L-band observations from space: new observations linking the Water and Carbon cycles

N. Rodriguez-Fernandez[1], A. Mialon[1], E. Bousquet[1], P. Richaume[1], J.C. Salazar-Neira[1], G. Pique[1], S. Boitard[1], A. Bouvet[1], S. Mermoz[3], T. Le Toan[1], Y. Kerr[1]

(1) CESBIO, Toulouse, France
(2) CEREMA, Toulouse
(3) Globeo, Toulouse, France

ESA 4th Carbon from Space 2022

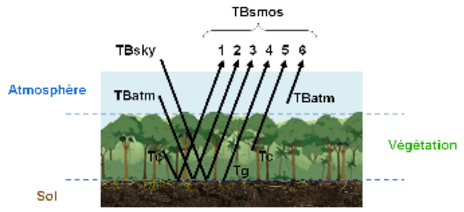
SMOS soil moisture and vegetation optical depth

- **Passive microwaves sensors measure the thermal emission from the Earth, which at these frequencies depends mainly of soil moisture and temperature**
- **The radiation is affected by the vegetation water content and structure creating a vegetation optical depth (VOD)**

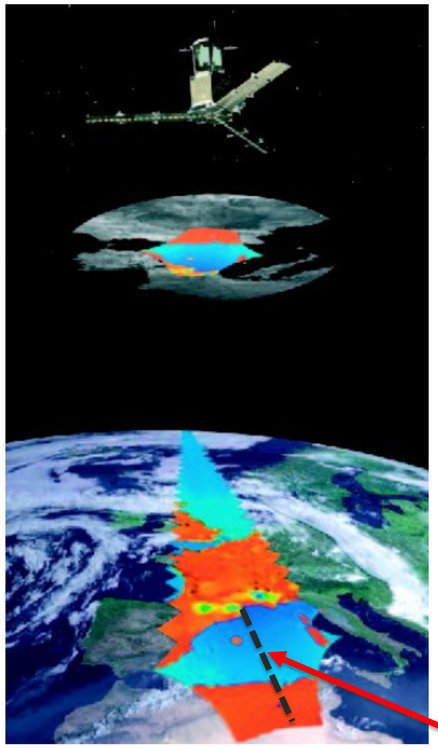
The Vegetation Optical Depth (τ), is frequency dependent

X band λ= 3 cm | L band λ= 21 cm | P band λ= 70 cm | VHF λ>3 m

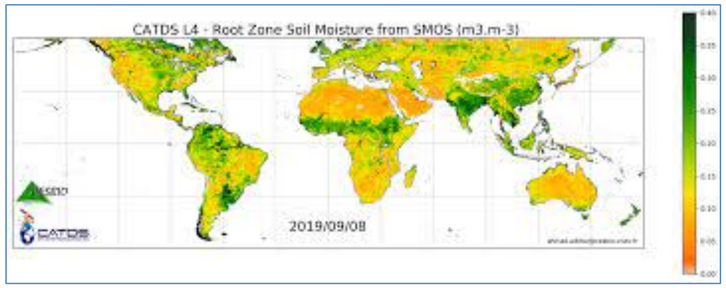
©Biomass, Thuy Le Toan

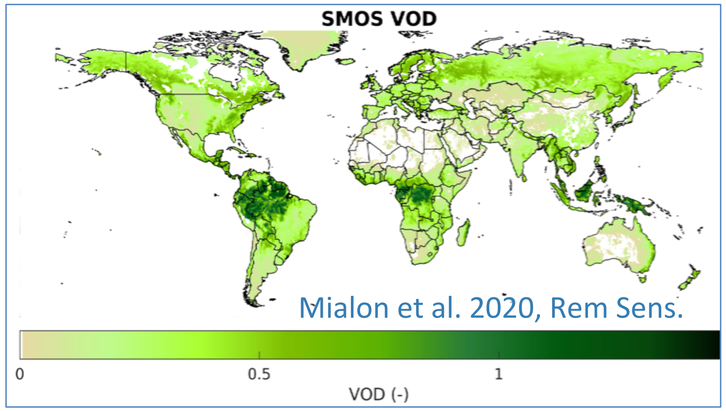


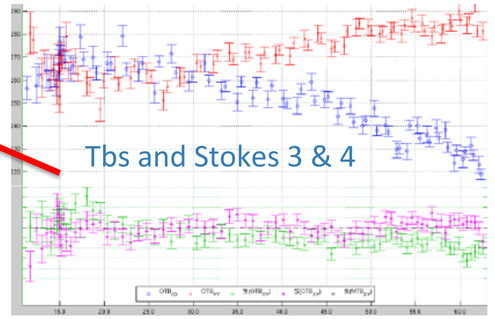
Kerr et al. (2012. TGARS)



Multi-incidence angle observations

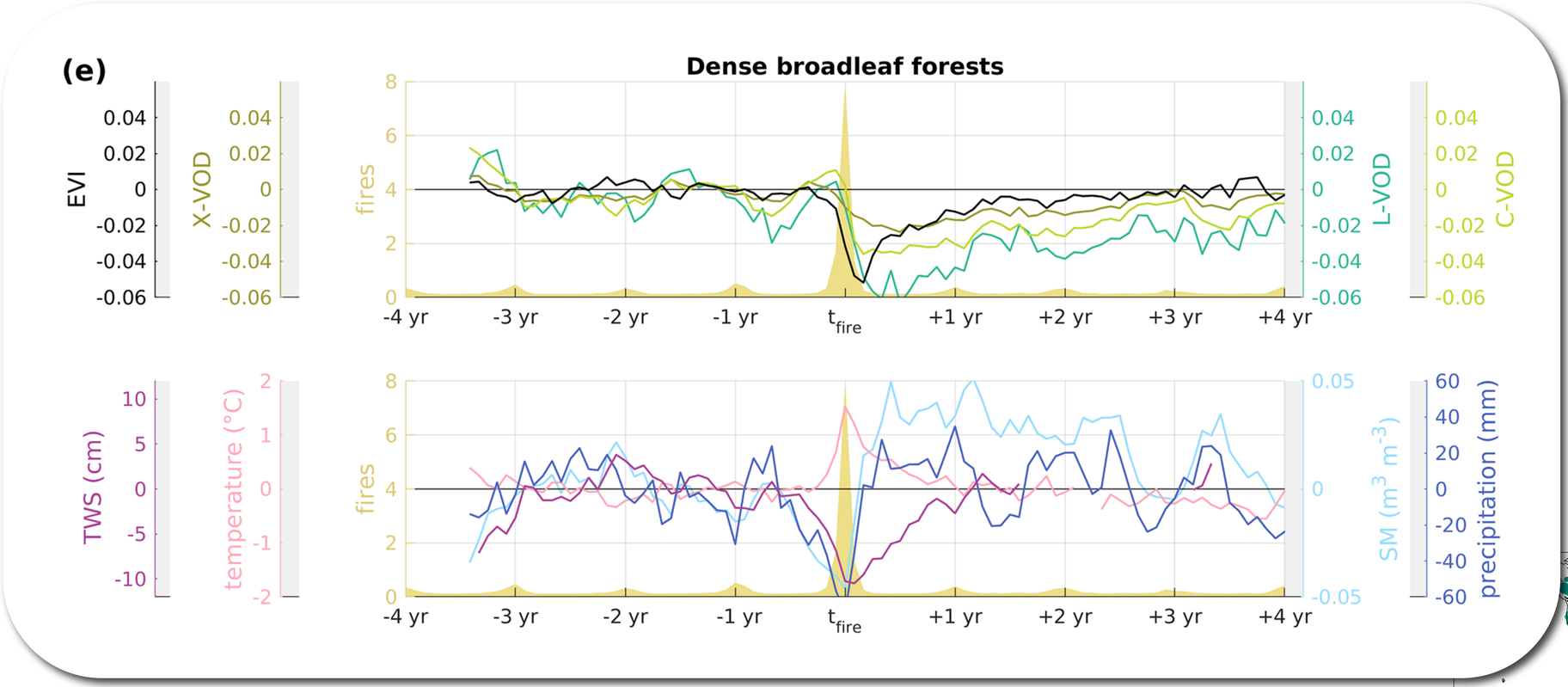




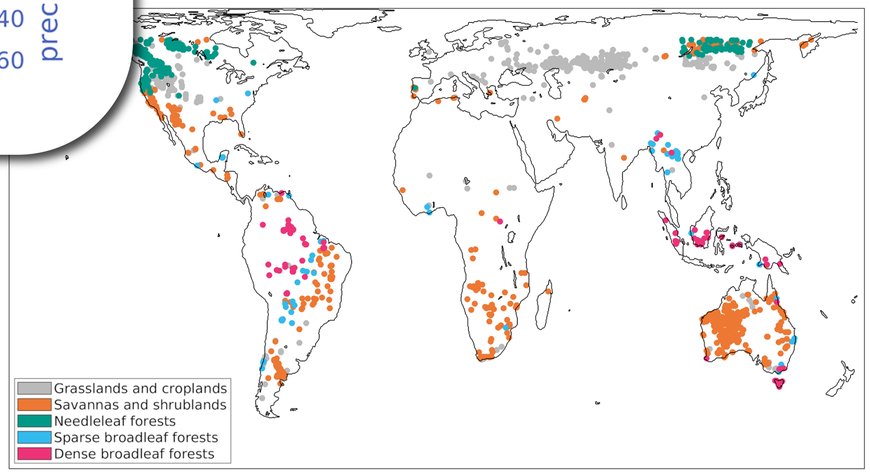


10º Incidence angle 60º

The long post-fire recovery of the equatorial forest



Bousquet et al. (2022, Biogeosci.)

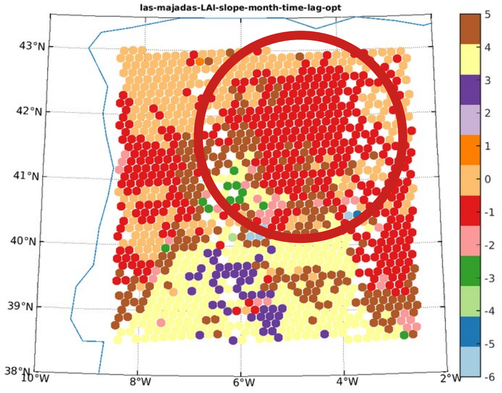


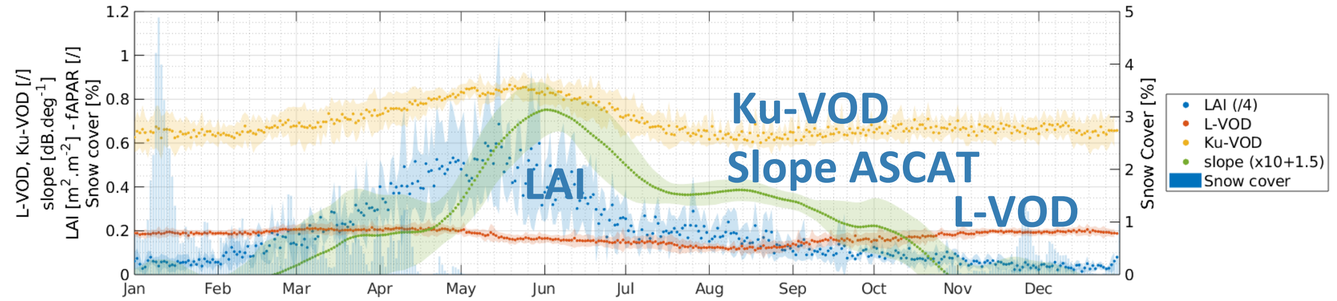
LAI, SMOS L-VOD, AMSR2 Ku-VOD, ASCAT slope

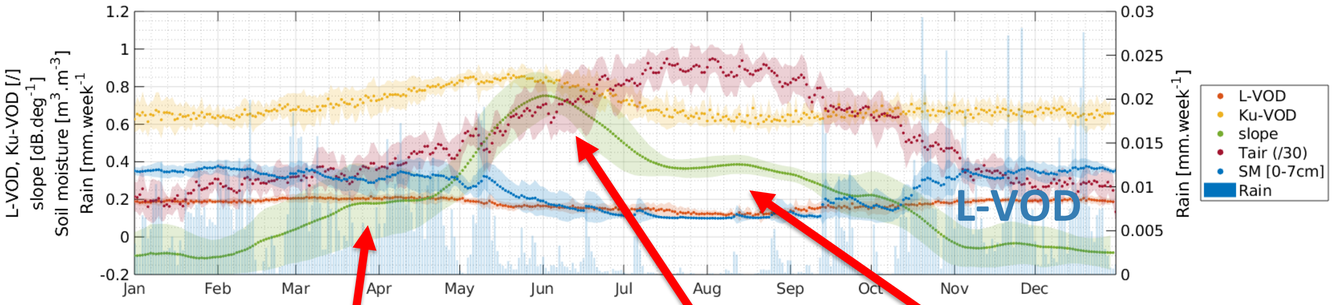
Land Carbon Constellation project esa

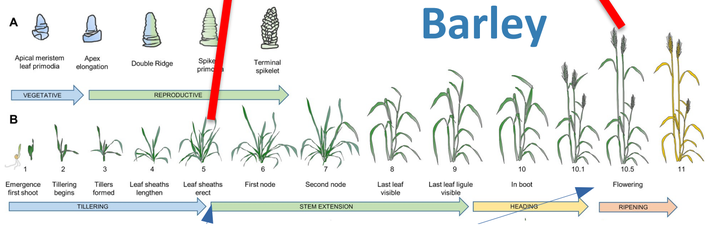
LM 103 px > 90% croplands

See **Segarra et al., 2020** for wheat phenological stages in the region









Wheat, Barley

Rye, Maize, artifact ?

Crops	*Relative surface*
Barley	12
Wheat	9
Rye	9
Peas	4.7
Natural veg	3.4
Grasslands	3
Maize	2.5
…	

- LAI cycle shorter than Ku-VOD and ASCAT-slope
- ASCAT-slope second peak at the end of the summer…
- Low amplitude cycle of L-VOD. Could be more related to water availability than to crops cycles

Pique et al. (in prep)

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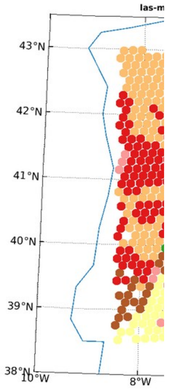
LAI, SMOS L-VOD, AMSR2 K-VOD, ASCAT slope

Land Carbon Constellation

esa



Bar
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Rye
Pea
Natu
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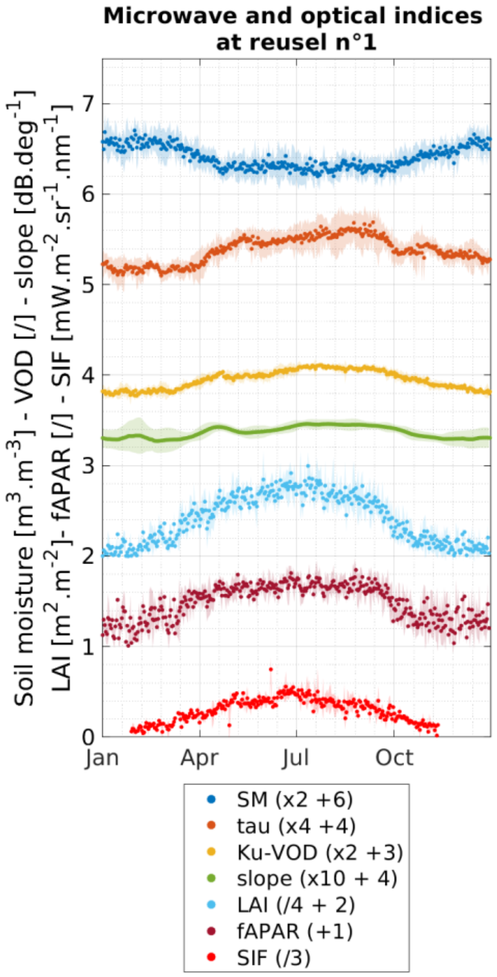

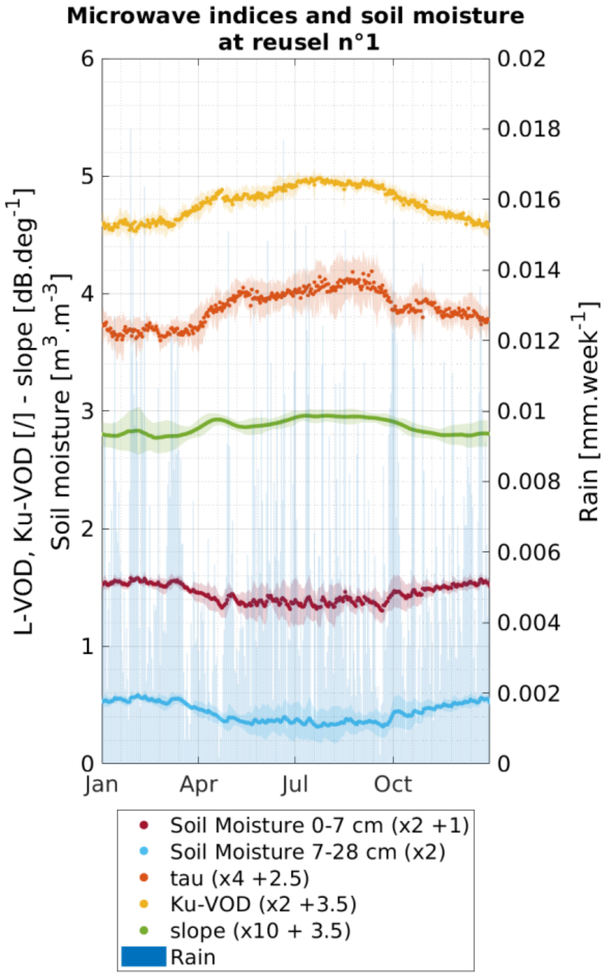

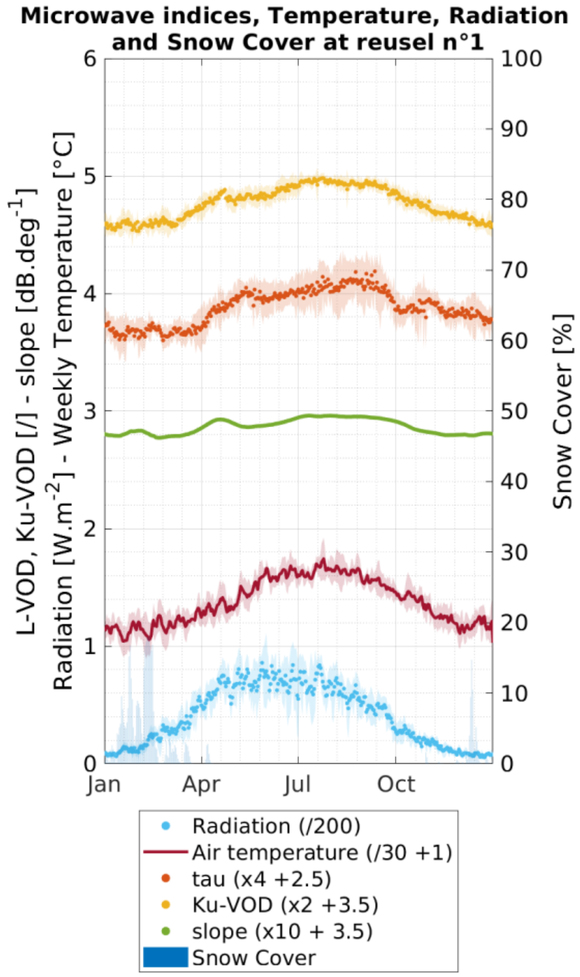

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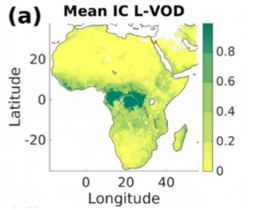
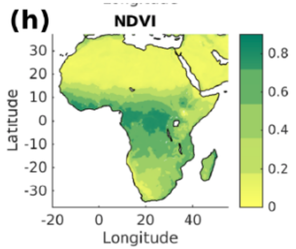
High sensitivity of L-VOD to AGB

SMOS + Veg
esa stse
support to science element

2011-2012 average

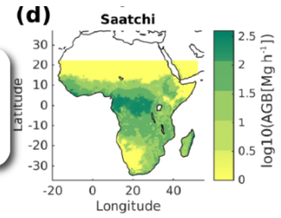
SMOS L-VOD
INRA-CESBIO (IC)
Fernandez-Moran et al.,
Rem. Sensing 2017

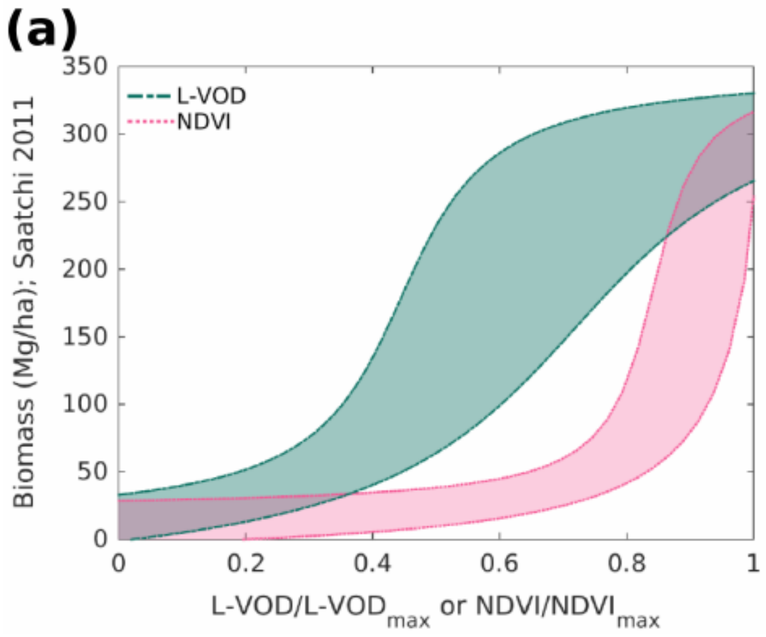


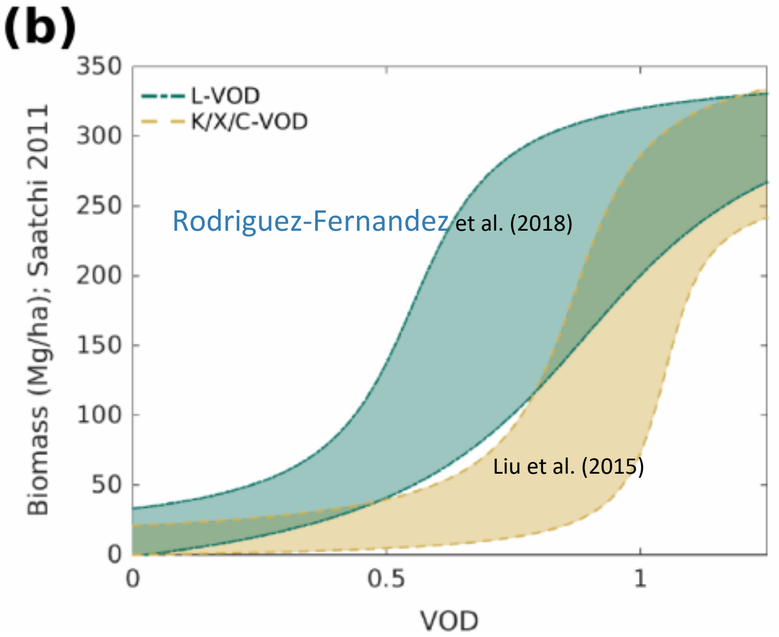


MODIS

Lidar, C-band
SAR, in situ
plots
Circa 2000







Rodriguez-Fernandez et al. (2018, Biogeosciences)

$$AGB = \frac{a}{(1 + exp(-b\,(vod - c)))} + d,$$

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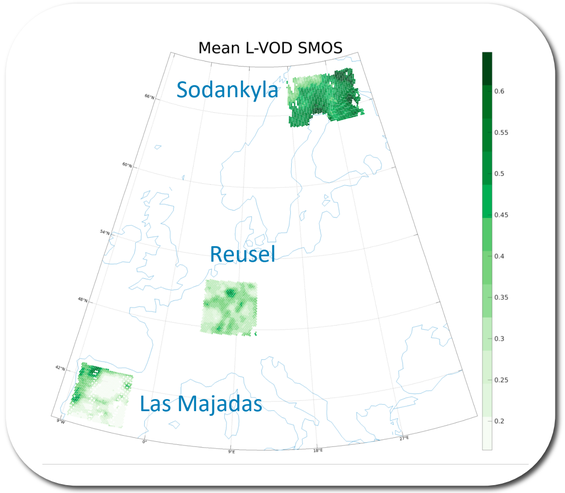
Microwave data versus ESA CCI Biomass

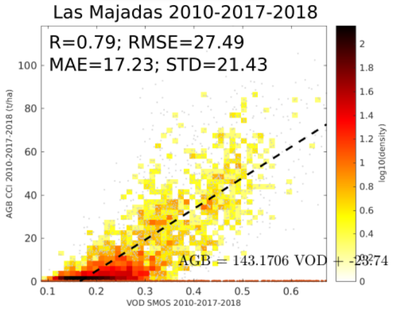
Land Carbon Constellation project esa

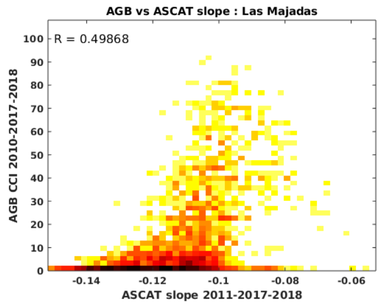


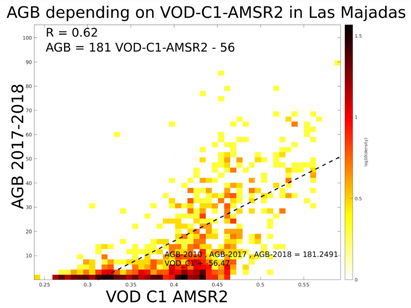
Community Session-Synergistic use of observations for constraining the carbon cycle across scales

Scholze et al.
Steele-Dunne et al.
Lemmetyinen et al.
Kaminski et al.

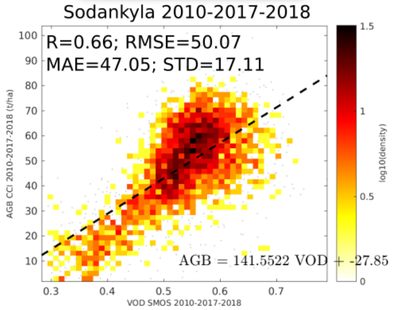
Spain

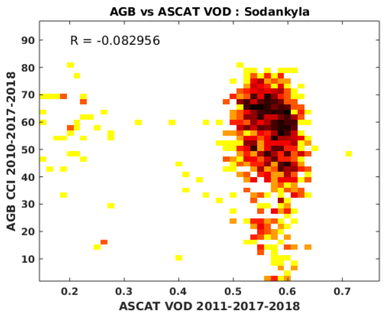


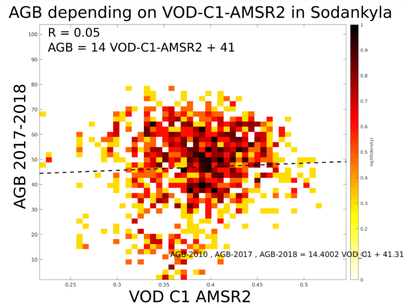




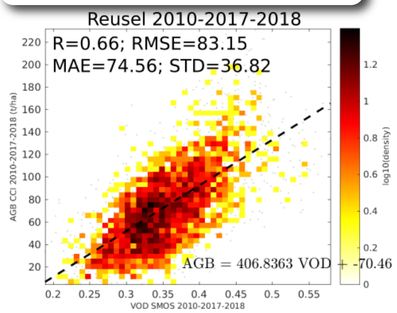
Finland

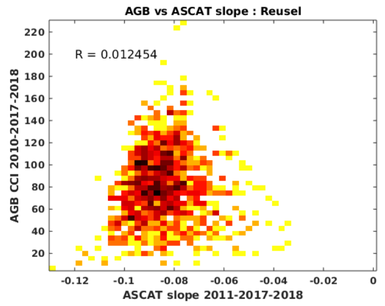


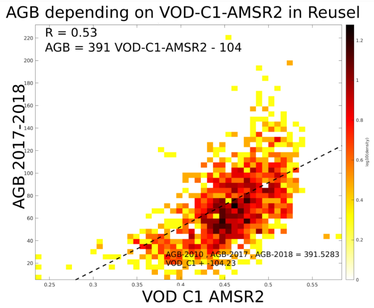




Netherlands







AGB vs SMOS L-VOD

AGB vs ASCAT slope

AGB vs AMSR2 C1-VOD

Rodriguez-Fernandez et al. (2022, IGARSS)

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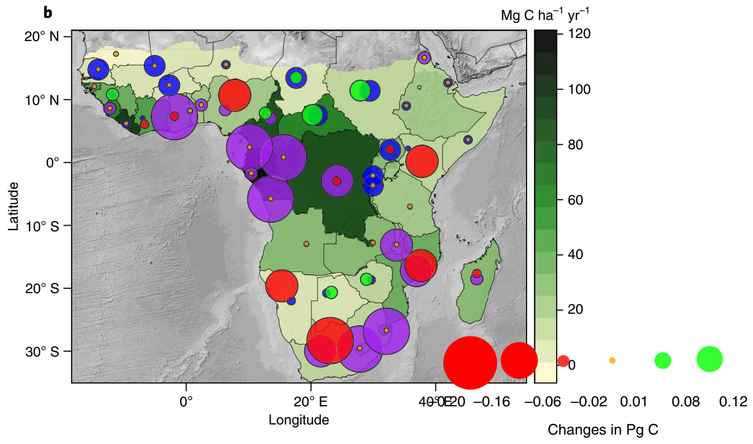
Using a spatial correlation to infer the temporal behavior…

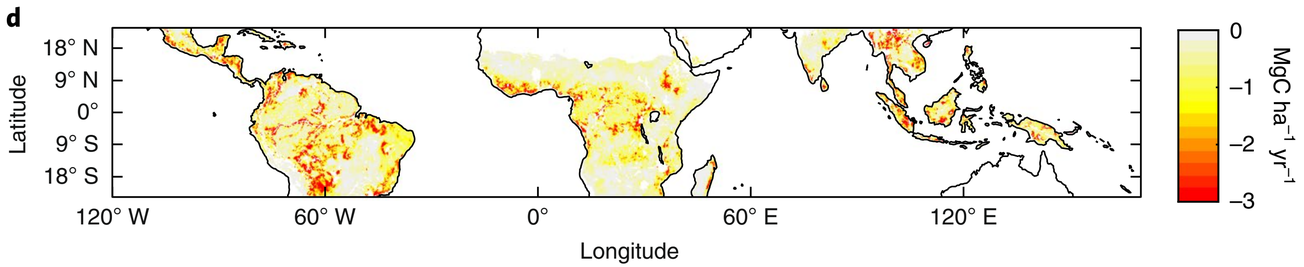
Brandt et al. , 2018, *Nature Ecology Evolution*



Net C changes (losses):
- drylands: −0.05 Pg /yr
- Humid areas −0.02 Pg /yr

Drylands showed a share of the total pool of African carbon stocks of 20% in L-VOD but only 6% in LPJ-GUESS and 8% in ORCHIDEE-MICT

C losses 2010-2016, Fan et al., 2019*, Nature Plants*

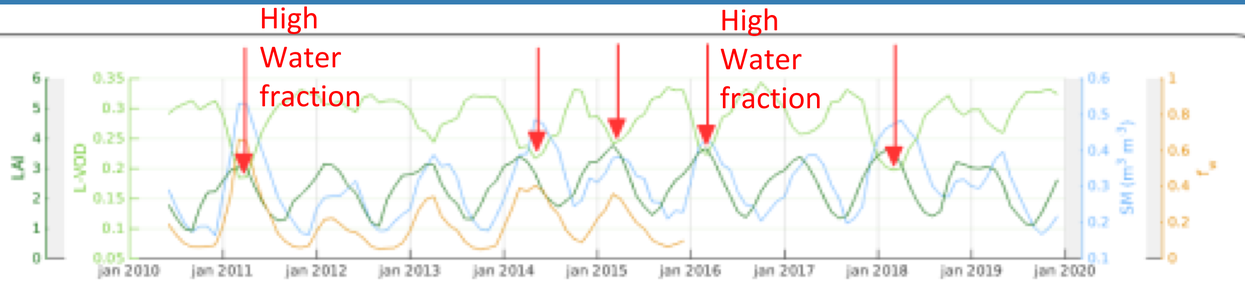


The aboveground carbon changes estimated by VOD in the tropical region during 2010-2016 indicate the tropical region acts as a net carbon source of 0.11 Pg/yr during 2010-2016. The declines in tropical aboveground carbon were found mainly in eastern America, African drylands and Indonesia.

Brandt et al. 2018, **Satellite-Observed Major Greening and Biomass Increase in South China Karst During Recent Decade,** *Earth's future.*
Brandt et al. 2018, **Satellite passive microwaves reveal recent climate-induced carbon losses in African drylands**, *Nature Ecology and Evolution*
Bastos et al. 2018, **Impact of the 2015/2016 El Niño on the terrestrial carbon cycle constrained by bottom-up and top-down approaches,** *Phil. Trans. of the Royal Society B*
Fan et al. 2019, **Satellite-observed pantropical carbon dynamics**, Nature Plants
…
Wigneron et al., 2020, **Tropical forests did not recover from the strong 2015–2016 El Niño event,** Science Advances
Qin et al. 2021, **Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon,** *Nature Climate Change*
…

VOD and AGB: Effect of inundated areas

Time series over seasonally inundated areas:
anomalous decrease of L-VOD during floods.



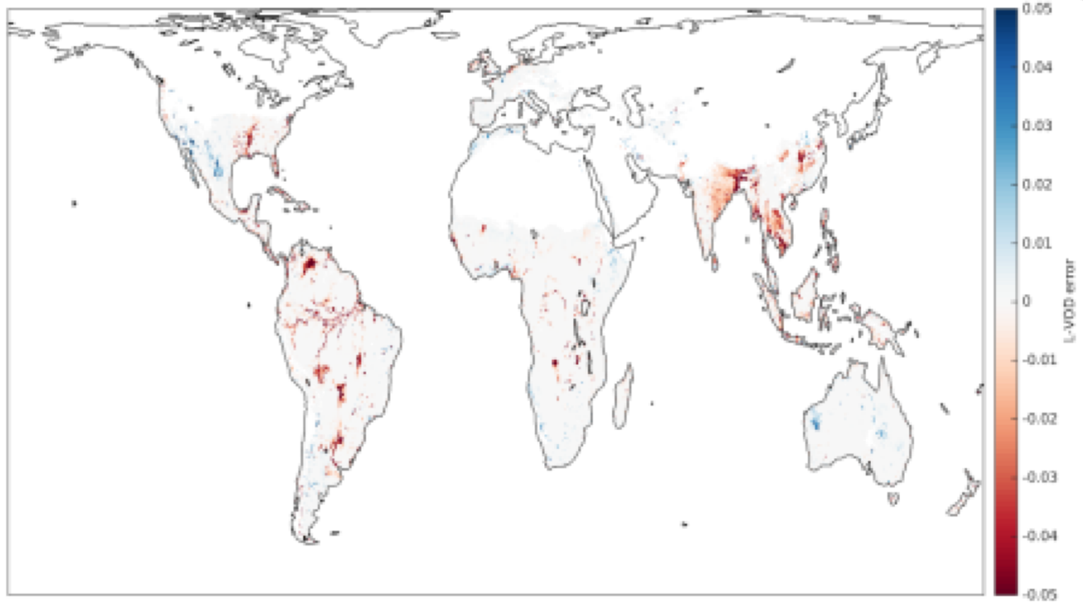
Time series of LAI, L-VOD, Soil Moisture, and water fraction over the Pantanal wetland (South America).

Modelling experiment in order to understand the impact of dynamic surface water on L-VOD retrieval.

Results :

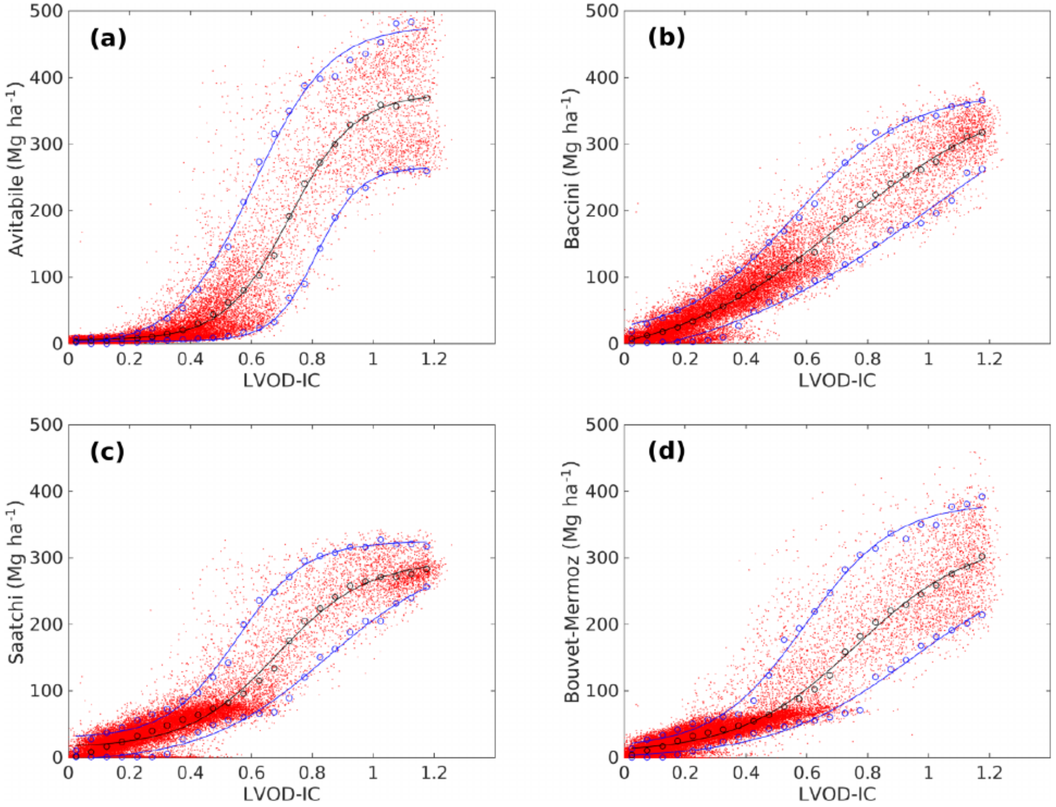
- L-VOD is underestimated during floods, by ~10 % over flooded forests, up to 100 % over flooded grasslands.
- L-VOD/AGB relationship : AGB is also underestimated, by 15/20 Mg ha^{-1} and up to 50 Mg ha^{-1} temporarily.

Bousquet et al. (2021, RSE)



Computation of the yearly mean L-VOD error at the global scale due to floods.

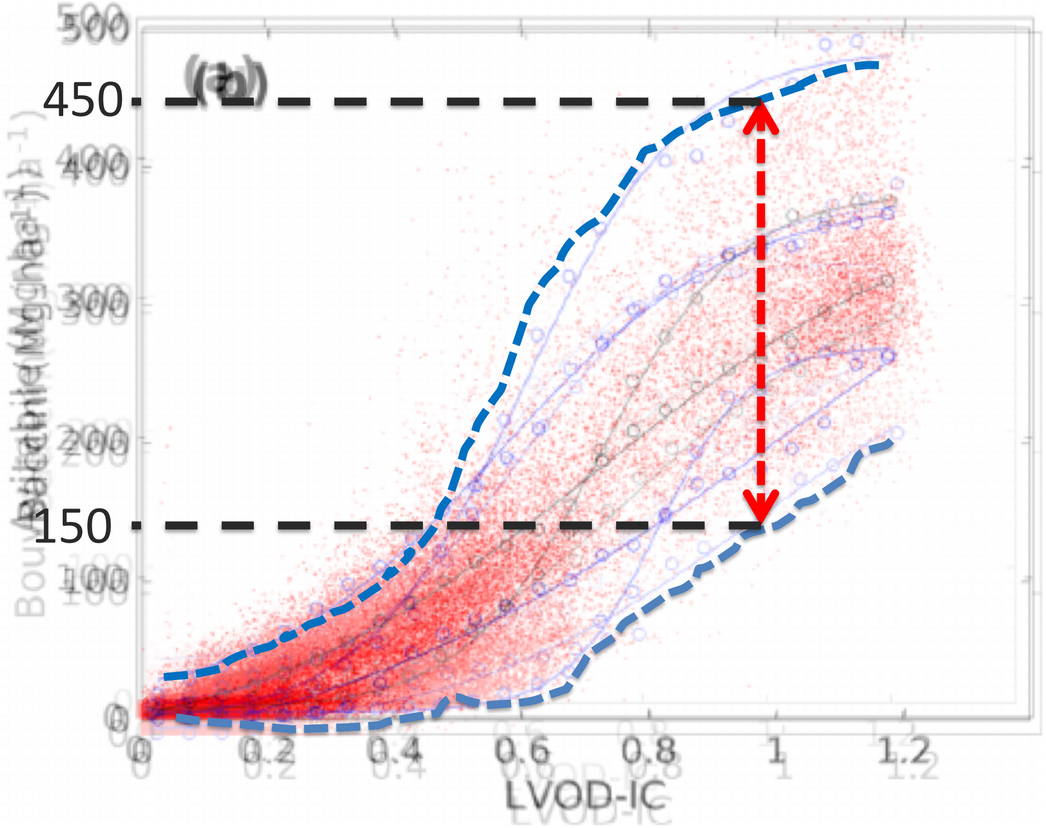
VOD and AGB: uncertainties



Rodriguez-Fernandez et al. (2018, Biogeosciences)

- AGB maps used as reference have many uncertainties, including those using currently available SAR data, which saturates in dense forest
- Which one to chose ?
- How to take into account the large dispersion ?
- What period should be used to compute the relationship ?

VOD and AGB: uncertainties



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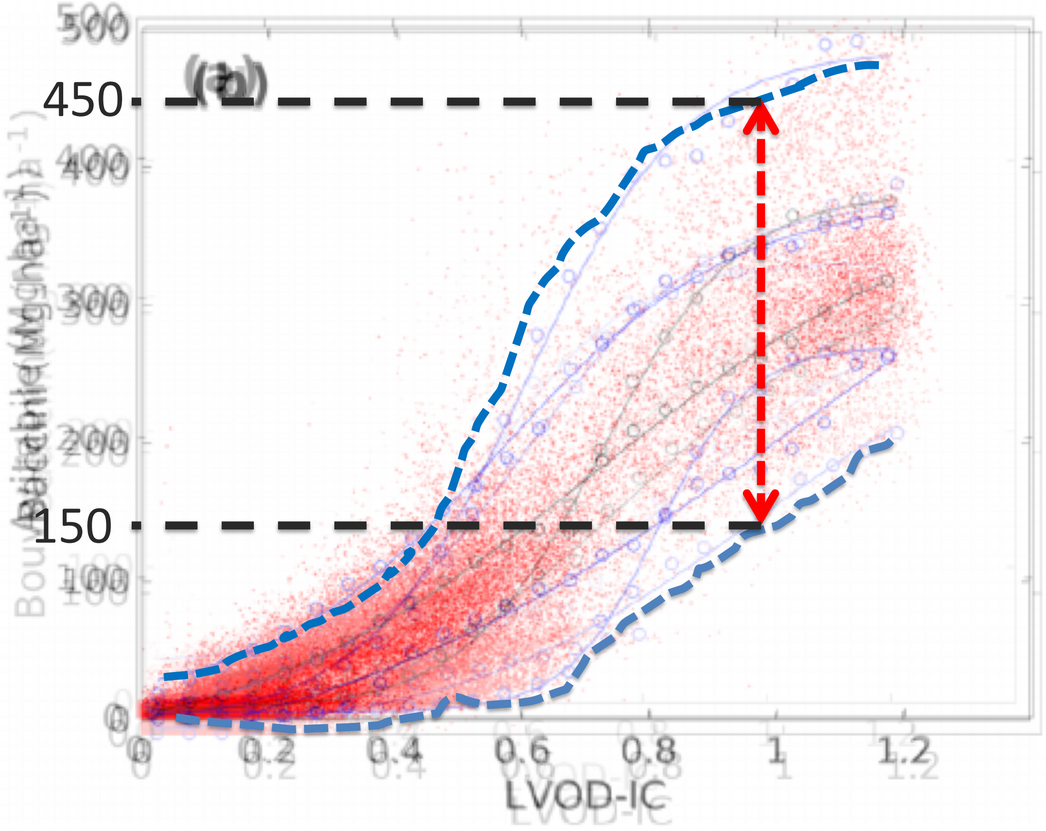
VOD and AGB: uncertainties



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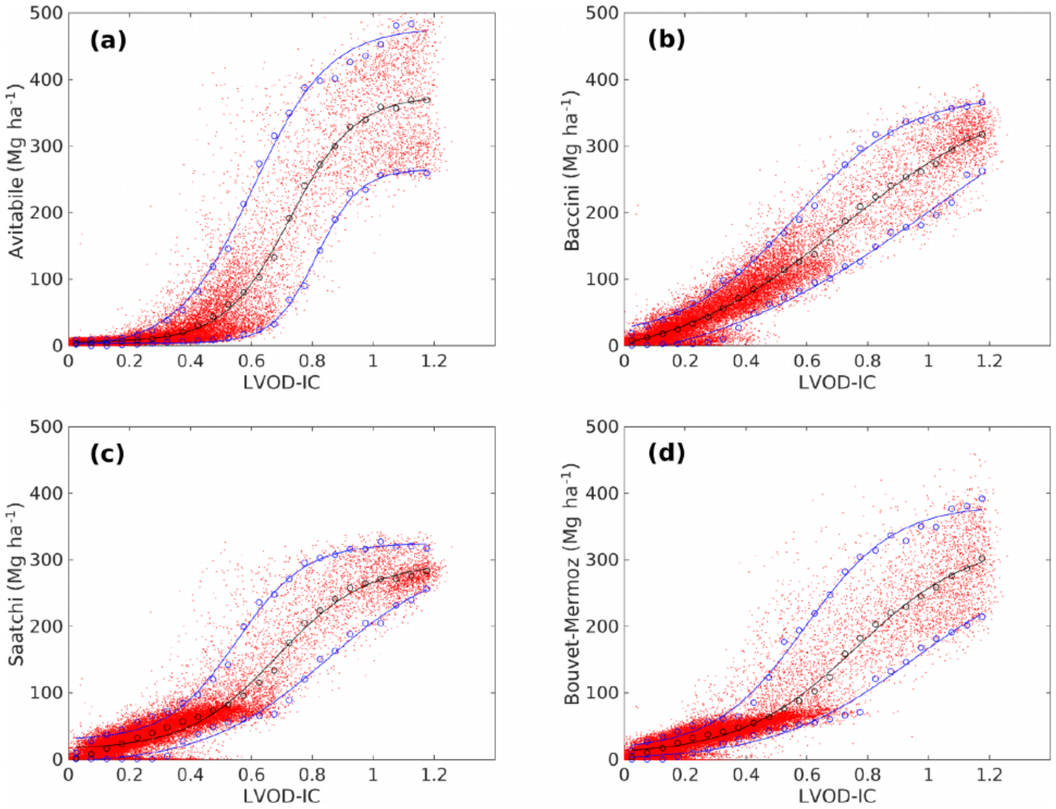
Interannual Variations of Vegetation Optical Depth are Due to Both Water Stress and Biomass Changes

Alexandra G. Konings[1], Nataniel M. Holtzman[1], Krishna Rao[1], Liang Xu[2], and Sassan S. Saatchi[3]

Geophysical Research Letters

RESEARCH LETTER
10.1029/2021GL095267

VOD and AGB: uncertainties



Rodriguez-Fernandez et al. (2018, Biogeosciences)

- AGB maps used as reference have many uncertainties, including those using currently available SAR data, which saturates in dense forest
- Which one to chose ?
- How to take into account the large dispersion ?
- What period should be used to compute the relationship ?

- Yearly AGB maps from VOD maps with respect different recent AGB data sets will be freely distributed by

CATDS
Centre Aval de Traitement des Données SMOS

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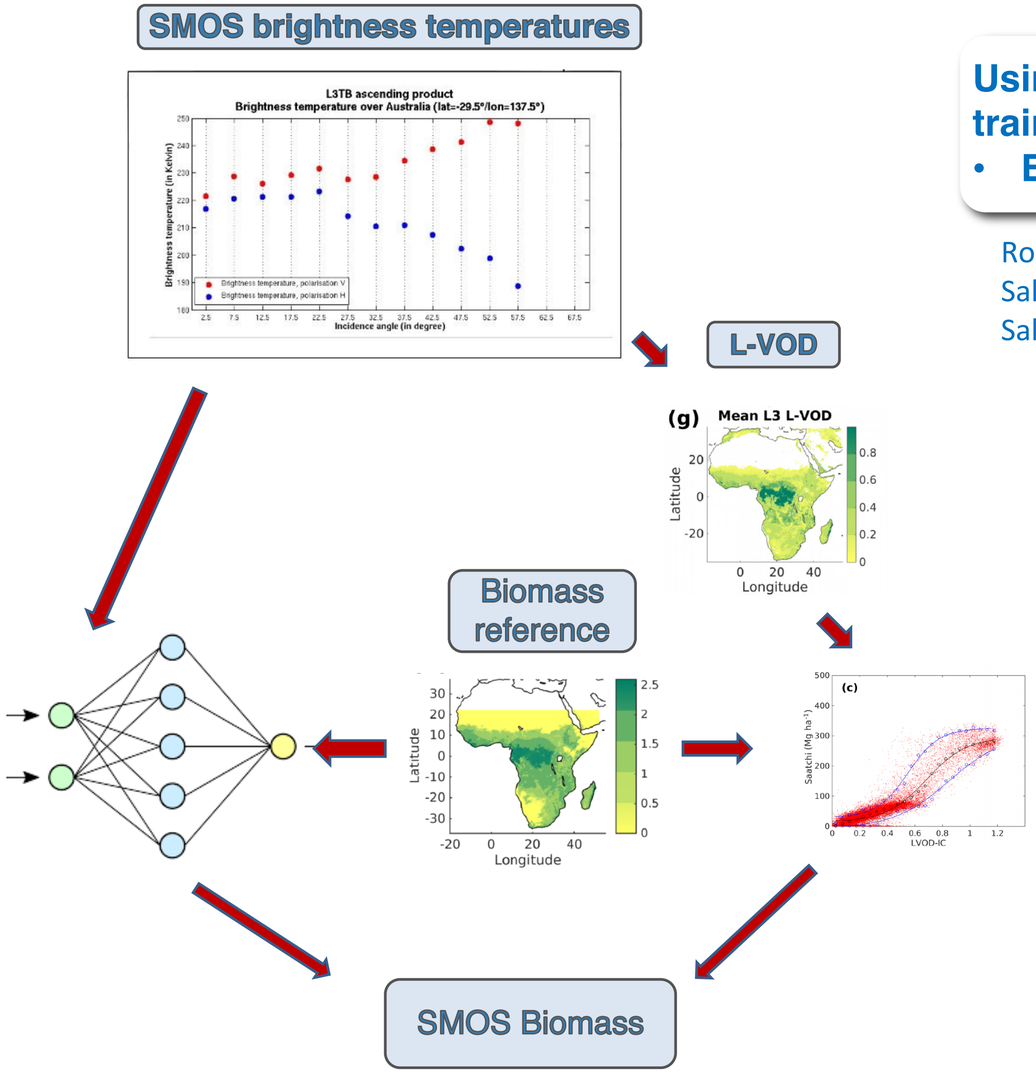
SMOS AGB without VOD



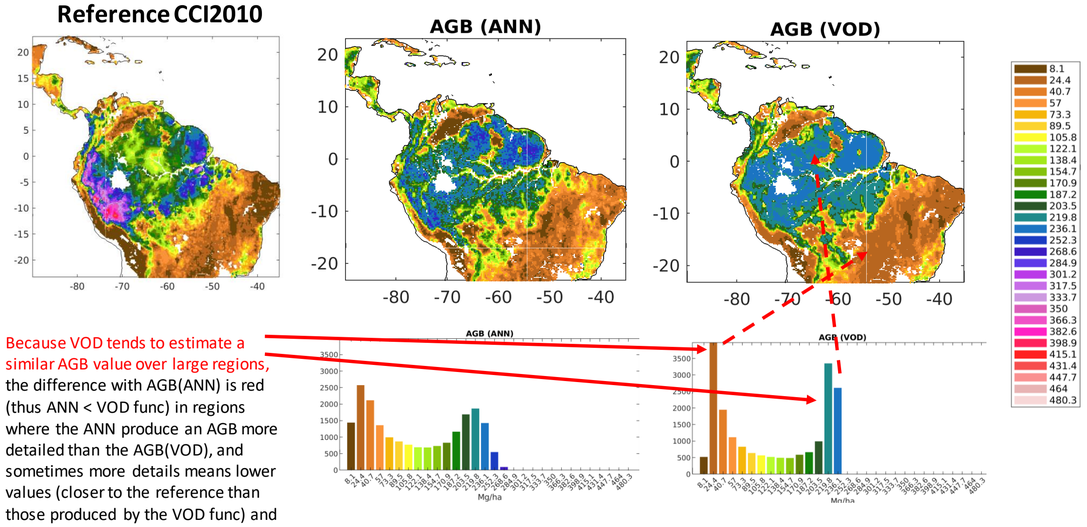
Using several years of AGB for the training simultaneously

- **ESA CCI Biomass**

Rodriguez-Fernandez et al. (2019, IGARSS)
Salazar-Neira et al. (2022, IGARSS)
Salazar-Neira et al. (submitted)

SMOSE
esa PMVOS
CESBIO
GlobEO Global Earth Observation
magellium
WSL
INRAE

Other goal:
Consistent X, C, and L-band VOD using 2-stream



Because VOD tends to estimate a similar AGB value over large regions, the difference with AGB(ANN) is red (thus ANN < VOD func) in regions where the ANN produce an AGB more detailed than the AGB(VOD), and sometimes more details means lower values (closer to the reference than those produced by the VOD func) and thus the red spots

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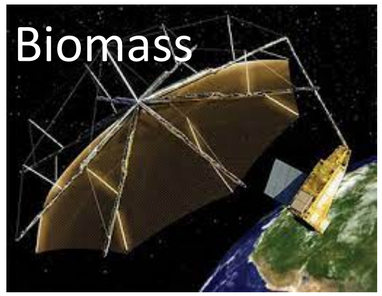
Summary

- **L-band observations allow to link components of both the water and carbon cycles**
- **L-VOD provides complementary information to radar, lidar and optical observations and VOD measured at other wavelengths**
- **Useful for a wide range of applications but …** should be used with care !
- **Future ?**
  - **Biomass P-band SAR** (Le Toan et al. (2011, RSE)
  - **Multi-incidenc angles L-band measurements with increased resolution:**

SMOS-HR (Rodriguez-Fernandez et al. 2022, IGARSS)



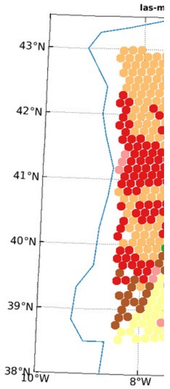
Nemesio.rodriguez@cesbio.cnes.fr

twitter @NemesioRF
@SMOS_satellite

LAI, SMOS L-VOD, AMSR2 K-VOD, ASCAT slope

Land Carbon Constellation

esa



Bar
Whe
Rye
Pea
Natu
Gra
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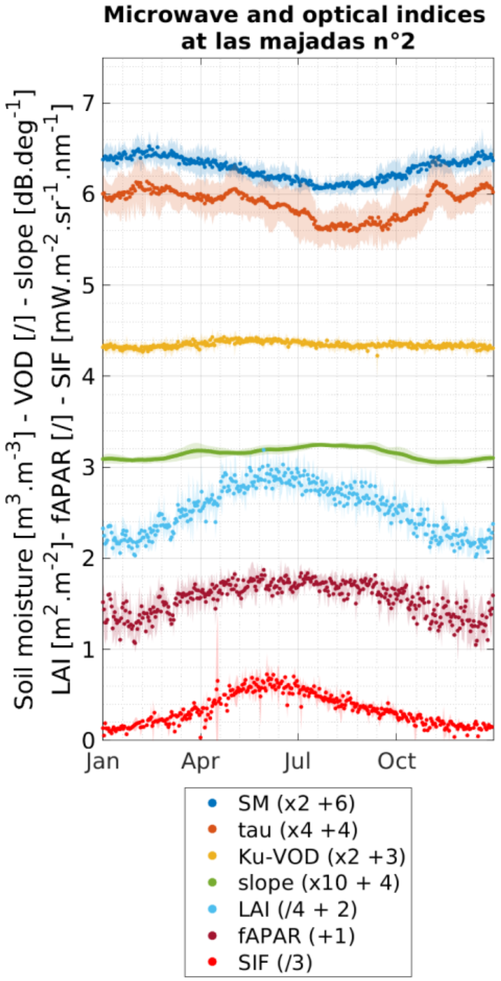

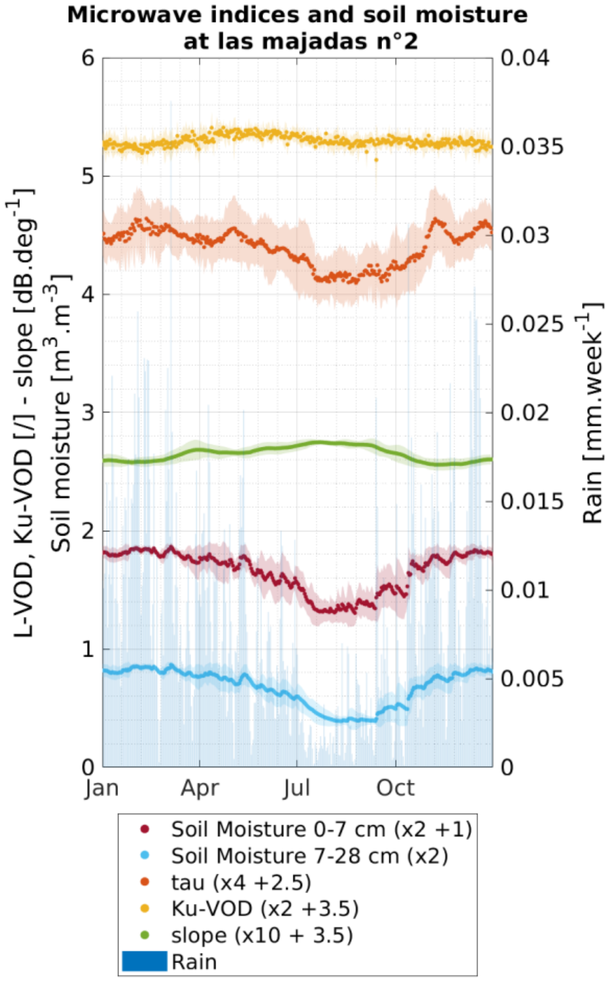

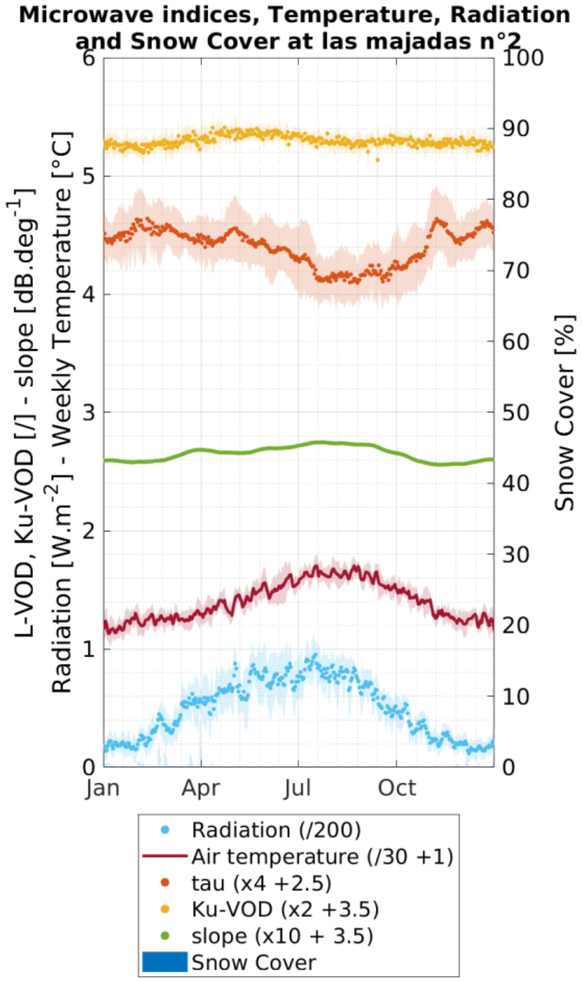

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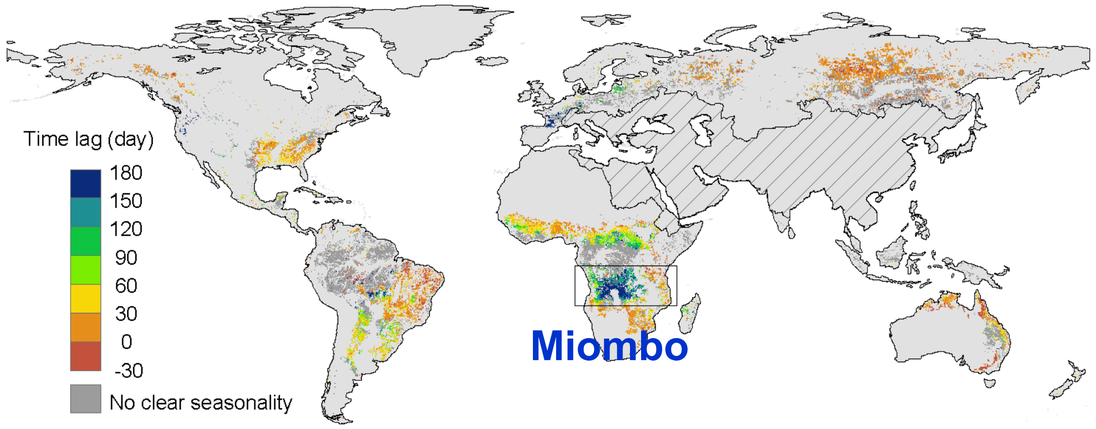
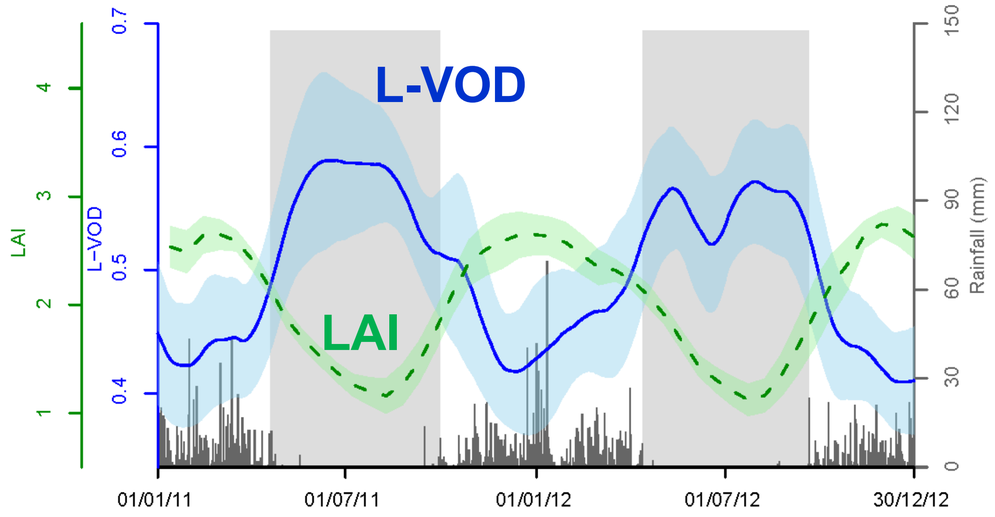
SMOS L-VOD and vegetation water content

Time lag between L-VOD and LAI





Tian et al. (2018, *Nature Eco&Evo)*

- **Different dynamics of L-VOD and LAI : up to 180 days shift in dry Tropical forests such as those in Miombo**
- **L-VOD is linked to vegetation water content**
- **In regions with woody vegetation the information in L-VOD is highly complementary to vegetation indices linked to leaves and more appropriate for herbaceous plants**
- **Trees may access deep soil water and have sophisticated hydraulic strategies**

Interannual Variations of Vegetation Optical Depth are Due to Both Water Stress and Biomass Changes

Alexandra G. Konings[1], Nataniel M. Holtzman[1], Krishna Rao[1], Liang Xu[2], and Sassan S. Saatchi[3]

Geophysical Research Letters

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