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BIOMASS Mission: Synergy with Contemporary Multi-sensor Missions for the Estimation of Biomass and Biomass Change

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1.CESBIO, 2. GlobEO; 3. SupAero ;4. CNES; 5. INRAE

BIOMASS key features

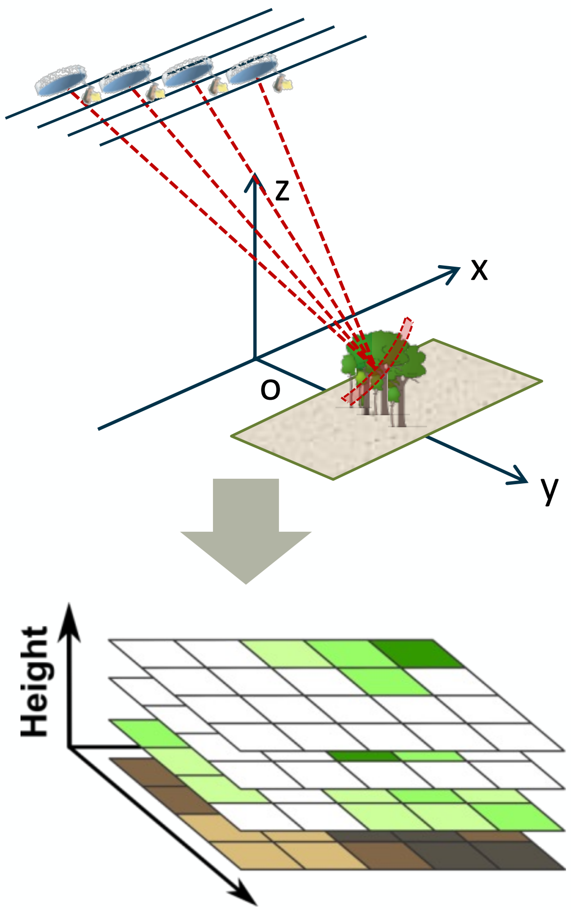
- BIOMASS objective is to reduce uncertainties in the calculations of terrestrial carbon stocks and fluxes, by **mapping of forest biomass** and using its variations **to quantify key fluxes, including deforestation, degradation, regrowth and land uptake**

- Biomass opportunities: **Long SAR wavelength**, **advanced PolSAR, PolInSAR**, **TomoSAR** techniques for 3D measurements of forest structure, enhanced sensitivity to AGB by cancellation of ground contribution

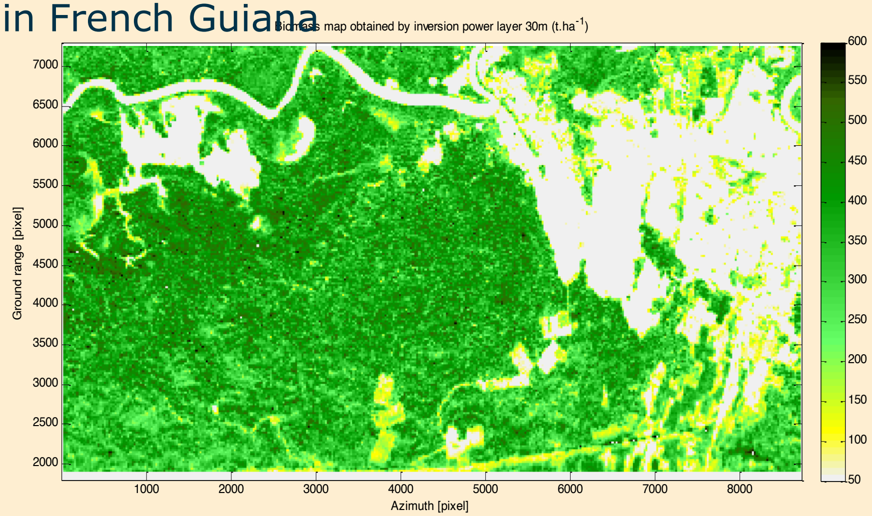
  → **Up to the maximum AGB observed in tropical forest (500 Mg/ha).**

Long wavelength and innovative tomography techniques allow to map the high range of biomass in tropical forests.

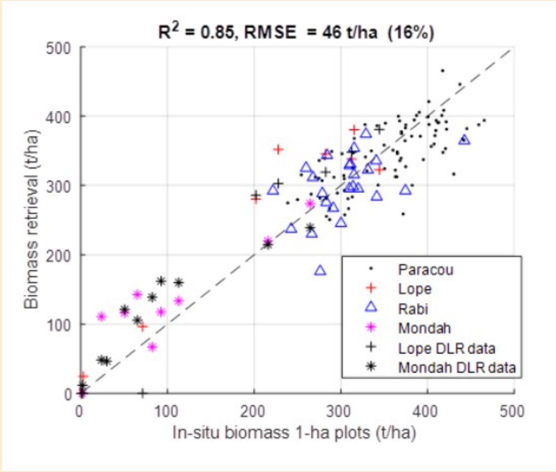
TomoSAR



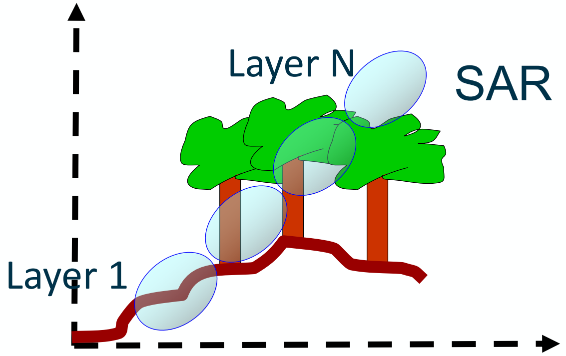
Biomass map of Paracou tropical forest in French Guiana



Multi-site assessment of AGB



By isolating the canopy contribution, TomoSAR increases the sensitivity of the backscatter to biomass, for biomass up to 500 t /ha.



SAR tomography resolution cell

Enables isolation of

- **canopy**
- **ground,**
- **topography**

D. Ho Tong Minh et al., 2013, 2016; Tebaldini et al., 2019

Synergy with other missions for biomass measurements

Biomass challenges: limited multi temporal observations; resolution 4 ha (AGB, Forest Height), 50 m (disturbances); uncertainties at low biomass range .

Use of other sensors/missions, with focus on free access data policy:

1. To improve estimation of low biomass for forest savannah, woodlands, forest regrowth:

   NISAR (ALOS4, SAOCOM)

2. To enhance performance of BIOMASS algorithm, by providing auxiliary information

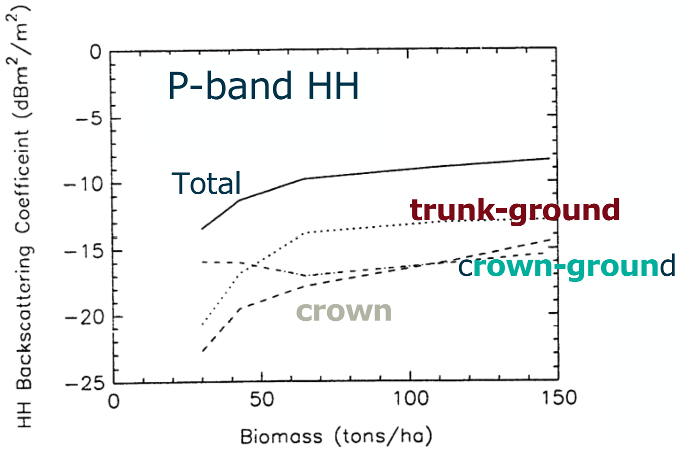
   GEDI : forest vertical profile for training

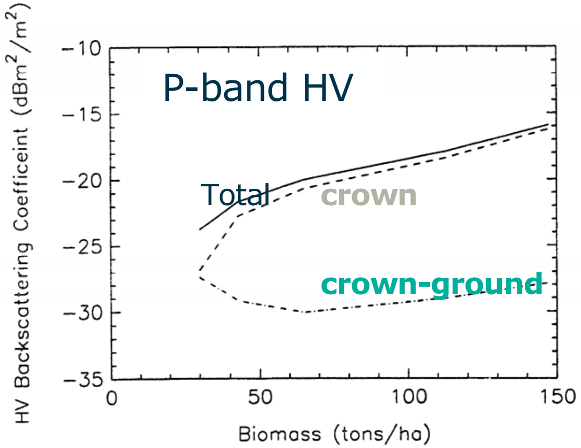
   Sentinel1,2, Landsat : for LULC forest mask

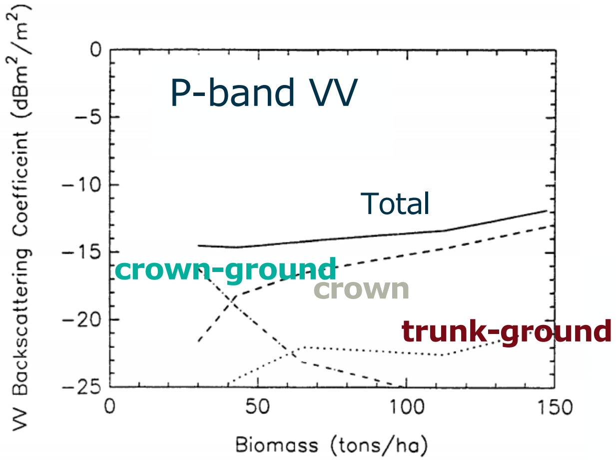
3. To improve estimation of biomass loss by deforestation/forest dagradation at higher spatial & temporal resolution

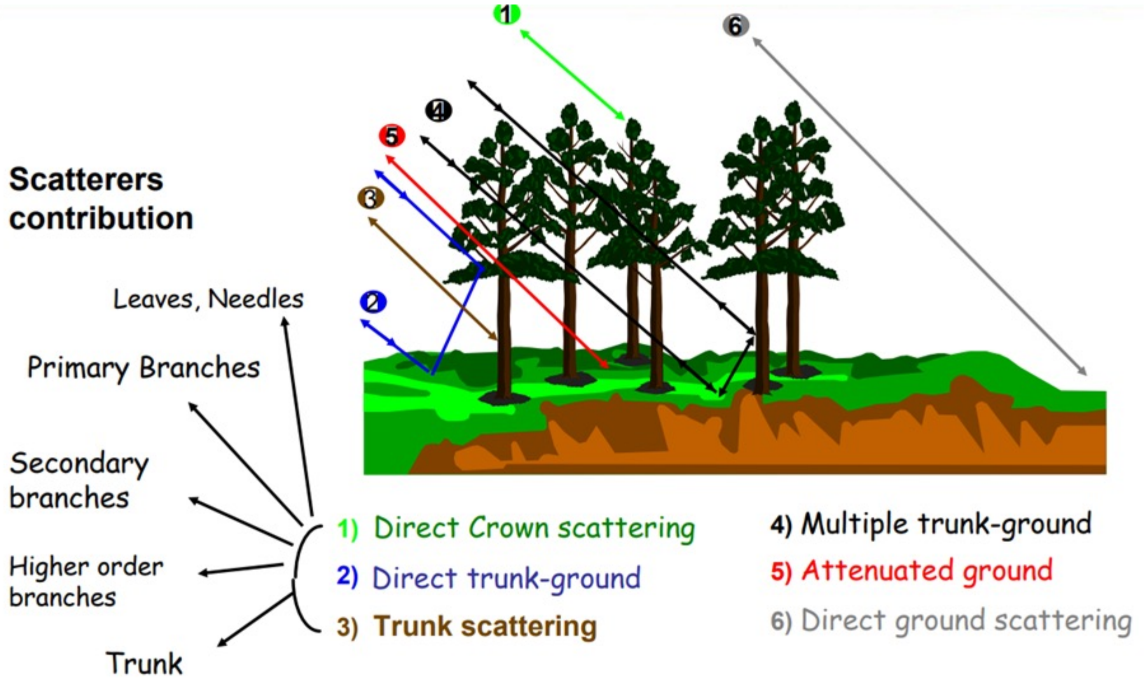
   Sentinel-1

Multi frequency synergy on radar scattering









Scattering mechanisms simulated by a R.T. model

- Le Toan, T., Beaudoin, A., Riom, J., & Guyon, D. (1992). Relating forest biomass to SAR data. *IEEE Transactions on Geoscience and Remote Sensing*, *30*(2), 403-411.
- Hsu, C. C., Han, H. C., Shin, R. T., Kong, J. A., Beaudoin, A., & Le Toan, T. (1994). Radiative transfer theory for polarimetric remote sensing of pine forest at P band. *International Journal of Remote Sensing*, *15*(14), 2943-2954.
- Beaudoin, A., Le Toan, T., Goze, S., Nezry, E., Lopes, A., Mougin, E., ... & Shin, R. T. (1994). Retrieval of forest biomass from SAR data. *International Journal of Remote Sensing*, *15*(14), 2777-2796.

Multi frequency synergy on radar scattering

At P-band, for low biomass (~< 50Mg/ha),

- *significant ground contribution (via ground-crown and trunk ground interaction mechanisms),*
- *low scattering and low attenuation due to the small size of vdegetation scatterers*

- *→ lower performance in AGB retrieval compared to higher AGB range*

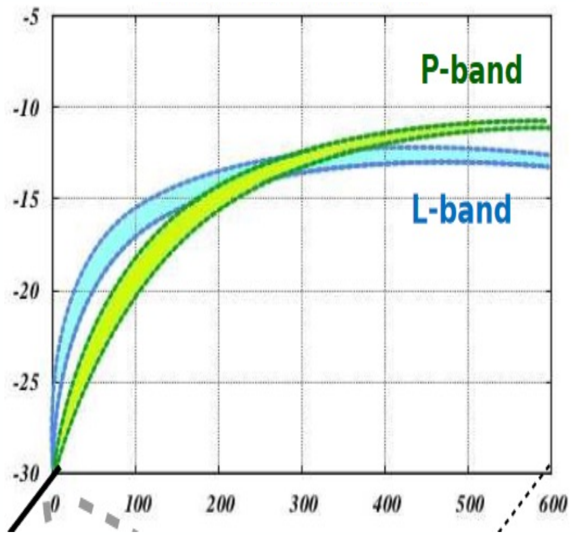
L band
λ= 27 cm

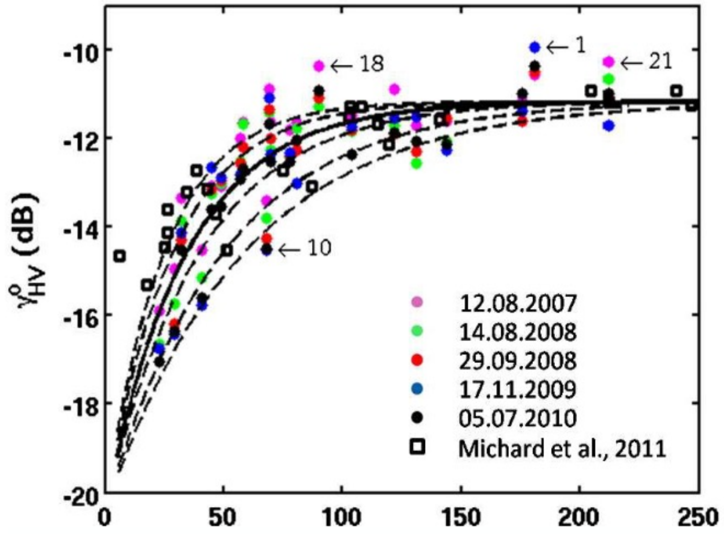
P band
λ= 70 cm

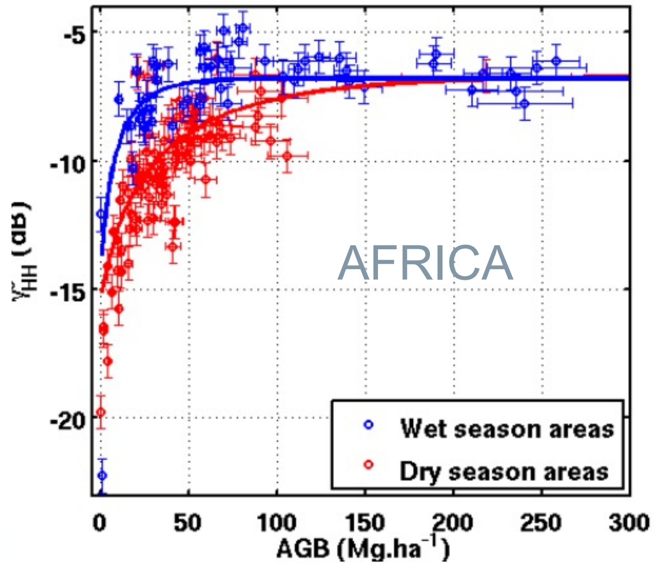
Multi frequency synergy on radar scattering
At L-band, sensitivity to biomass in the low AGB range

At L-band, in the biomass range of 10-100 Mg/ha, higher sensitivity to AGB, with temporal variation due to soil and vegetation water content. Averaging dense time series of NISAR (ALOS4, SAOCOM) will reduce the temporal effect

ALOS-PALSAR





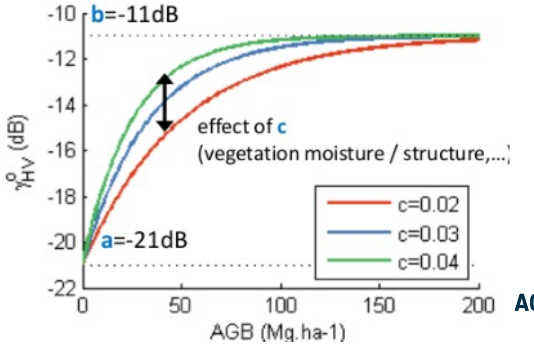


Mermoz, S., Le Toan, T., Villard, L., Réjou-Méchain, M., & Seifert-Granzin, J. (2014). Biomass assessment in the Cameroon savanna using ALOS PALSAR data. Remote sensing of environment, 155, 109-119

Simplified Water Cloud Model (WCM):

$$\gamma^0 = \gamma^0_{ground} \cdot e^{-c.AGB} + \gamma^0_{veg} \cdot (1-e^{-c.AGB})$$

$$= a e^{-c.AGB} + b(1-e^{-c.AGB})$$



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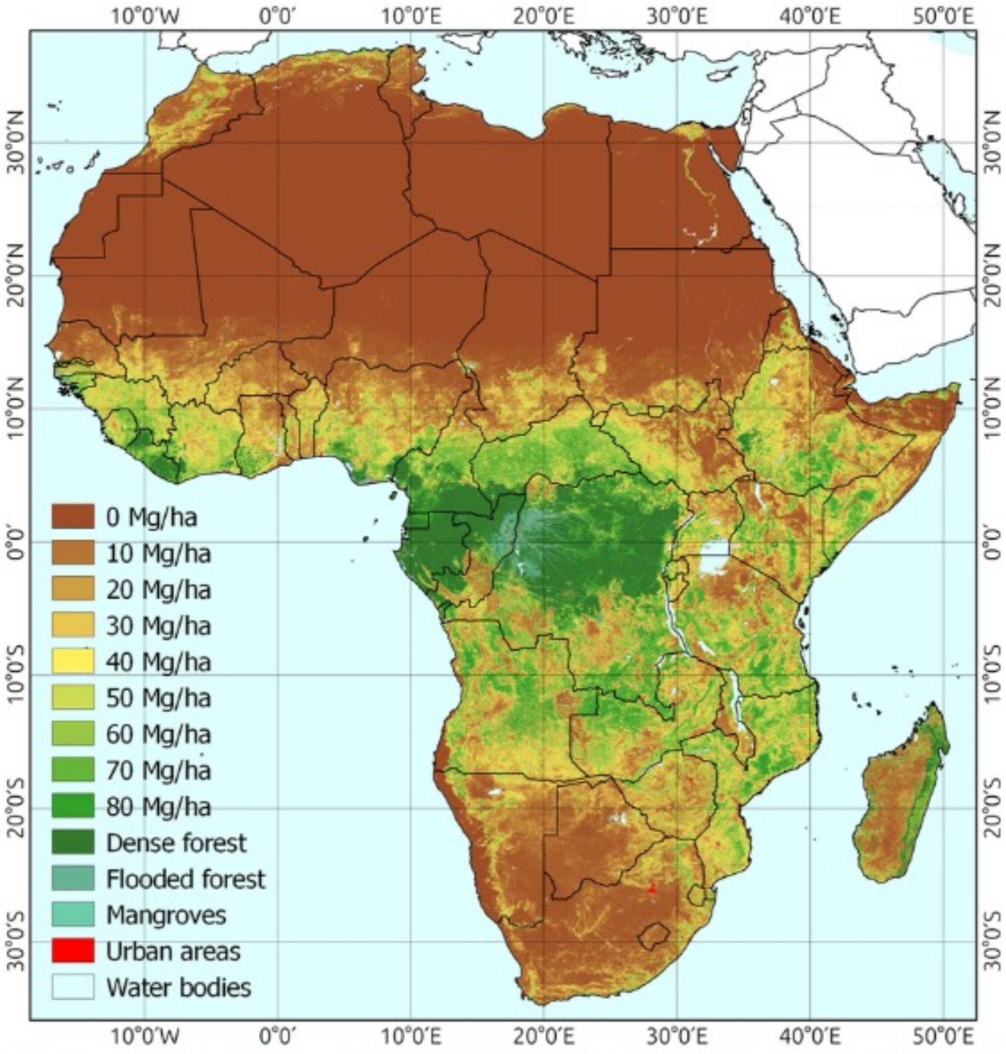
For lower AGB (< 100 t/ha): benefit from higher sensitivity of L-band to AGB –Synergy with NISAR, SAOCOM, ALOS-4

Example: Biomass map of of savannah and woodland in Africa, limited to AGB < 80 Mg/ha

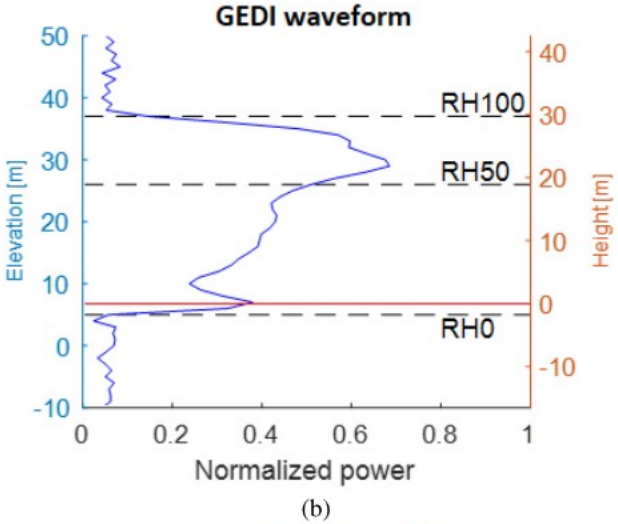
Bouvet, A., Mermoz, S., Le Toan, T., Villard, L., Mathieu, R., Naidoo, L., & Asner, G. P. (2018). An above-ground biomass map of African ***savannahs and woodlands*** *at 25 m resolution derived from ALOS PALSAR. Remote sensing of environment, 206, 156-173.*

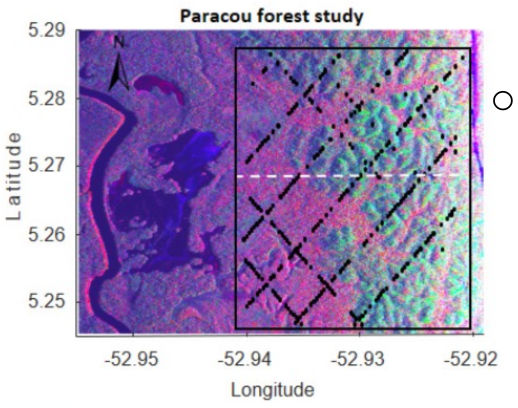


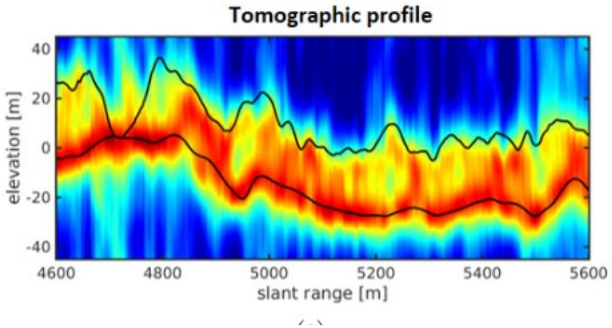
Synergy approaches to generate higher level products, e.g. from BIOMASS and NISAR

- Integrate both BIOMASS and NISAR data in the PolSAR algorithm
- Bayesian approach for combination of AGB retrieved separately from BIOMASS and NISAR
- Error estimation scheme
- Data and algorithm access via MAAP for testing. (Importance of reference data).

GEDI for training Biomass algorithms







- GEDI and P-band TomoSAR can measure surface elevation, vegetation heights, and vertical profiles .
- GEDI measurements can be used in the training of the BIOMASS algorithms and in the determination of site-specific processing parameters
  - In POLSAR algorithm (Presentation M. Soja)
  - In TomoSAR (Presentation Di. Ho Tong Minh, L. Ferro Famil)

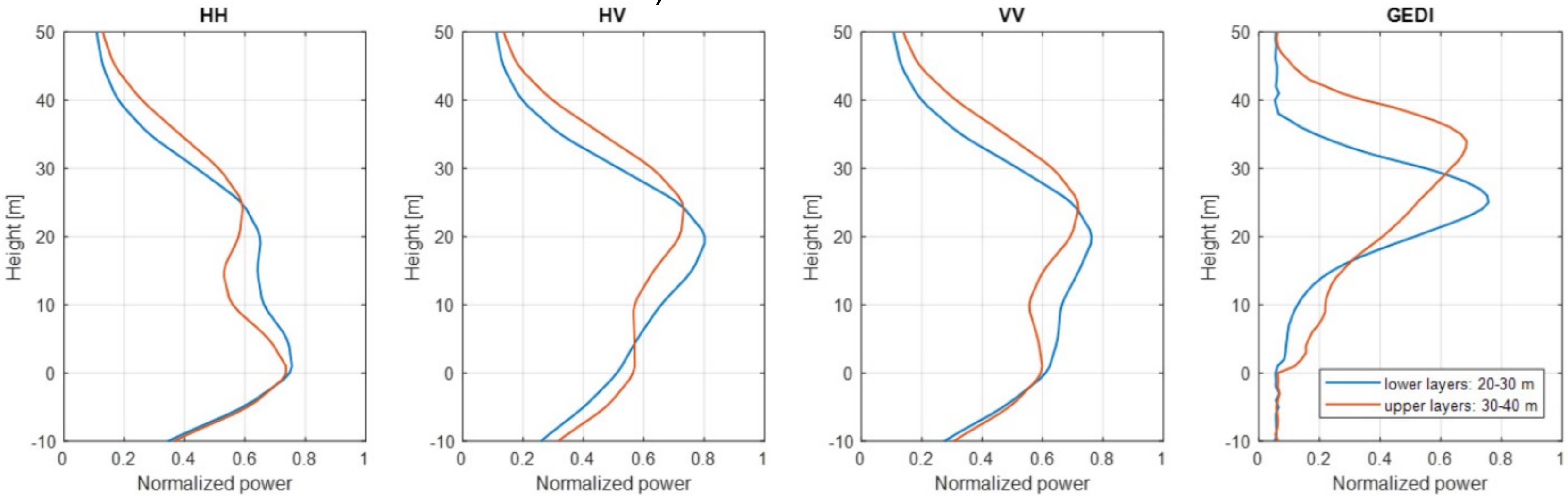


Fig. 5. Vertical profiles at different layers from both TomoSAR and GEDI.

Ngo, Y. N., Huang, Y., Minh, D. H. T., Ferro-Famil, L., Fayad, I., & Baghdadi, N. (2022). Tropical forest vertical structure characterization: From GEDI to P-band SAR tomography. IEEE Geoscience and Remote Sensing Letters.

Quantification of biomass change and Detection of disturbances

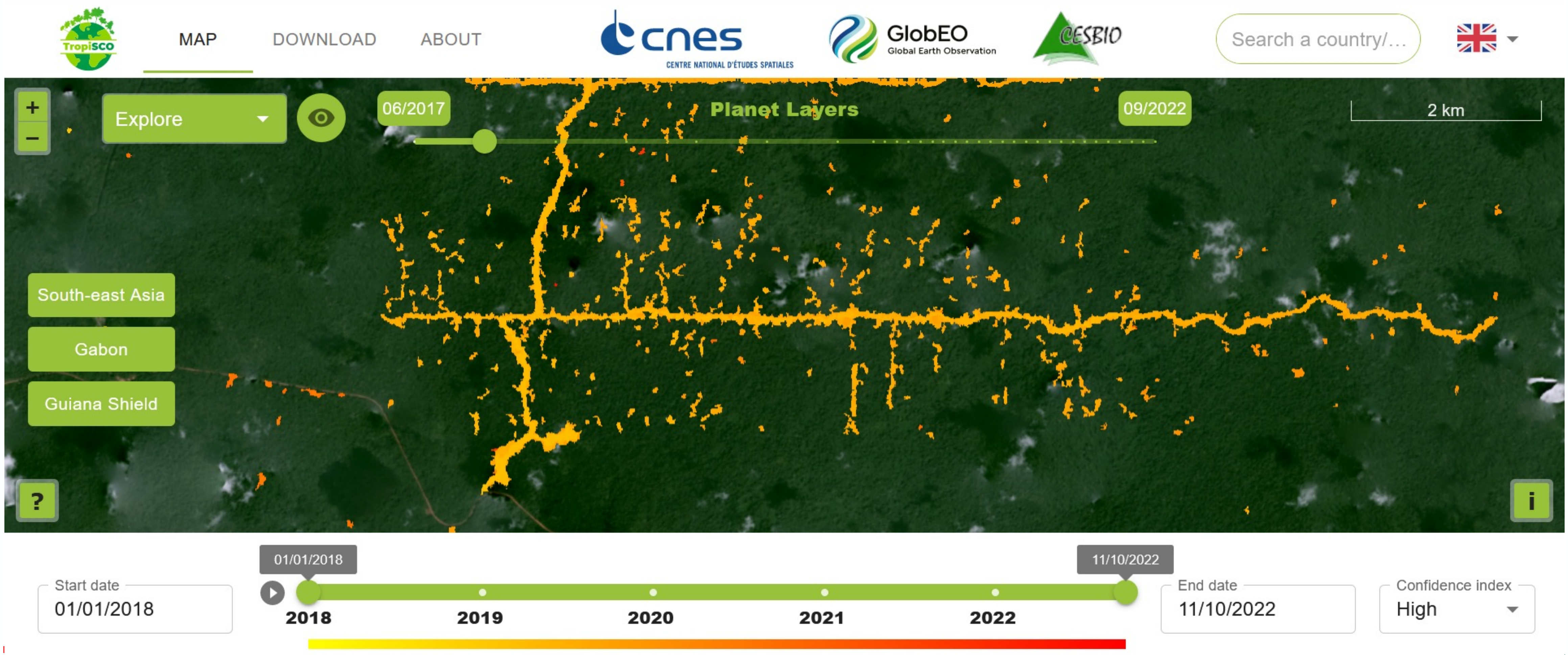
1. The Biomass forest disturbance/degradation products were defined as yearly products , at a resolution of ~ 50 m. So that the AGB loss could be directly inferred from change in AGB maps.

2. To enhance the spatial and temporal resolution of forest disturbances products (disturbed area and biomass loss) required for national reporting (REDD+, MRV, SDG..) the alternative is to use more frequent and higher resolution disturbance detection with operational satellite missions (Sentinels, Landsat..), and AGB values from BIOMASS for AGB loss.

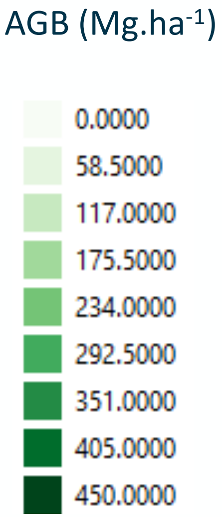
3. In tropical forests, preferred use of SAR data for disturbance detection:
   NISAR, every 12 days
   Sentinel 1 A and C: every 6/12 days, 10 m resolution

Change in AGB by combining forest cover change and AGB map

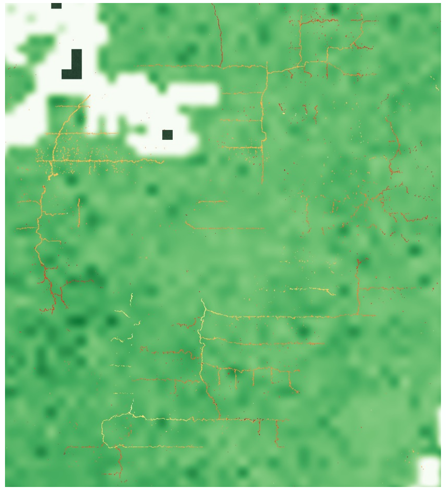
Ex: TropiSCO developed by GlobEO and CESBIO to provide maps of forest cover loss using Sentinel-1 data every 6 or 12 days.
https://www.tropisco.org/   *Cf. Presentation of Stephane Mermoz*



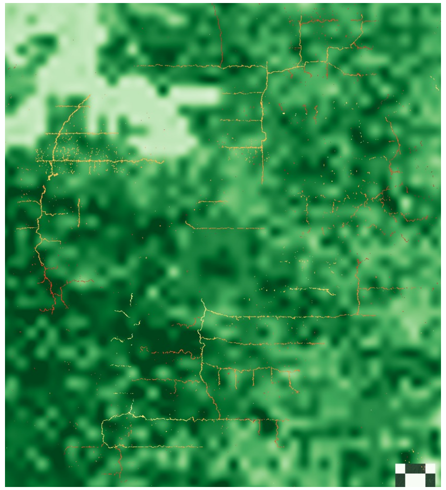
Carbon loss derived from loss of forest cover and available AGB maps



Saatchi



Avitabile

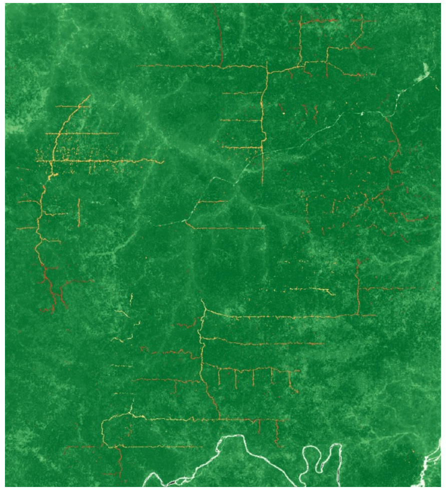


→ **BIOMASS map**

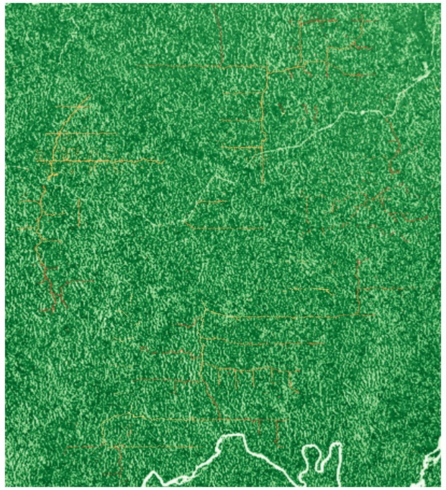
2018-2022 Carbon loss (MtC):

Saatchi	Avitabile	Baccini	CCI 2010	CCI 2018
0.320	0.440	0.466	0.408	0.439

Baccini

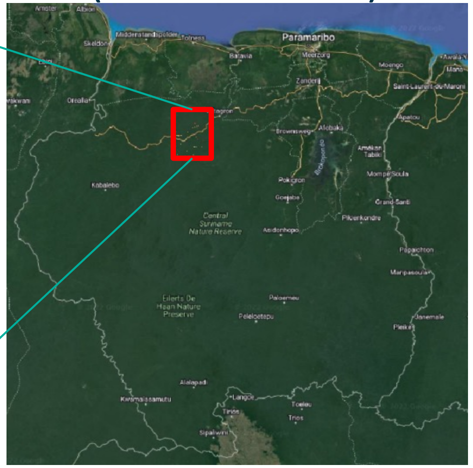


CCI Biomass 2010

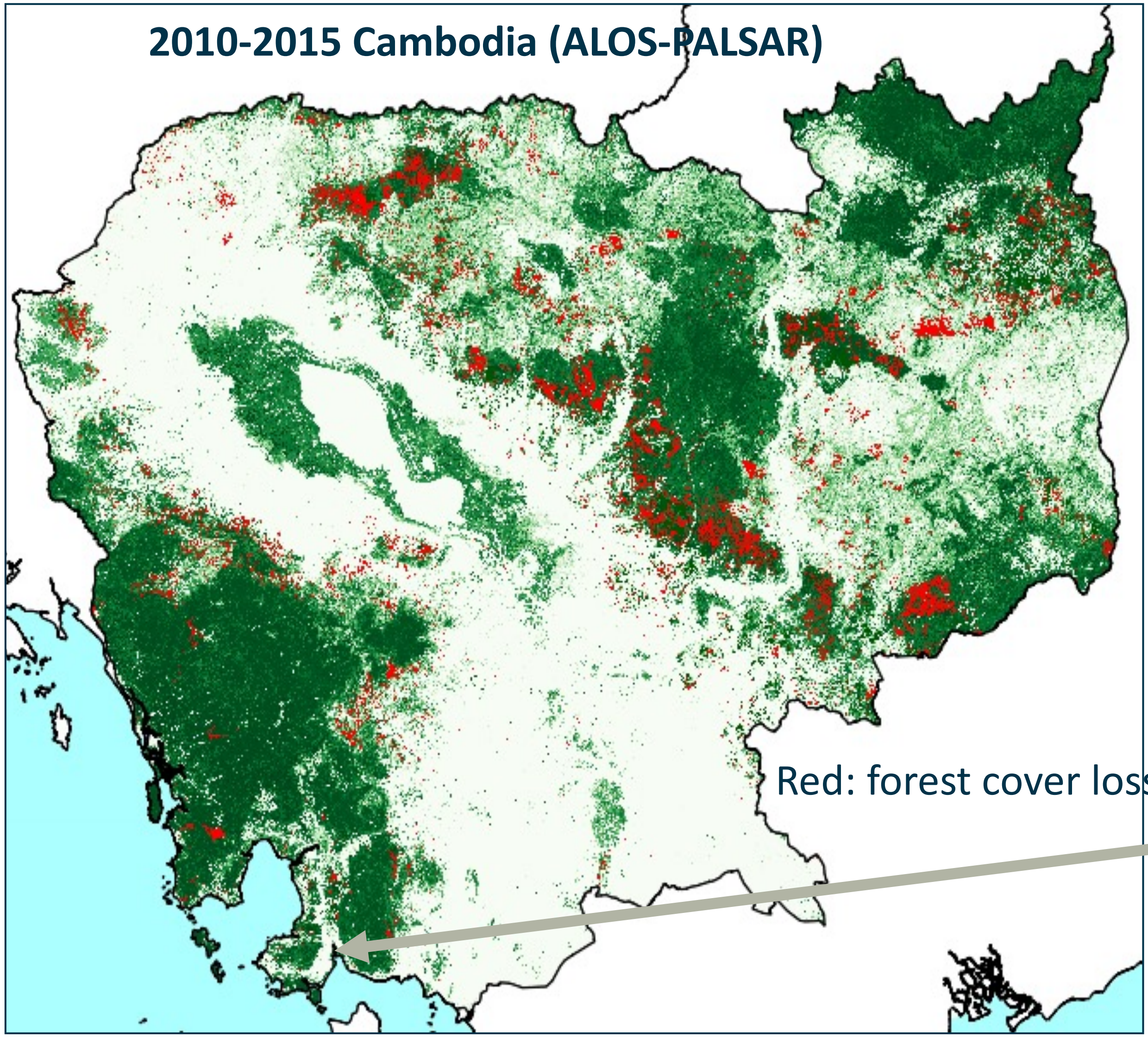


CCI Biomass 2018

Site in Suriname (40km × 44km)



Forest loss detection at national scale: Cambodia

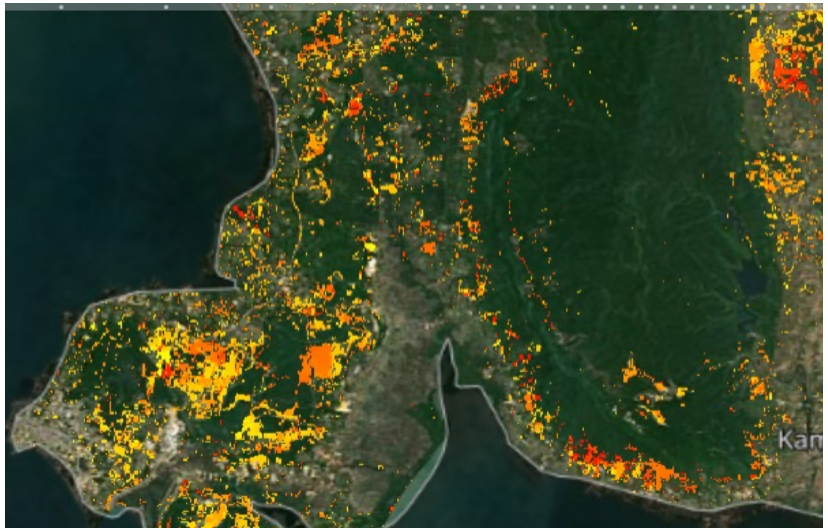


Annual disturbance rate = -1.45%

AGB Loss = 134 Mt (Saatchi) or 114 Mt (Baccini)

National Park, Feb 2023

2018-2023 (Sentinel-1 TropiSCO)



Joint use of BIOMASS with other missions for scientific products

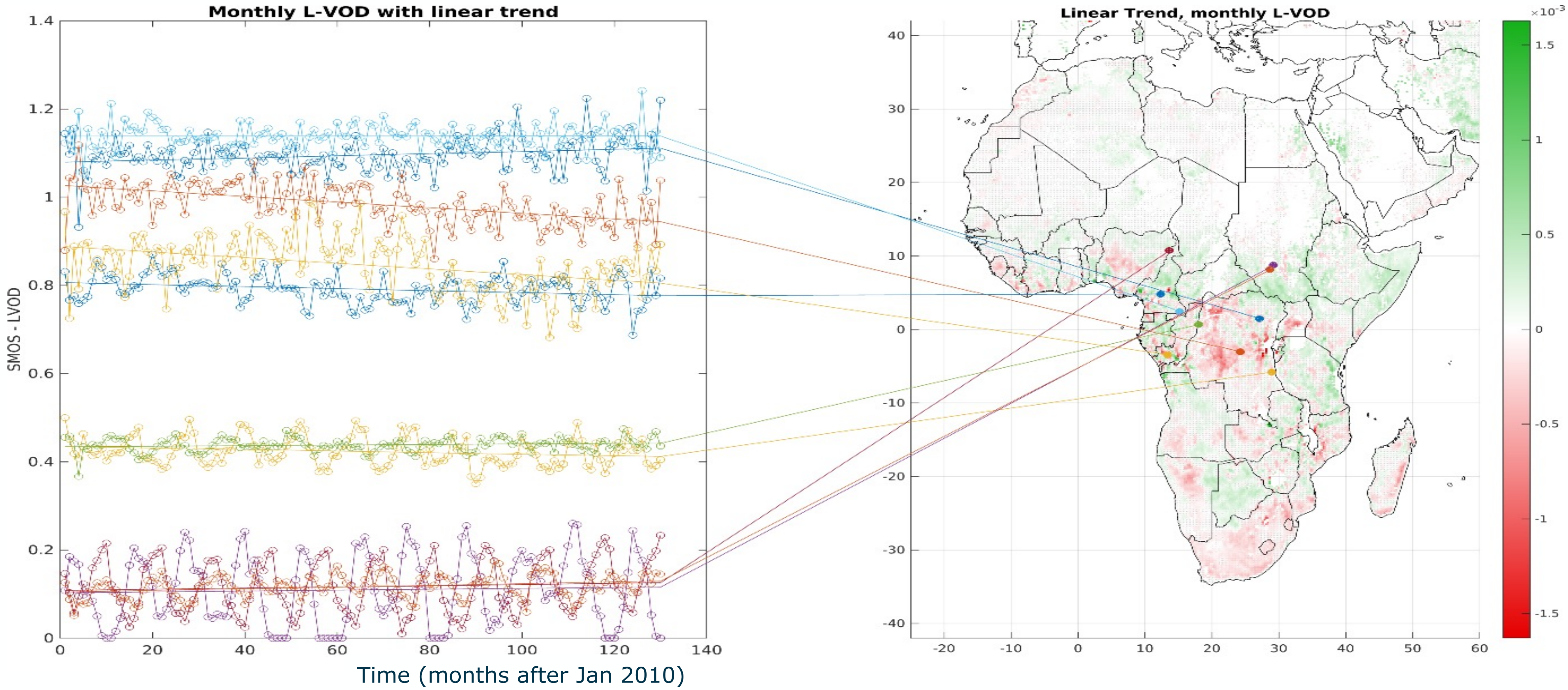
1. To calibrate long time series of EO data in AGB for longer term AGB changes

2. In models calculating terrestial carbon fluxes

3. For calibrating / testing forest ecosystem changes

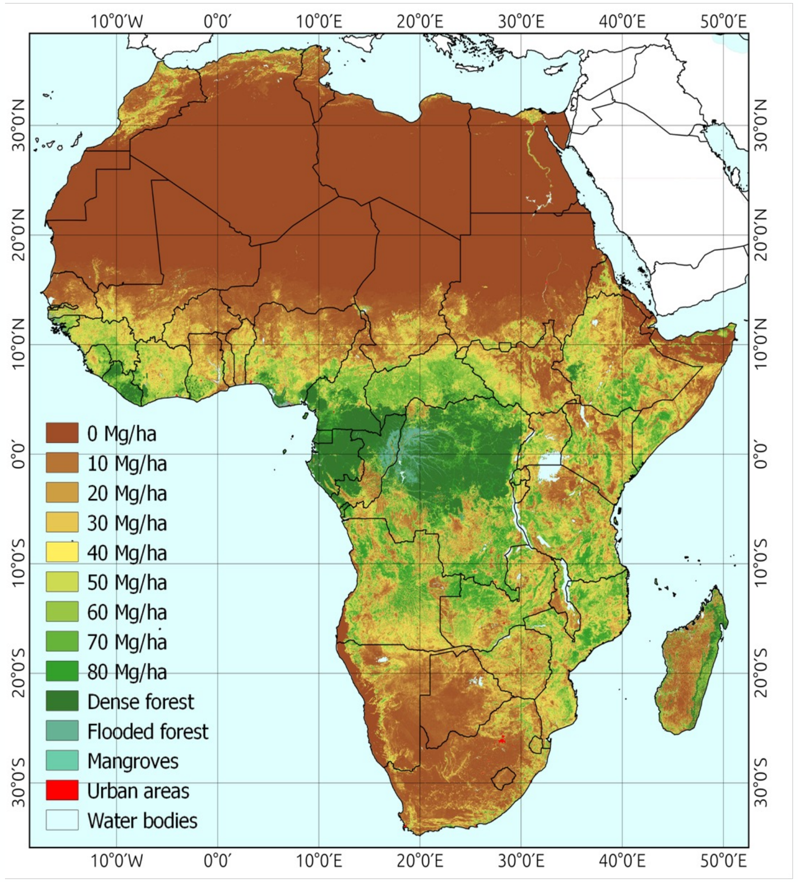
Use of long time series data to track changes in AGB and to identify their causes

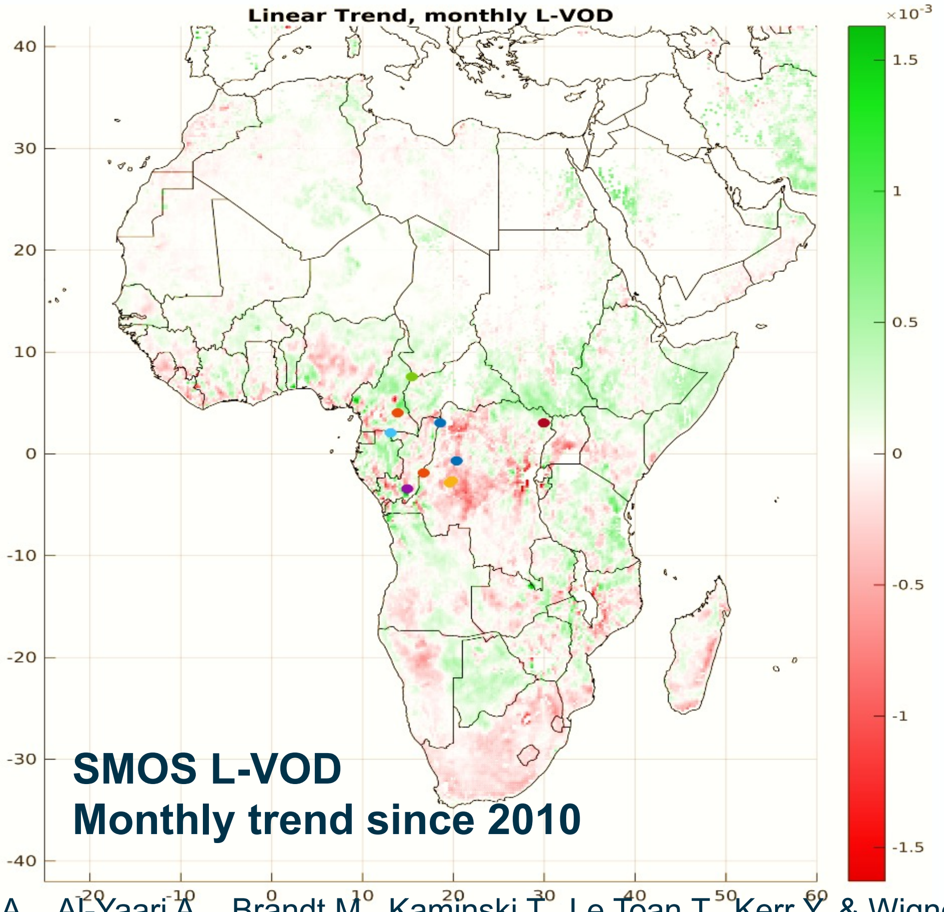
Trend in monthly variation of SMOS L-band VOD data since 2010



Use of long time series data to track changes in AGB and to identify their causes

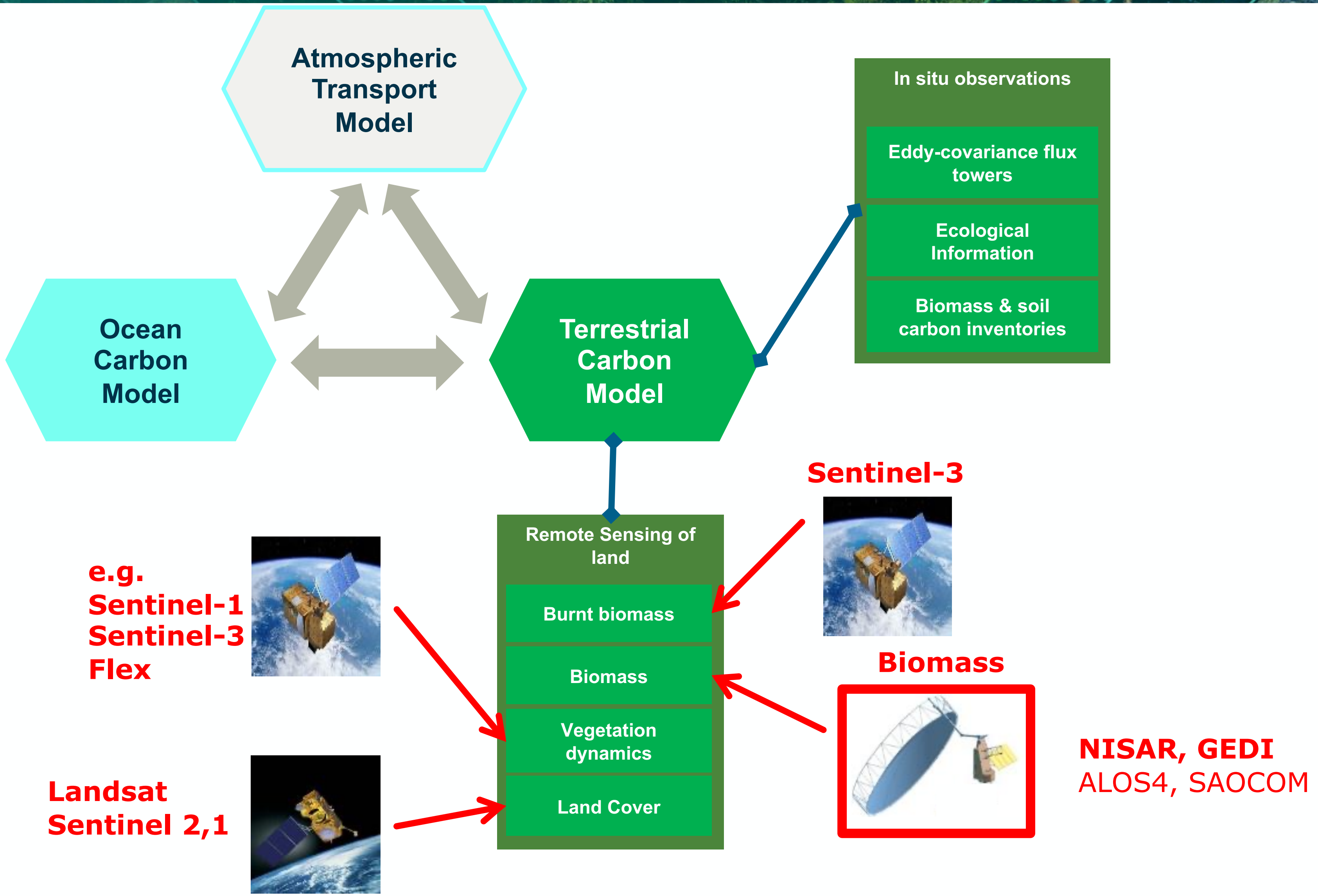
SMOS data currently calibrated by CCI Biomass (*presentation O. Cartus*)
BIOMASS could be used to calibrate SMOS data, in particular at high AGB range



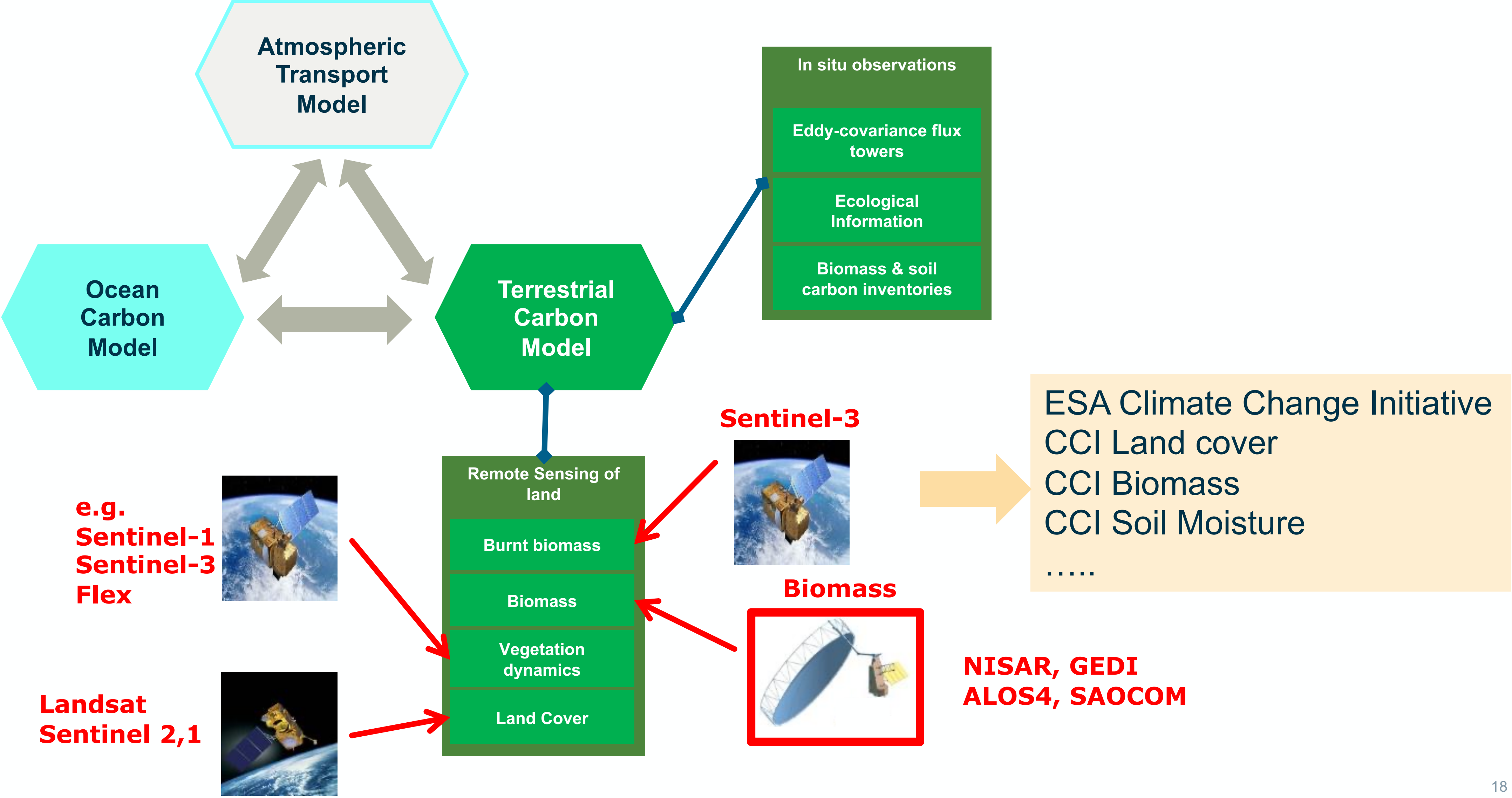


Rodríguez-Fernández, N. J., Mialon, A., Mermoz, S., Bouvet, A., Richaume, P., Al Bitar, A., Al-Yaari A., Brandt,M., Kaminski T., Le Toan,T., Kerr Y. & Wigneron, J. P. (2018). An evaluation of SMOS L-band vegetation optical depth (L-VOD) data sets: high sensitivity of L-VOD to above-ground biomass in Africa. *Biogeosciences*, *15*(14), 4627-4645

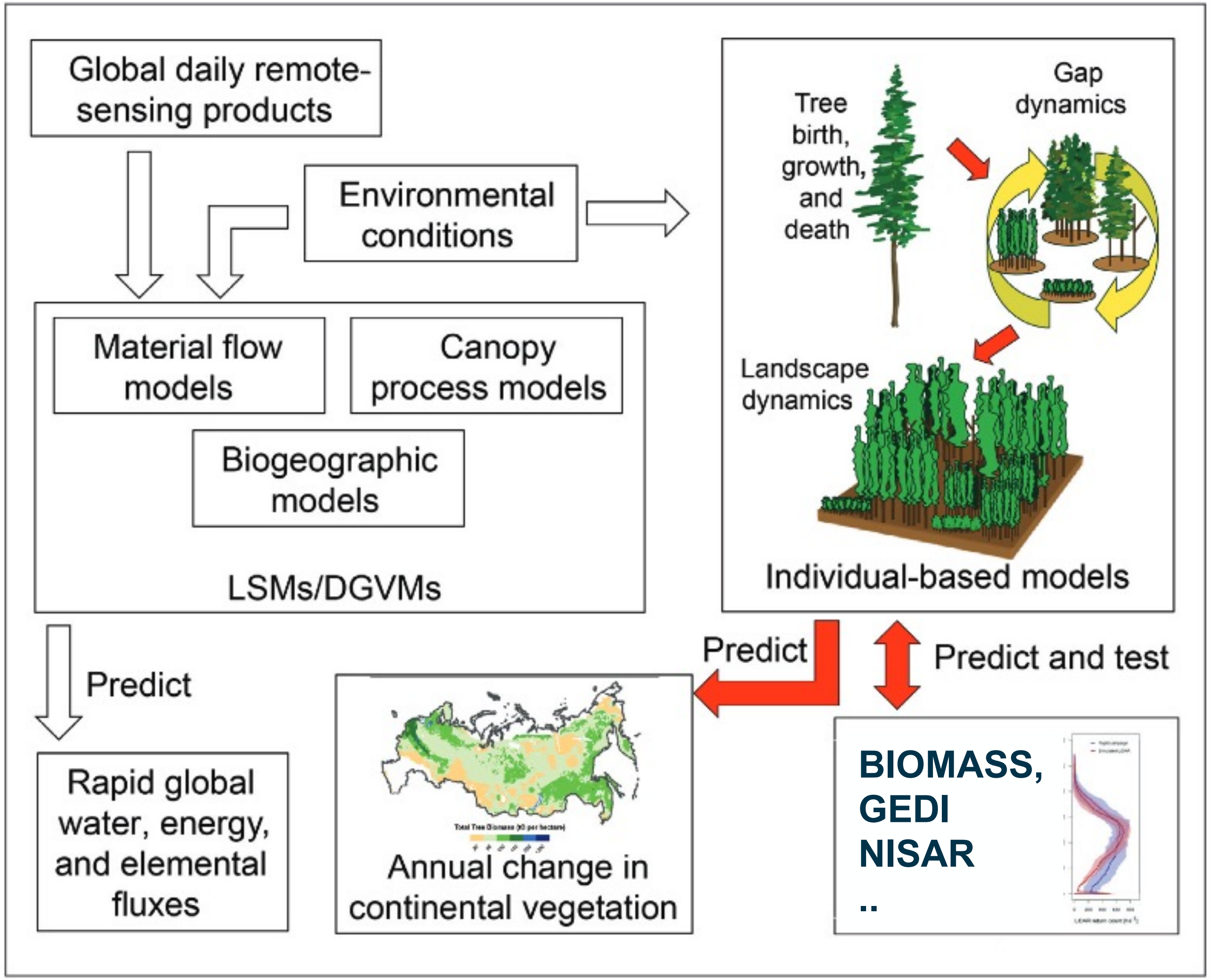
Biomass in the Global Carbon Data Assimilation System



Biomass in the Global Carbon Data Assimilation System



BIOMASS & other missions for testing ecological models



1. Present and next-generation remote-sensing can measure forest biogeo-chemistry and structural change.
2. Individual-based models can predict the fates of vast numbers of simulated trees, all growing and competing according to their ecological attributes in altered environments.
3. The model–data comparison allows the detailed prediction, observation, and testing of forest ecosystem changes under novel environmental conditions.

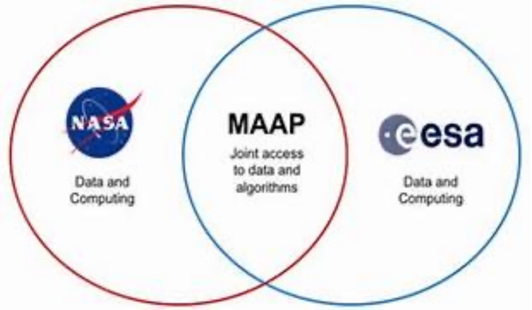
Shugart, H. H., Asner, G. P., Fischer, R., Huth, A., Knapp, N., Le Toan, T., & Shuman, J. K. (2015). Computer and remote-sensing infrastructure to enhance large-scale testing of individual-based forest models. *Frontiers in Ecology and the Environment*, *13*(9), 503-511.

Concluding remarks

1. Biomass, the living part of vegetation systems, plays a crucial role in climate. **Forest biomass and its change is a key part of the climate problem and its solution.** Mapping aboveground biomass is therefore a priority of several ongoing, new and upcoming spaceborne missions, including Biomass, NISAR, GEDI, ALOS-4. And SAOCOM, Sentinels, SMOS

2. The joint use of different missions is expected **to enhance measurements of** biomass and its **change**, **Towards unified and agreed AGB maps**.

3. The access to data and algorithms, via the ESA-NASA Multi-mission Algorithm and Analysis Platform (MAAP) for Biomass,NISAR, and GEDI will facilitate the joint development by the community.



4. Biomass products will be used with other EO and in situ data in models to calculate and predict forest **Ecosystem changes**, and forest **Carbon sources and sinks**, to support options of *attenuation and adaptation*.