Forest emission at L-band: Modeling, applications and the experience of SMOS

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Summary

Forest modeling at L band: motivations, selected approach, comparisons with experimental data.

Application to spaceborne signatures: simplified input data set, calibration of a first order RT model, main outcomes, critical issues.

The experience of SMOS: current 2-parameter retrieval algorithm, results obtained by a 3-parameter algorithm, currently retrieved vegetation optical depth (VOD) and soil moisture (SM) over forests.

Possible active/passive instruments synergy.

Suggestions for future work and experiments.

Modeling: motivations

Science;

Need to create a synthetic data base of forest emission data at L band, since few measurements were available;

Need to get an insight into complex forest issues: multiple scattering, different roles of forest components (trunks, branches, leaves, litter) for a given biomass.

Modeling: selected approach

The model developed at Tor Vergata University adopted the discrete approach, mostly used for radar studies, in the passive version.

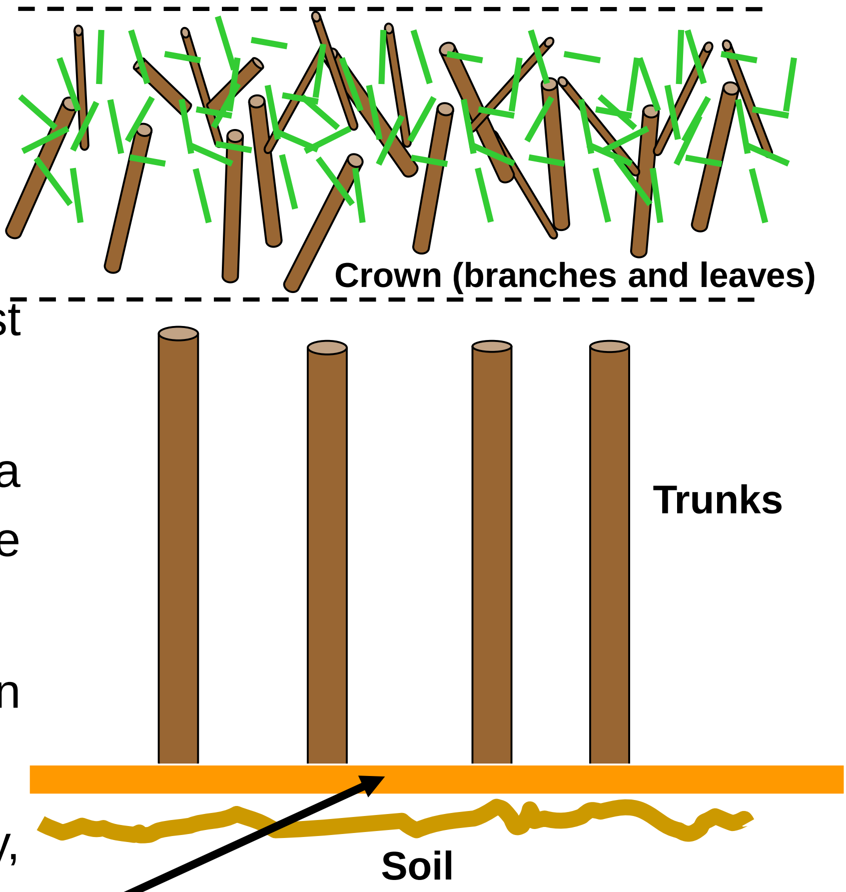
Considers the geometry of different forest components, and multiple scattering.

Modeling: selected approach

Basic aspects

(Ferrazzoli and Guerriero 1996)

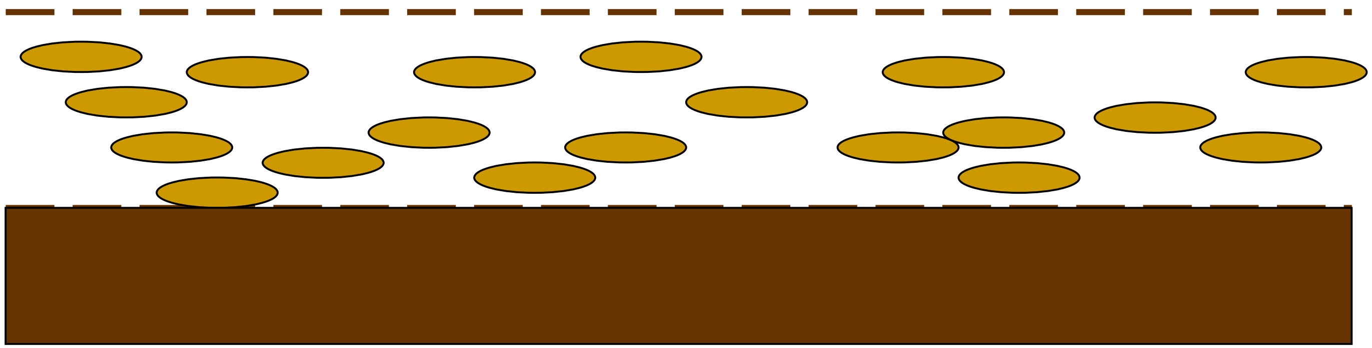
- Is based on radiative transfer theory;
- Adopts a discrete approach to represent forest elements;
- Combines contributions of forest elements by a matrix algorithm which includes multiple scattering;
- Combines vegetation scattering with reflection and scattering from the soil;
- Computes the emissivity of the whole canopy, soil and single components.



Includes the litter as a dielectric layer, with reflections at upper and lower interfaces (Della Vecchia et al., 2007)

Modeling: Litter characterization (1)

Litter is described as a continuous layer made by a mixture of air and dielectric material.



Empirical formulas relate:

•Litter biomass to LAI (through litter-fall estimates by Cannell, 1982)

•Litter thickness to biomass (Putuhena et al. 1996)

•Litter moisture to soil moisture (Bray experiment)

Permittivity of dielectric material is computed by means of vegetation permittivity routine

Permittivity of litter mixture is computed by “refractive” mixture formula (Ulaby et al. 1986)

Modeling: Litter characterization (2)

Steps

- Computation of reflectivity for soil+litter layer composite, using a coherent multiple reflection model (Ulaby et al. 1982), as a function of layer thickness
- Smoothing, to account for spatial inhomogeneities in the horizontal plane
- Computation of the permittivity of an equivalent uniform half-space with flat interface
- Introduction of roughness
- Computation of bistatic scattering coefficient (by IEM)
- Combination with standing vegetation contributions

Modeling: Required input data

Required Inputs:

- Soil moisture
- Soil roughness
- Litter coverage
- Tree density (ha^-1)
- Distribution of dimensions for trunks, branches, leaves
- Distribution of orientations for trunks, branches, leaves
- Permittivity of trunks, branches, leaves

Available by:

- Direct measurements (in case of campaigns)
- Allometric equations
- Literature data

Previous comparisons with experimental data

The model was tested vs. ground-based and airborne measurements collected over various forests

- Les Landes (France), Pine (Della Vecchia, P. Ferrazzoli, J.-P. Wigneron, J. Grant, IEEE GRS Letters, 2007)

- Tuscany (Italy), Broadleaf (A. Della Vecchia, P. Ferrazzoli, L. Guerriero, R. Rahmoune, S. Paloscia, S. Pettinato, E. Santi, IEEE TGRS, 2010)

- Finland, mixed (R.Rahmoune, A.Della Vecchia, P.Ferrazzoli, L.Guerriero, F.Martin-Porqueras, Proc. IGARSS 2009)

- Australia, Eucalyptus (R. Rahmoune, P. Ferrazzoli, J. P. Walker, J. P. Grant, Proc. MICRORAD 2010)

Application to spaceborne signatures

- Spaceborne missions are finalized to retrieve physical parameters, particularly soil moisture at L band.
- Retrieval algorithms are based on forward models and retrieval techniques
- 1st order Radiative Transfer (RT) model is used for soil covered by vegetation
- There is need to relate RT parameters to variables available at large scale.
- We selected Leaf Area Index (LAI).

Generation of the input data set

- LAI from available data bases (e.g. ECOCLIMAP)
- Empirical relationships between LAI and Leaf dry biomass (Bartelink, 1997).
- Typical values of vegetation moisture and permittivity (from active remote sensing literature)
- Distributions of dbh (diameter at breast height)
- Single tree allometric equations for different forest kinds (Jenkins et al., 2003)

Generation of the input data set (litter)

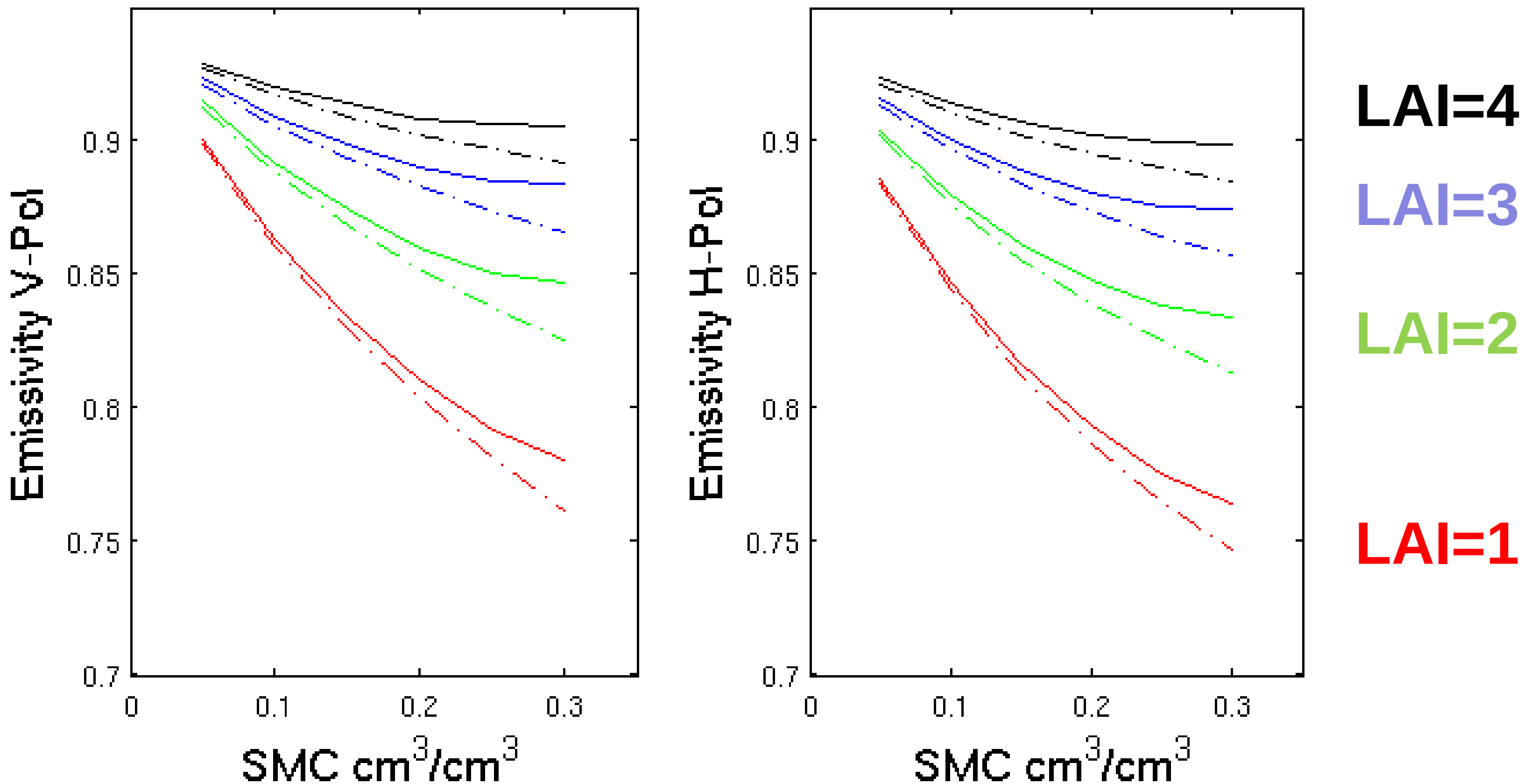
- Empirical relationships between LAI and Leaf dry biomass (Bartelink, 1997).
- Relationships between litter biomass (“litter-fall”) and leaf dry biomass (Cannel, 1982). (High variability related to climatic conditions, to be investigated)
- Relationships between litter thickness and litter biomass (Yoshinobu et al., 2004).

Parametric simulations for deciduous forests, in full leaf development

Emissivity as a function of SMC at L band

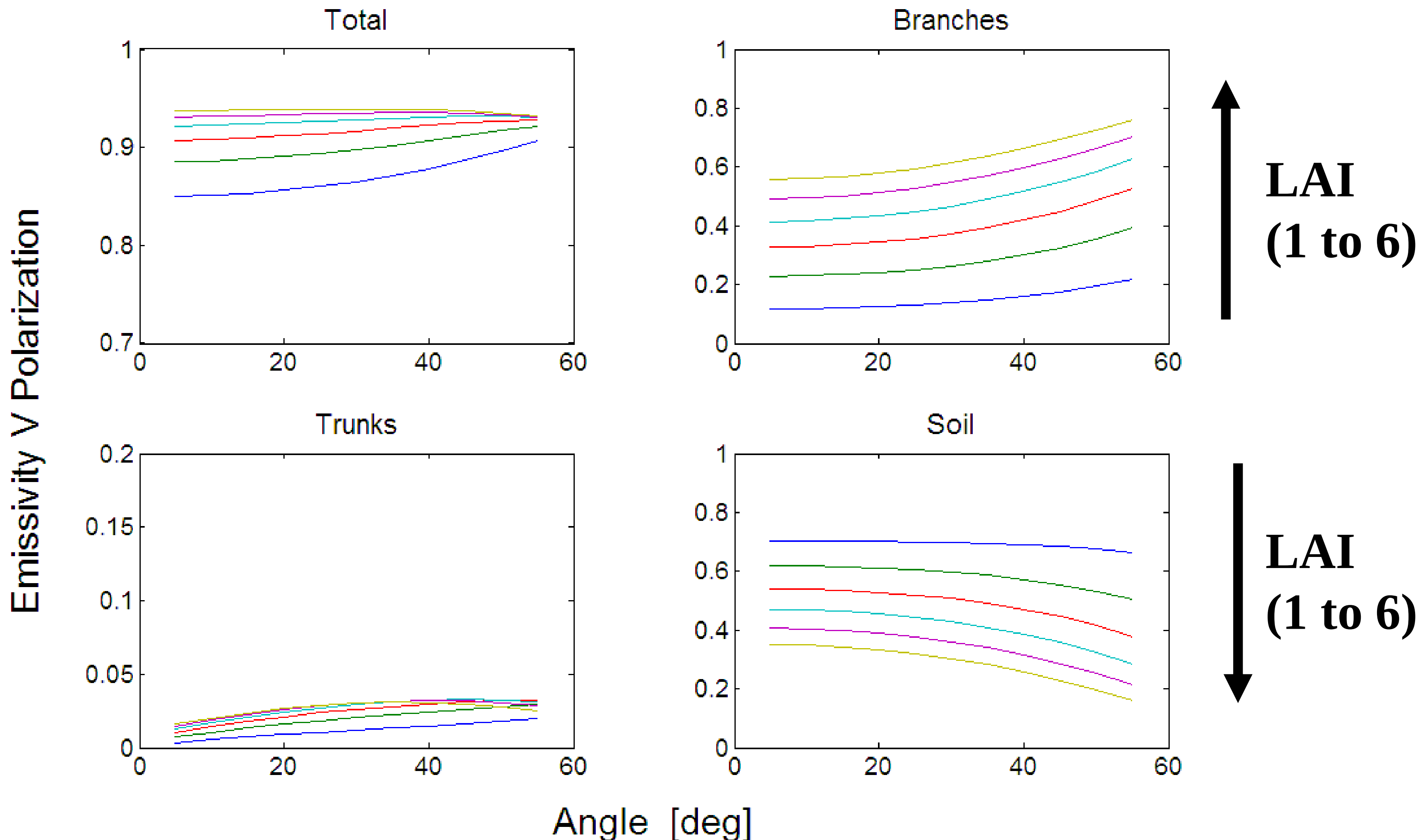
With litter

Without litter



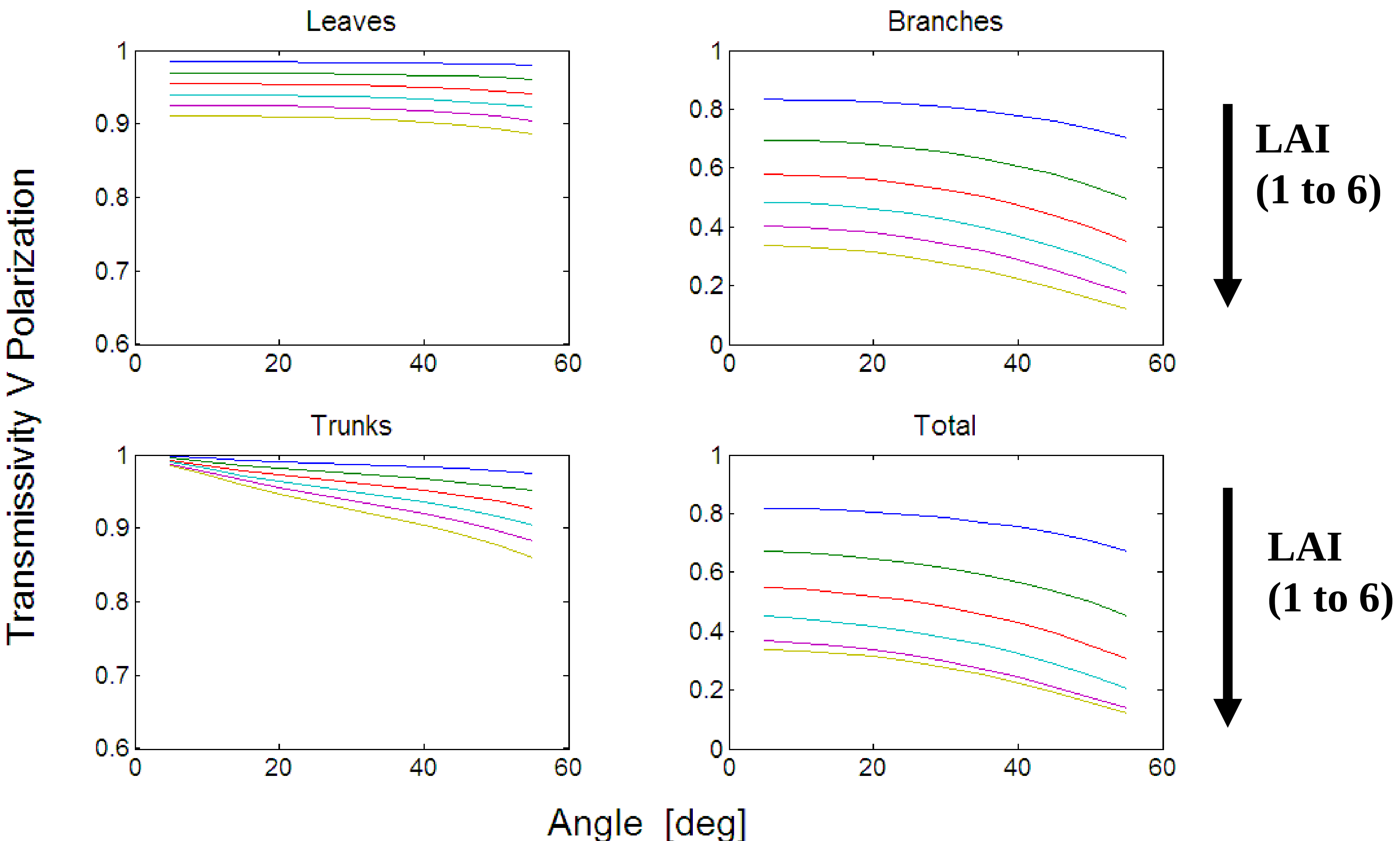
Examples of emissivity trends

Total emissivity and components vs. angle, L band, V polarization SMC = 10%, Broadleaf forests.



Examples of transmissivity trends

Transmissivity of components and total vs. angle, L band, V polarization, Broadleaf forests.



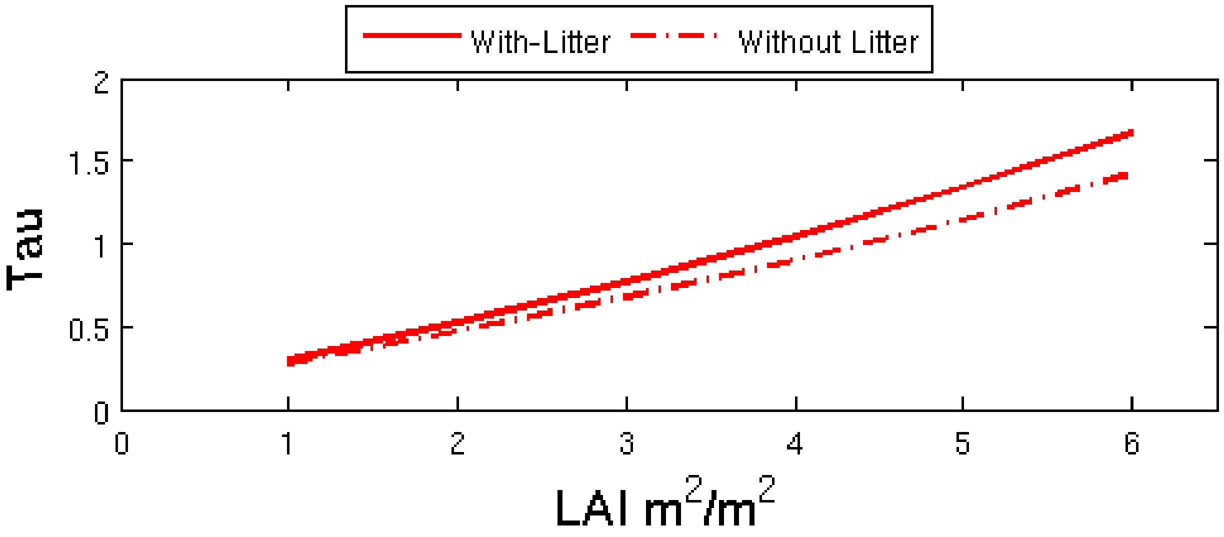
Fitting the parameters of a simple RT model

Model outputs have been used to fit the albedo and the optical depth of an “equivalent” 1st order RT model.

Steps

- A soil roughness hstd (1.5 cm) was selected
- The roughness factor h of the simple model was set by imposing the surface emissivity of the simple model to be equal to the surface emissivity of the physical model
- The physical model was run at both polarizations, an angular range 5°-55° and a SMC range 5%-30%
- The simple model was run for the same conditions
- **ω** and **τ** were selected in order to have the minimum rms difference between outputs of the two models

Fitting the parameters of a simple RT model



ω=0.08

Estimate of ω and τ

a) In full leaf development ($LAI = LAI_{max}$)

$LAI = f_F\, LAI_F + f_V\, LAI_V$

$\tau = f_F\, \tau_F + f_V\, \tau_V$

$\tau_V = b_V\, LAI_V$ (herbaceous vegetation)

Running the theoretical model and fitting the outputs to RT-0:

$\tau_F = \tau_{FW}$ (wood) + τ_{FL} (leaf) + τ_L (litter) = $b_F\, LAI_F$

$\omega = 0.08$

b) In other seasons ($LAI < LAI_{max}$)

τ_{FW} (wood) and τ_L (litter) unchanged

τ_{FL} (leaf) and τ_V (herbaceous vegetation) related to LAI

$\omega = 0.08$

Comments

Important outcomes from preliminary modeling work (confirmed by real spaceborne signatures):

- The most important effects depend on branches;
- Seasonal variations are small;
- Maximum LAI is an important parameters, at least at continental scale;
- Reasonable estimate of optical depth, at least for broadleaf forests.

Comments

However, problems were found:

- The procedure suffers several approximations, since the complexity of the forest cannot be represented by the single LAI max parameter (particularly for needleleaf forests);
- LAI is also contributed by understorey;
- At large scale inhomogeneity effects must be considered;
- Litter effects are difficult to be predicted, and strongly depend on climate;
- Most of experiments and model tests were limited to Boreal regions of Europe and US.

Overall, after some years of spaceborne data availability:

- Coefficients relating VOD to LAImax were reduced (by a 0.6-0.8 factor)
- The most appropriate albedo was 0.06.

The SMOS SM L2 Algorithm

❖An RT-0 forward model is run for each angle and for each land cover of SMOS pixels. Inputs: land cover, ECMWF, ECOCLIMAP

❖Outputs are aggregated for SMOS pixels, and compared with measurements.

❖Simulated T_B's are compared vs. measured T_B's. An iterative procedure is started to minimize the "cost function".

❖SM and optical depth of the dominant cover type (low vegetation or forest) are retrieved as outputs of this iterative procedure (2P algorithm).

The forward model for forests

RT-0 inputs for soil: SM (first guess), h

RT-0 inputs for vegetation: τ (first guess), ω

h = 0.3 (fixed)

SM by ECMWF

τ (first guess) and ω are obtained using the already indicated procedure.

The 3P algorithm

A 3-parameter retrieval exercise was made off-line. In this case SM, τ and ω were simultaneously retrieved. This method is not proposed as operational, since produces unstable solutions for mixed pixels.

However, it provided useful results when the forest fraction (FFO) was close to 100%.

Four 8-day intervals of 2011 and 2012 were selected.

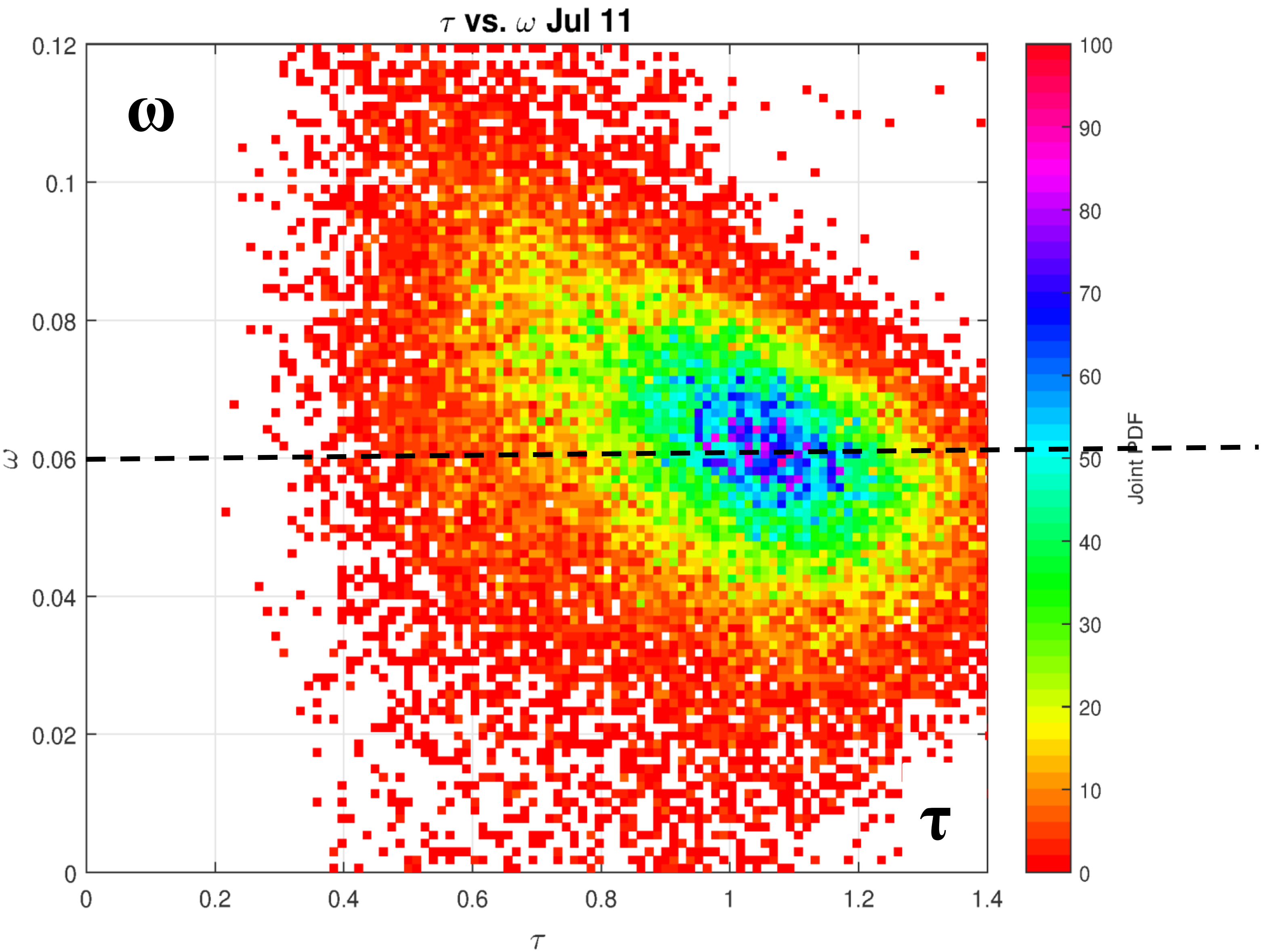
3-parameter retrieval results over Pantropical forests (latitude <20°), for four 8-day time intervals

Forest fraction	Time interval	Number	τ mean	τ std	ω mean	ω std
90%-95%	February 2011	9766	0.88	0.26	0.055	0.025
95%-100%	February 2011	32920	0.94	0.23	0.064	0.019
90%-95%	July 2011	10379	0.90	0.25	0.054	0.024
95%-100%	July 2011	33905	0.96	0.22	0.062	0.018
90%-95%	November 2011	10365	0.87	0.26	0.051	0.023
95%-100%	November 2011	34316	0.93	0.22	0.059	0.018
90%-95%	February 2012	10145	0.91	0.27	0.051	0.024
95%-100%	February 2012	33806	0.98	0.23	0.060	0.019

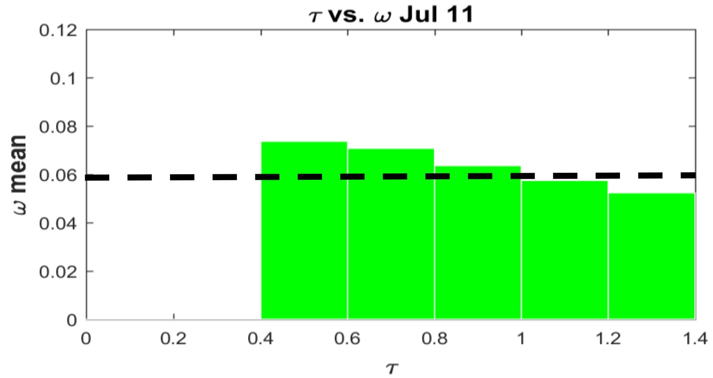
3-parameter retrieval results over two continents for 8 days in July 2011

Forest fraction	Continent	Number	τ mean	τ std	ω mean	ω std
90%-95%	South America	5815	0.92	0.25	0.057	0.027
95%-100%	South America	24446	0.98	0.21	0.064	0.017
90%-95%	Africa	3914	0.79	0.25	0.049	0.042
95%-100%	Africa	7463	0.81	0.23	0.060	0.038

Scatterplot of retrieved ω vs. retrieved τ. July 2011, Pantropical forests, Forest fraction > 95%

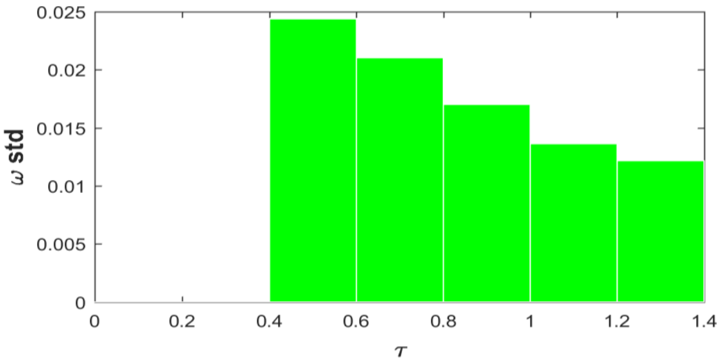


July 2011, Pantropical forests, Forest fraction>95%

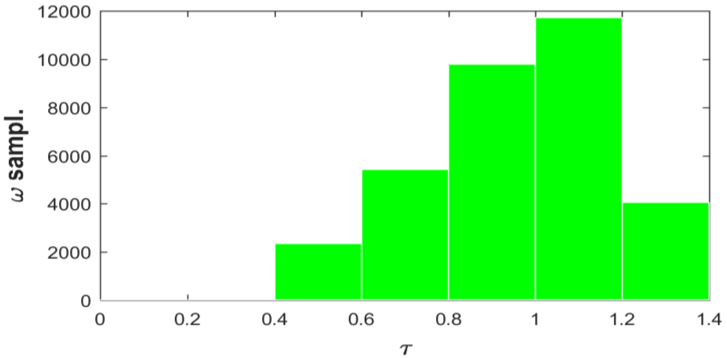


0.06

ω mean vs. τ

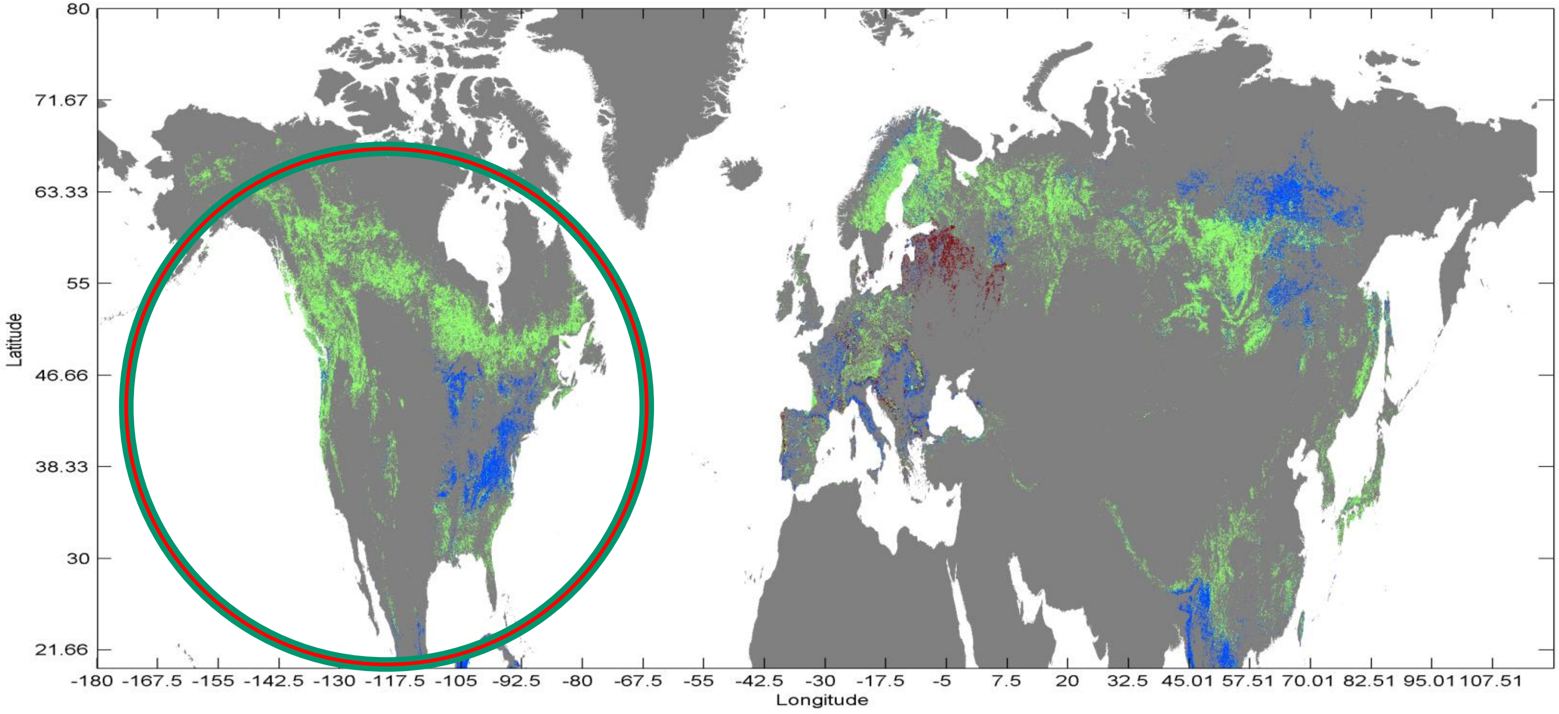


ω std vs. τ

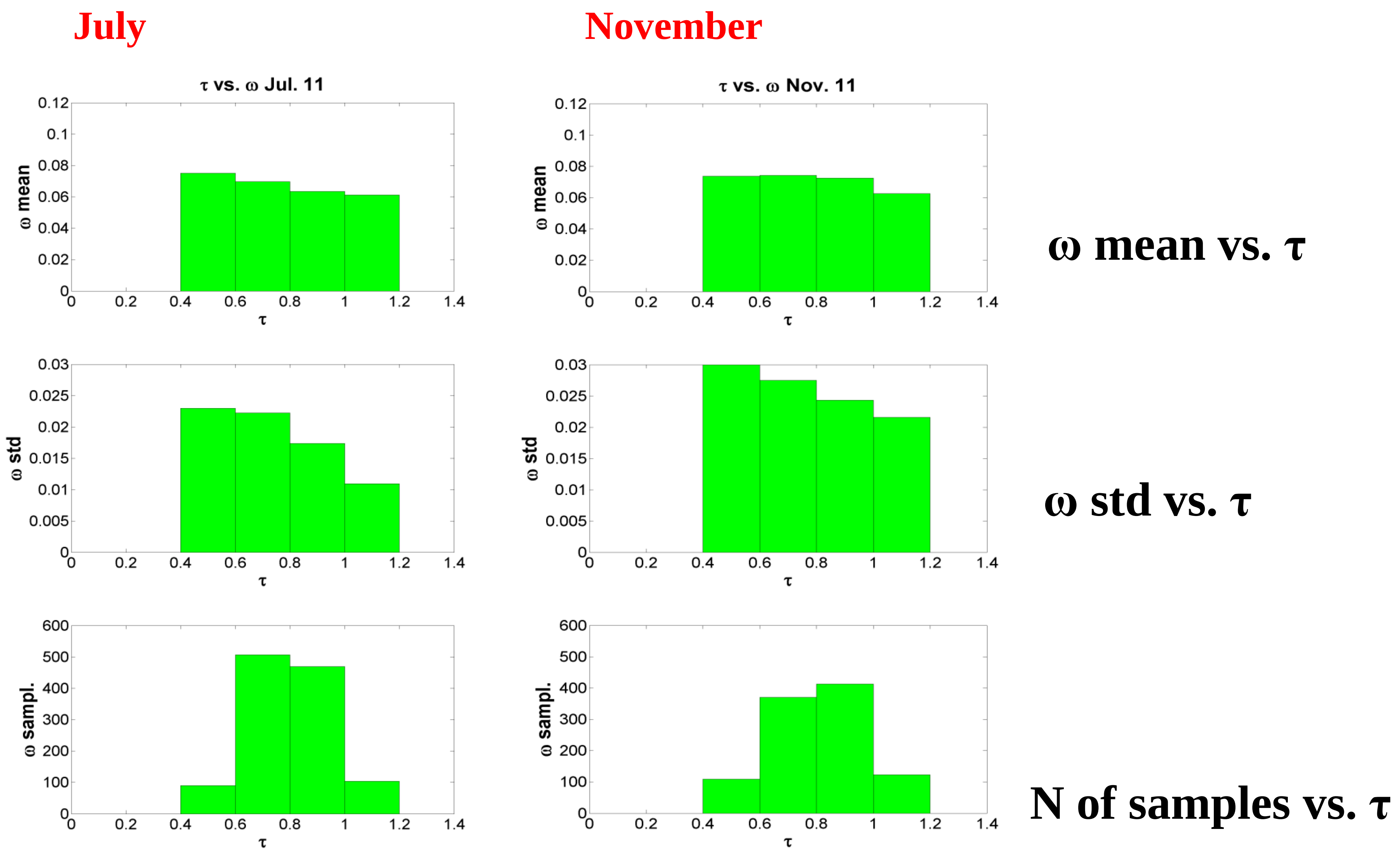


N of samples vs. τ

Boreal forests of North America with Forest fraction >95%
Needleleaf (green)
Broadleaf (blue)

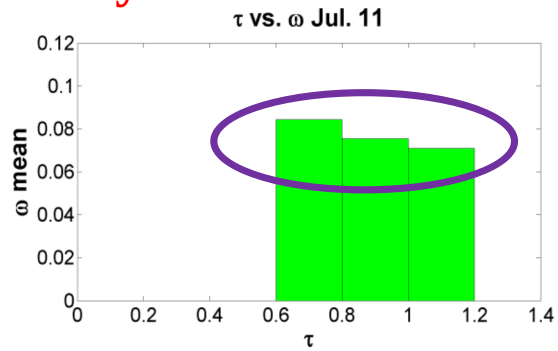


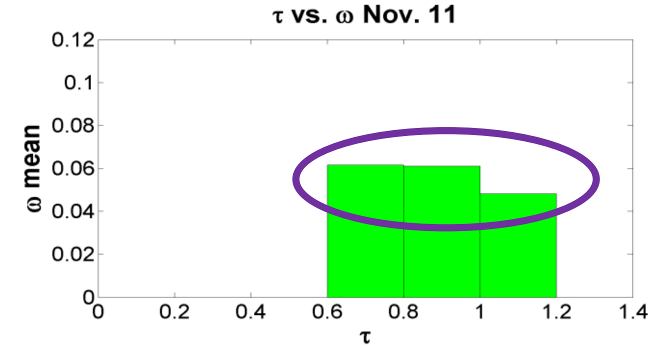
Broadleaf forests of North America, Forest fraction>95%



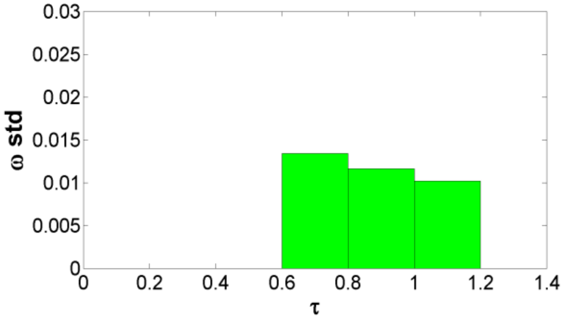
Needleleaf forests of North America, Forest fraction>95%

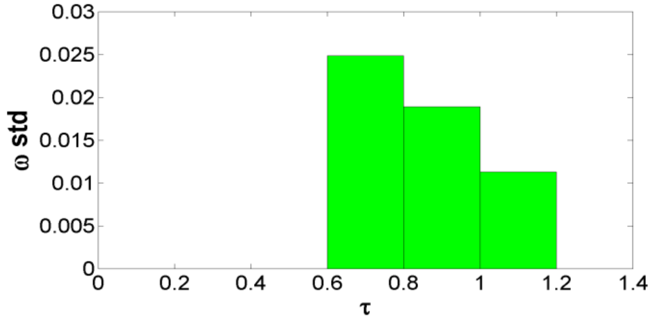
July **November**



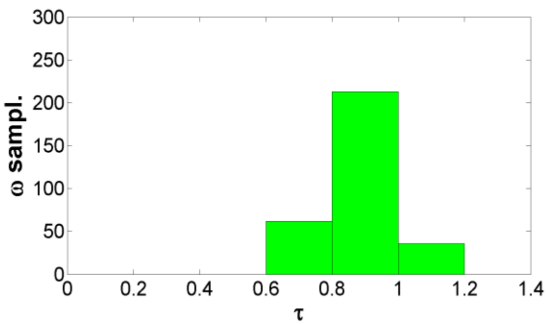


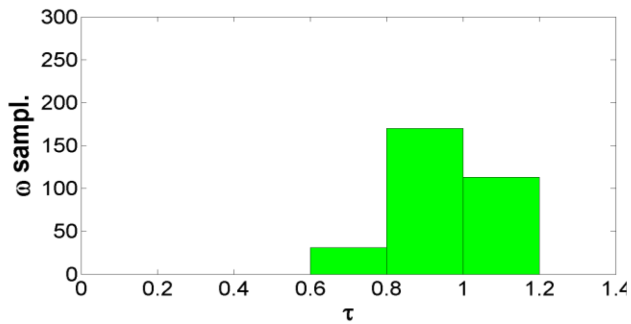
ω mean vs. τ





ω std vs. τ





N of samples vs. τ

Comments about albedo results

For tropical forests with FFO>95% the value $\omega=0.06$ is confirmed, on average, but with a slight decreasing trend vs. τ

For Boreal forests, similar values are observed in July, but there is a decrease in November for needleleaf.

The std of ω decreases when increasing τ

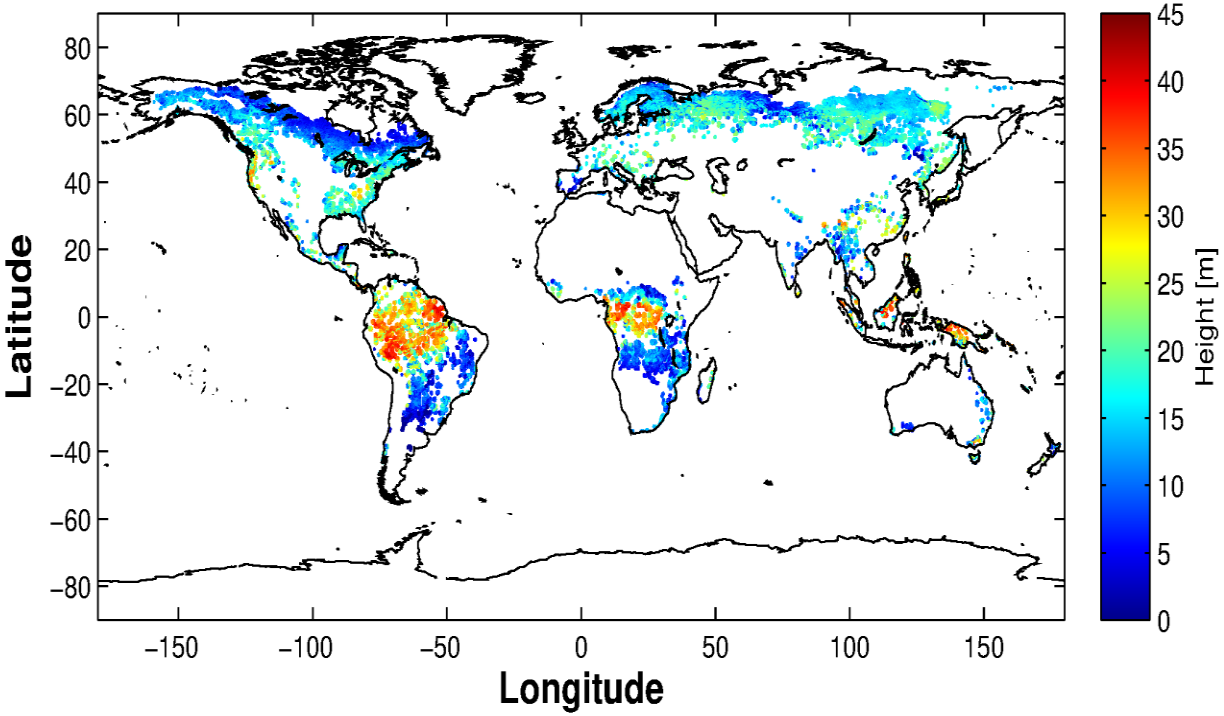
Analysis of VOD and SM retrievals obtained by current (620) SMOS L2 algorithm

SM: main objective of the mission.

VOD (vegetation optical depth τ) also important:

- To improve the performance of the algorithm;
- To achieve a new product, with applications to monitoring of carbon storage and exchange.

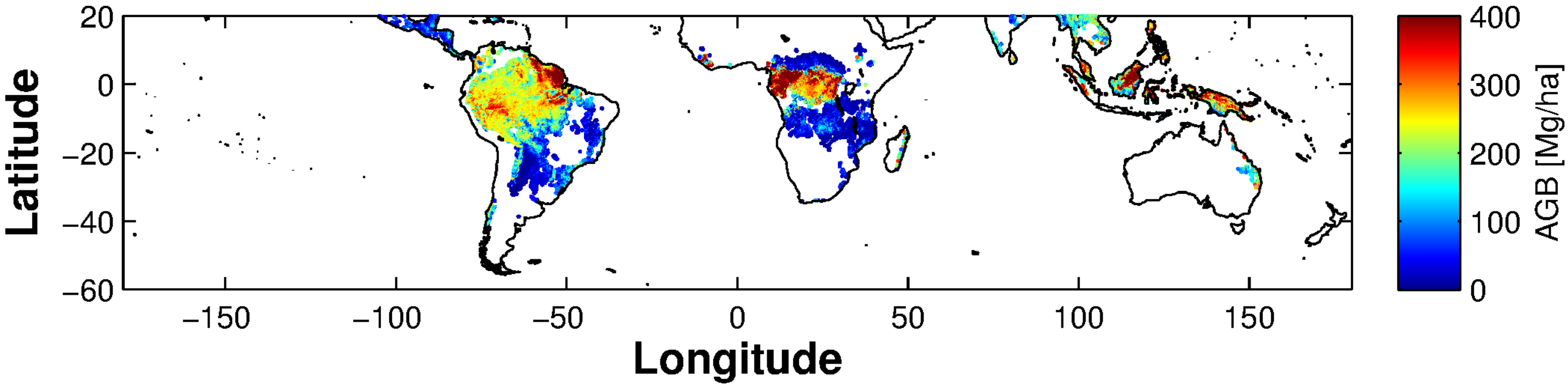
Comparison between VOD and Forest Height data base



Simard et al., (2009): Estimated by ICESat GLAS over lidar tracks, with MODIS ancillary data to fill cross track Lidar gaps. The extention is obtained using Random Forest Model.

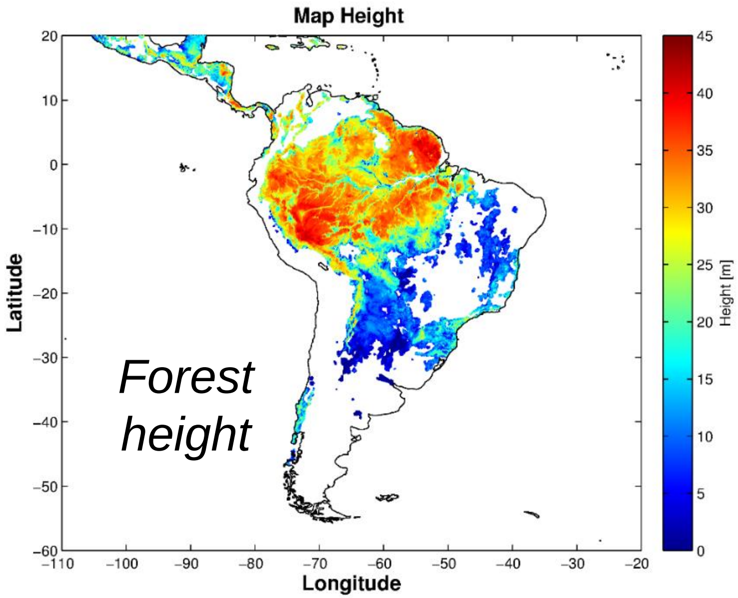
The database also provides the RMSE computed comparing direct Lidar measurements and model predictions. We only selected data with RMSE < 5m.

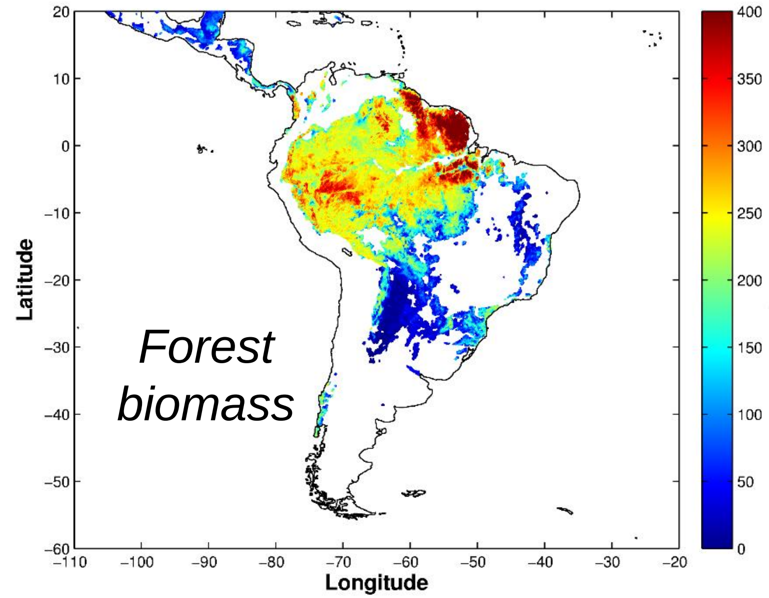
Comparison between optical thickness and a novel AGB database

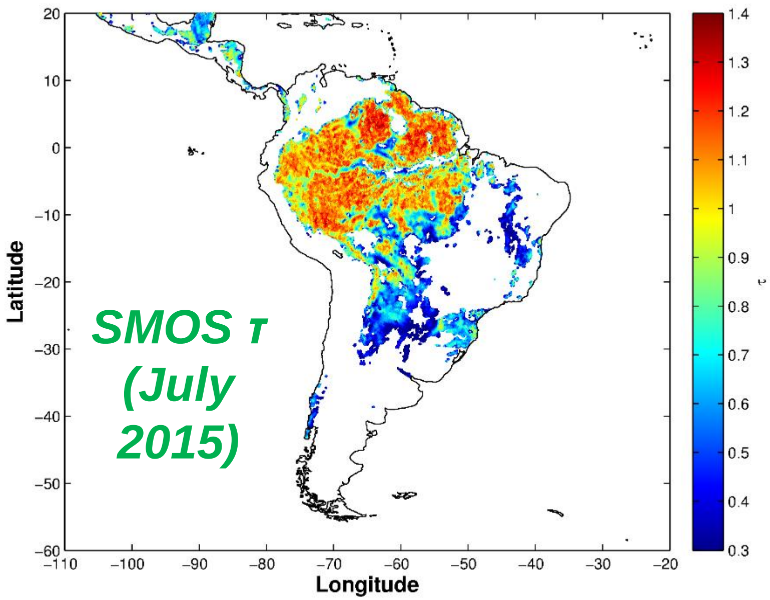


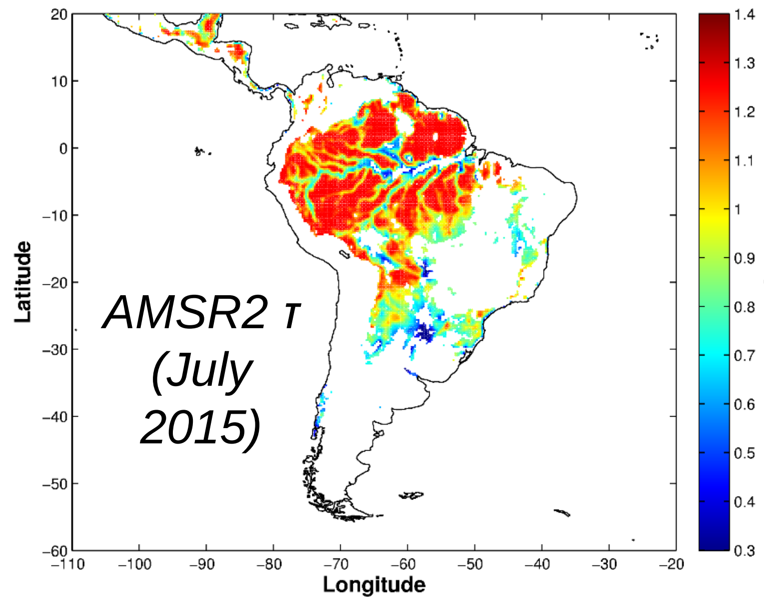
Pantropical AGB database by Avitabile et al. (2015): Fusion of previous AGB maps (Baccini et al., Saatchi et al.) reported an RMSE 15 - 21 % lower than that of the inputs maps and unbiased estimates.

South America (Forest fraction > 70%):

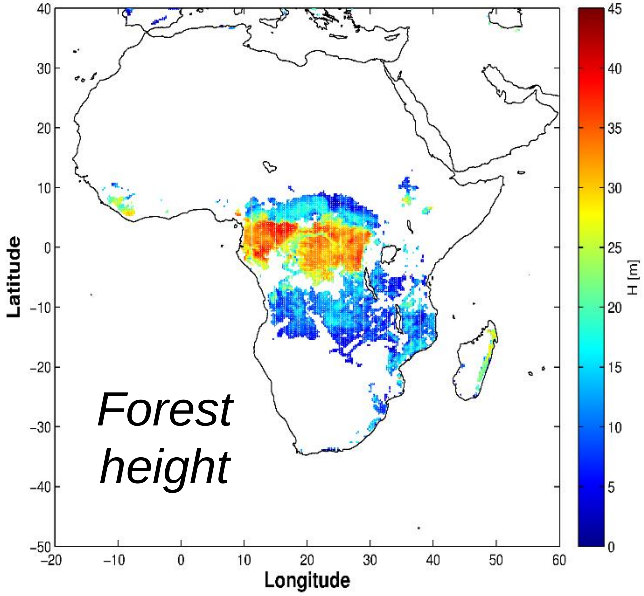


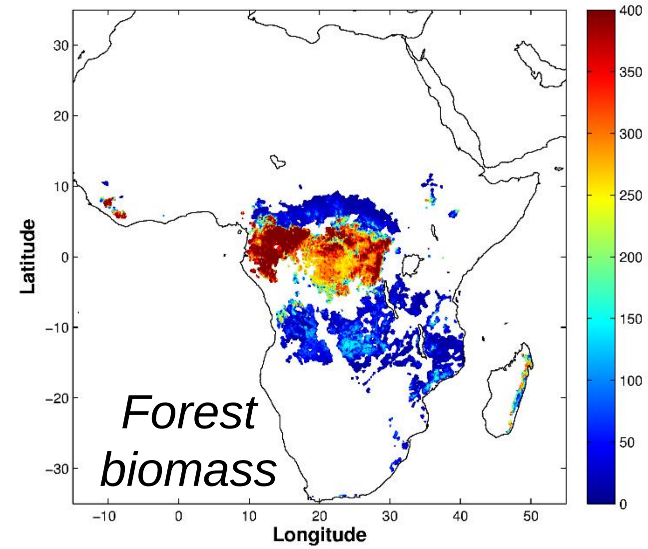


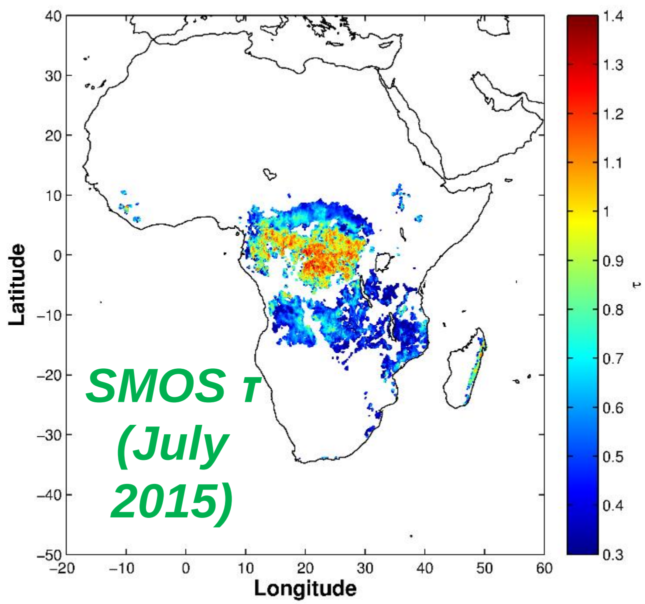


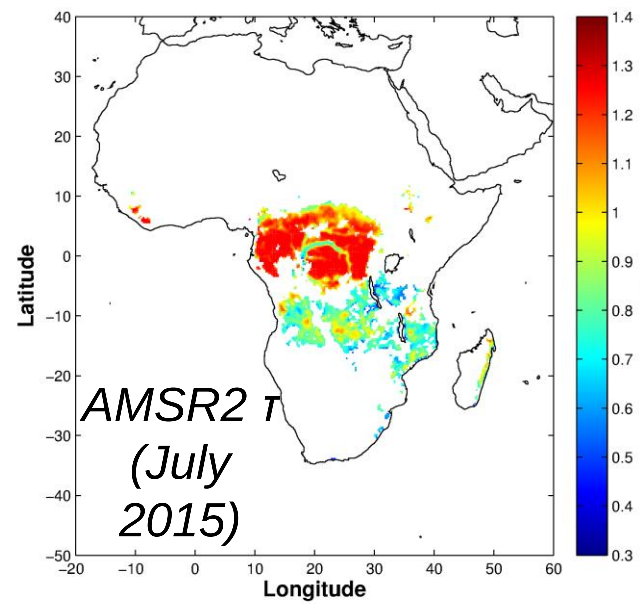


Africa (Forest fraction > 70%):









Comparison between VOD (SMOS and AMSR2) and forest parameters (par.). Average July 2015

Test:

τ vs. par. correlation (R^2)

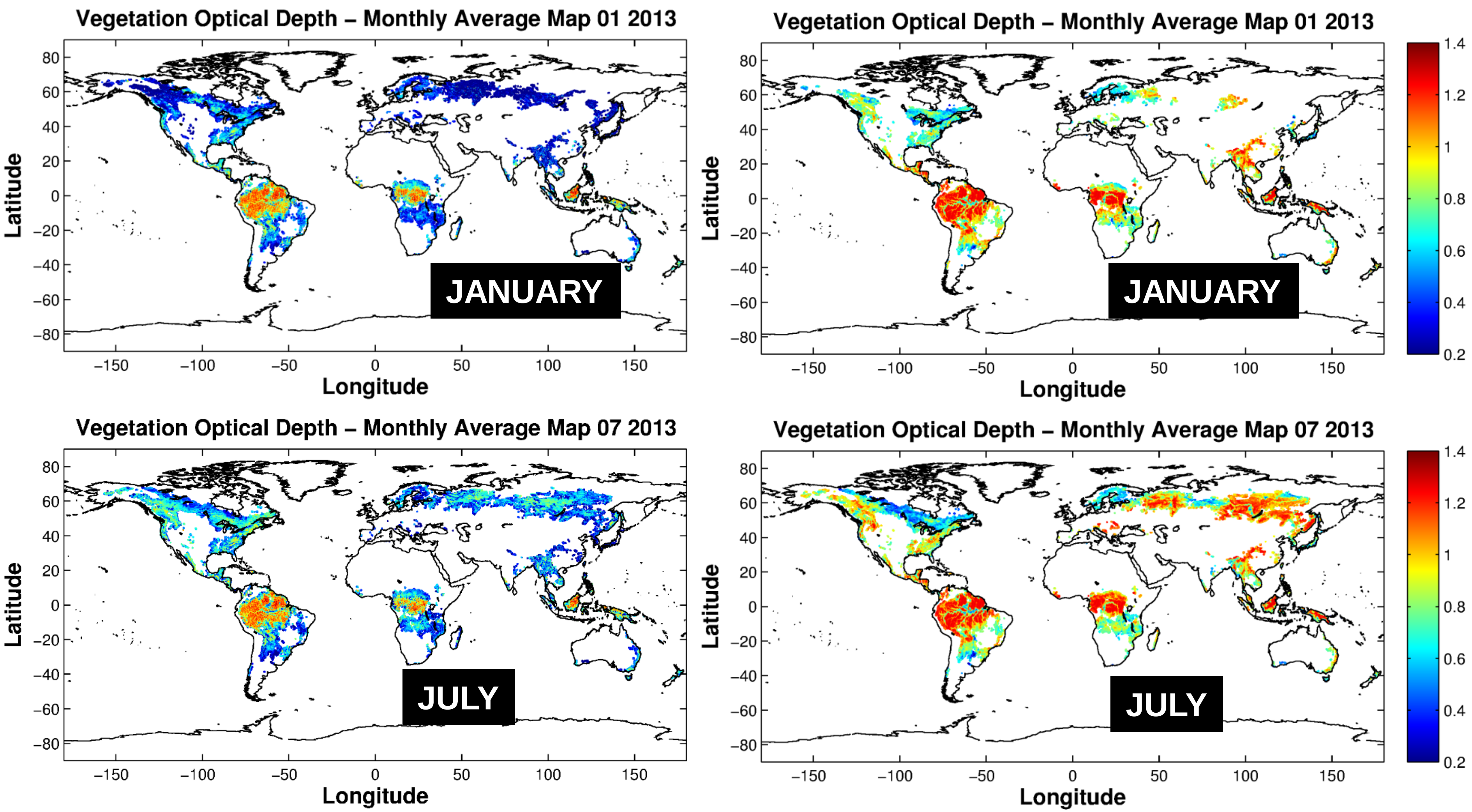
τ = b1 par. + b2

par. $\left\{ \begin{array}{l} \text{Forest height by Simard et al. (2011)} \\ \text{AGB by Avitabile et al. (2015)} \end{array} \right.$

	R^2 SMOS	b1 SMOS	b2 SMOS	R^2 AMSR2	b1 AMSR2	b2 AMSR2
Forest Height South America	0.72	0.022	0.31	0.55	0.016	0.63
Forest Height Africa	0.67	0.020	0.29	0.64	0.017	0.64
Biomass South America	0.62	0.002	0.42	0.34	0.001	0.77
Biomass Africa	0.57	0.002	0.45	0.45	0.001	0.83

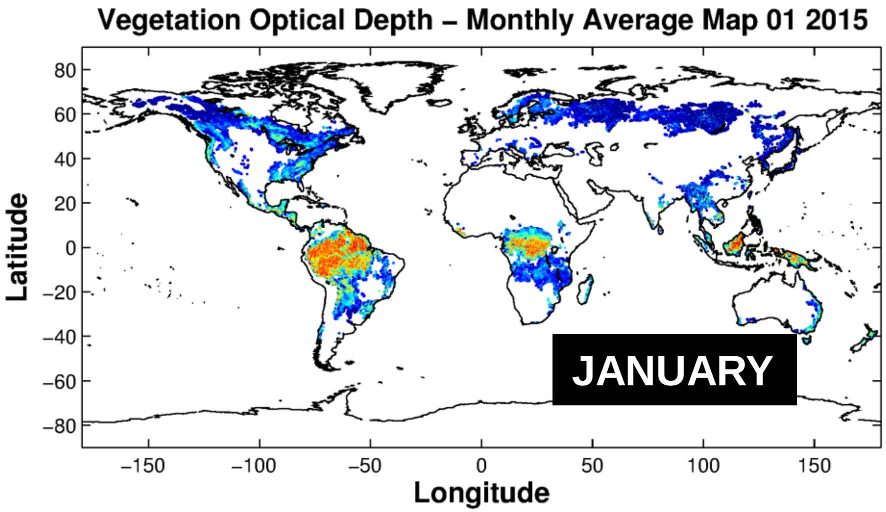
Seasonal maps (2013)

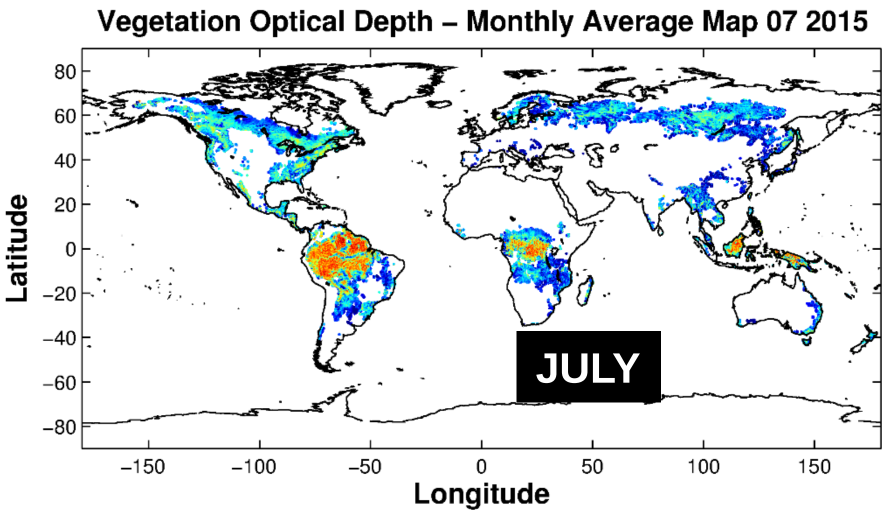
SMOS τ *AMSR2 τ*



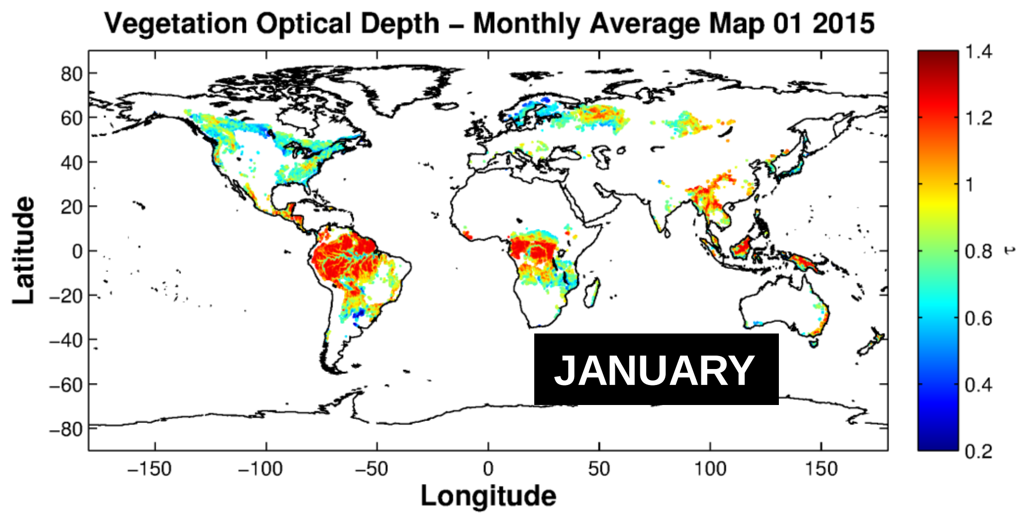
Seasonal maps (2015)

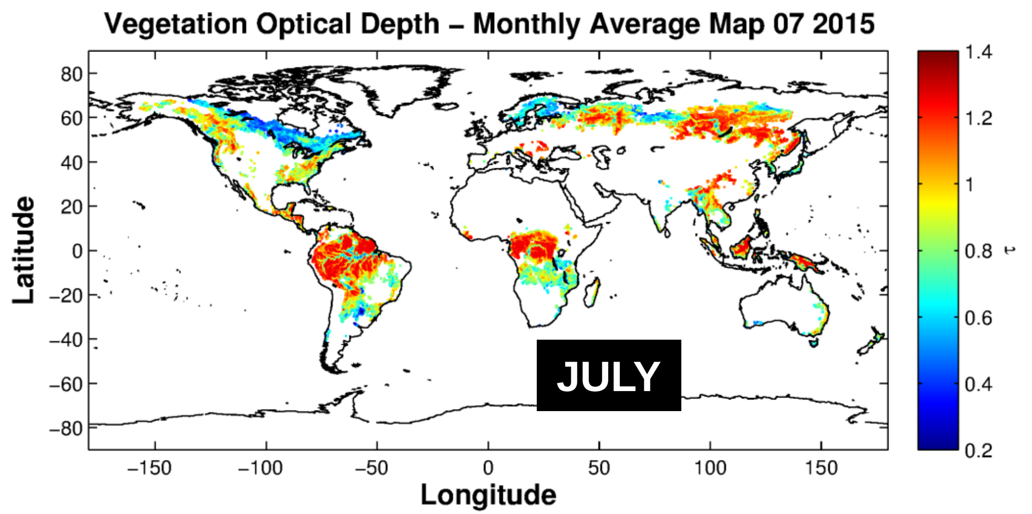
SMOS τ





AMSR2 τ





Conclusions about VOD Investigations

- ✓ Comparison between VOD and two databases including the novel AGB dataset (Avitabile et al, 2015).

- ✓ Linear regression analysis with different forest parameter registers an overall better performance of L band

- ✓ b2 coefficient represents the intercept of linear regression due to contribution of understory and short trees. C band shows higher b2 as expected

- ✓ SMOS VOD shows temporal stability, particularly in tropical forests

Overall, SMOS optical depth can be a possible new contributor data source for estimating forest biomass (or wood volume) and its changes at global scale.

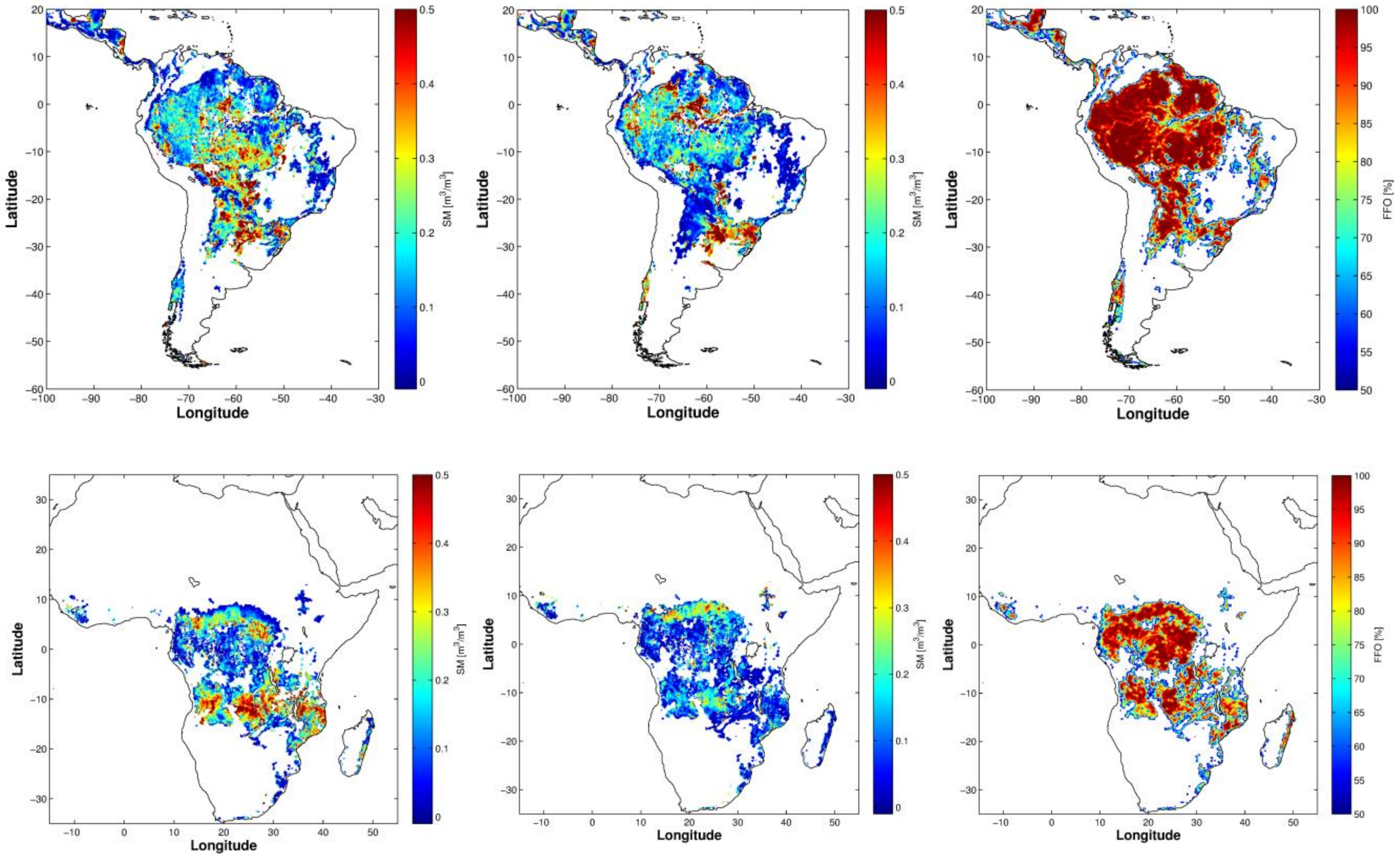
Reference: Vittucci et al, RSE, 2016

SM retrieval results (8-day average maps)

8 days February 2011

8 days July 2011

Forest fraction



Analysis of V620 TB's and retrievals on forest nodes of the Scan-Snotel Network

- For each SCAN-SNOTEL node, the closest SMOS node was taken in order to make the comparison.
- Multitemporal trends of 2015 have been plotted for:

Retrieved SM;

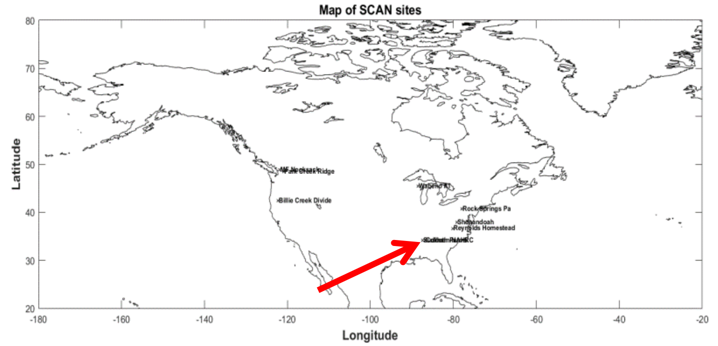
Measured SM;

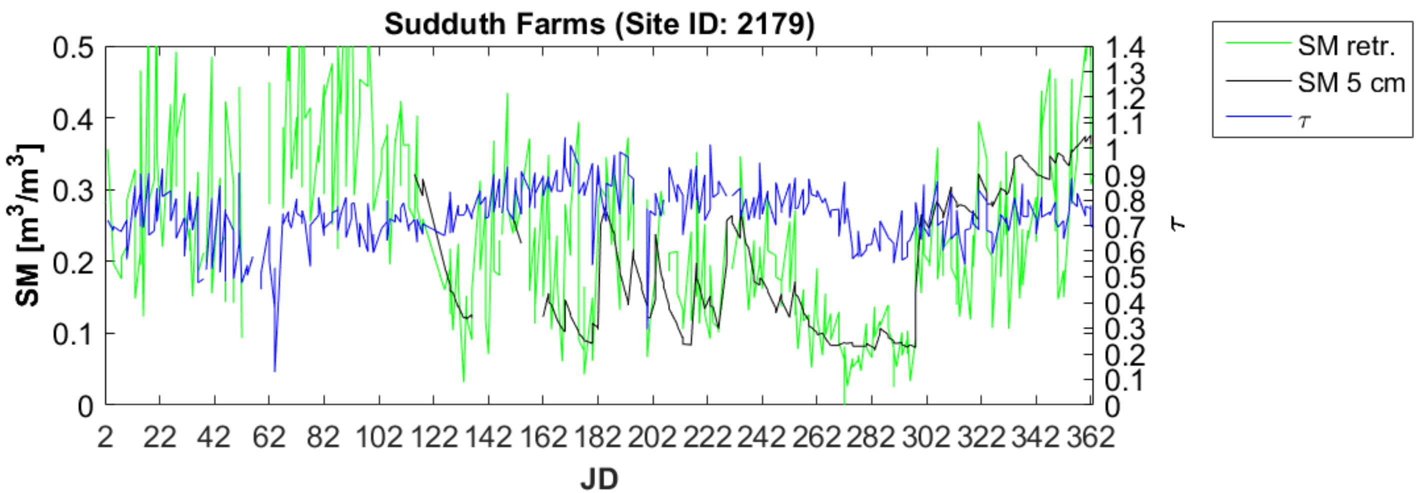
Retrieved τ *;*

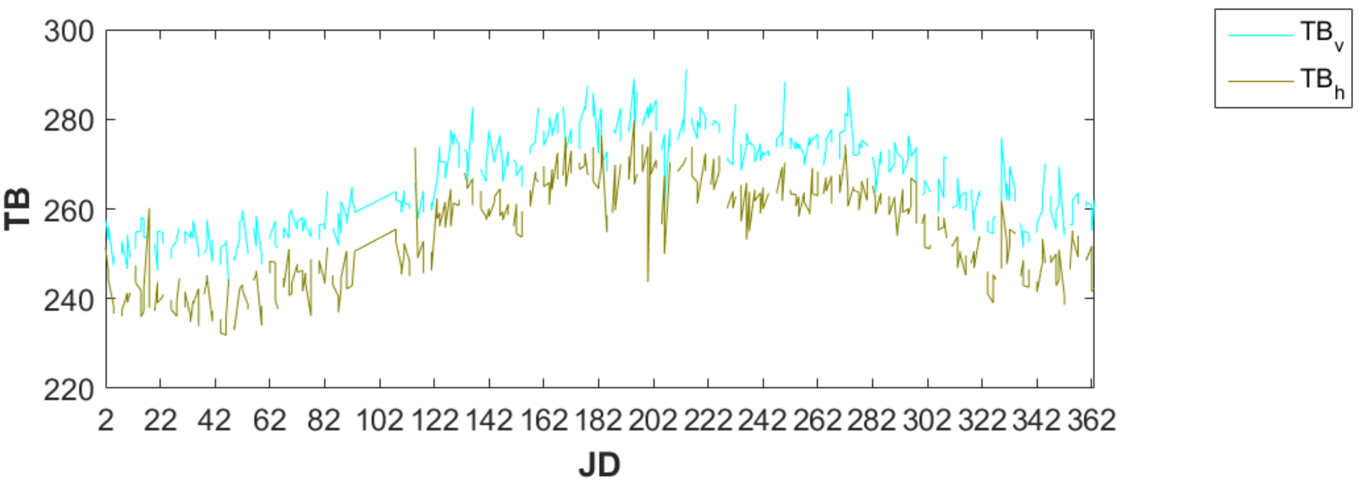
Average TBV in a 37.5°-42.5° range;

Average TBH in a 37.5°-42.5° range.

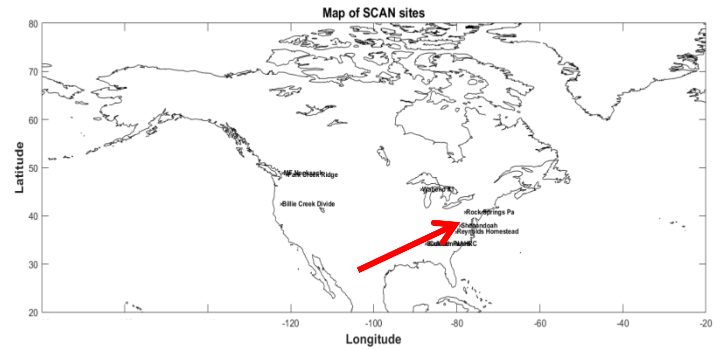
Node 2179: Sudduth Farms

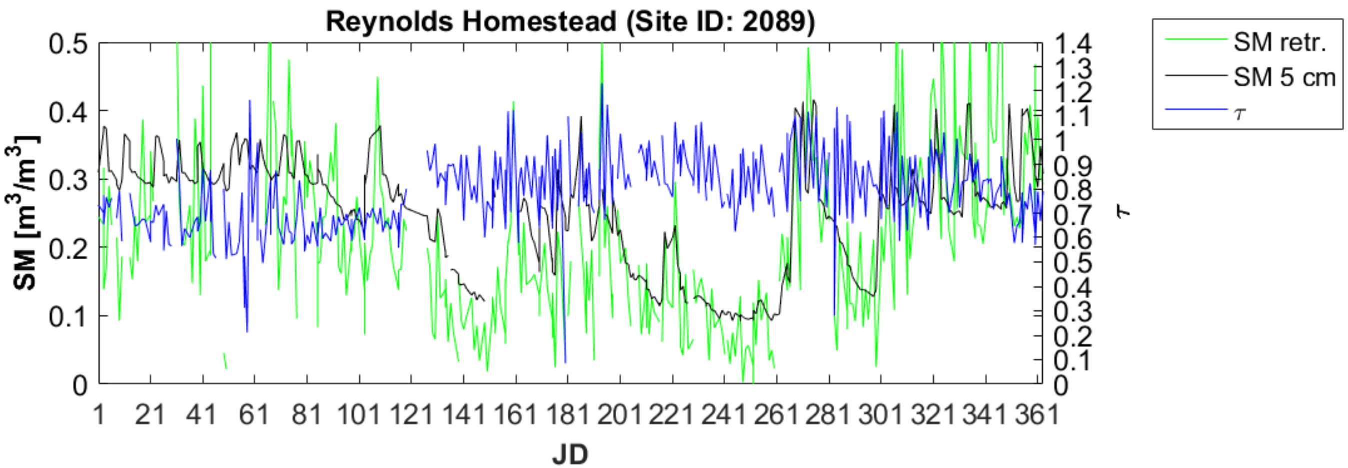


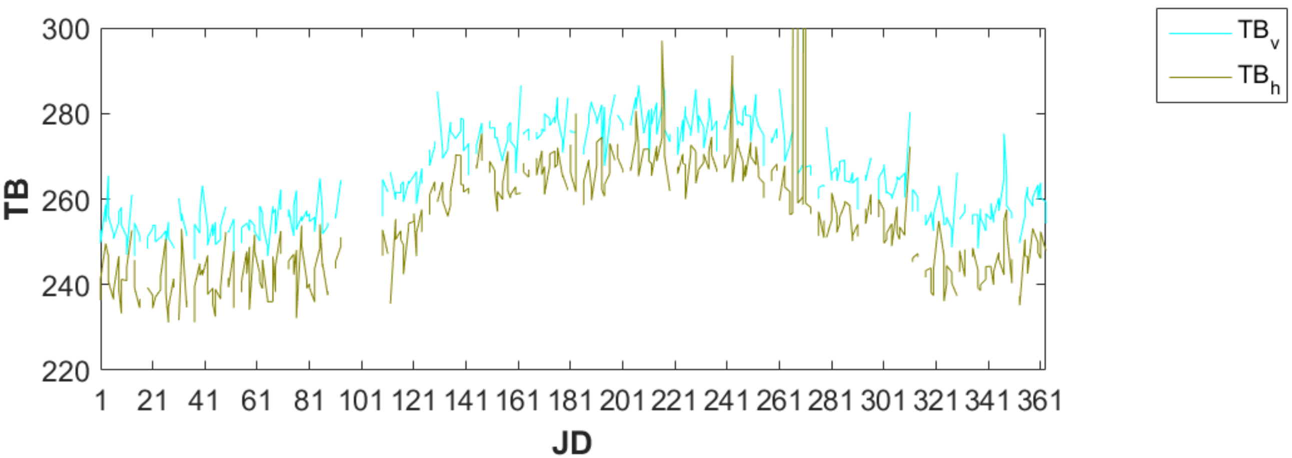




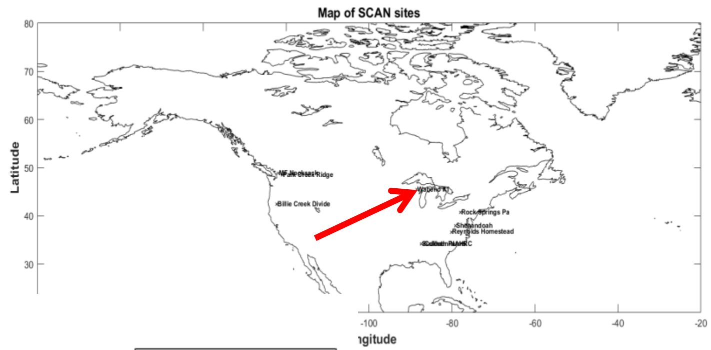
Node 2089: Reynolds Homestead

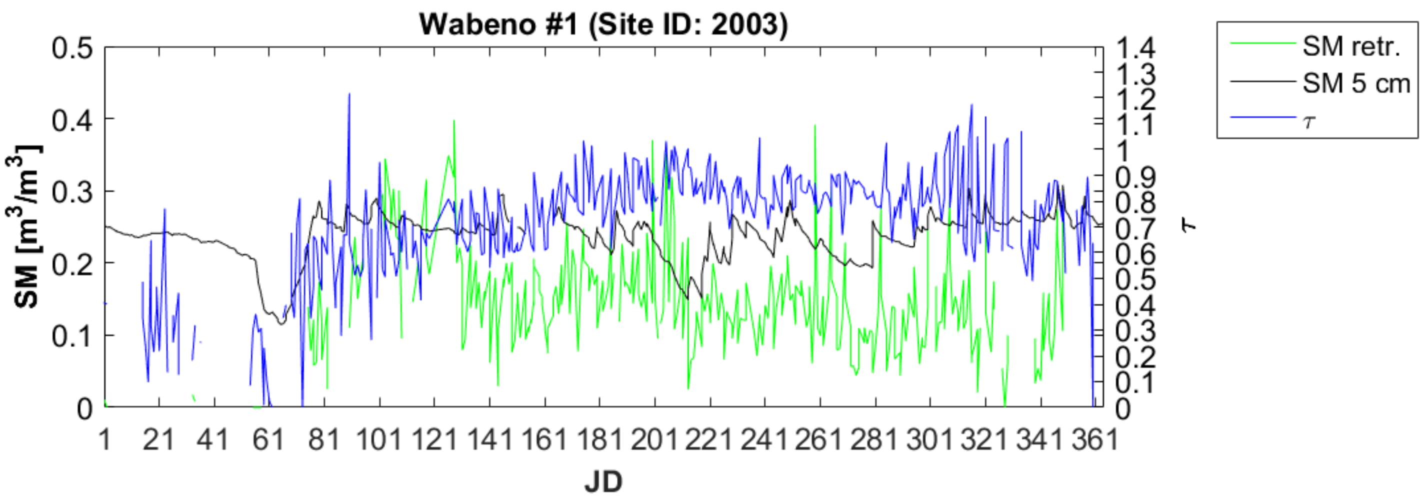


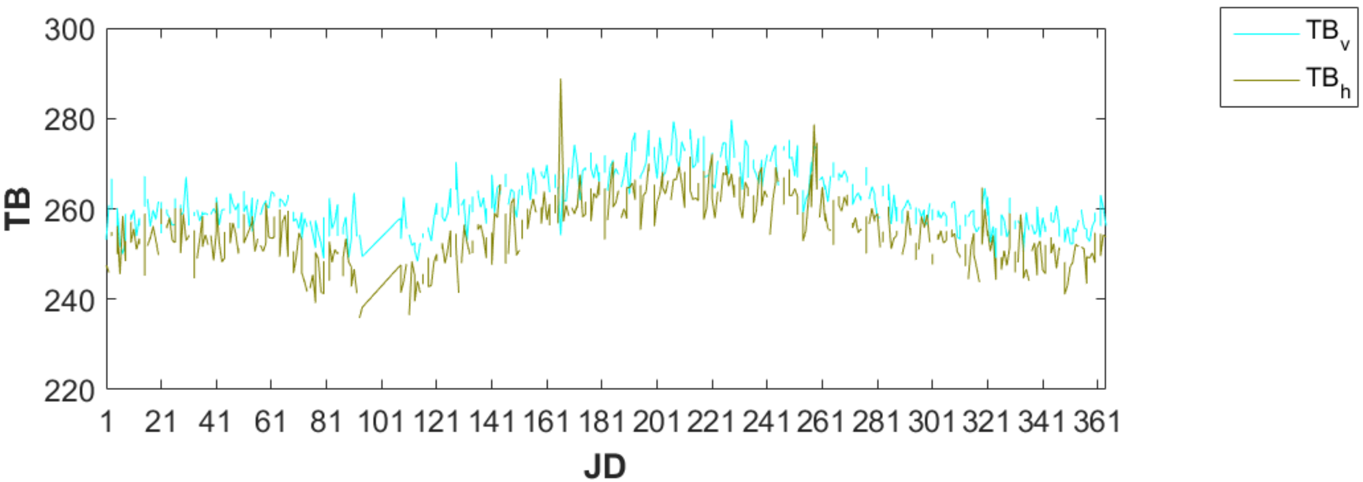




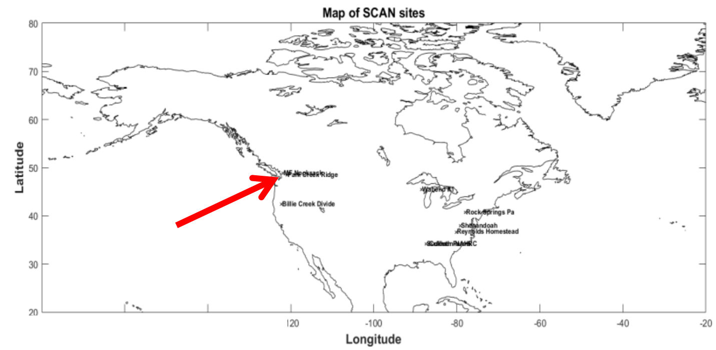
Node 2003: Wabeno 1

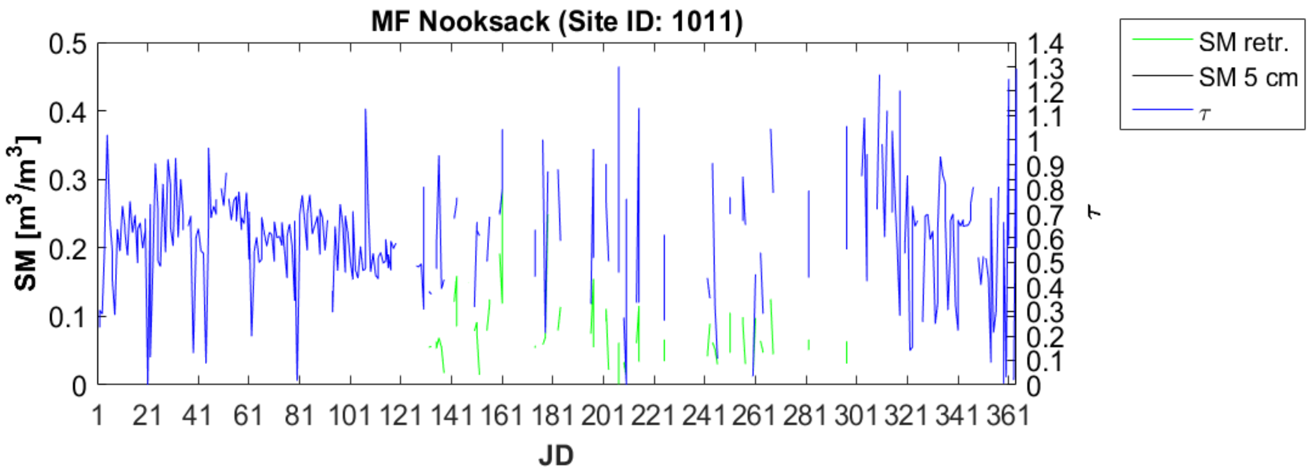


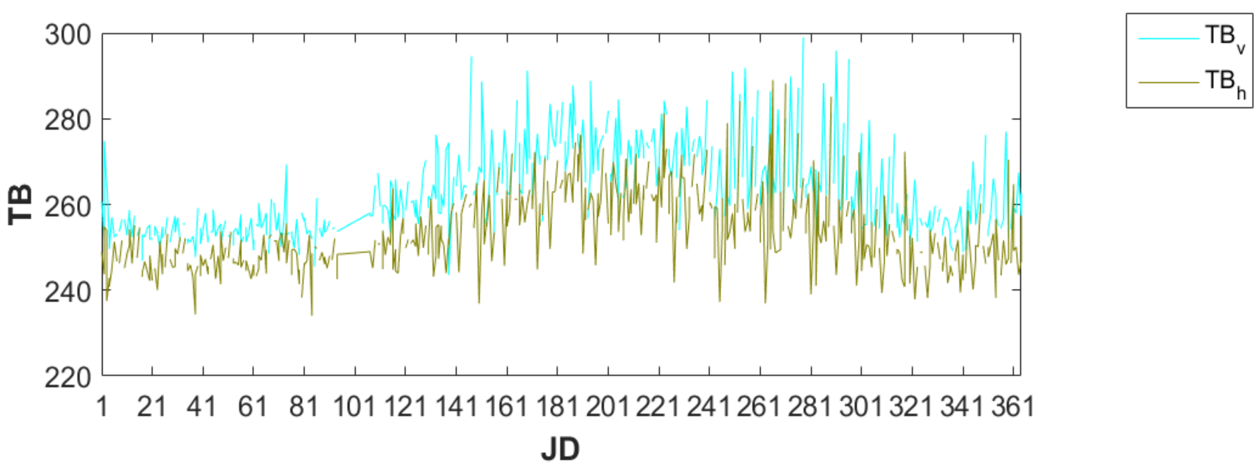




Node 1011: MF Nooksack







Problems

- Underestimation of SM at the highest latitudes (forward model: ω?, soil permittivity?).

- Underestimation of SM or retrieval failure for forest fractions in a 70%-90% range (land cover, simulation of TB in not retrieved fraction).

- Missing or suspicious ground measurements (e.g. SM=0 for long time intervals). One sample per SMOS pixel is not sufficient.

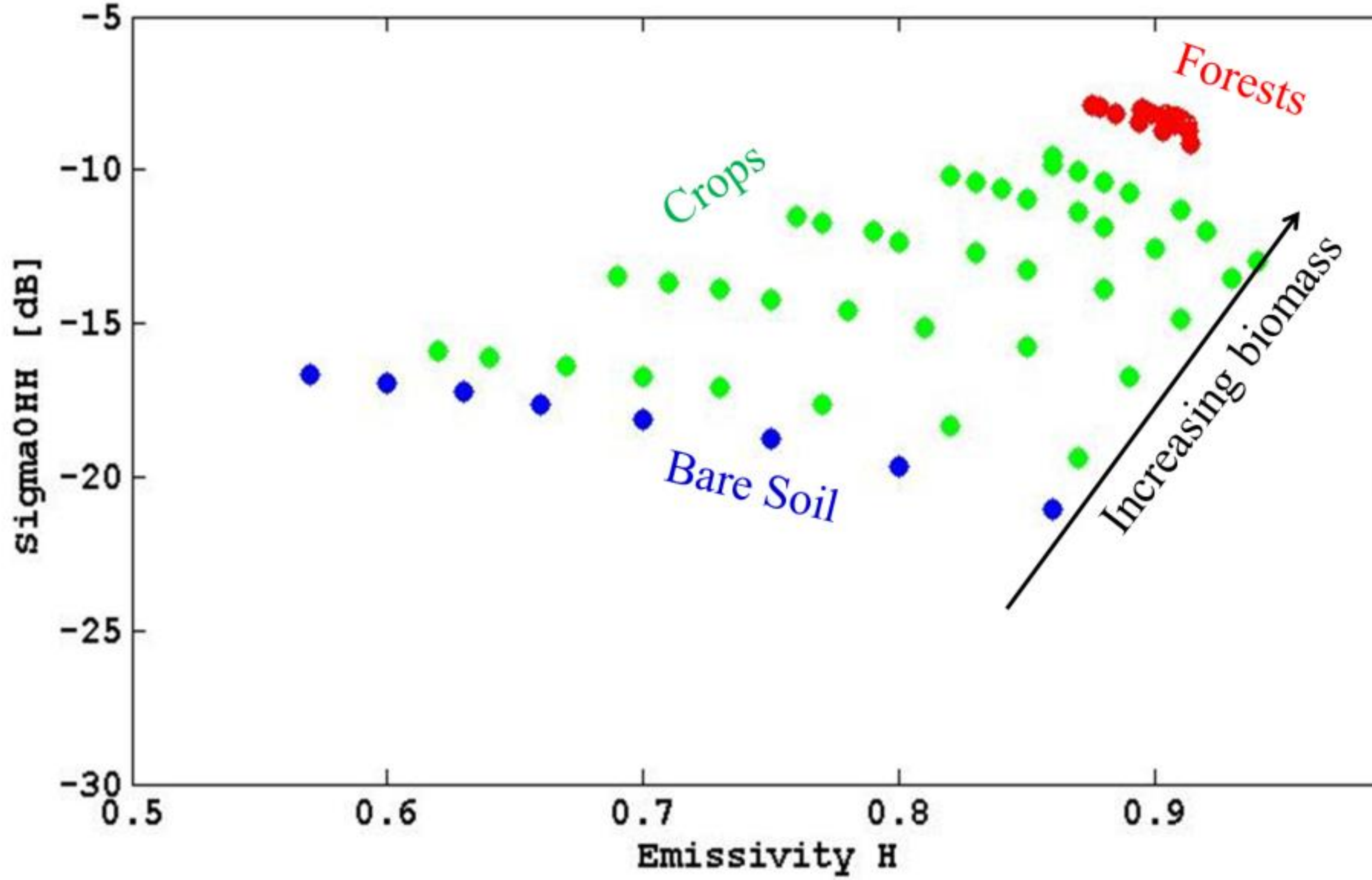
Retrieval is difficult at higher latitudes and/or lowest temperatures, not necessarily below freezing values

Investigations in progress:

- Changes in wood permittivity;
- Changes in soil permittivity, for a given SM (organic soils);
- Deeper and more stable litter;
- Higher differences between canopy and soil temperatures.

Active-Passive sinergy at L band: Model simulations

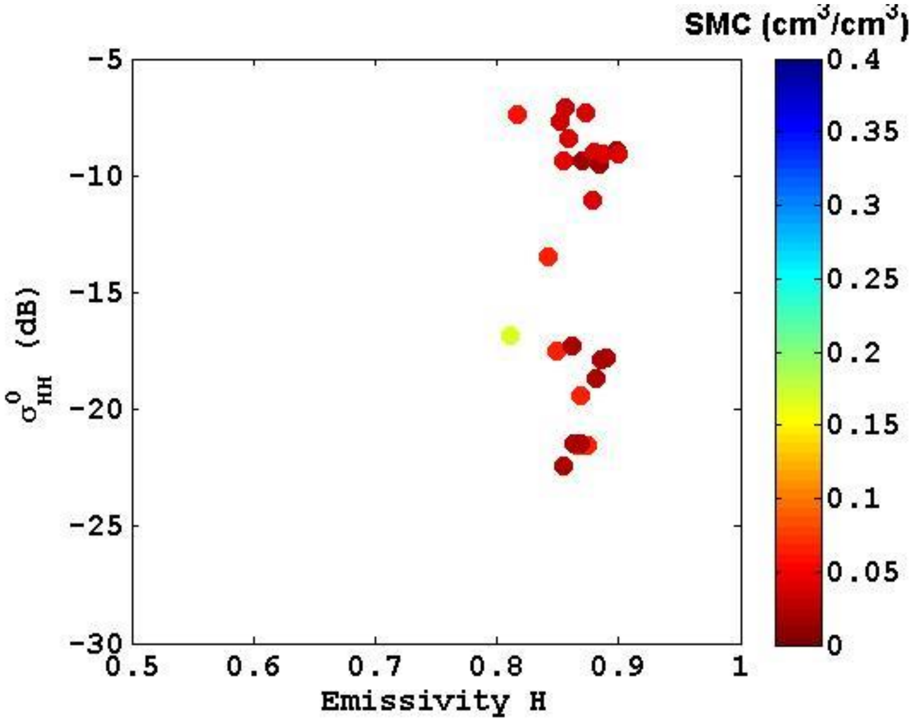
(Guerriero et al, JSTARS 2016)

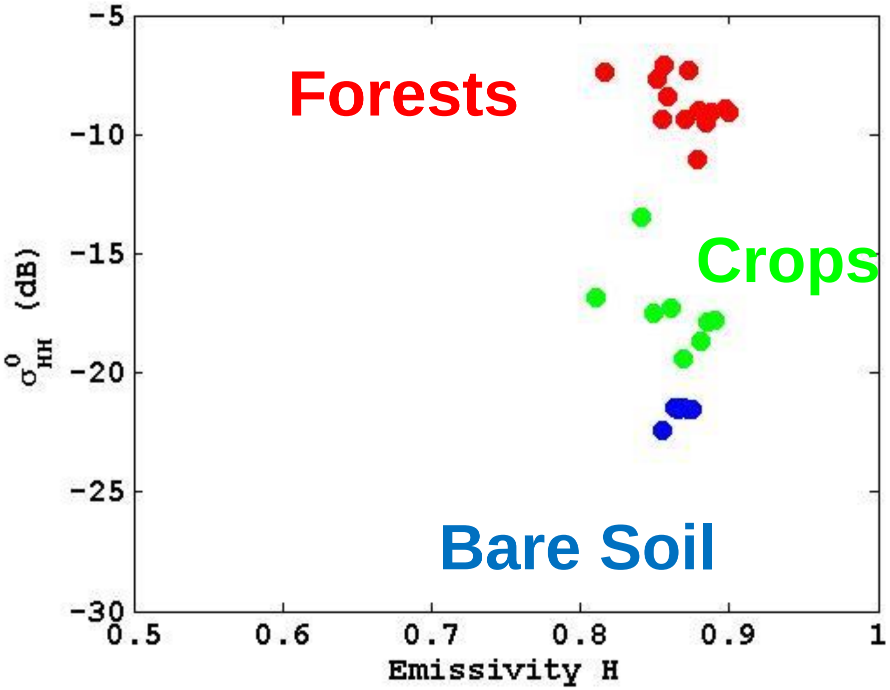


Active-Passive Experimental data

SMAPEX 2011

Airborne campaign over the Gillenbah Forest (Australia) with PLMR radiometer and PLIS scatterometer.





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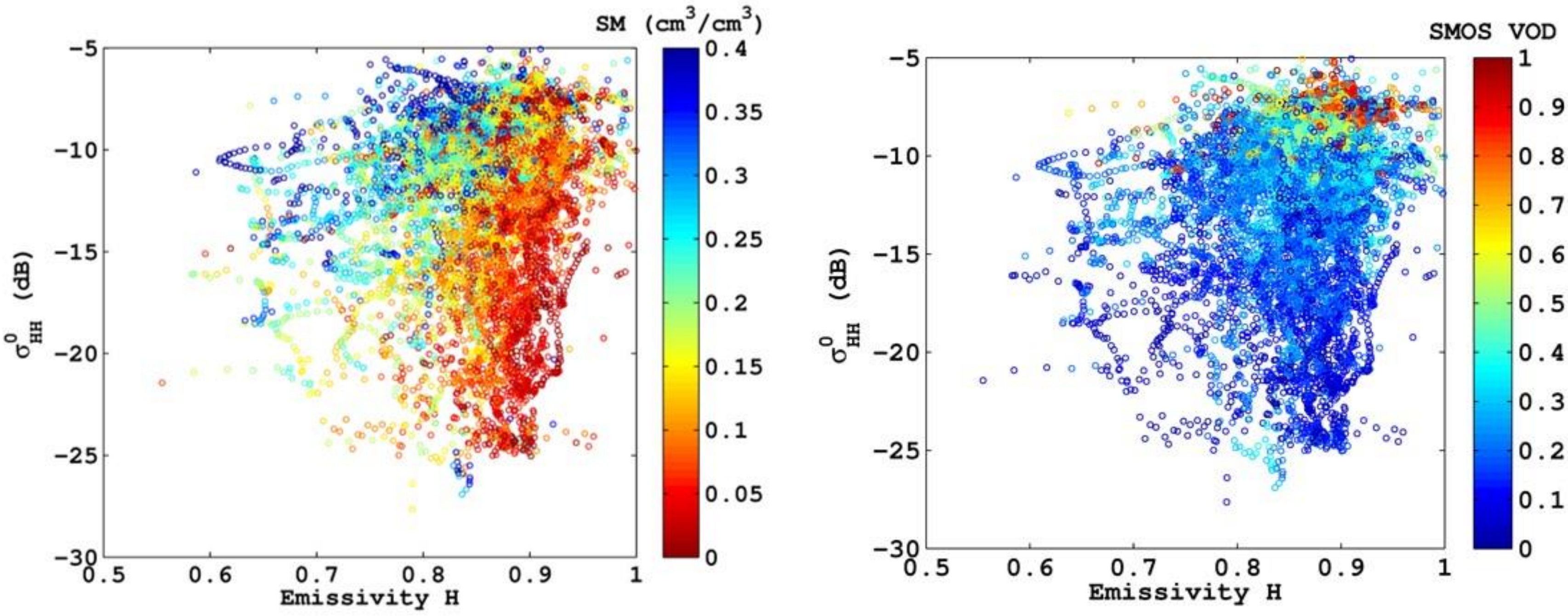
AQUARIUS AND SMOS

σ°HH and *e*H data from Aquarius (beam 3) are combined with SMOS L3 Vegetation Optical Depth (VOD) and Soil Moisture (SM), for the closest pixels.

All orbits on 1, 2, 3 July 2012. Pixels with RFI were discarded.



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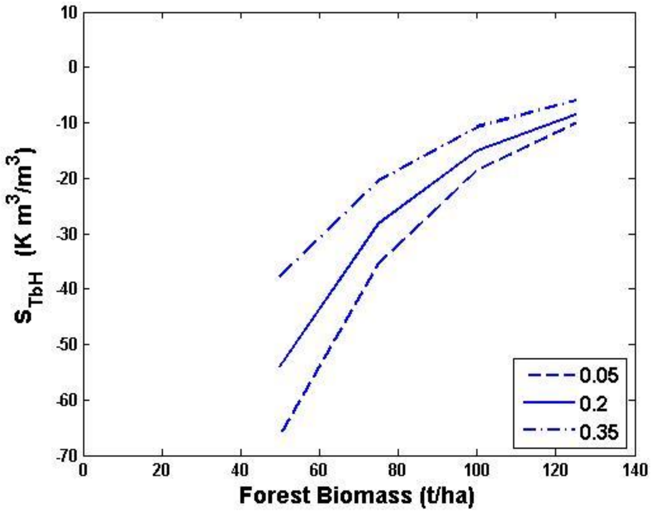
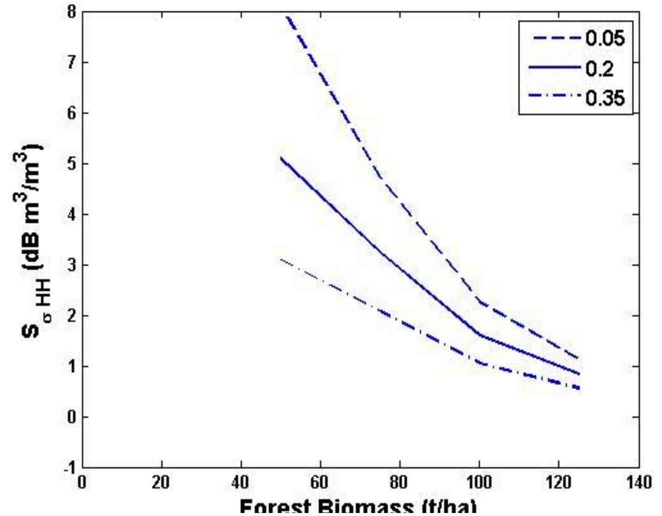
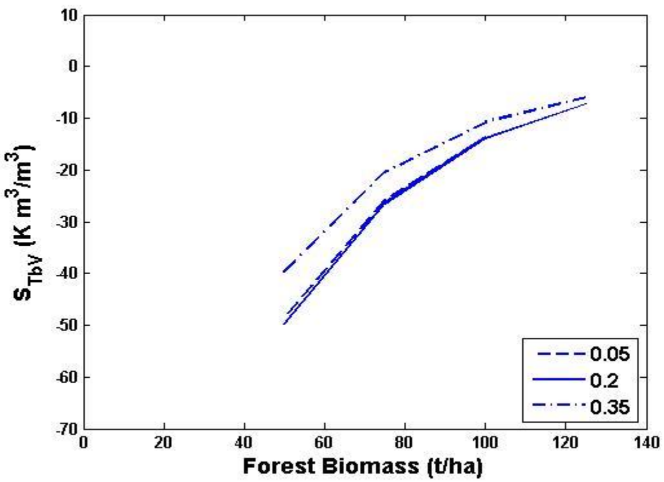
Simulated sensitivities to SM

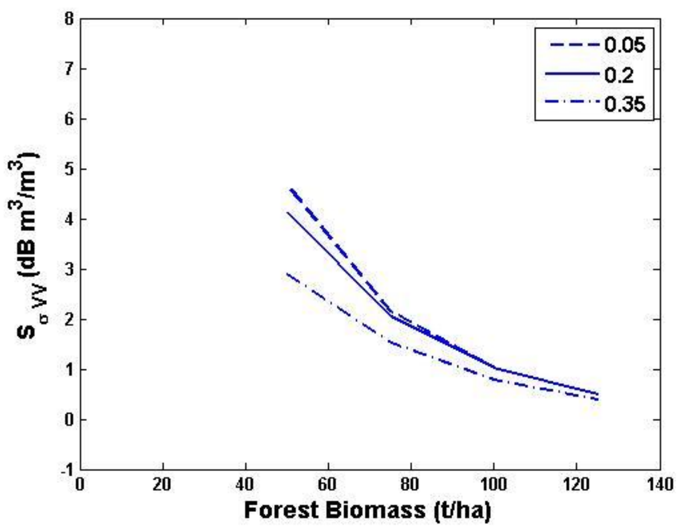
Brightness Temperature

Backscattering coefficient









L band radar:

Useful to precisely identify forest cover,
but
poor dynamic range related to SM variations under forests.

Further investigations with L and C band are in progress:
SIMULATING L/L-BAND AND C/L-BAND ACTIVE-PASSIVE COVARIATION OF CROPS WITH THE TOR VERGATA SCATTERING AND EMISSION MODEL FOR A SMAP-SENTINEL 1 COMBINATION
M. Link, D. Entekhabi, T. Jagdhuber, P. Ferrazzoli, L. Guerriero, M. Baur, R. Ludwig
Presentation at IGARSS 2017

Suggestions for future experiments

- Select pixels at different latitudes;
- Cover SM measurements with sufficient sampling;
- Consider the fundamental importance of branches;
- Investigate seasonal variations of wood permittivity and litter properties;
- Monitor vertical distribution of temperature.