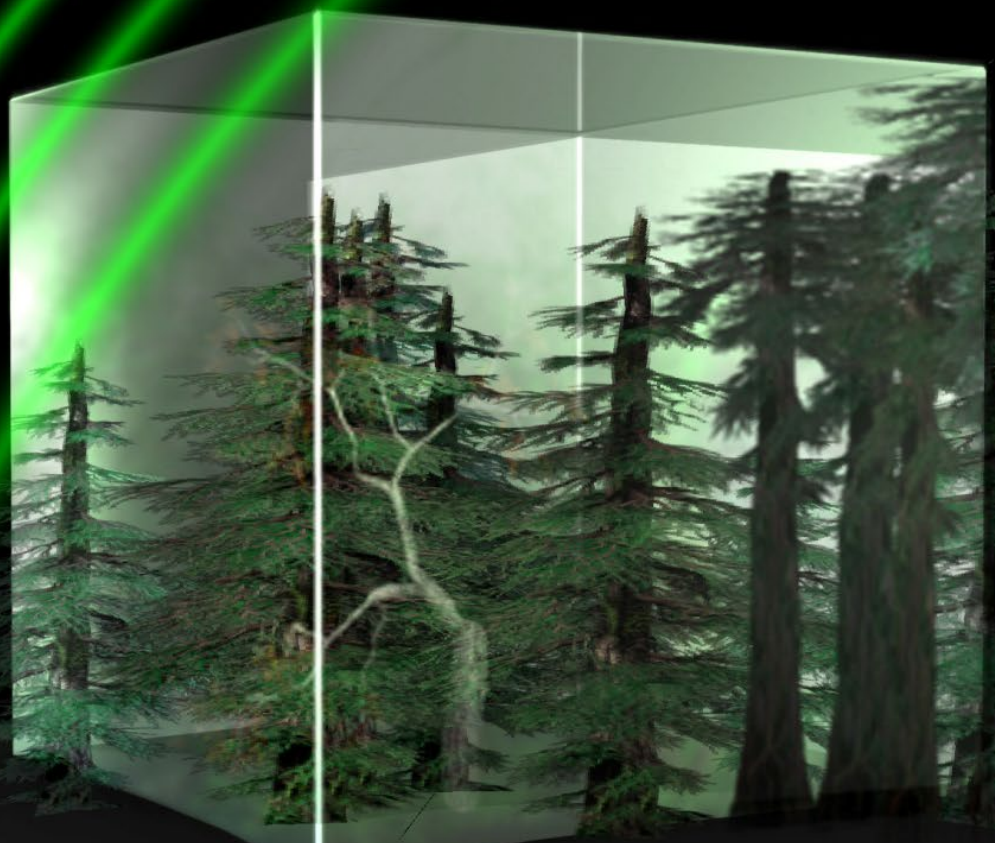
The BIOMASS mission to observe tropical forests

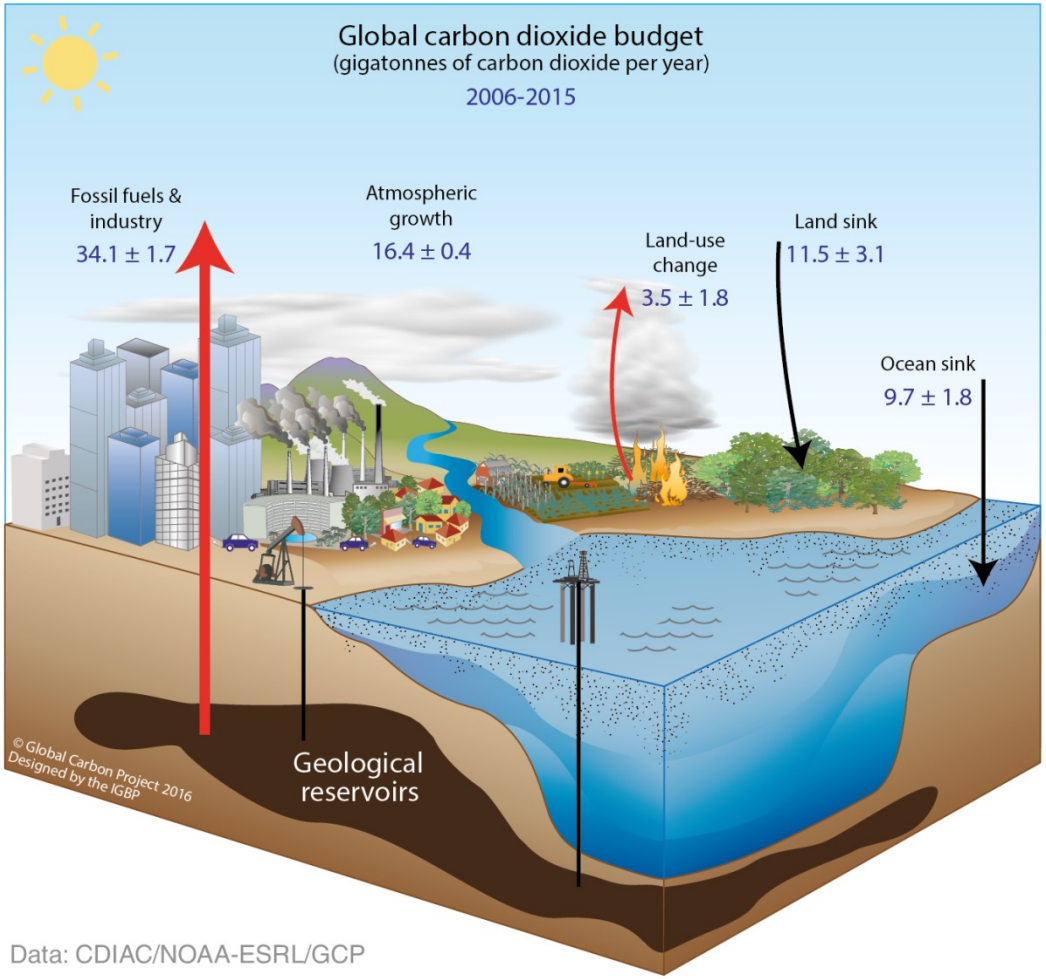


Thuy Le Toan, CESBIO, France

and the Biomass Mission Advisory Group

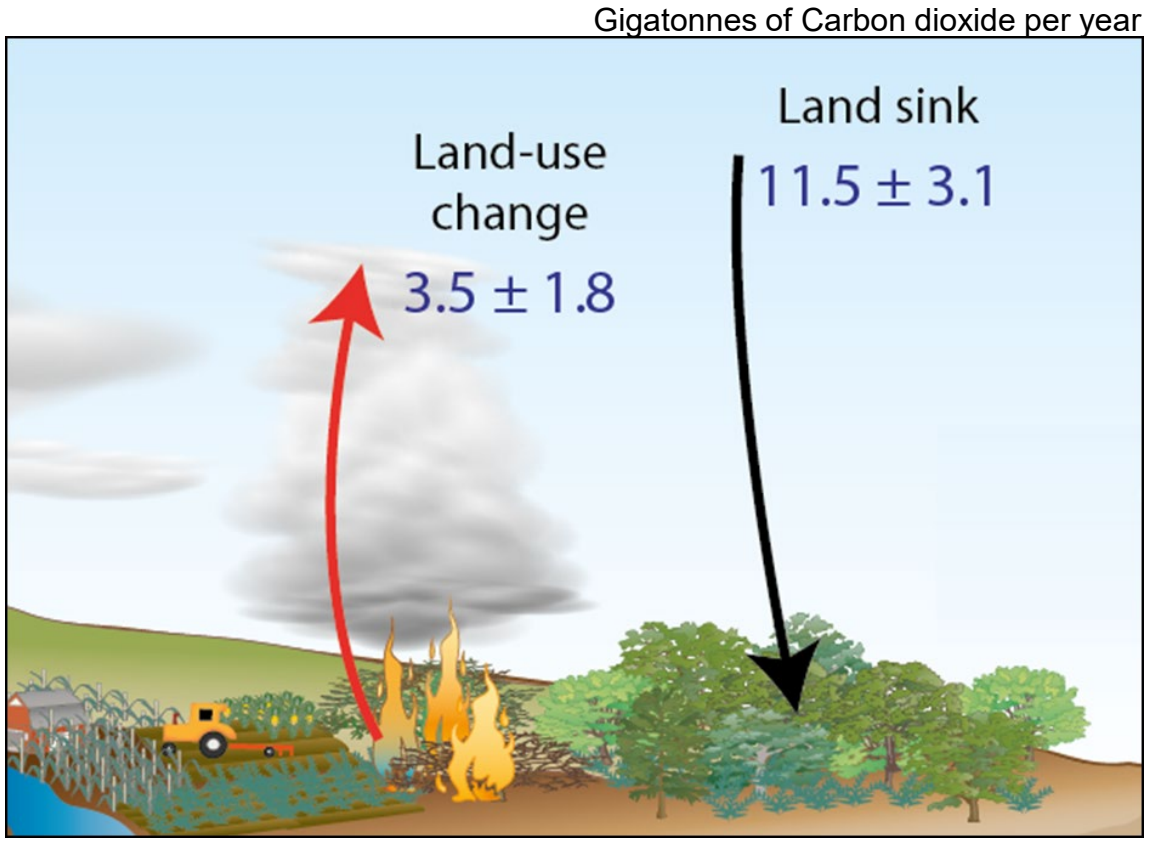
Shaun Quegan, Jerôme Chave , Jorgen Dall, Kostas Papathanassiou, Philippe Paillou, Markus Reichstein, Sassan Saatchi, Hank Shugart, Stefano Tebaldini, Lars Ulander, Matthew Williams, Klaus Scipal

The science question: role of forests in the global carbon cycle



Source: CDIAC; NOAA-ESRL; Le Quéré et al 2016; Global Carbon Budget 2016

Large uncertainties in terrestrial carbon sources and sinks



Science Issue: uncertainties on the **spatial distribution**, the **quantity** and **dynamics** of **forest carbon stocks, sources and sinks**

Fate of anthropogenic CO_2 emissions (2008–2017)
The budget imbalance reflects the gap in our understanding

Sources = **Sinks**

34.4 $GtCO_2$/yr

87%

13%

5.3 $GtCO_2$/yr

17.3 $GtCO_2$/yr

44%

29%

11.6 $GtCO_2$/yr

22%

8.9 $GtCO_2$/yr

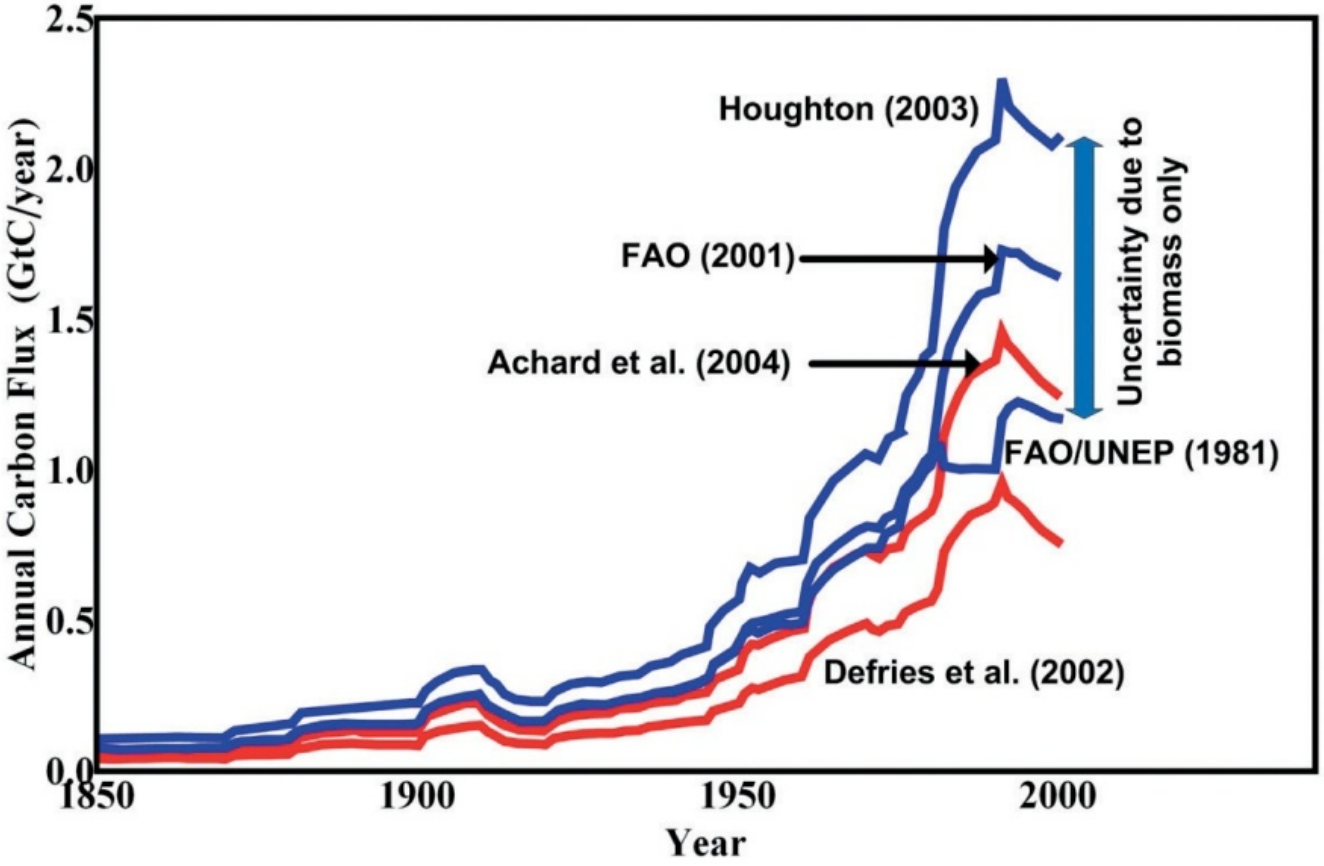
Budget Imbalance:
(the difference between estimated sources & sinks)

5%

1.9 $GtCO_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Le Quéré et al 2018; Global Carbon Budget 2018

Large uncertainties in the carbon released by deforestation (land use change)



→ The need of biomass information is crucial in the tropics (deforestation, regrowth)

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Forest biomass, a key component in the carbon cycle, is an Essential Climate Variable

1. Biomass is ~50% carbon
2. Forests hold 70–90% of Earth's above-ground biomass, with the majority of forest biomass located within the Tropics
3. Forest biomass is very poorly known and is a major source of uncertainty in carbon flux estimation.

Biomass = dry weight of woody matter + leaves (tons/hectare)

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Information required to meet the science objective

1. The **crucial information need** is in the tropics:
   - –deforestation (~95% of the Land Use Change flux)
   - –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. **Repeated measurements** over multiple years to identify deforestation and growth

Why are tropical data most uncertain and so important?

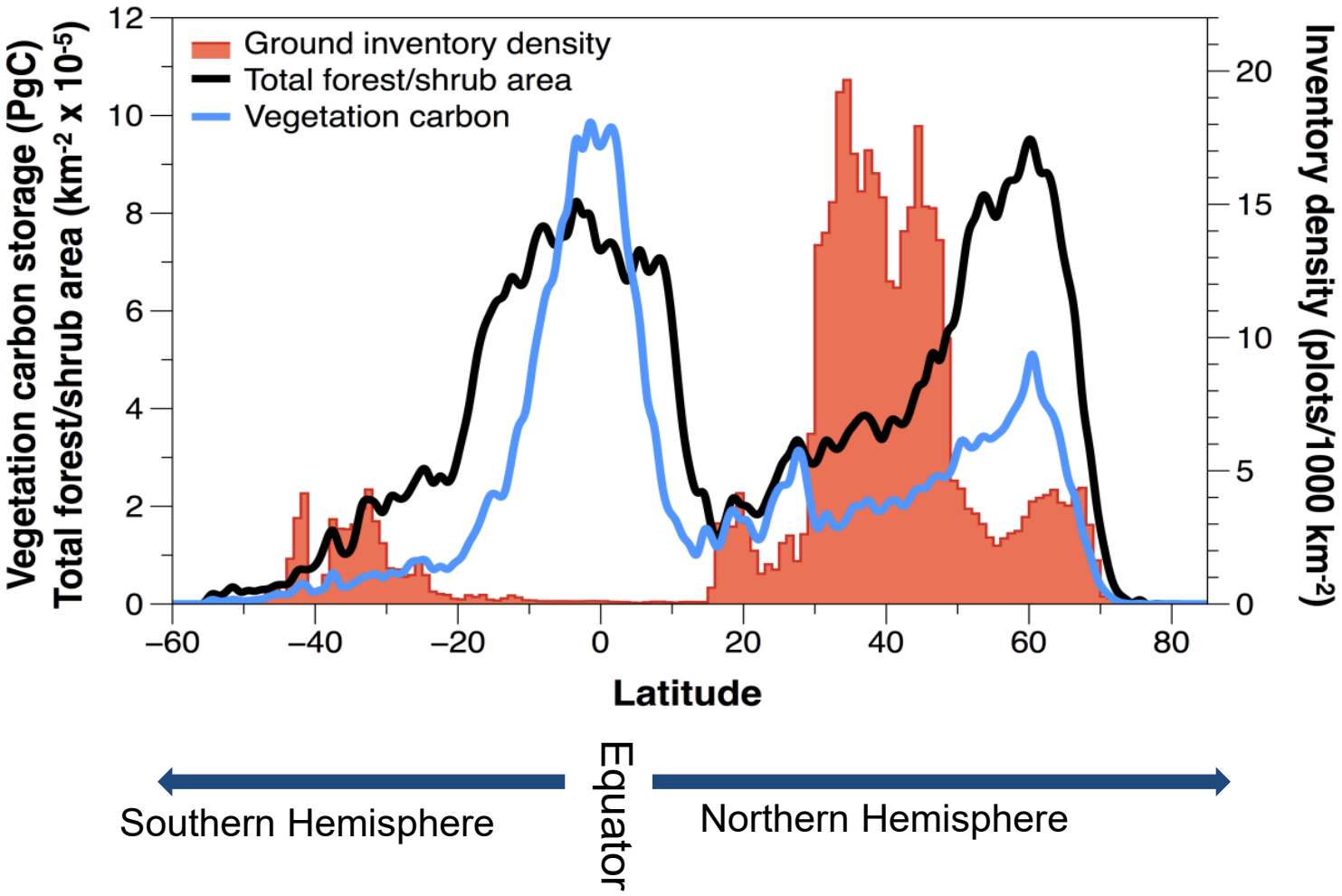
1. Tropical biomass = 350-680 billion tons
2. Uncertain due to biodiversity and poorly coordinated/sparse measurements

Global Forest Carbon Budget is most uncertain in the Tropics

Carbon sink/source	Giga tons Carbon per year
Boreal	0.5±0.1
Temperate	0.7±0.1
Tropical Intact	**1.0±0.5**
Tropical regrowth	**1.7±0.5**
Tropical de-forestation	**-2.8±0.5**

Pan et al., 2011

The tropical belt is what matters



Schimel et al., GCB 2015

Beyond the carbon cycle, tropical forests are one of the Earth's most precious resources to sustain

SUSTAINABLE DEVELOPMENT GOALS

Pressing need for forest Information in policy

LIFE ON LAND: WHY IT MATTERS

What's the goal here?

To sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.

Why?

Forests cover nearly 31 per cent of our planet's land area. From the air we breathe, to the water we drink, to the food we eat–forests sustain us.

Think about it. Around 1.6 billion people depend on forests for their livelihood. Almost 75 per cent of the world's poor are affected directly by land degradation. Did you know that forests are home to more than 80 per cent of all terrestrial species of animals, plants and insects? And of the 8,300 animal breeds known, 8 per cent are extinct and 22 per cent are at risk of extinction.

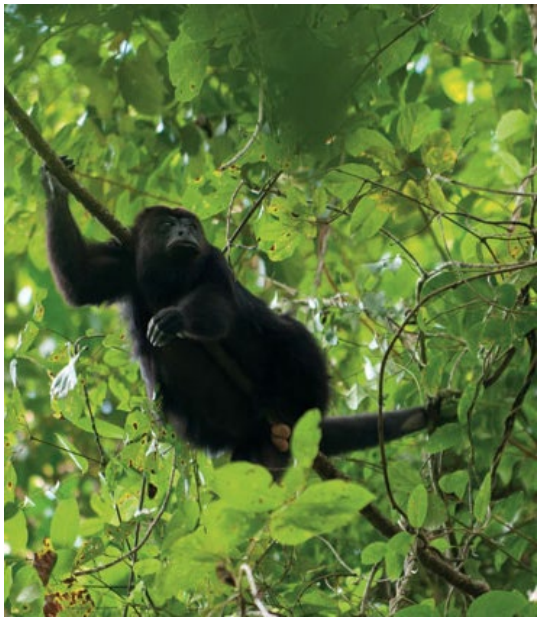
Biodiversity and the ecosystem services it underpins can also be the basis for climate change

15 LIFE ON LAND

Around **1.6 billion** people depend on **forests** for their livelihood.

Biomass provide information useful for the ecosystem services

- 1.6 Billion of people rely on the forests for their subsistance
- ¾ of accessible fresh water are from forest watersheds
- Forest provides the major source of energy for about 2.6 Billions of people
- Forest is a major life reservation: 31% of the land surface, and contains more than 2/3 terrestrial live species, plants and animals.

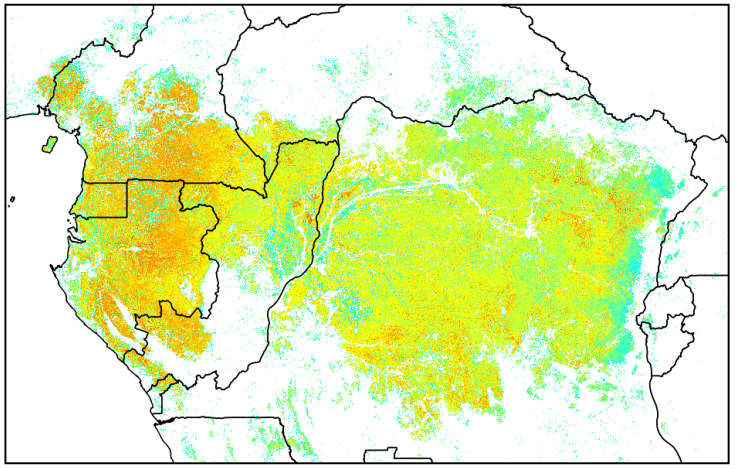


Singe hurleur

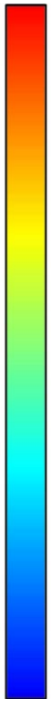
For tropical forests biomass, no dedicated sensors

The Congo basin

AGB map at 1 km – Saatchi et al.



AGB
500 t/ha



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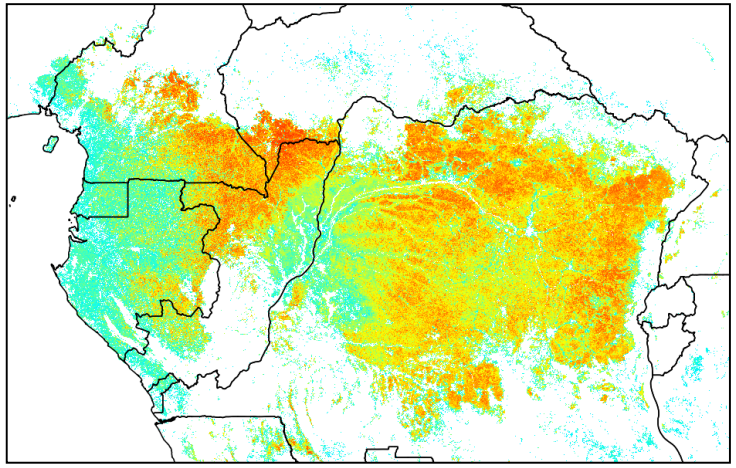
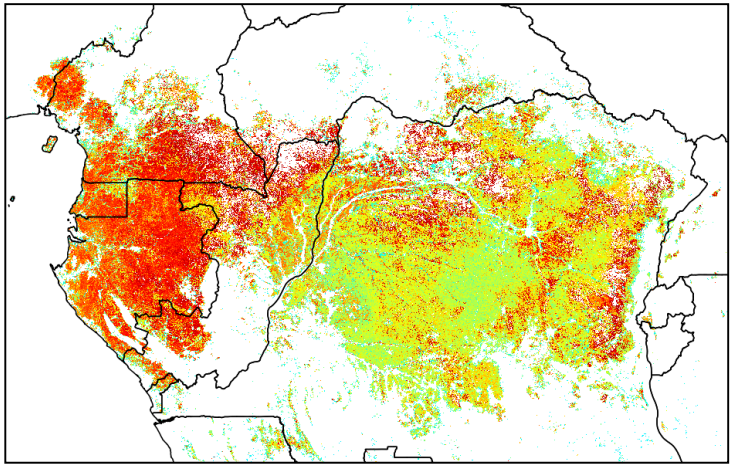
Agreement between existing biomass maps ?

Based mainly on IceSAT/GLAS MODIS and in situ data

AGB map at 500 m – Baccini et al.



AGB map at 1 km – Avitabile et al.



The Biomass mission was proposed and selected as the 7th Earth Explorer Mission

2005: A P-band SAR payload was proposed to provide the spatial distribution and dynamics of forest biomass.
2013: Biomass selected to become the 7th ESA Earth Explorer Mission
2022: Expected launch

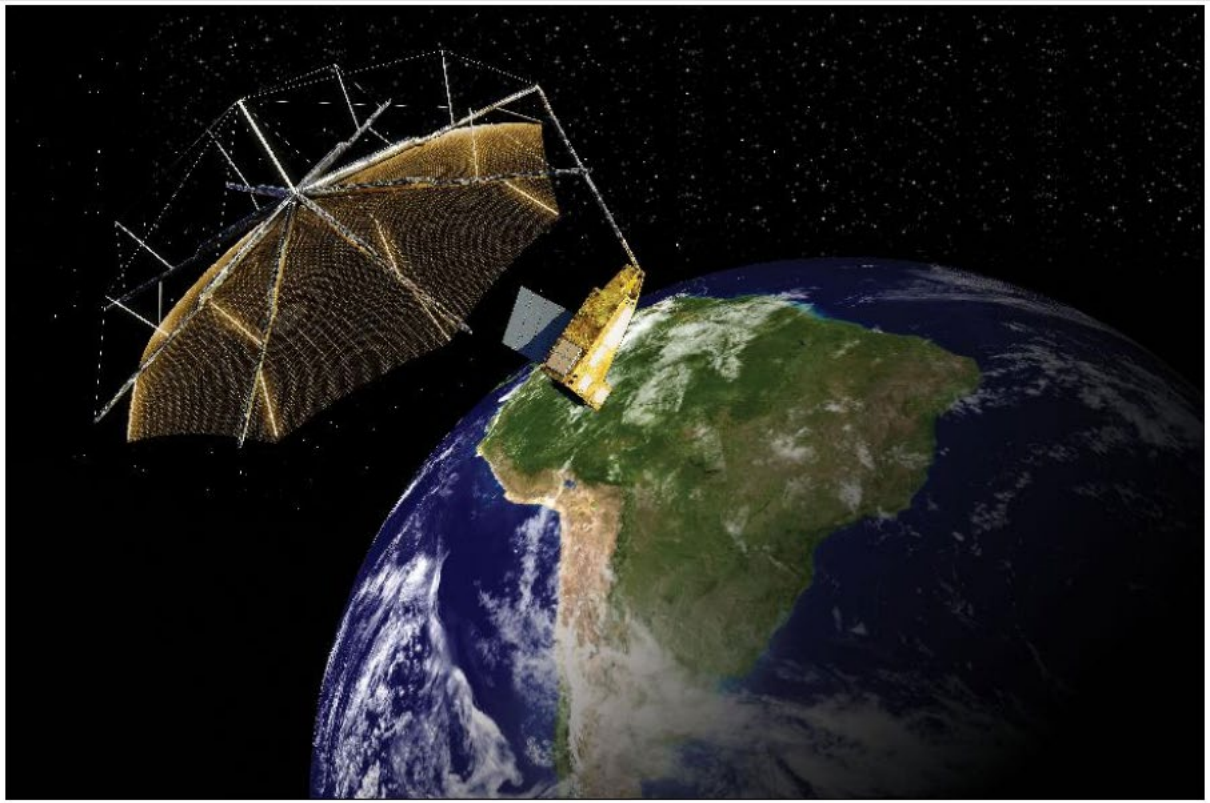


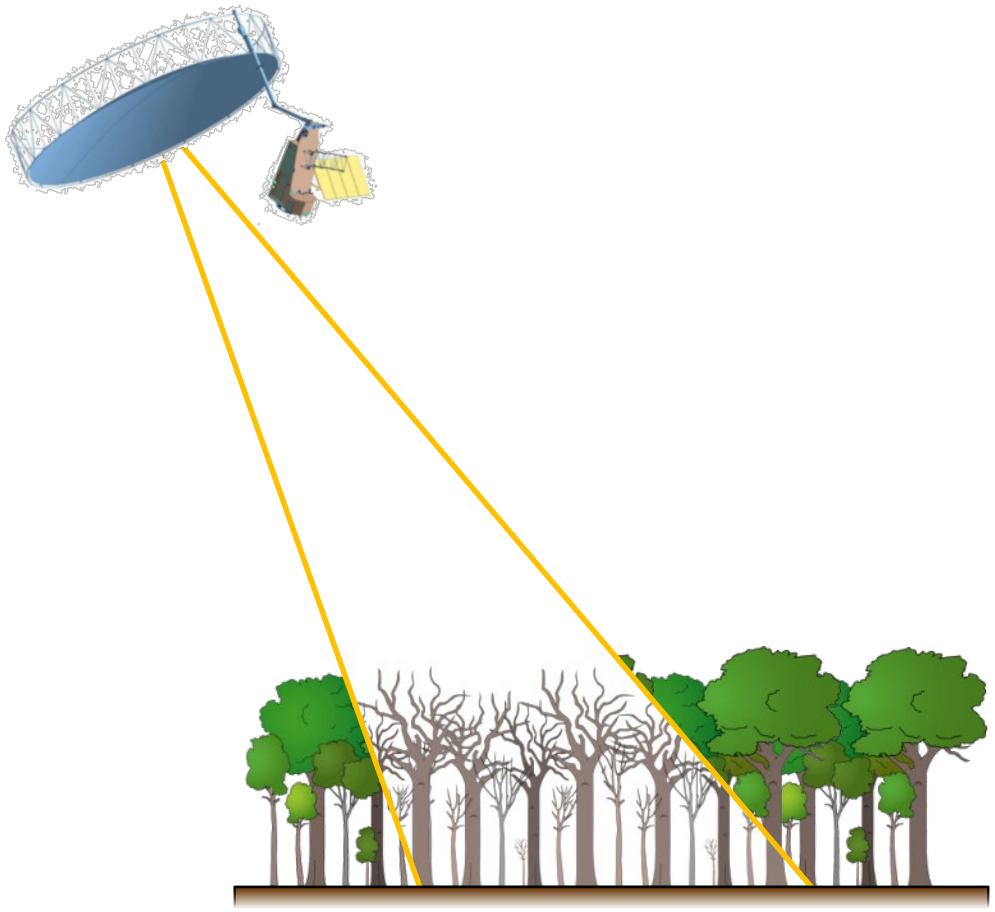
Figure 5: Artist's rendition of the BIOMASS satellite configurations (image credit: Airbus DS)

Why a P-band SAR to measure the world forest biomass ?

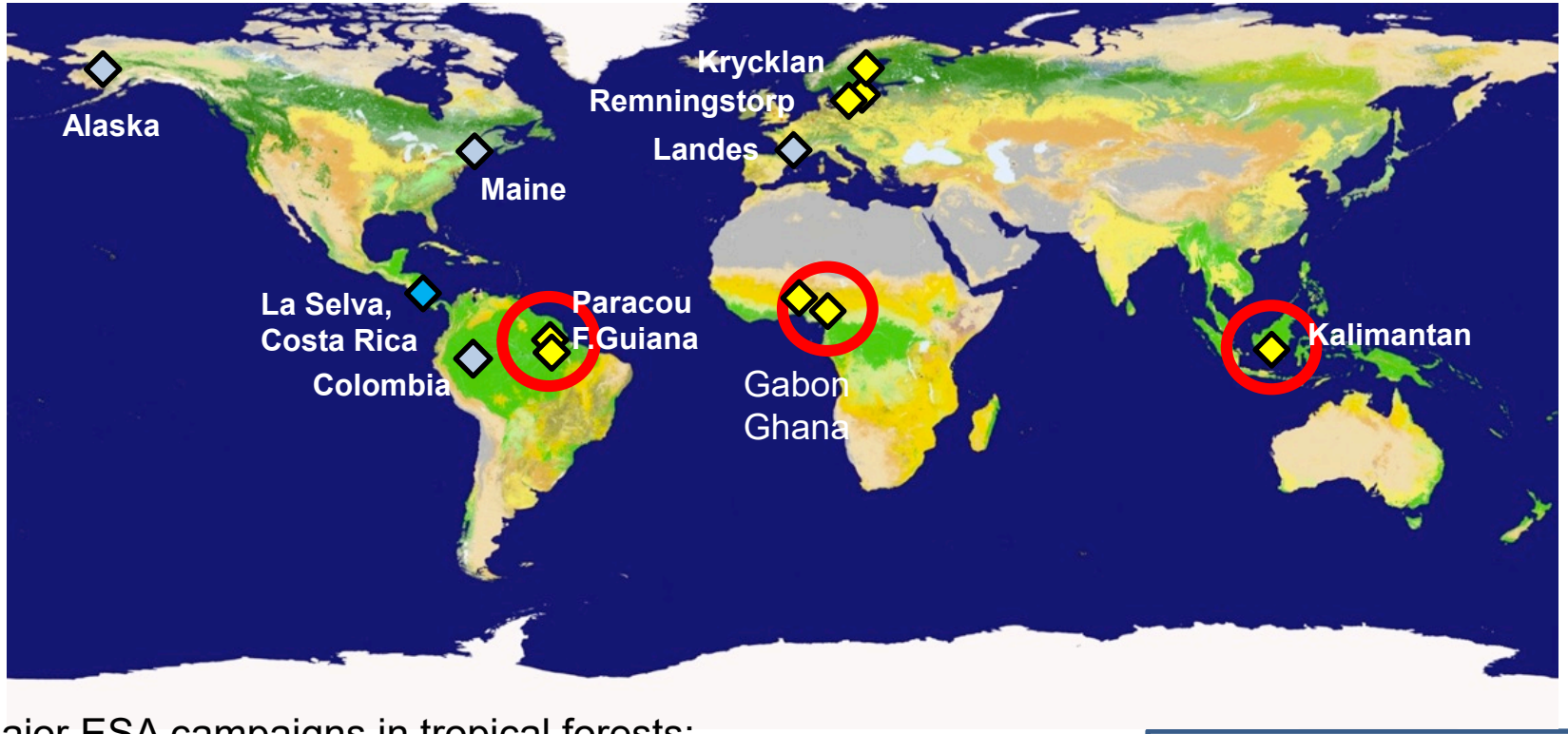
Mapping forest biomass requires a radar sensor with long wavelength:

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



Campaigns used to address questions, develop retrieval methods and assess performance



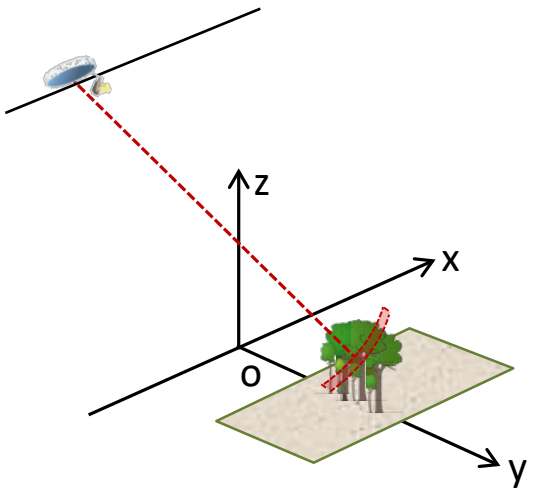
Major ESA campaigns in tropical forests:

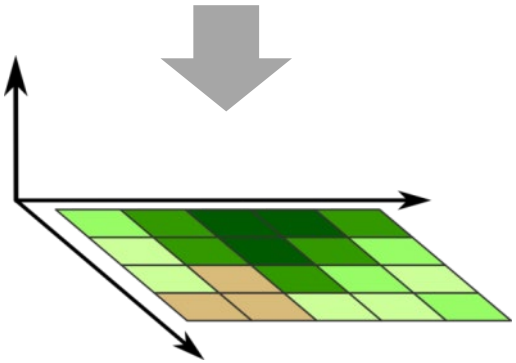
1. Kalimantan 2004 (Indrex)
2. F. Guiana 2009 (TropiSAR), 2011-13 -18(TropiScat)
3. Gabon 2016-2017 (AfriSAR),
4. Ghana 2016 (Afriscat)

ESA campaigns
non-ESA campaigns

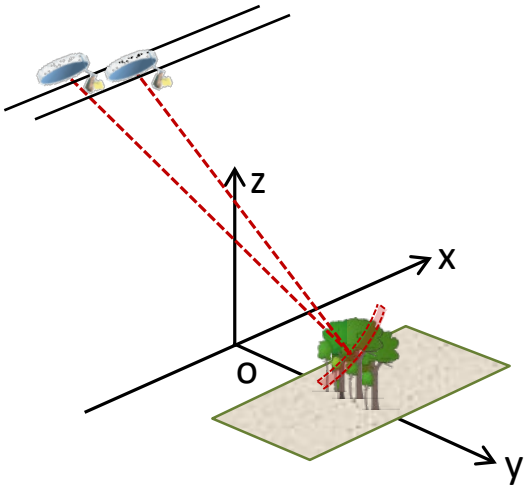
From observation concept to mission requirements : 3 independent types of information for biomass

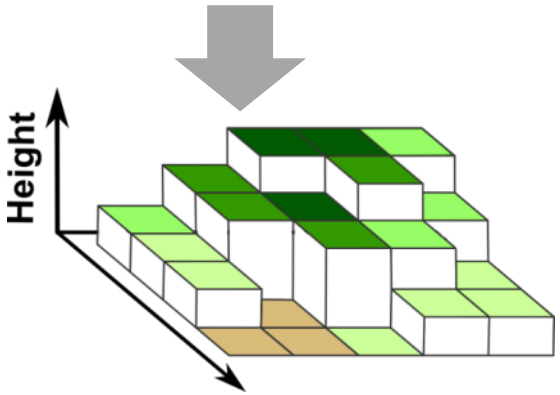
PolSAR
(SAR Polarimetry)



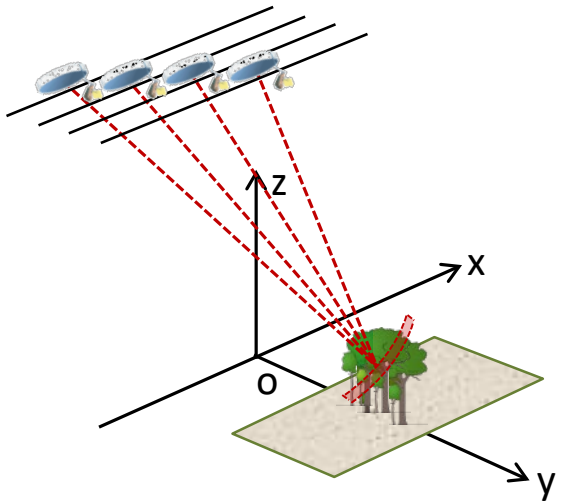


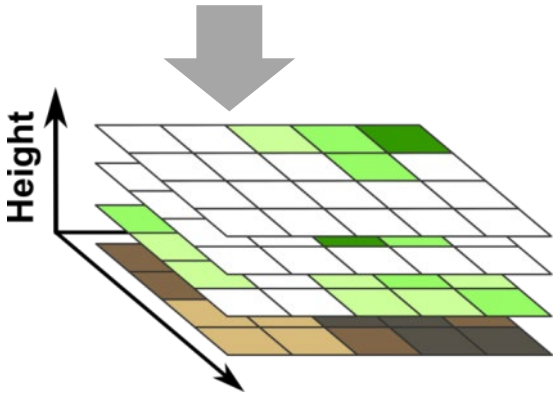
PolInSAR
(Polarimetric SAR Interferometry)





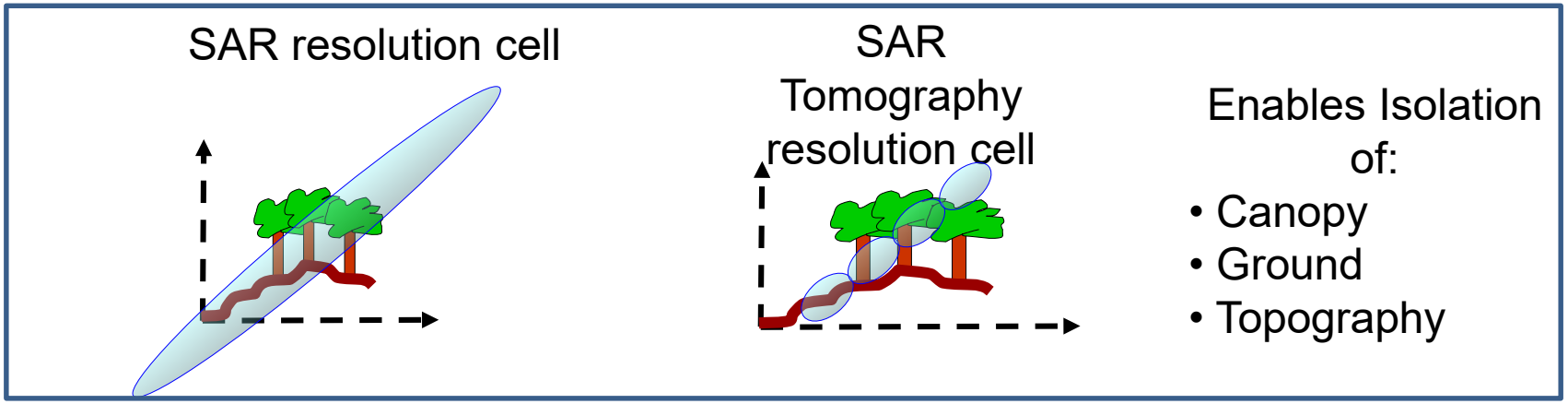
TomoSAR
(SAR Tomography)

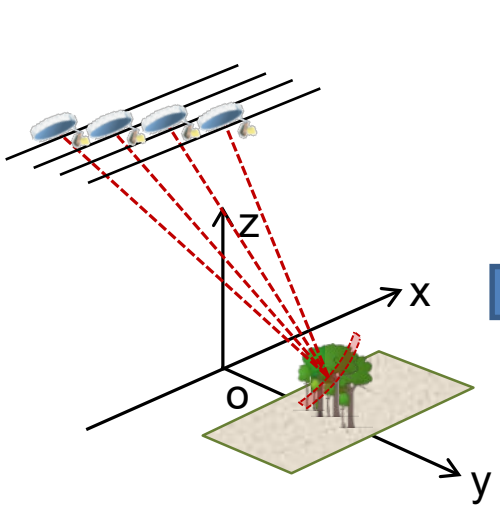


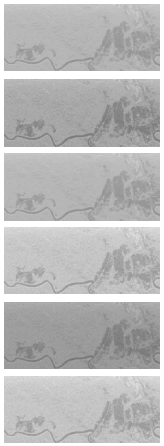


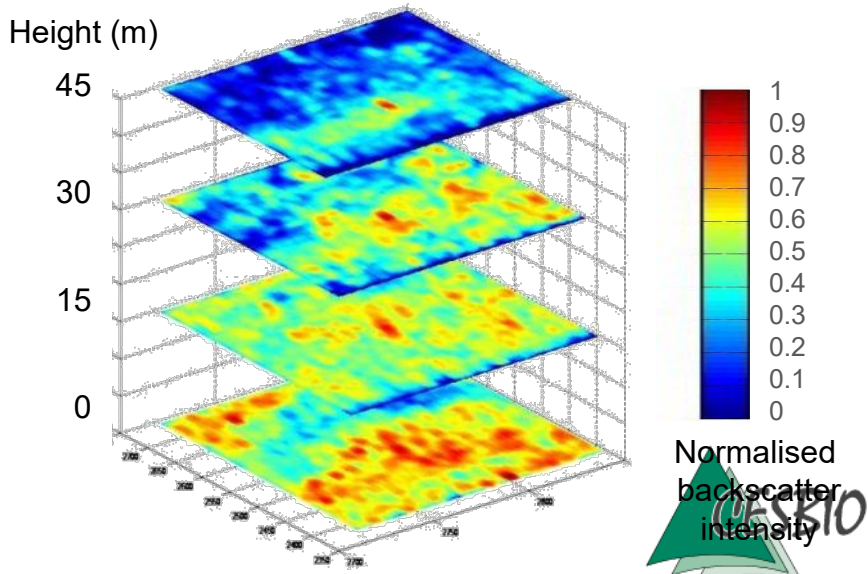
TomoSAR provides 3 D images of the forests

Tomography generates images of different forest layers from multi-orbit SAR acquisitions



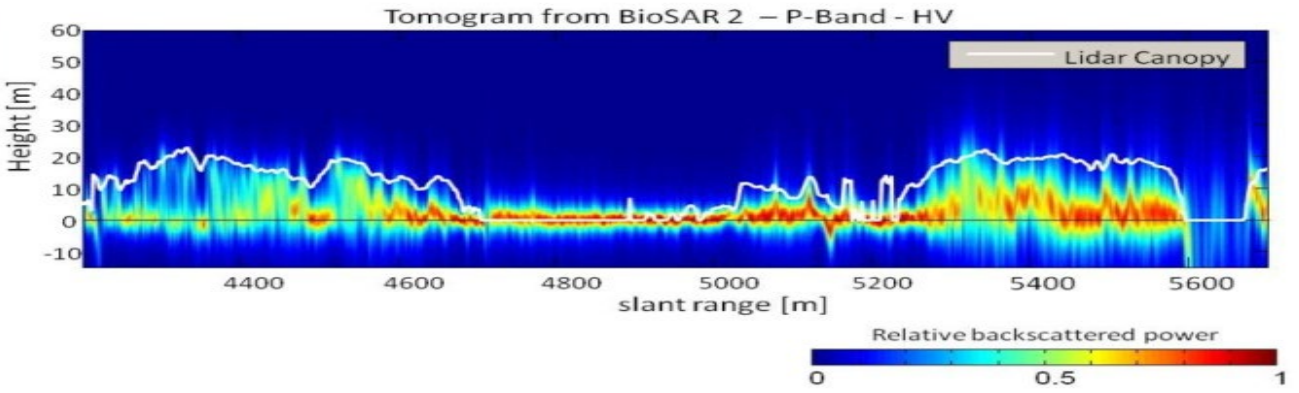




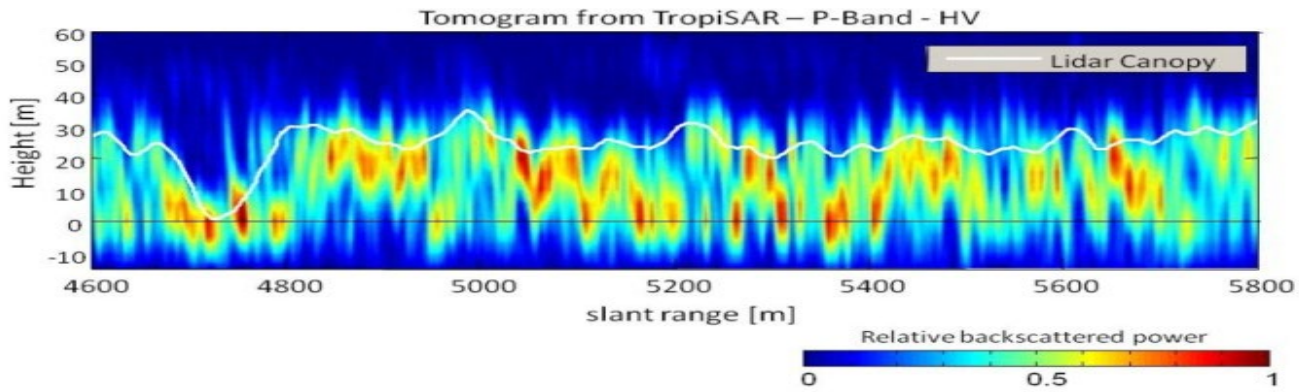


Innovative tomography techniques allow 3D measurements

Boreal forest



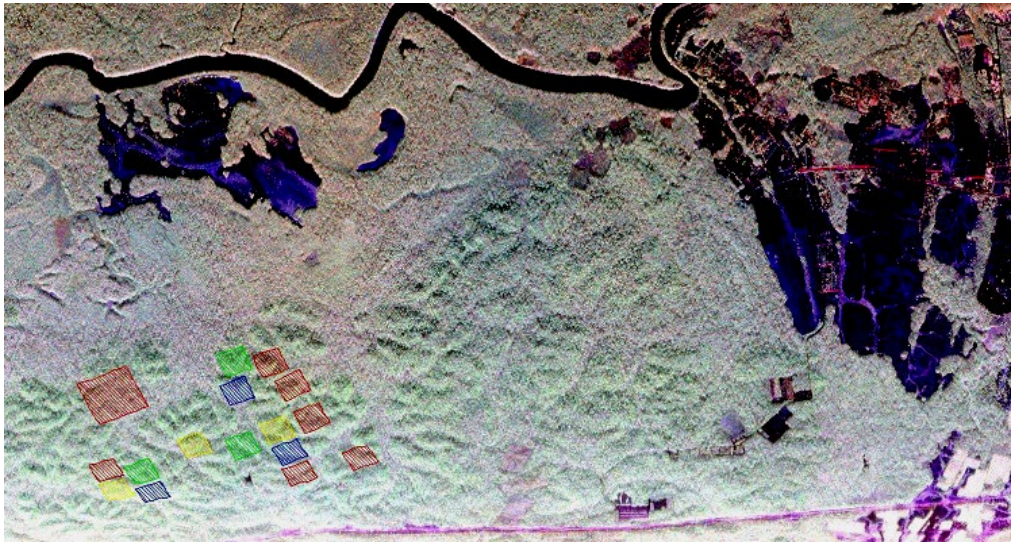
Tropical forest



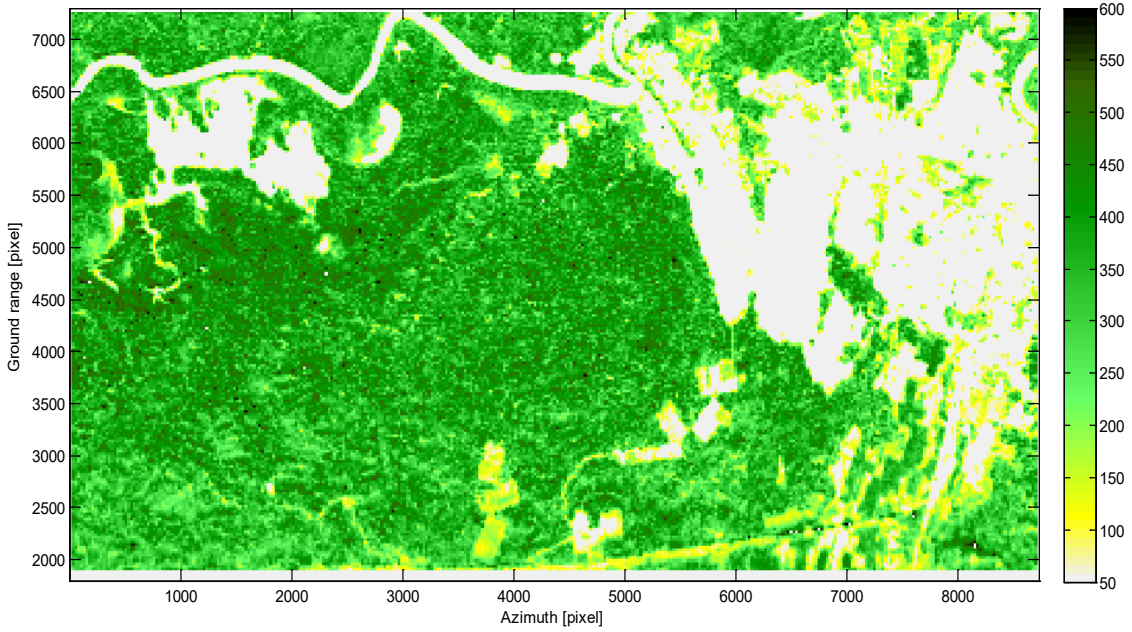
TomoSAR:

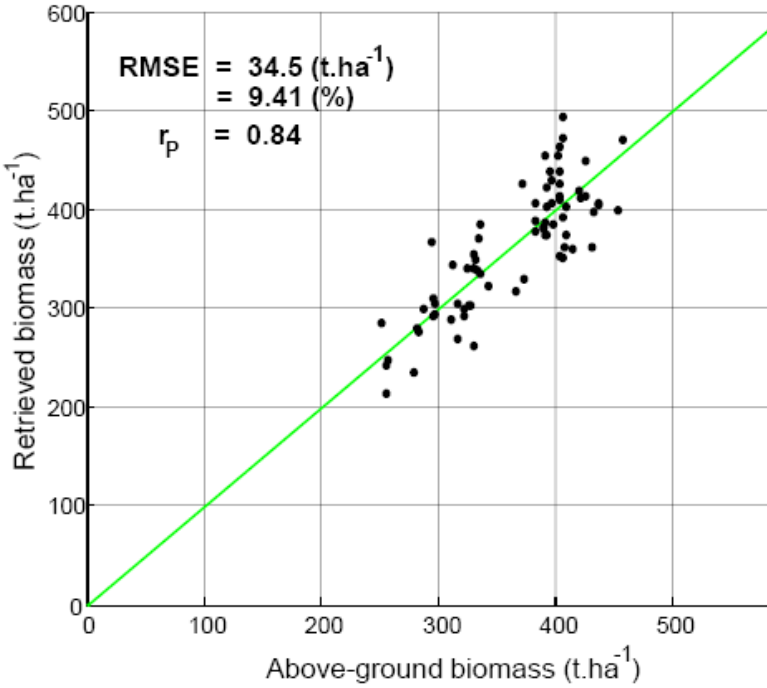
- Provides a 3D reconstruction of forest backscatter.
- Allows an interpretation of scattering processes

SAR Tomography provides high accuracy biomass



P-band SAR image





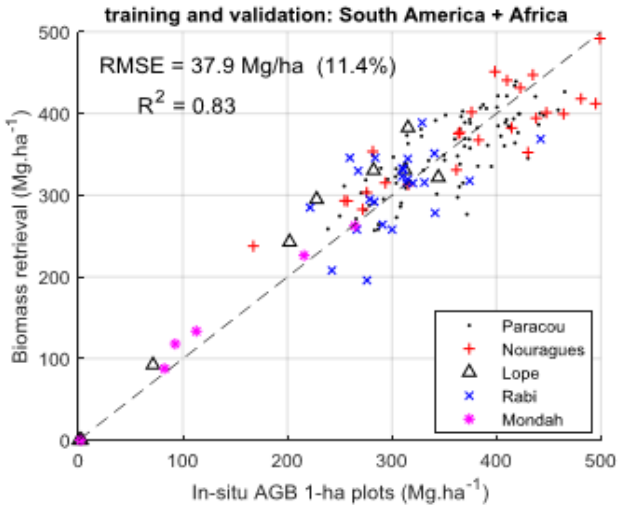
Ho Tong et al., 2015, 2016

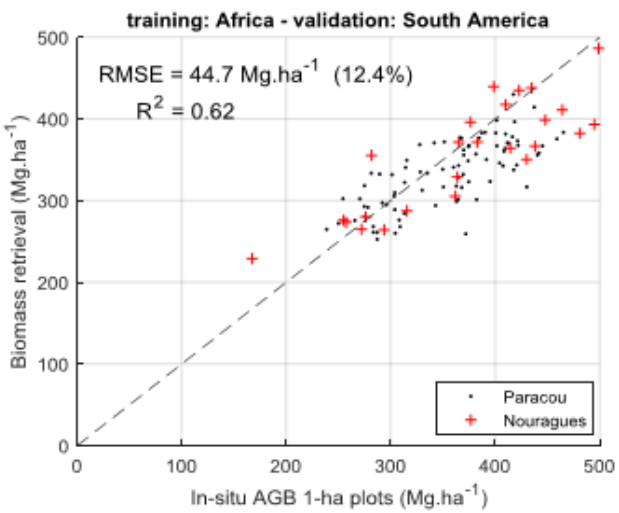
BIOMASS map at 50 m, by tomography

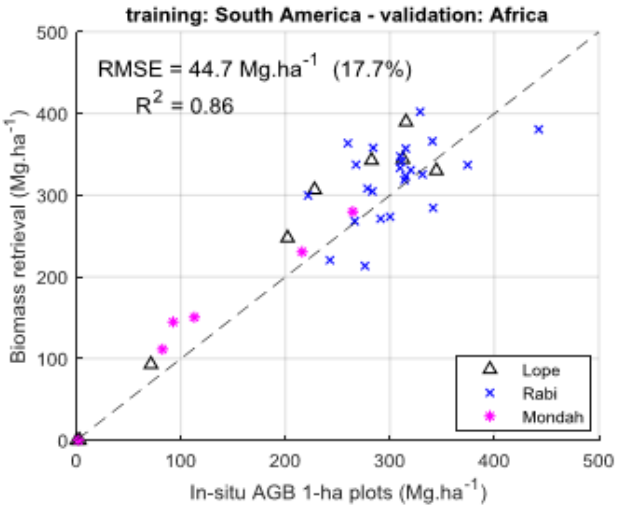
Innovative tomography techniques allow AGB up to 500t/ha

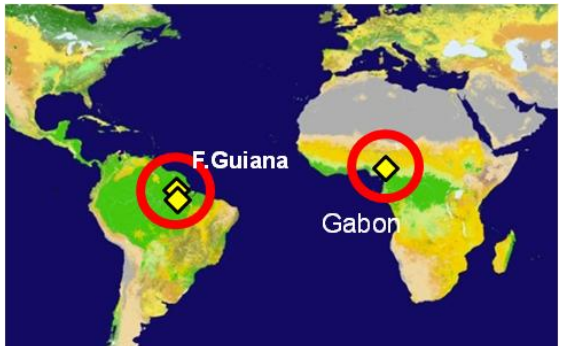
Cross-continental robustness and transferability of tropical forest biomass estimation by SAR tomography

Yen-Nhi Ngo[a,1], Dinh Ho Tong Minh[a,1,2], Doyle McKey[b], Ludovic Villard[c], Stefano Tebaldini[d], Mauro Mariotti d'Alessandro[d], Jérôme Chave[e], Clément Albinet[f], Klaus Scipal[g], and Thuy Le Toan[c]



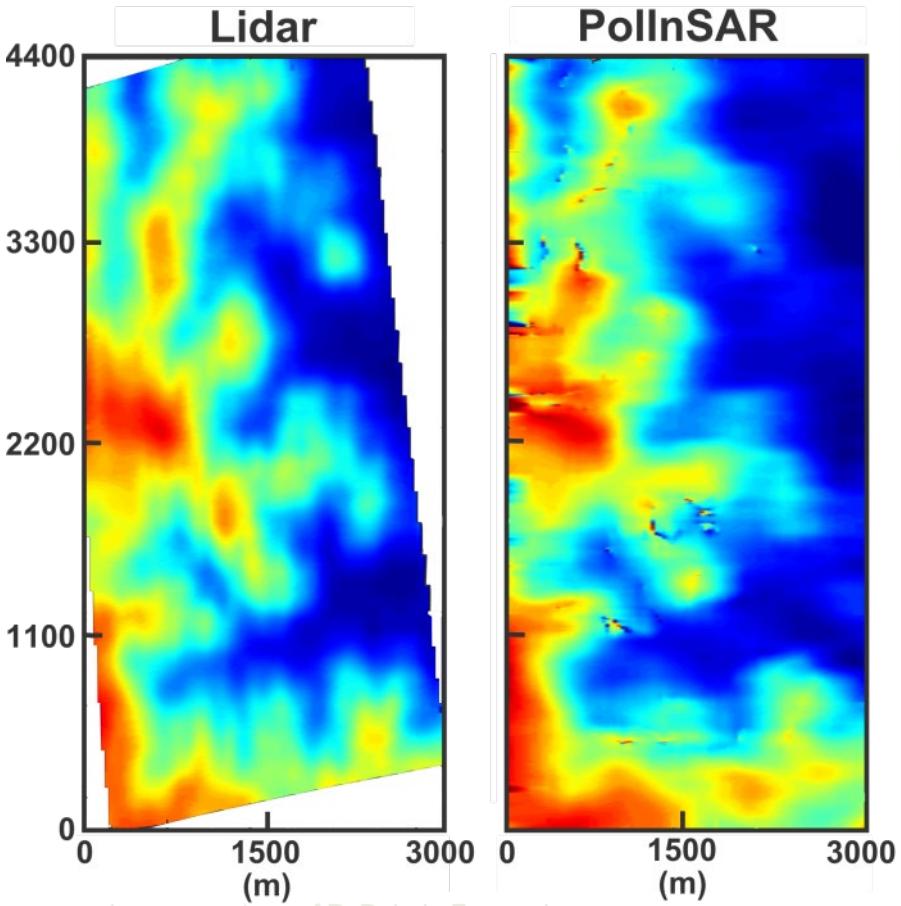


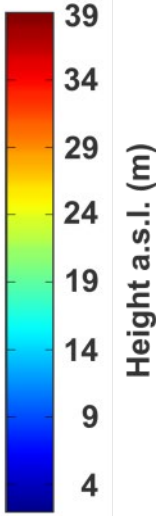


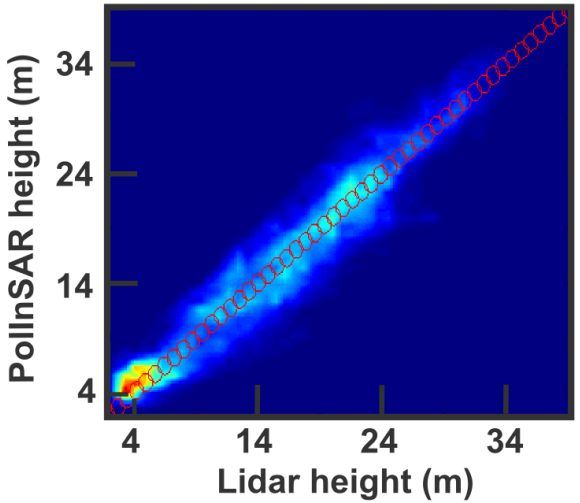


Biomass will allow DEM production under dense tropical forests

TropiSAR data







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

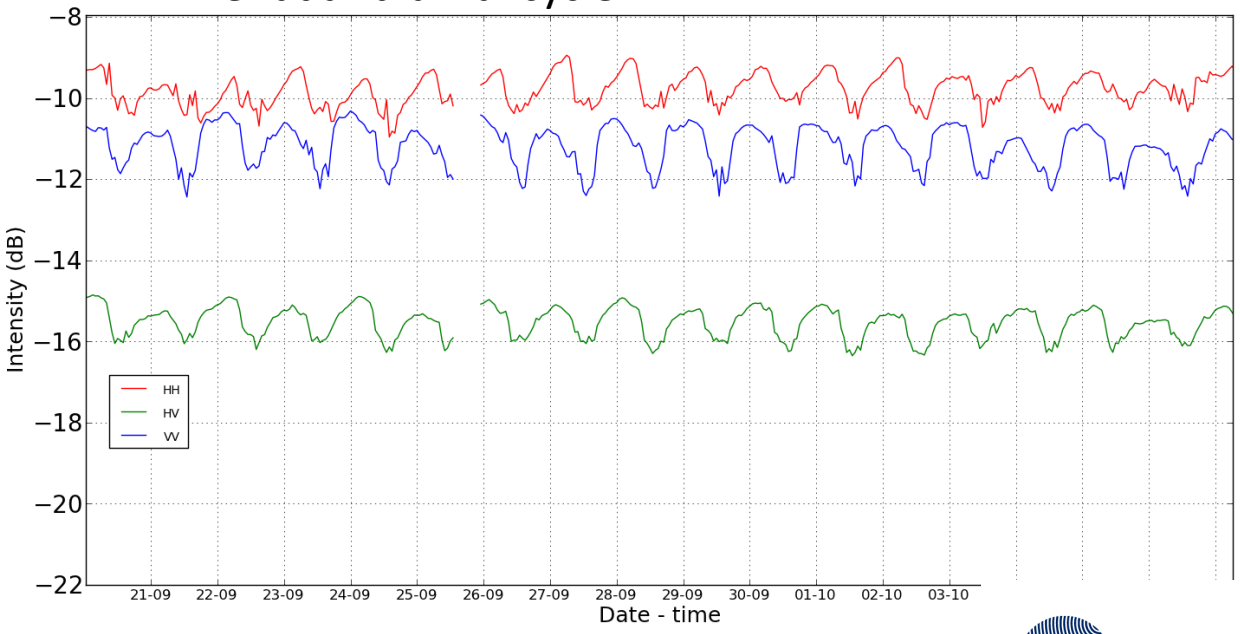
Image courtesy of P. Dubois-Fernandez

Ground based radar to observe and interpret radar temporal variations

TropiScatt experiment:

- Tower-based P-band tomographic measurements.
- Measurements every 15 minutes.
- Started December 2011, up to 2013.

Ex: The radar diurnal cycle



Optional Orbit

How to ensure **temporal correlation** is high to improve PolInSAR?

Tomographic phase

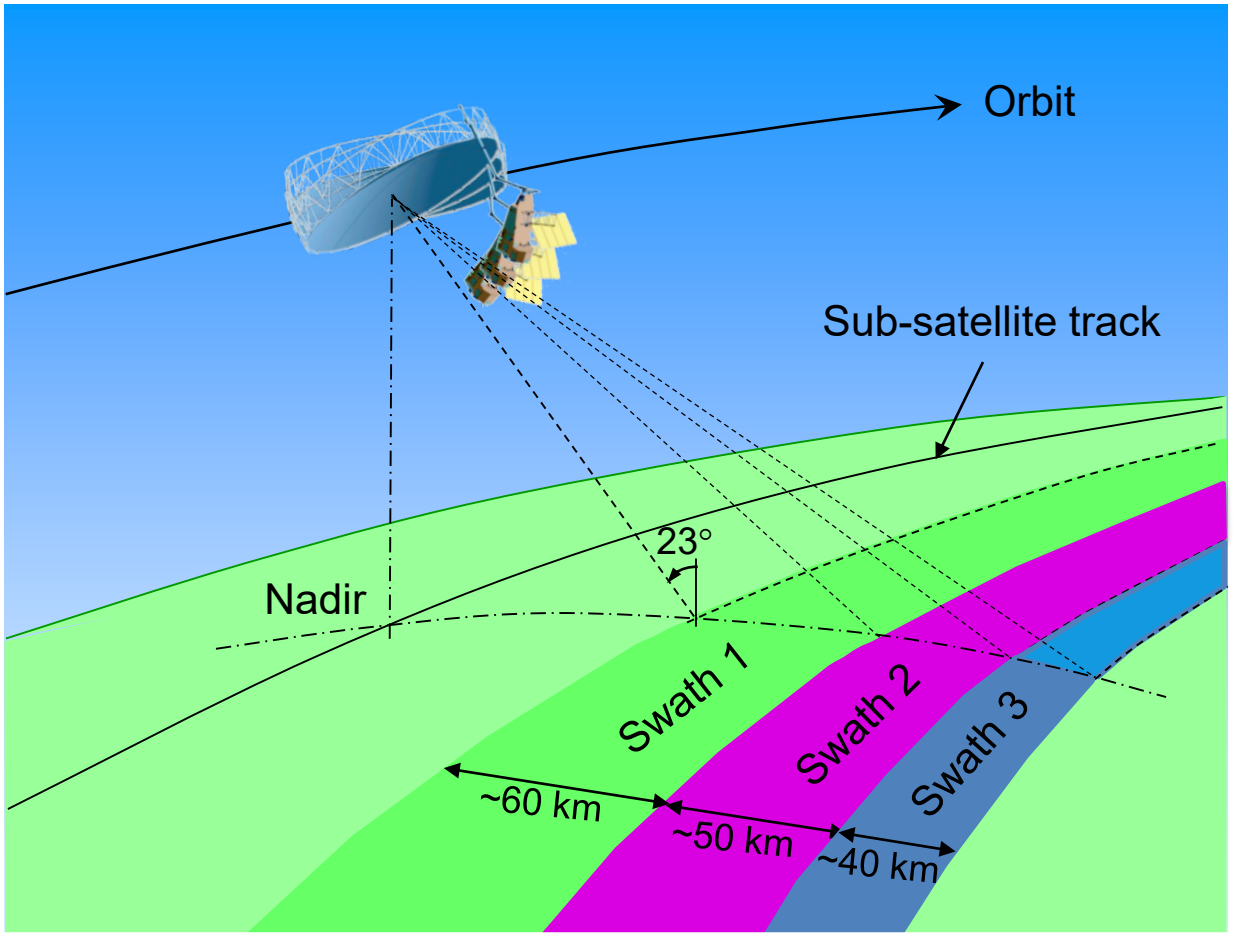
- Duration 15 months
- Drifting sun-synchronous
- Ground track control (*B*=~1.6 km)
- Repeat cycle 3 days
- Global coverage in 1 year
- Local time 06:00 and 18:00
- Altitude 666-637 km

Nominal phase

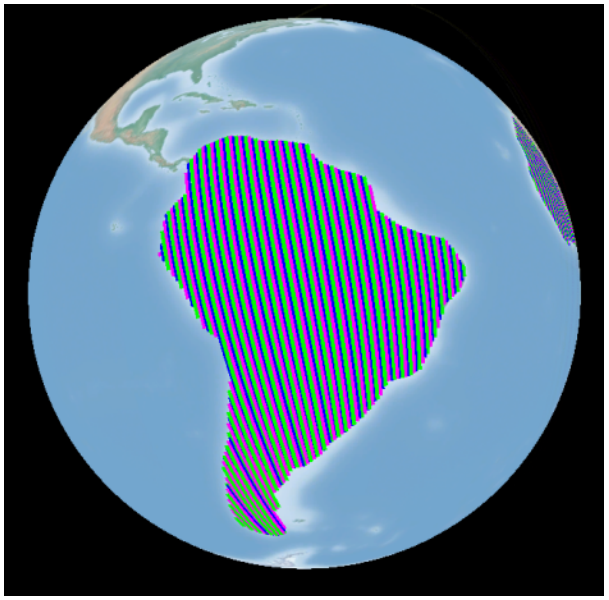
- Duration 4 years
- Drifting sun-synchronous
- Ground track control (*B*=~2.9 km)
- Repeat cycle 3 days
- Global coverage in 7 months
- Local time 06:00 and 18:00
- Altitude 666-637 km

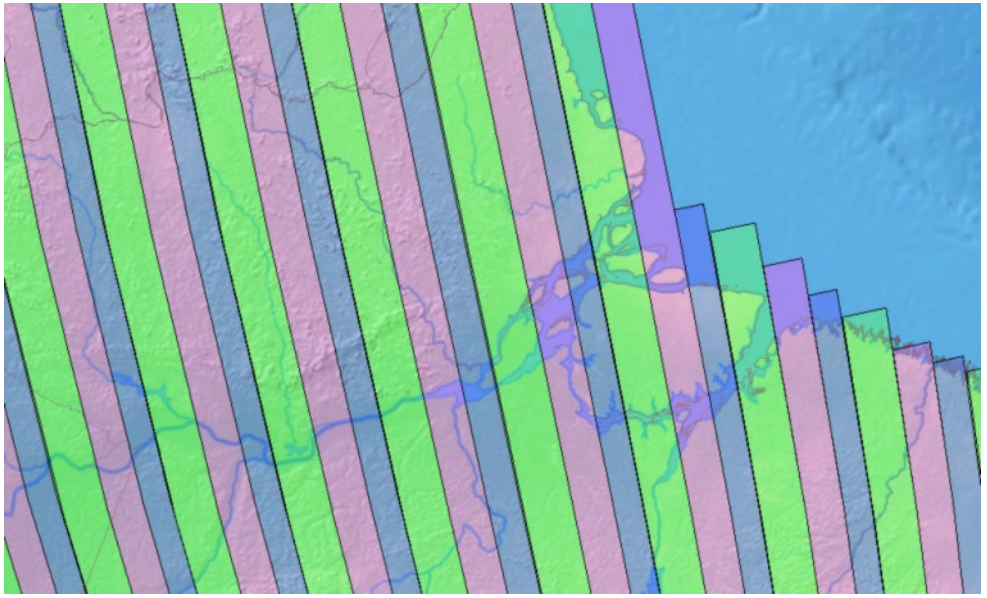
Payload overview

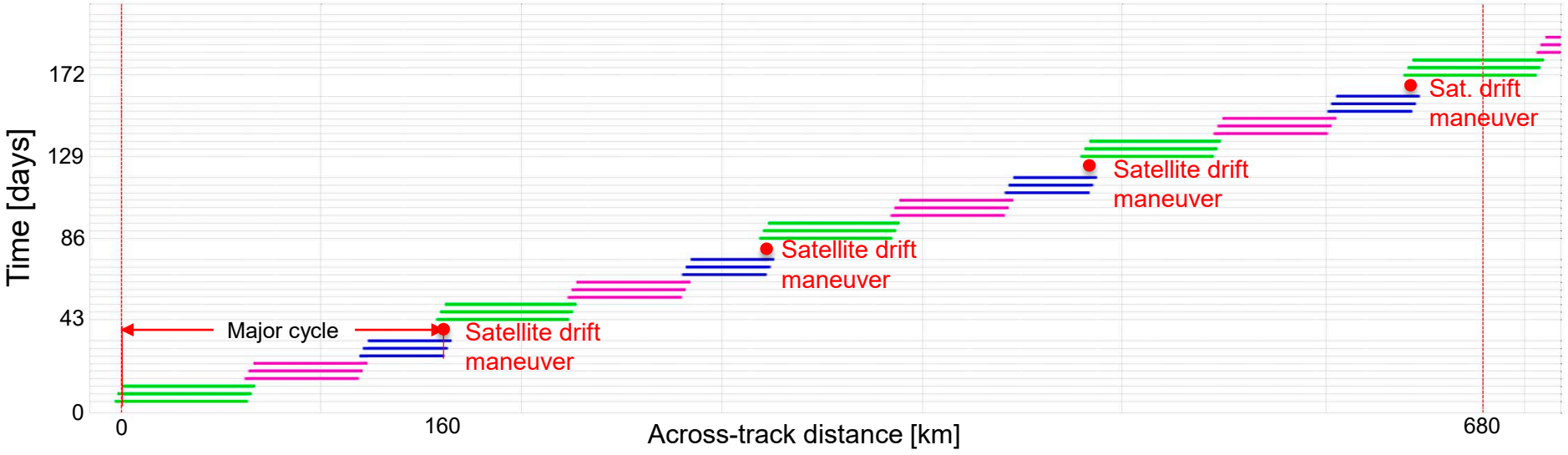
- P-band (435 MHz) Synthetic Aperture Radar (SAR)
- Bandwidth of 6 MHz
- Full polarimetric SAR
- Multi-pass interferometry
- Single antenna beam
- Stripmap mode
- Satellite roll for beam repointing



Optional Coverage Strategy (Nominal phase)



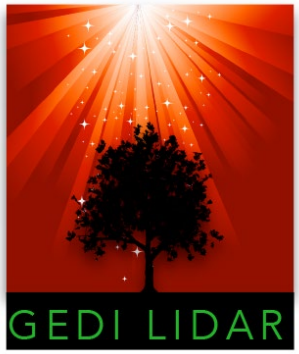


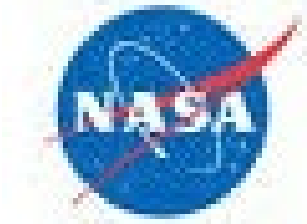


Summary

1. Biomass addresses critical & urgent scientific, political and societal objectives
2. Biomass measurements give key information on the Land Use Change flux (both emissions and uptake), forest mortality, and carbon dynamics.
3. Biomass is a true Earth Explorer (the first space tomographic mission ever, the first P-band mission) and will provide a unique vision of the Earth, extending beyond biomass into ionosphere, ice, geomorphology and applications requiring a true surface DEM.
4. Synergy with other spaceborne missions in forest observations

Within few years, spaceborne missions to monitor the Earth's forests





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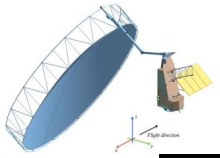
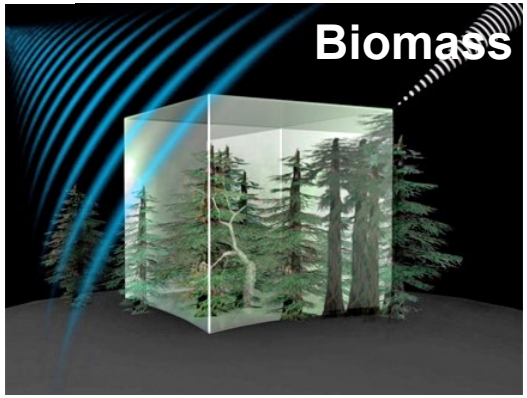
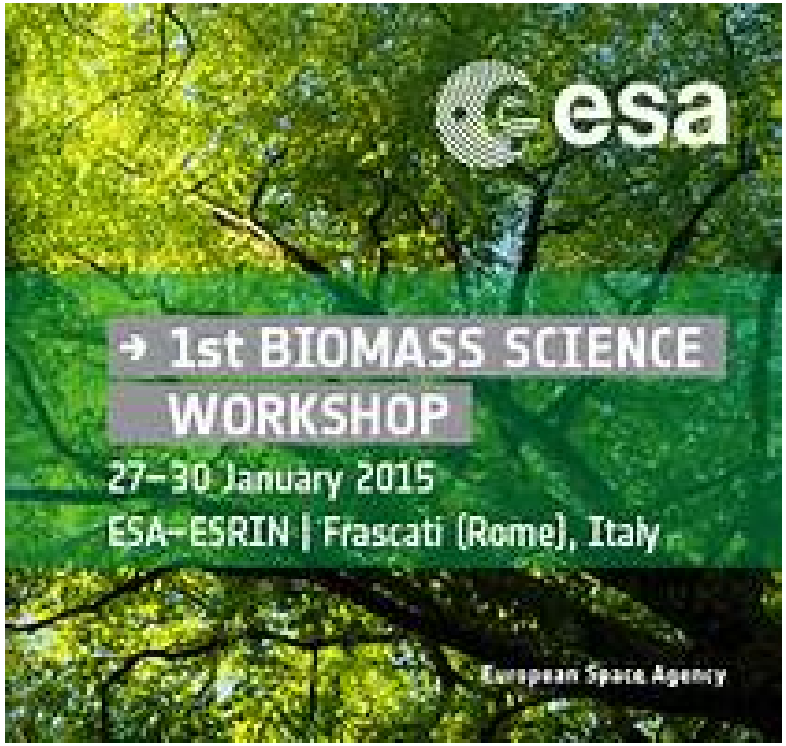




These missions bring together the ecology, modelling, policy and EO communities

- to gain a common view of the current status of our knowledge on global forest
- to define how these communities can work together to best exploit the missions data.




Thank you!