SMOS Long term Validation and Forest retrievals

Yann Kerr
Paolo Ferrazzoli, Cristina Vittucci
Mike Schwank
And
The SMOS team

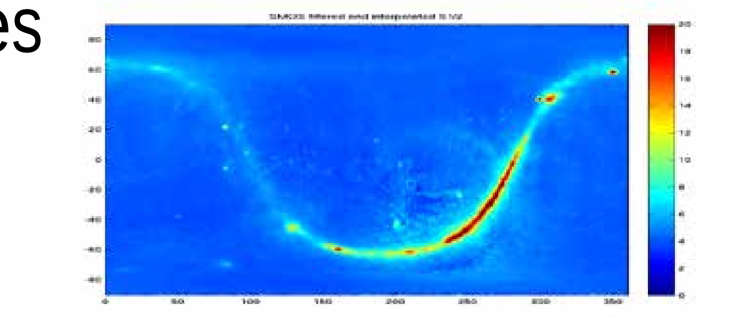
layout

- Calibration
- Validation of SM
- Validation of VOD
- Validation for Forest
- SNOW and forest
- Concluding remarks

First step: Calibration

q Comparison at TB level are conducted over various surfaces of known temperatures

- v Galactic background
- v Ice sheet (Antarctica)
- v Ocean bodies



SMOS' view of the Galaxy

q Or other similar sensors

- v Based on near simultaneous, **iso geometry**
  - ØLand
  - ØOcean
- v Ice core around Dome Concordia
- v Compared TBs are ToA, without reflexion foreign source corrections (gal, sun, moon)

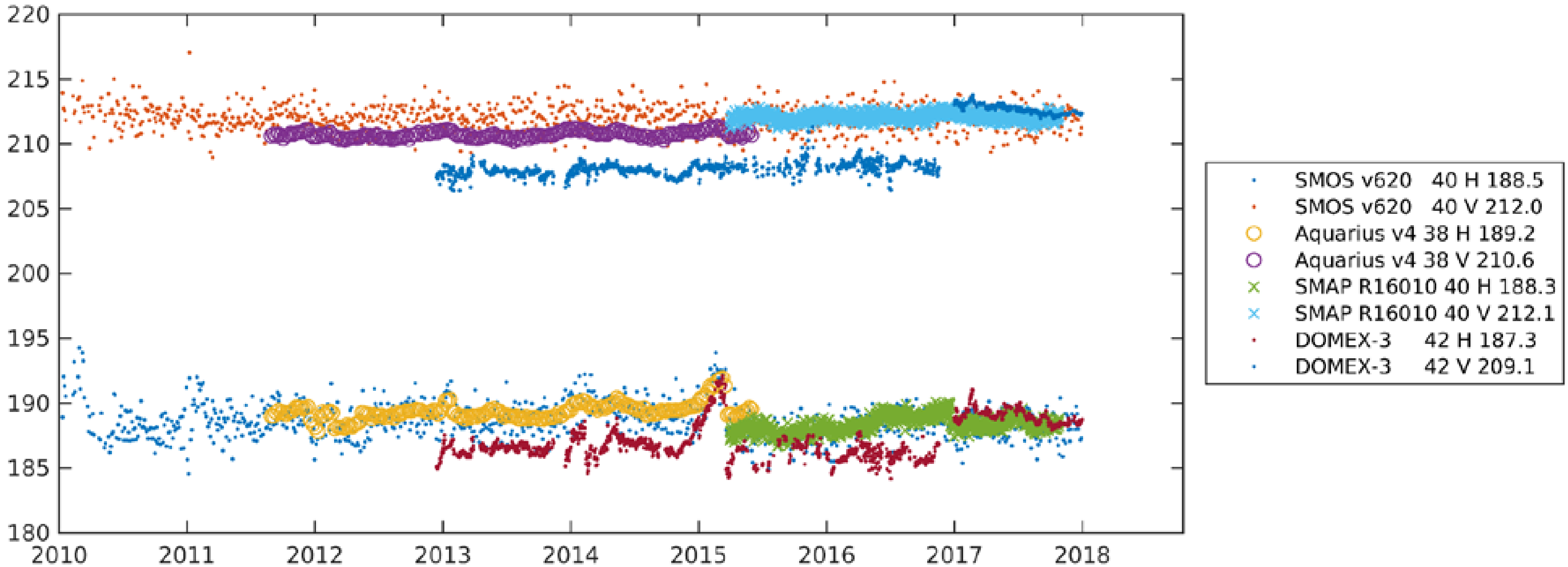
q NB SMOS BT available in NRT since the beginning

Level 1 validation

SMOS different from SMAP rely on colad (Deep sky) and hot target (noise source)
Interferometer using 3 NIR
no spill over, reflector characteristics, radome to account for

Close agreement between SMOS, SMAP and Aquarius
Latest DomeX calibration also improves match (reprocessing is on-going)

See also Bindlish & Chan



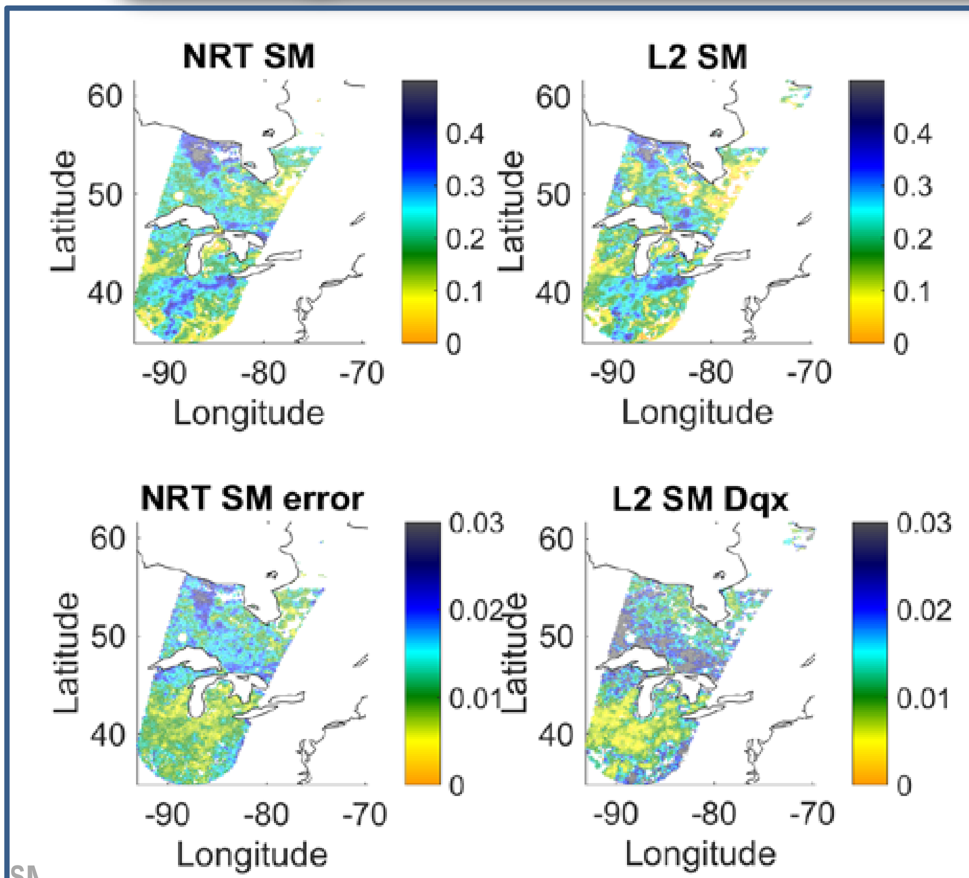
SMOS SM products to be validated

- Standard products
  - Level 2
    - New version includes better L1 (GIBBS2, Sun corrections, galactic, ...)
    - Implemented in V7 à organic soils, new forest parameterisation
  - Level 3
    - Bug identified and being corrected
  - L2 SM near real time
    - New version implemented at ECMWF
    - Used in assimilation Scheme
- Science products
  - Root zone soil moisture
  - SMOS-IC
    - Same as L2 but without antenna pattern correction and main land use retrievals
    - Trained on ISMN
    - Fast computations

Near Real Time SM

- Training on SMOS Level 2 v620 SM
- Similar performances (slightly better indeed)
- Much faster ! Less than 3.5 hours after sensing

Rodriguez-Fernandez et al. (2017, HESS)



Implemented by : ECMWF

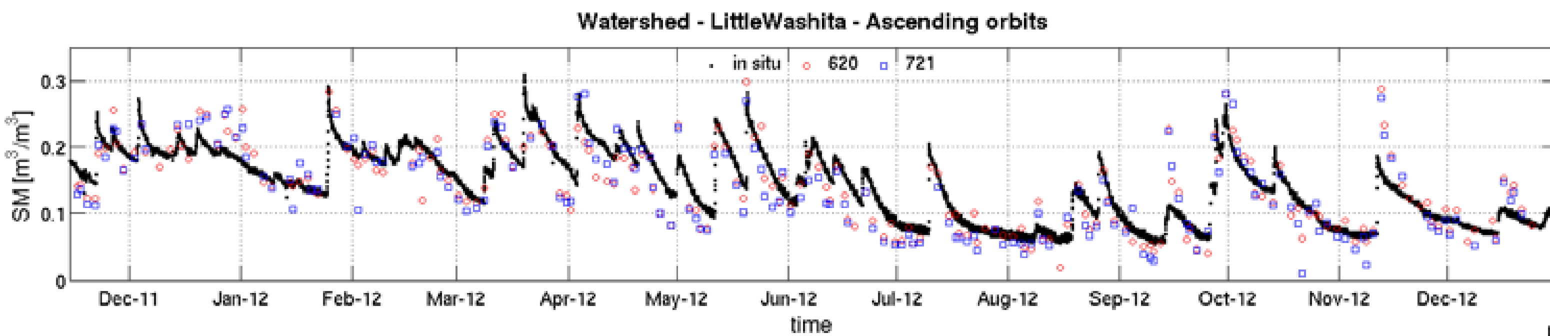
With support by : CESBIO

Delivered to : esa

Disseminated by: EUMETSAT, esa

Validation scheme (1/3)

- « Matchups » concept
  - Issues with continuity (9 years is long!)
  - approach (model based) deficient à knowledge of the area)
  - Limited results (UDB, VAS, …)
- Core sites
  - Based on available reliable areas
    - USDA watersheds
    - Australian sites (AACES, J Walker)
    - Specifically designed sites (HOBE)
    - Science based sites (Berambadi (India) also used for 1 km products, Igarka (Russia), Davos (Switzeland), Sodankylä (Finland), St hilaire and SMOSRex (France), Poland, Tibet, …)
  - Not enough of them!

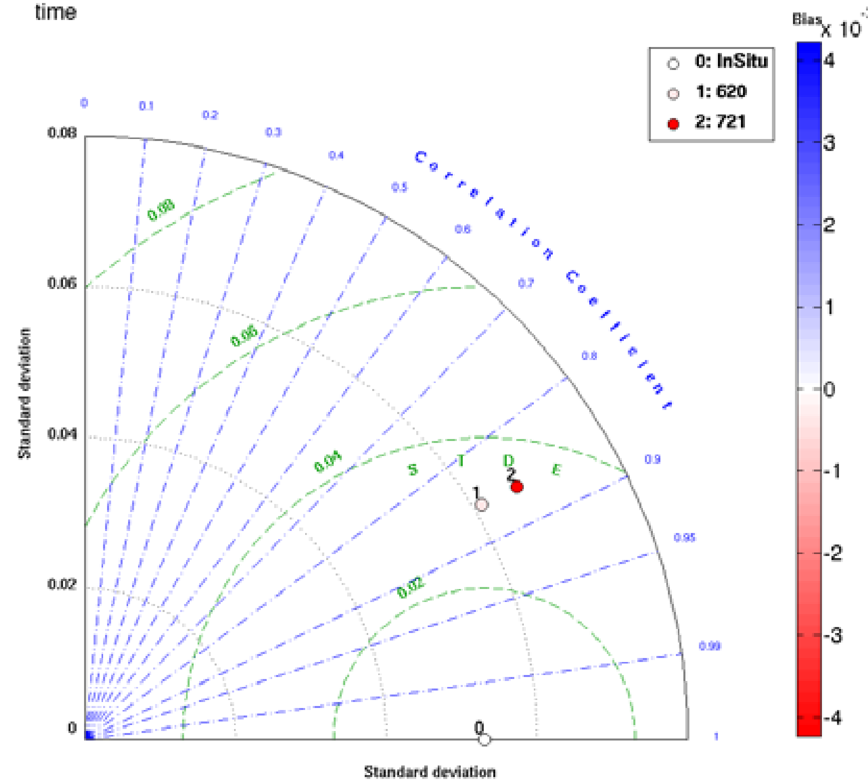


Δ Stats: Series minus Insitu - Intersected Valid Retrievals

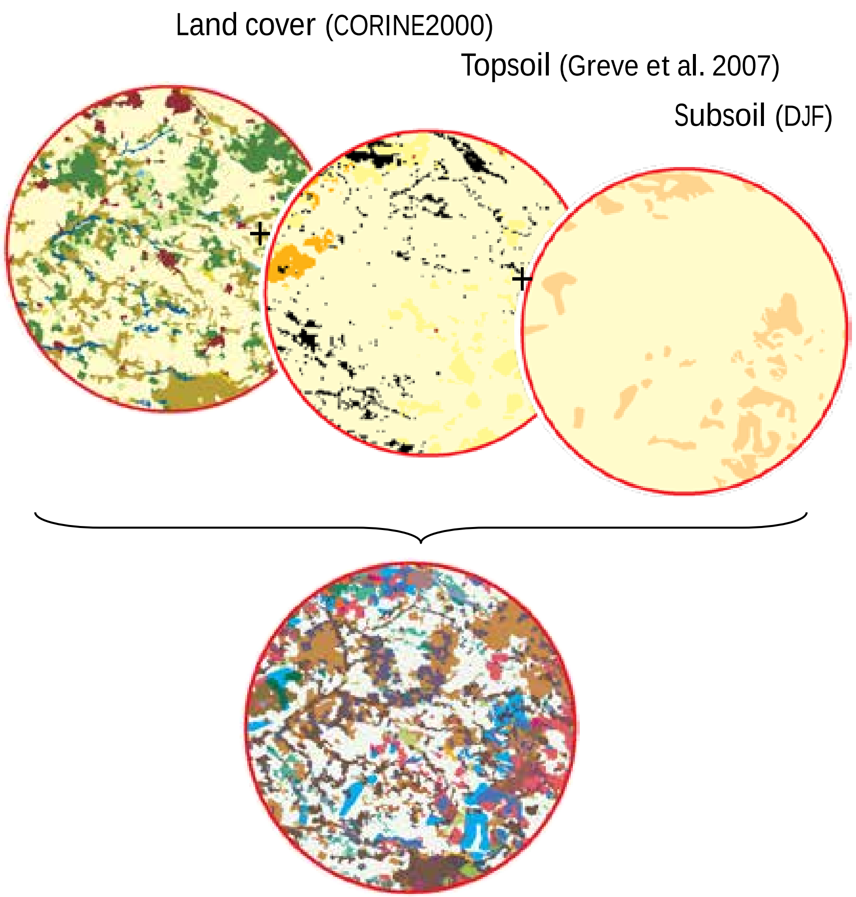
Series	ρ	μ	σ	RMSE	#kept	#total
620	0.86	-0.000	0.031	0.031	182	205
721	0.86	-0.004	0.034	0.034	182	187

Stats Series/Insitu

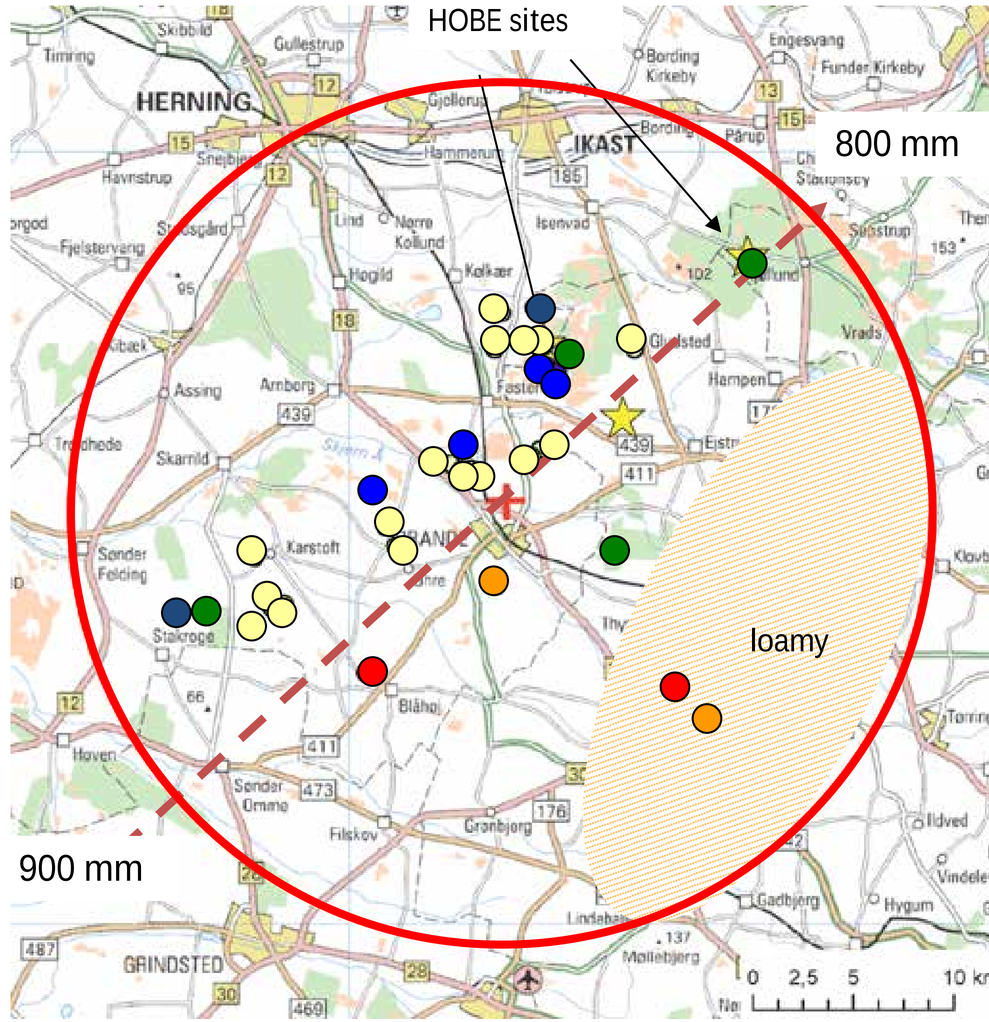
Series	μ_{Series}	μ_{Insitu}	σ_{Series}	σ_{Insitu}
620	0.142	0.143	0.061	0.053
721	0.138	0.143	0.066	0.053



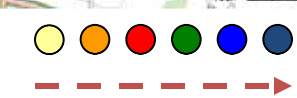
Soil moisture & temperature network, 30 stations: since Jan 2010
Decagon 5TE sensors at 0-5, 20-25 and 50-55cm depth + organic layer



6 composite classes = 82%

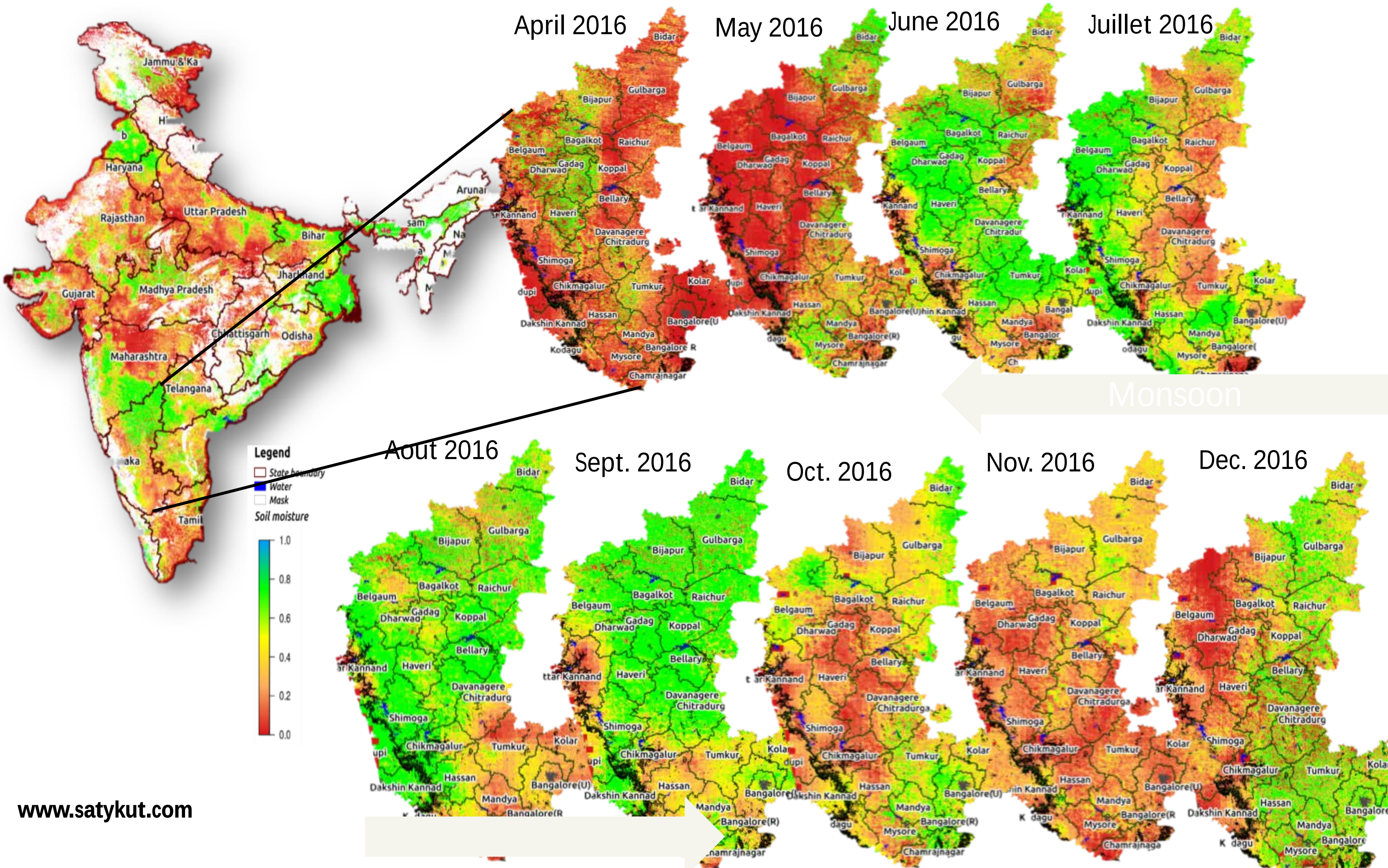


à stations distributed among them according resp. fractions...
à aligned along long-term annual precipitation gradient:



S. Bircher

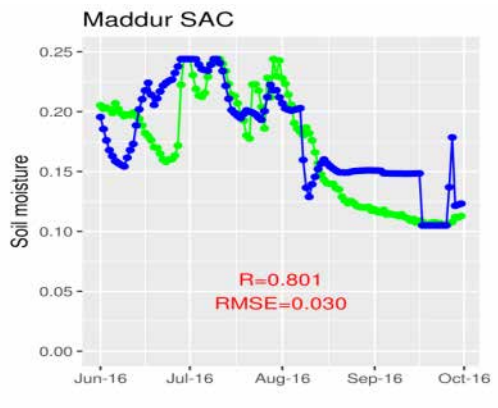
Sub-kilometric soil moisture (SMOS+S1 -500m)

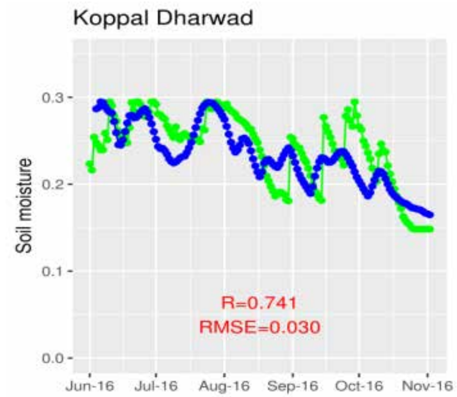


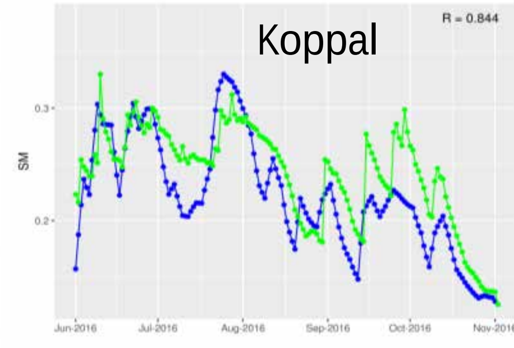
www.satykut.com

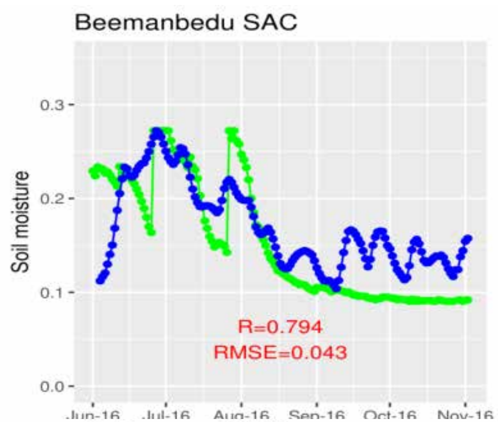
Al Bitar, Tomer

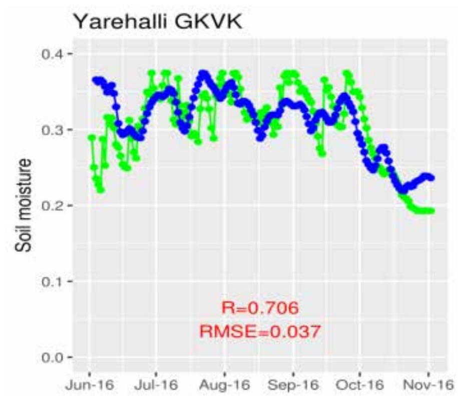
Validation of MAPSM: SMOS+S1

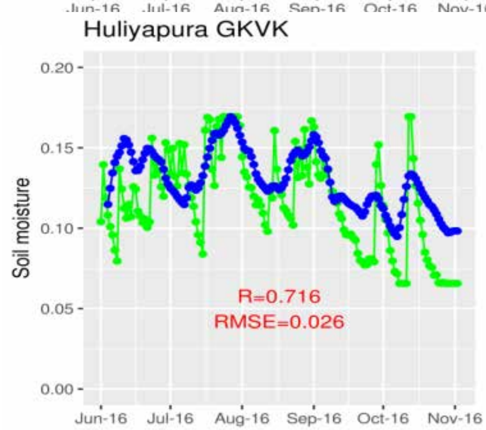


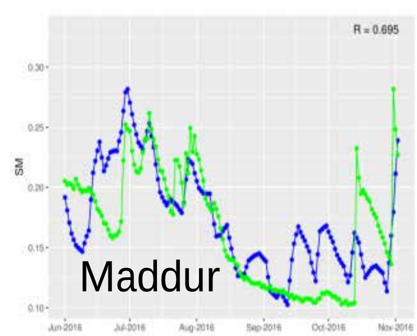












airfax 2018 10 23 YHK

Al Bitar, Tome

Active/Passive Remote Sensing of Snow

SNF-Proposal “APRESS ”

Applicant:

Mike Schwank, WSL-Birmensdorf

Partners:

Martin Schneebeli, SLF-Davos
Andreas Wiesmann, GAMMA
Juha Lemmetyinen, FMI

Emploee:

Reza Naderpour

Requested Funding:

300 kCHF » 273 k€

Decision Date:

1st October 2018

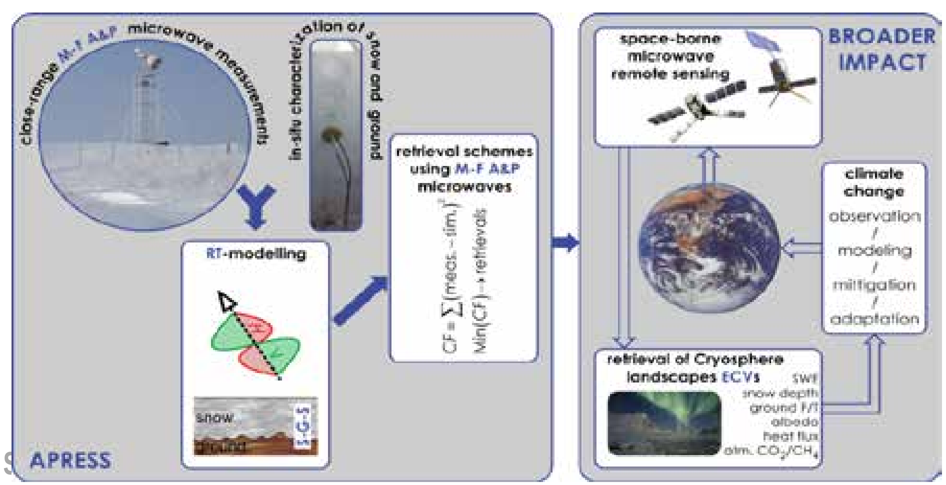
Duration:

» 2 years: 1st April 2019 – 31 March 2021

APRESS Goals:

Methodical research to advance synergistic use of Multi-Frequency Active & Passive (M-F A&P) microwave data.

Improve / develop retrieval approaches for estimation of state parameters over the Earth’s cryosphere.



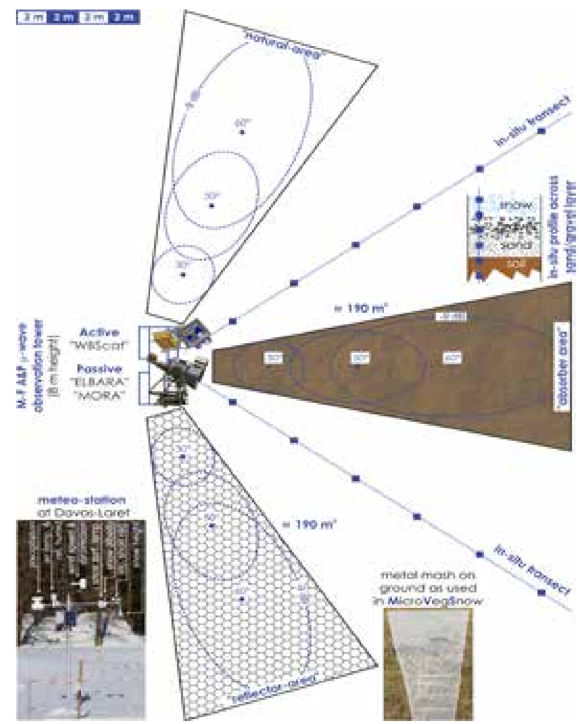
Two Winter-Campaigns:

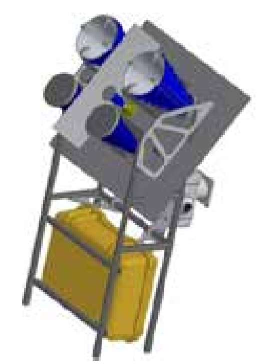
2019/20: Davos & 2020/21: Sodankylä

Microwave Sensors:

Passive: L- and X-band (ELBARA, MORA)

Active: L- to Ka-band (WBScat)

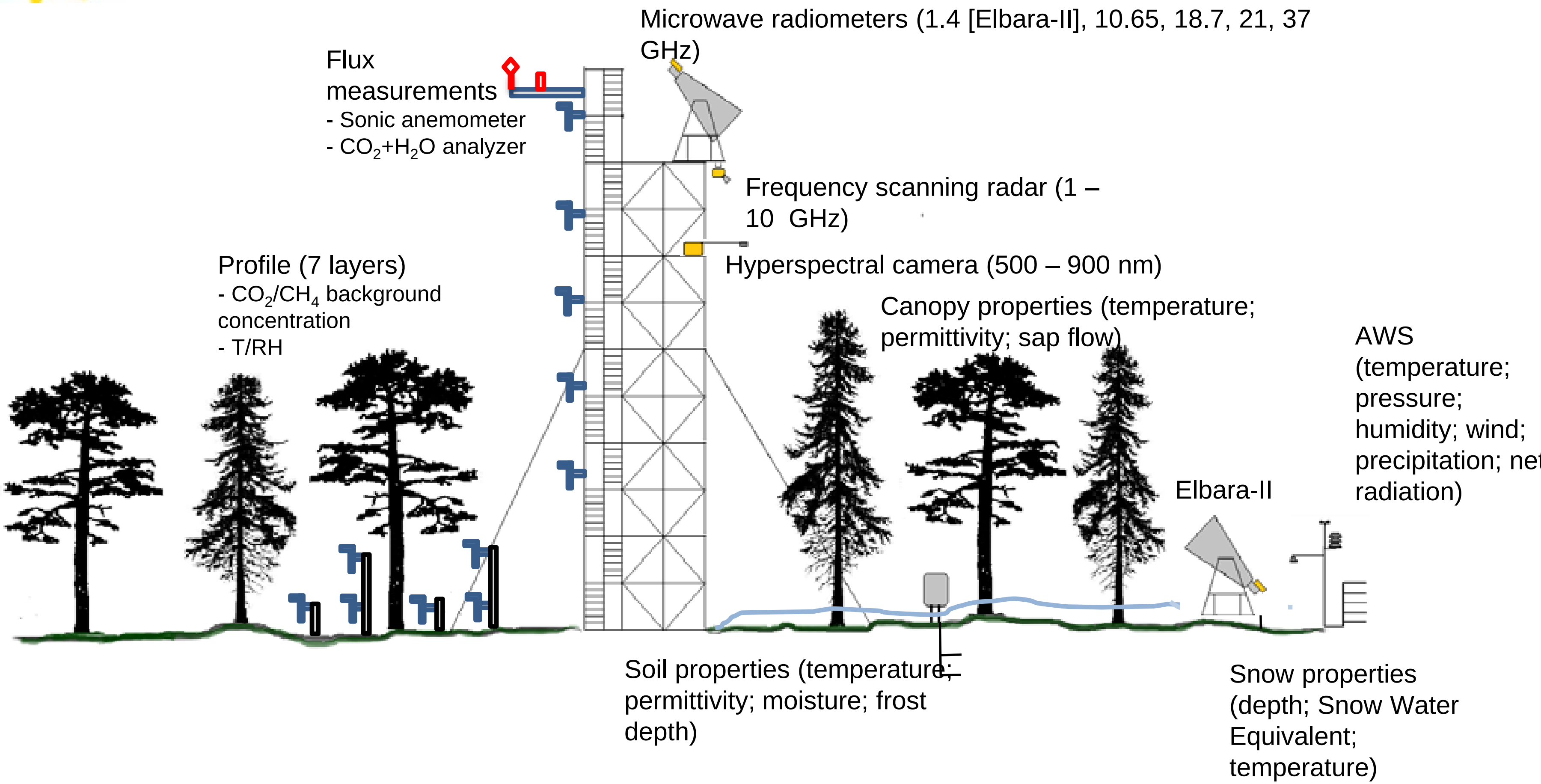




WBScat (SAR, L – Ka-band Scatterometer)

developed by GAMMA under ESA-contract with WSL-contribution for L-band part.

Test in Davos during winter 2018/19



Microwave radiometers (1.4 [Elbara-II], 10.65, 18.7, 21, 37 GHz)
Flux measurements
- Sonic anemometer
- CO_2+H_2O analyzer
Frequency scanning radar (1 – 10 GHz)
Hyperspectral camera (500 – 900 nm)
Profile (7 layers)
- CO_2/CH_4 background concentration
- T/RH
Canopy properties (temperature; permittivity; sap flow)
AWS (temperature; pressure; humidity; wind; precipitation; net radiation)
Elbara-II
Soil properties (temperature; permittivity; moisture; frost depth)
Snow properties (depth; Snow Water Equivalent; temperature)

ICOS tower

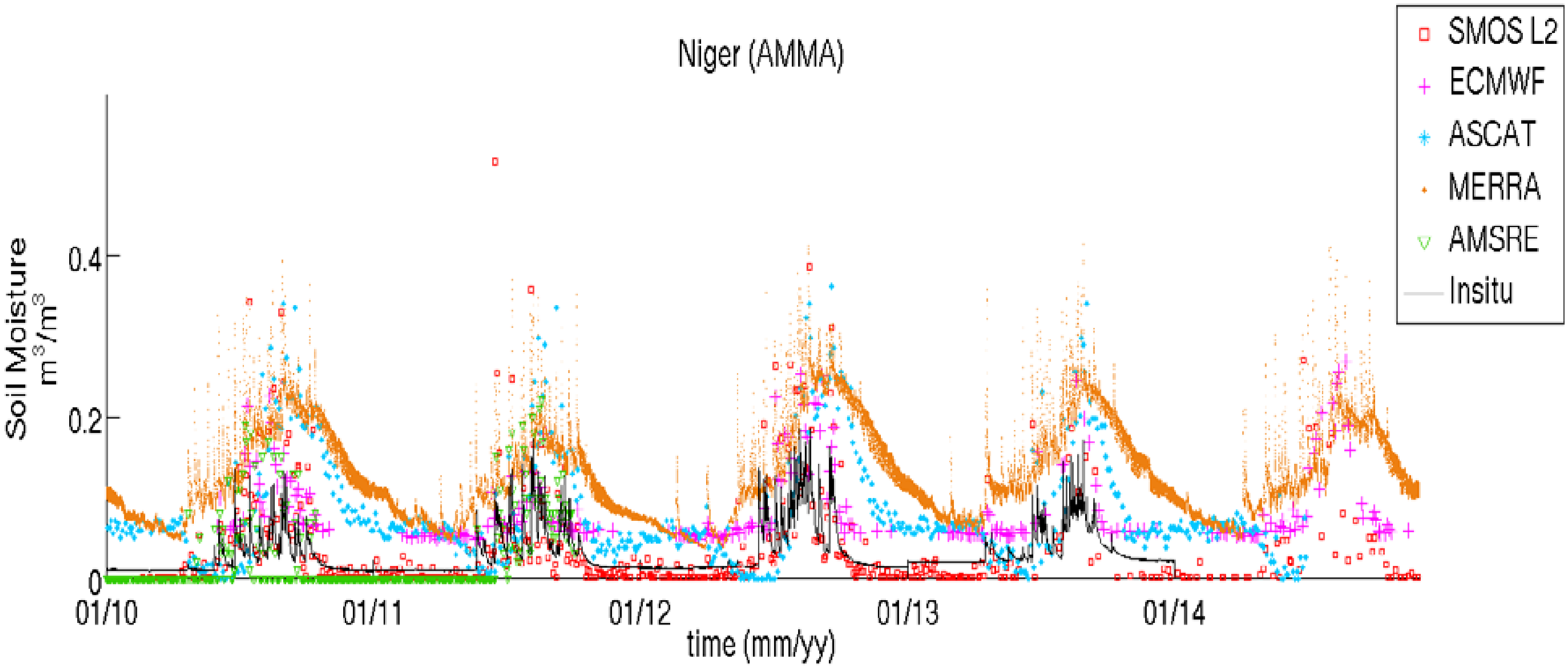
- 24 m high platform overlooking scots pine forest
- Setup following ICOS (Integrated Carbon Observation System) standards
  - CO_2 flux; CO_2, CH_4 background concentration
  - meteorological measurements, surface measurements
- RS equipment:
  - Elbara II (1.4 GHz)
  - High frequency dual pol radiometers (10.65, 18.7, 21, 37 GHz)
  - Fully polarimetric radar (1-10 GHz)
  - Hyperspectral camera (500-900 nm)
  - Webcams
  - Additional Elbara II at ground level (upward-looking canopy transmissivity)
- Supporting in situ instrumentation:
  - Soil moisture and temperature profile
  - Sap flow (dendrometers)
  - Vegetation temperature
  - Vegetation permittivity
  - Snow depth, SWE, temperature
  - Frost tubes
- Situation September 2018
  - RS equipment installed in tower; start of measurements October 2018
  - second ground-level Elbara-II: installation October 2018
  - ICOS installation completed
  - Supporting in situ instrumentation: completion in October 2018

Validation scheme (2/3)

- Sparse networks
  - Pros
    - Easily accessible
    - Somewhat normalised , QC etc… (ISMN)
  - Main caveats
    - not representative of all biomes (Tropical, Boreal,…)
    - Often used for tuning / parameter fitting
    - Not necessarily representative of the pixel
- Models
  - Global but not necessarily valid everywhere
  - Can be severly biased
  - But scale similar to taht of satellite data

Models and “proxy” sensors give erroneous estimates

A. Mialon



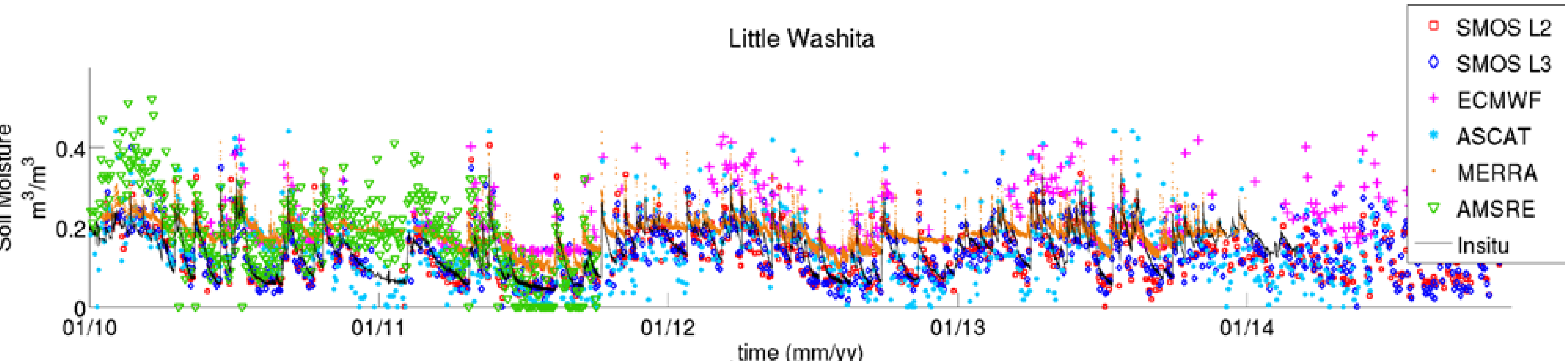
Very important region:

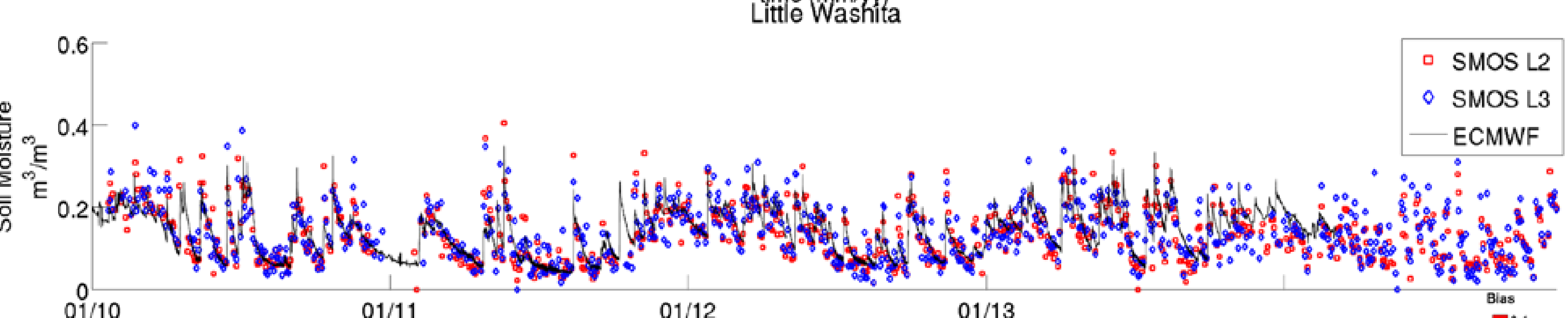
- Hotspot (land feedback to atmosphere, Koster et al., Seneviratne et al.)
- Very little in situ data to constrain weather models -> Remote sensing

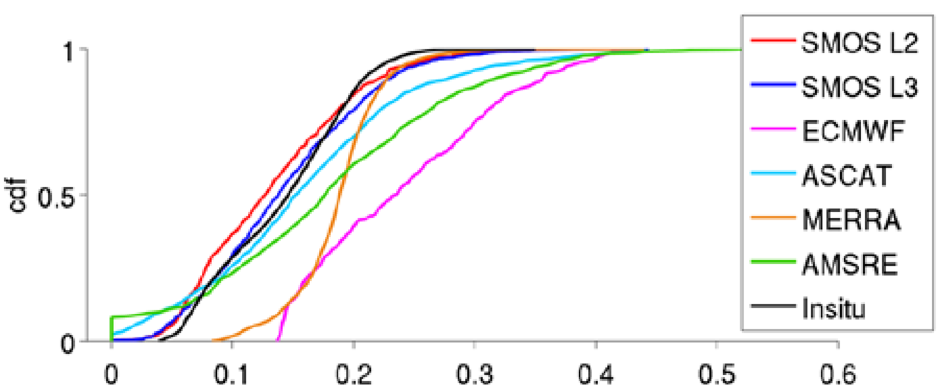
Validation scheme (3/3)

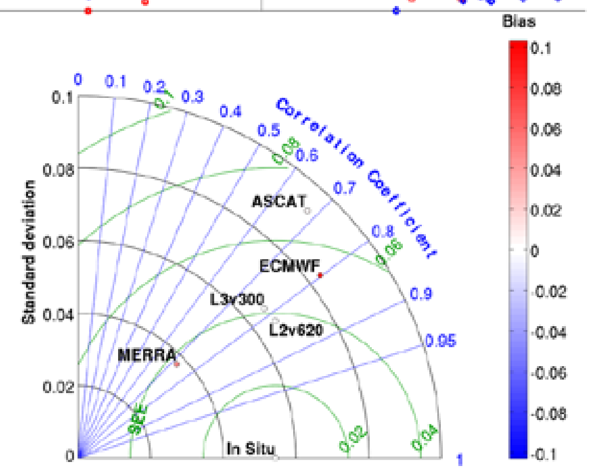
- Satellite data
  - See next talk
  - To be noted
    - Approach more important than Sensor when all are good
- Field campaigns
  - Not very conclusive in Europe
  - For validation or for science ?
  - SMAP VEX

Little washita = temperate - flat

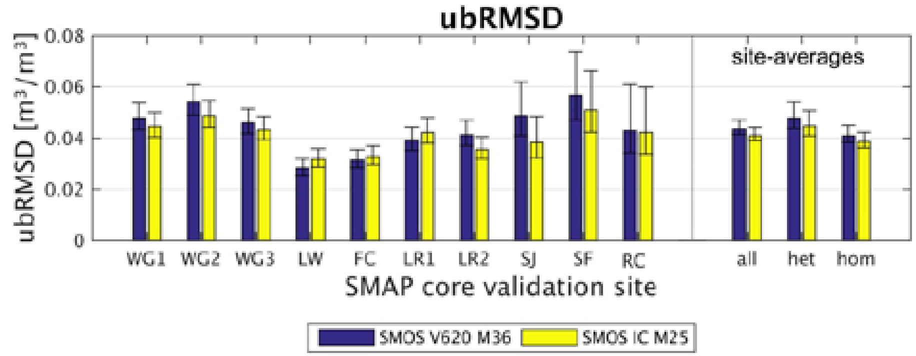




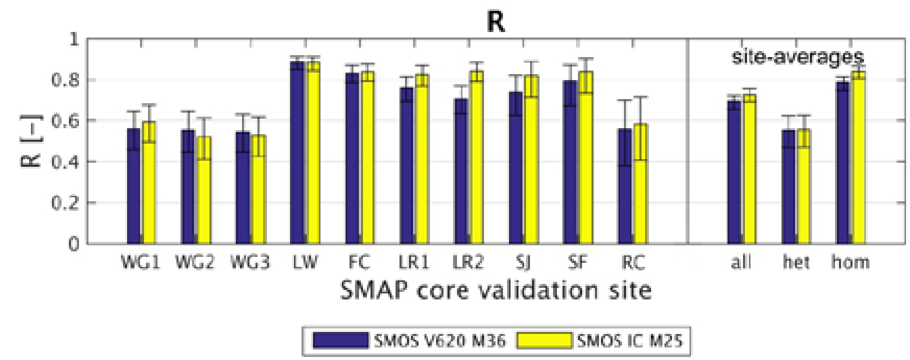




5-year time period (1 June 2010 ->31 May 2015)



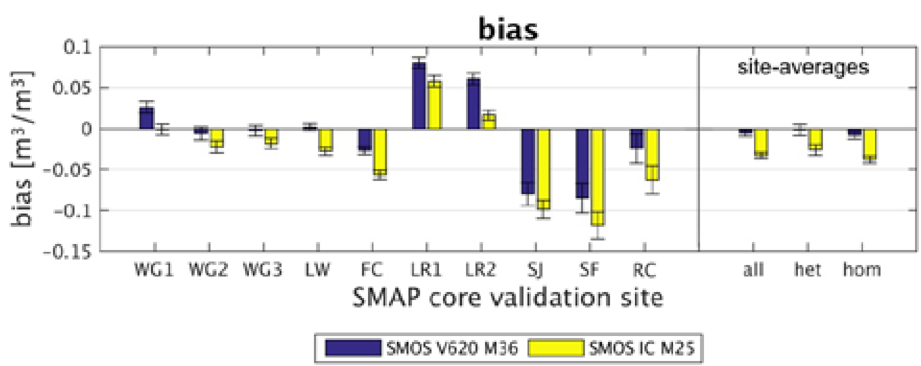
J. Quets, G. De Lannoy et al., 2017



(2) Intercomparison over the core SMAP cal / val sites

-SMOS IC V1

-L2 V620



L-VOD

q With multi angular views SMOS delivers SM + VOD

q Varies with time

v AGB

v VWC

q Has not yet unravelled all its potential

v First analysis very early (Ferrazzoli, Rahmoune, Vittucci)

v Comparison with AGB

q Main issue is with Validation!

v How

v What with

v ...

Forests

q Short summary of CalVal 2017 presentation

q New results

By Ferrazzoli and Vittucci
Tor vergata University

Requirements for spaceborne missions, including SMOS

- 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).

Preliminary fitting of RT parameters for forests

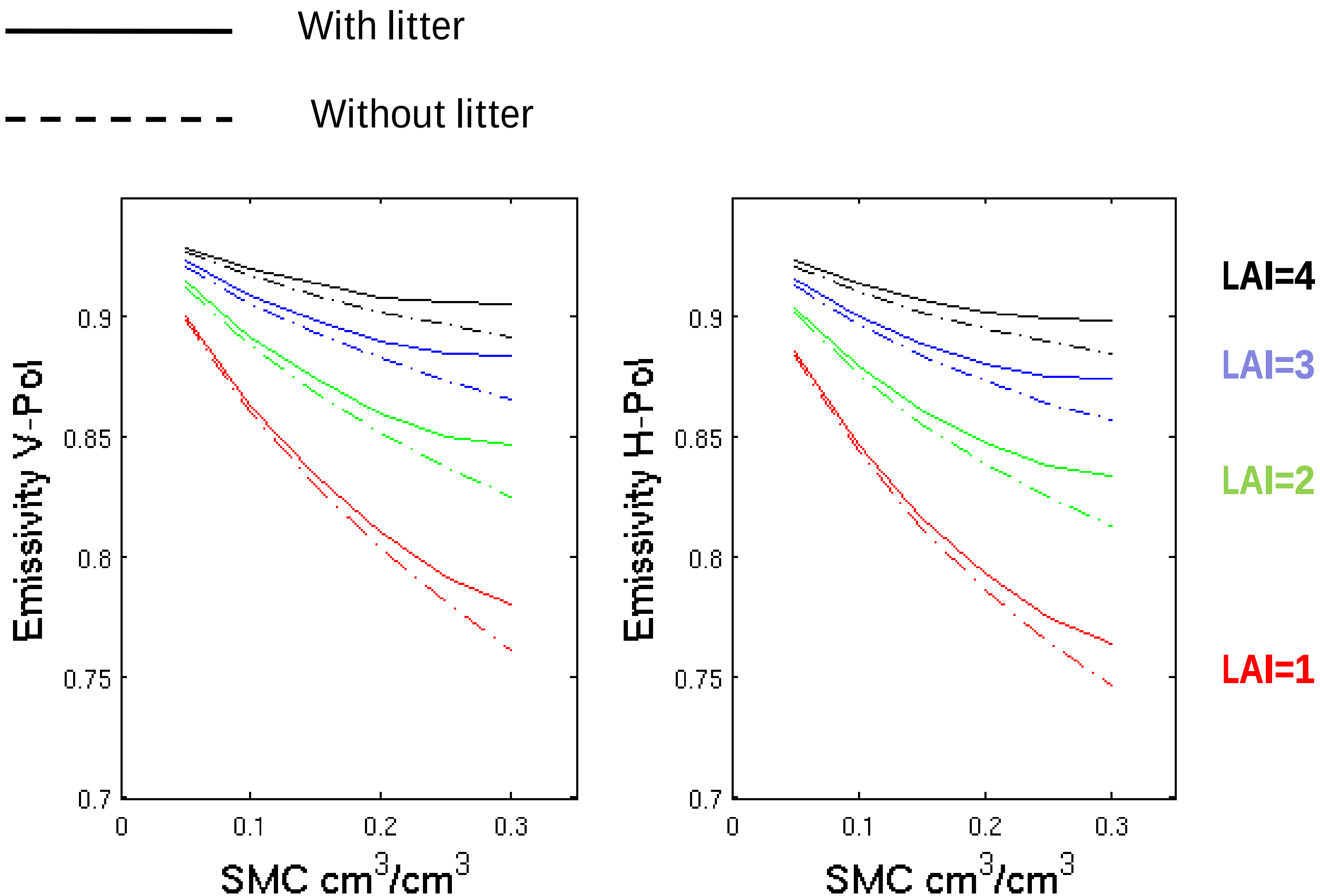
A discrete model was run. Model outputs were used to fit the albedo and the optical depth of an "equivalent" 1st order RT model.

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.

Examples of model simulations for deciduous forests, in full leaf development

Emissivity as a function of SMC at L band



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.

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:

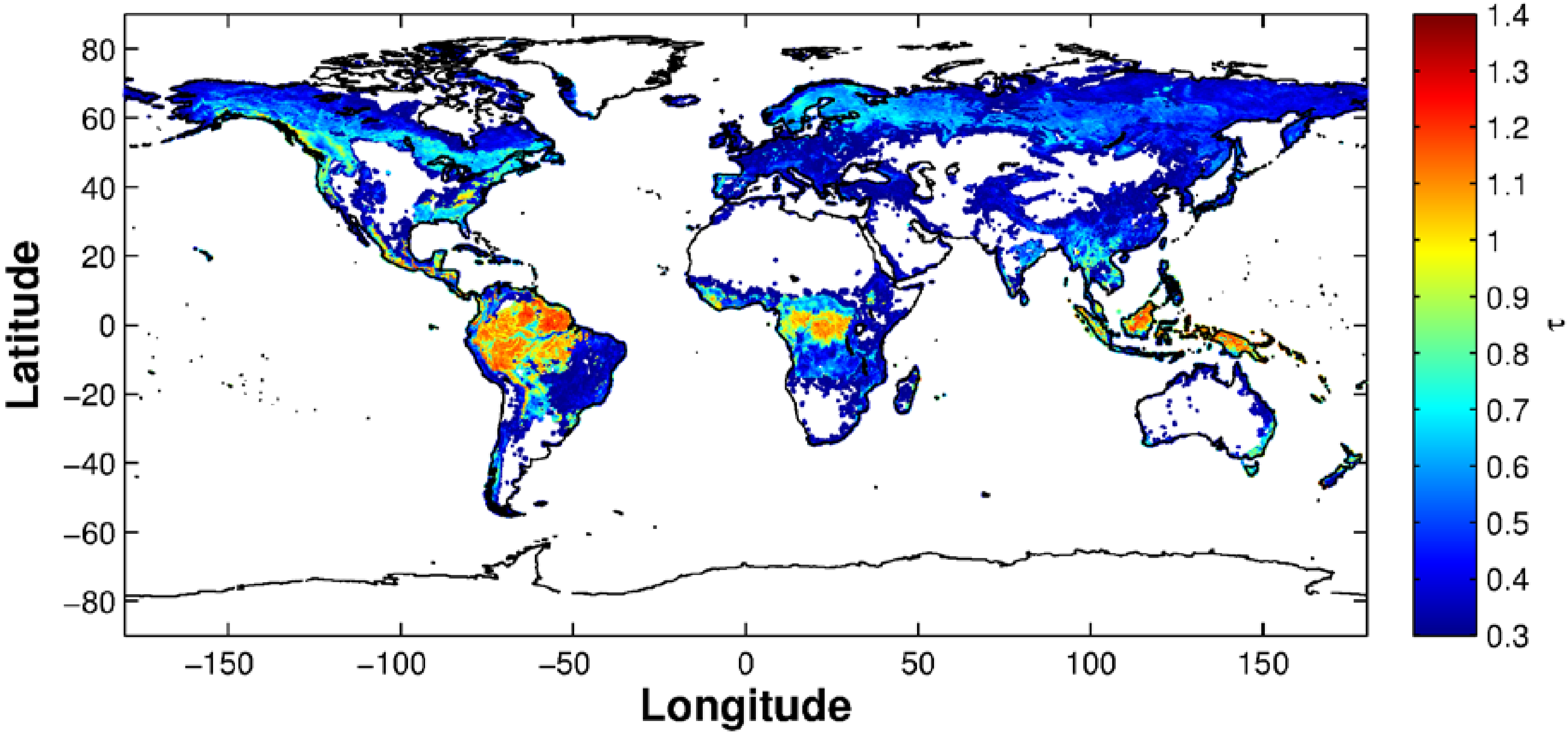
- The procedure suffers several approximations, since the complexity of the forest cannot be represented by the single LAI max parameter (particularly for needleleaf forests);
- LAI is also contributed by understorey;
- At large scale inhomogeneity effects must be considered;
- Litter effects are difficult 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:

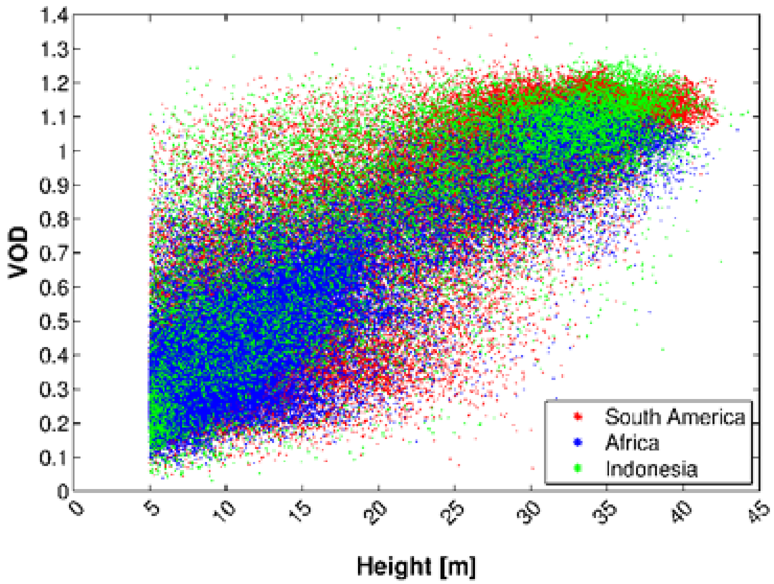
- Coefficients relating VOD to LAImax were reduced (by a 0.6-0.8 factor)
- The most appropriate albedo was 0.06.

Results obtained by SMOS L2 algorithm, 650 version

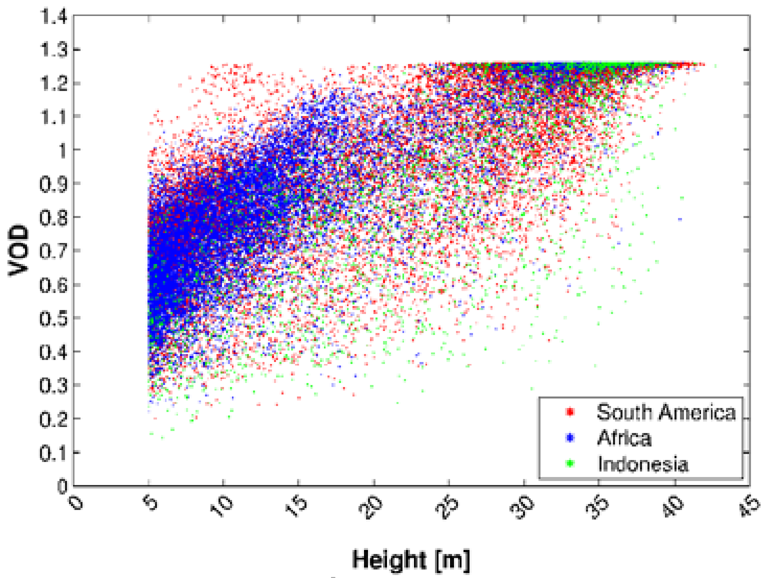
SMOS LVOD map (2015 average, LVOD>0.3 threshold)



Previous works monitored forest evolution using long term AMSR C-band VOD (CVOD), but CVOD saturates earlier than LVOD.



SMOS LVOD (2015 average) vs forest height



AMSR2 CVOD (2015 average) vs forest height

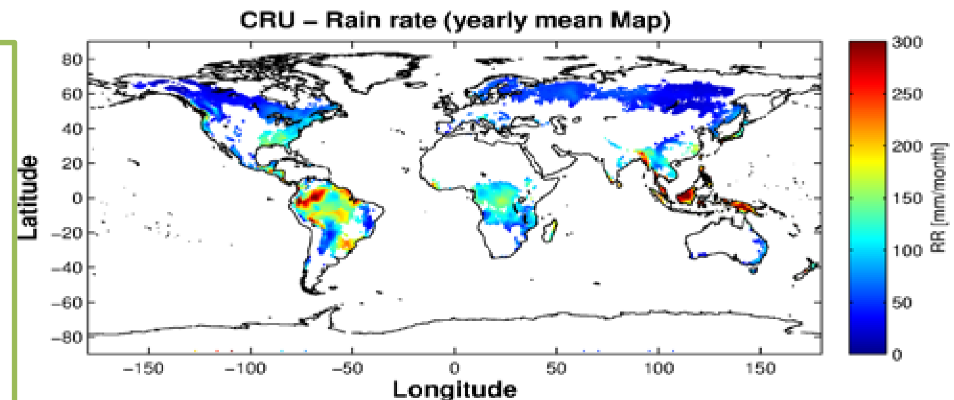
K

Comparisons with Climatological Research Unit (CRU) Dataset

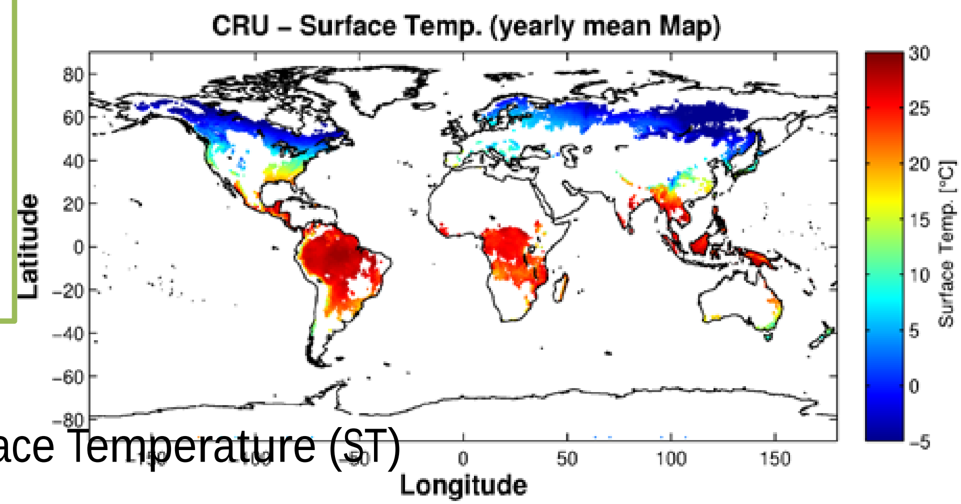
The Climate Research Unit data set is gridded to 0.5x0.5 degree resolution, based on analysis of over 4000 individual weather station records.

Examples:

Rainfall



Surface temperature



Yearly Surface Temperature (ST)

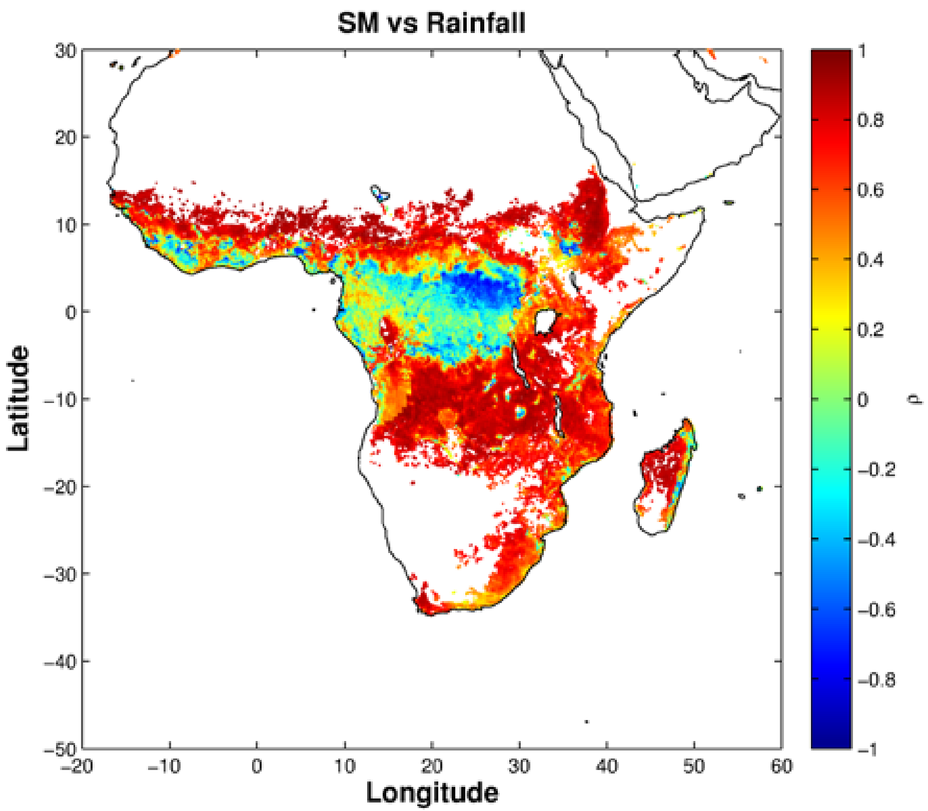
For areas with average vegetation height > 5m (from ICESAT lidar estimates) we have generated:

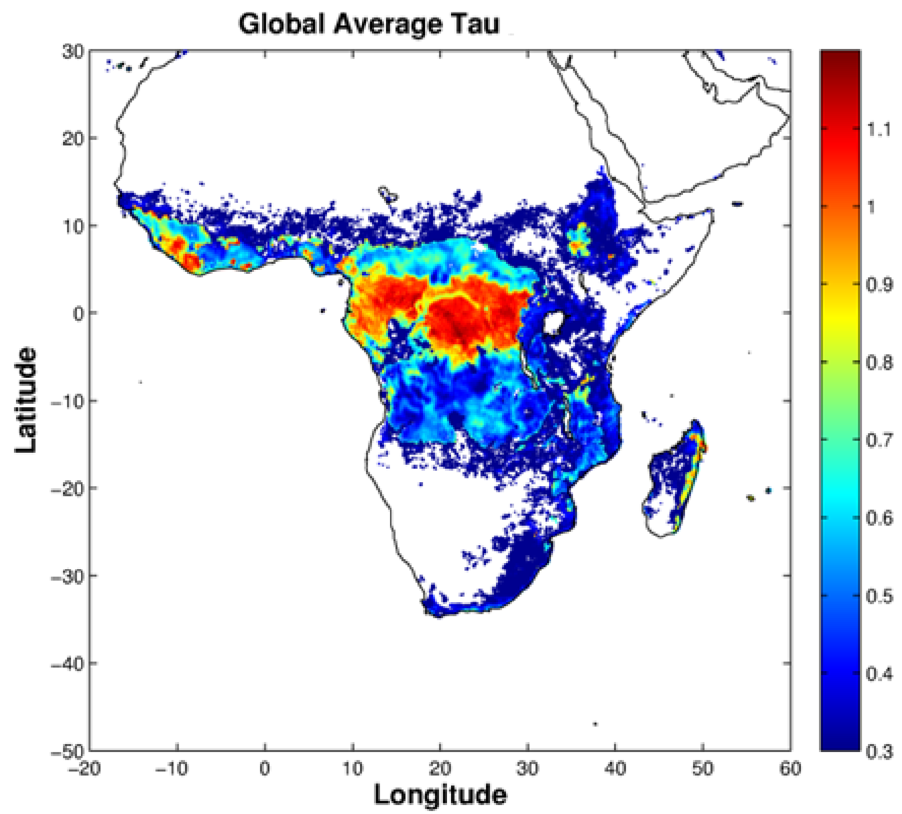
- Maps of correlation coefficients of retrieved SM vs rainfall R (monthly averages);
- Multitemporal trends of rainfall, temperature, retrieved SM, retrieved VOD for selected pixels.

Time interval: 2013-2016.

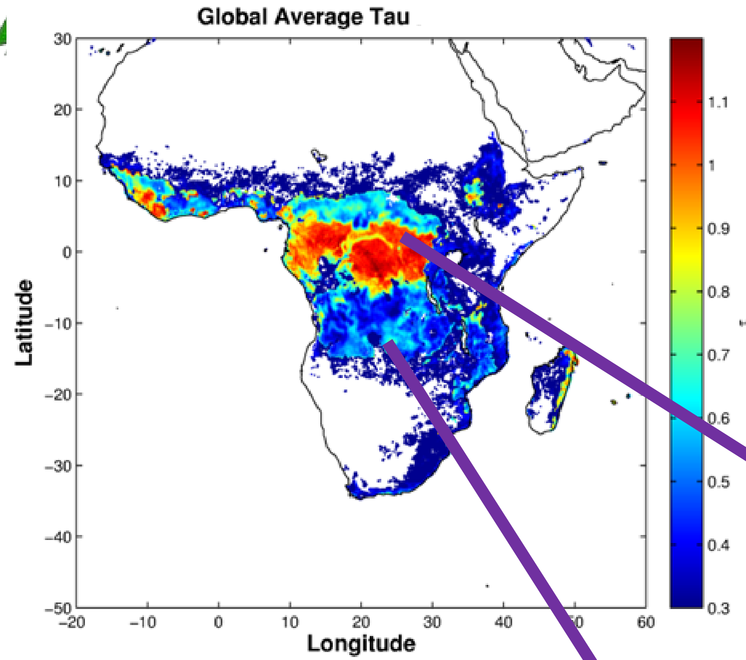
SM vs R correlation coeff.

LVOD

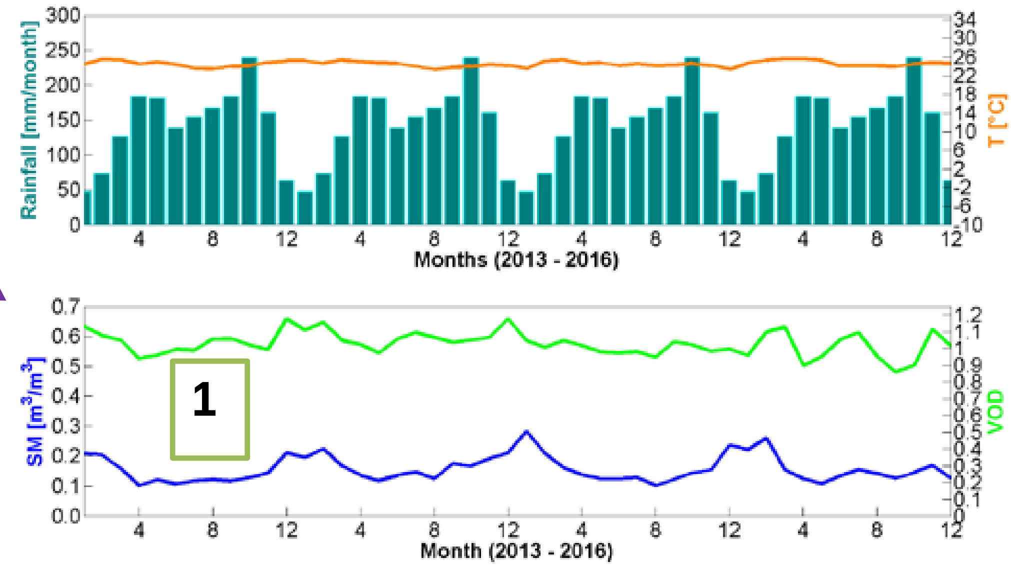


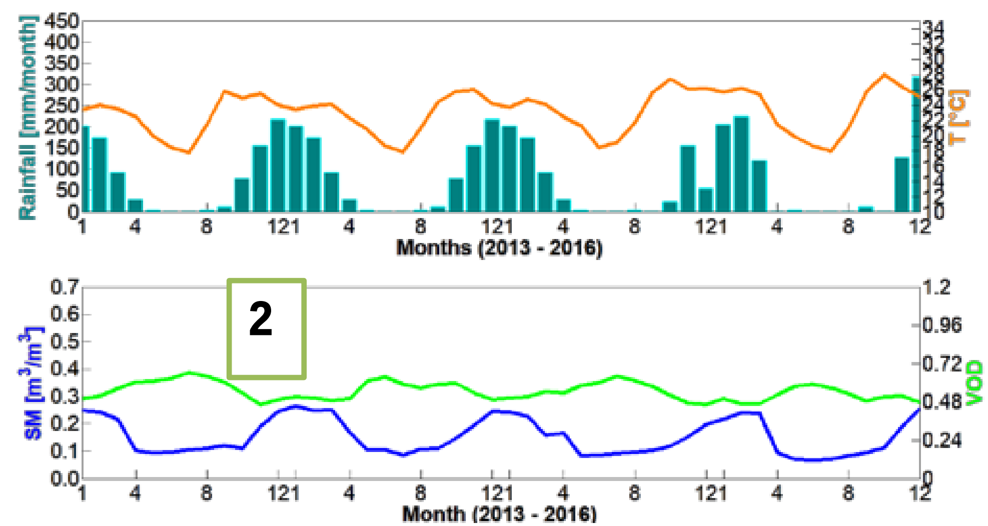


SM vs R correlation is kept up to LVOD ~ 0.7
Negative correlation along Ituri river (Congo)



Rainfall, Surface temperature, SM, LVOD



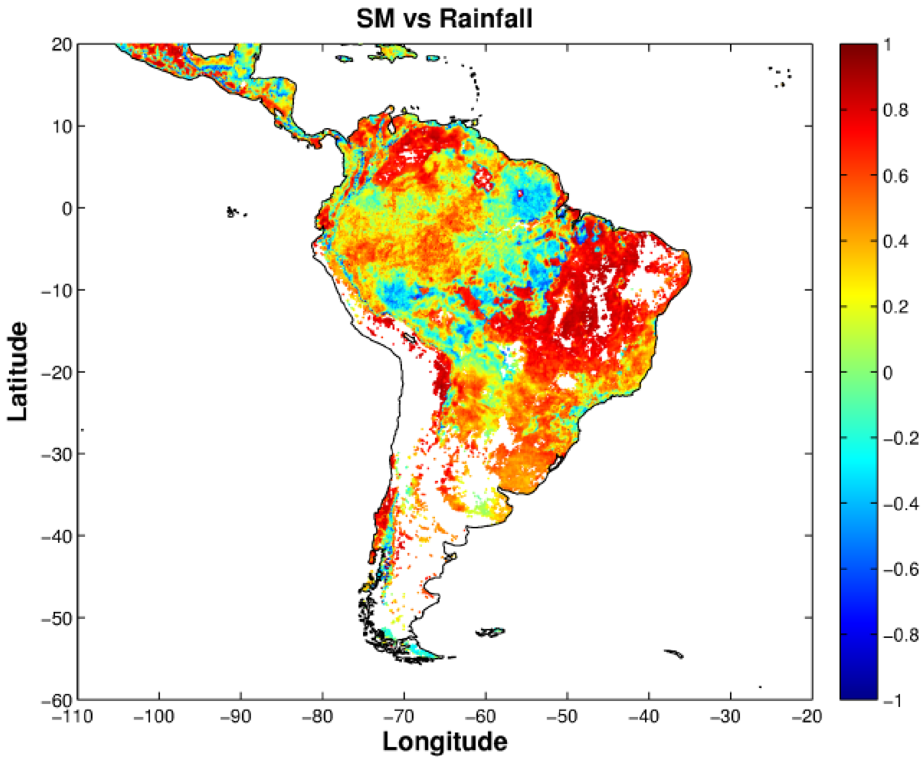


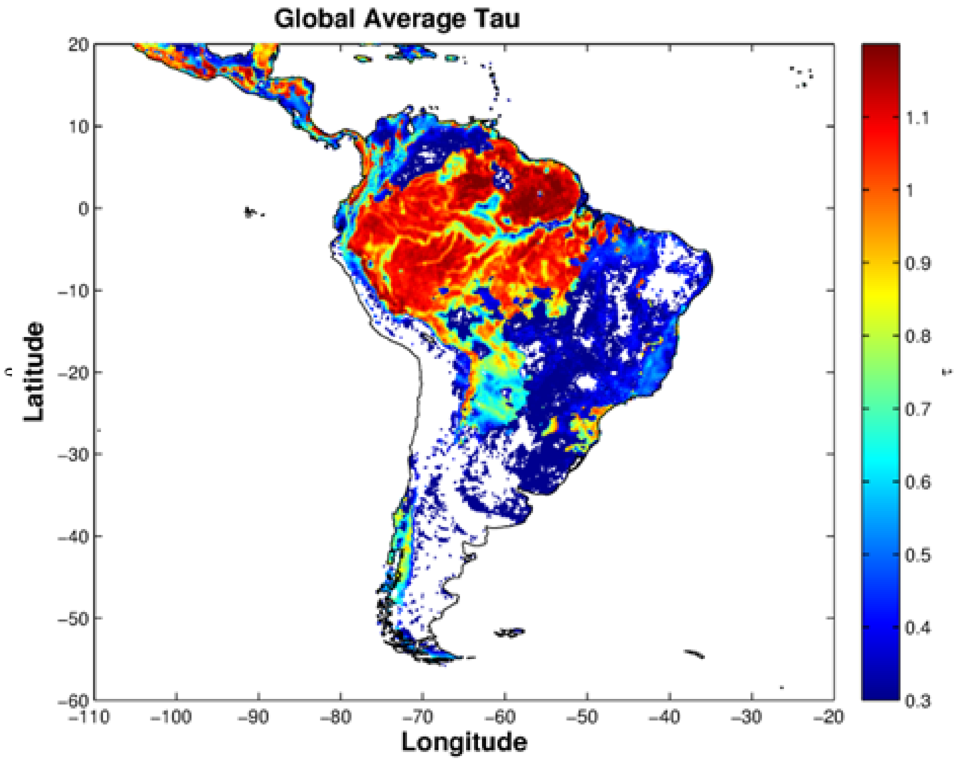
1: Very dense forest (Congo): SM increases slightly after the end of rainy season.

2: Woody Savannah: Good SM vs rainfall correlation.

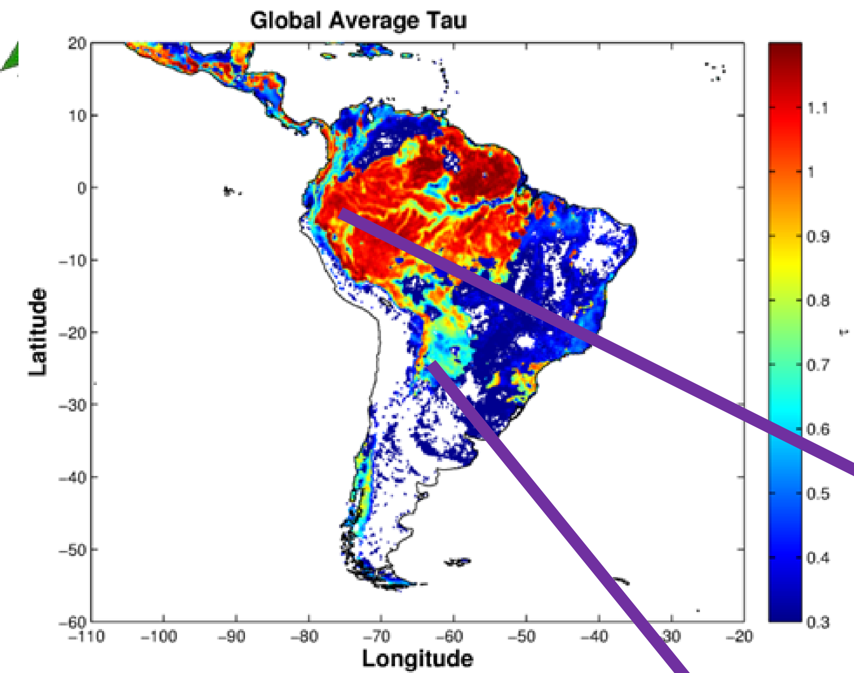
SM vs R correlation coeff.

LVOD

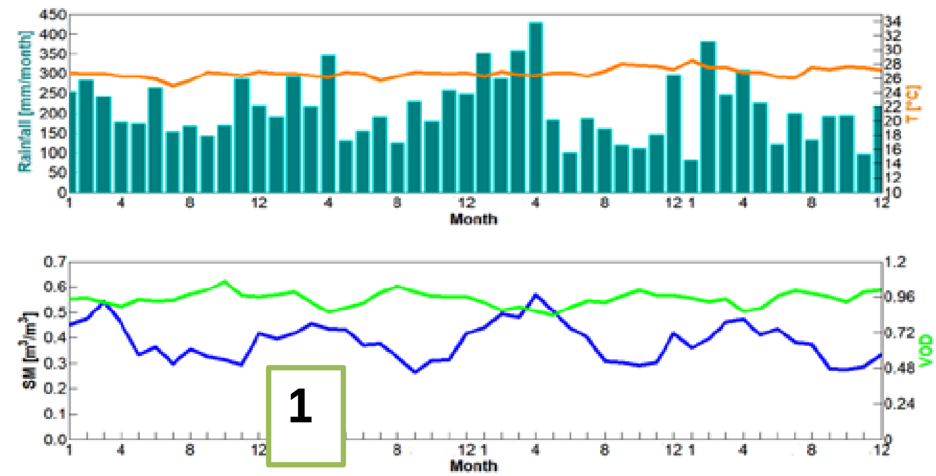


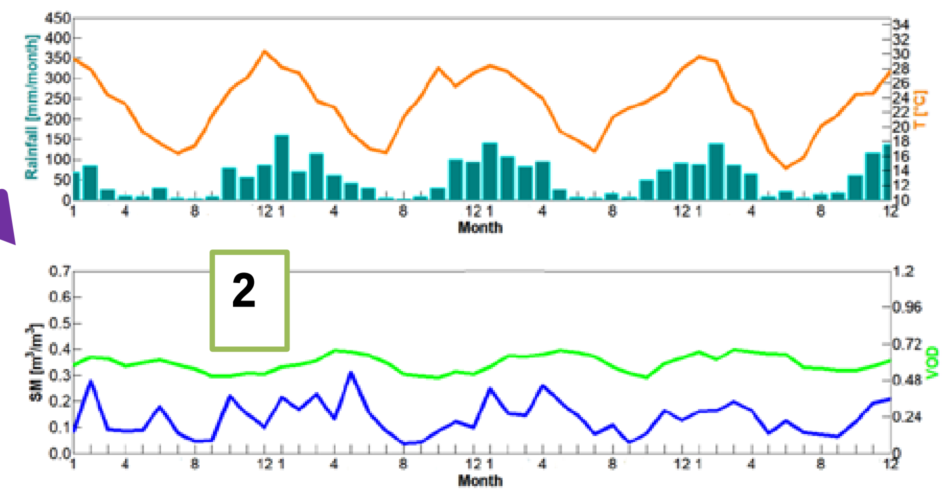


SM vs R correlation is kept up to LVOD ~ 0.7;
Complex behaviors for higher LVOD.



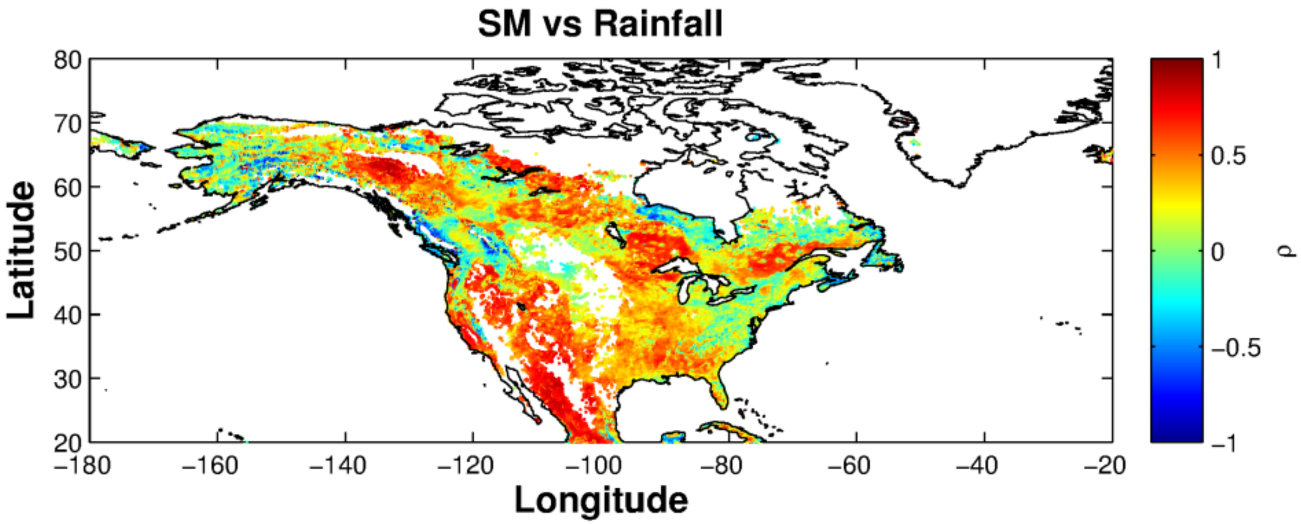
Rainfall, Surface temperature, SM, LVOD



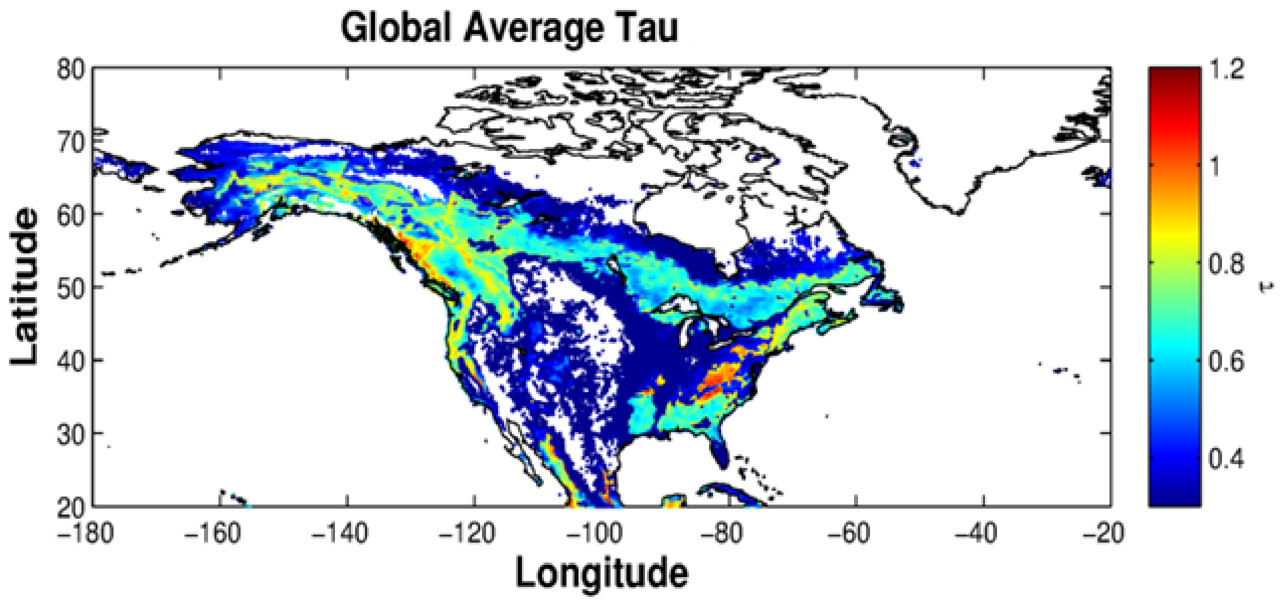


1: Dense and rainy forest (Perù): Difficult retrieval, but with maxima in very rainy months.

2: Subtropical Chaco: Good SM vs rainfall correlation.

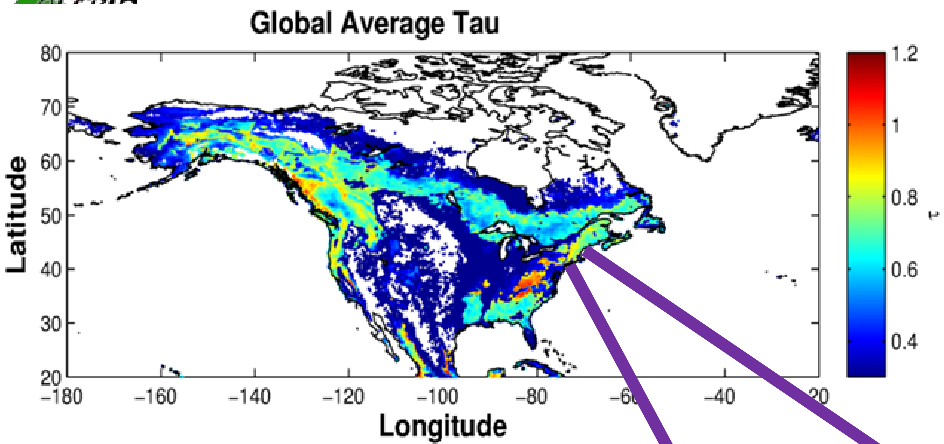


SM vs R correlation coeff.

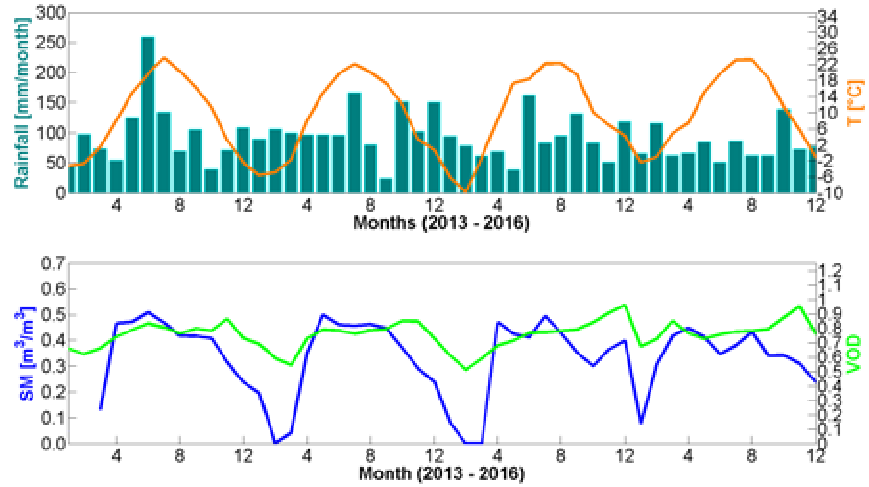


LVOD

SM vs R correlation is kept up to LVOD ~ 0.7;
High correlations in several northern areas.



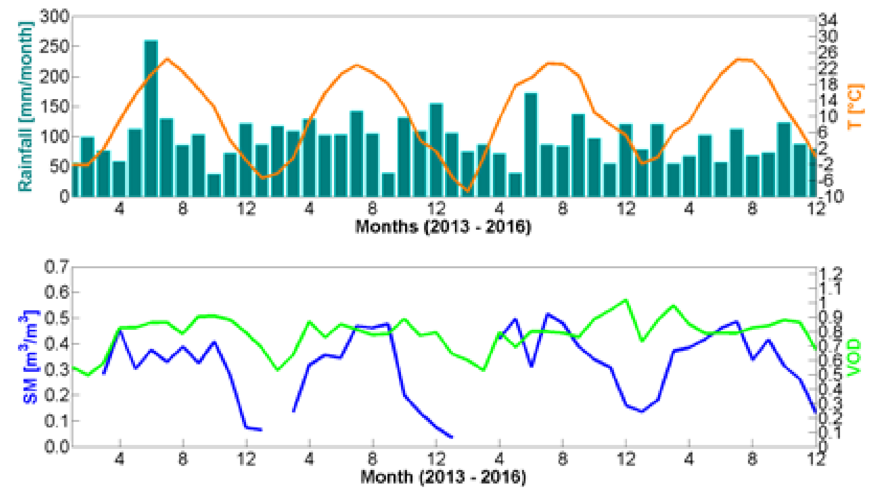
Rainfall, Surface temperature, SM, LVOD



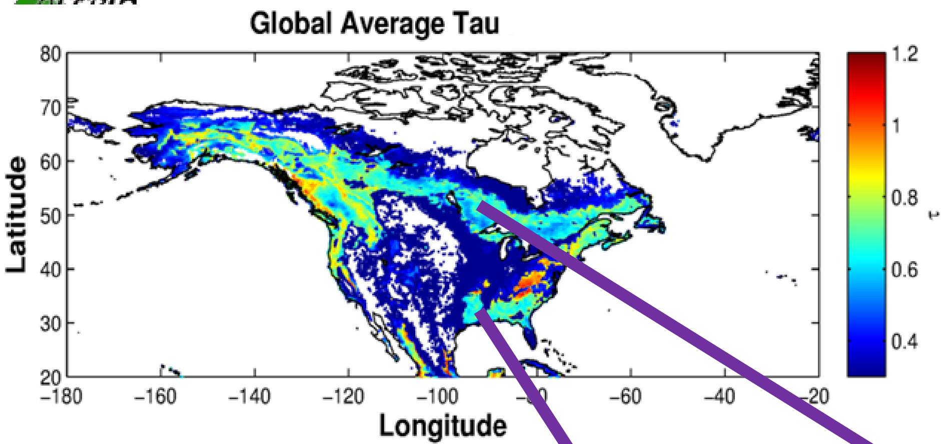
Pixels around Harvard and Millbrook sites:

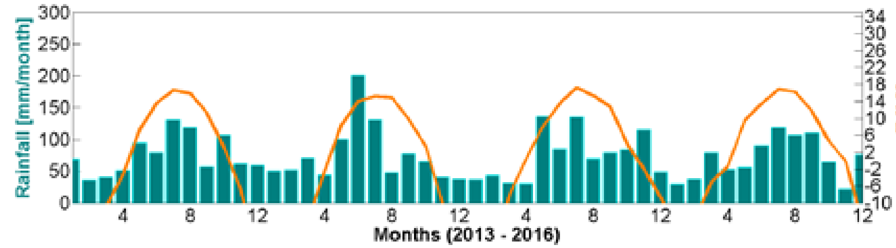
SM is mostly driven by melting/drying processes.

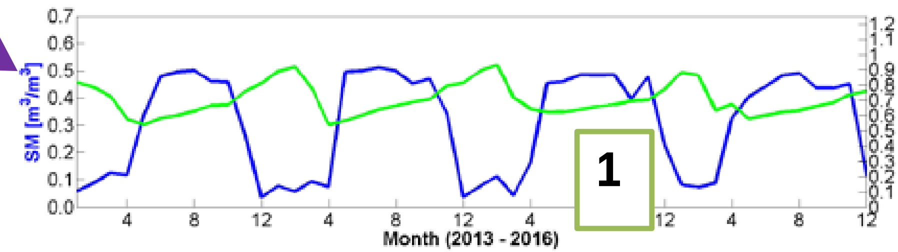
Retrieval fails in coldest months.



Rainfall, Surface temperature, SM, LVOD

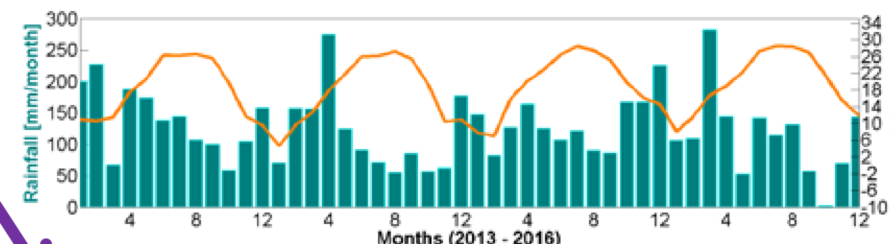


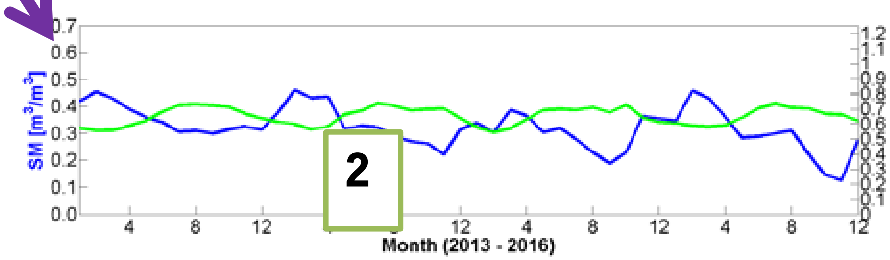




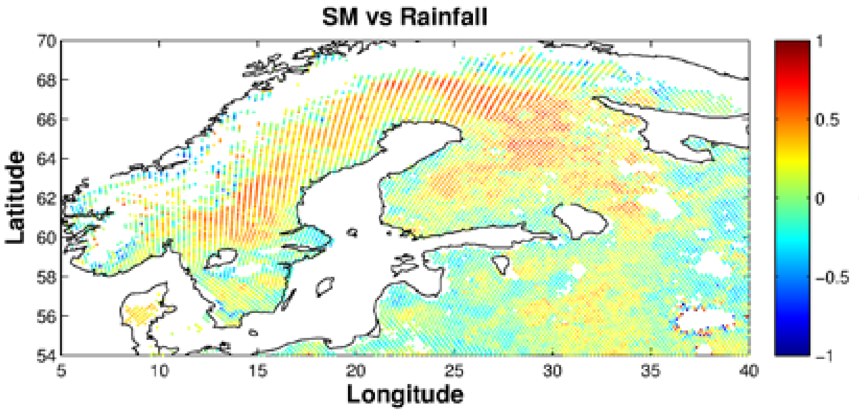
1: Forest in cold area.
SM correlated with both temperature and rainfall.

2: Forest in warm, rainy area.
SM correlated with rainfall.

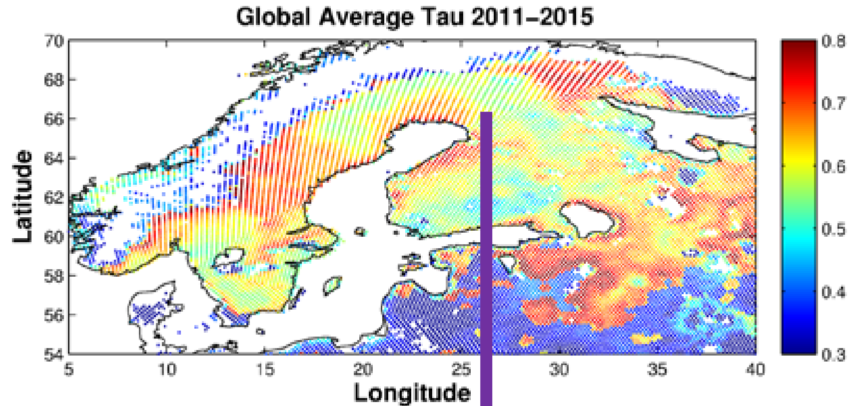




SM vs R correlation coeff.

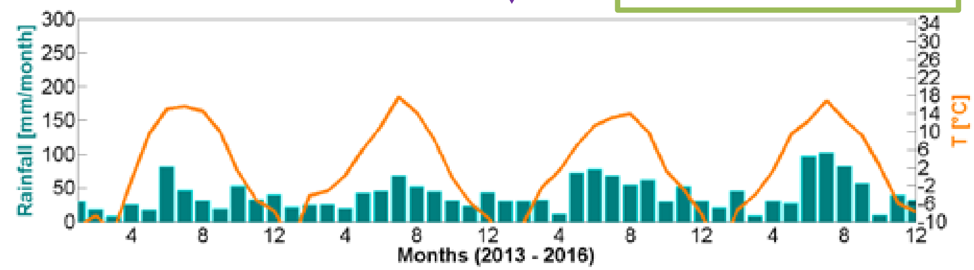


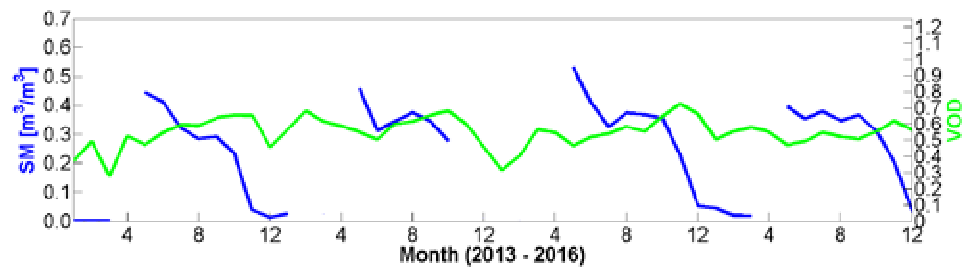
LVOD

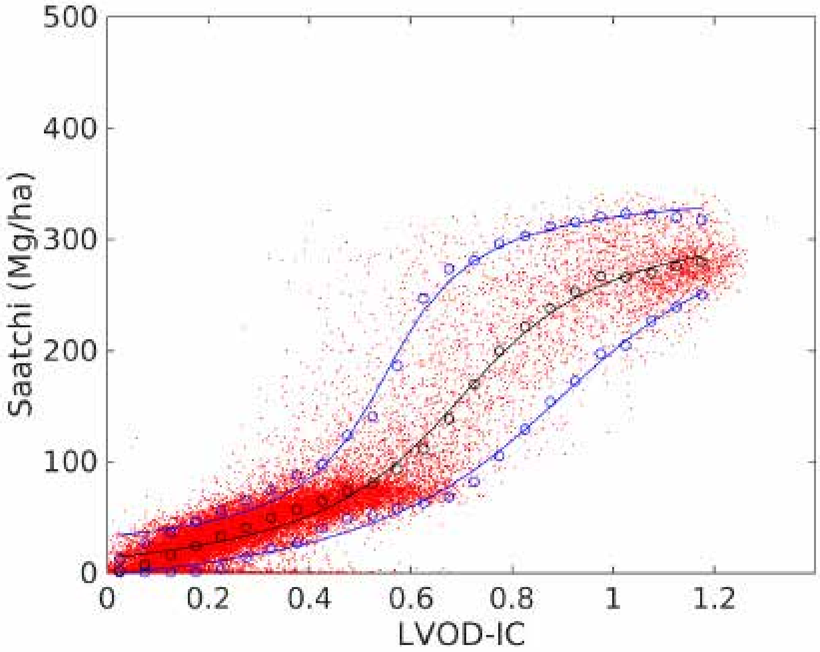


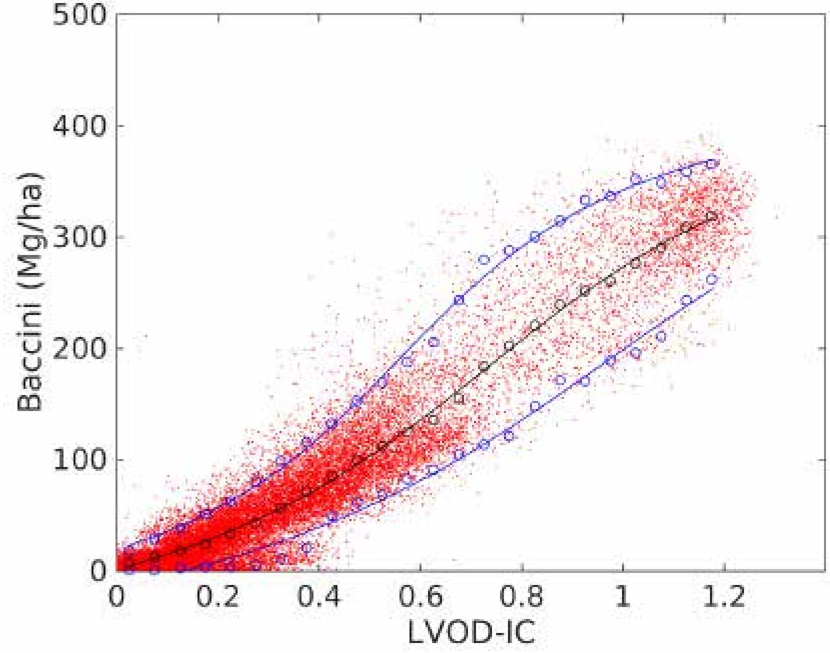
SM is mostly driven by melting/drying processes. Retrieval fails in cold months.

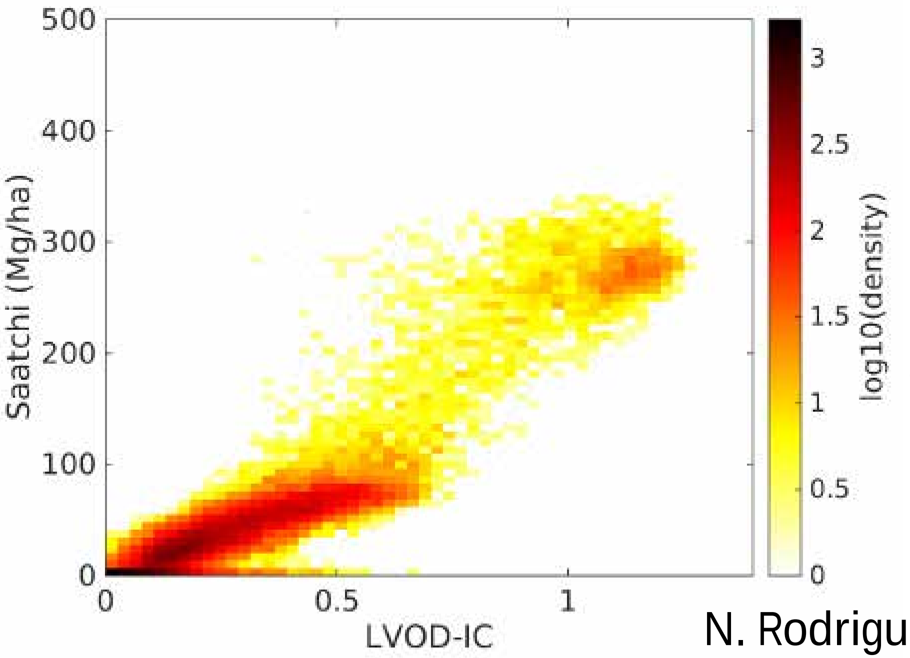
Sodankyla

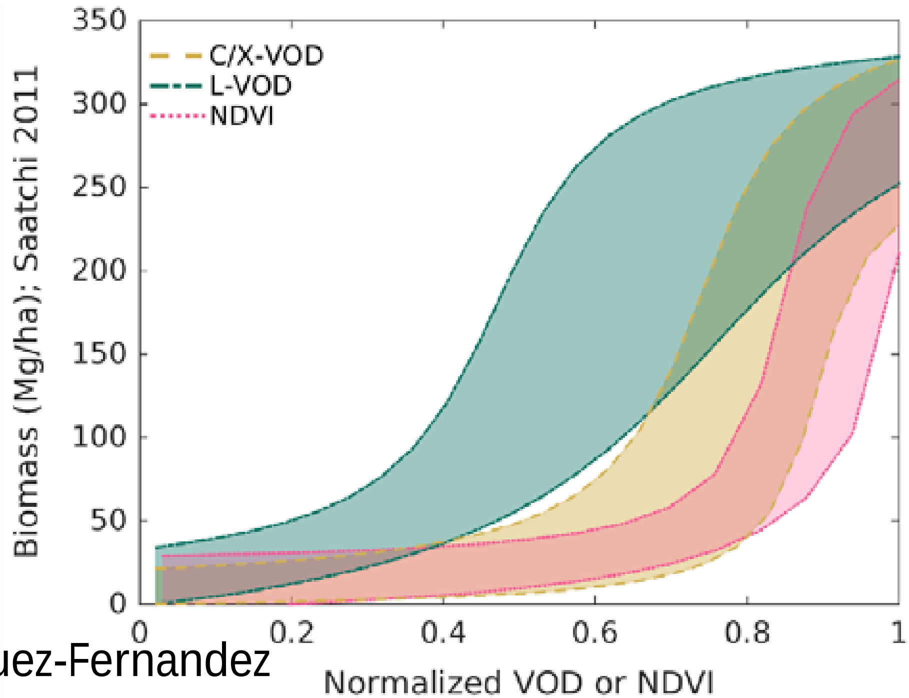












N. Rodriguez-Fernandez

RESEARCH ON L-BAND RADIOMETRY APPLIED TO
A) SNOW
B) FOREST

M. Schwank, R. Naderpour, Ch. Mätzler, J. Lemmetyinen, K. Rautiainen

WSL

GAMMA REMOTE SENSING

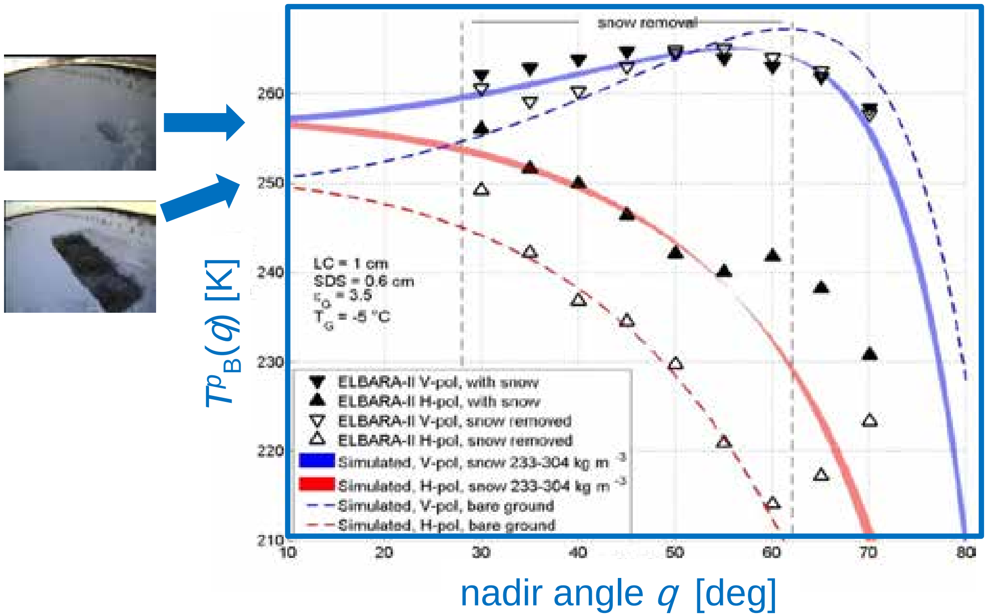
FMI

A) SNOW: *Background*

Dry Snow is largely transparent at L-band, but impacts brightness temperature via refraction and impedance matching!

«

Theoretically and experimentally proved.



L-band T_B contains information on snow properties (e.g. density and liquid water).
Development of retrieval approaches to estimate snow properties from L-band T_B.

2014 — L-band Specific Emission Model

2015 — Snow density & Ground permittivity (ρ_S, ε_G) retrieval algorithm

2016 — (ρ_S, ε_G) based on close-range measurements.

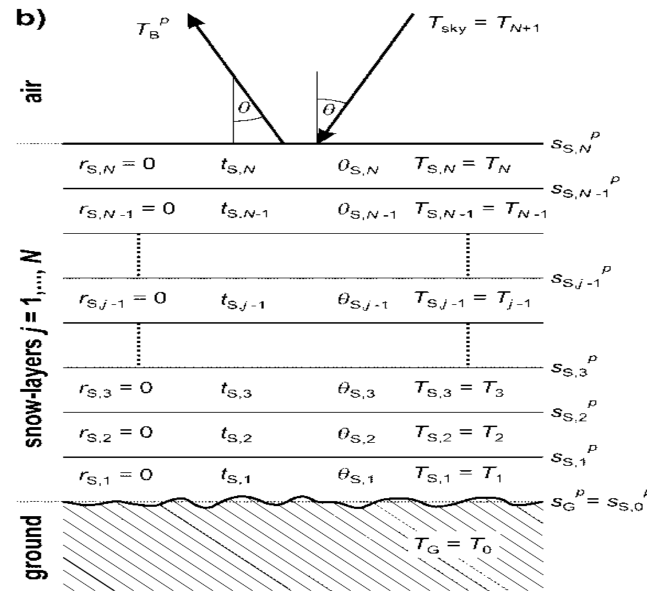
2017
- (ρ_S, ε_G)-sensitivities to "Geophysical Noise".
- Winter campaign at Davos, Switzerland.

2018
- (ρ_S, ε_G)-sensitivities to "Melting Effects".
- Snow Liquid Water Retrieval

• • •

A) SNOW: *L-Band Specific Microwave Emission Model of Layered Snowpacks (LS-MEMLS)*

- **Layers in MEMLS characterized with:**
  transmissivity t_j
  reflectivity r_j
  temperature T_j
  interface reflectivity s_j^p
- **Vertical fluxes (incoherent) linked via boundary conditions at layer interfaces, and via Kirchhoff's law.**
- **Multiple reflections**
- **Volume scattering** (considered in r_j)



- **LS-MEMLS developed as part of MEMLS & L-MEB**
- **No volume scattering at L-band (r_S = 0)**
- **1-layer LS-MEMLS is simple enough for use in a retrieval algorithm (via minimizing Cost Function).**

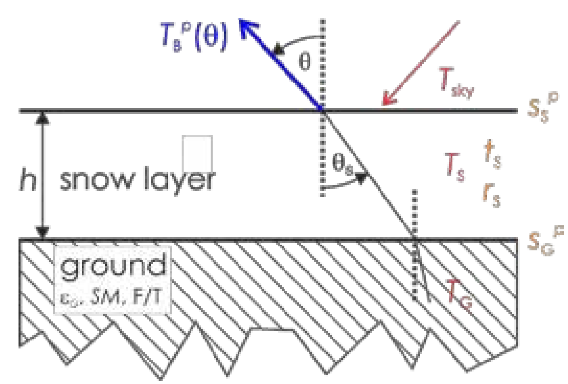
$$CF(r_S, e_G) \equiv \sum_{\theta,p} \frac{\left(T_B^p(\theta) - T_{B,sim.}^p(\theta, r_S, e_G)\right)^2}{\left(\Delta T_{B,RMA} + \Delta T_{B,RFI}^p(\theta)\right)^2}$$

$$T_B^p = e_G^p T_G + e_S^p T_S + e_{sky}^p T_{sky}$$ *Kirchhoff's formulation:*

$$e_G^p = \frac{(1 - s_G^p)(1 - s_S^p)t_S}{1 + r_S^2 s_G^p s_S^p - r_S(s_G^p + s_S^p) - s_G^p s_S^p t_S^2}$$

$$e_S^p = \frac{(1 - s_S^p)(1 - r_S - t_S)(1 - r_S s_G^p + s_G^p t_S)}{(1 - r_S s_G^p)(1 - r_S s_S^p) - s_G^p s_S^p t_S^2}$$

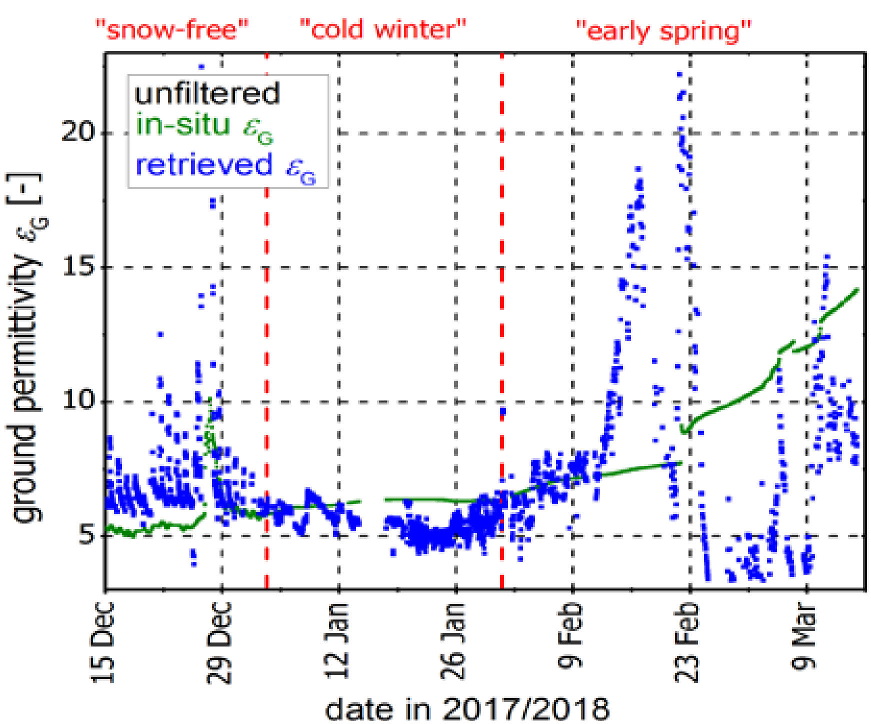
$$e_{sky}^p = 1 - a_G^p - a_S^p$$

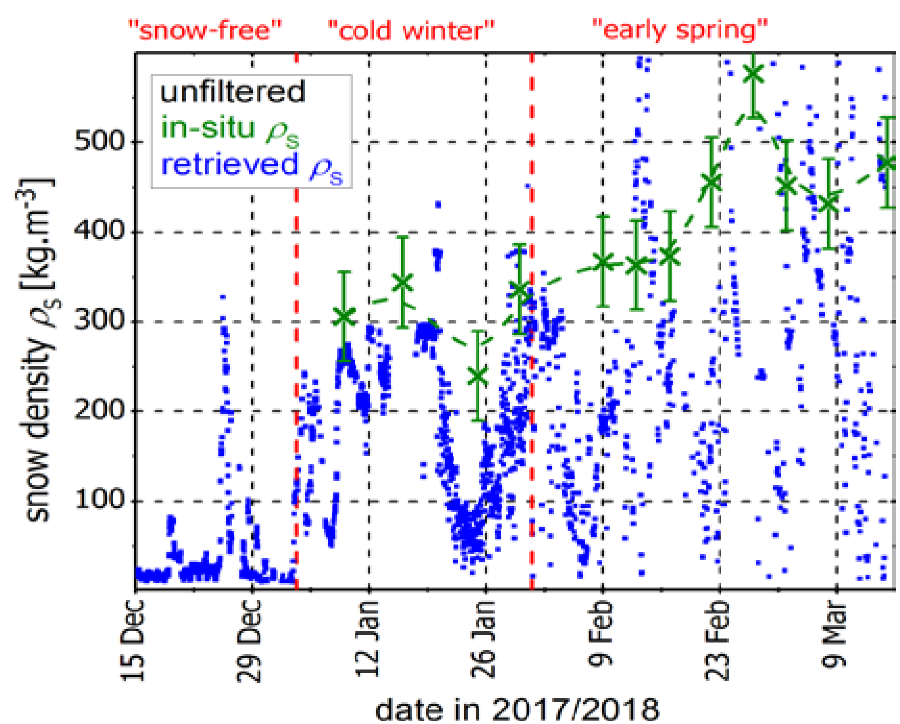


A) SNOW: *Snow Density & Ground Permittivity (r_S, e_G) retrieved from tower-based $T_B^p(q)$:*

- Tower-based $T_B^p(q)$ for q = 35°, 40°,…,60° and p = H, V used to retrieve (e_G, r_S)
- UNFILTERED retrievals (e_G, r_S) are shown.
- Retrieved r_S is expected to be representative of the lowest 10cm of the snowpack
- Ground was frozen during "snow-free" period.
- Snow was dry during "cold winter" period.

Increased r_S–retrievals « detection of onset of dry snow cover with the beginning of the "cold winter" period.



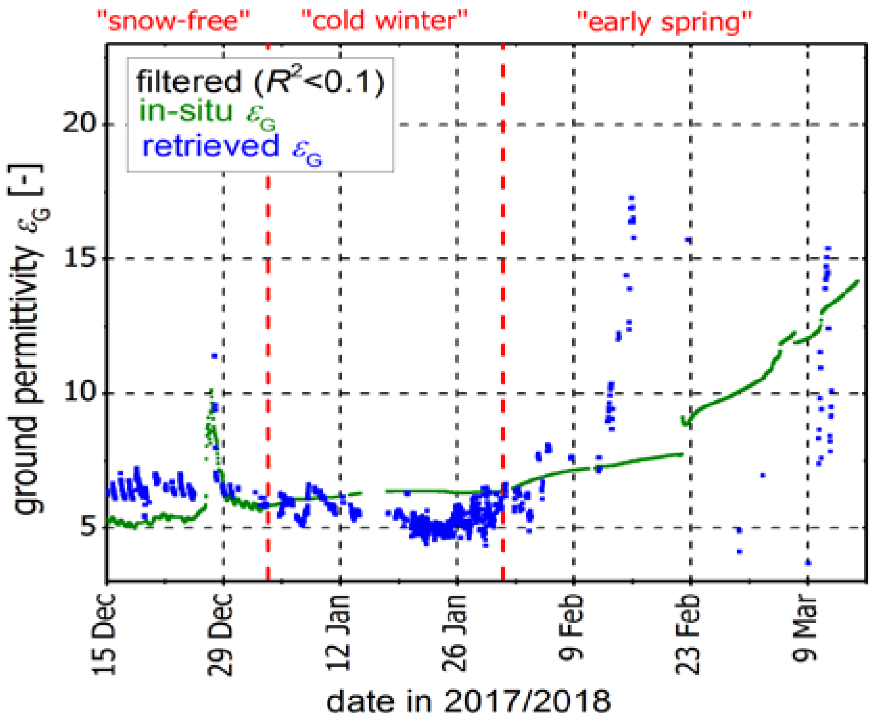


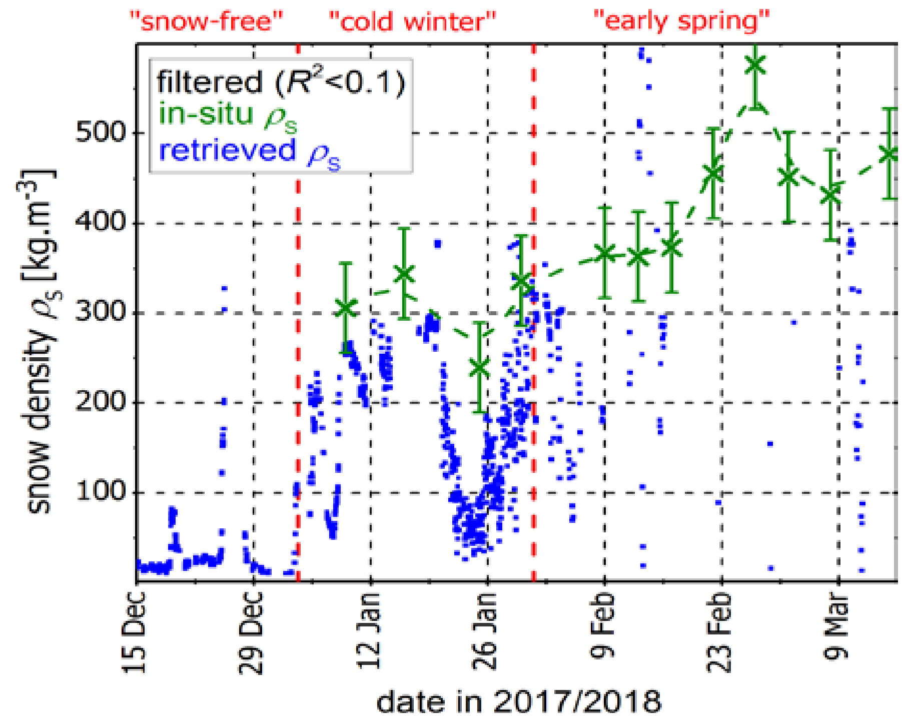
A) SNOW: *Snow Density & Ground Permittivity (ρ_S, ε_G) retrieved from tower-based $T_B^p(\theta)$:*

Reliable retrievals (ε_G, ρ_S) are expected to be UNCORRELATED.

- Retrieval pairs (ε_G, ρ_S) with low correlation $R^2 < 0.1$ between ε_G and ρ_S are expected to be more "reliable" than highly correlated (ε_G, ρ_S).
- Condition $R^2 < 0.1$ (computed from 12 hour sliding windows) is used as quality-flag for identification of "reliable" retrieval pairs (ε_G, ρ_S).

- With the beginning of the "early spring" period, the number of "reliable" retrievals ($R^2 < 0.1$) is reduced significantly.
- Quality-flag $R^2 > 0.1$ detects unrealistic daily variations.
- Large deviations between retrievals ε_G^{RM} and in-situ ε_G during "early spring" period are detected.

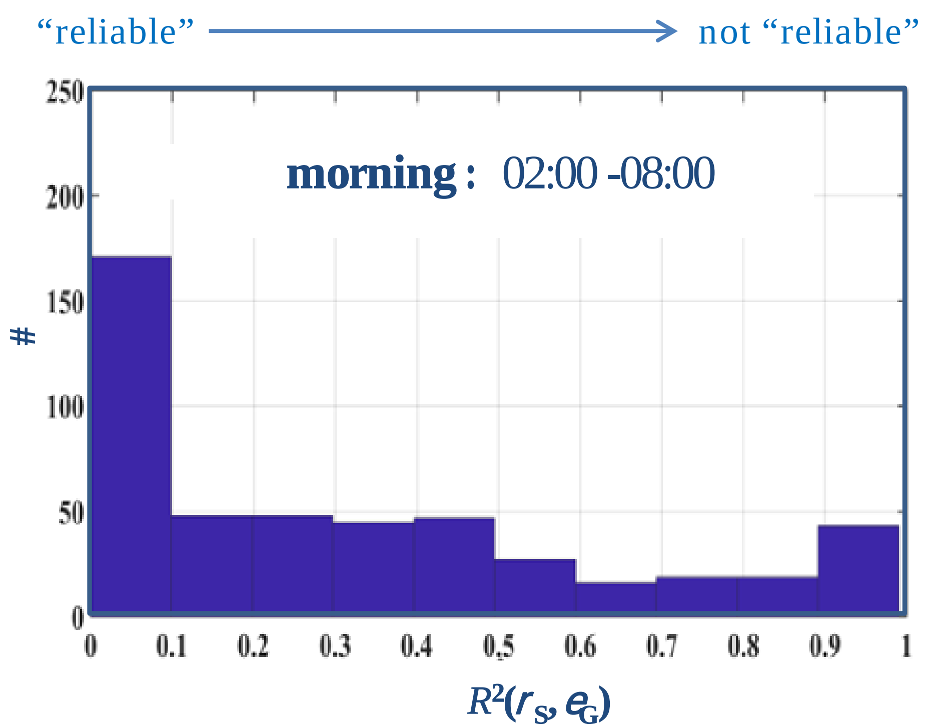


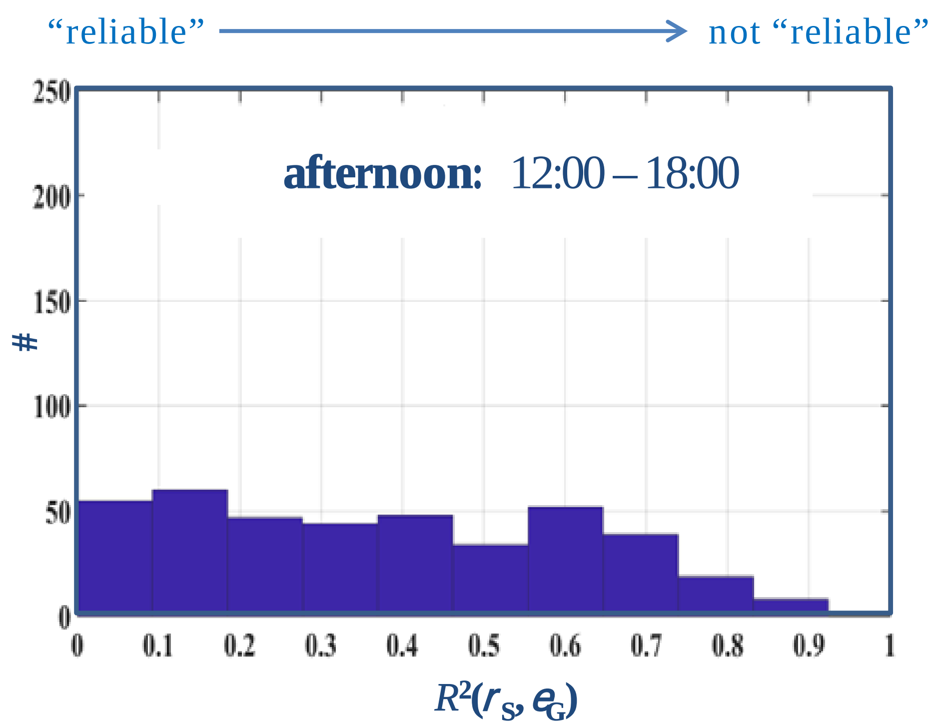


A) SNOW: *Snow Density & Ground Permittivity (r_S, e_G) retrieved from tower-based $T_B^p(q)$:*

Histograms of correlations R^2 between retrievals e_G and r_S derived from morning (left) and afternoon measurements $T_B^p(q)$.

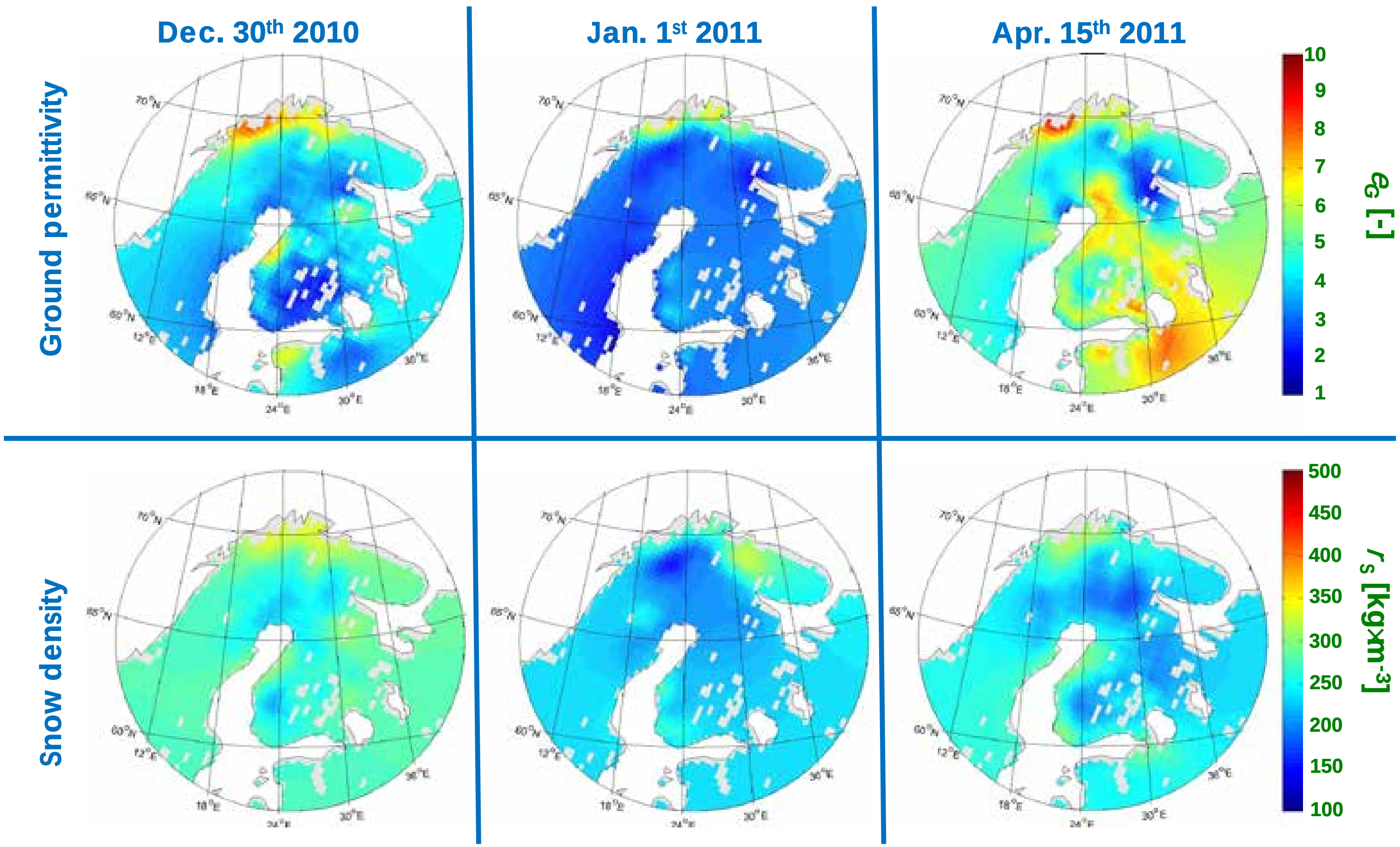
- more low-correlated retrievals during mornings than during afternoons.
- more reliable retrievals during morning than during afternoons resulting from moist snow during afternoons & re-freezing over night.
- Theoretical study (not shown) confirms that liquid water in snow leads to increased R^2 between retrievals.





A) SNOW: *Snow Density & Ground Permittivity (r_S, e_G) retrieved from SMOS L3 $T_B^p(q)$:*

- Demonstration retrievals (r_S, e_G) based on weekly averaged SMOS L3 $T_B^p(q)$ at q = 30° - 60°, p = H & V
- Reasonable patterns but validation is still outstanding.



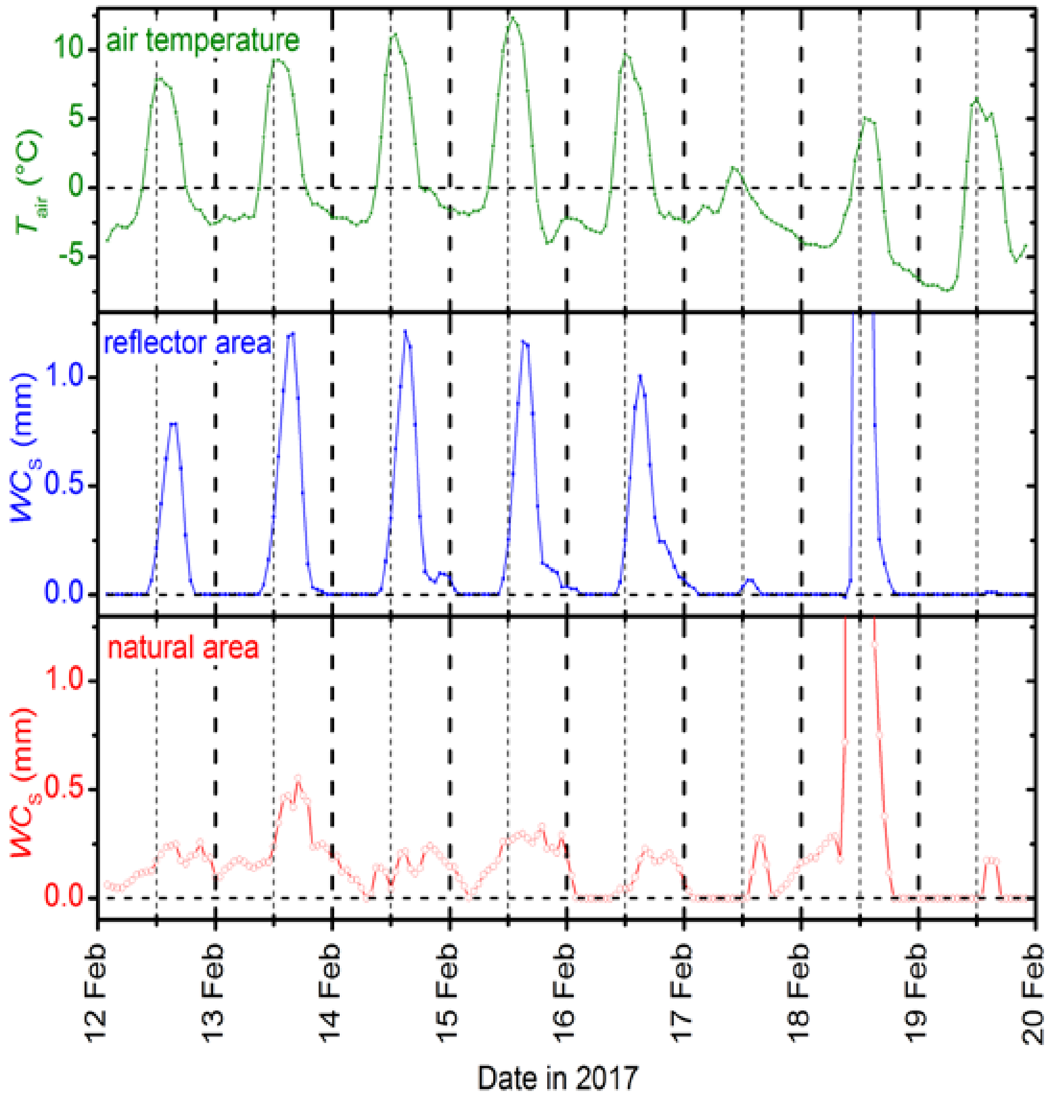
A) SNOW: *Snow liquid-water column WC_S retrieved from tower-based $T_B^p(\theta)$:*

Snowpack liquid-water column WC_S (mm): $WC_S = \int_0^{h_S} W_S(z) \cdot dz$

single-layer snowpack $\rightarrow WC_S \equiv W_S \cdot h_S$

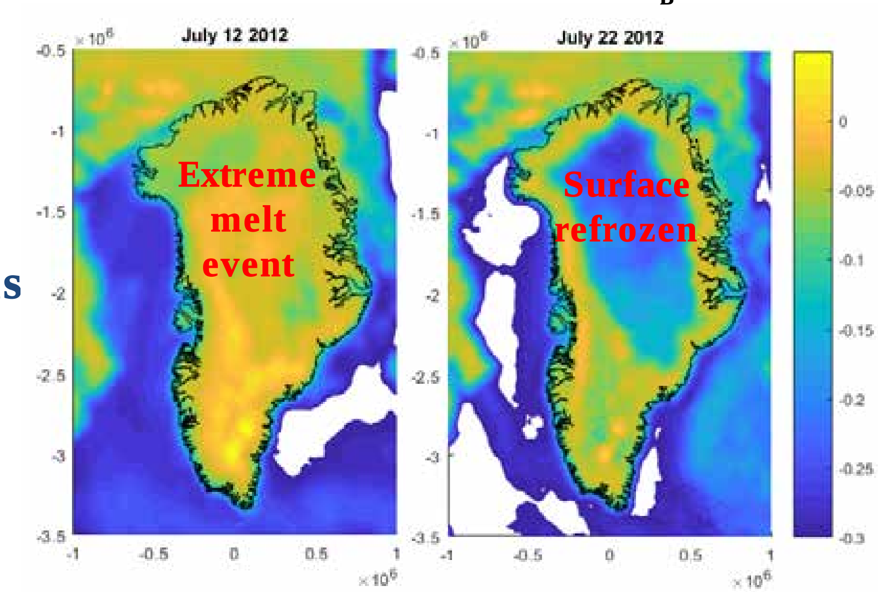
$h_S = 0.6$ m

- Synchronicity between T_{air} raising above 0°C and WC_S & WC_S.
- Synchronicity between reference WC_S retrieved from $T_{B,R}{}^p$ over areas with reflector placed beneath snow and WC_S retrieved from $T_{B,N}{}^p$ over natural snow-covered areas.
- Diurnal afternoon-peaks in WC_S are slightly shifted in time compared with T_{air}.
  Û latent-heat of snow
- "rain on snow event" clearly detected (18 Feb. 2017)
- **Evidence that WC_S can be estimated from L-band T_B over natural snow-covered grounds.**



A) SNOW: *Snow liquid-water retrieved from SMOS $T_B^p(q)$ over Greenland:*

XPGR derived from SSMIS T_B's



Snow-Melt detection based on difference between passive 19 GHz and 37 GHz channels

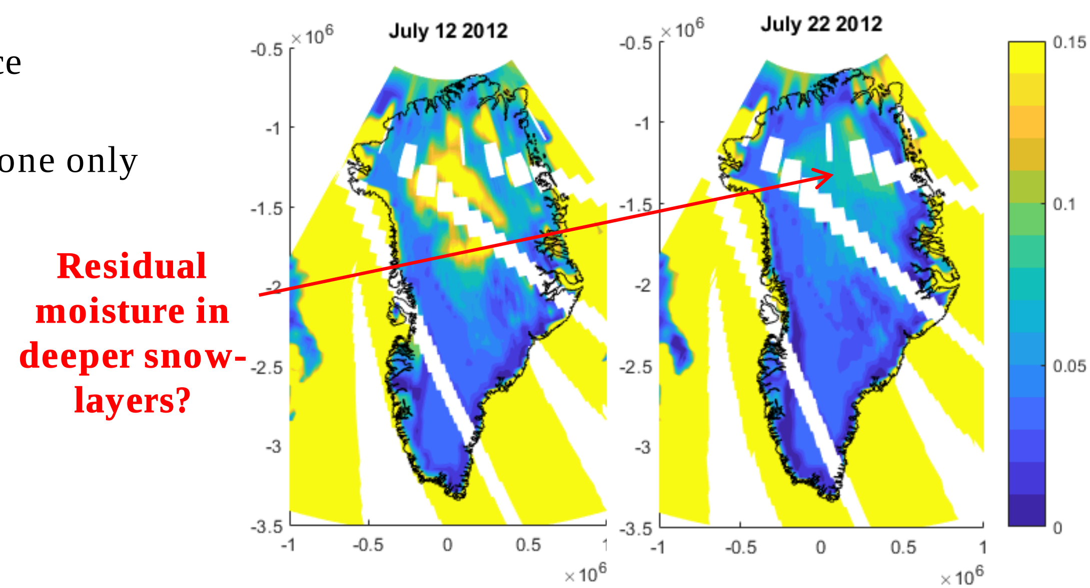
$$\mathrm{XPGR} = \frac{T_\mathrm{B}(19H) - T_\mathrm{B}(37V)}{T_\mathrm{B}(19H) + T_\mathrm{B}(37V)}$$

- Only sensitive to upper few cm of snowpack
- Very much empirical (unphysical) retrieval approach

Snow-Melt detection based on SMOS T_B^p(q):

- Greater sensitive depth
  Þ volume information rather than just surface information
- EM (LS-MEMLS) implemented for ablation zone only (Clear snow/ice interface)

snow wetness [%] retrieved from SMOS



A) SNOW: *Conclusions / Summary:*

1. L-band Specific Microwave Emission of Layered Snowpack (LS-MEMLS).
   a) dry snow impacts L-band T_B^p although it is transparent at L-band.
   b) (e_G, r_S) retrieval scheme uses single-layer LS-MEMLS and assumes snow as dry.

2. Demonstration of (e_G, r_S) retrievals based on tower-based measurements $T_B^p(q)$.
   a) reasonable agreement with in-situ data
   b) demonstrated $R^2(r_S^{"V"}, e_G^{"V"})$ based quality-flags

3. Retrievals (e_G, r_S) become correlated for moist snow conditions.
   a) Respective coefficient of determination $R^2 < 0.1$ is used as flag to identify "reliable" retrieval pairs (e_G, r_S).

4. Demonstration maps of retrievals (e_G, r_S) based on SMOS data have been produced.
   a) Validation of retrievals (e_G, r_S) based on satellite data is still outstanding.
   b) Use of density retrievals to improve SWE estimates?

5. L-band T_B^p contain volume information on liquid-water of seasonal snowpacks.
   a) demonstrated based on tower-based measurements of T_B^p.
   b) demonstrated based on SMOS measurements (over Greenland).

B) FOREST: 2S EM ® TO EM: *Overview*

SMOS 2S study goals (2013 + 1 year):

Potential of updating current SMOS L2 SM processor with Two-Stream (2S) Emission Model (EM) as a replacement of the Tau-Omega (TO) EM.

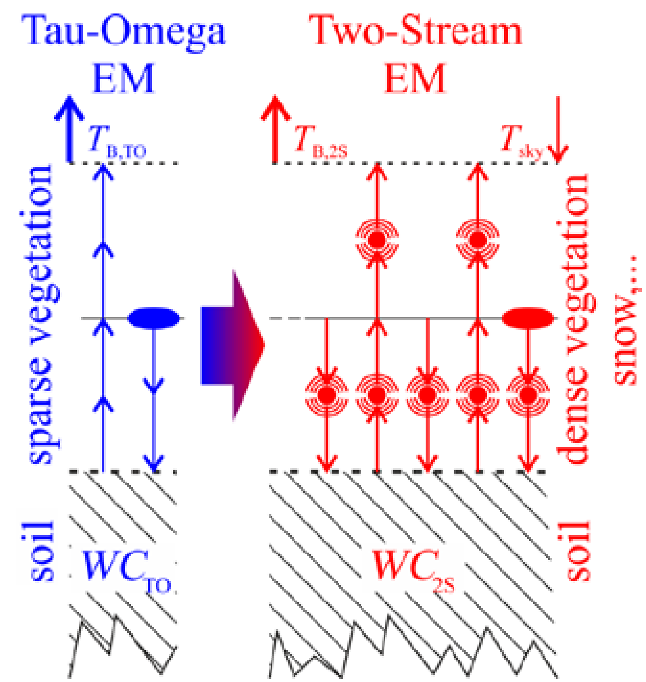
2S EM has certain advantages over TO EM:

a) Consideration of multiple reflections & multiple scattering (relevant for dense vegetation, e.g. forests).

b) Wider applicability range (e.g. "soft-layer" assumption not necessary. Suited for vegetated ground (incl. forest) and snow (unification of retrieval algorithms using a consistent EM is a conceptual advantage of implementing 2S EM as a replacement for TO EM).

c) 2S EM includes TO EM for sparse vegetation.

d) Formulation of the single layer 2S EM is as simple as TO EM (2S EM is as suitable as TO EM for implementation in a retrieval algorithm)



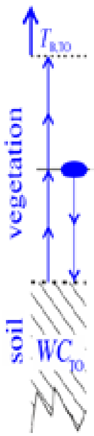
Resumed in 2017 –

- Paper submitted to MDPI Remote Sensing: "Tau-Omega"- and Two-Stream Emission Models used for Passive L-band Retrievals: Application to Close-Range Measurements over a Forest. The next slides provide a summary.

B) FOREST: 2S EM ® TO EM : *Formulation of TO EM and 2S EM*

$$T_{B,EM}^{p,\theta} = T_s \cdot e_{s,EM}^{p,\theta} + T_v \cdot e_{v,EM}^{p,\theta} + T_{sky} \cdot e_{sky,EM}^{p,\theta}$$

Kirchhoff formulation for EM = {TO, 2S}



$$T_{B,TO}^{p,\theta} = f(\tau_{TO}, \omega_{TO}, WC_{TO})$$

$$e_{s,TO}^{p,\theta} = t_{TO}^{\theta}\left(1 - s_s^{p,\theta}\right)$$

$$e_{v,TO}^{p,\theta} = (1 - \omega_{TO})\left(1 - t_{TO}^{\theta}\right)\left(1 + s_s^{p,\theta} t_{TO}^{\theta}\right)$$

$$e_{sky,TO}^{p,\theta} = 0$$

$$t_{TO}^{\theta} = \exp(-\tau_{TO}/\cos\theta)$$

$$T_{B,2S}^{p,\theta} = f(\tau_{2S}, \omega_{2S}, WC_{2S})$$

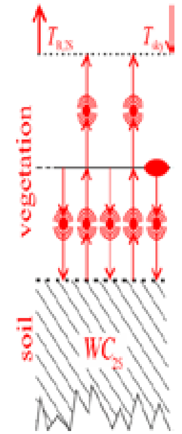
$$e_{s,2S}^{p,\theta} = t_v^{\theta}\left(1 - s_s^{p,\theta}\right) / \left(1 - s_s^{p,\theta} r_v^{\theta}\right)$$

$$e_{v,2S}^{p,\theta} = \left(1 - r_v^{\theta} - t_v^{\theta}\right)\left(1 + s_s^{p,\theta} t_v^{\theta}\right) / \left(1 - s_s^{p,\theta} r_v^{\theta}\right)$$

$$e_{sky,2S}^{p,\theta} = \left(1 - e_{s,2S}^{p,\theta} - e_{v,2S}^{p,\theta}\right)$$

$$t_v^{\theta} = \frac{2 \cdot \exp\left(\tau_{2S}\sqrt{1 - \omega_{2S}^2}/\cos\theta\right) \cdot \left[1 - \omega_{2S}^2 + \sqrt{1 - \omega_{2S}^2}\right]}{\exp\left(2\tau_{2S}\sqrt{1 - \omega_{2S}^2}/\cos\theta\right) \cdot \left[2 - \omega_{2S}^2 + 2\sqrt{1 - \omega_{2S}^2}\right] - \omega_{2S}^2}$$

$$r_v^{\theta} = \frac{\omega_{2S} \cdot \left[\exp\left(2\tau_{2S}\sqrt{1 - \omega_{2S}^2}/\cos\theta\right) - 1\right] \cdot \left[1 + \sqrt{1 - \omega_{2S}^2}\right]}{\exp\left(2\tau_{2S}\sqrt{1 - \omega_{2S}^2}/\cos\theta\right) \cdot \left[2 - \omega_{2S}^2 + 2\sqrt{1 - \omega_{2S}^2}\right] - \omega_{2S}^2}$$



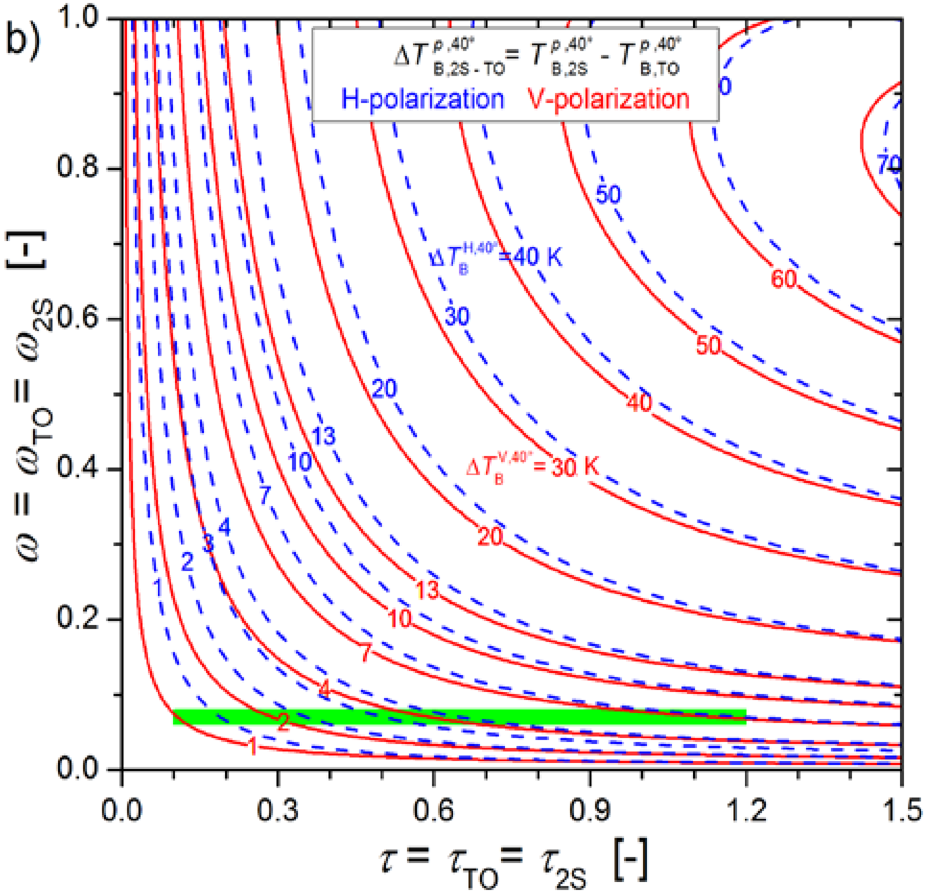
- Scattering considered as a loss mechanism only.
- Þ underestimation of emitted radiation.
- Neglect of multiple reflections between vegetation and soil.
- Inconsistent with Kirchhoff's law.

- Considers multiple scattering in vegetation, multiple reflections between vegetation and the soil surface, and consistent with Kirchhoff's law.
- Formulation is as simple as TO EM.

B) FOREST: 2S EM ® TO EM: *Comparison between* $T^{p,\theta}_{B,TO}(\tau,\omega)$ « $T^{p,\theta}_{B,2S}(\tau,\omega)$

- TO EM and 2S EM converge for sparse vegetation.
- Differences of several kelvins (> instrument noise of SMOS and SMAP) for *t* and *w* typical of forests.

  Þ TO-retrievals ¹ 2S-retrievals.



Contour plot of differences $\Delta T^{p,\theta}_{B,2S-TO}(\tau,\omega) \equiv T^{p,\theta}_{B,2S}(\tau,\omega) - T^{p,\theta}_{B,TO}(\tau,\omega)$ simulated for θ = 40°.

Blue dashed contours are for p = H, red solid contours are for p = V.

B) FOREST: 2S EM ® TO EM: *Reasoning and computation of 2S-equivalent $w_{2S,eq}$*

Transformation $\omega_{TO} \mapsto \omega_{2S,eq}$ of ω_{TO} to 2S-equivalences ω_{2S} is mandatory for retrievals (WC_{2S}, τ_{2S}) which are comparable with (WC_{TO}, τ_{TO}).

Because (WC_{RC}, τ_{RC}) achieved with Retrieval Configuration RC = {TO, 2S} assume respective scattering albedo $\omega_{TO} \simeq 0.08$ and $\omega_{2S,eq} = 0.1246 > \omega_{TO}$ as constant.

Approach to transform $(\tau_{TO}, \omega_{TO}, WC_{TO}) \mapsto (\tau_{2S,eq}, \omega_{2S,eq}, WC_{2S,eq})$:

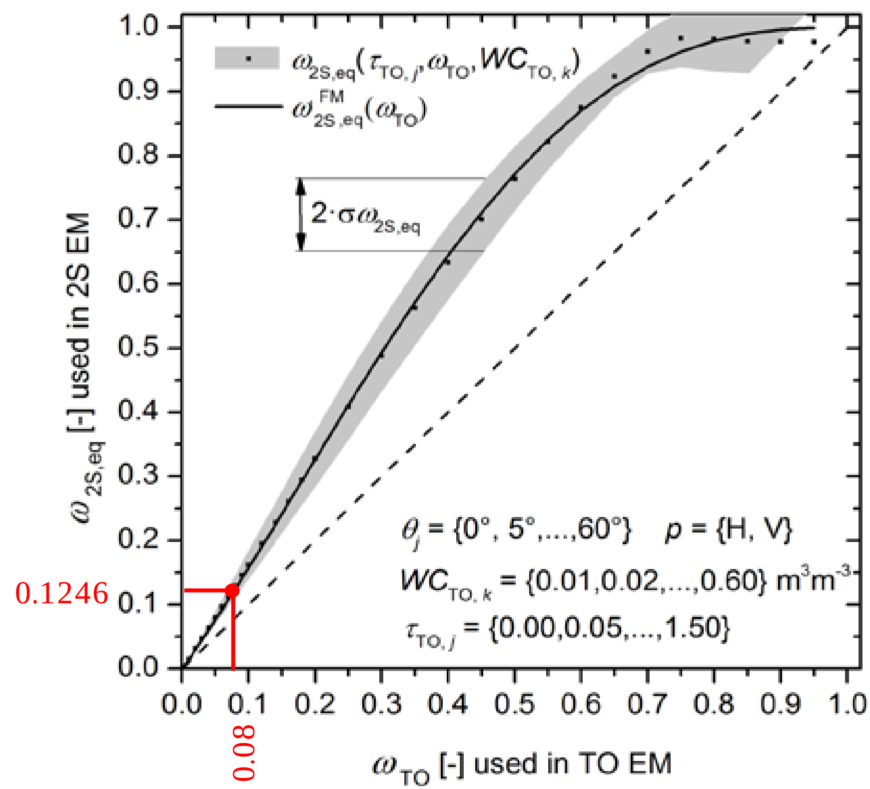
2S system emissivities $e_{2S,sys}^{p,\theta_j}$ must be as similar as possible to TO emissivities $e_{TO,sys}^{p,\theta_j}$.

Þ Minimize $CF = \sum_{p,\theta_j} \left(e_{TO,sys}^{p,\theta_j} - e_{2S,sys}^{p,\theta_j}\right)^2$

Þ $\omega_{2S,eq} = f(\tau_{TO}, \omega_{TO}, WC_{TO})$

Fast Model $\omega_{2S,eq}^{FM}(\omega_{TO})$ solely dependent on ω_{TO}.

Because sensitivity of $\omega_{2S,eq}$ to τ_{TO} and WC_{TO} are of second order.

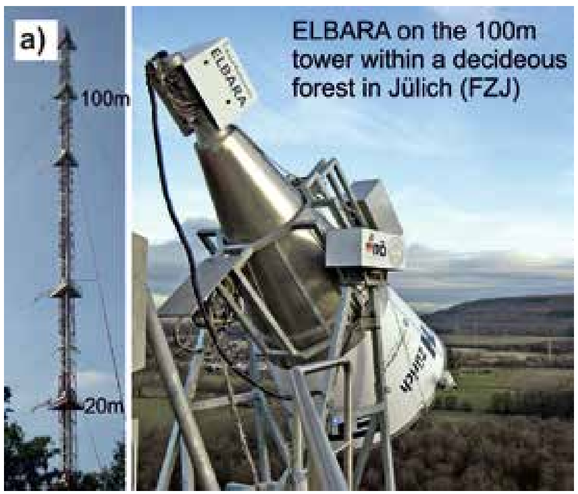


2S-equivalences $\omega_{2S,eq}(\omega_{TO})$ computed from ω_{TO} used with TO EM. Dots are $\omega_{2S,eq}(\omega_{TO})$ computed from $\omega_{2S,eq}(\tau_{TO,j}, \omega_{TO}, WC_{TO,k})$ averaged over $\tau_{TO,j}$ and $WC_{TO,k}$; gray-shaded area represents the ± uncertainty $\sigma\omega_{2S,eq}(\omega_{TO})$ due to second order depencencies on τ_{TO} and WC_{TO}; the Fast Model (FM) $\omega_{2S,eq}^{FM}(\omega_{TO})$ is shown with the solid line.

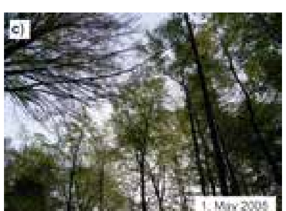
B) FOREST: 2S EM ® TO EM: *Retrievals* (WC_{RC}, τ_{RC}) *from tower-based* $T_B^p(\theta)$

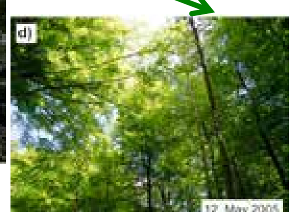
Forest Soil Moisture Experiment (FOSMEX):

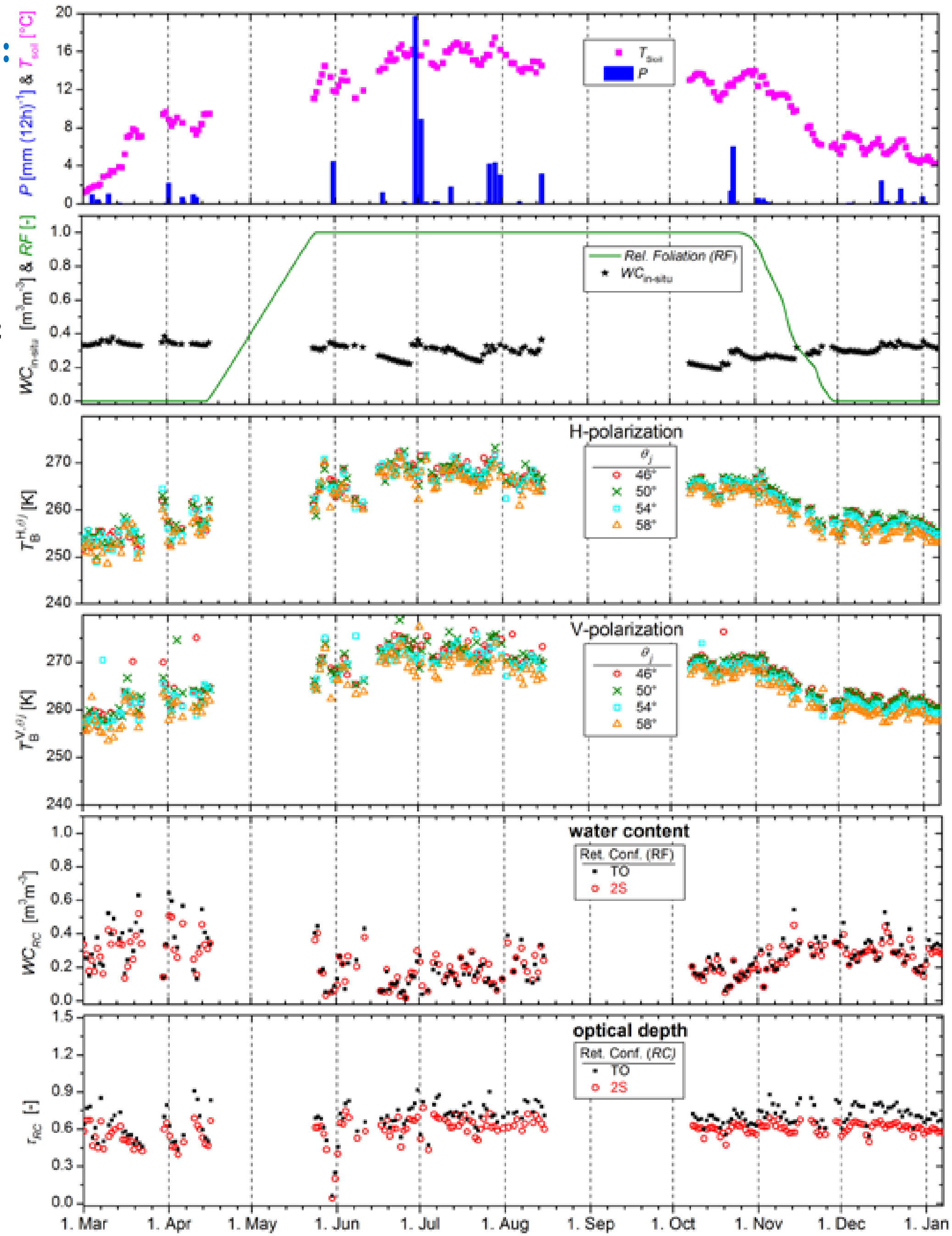
- January 2005 - January 2006
- Research Centre Jülich (FZJ, Germany)
- deciduous forest (oak, birch, beech)
- tree age 40 - 80 years
- average crown height ~ 24 m
- column density of dry biomass ~15 kg m^{-2}
- max. column density of fresh leaves ~1.14 kg m^{-2}



forest development 2005







B) FOREST: 2S EM ® TO EM: *Retrievals* (WC_{RC}, τ_{RC}) *from tower-based* $T_B^p(q)$

In-situ observations:

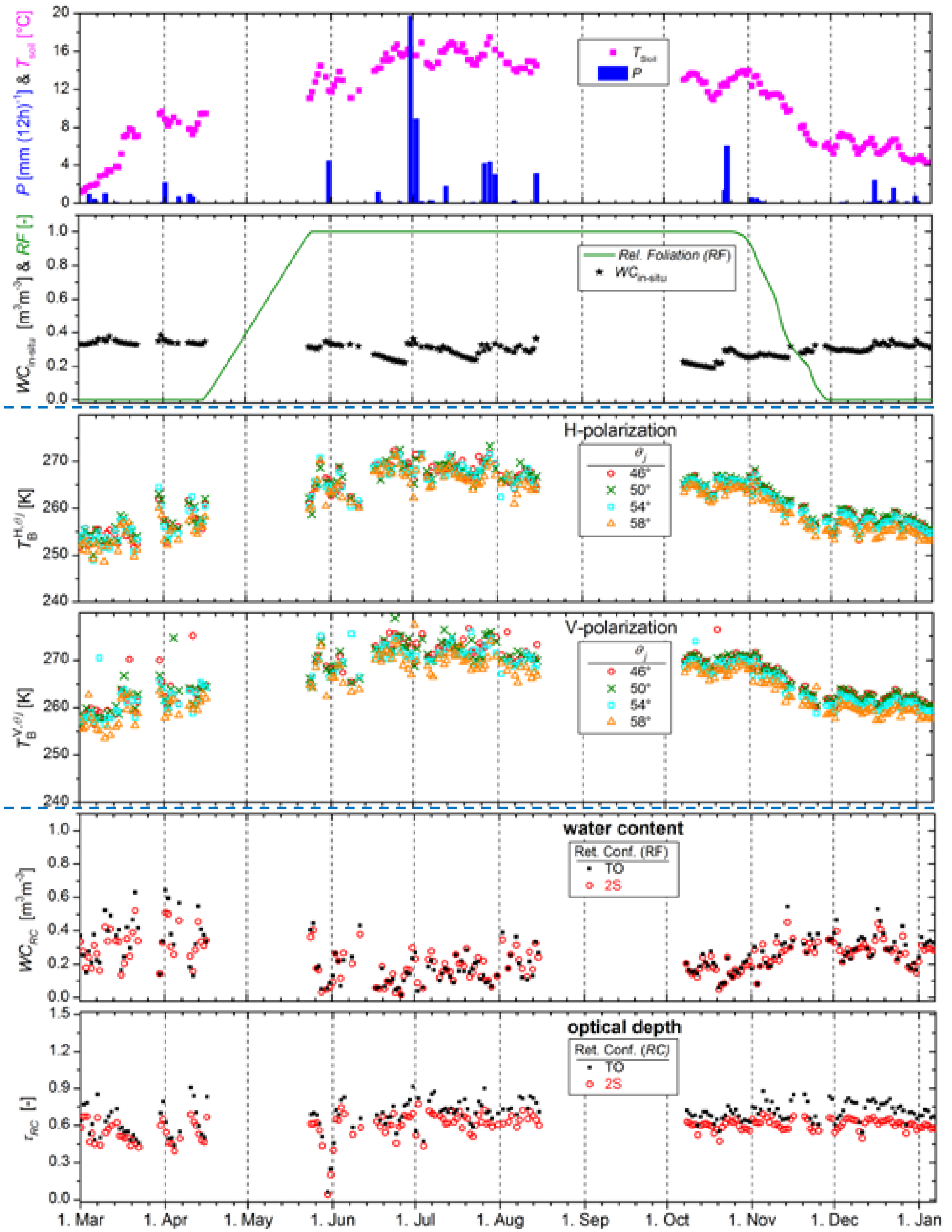
Air temperature T_{soil} and
precipitation P

Soil water-content $WC_{in\text{-}situ}$ and
Relative Foliation RF

L-band $T_B^p(q)$ @ p = {H,V} 4AM-8AM

q = {46°, 50°, 54°, 58°}

- T_B^p follow Seasonal patterns of RF and T_{soil}
- T_B^p respond (decrease) to strongest rain periods



Retrievals (WC_{RC}, τ_{RC}) for RC={TO,2S}

- Very similar WC_{RC} for RC = {**TO**, **2S**}
  Þ $\omega_{TO} = 0.08 \mapsto \omega_{2S,eq} = 0.1246$ is adequate
- Responses of WC_{RC} to strongest rain periods

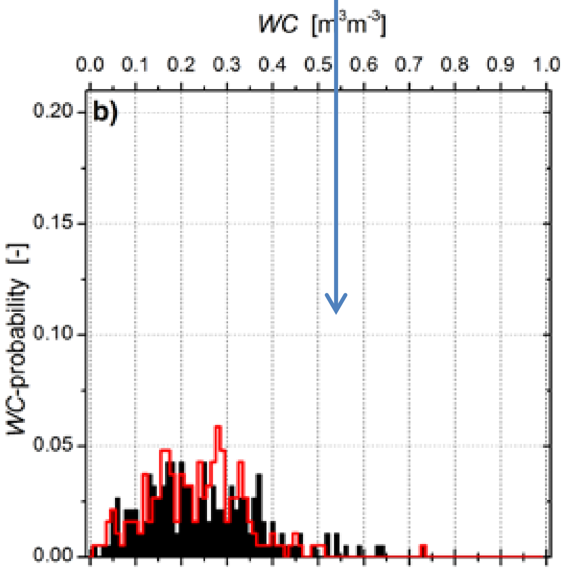
	$\langle\tau_{RC}\rangle \pm \Delta\tau_{RC}$	
RC	TO	2S
foliage-free	0.6756 ± 0.1116	0.5754 ± 0.0726
fully foliated	0.7113 ± 0.0875	0.6229 ± 0.0694

- Larger optical depth during foliated period than during foliage free period.

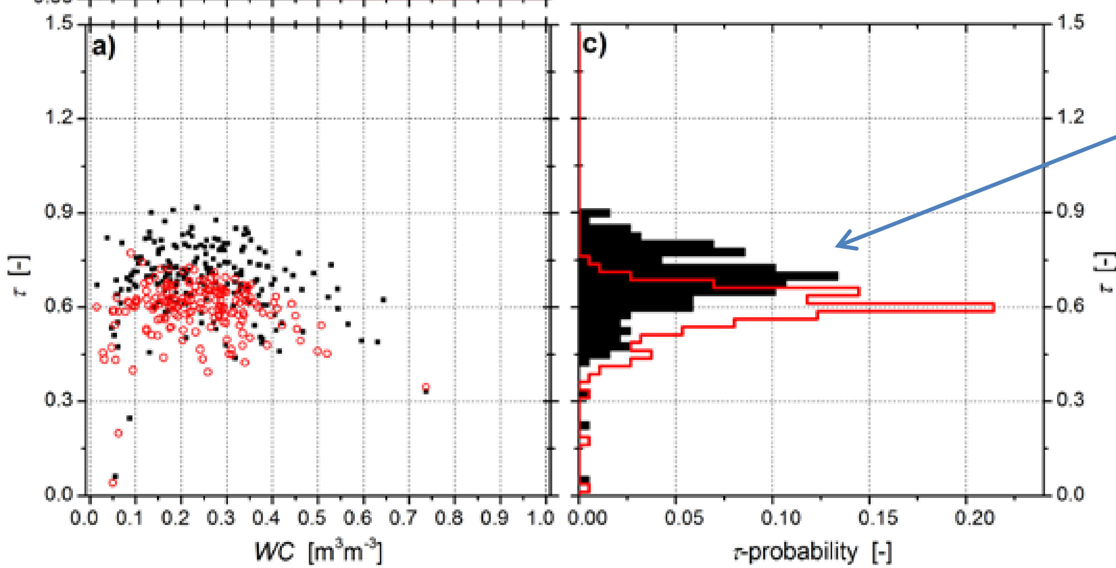
B) FOREST: 2S EM ® TO EM: *Retrievals* (WC_{RC}, τ_{RC}) *from tower-based* $T_B^p(q)$

Small impact of TO EM ® 2S EM on *WC* retrievals under forest canopy:

- Indirect impact of TO EM ® 2S EM on SMOS *WC* retrievals via $T_B^{p,\theta}$ of non-nominal pixel fraction (forest).



(a) Scatter plots of retrievals (WC_{RC}, τ_{RC}) derived from FOSMEX $T_B^{p,\theta}$ achieved with *RC*={**TO**, **2S**}. Histograms in **(b, c)** represent probabilities of respective retrievals.



Noticeable impact of TO EM ® 2S EM on *t* retrievals:

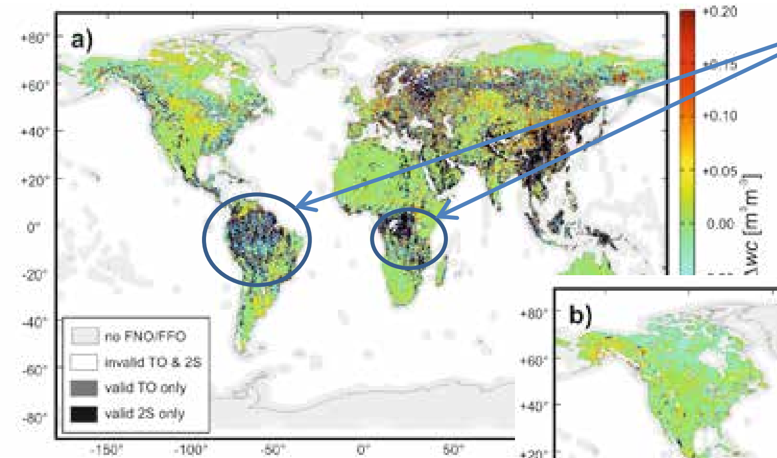
- t_{TO} (> t_{2S}) overestimates due to inadequate representation of scattering in TO EM
- Use of 2S EM is recommended for retrievals over forested areas!

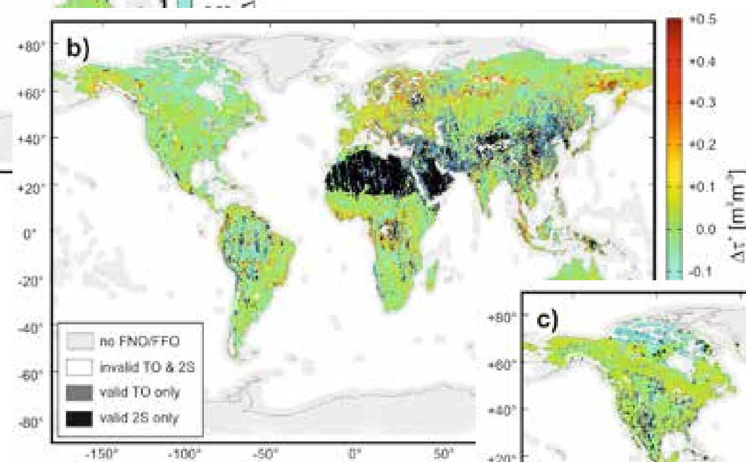
B) FOREST: 2S EM ® TO EM: *Retrievals* $(WC_{RC}, \tau_{RC}, \omega_{RC})$ *from SMOS* $T_B^p(\theta)$

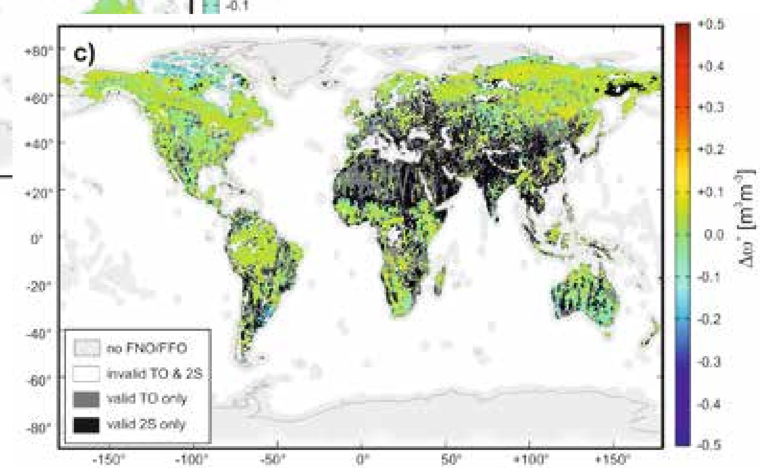
Global retrieval differences $((RC = \text{2S}) - (RC = \text{TO}))$

w retrieved simultaneously with *WC* and *t* because transformation $\omega_{\text{TO}} \mapsto \omega_{\text{2S,eq}}$ was not developed at that time!

- *RC* = 2S converges at least as often as operational *RC* = TO
- Green pixels indicate pixels with unchanged retrievals.
- Other colors indicate pixels with altered retrievals.







B) FOREST: *Conclusions / Summary:*

1. 2S EM has certain advantages over TO EM:
   a) Consideration of multiple reflections between vegetation and soil
   b) More correct representation of multiple scattering within vegetation
   c) Above points a) & b) become increasingly relevant for dense vegetation
   d) 2S EM has a wider applicability range, and converges to TO EM for sparse vegetation.

2. Retrieval Configuration *RC* = 2S (using 2S EM) and *RC* = TO (using TO EM):
   a) *RC* = 2S is as simple to implement as *RC* = TO currently used by SMOS & SMAP.
   b) Translation $\omega_{\mathrm{TO}} \mapsto \omega_{\mathrm{2S,eq}}$ is developed to achieve 2-parameter retrievals (WC_{RC}, τ_{RC}) that are comparable for *RC* = TO and *RC* = 2S.

3. (WC_{RC}, τ_{RC}) retrievals for *RC* = {TO,2S} :
   a) *Derived from tower-based* $T_B^p(q)$:
      i) Very small “direct” impact of TO EM ® 2S EM on retrieved *WC*.
         Expected indirect impact on SMOS *WC* retrievals via $T_B^p(q)$ of non-nominal pixel fraction (forest).
      ii) Retrievals t_{TO} are too high due to wrong representation of multiple scattering and neglect of multiple reflection in TO EM.
      iii) *RC* = 2S should be used for retrievals over forests!
   b) Demonstration maps derived from SMOS data:
      i) Technically speaking *RC* = 2S works at least as good as *RC* = TO.
      ii) Validation and implementation in operational algorithm still outstanding.

Summary

- Need for reliable BT first
- Validation is complexe
  - Need for more well designed dense networks
  - Over more biomes
- Issue of representativity of ground measurements (Molero et al 2018)
- Issue with data sets used for « calibration »/ Training and validation
- Need for specific exercises and standard approaches
- « torture numbers … they’ll confess anything »
- Need for objective approaches
  - Exemple of « blind tests »