



LPVE23 - 10 YEARS OF SMOS PASSIVE MICROWAVE VEGETATION OPACITY STUDY

12-14 June 2023 | ESA-ESRIN | Frascati (Rome), Italy

10 YEARS OF SMOS PASSIVE MICROWAVE VEGETATION OPACITY STUDY

TEAM

- CESBIO: **Arnaud Mialon**, Némésio Rodriguez, César Salazar, Simon Boitard, Alexandre Bouvet, Philippe Richaume, Yann Kerr
- EMMAH (INRAE) : Marie Weiss, Hongliang Ma, Frederic Baret
- globEO : Stéphane Mermoz
- WSL : Yiwen Zhou and Mike Schwank
- Magellium : Beatrice Berthelot, Nuria Duran-Duran, Daria Malik
- ESA : Matthias Drusch



ESA AO/1-10908/21/NL/IA

Context:

- Evaluate different index derived from satellite to monitor the vegetation
⇒ **Synergy between optical and microwave to characterize the vegetation**
- 2-year project: June 2022 - May 2024

Objectives: create 20-year dataset of vegetation index

- Optical: LAI, FAPAR, FCOVER, NDVI, PAR
- Passive microwaves: AMSRE, AMSR2 and SMOS

Scientific questions

- Optical
 - derive a Leaf Water Content
- Microwave
 - Improve radiative transfer model (VOD and ω)
 - Estimate Above Ground Biomass

<https://osmose.magellium.com/>



CONTENT to give an overview of the whole project

I. Optical activities

- I.a data processing
- I.b leaf water content

II. Microwaves

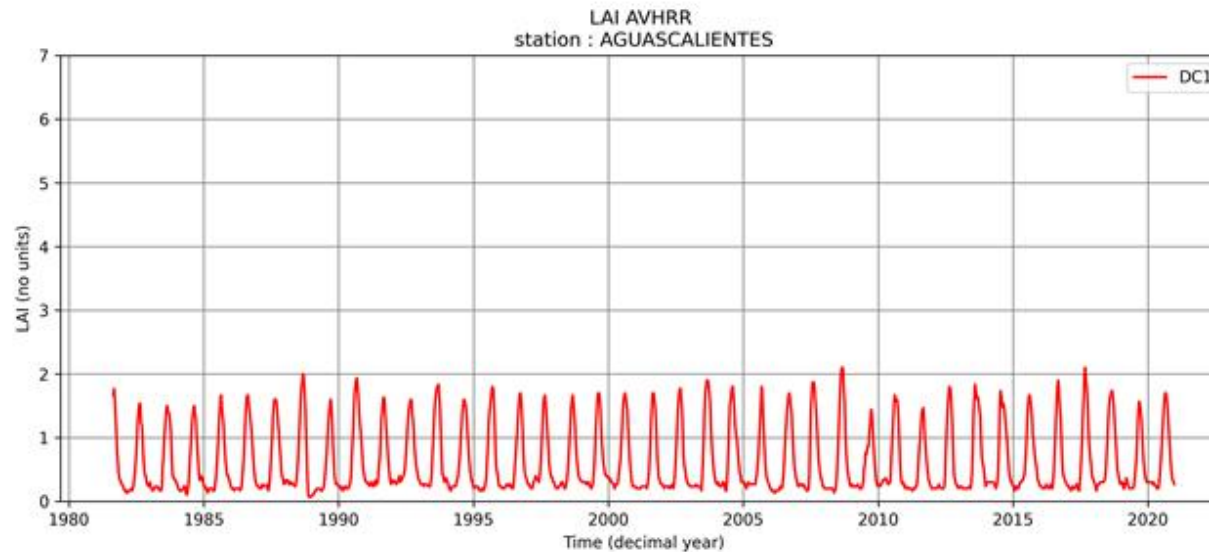
- II.a Tau/Omega
- II.b Neural Network

III. Next Step

I. OPTICAL

Current activities

- a. Optical datacube (*Magellium*)
- b. Create Leaf Water Content (*INRAE: Marie Weiss, Hongliang Ma*)



LAI AVHRR 30 years

I.a. OPTICAL: Datacube 1 content

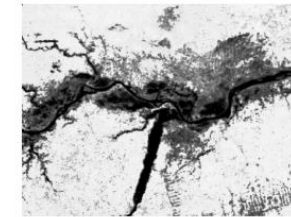
*Data processing, archive :
Daria Malik, Beatrice Berthelot*



<p><u>MODIS (NASA)</u></p>	<ul style="list-style-type: none"> • MCD43C4 v6.1 – Daily BRDF/Albedo Nadir BRDF-adjusted Reflectance • MCD18C2 v6.1 – Daily Photosynthetically Active Radiation (PAR) • MOD13C1 v6.1 – 16-Day Vegetation Indices • MCD15A2H v6.1 – 8-Day LAI/FPAR
<p>AVHRR (Theia)</p>	<ul style="list-style-type: none"> • 10-Day LAI • 10-Day FAPAR • 10-Day FCOVER
<p>SPOT / PROBA-V / S3-OLCI (Copernicus)</p>	<ul style="list-style-type: none"> • 10-Day LAI • 10-Day FAPAR • 10-Day FCOVER • 10-Day NDVI • 10-Day Top-of-Canopy Reflectance

I.a. OPTICAL: Datacube 1 content

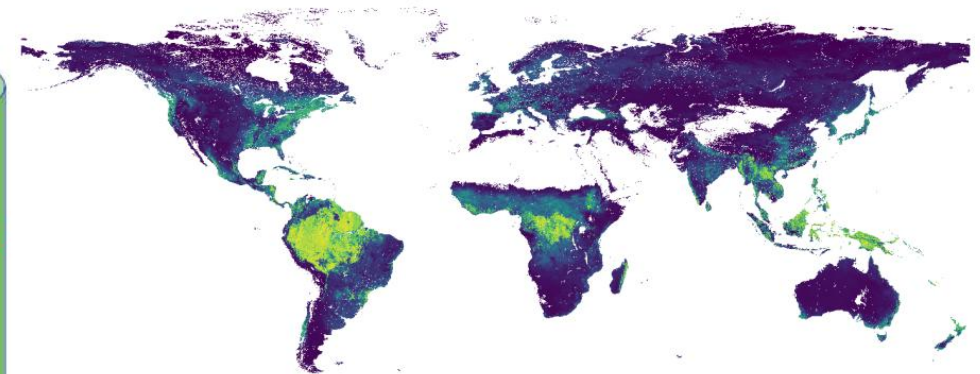
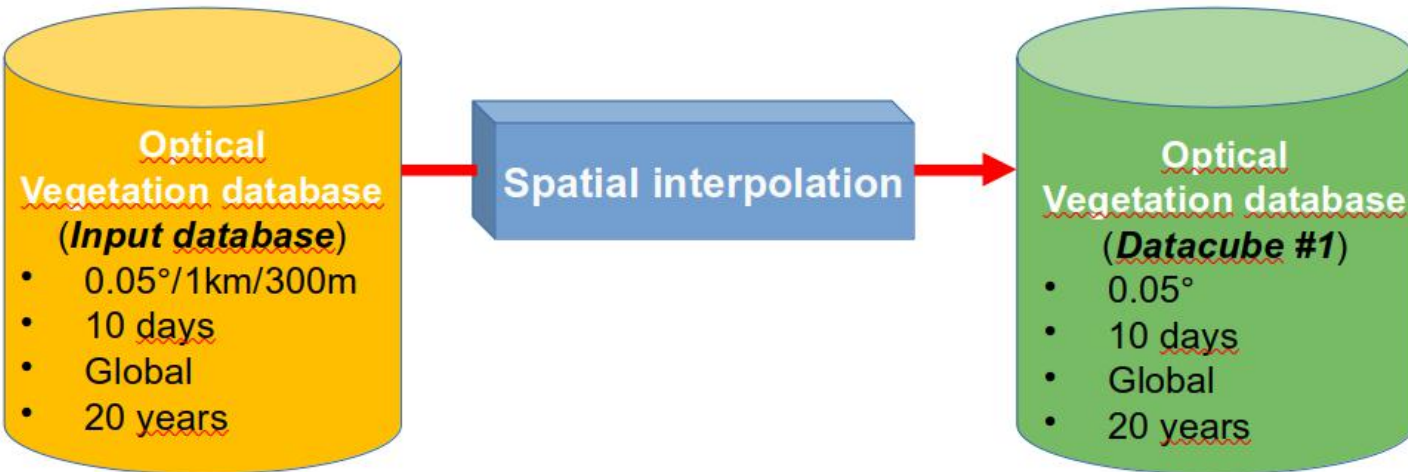
- Geographic latitude/longitude projection
- Global map (-180°W → +180°E, -90°S → +90°N)
- 0.05° spatial resolution
- Image size 3600 lines x 7200 columns



Lat/lon projection,
1km resolution



Lat/lon projection,
0.05 deg resolution

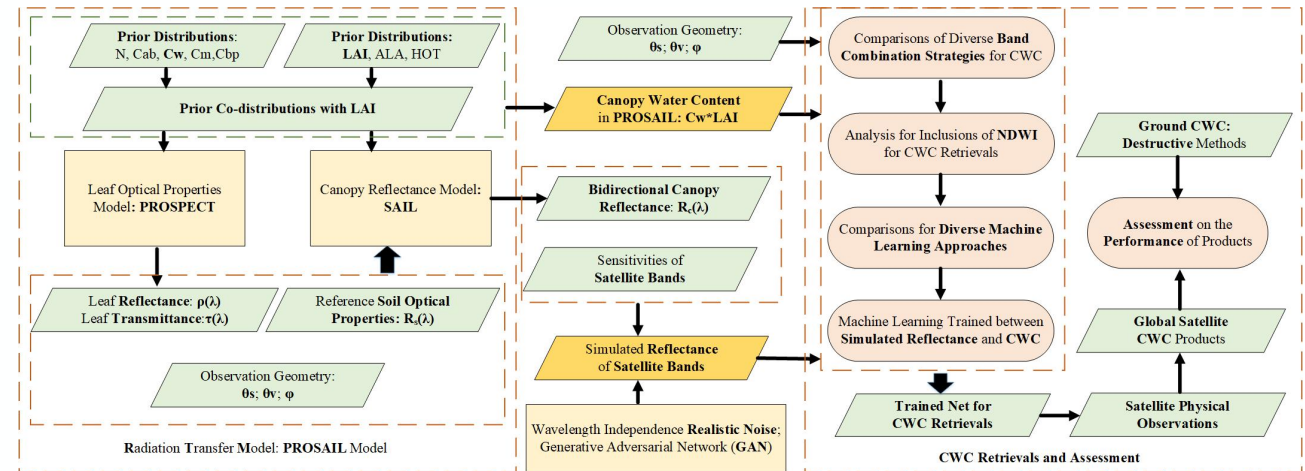


Example of merged and reprojected LAI MODIS tiles
(product MCD15A2H)

I.b. OPTICAL: Leaf Water Content (*INRAE Marie Weiss, Hongliang Ma*)

Retrieve Leaf Water Content - CWC

- use radiative model PROSAIL
- via **Cw*LAI**



Model parameters

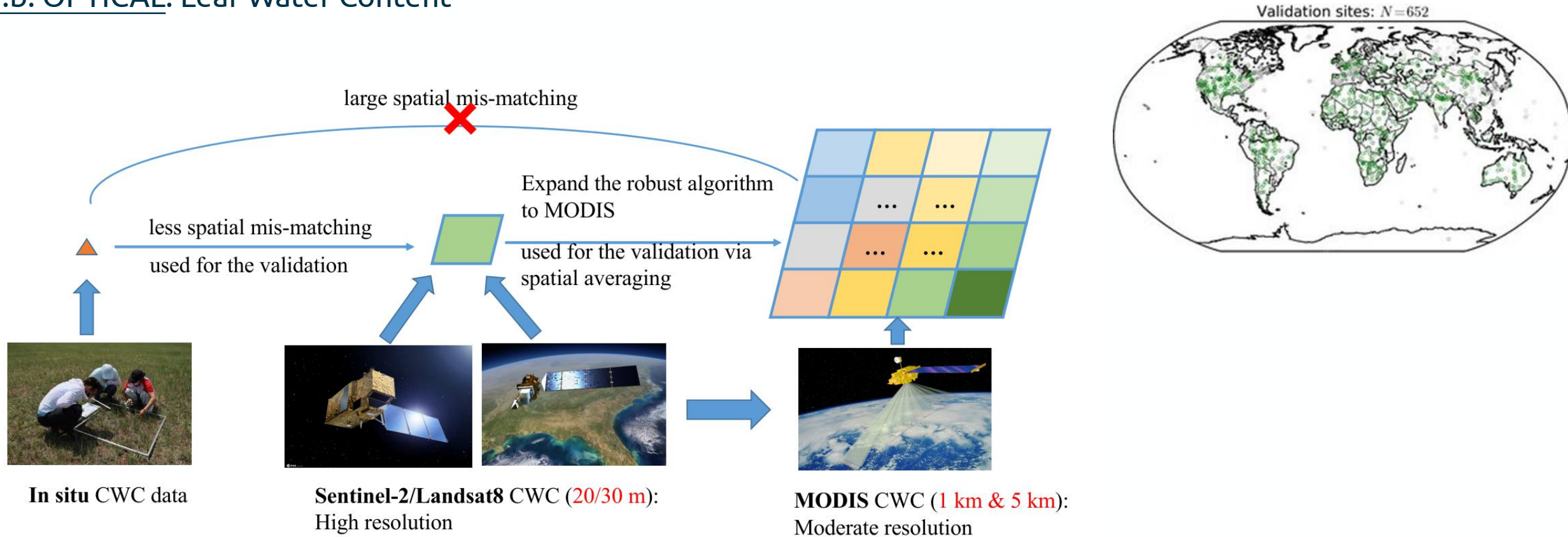
	Variable	Minimum	Maximum	Mode	Std	Nb_Class
Canopy	LAI	0.0	15.0	2.0	3.0	6
	ALA (°)	30	80	60	30	3
	Crown Cover	1.0	1.0	0.8	0.4	1
	HsD	0.1	0.5	0.2	0.5	1
Leaf	N	1.20	1.80	1.50	0.30	3
	Cab (µg.cm ⁻²)	20	90	45	30	4
	Cdm (g.cm ⁻²)	0.0030	0.0110	0.0050	0.0050	4
	Cw Rel	0.60	0.85	0.75	0.08	4
Soil	Cbp	0.00	2.00	0.00	0.30	3
	Bs	0.50	3.50	1.20	2.00	4
Atmosphere	P (mbar)	950	1080	1013	15	1
	t550	0.00	0.80	0.35	0.30	1
	H2O (cm)	1.00	6.50	3.83	1.50	1
	O3 (dbs)	0.20	0.50	0.35	0.10	1
Nb_Sims						41472

Improvements for leaf traits: Three key parameters linked to **leaf water content (Cw)**: **Cab**, **Cdm** and **Cw_Rel**, considering the **open plant traits database (e.g., TRY)**

Improvements for soil background: considering the **open soil reflectance database (e.g., OSSL)**

*Cab: chlorophyll concentration
*Cdm: dry matter content

I.b. OPTICAL: Leaf Water Content



Strategy: Develop the CWC product from Sentinel-2/Landsat8 firstly and then implement it to MODIS

I.b. OPTICAL: Leaf Water Content

First analysis to improve Leaf Water Content retrievals

- Improve the inputs of PROSAIL model using the open databases of TRY and OSSL
- Include :
Green+Red+NIR+SWIR1+ SWIR2 +NDII+NDWI+Angles

$$NDWI_{1240} \quad NDWI_{1240} = \frac{NIR_{860} - SWIR_{1240}}{NIR_{860} + SWIR_{1240}}$$

- Consider NDWI and NDII for the improvement of SNAP (both for S2A and S2B)
- satellite geometry (angles)

Marie Weiss:
marie.weiss@inrae.fr

Hongliang Ma:
hongliang.ma@inrae.fr

II. MICROWAVE: Context

- Missions
 - SMOS
 - 14 years: 2010 - 2023
 - 25 km output products
 - L band: 1.4 GHz
 - Provide complete coverage of the Earth surface in 3/4 days
 - L-band sensitive to water content (*Jackson and Schmugge 1991*)
 - AMSRE
 - 2002-2011
 - bands: C (6.93 GHz), X (10.65 GHz), K (18.7 GHz)
 - 0.25° grid Brightness Temperatures
 - AMSR2
 - 2011-....
 - bands : C (6.93/7.3 GHz), X (10.65 GHz), K (18.7 GHz)
 - 0.25° grid Brightness Temperatures
- Used to estimate the Above Ground Biomass
 - a. Radiative transfer model
 - b. Neural network approach

II. MICROWAVE : Estimate the Above Ground Biomass

a. Use of a radiative transfer model

Fan et al. Nature plants 2019

Liu et al. Nature

Rodriguez et al., Biogeosciences 2018

II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

standard approach : L-MEB model (*Wigneron et al. 2007*)

$$T_{B,tot}(P, \theta) = e_s T_s \gamma + (1 - \omega) (1 - \gamma) T_v + (1 - \omega) (1 - \gamma) T_v (1 - e_s) \gamma + T_{B,sky} \gamma^2 (1 - e_s)$$

1. soil

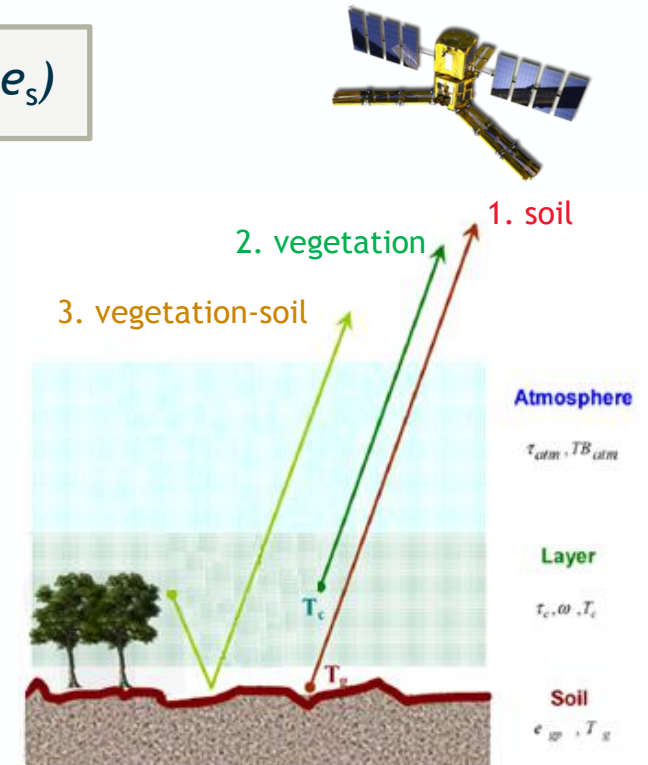
2. vegetation

3. vegetation-soil

4. sky

- e_s soil emissivity; linked to soil moisture through dielectric constant
- T_s physical temperature of soil
- T_v physical temperature of vegetation
- ω **single scattering albedo of vegetation (omega)**
- γ **canopy transmissivity \Rightarrow vegetation optical depth VOD, τ**
- T_{Bsky} sky brightness temperature
- P polarisation (H or V)
- θ incidence angle

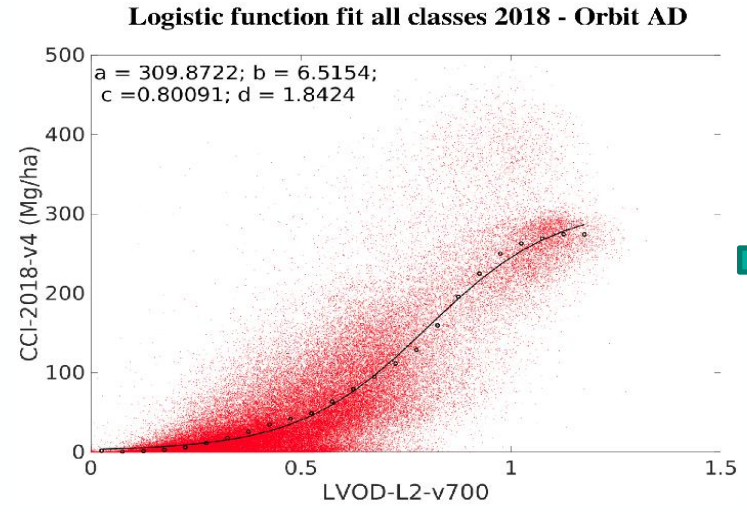
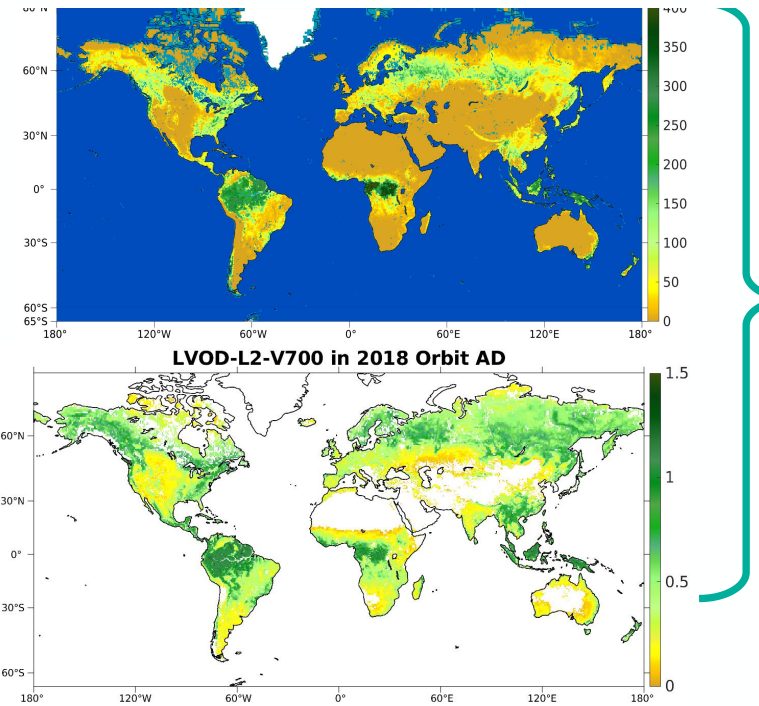
$$\gamma = e^{\frac{-\tau}{\cos \theta}}$$



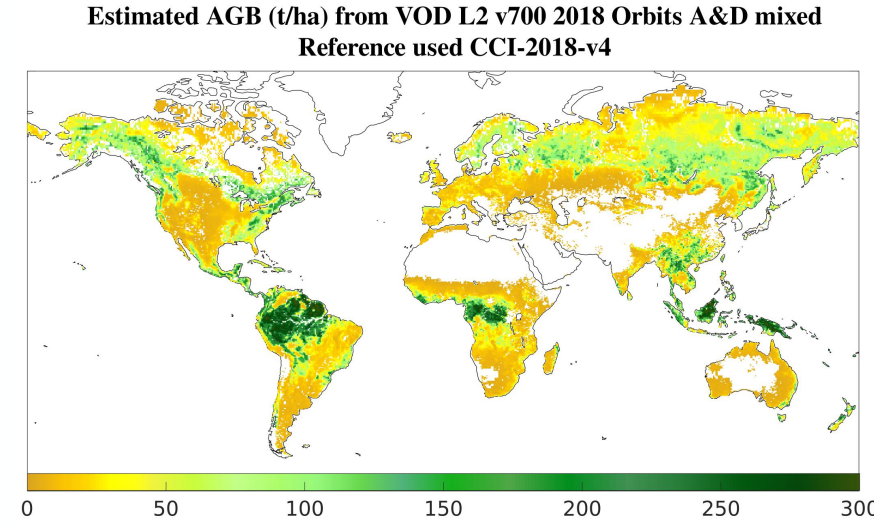
II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

standard approach

AGB of reference: CCI biomass 2018
version 4, Santoro et al.



Relationship VOD - AGB



**Multi year AGB 2010-2022
=
SMOS yearly VOD + relationship for a year**

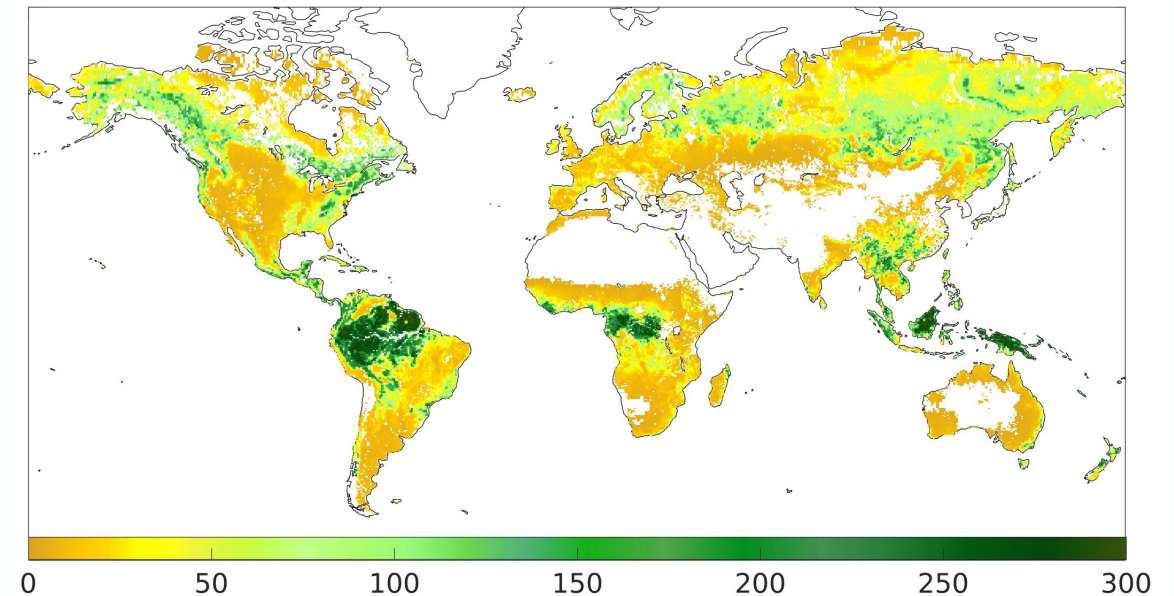
II.a. MICROWAVE : Estimate the Above Ground Biomass Use of a radiative transfer model

Simon Boitard, Némésio Rodriguez, Arnaud Mialon CESBIO

Based on

- SMOS level 2 VOD version 700
- Biomass of reference:
 - CCI version 4
 - Avitabile et al.
 - Next : Saatchi et al., Tree Height (GEDI/Icesat2)

Estimated AGB (t/ha) from VOD L2 v700 2018 Orbits A&D mixed
Reference used CCI-2018-v4



- Info and Technical Note:
<https://www.catds.fr/Products/Available-products-from-CEC-SM/L4-Land-research-products/L4-Above-Ground-Biomass>
- Data: https://data.catds.fr/cecsm/Land_products/L4_Above_Ground_Biomass/
- Boitard et al. 2023, in prep. for ESSD



II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

Mike Schwank, Yiwen Zhou - WSL

Objectives:

- Improve/validate/calibrate: τ and ω
- Define dependency with frequency
⇒ Applications to C, X, K bands: use of AMSRE, AMSR2
- Use of «Two Stream» radiative transfer model
- Assess what is monitored by L, C, X - VOD

References

- *Zhou et al., 2023, in preparation*
- *Yiwen Zhou et al., IGARSS 2023*

MODELLING SCATTERING ALBEDO OF TREES FROM 1 TO 37 GHZ AND ITS APPLICATION TO VOD RETRIEVAL

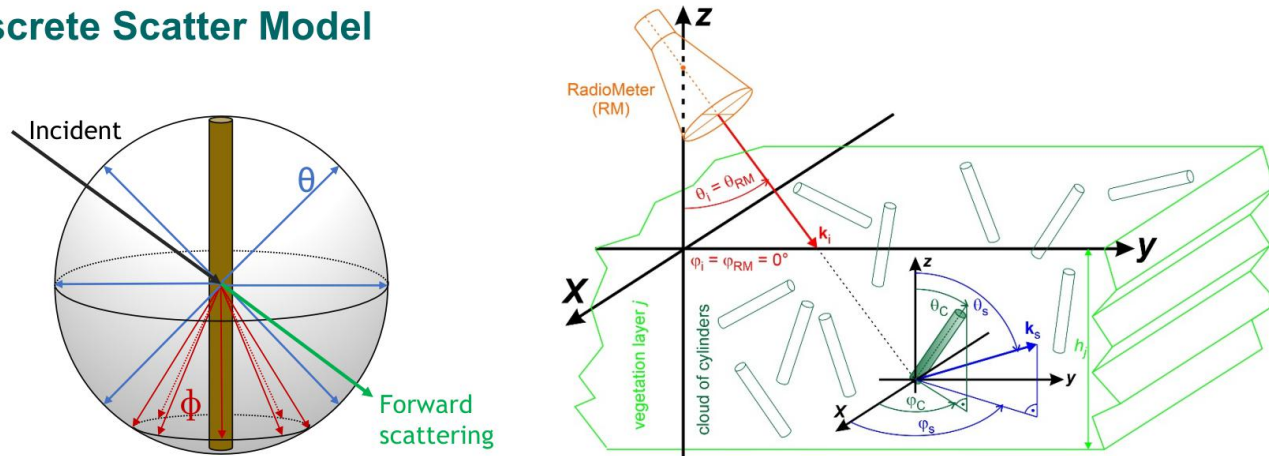
II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

Improving τ and ω Mike Schwank, Yiwen Zhou (WSL)

Use a complex permittivity model

N. S. Chauhan et al. 1994 "Discrete scatter model for microwave radar and radiometer response to corn: comparison of theory and data" IEEE TGRS

Discrete Scatter Model



Scattering amplitude theorem and formula

Extinction Coefficient

$$\kappa_{ep}(\text{freq}) = \frac{4\pi}{k_0 \cos \theta} \sum_{j=1}^n \rho_j \text{Im} \left\{ \left\langle f_{pp}^{(j)}(\hat{i}^-, \hat{i}^-, \text{freq}) \right\rangle \right\}$$

where :

n – number of vegetation constituent types

ρ_j – density of j th type of vegetation constituents

$f_{pp}^{(j)}(\hat{i}^-, \hat{i}^-, \text{freq})$ – forward scattering amplitude - E_s/E_i

$\langle \rangle$ – average based on plant component orientation PDF

Scattering Coefficient

$$\kappa_{sp}(\text{freq}) = \int_{4\pi} d\Omega_s \sum_{q=h,v} \sum_{j=1}^n \rho_j \left\langle \left| f_{pq}^{(j)}(\theta_s, \varphi_s, \theta_i, \varphi_i; \text{freq}) \right|^2 \right\rangle$$

where Ω_s - solid angle over the sphere

$|f_{pq}^{(j)}(\theta_s, \varphi_s, \theta_i, \varphi_i; \text{freq})|$ - scattering amplitude with (θ_i, φ_i) incident angle and (θ_s, φ_s) scattering angle

Albedo

$$\omega(\text{freq}) = \kappa_{sp}(\text{freq}) / \kappa_{ep}(\text{freq})$$

Extinction coefficient: κ_{ep}

Scattering coefficient: κ_{sp}

ω = Albedo: $\kappa_{sp} / \kappa_{ep}$

II.A. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

Improving τ and ω *Mike Schwank, Yiwen Zhou (WSL)*

Discrete model to describe the trees

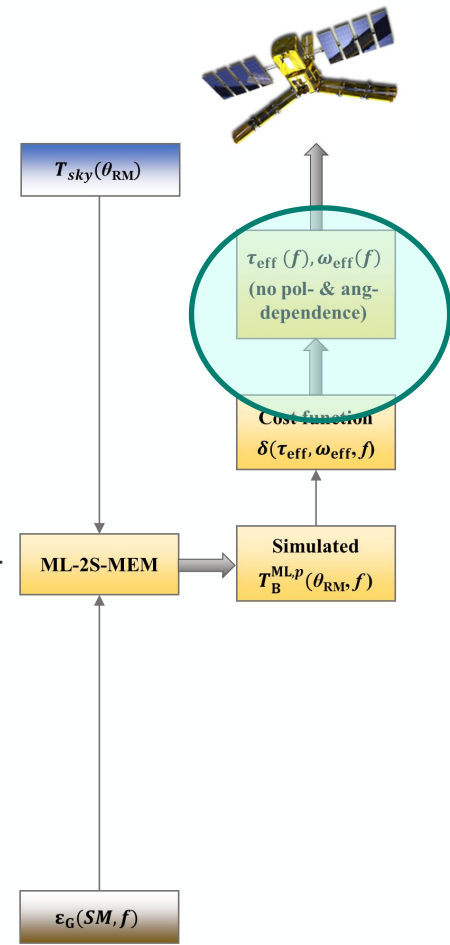
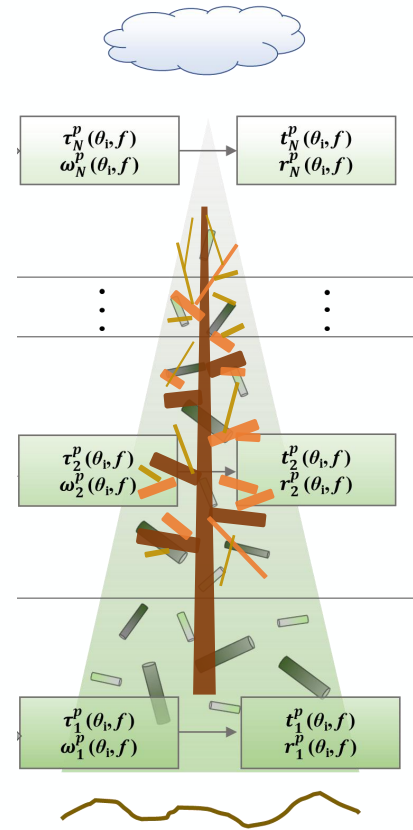
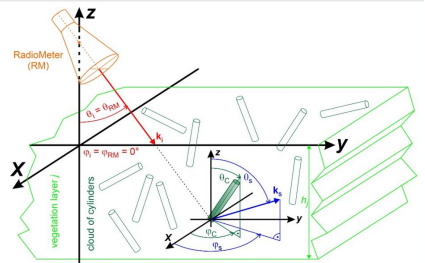
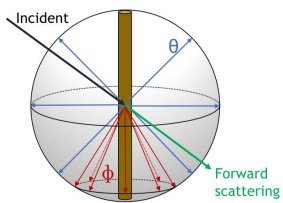
- Components of trees : trunk, branches, small elements
- Multi-layers
- Radius of branches, Density of components per layers ...



II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

«real» Permittivity from all components of a tree

Discrete Scatter Model



Optimized

- Ω
- τ

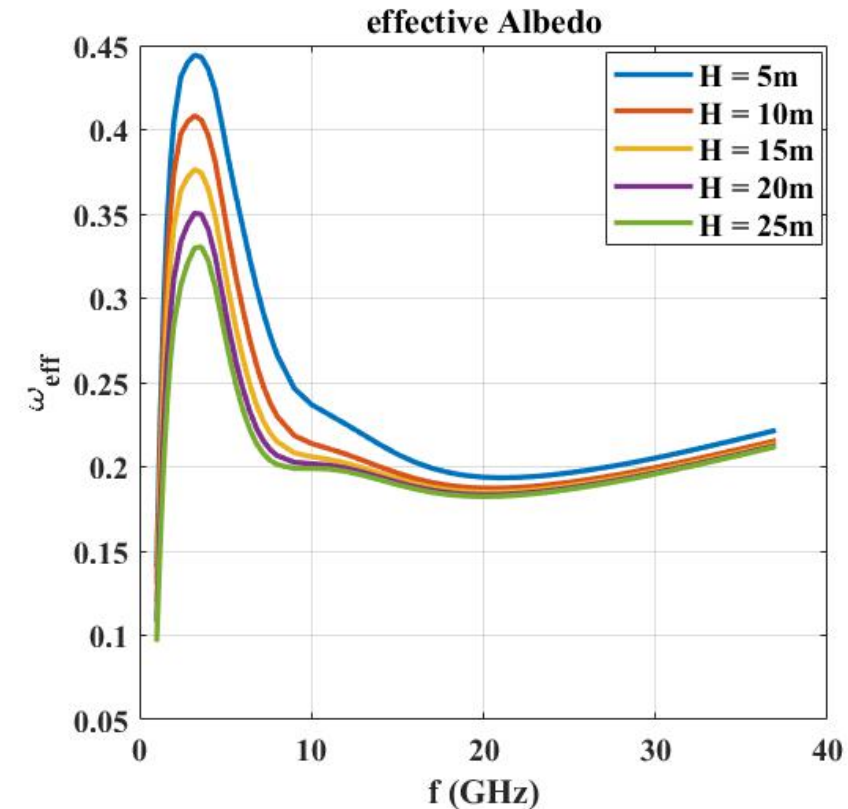
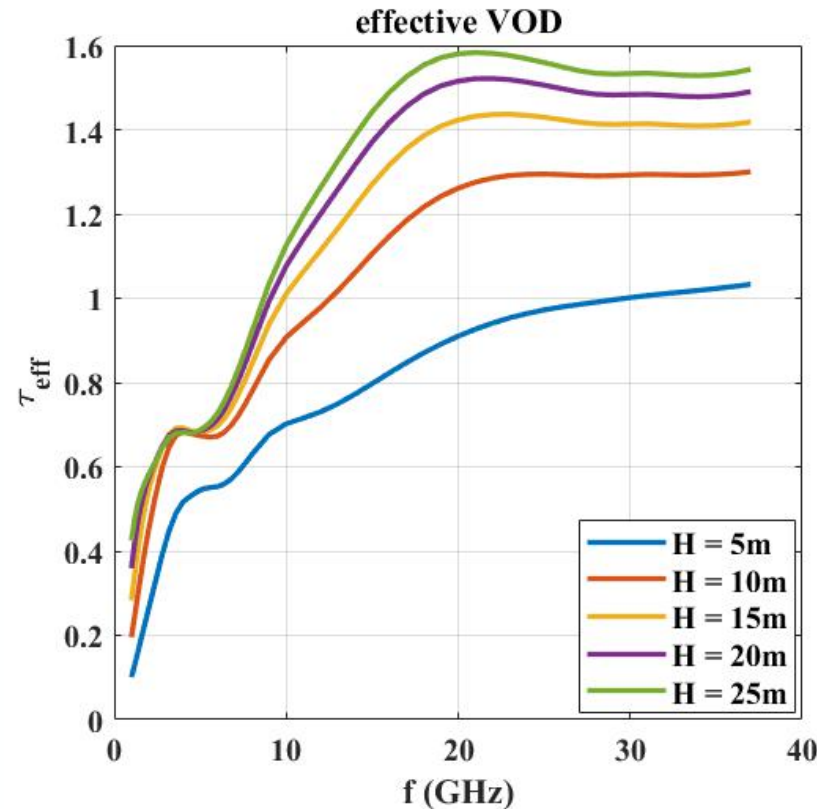
for SMOS/AMSRE retrieval

II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

Improving τ and ω , Mike Schwank, Yiwen Zhou

First Results: τ_{eff} and ω_{eff}

- Multi-frequency
- for different tree height H



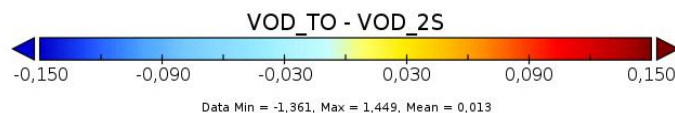
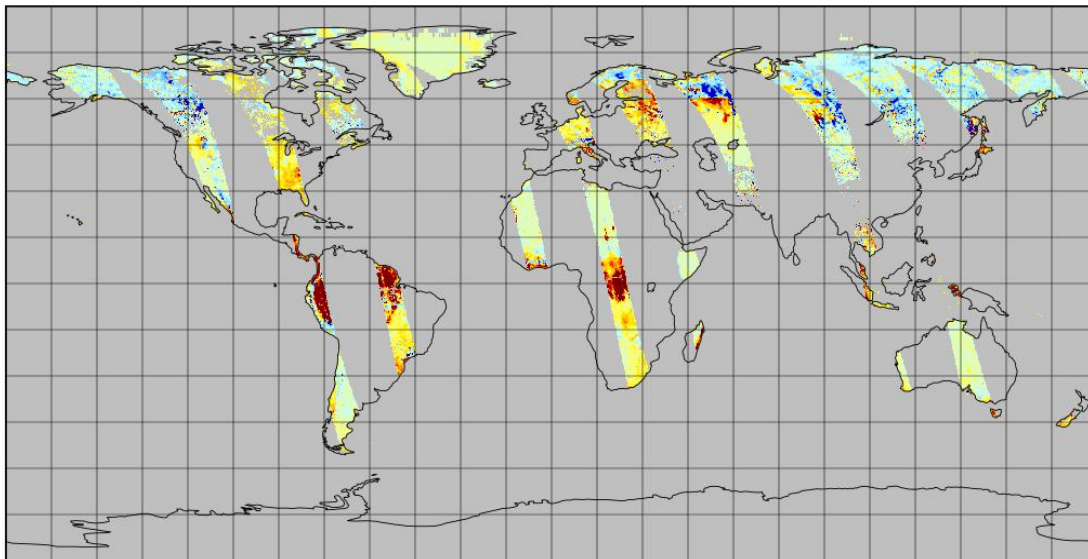
Zhou et al., 2023, in preparation

II.a. MICROWAVE : Estimate the Above Ground Biomass, Use of a radiative transfer model

Improving τ and ω , Mike Schwank, Yiwen Zhou

Comparison with regular L band VOD

Vegetation Optical Thickness at Nadir



- First analysis
 - VOD is lower than «common» VOD_{L-MEB}
 - How to validate this VOD
- current activities
 - process longer time series VOD
 - evaluation with Above Ground Biomass (CCI Biomass, Tree Height)

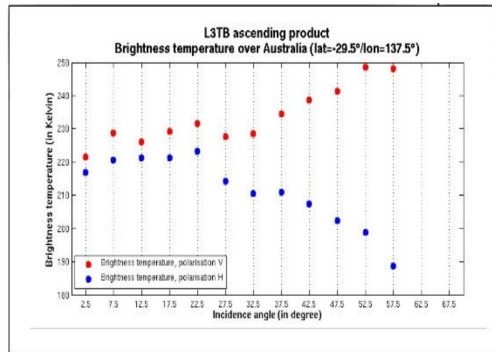
II.b. MICROWAVE : Estimate the Above Ground Biomass, Use of a neural network approach

- **César Salazar , Ph. D.** (supervisors N. Rodriguez-Fernandez and A. Mialon)
julio-cesar.salazar-neira@univ-tlse3.fr
- October 2021 - September 2024
- Collaboration with the BIOMASS team (Thuy LeToan, Alexandre Bouvet et Stéphane Mermoz)

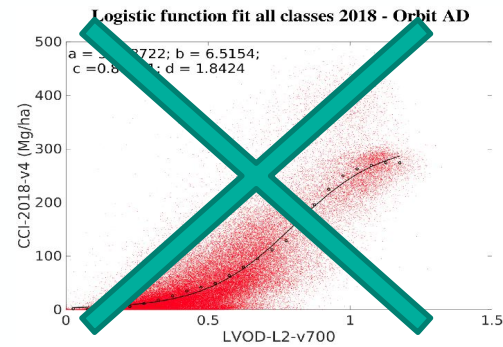
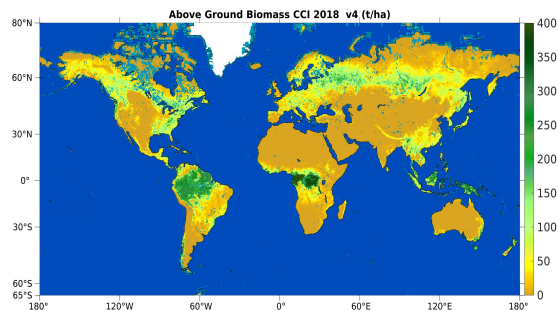
II.b. MICROWAVE : Estimate the Above Ground Biomass, Use of a neural network approach

Ph. D. C ezar Salazar, Nemesio Rodriguez

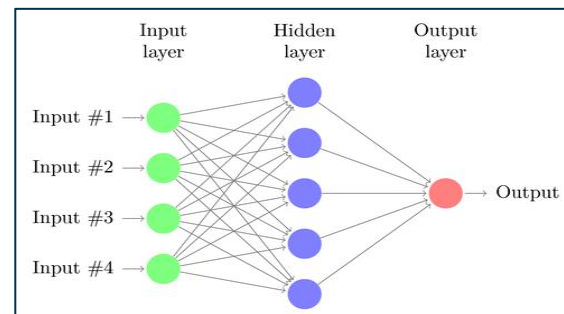
SMOS brightness temperatures



Biomass exple : CCI biomass version 4, Santoro et al.

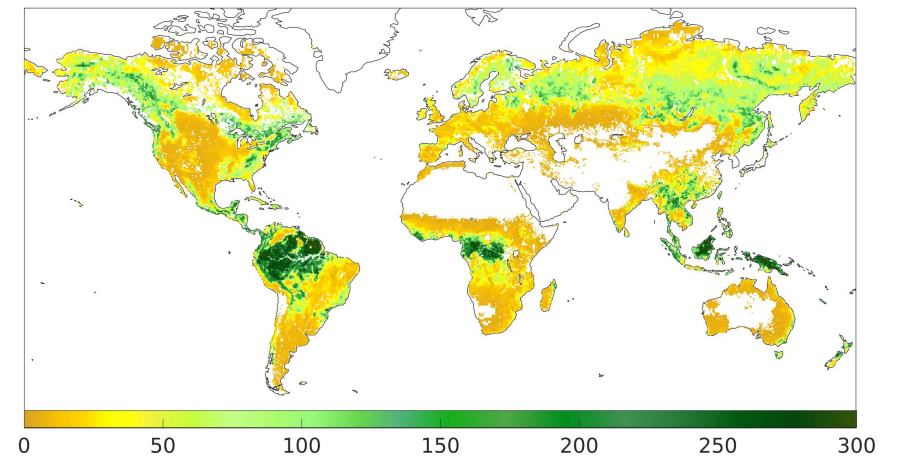


Neural Network



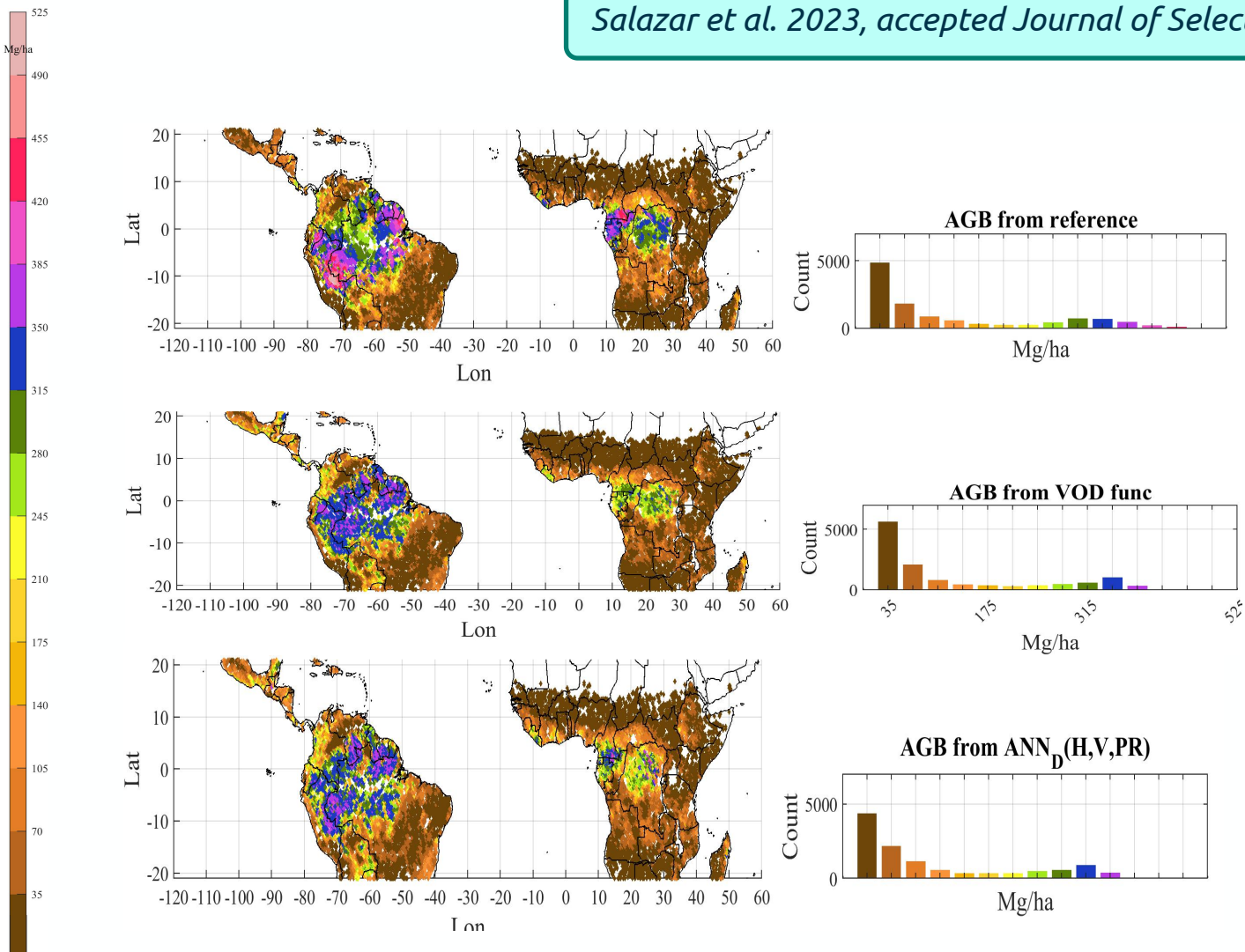
SMOS AGB

Estimated AGB (t/ha) from VOD L2 v700 2018 Orbits A&D mixed
Reference used CCI-2018-v4



- Rodriguez-Fernandez et al. (2019, IGARSS)
- Salazar et al. 2023, accepted JSTAR

Salazar et al. 2023, accepted Journal of Selected Topics in Applied earth observations and Remote sensing



- CCI Biomass 2018: reference
- from VOD function
- from TB and Neural Network

Validation

Different wavelengths :

- Penetration depth depends on the wavelength
- L, C very sensitive to vegetation water content
- X, K bands ~ optical

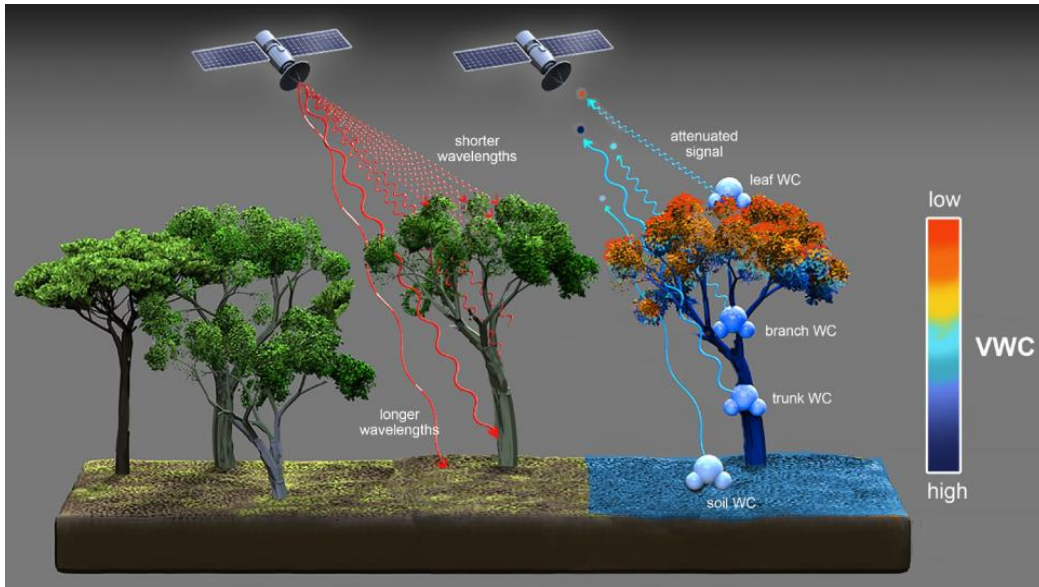
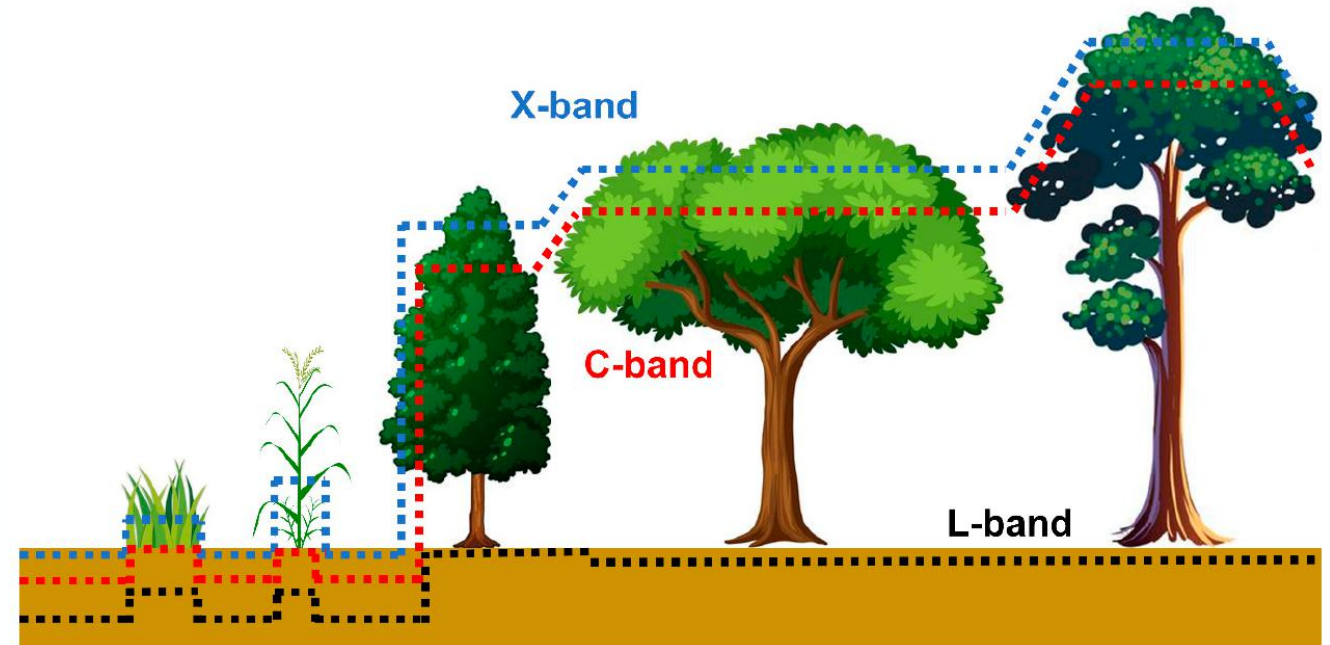


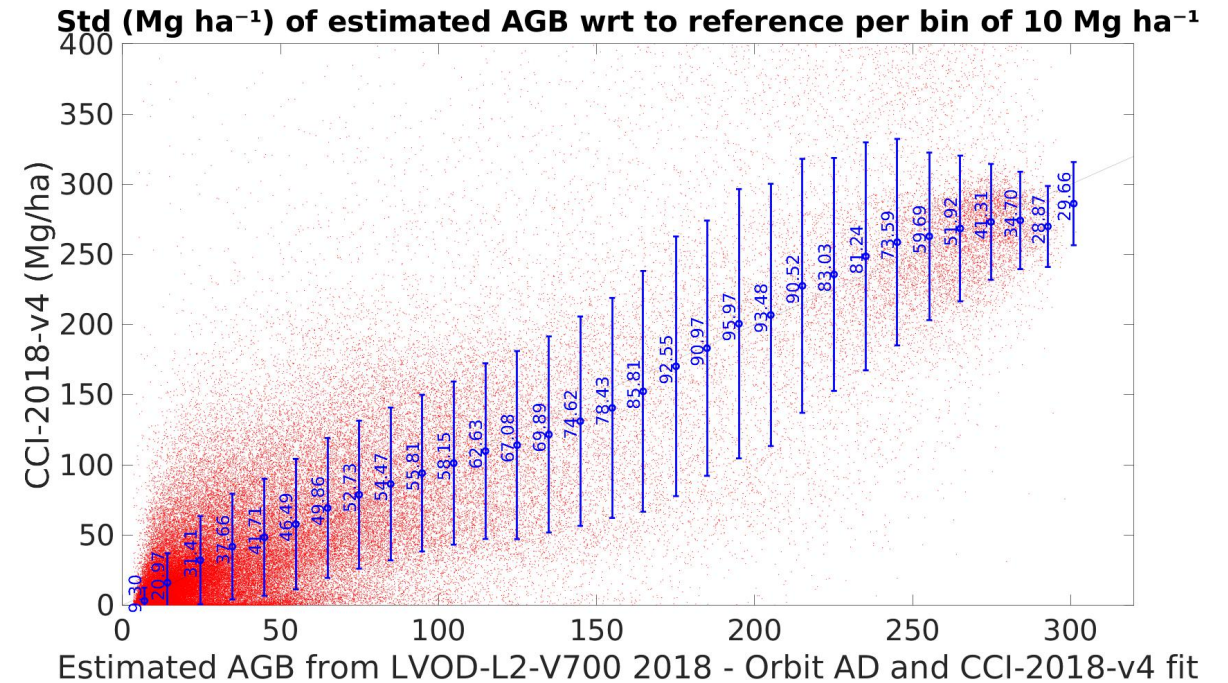
figure ©Konings et al. 2021



Frappart et al., 2020, Remote Sensing

Validation : challenging tasks

- We can estimate the uncertainties of satellite sensor through the model
- How to validate the VOD, which is modeling/radiative parameter ?
at 25 km ...
 - Use different AGB (Radar) for evaluation that have their own uncertainties
 - Use field compaigns: tropirad (french Guyana) very local



Validation

Strategy: use of different Above Ground Biomass estimates

Référence	Coverage	Spatial resol.	Temporal resol.	Remarks
Santoro 2021	Global	100m	2010-2017-2018-2019-2020	2019 And 2020 almost ready
Xu 2021	Global	10km	2000 to 2019	-
Avitabile 2016	Global	1km	2010	-
Saatchi 2020	Global	100m	2019-2020-2021	No yet available
Ometto 2014	Brazil	100m	2016	-

Way forward

I. OPTICAL

- Optical datacube
- Validation for Leaf Water Content

II. MICROWAVE

- Improve the τ and ω (scattering in the vegetation layer):
 - Consider various species (geometry)
 - holes in the forest
- Above Ground Biomass estimates from passive microwaves
 - Use of Tree height as the reference
 - Estimates from Neural Network: combine AMSRE+SMOS
 - Dataset available www.catds.fr
- next year Synergies between Optical/Microwave : time series analyses
- Define a set up for validation: future campaign/site

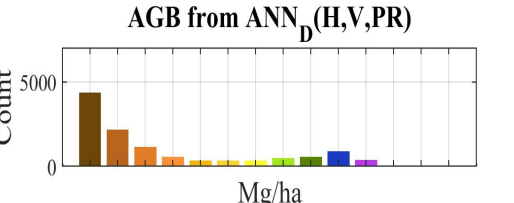
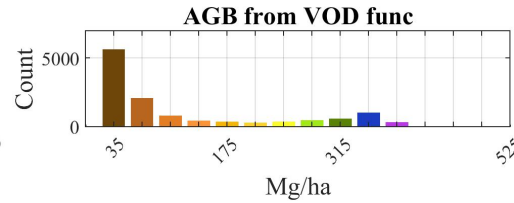
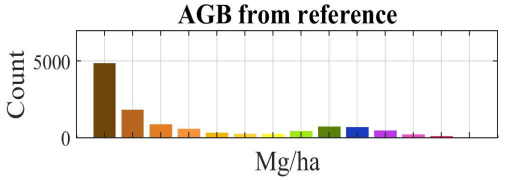
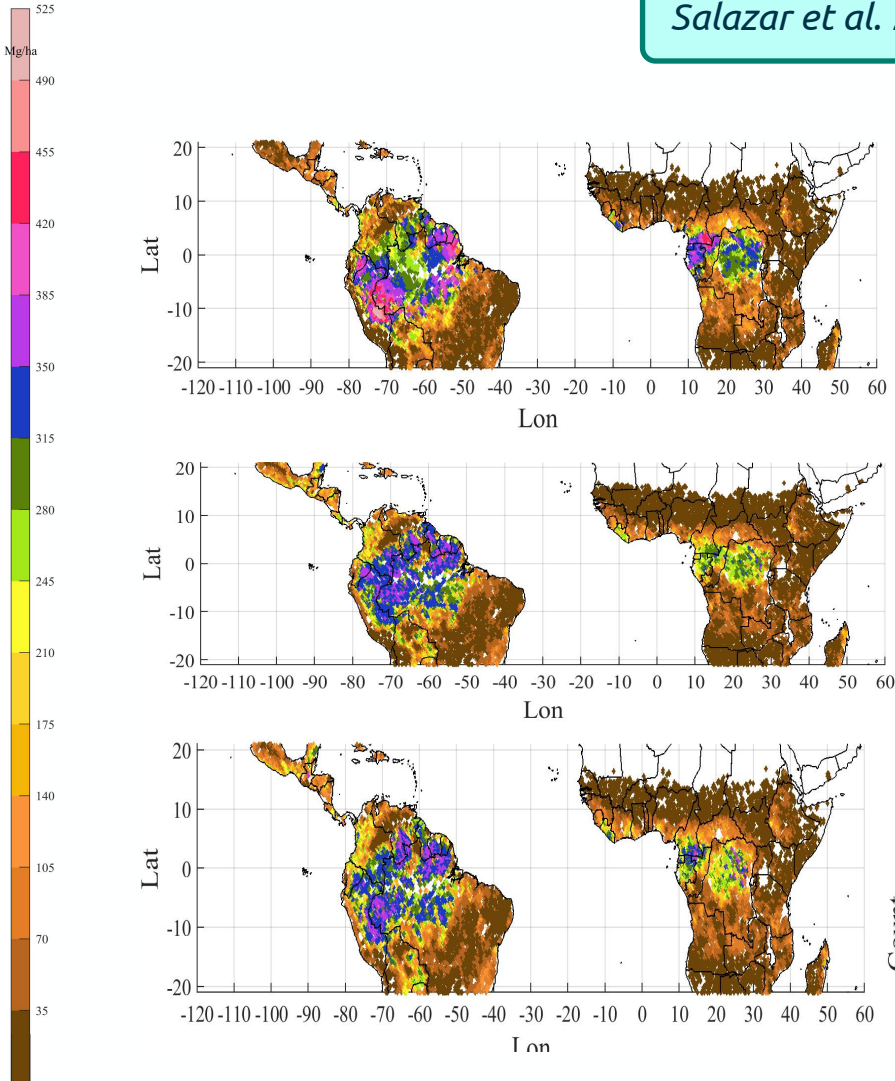
Thanks for your attention

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<https://osmose.magellium.com/>



Salazar et al. 2023, accepted Journal of Selected Topics in Applied earth observations and Remote sensing



- CCI Biomass 2018: reference

- from VOD function

- from TB and Neural Network

ANN with different configurations inputs

- SMOS : TB V/H, Pol. Ratio
- SMOS : TB, Emissivity, Pol. Ratio
- SMOS : TB H, VOD, Pol. Ratio

I.b. OPTICAL: Leaf Water Content

*Cab: chlorophyll concentration
*Cdm: dry matter content

	Variable	Minimum	Maximum	Mode	Std	Nb_Class
Canopy	LAI	0.0	15.0	2.0	3.0	6
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Improvements for soil background: considering the open soil reflectance database (e.g., OSSL)

Primary parameters using for PROSAIL

$$NDWI_{1240} = \frac{NIR_{860} - SWIR_{1240}}{NIR_{860} + SWIR_{1240}}$$

$$NDWI_{1640} = \frac{NIR_{860} - SWIR_{1640}}{NIR_{860} + SWIR_{1640}}$$

$$NDWI_{2130} = \frac{NIR_{860} - SWIR_{2130}}{NIR_{860} + SWIR_{2130}}$$

Inclusions of optical indices: to investigate the enhancements of these indices for CWC retrievals

Compare different band combinations for CWC retrievals

Extinction Coefficient

$$\kappa_{ep}(\text{freq}) = \frac{4\pi}{k_0 \cos \theta} \sum_{j=1}^n \rho_j \text{Im} \left\{ \left\langle f_{pp}^{(j)}(\hat{i}^-, \hat{i}^-, \text{freq}) \right\rangle \right\}$$

where :

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ρ_j – density of j th type of vegetation constituents

$f_{pp}^{(j)}(\hat{i}^-, \hat{i}^-, \text{freq})$ – forward scattering amplitude - E_s/E_i

$\langle \rangle$ – average based on plant component orientation PDF

Scattering Coefficient

$$\kappa_{sp}(\text{freq}) = \int_{4\pi} d\Omega_s \sum_{q=h,v} \sum_{j=1}^n \rho_j \left\langle \left| f_{pq}^{(j)}(\theta_s, \varphi_s, \theta_i, \varphi_i; \text{freq}) \right|^2 \right\rangle$$

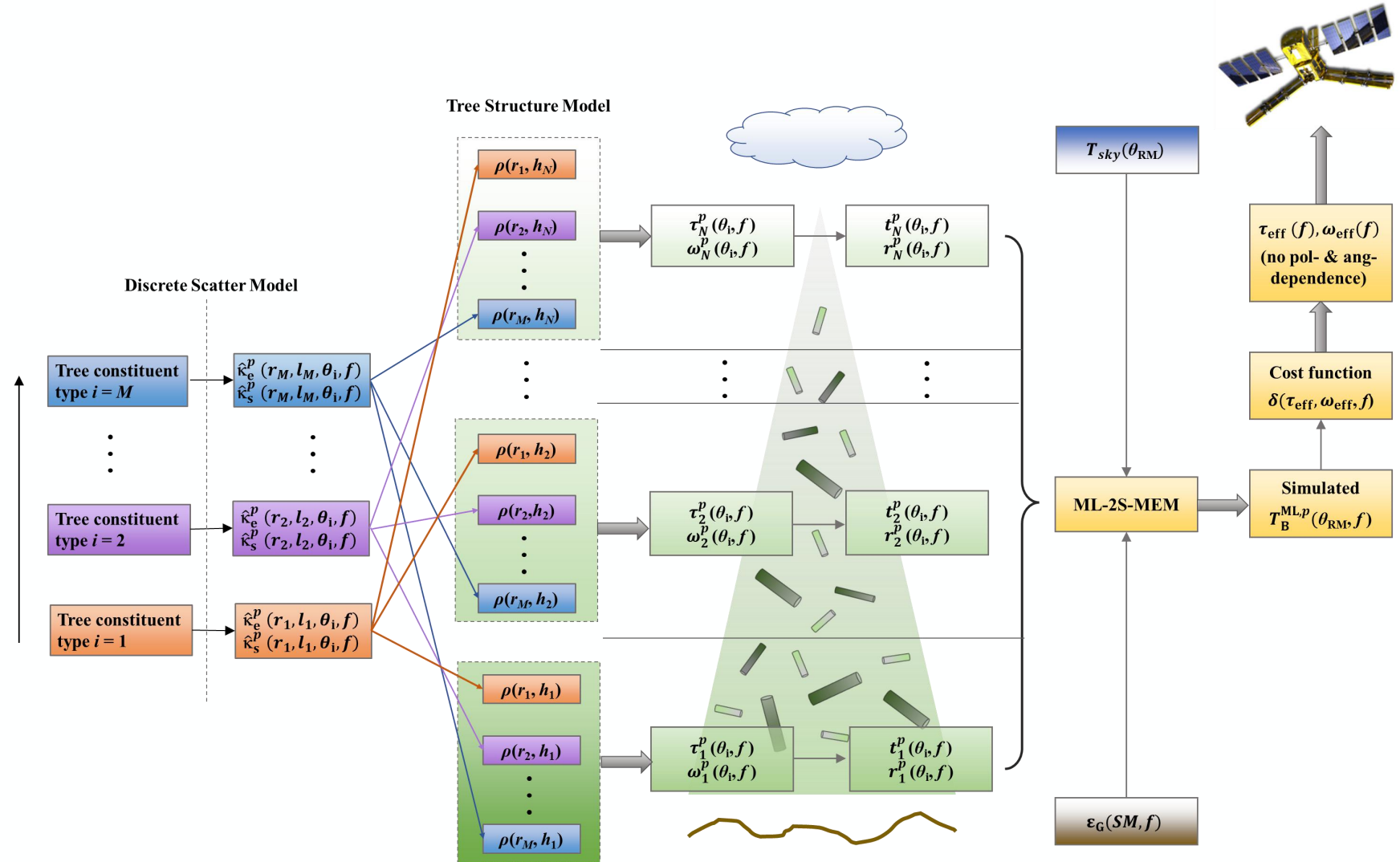
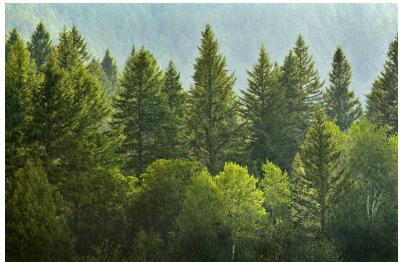
where Ω_s - solid angle over the sphere

$|f_{pq}^{(j)}(\theta_s, \varphi_s, \theta_i, \varphi_i; \text{freq})|$ - scattering amplitude with (θ_i, φ_i)

incident angle and (θ_s, φ_s) scattering angle

Albedo

$$\omega(\text{freq}) = \kappa_{sp}(\text{freq}) / \kappa_{ep}(\text{freq})$$

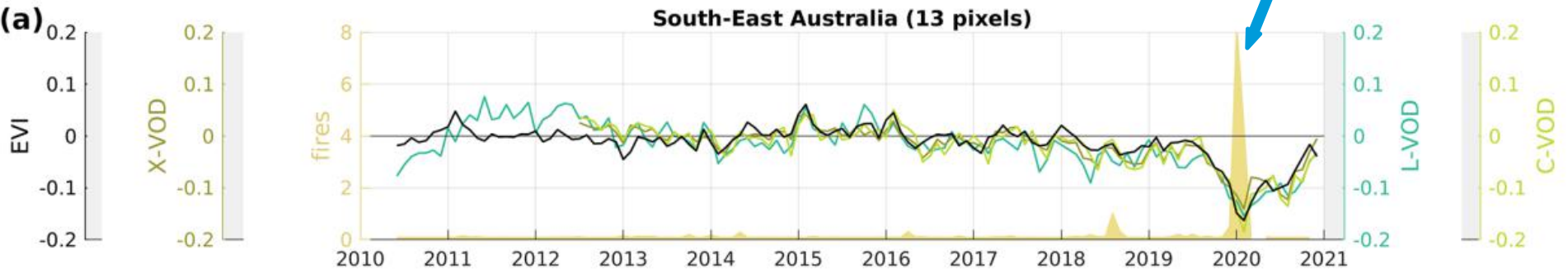


Bousquet et al. 2022

• Australia : dry Vegeation



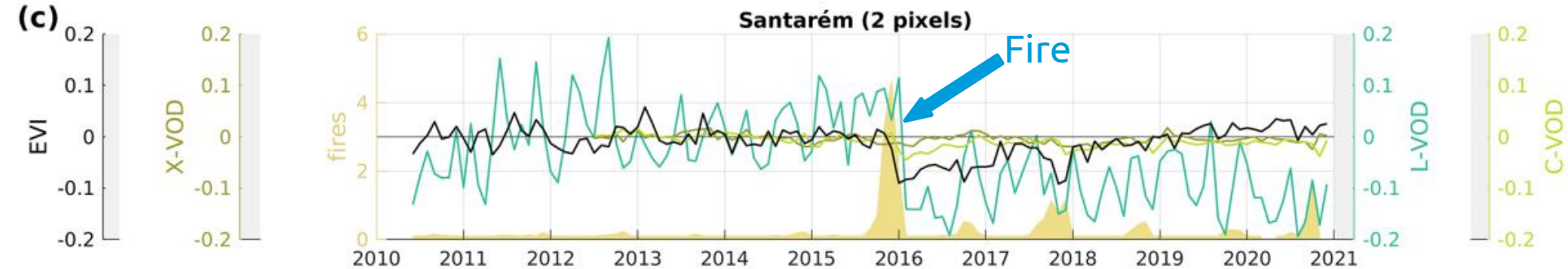
EVI, VOD : same trend



• Amazonia : wet Forest



Post feux : negative anomalies SMOS VOD



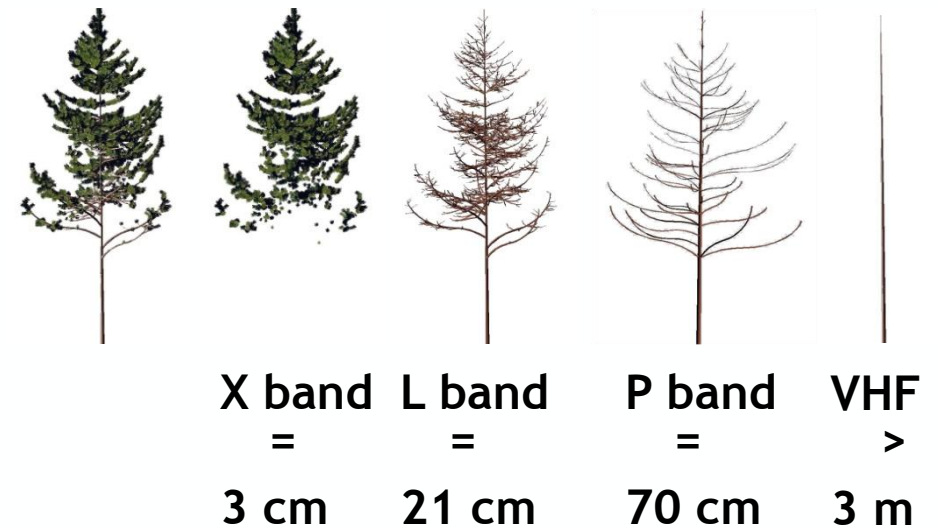
MICROWAVE : Estimate the Above Ground Biomass

1. Use of a radiative transfer model

VOD : Vegetation Optical Depth au nadir, τ

$$\gamma = e^{\frac{-\tau}{\cos \theta}}$$

- Not a geophysical parameter
Difficult to validate and to measure in-situ



*Vegetation «seen» at various frequencies
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Forest-hole correction

$$\beta \equiv \frac{\text{area of "forest holes"}}{\text{"forested area"}}$$

