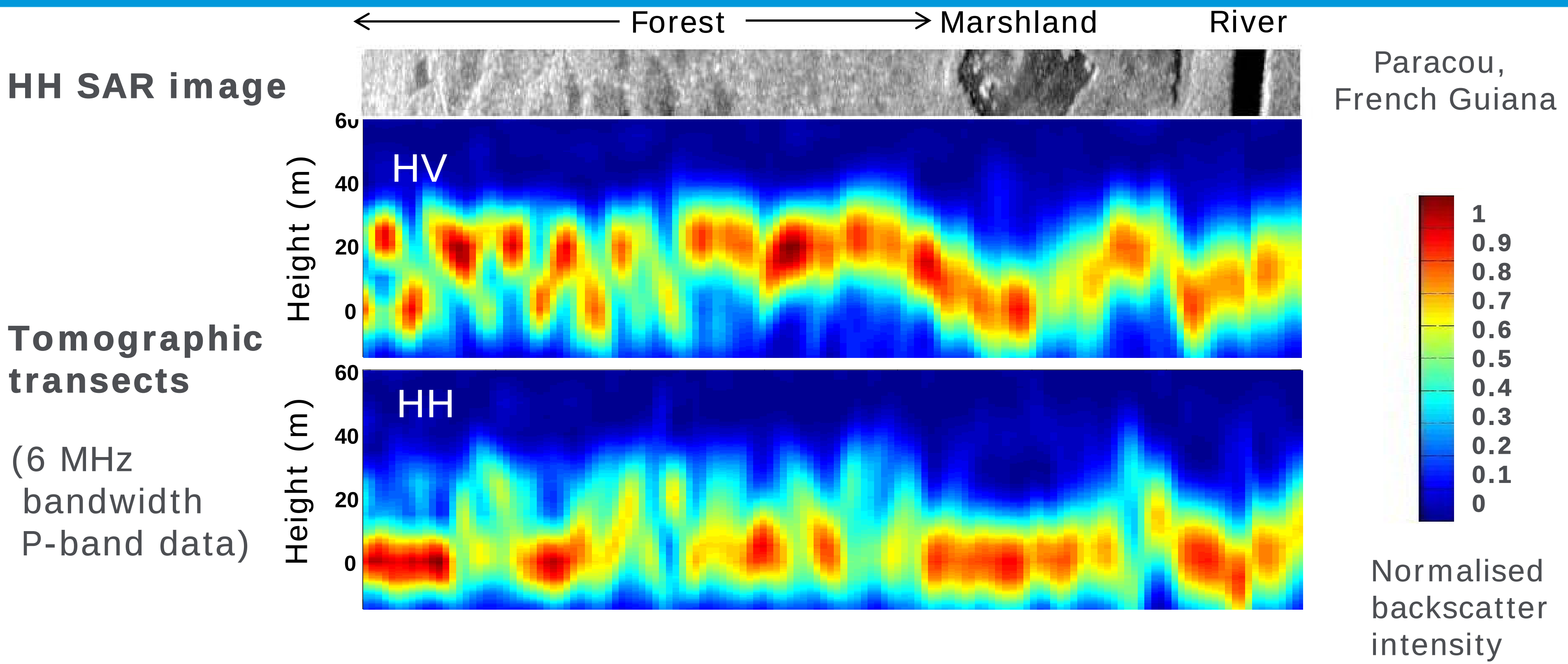


SAR tomography, a new concept to explore 3D forest structure

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



SAR tomography provides basic information to improve Biomass retrieval algorithms



TomoSAR:

1. Provides a 3D reconstruction of forest backscatter.
2. Allows an interpretation of scattering processes
3. Gives guidance to the PolSAR and PolInSAR retrieval algorithms.

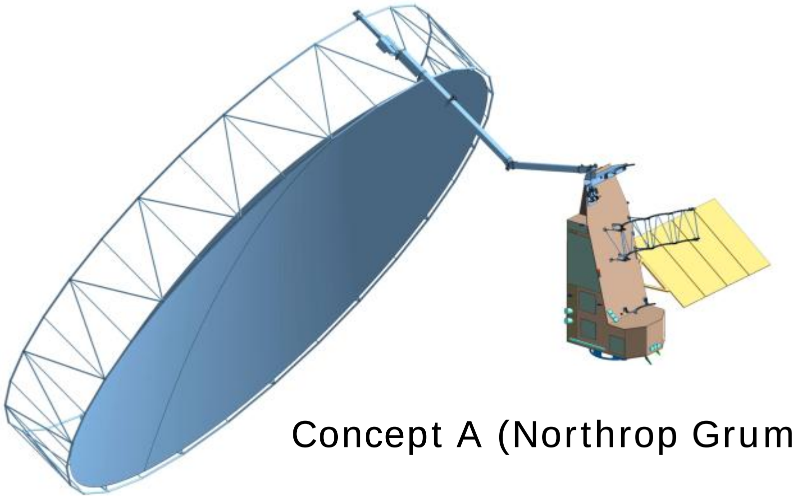
From observation concept to mission requirements

What do we need?

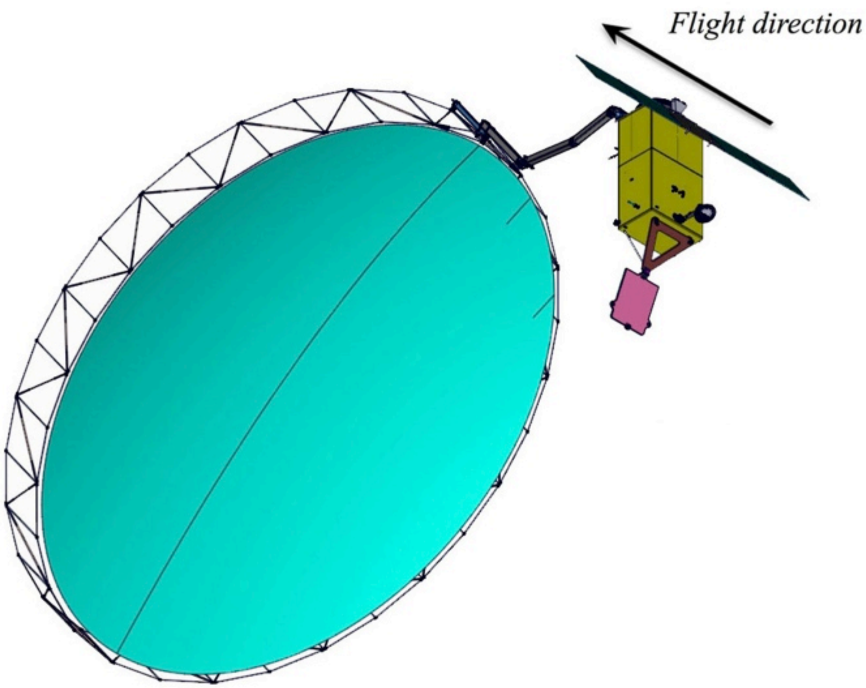
1. A P-band SAR with multiple polarisations
2. Satellite orbits that allow interferometry
3. Repeated observations over short time intervals
4. A tomographic phase to gain understanding and reference information
5. Dawn/Dusk Orbit

Design drivers

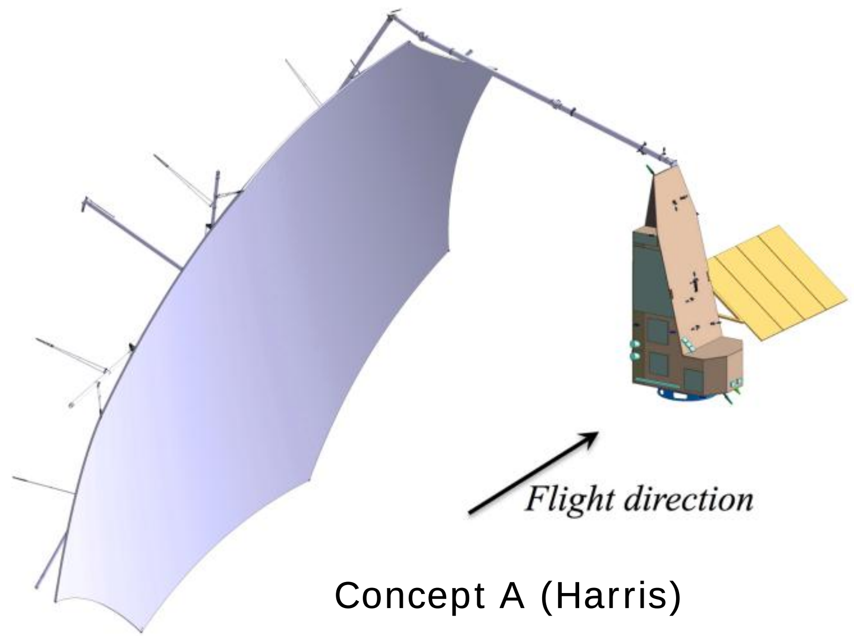
1. Single satellite
2. Vega launcher compatibility
3. P-band SAR



Concept A (Northrop Grumman)



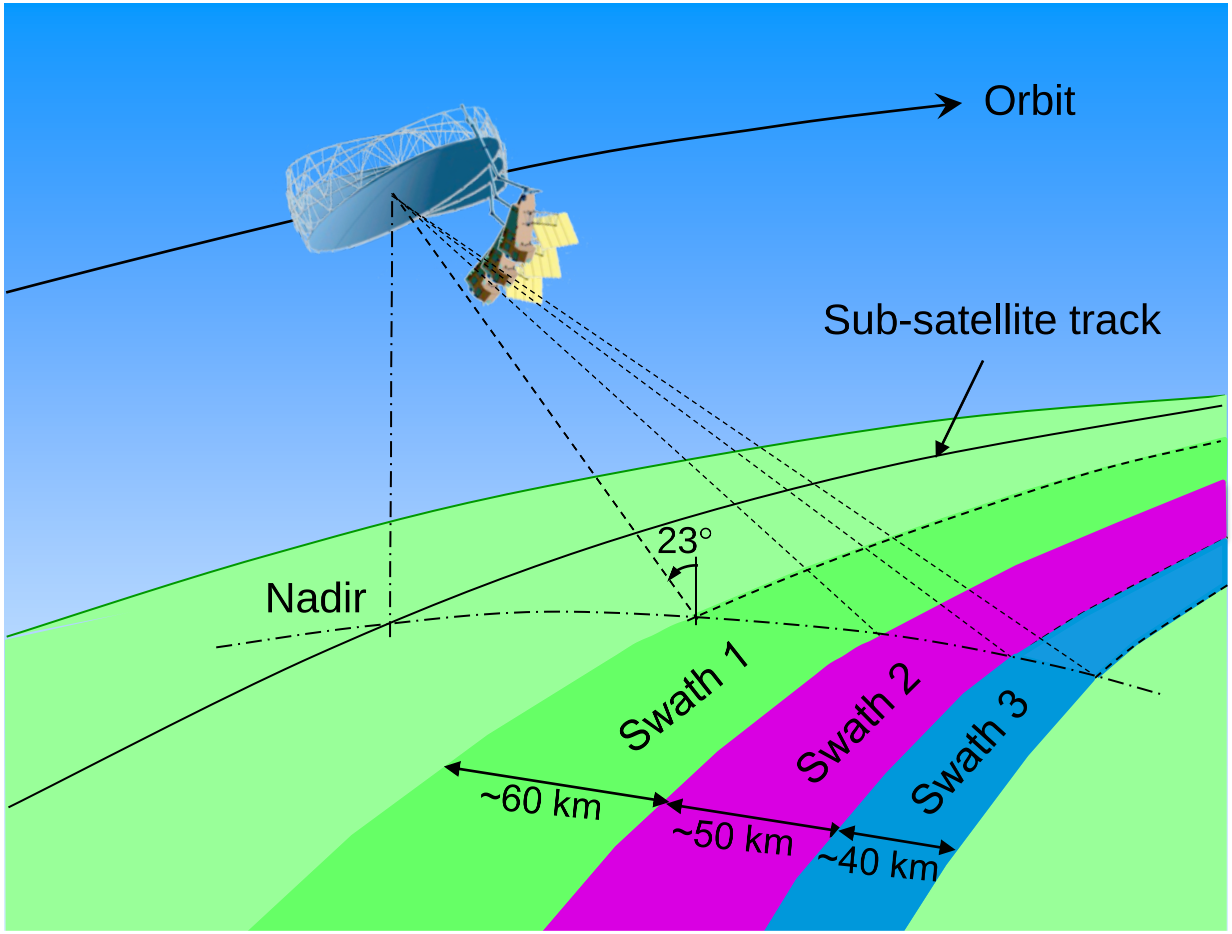
Concept B (Northrop Grumman)



Concept A (Harris)

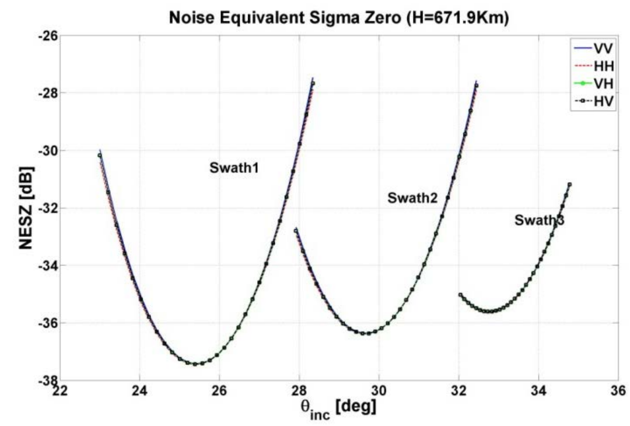
Payload overview

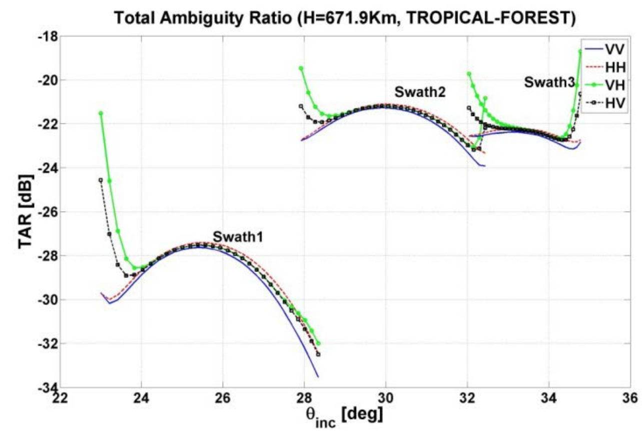
- P-band (435 MHz) Synthetic Aperture Radar (SAR)
- Bandwidth of 6 MHz
- Full polarimetric SAR
- Multi-pass interferometry
- Single antenna beam
- Stripmap mode
- Satellite roll for beam repointing



System performance at Level 1B

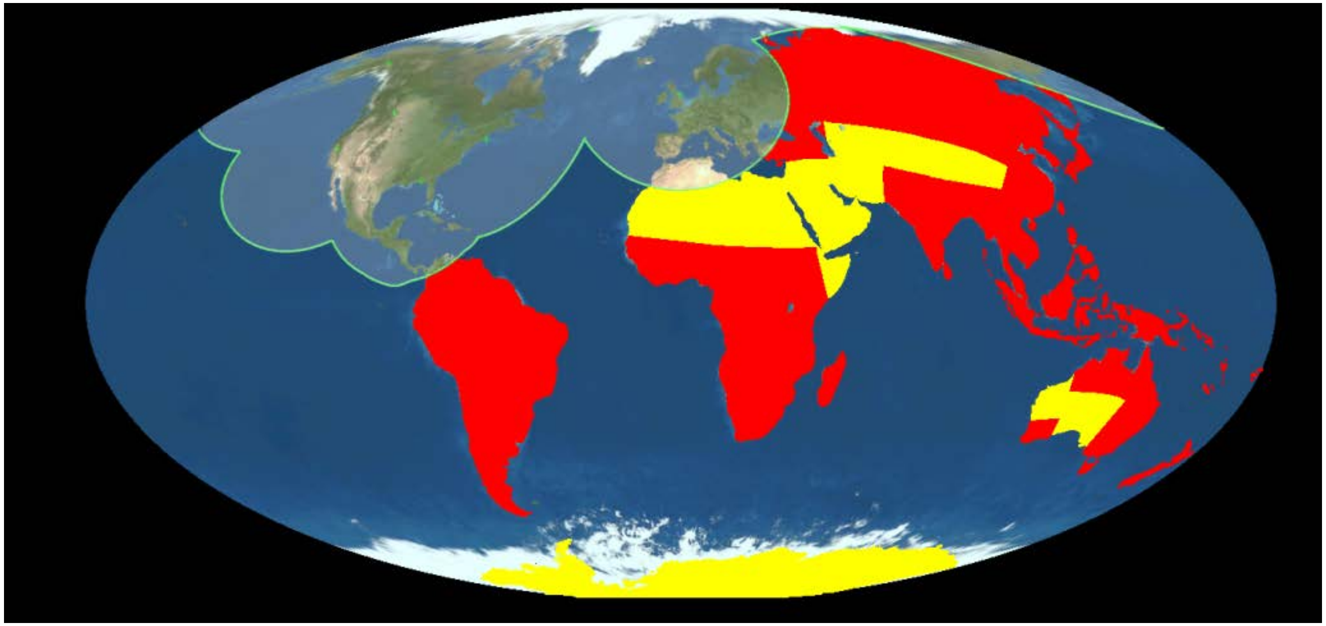
Key Parameters	Requirement	Concepts A and B
Sensitivity (NESZ)	≤ -27 dB	≤ -27 dB ✔
Total Ambiguity Ratio	≤ -18 dB	≤ -18 dB ✔
Geometric Resolution	≤ 60m x 50m	≤ 60m x 50m ✔
Effective Number of Looks	≥ 6	≥ 6 ✔
Radiometric Stability	≤ 0.5 dB	≤ 0.35 dB ✔
Absolute Radiometric Bias	≤ 1.0 dB	≤ 0.45 dB ✔
Crosstalk	≤ -25 dB	≤ -25 dB ✔
Dynamic Range	35 dB	35 dB ✔





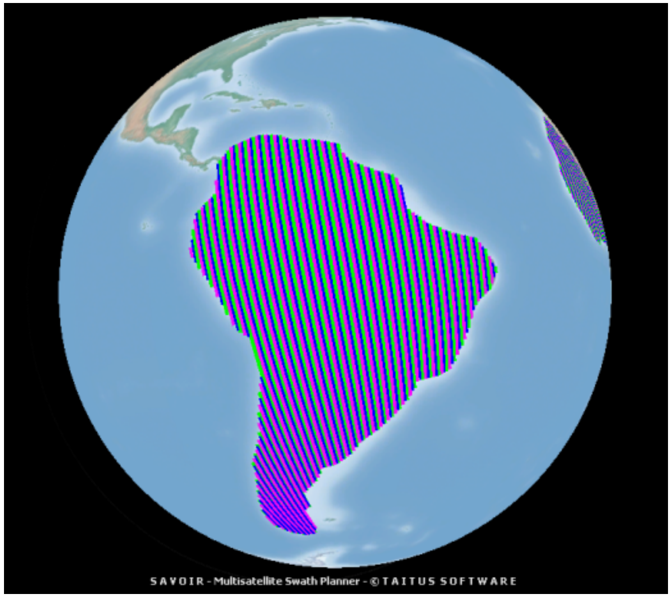
Coverage

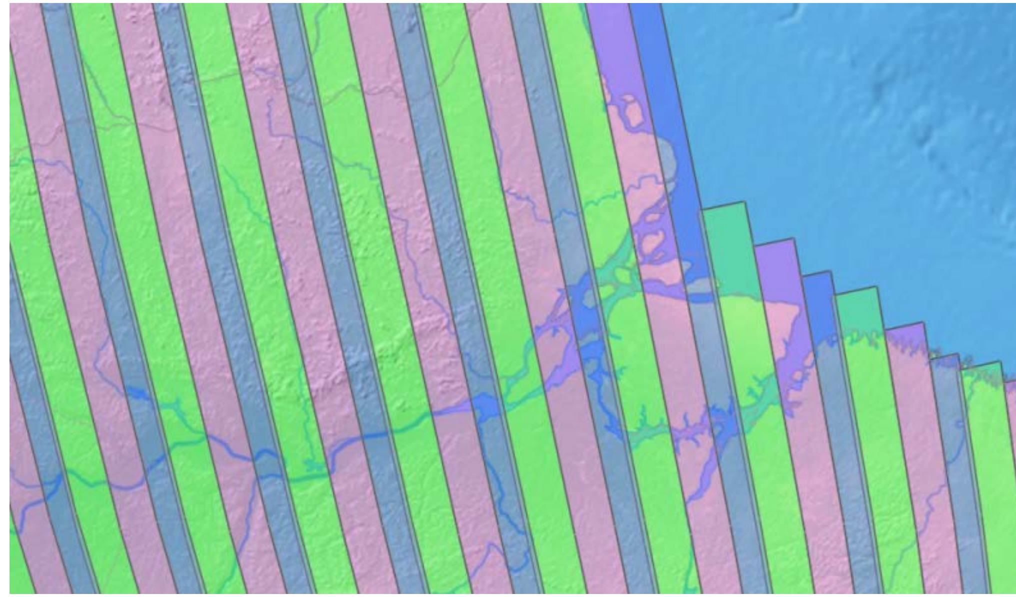
1. Acquisition mask restricted by US Space Objects Tracking Radar (SOTR)
2. Systematic Acquisitions
3. Acquisition in both ascending and descending passes
4. Two mission phases:
   - **TOM** Tomography with 7 acquisitions for a given location
   - **INT** Interferometry with 3 acquisitions for a given location

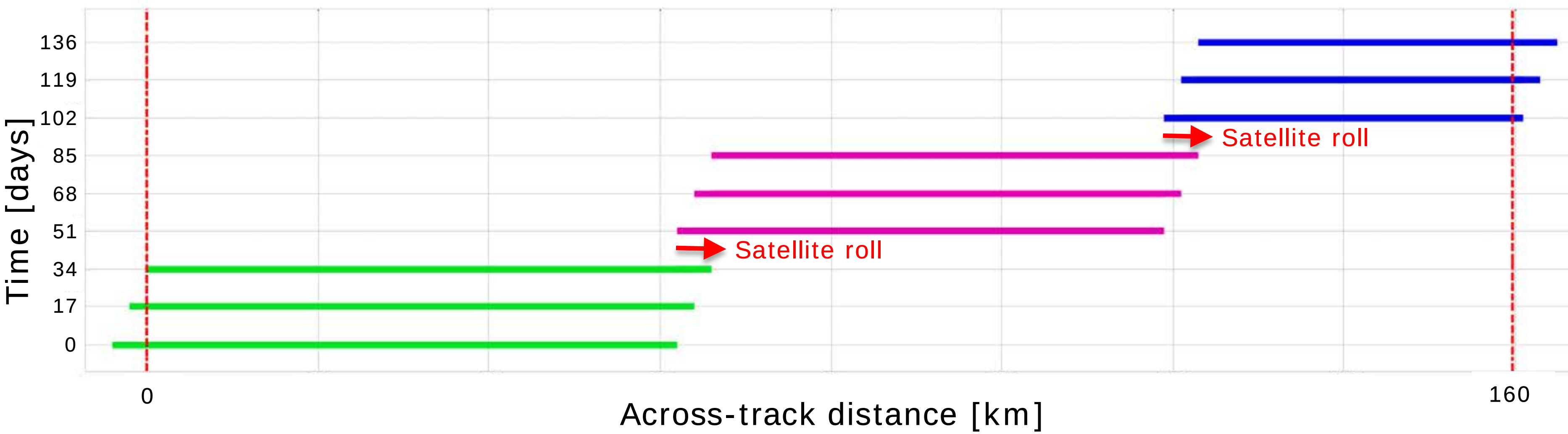


(Red = Primary objective coverage mask, Yellow = Secondary objective coverage mask)

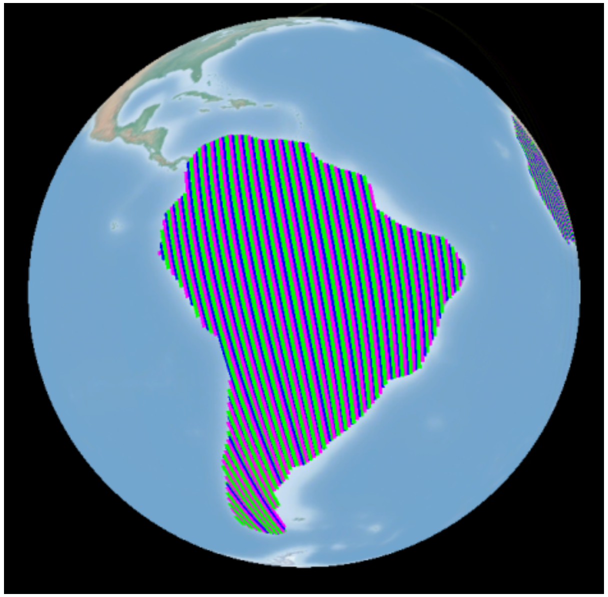
Coverage Strategy (Interferometry phase)

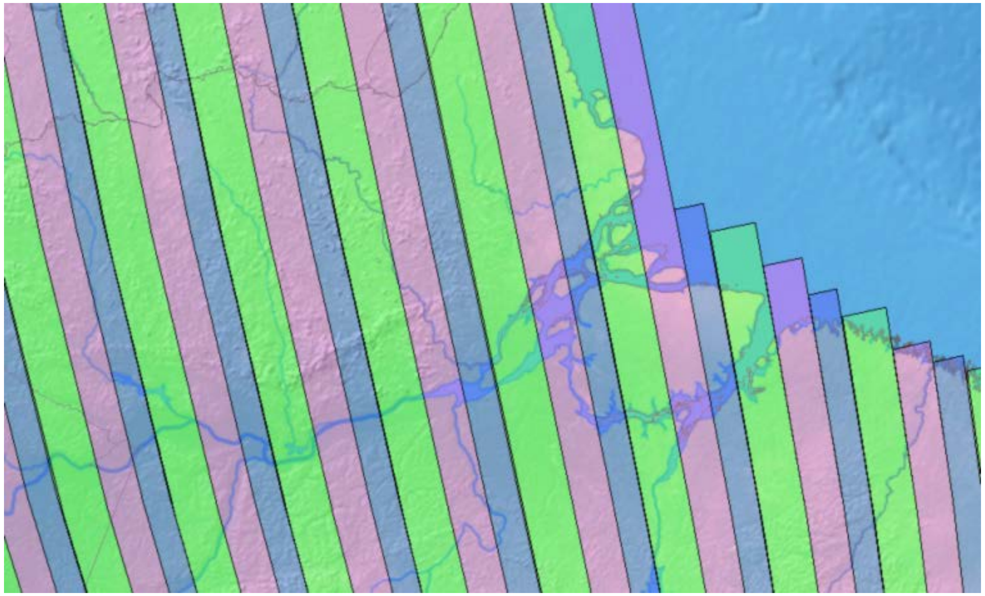


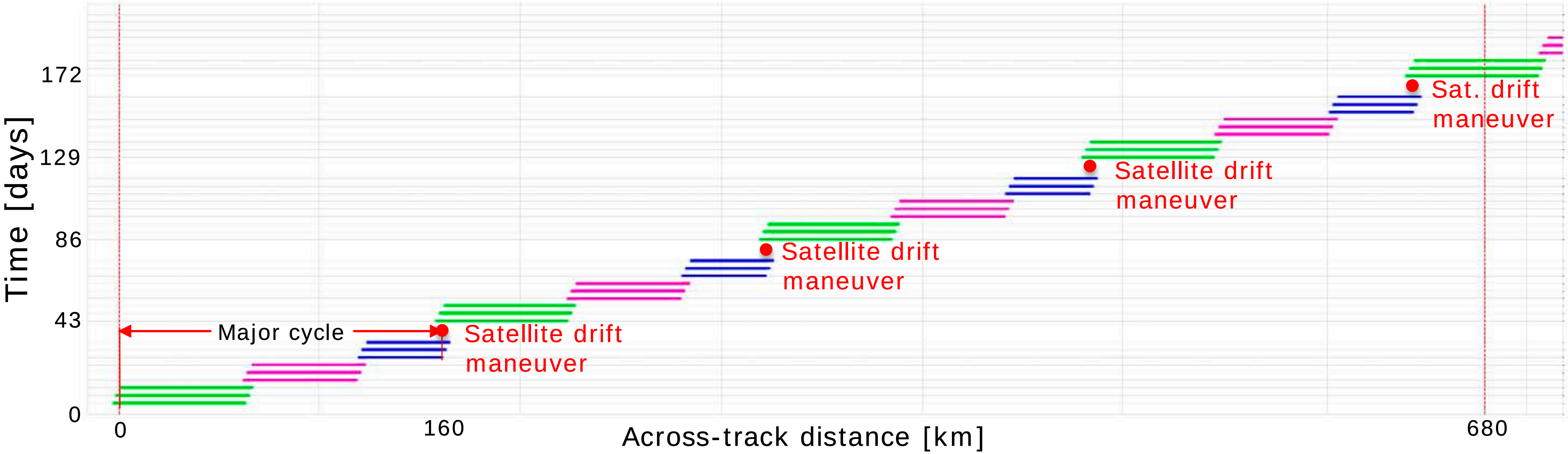




Reducing the repeat cycle time

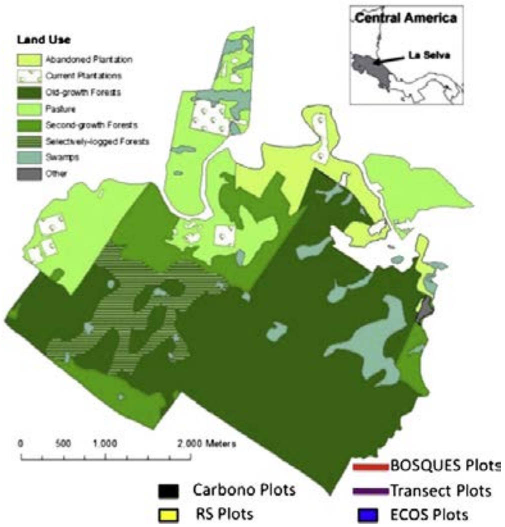




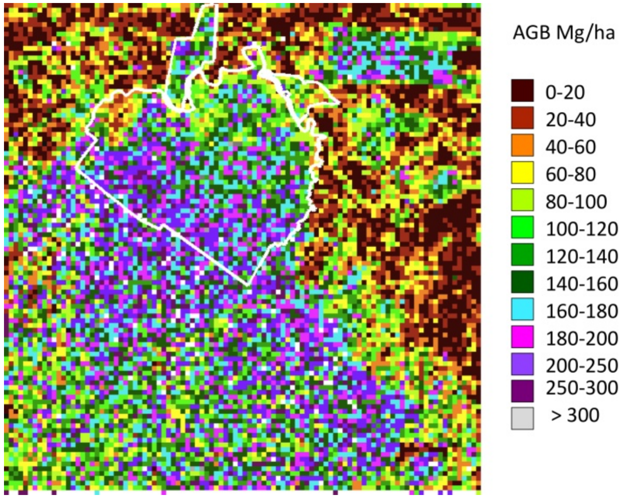


Tropical biomass: La Selva, Costa Rica

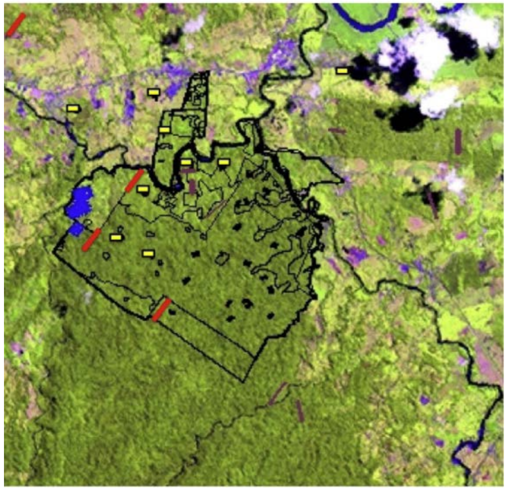
Land use: La Selva Biological Station



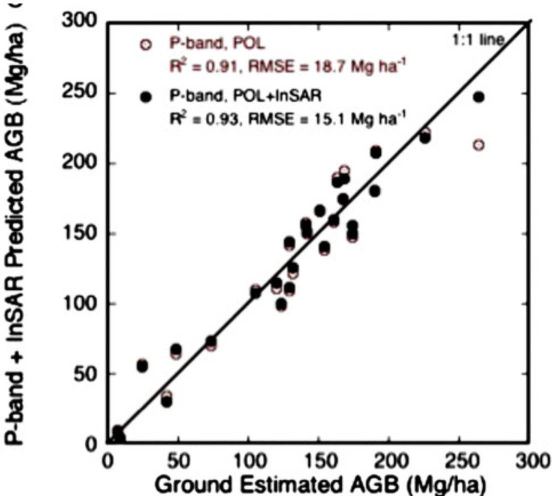
Biomass from NASA AirSAR P-band polarimetry & forest height



Landsat image with sample plots marked



Accuracy assessment: radar estimates vs ground estimates



Summary – Biomass a true Earth Explorer

1. Biomass implementation started in Nov. 2013. The anticipated launch will be in 2020.

2. Biomass is the first P-band and first radar tomographic space mission; it is a true Earth Explorer.

3. Biomass addresses urgent scientific, political and societal issues: its products can be immediately exploited by the global community of carbon cycle and climate scientists, the UN, carbon traders and resource managers.

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

Biomass will allow DEM production under dense tropical canopies

TropiSAR data

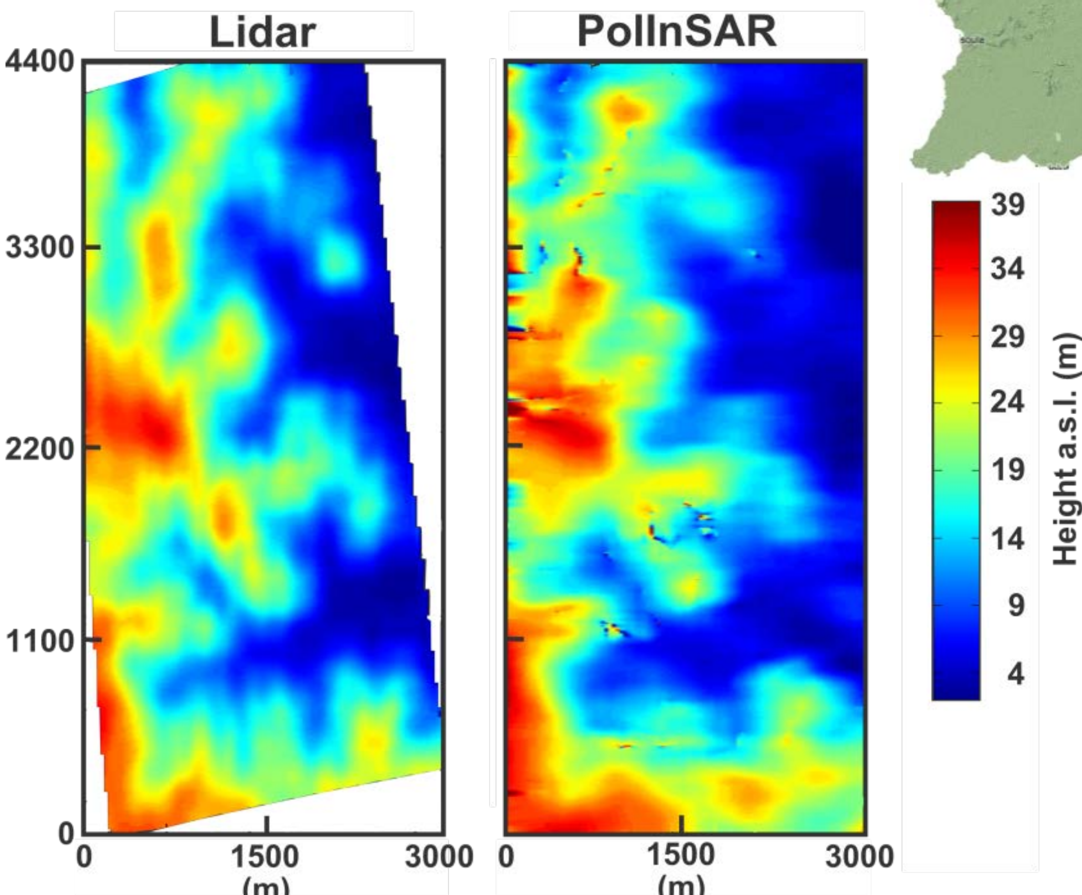
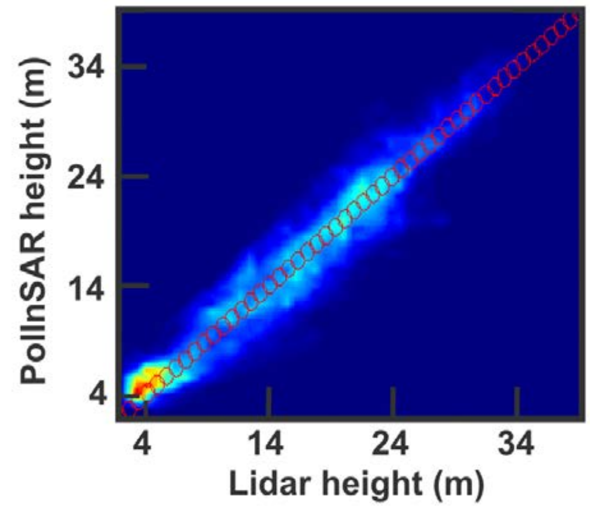


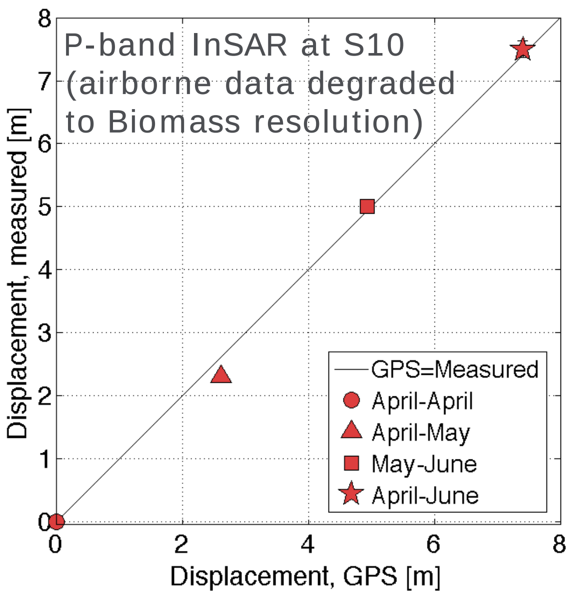
Image courtesy of P. Dubois-Fernandez

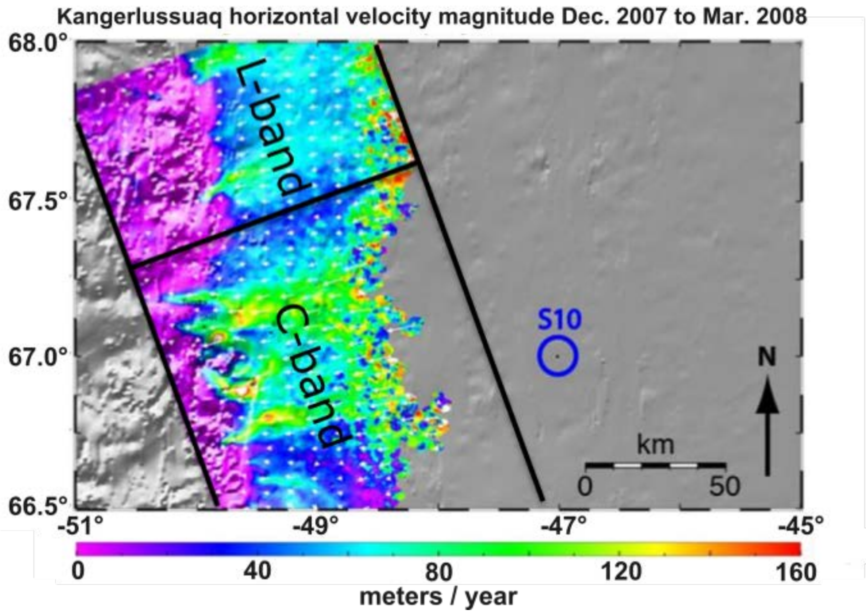


90m x 90m DEM feasible with **~ 2 m height accuracy** from Biomass

P-band extends the range of measurable glacier and ice sheet velocities

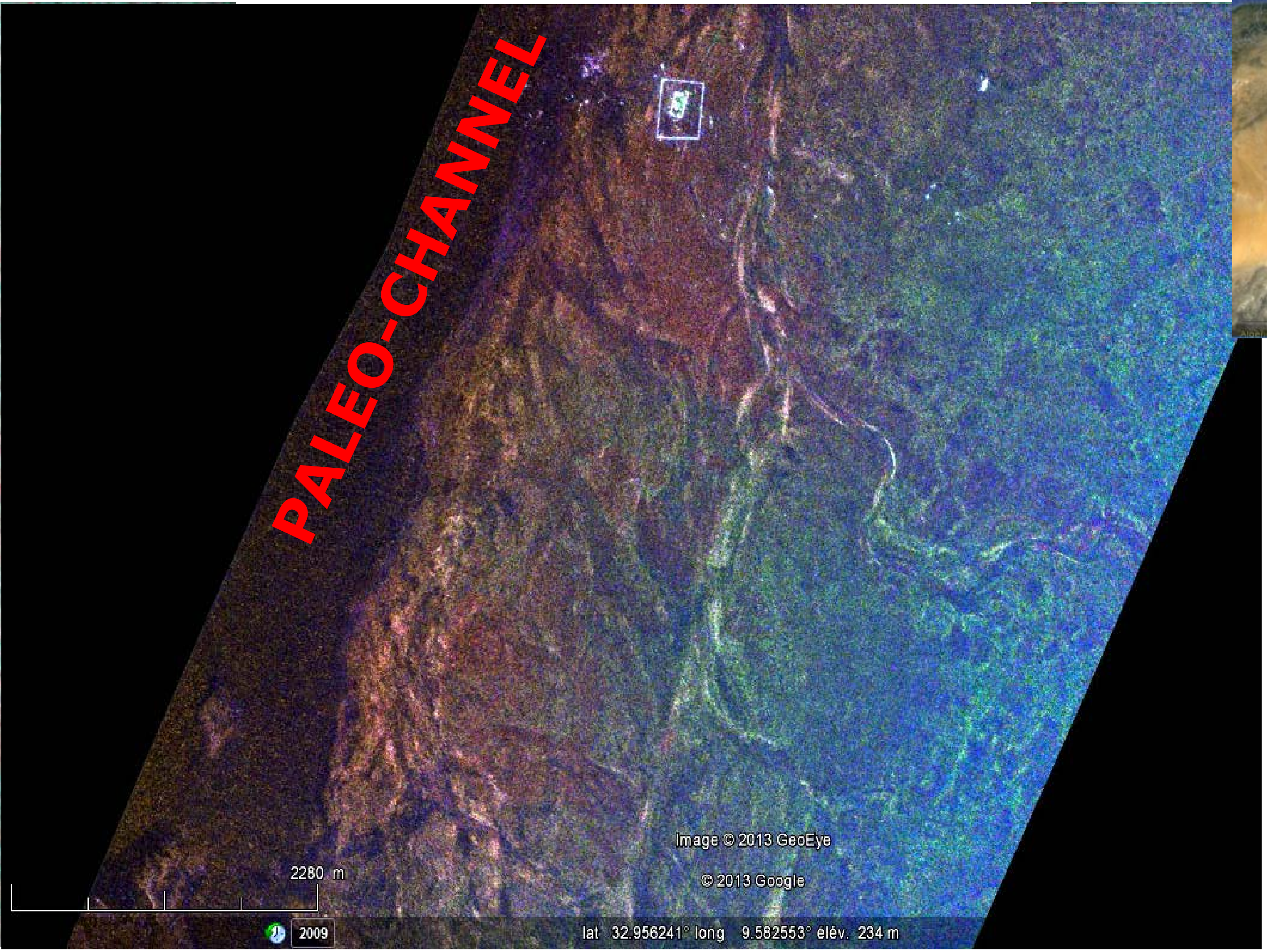
1. P-band is likely to provide better velocity measurements than higher frequencies in areas where the ice does not have crevasses and other features, e.g. above the equilibrium line.
2. Correction for ionospheric scintillations may be insufficiently accurate.





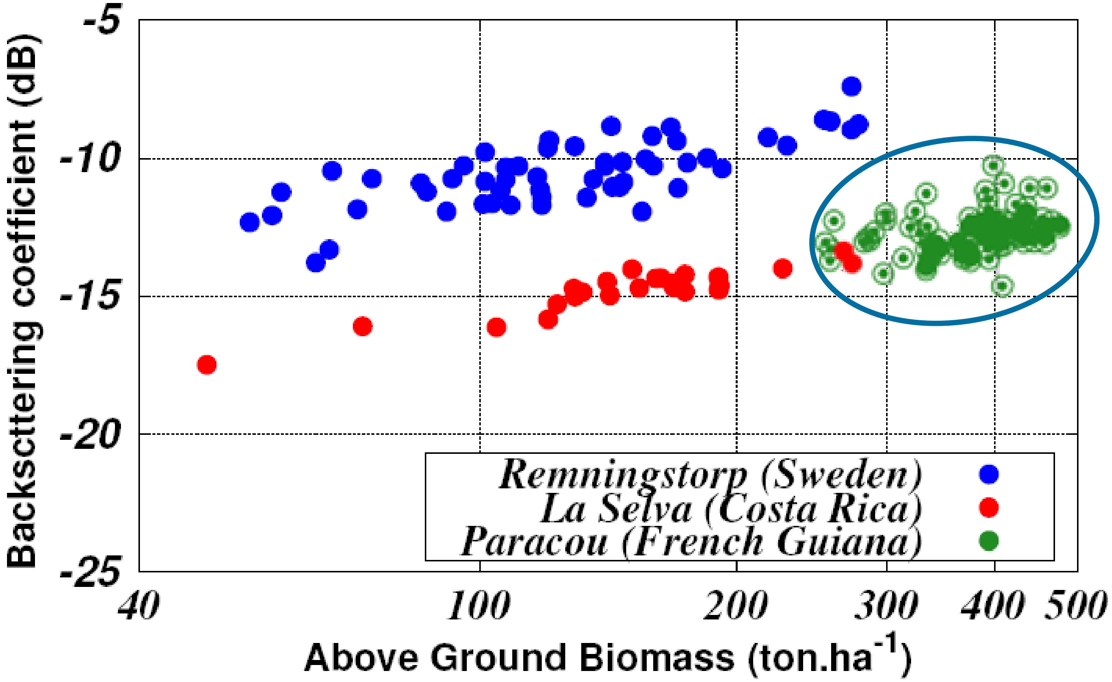
P-band enhances subsurface imaging in arid zones

P-band SAR



In tropical forest, topography has important effects on the backscatter–biomass relationship

Tropical forest, French Guiana



In tropical forest, topography has important effects on the backscatter–biomass relationship

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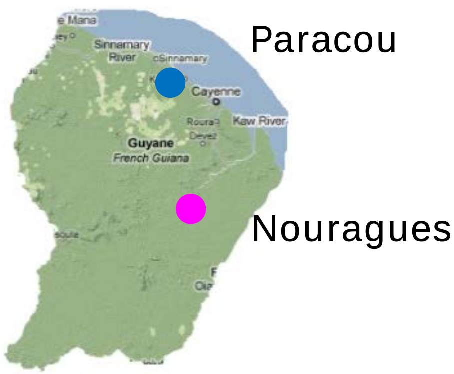
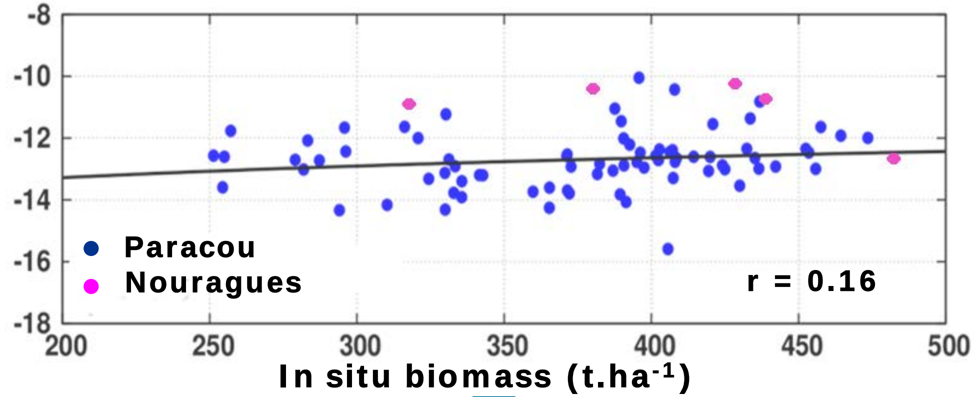
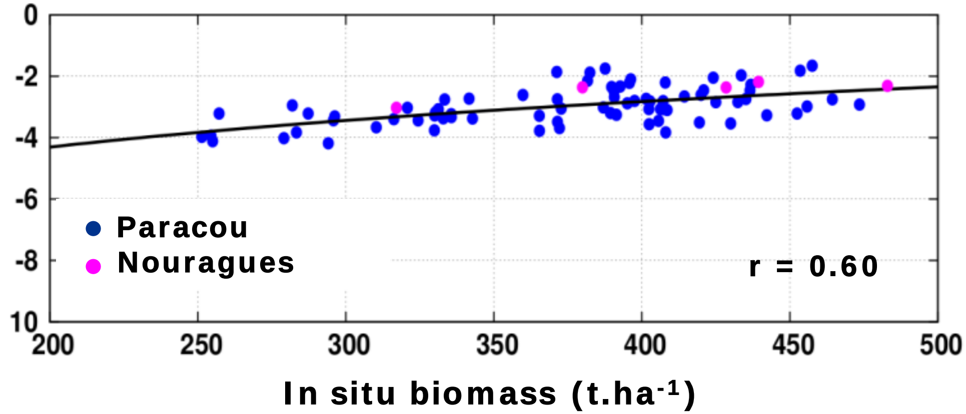


Backscatter at single polarisation (HV) in dB



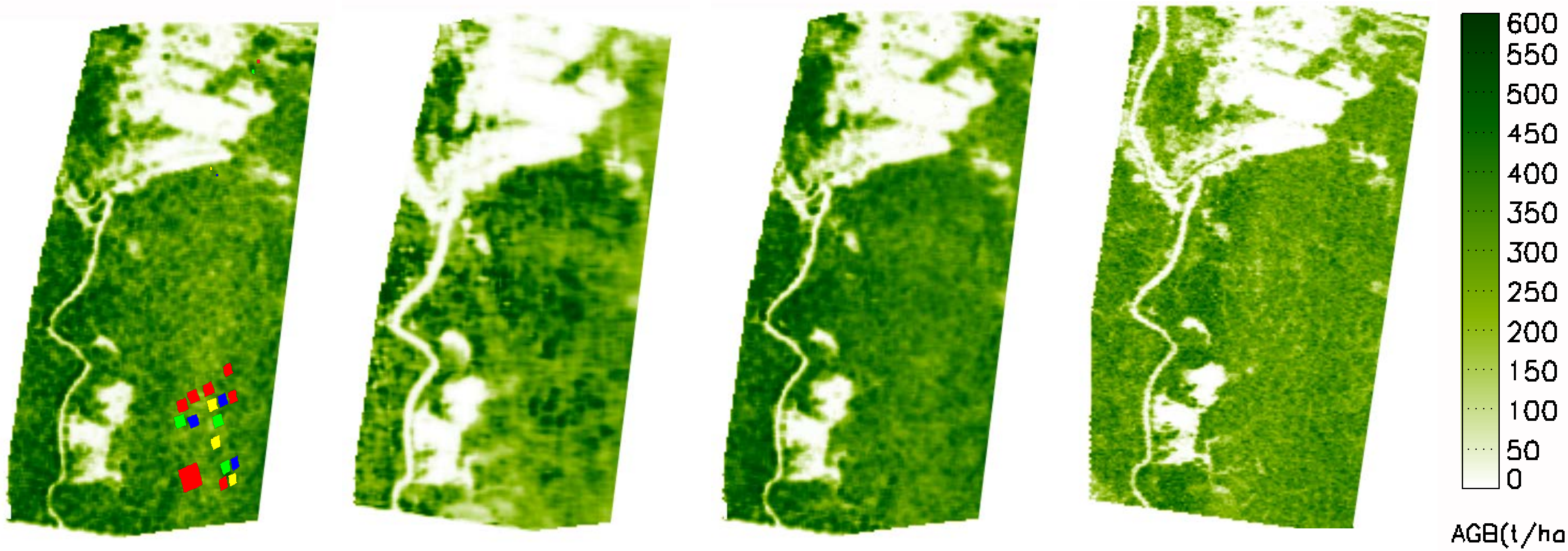
Correction for topographic effects and scattering mechanisms using polarimetry and a DEM.

Polarimetric biomass indicator (dB)



Combining estimators improves performance in tropical forests (1)

PolSAR	PolInSAR	PolSAR + PolInSAR	Tomography

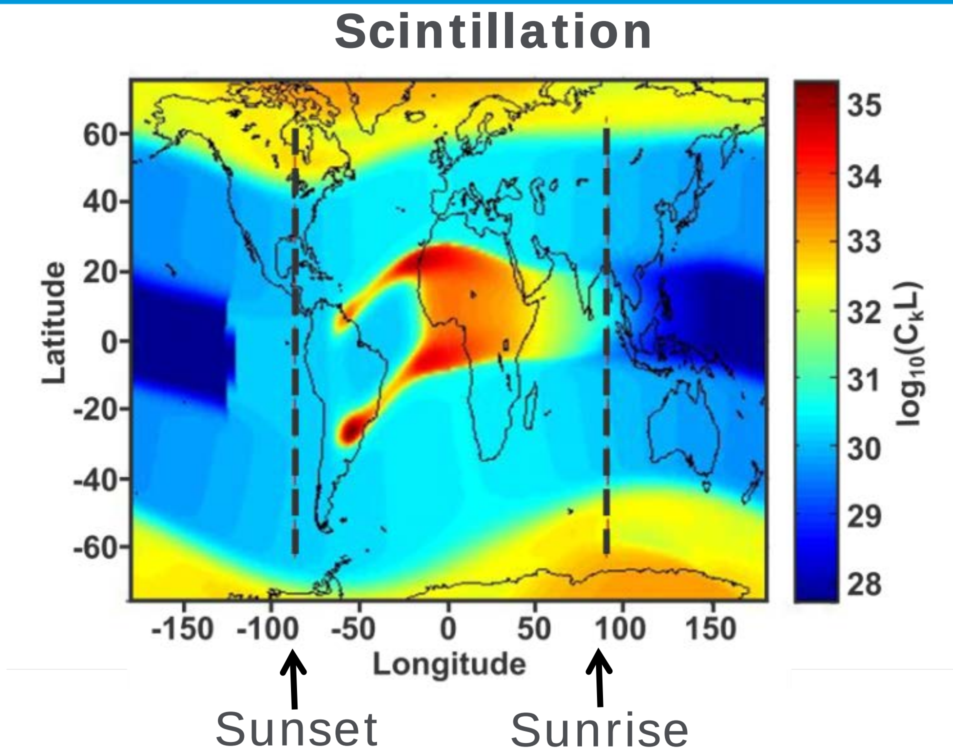


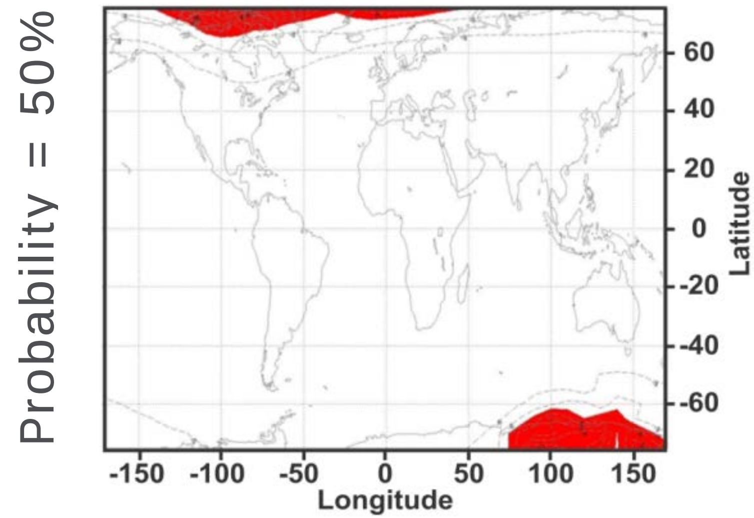
17 %	15 %	12.5 %	10 %

$$\frac{\text{RMS biomass error (estimated - in situ)}}{\text{mean biomass}}$$

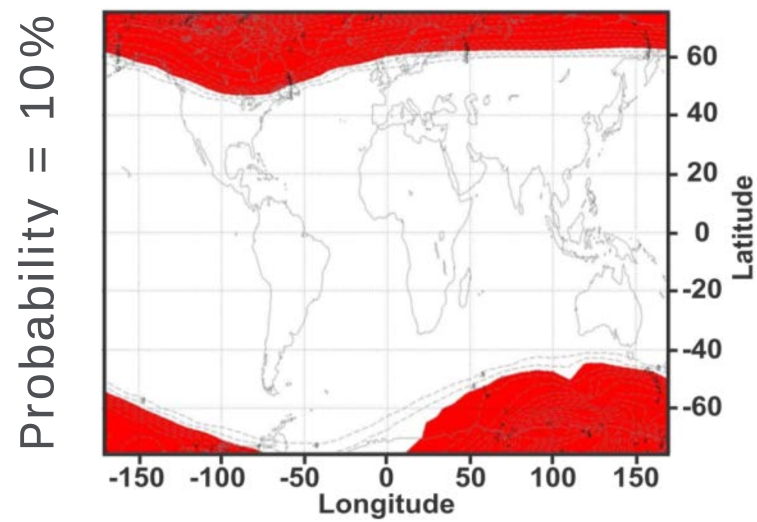
Paracou, French Guiana, 6 MHz data; in situ biomass = 260-430 ton/ha

(a) Small scale ionospheric structure: scintillations





Degradation region, median solar conditions

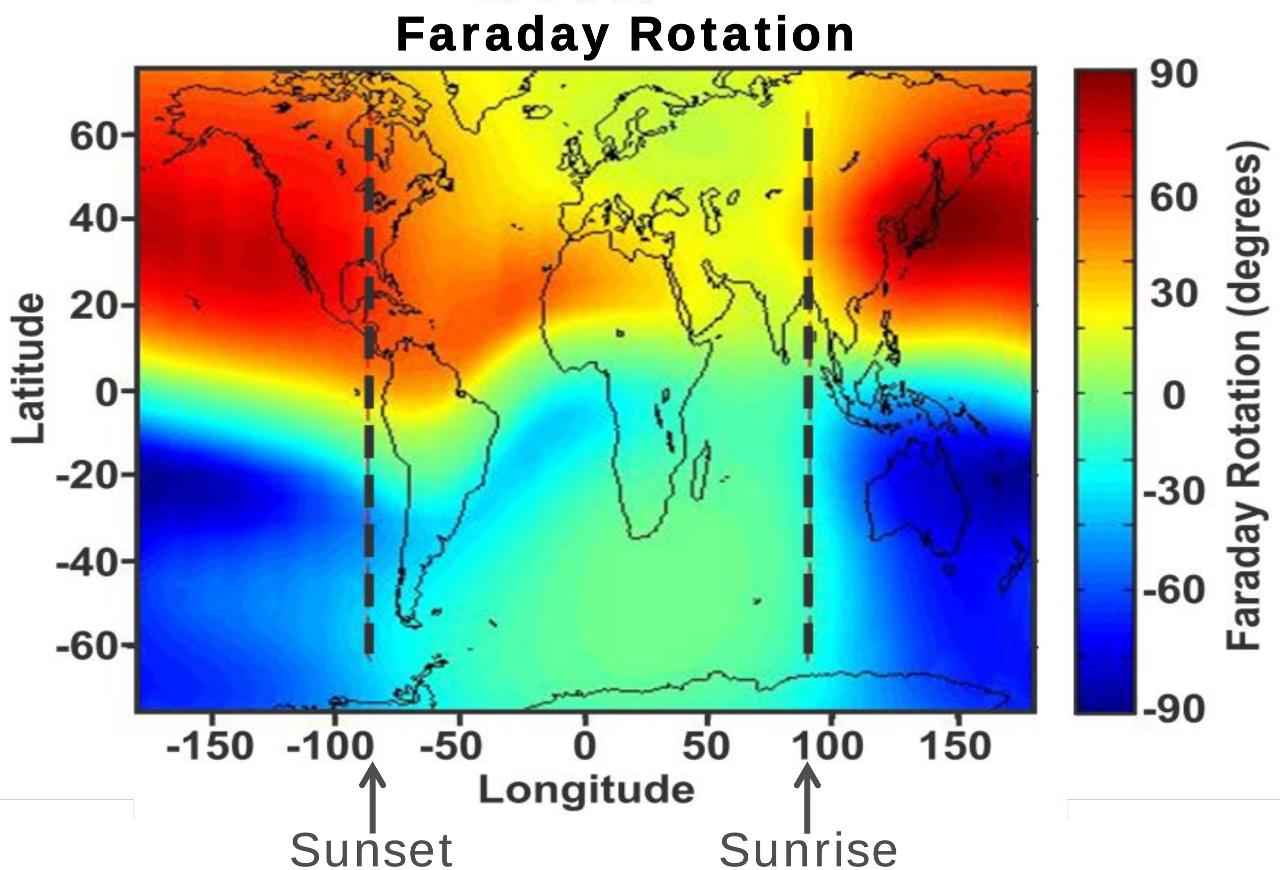


Scintillation causing blurring & loss of contrast.

The dawn-dusk orbit avoids the severe equatorial conditions, but not the auroral zone.

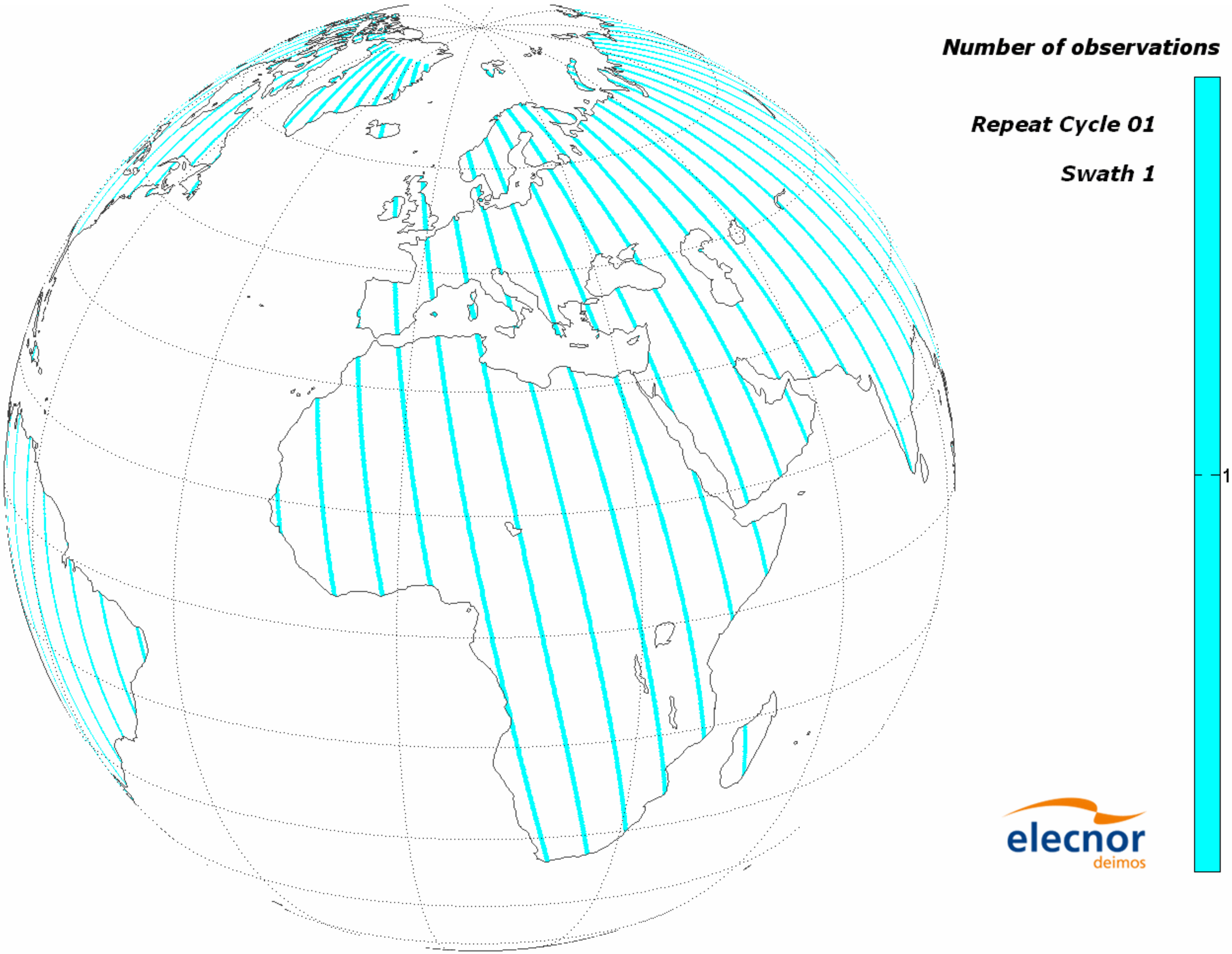
Correction of moderate scintillation has been demonstrated.

(b) Large scale ionospheric structure: Faraday rotation



- Faraday rotation corrupts polarimetry
- Can be corrected to better than 1º using the Biomass polarimetric data themselves
- Total Electron Content is measured, allowing Biomass to measure ionospheric structure

Coverage build-up



INT phase with 4 days repeat cycle

P-band vs L-band