ECMWF contribution to SMOS

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Global Monitoring and Data Assimilation Study

- **1- Global Monitoring**
  - Objectives
  - The Community Microwave Emission Model (CMEM)
  - The ALMIP-MEM Study
  - Near future SMOS monitoring
-
- 2- Data Assimilation Study
  - Exploitation of satellite data in the IFS
  - Operational requirements

SMOS Data Monitoring - Objectives

Monitoring has been a core activity at ECMWF for many years. It is done routinely for each data set used in operational data assimilation system.

For Numerical Weather Prediction applications, monitoring results in comparison between forecast and observed data.

For SMOS: monitoring of L1c TBH and TBV will be performed globally and results will be made available on the ECMWF products web page.

Passive monitoring: Simulate First Guess (FG) brightness temperatures and compare to observations (OBS-FG).

Active monitoring: when data are assimilated: analysis departure (OBS-ANA).

Ocean surfaces: passive monitoring of SMOS L1c TB.

Land surfaces: start with passive monitoring of L1cTB and switch to active monitoring when SMOS data used in operation (only in case of positive or neutral impact on the forecasts).

A key component of the monitoring is the forward operator that transforms model variables into observed variables.

The Community Microwave Emission Model (CMEM)

- CMEM has been developed as the ECMWF forward operator for low frequency passive microwave brightness temperatures at 1 to 20 GHz.

- I/O interfaces for the Numerical Weather Prediction Community.

- CMEM's physics is modular based on the parametrizations of the L-Band Microwave Emission of the Biosphere (LMEB, Wigneron et al., 2007) and Land Surface Microwave Emission Model (LSMEM, Drusch et al., 2007).

- CMEM Input/Output interface is flexible: grib (gribex, gribAPI), netcdf, ascii.

- CMEM is a Fortran 90 software, portable for unix/linux systems
- Last tagged version is cmem_v2.0

CMEM Modular Physics

Modular physics <-> Modular code structure

Allows accounting for different parametrisations for each component

- **Soil dielectric mixing model**

  (Wang & Schmugge / Dobson / Mironov)

- **Effective temperature model**

  (Choudhurry / Wigneron / Holmes)

- **Soil roughness model**

  (None = Smooth / Choudhurry / Wegmuller / Wigneron 01/07)

- **Smooth surface emissivity model**

  (Fresnel / Wilheit)

- **Vegetation opacity model**

  (None / Kirdyashev / Wegmuller / Wigneron / Jackson)

- **Atmospheric radiative transfer model**

  (None / Pellarin / Liebe / Ulaby)

  Equivalent to LMEB when options in red are chosen

SOIL

VEGETATION

ATMOSPHERE

Sea Surface Salinity

Ocean Salinity in the Integrated Forecast System

Forward modeling: TBocean = TB_flat + TB_rough
- TB_flat in CMEM (Klein and Swift 1977)
- Tbrough: SMOS L2 algorithm (P. Spurgeon, ARGANS)

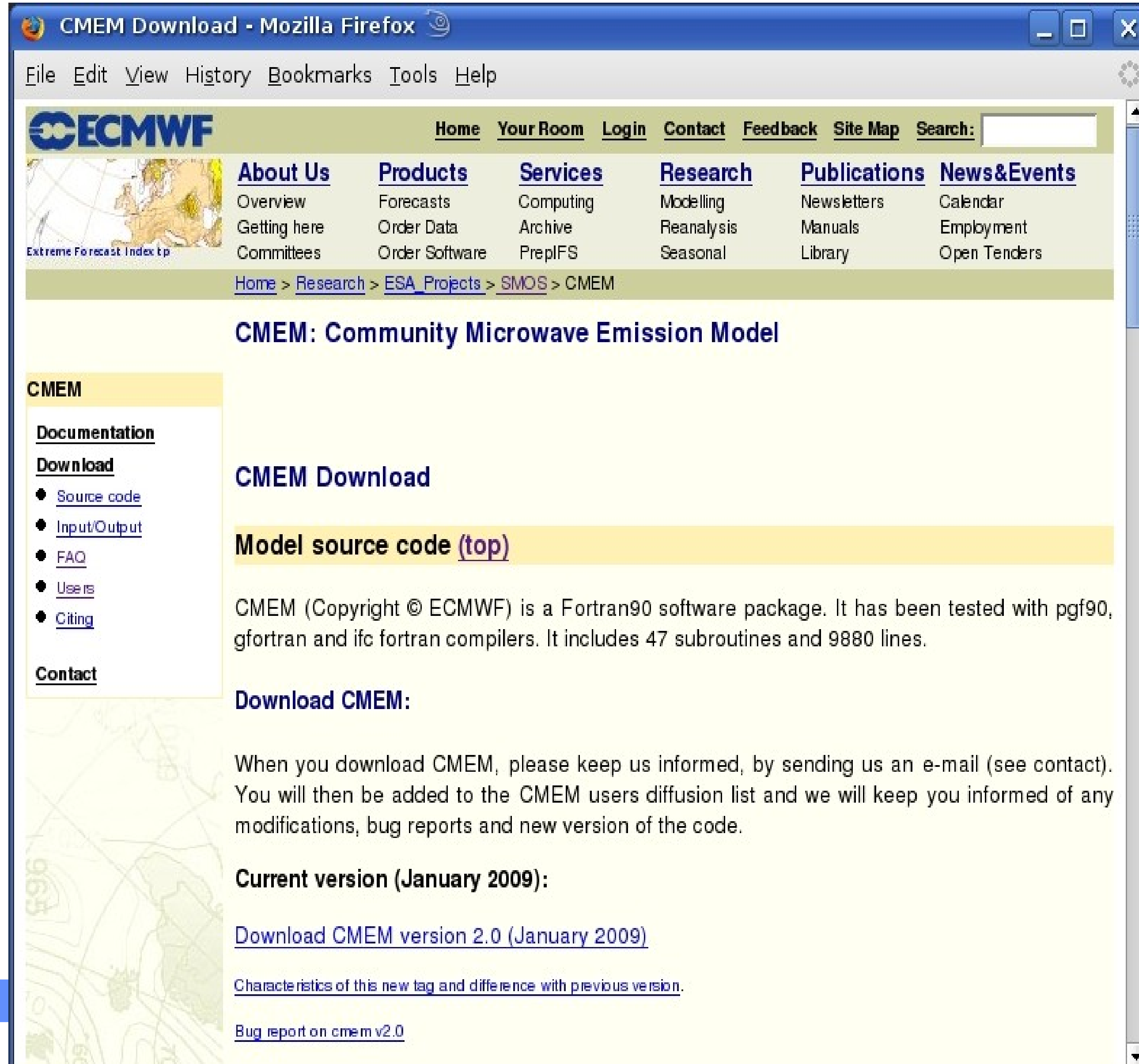
Needs to be added as a module, in CMEM
Additional inputs (flaged for SSS only): Wind components, SSS, Wave Height

Roughness TB models: 3 different approaches
- Model-1(L2 default): 2-scale approach
  (Durden & Vesecky 1957,Dinnat et al., 2002)
- Model-2: foam contribution (Reul et al. 2003)
- Model-3: semi-empirical model (Gabarro et al.2008)

→ Collaboration ECMWF / ARGANS / LOCEAN

CMEM Web interface

http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_index.html



- Documentation
- Source
- I/O templates
- FAQ
- Users
- Bug report
- Contacts

References:
Holmes et al. IEEE TGRS, 2008
Drusch et al. JHM, 2009
de Rosnay et al. JGR, 2009
Muñoz Sabater et al., sub 2009

ALMIP-MEM

AMMA Land Surface Model Intercomparison Project – Microwave Emission Model

Context: SMOS / AMMA (African Monsoon Multidisciplinary Analysis)

ALMIP (**AMMA Land Surface Model Intercomparison Project**, **Boone et al.,, 2009**)

Concept:

- Combined **8 LSMs and 12 microwave models (MWM)** inter-comparison
- Simulation of C-Band Brightness Temperature (TB) for 2006 over West Africa
- Evaluation against AMSR-E (C-band)

Aim:

- Sensitivity of simulated TB to the LSM and MWM parametrisations
- Identify key parametrisations for the CMEM forward operator

ALMIP-MEM

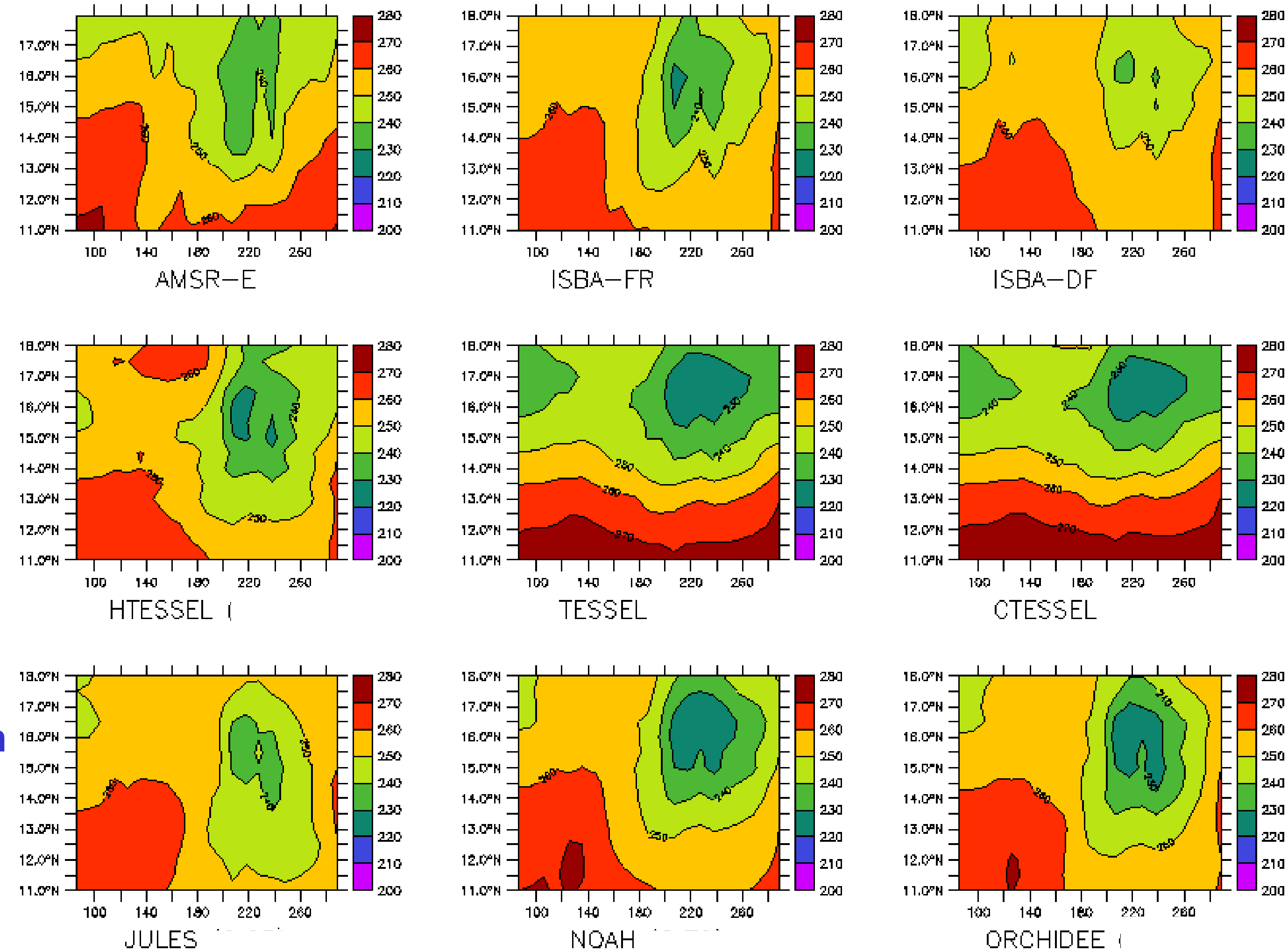
Time-latitude TB
(at horizontal Pol)
Average 10W-10E

AMSR-E
8 ALMIP-MEM LSM

CMEM configuration 10
(Wang&Schmugge
+ Kirdyashev)

Bias correction
Applied for each LSM

- Time-latitude wet Patch
Well captured by most
of the LSMS

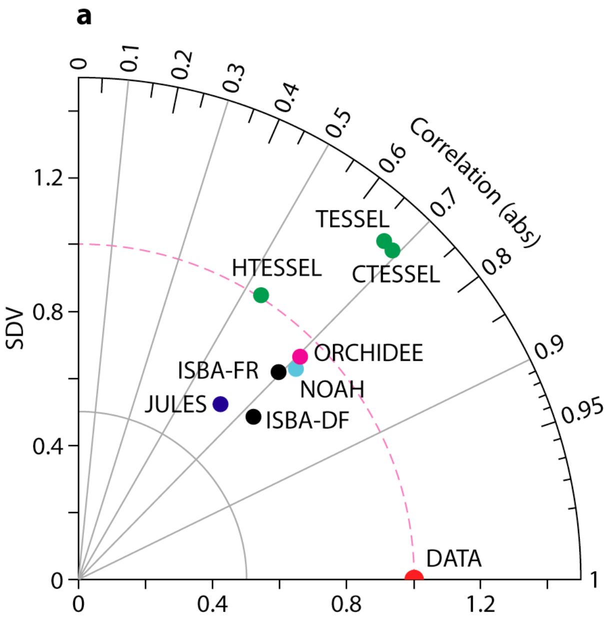


ECMWF

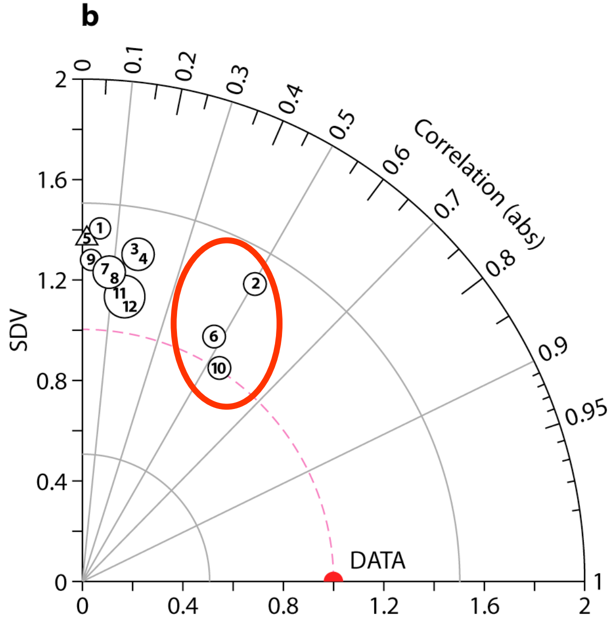
Comparison between simulated and observed TBH over West Africa

Taylor Diagram for the year 2006

1 MW Model, 8 LSMs



12 MW models, 1 LSM



Large scatter for LSM and MW models

Best MW modelling configuration: Kirdyashev and Wang & Schmugge models

-> Key parametrisation identified.

CMEM and the ALMIP-MEM study

ALMIP-MEM:

- Based on LSM community experience in inter-comparison (PILPS, GSWP2), but focus on West Africa and extended to compare different combinations of LSMs and radiative transfer models
- **1st inter-comparison exercise of land surface MW emission models**
- Coupled LSM-CMEM models capture convective system occurrence in Sahel, as well as latitude-time feature of TB
- **Sensitivity of simulated TB to MW models as important as that to LSMs**
- Robustness of the Kirdyashev opacity model to simulate TB in best agreement with AMSR-E measurements, for any LSM.

Consistence between Skylab (Drusch et al., 2009) and ALMIP-MEM (de Rosnay et al., 2009), although different angle, freq, LSM, scale are considered

High importance of MW modelling approach for SMOS monitoring and assimilation study

SMOS Data Monitoring

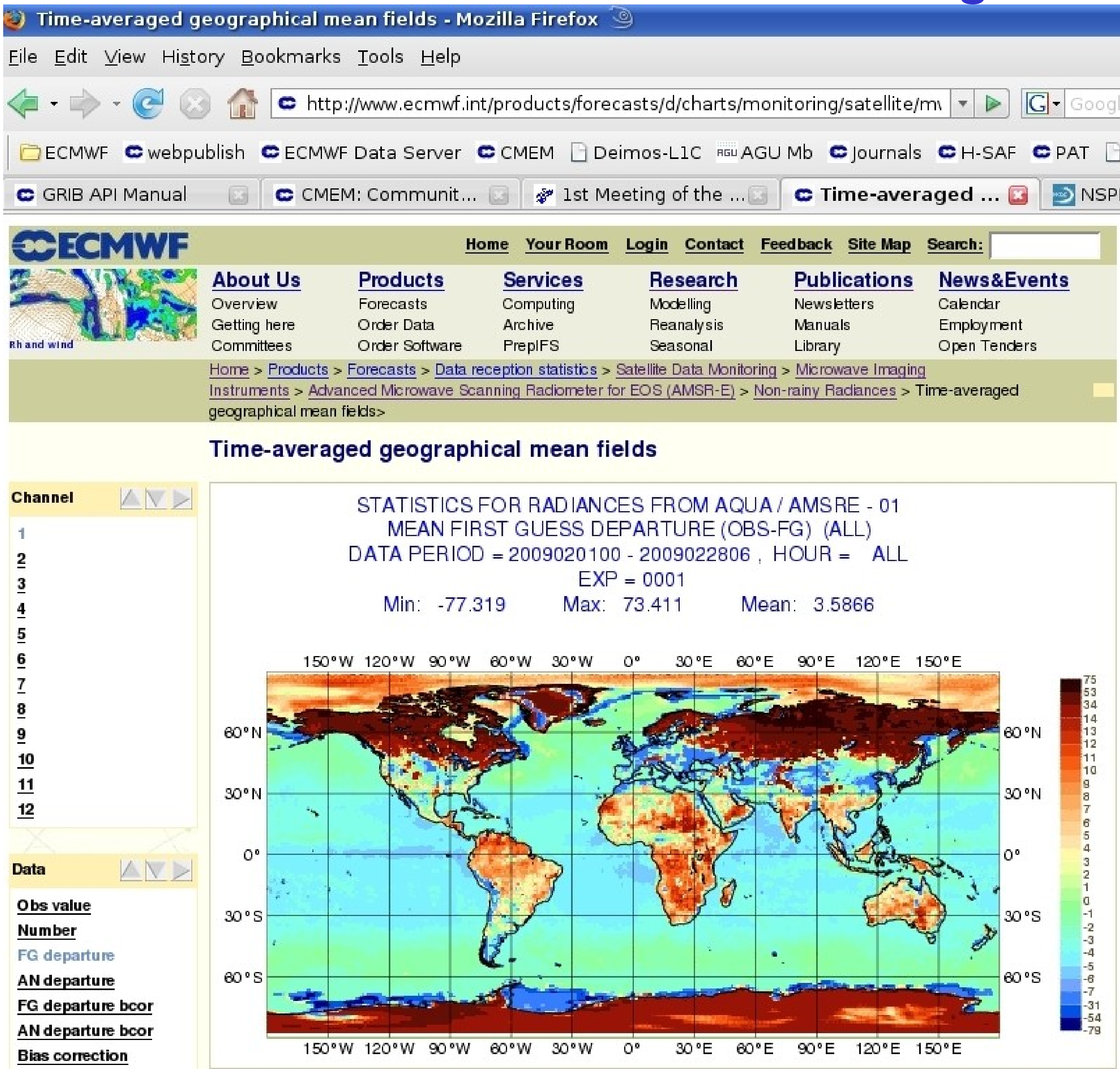
- Based on ECMWF IFS (Integrated Forecasts System) and using forward modelling

ECMWF monitoring page for microwave instruments

SMOS Data Monitoring

ECMWF monitoring page for microwave instruments

Data Monitoring



Example of AMSR-E Monitoring

SMOS: channel to be replaced by angles

ECMWF

Data Monitoring

Usual monitoring:
- Time-averaged geographical mean fields
- Hovmoeller zonal mean fields
- Time series of area averages

SMOS opens new possibilities for monitoring,
e.g. Angular dependency of FG – AN

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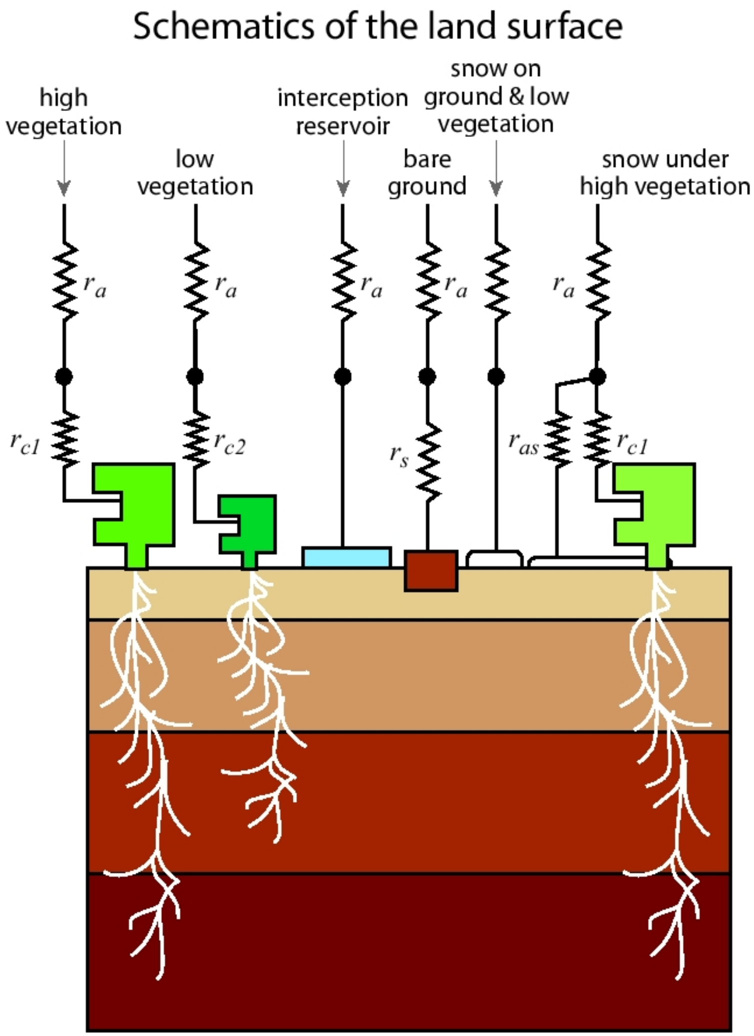
Current soil moisture analysis in operation at ECMWF
Optimum Interpolation (OI)

HTESSEL Land Surface Model



Link between soil variables and surface boundary layer (SBL):

- **Soil Moisture and Surface EvapoTR:**
  - **SM above field Capacity -> Hi LE**
  - **SM below wilting point -> Low LE**
- **Soil Moisture and Screen level Parameters:**
  - **Too low SM -> SBL too dry & too warm**
  - **Too high SM -> SBL too moist & too cold**

→ The analysis increments for the T2m and RH2m analysis are used to compute the soil moisture increments

$$DQ_i = A_i\left(T^a - T^b\right) + B_i\left(\mathrm{rH}^a - \mathrm{rH}^b\right)$$

Current OI weaknesses

- Link between screen parameters (T2m RH2m) and soil parameters relies on very complex and non-linear land-surface-atmosphere processes

- OI includes many thresholds to switch off the OI in conditions of wind, soil freezing, snow, precipitation

- Complexity of the Land surface model HTESSEL increases for future NWP applications (now HTESSEL, current work on CTESSEL)

- OI Not flexible to include new type of observations that are more directly linked to soil moisture or vegetation:
    - SM form active microwave (ERS, ASCAT, SMAP)
    - SM from passive microwave (SMOS, AMSR-E, SMAP)
    - Leaf Area Index (MODIS, SPOT-VEGETATION)

The simplified Extended Kalman Filter surface analysis

The analysis is obtained by an optimal combination of the observations and the background (short-range forecast):

$$\mathbf{x_a}(t) = \mathbf{x_b}(t) + \mathbf{K}\left(\mathbf{y}(t) - \mathbf{H}\mathbf{x_b}(t)\right)$$

where $\mathbf{K}$ is the gain matrix:

$$\mathbf{K} = (\mathbf{B}^{-1}(t) + \mathbf{H}^T(t)\mathbf{R}^{-1}\mathbf{H}(t))^{-1}\mathbf{H}^T(t)\mathbf{R}^{-1}$$

The observation operator $\mathbf{H}$ is the Jacobian matrix of:

$$H_{ij} = \frac{\delta y_i}{\delta x_j} \simeq \frac{y_i\left(x + \delta x_j\right) - y_i\left(x\right)}{\delta x_j}$$

In finite differences, the elements of the Jacobian matrix are estimated by perturbing individually each component x_j of the control vector $\mathbf{x}$ by a small amount δx_j.

Comparison between the OI and the EKF soil moisture analysis

Experimental setup

- IFS CY33R1, T159 for May 2007, 6h assimilation window
- Observations T2m and Rh2m
- Observation errors: σ_{T2m} =2K; σ_{RH2m}=10% ; σ_B=0.01m^3m^{-3}
- Matrix B not cycled
- Two experiments:
    - OI experiment (SM and ST)
    - EKF experiment (SM)

Comparison between OI and SEKF

OI Gain matrix coefficients

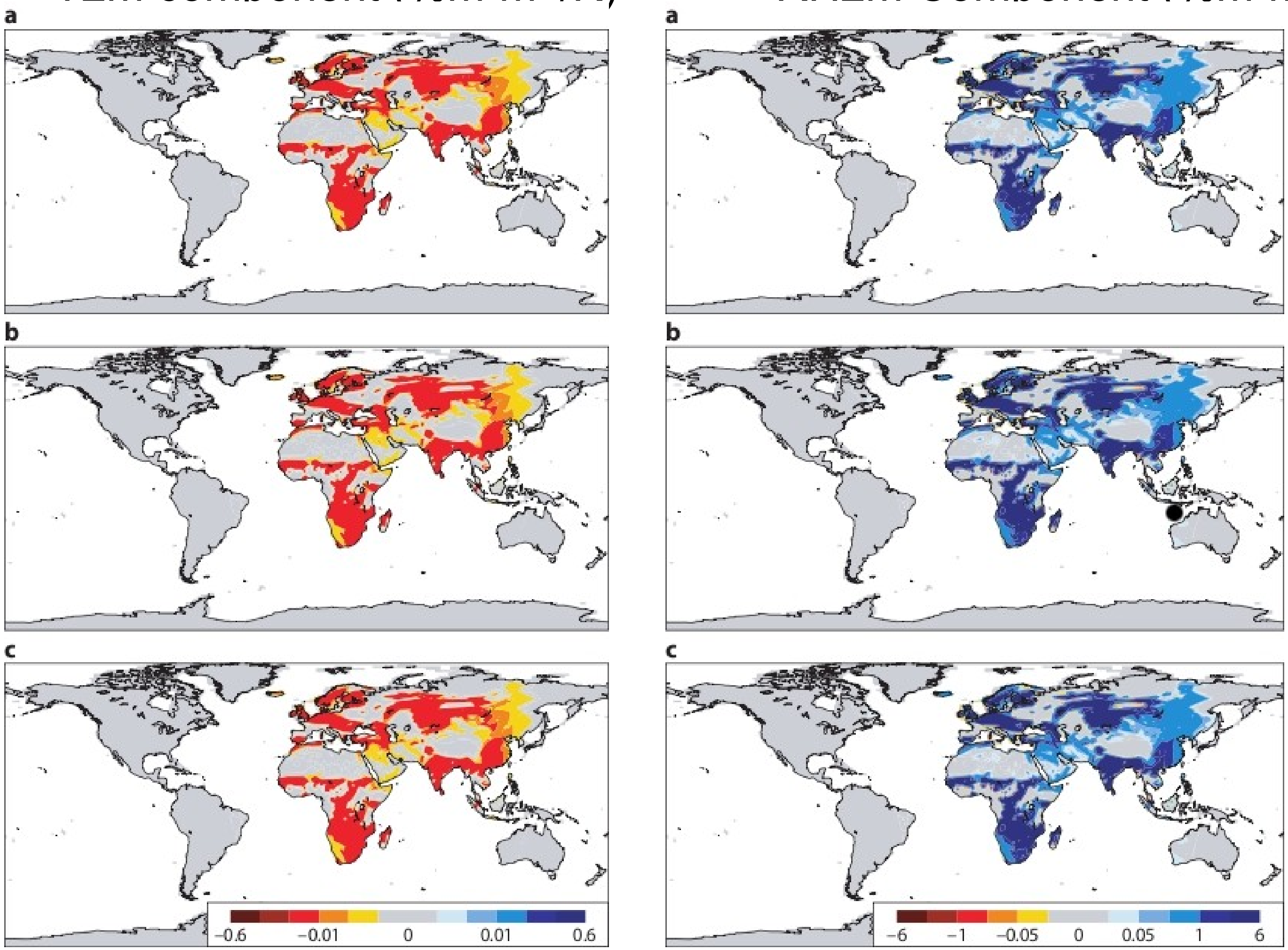
Case Study: 01 May 2007 12UTC

T2m component (%m^3m^{-3}/K) | RH2m Component (%m^3m^{-3})

Top 0-7cm

Layer2 7-28cm

Layer3 0.28-1m



-0.6 -0.01 0 0.01 0.6

-6 -0.1 0 0.1 6

- Opposite sign
- 1 order of magnitude larger for RH than T2m
- Limited to 20W-130E
- Low values over mountains, snow, deserts

Comparison between OI and SEKF
SEKF Gain matrix coefficients
Case Study: 01 May 2007 12UTC

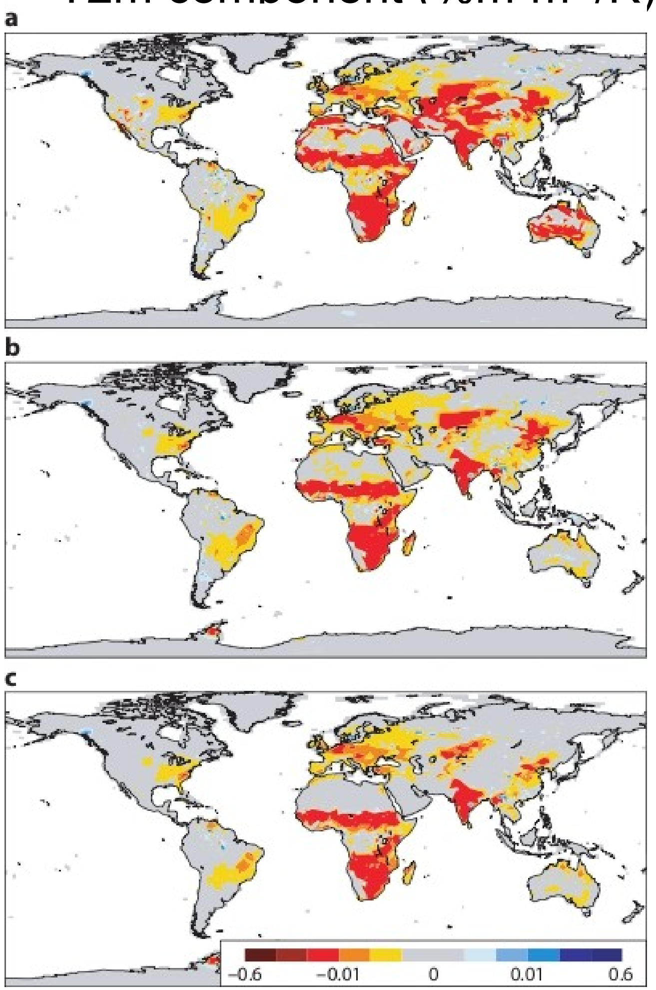
T2m component (%m^3m^{-3}/K)

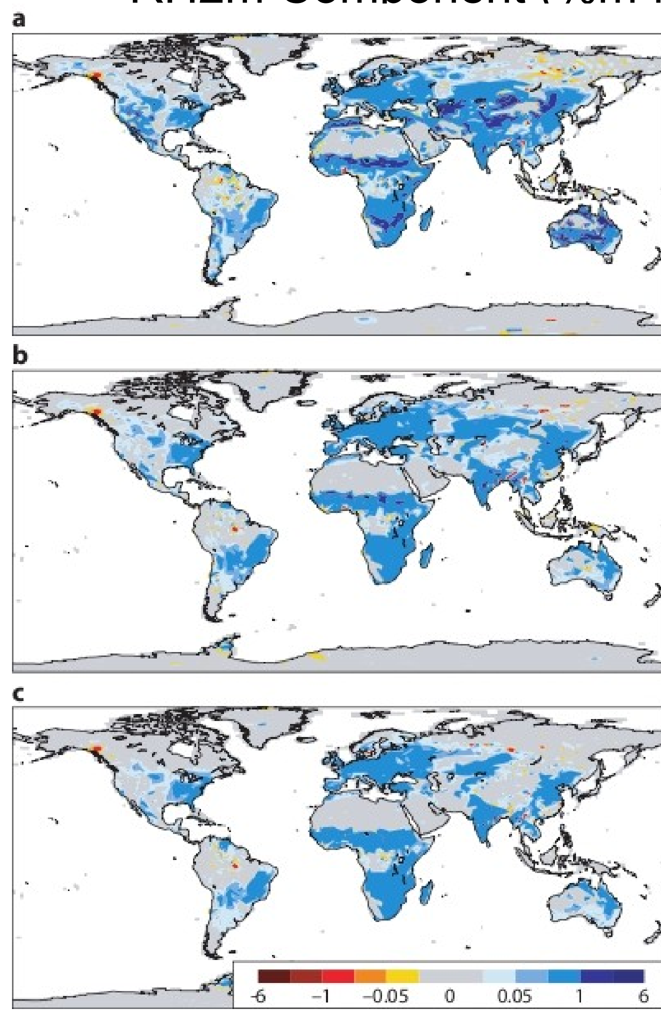
RH2m Component (%m^3m^{-3})

Top
0-7cm

Layer2
7-28cm

Layer3
0.28-1m





-0.6 -0.01 0 0.01 0.6

-6 -0.1 0 0.1 6

- Similar pattern
- Same order of magnitude than OI gain
- Extended to the global scale
- Reduced gain at depth -> hydrological consistency

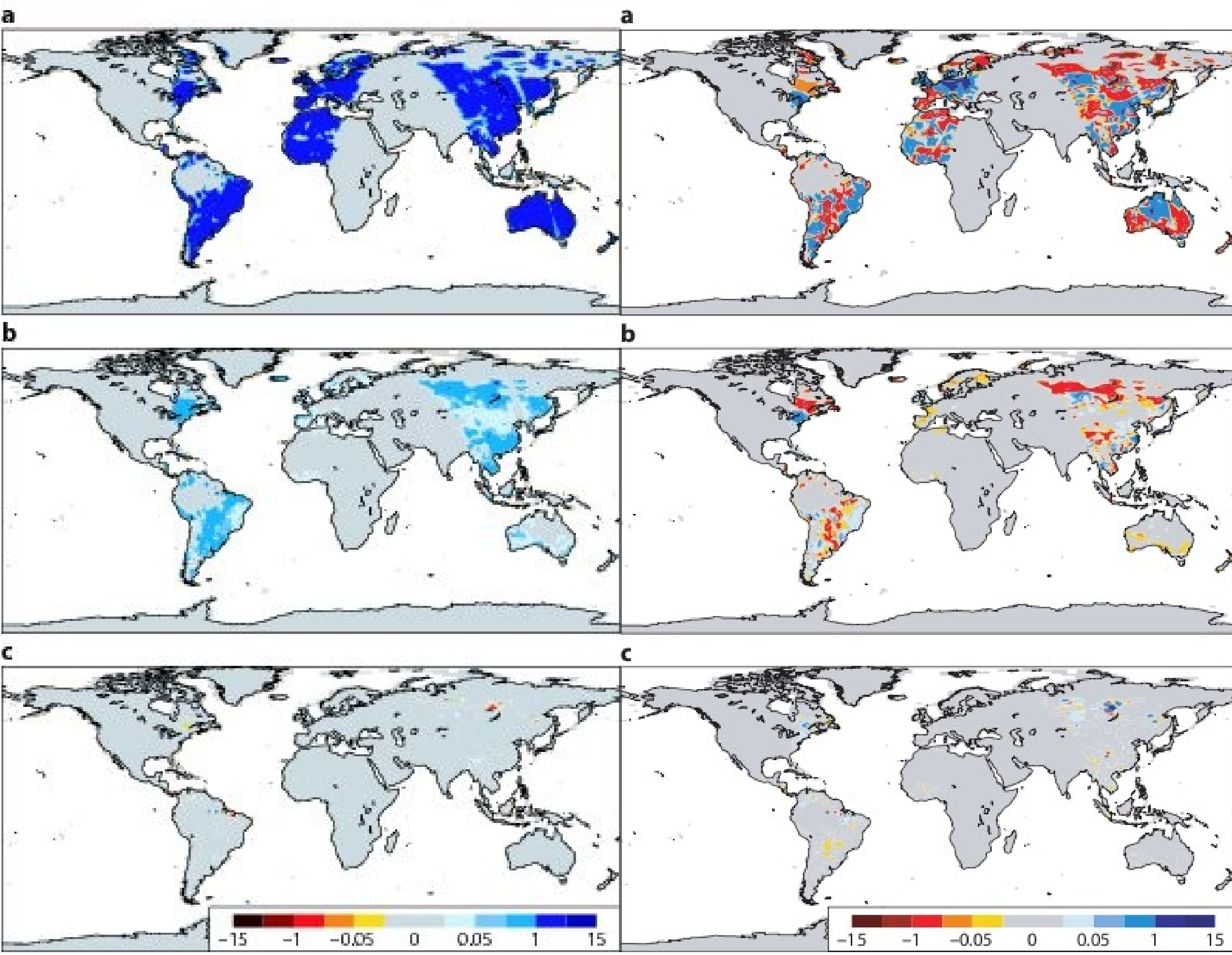
Drusch et al., 2009

ECMWF

ASACT assimilation in the EKF:
1-3 May 2007, T159

Scipal et al., in prep

Gain 10 x (m3/m3)/(m3/m3)   Increment (mm)



Top layer
0-7cm

- Values at high latitudes
- No gain over tropical Forest

Layer 2
7-28 cm

-Similar amplitude at night (US) and at day (Europe)

Layer 3
0.28-1m

ECMWF

EKF surface analysis system

- Accounts for the complex and non-linear link between screen parameters (T2m RH2m).
- B cycling investigated (Muñoz Sabater et al., poster).
- Provide similar results than the OI when screen level parameters are used.
- Flexible to include satellite data that are more directly linked to soil moisture, such as SMOS brightness temperatures.

Operational implementation:

The EKF surface analysis is far more expansive than the OI (x 1000 in CPU)

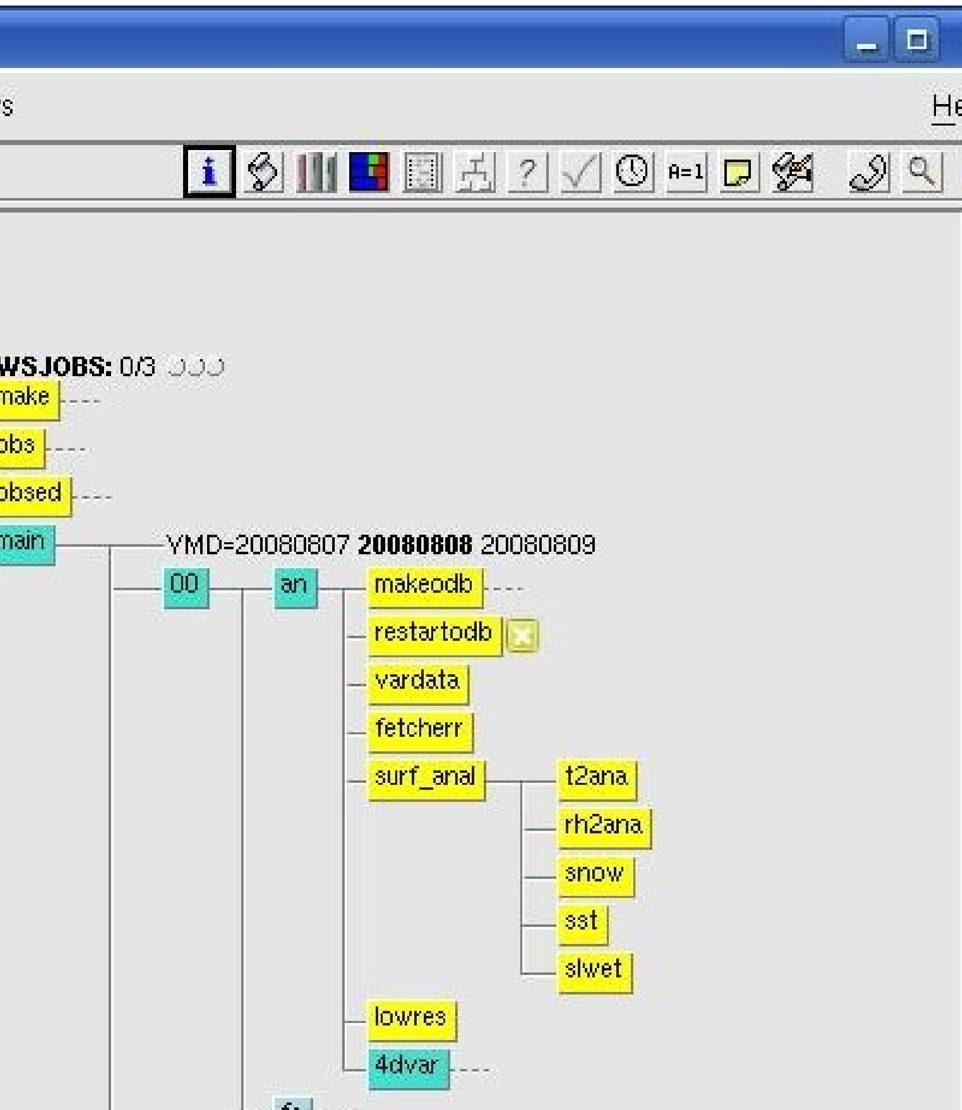
- The main costs is due to the perturbed coupled simulations required to estimate the Jacobian matrix (1 simulation per analysed layer)

- High resolution needed because of surface heterogeneities

-> need to reduce the cost of the EKF surface analysis in order to use satellite data in operations

Surface Analysis

Operational implementation of the EKF surface analysis:



1- The EKF surface analysis moved **before** the 4DVAR

→ allows more time for the surface analysis than in the current operations

2- Jacobians computation decoupled from the atmosphere

→ reduces the cost of the EKF by a factor 4

Just submitted for the last IFS version (CY 35R3)

Summary

ECMWF contribution to SMOS includes two main components:
- SMOS data monitoring
- SMOS data Assimilation

For both of them the CMEM forward model has been developed, validated, and it is being implemented in the IFS.

For the data assimilation study, an EKF surface analysis will be implemented in the operational Integrated Forecasts System (IFS) (end of 2009).

More information on the ECMWF contribution to the SMOS project on: http://www.ecmwf.int/research/ESA_projects/SMOS/

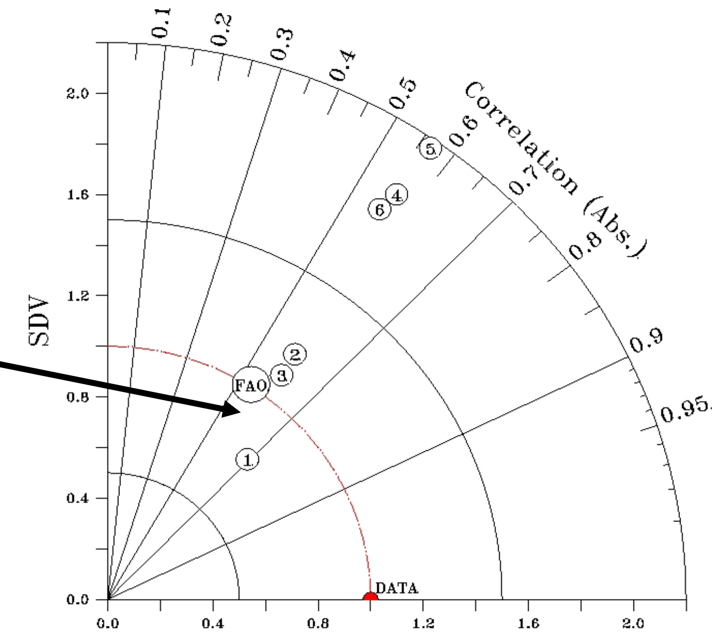
Impact of soil texture on TB errors with HTESSEL
(additional/complementary study)

Taylor Diagram for the year 2006
HTESSEL with different soil texture maps

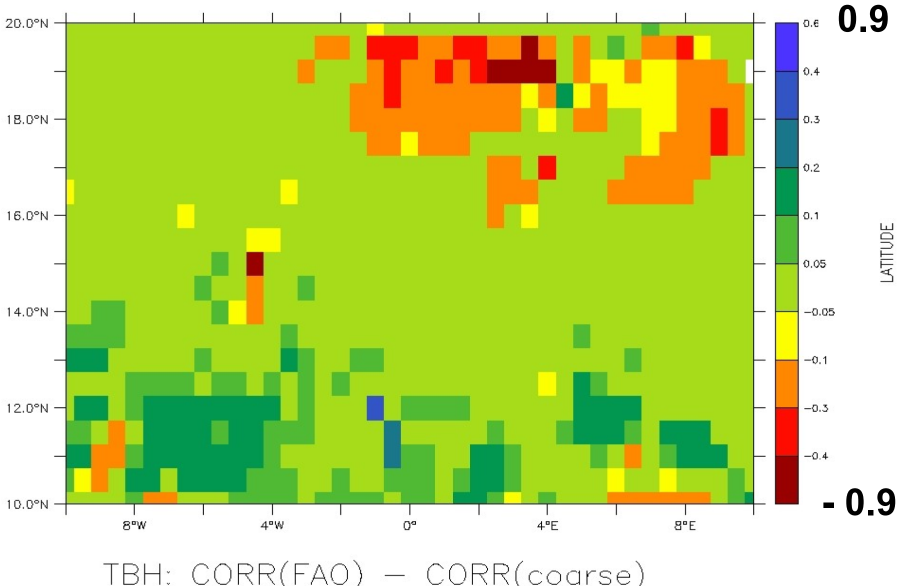
Coarse textured soil lead to better agreement between simulated and observed TB

Impact of texture on soil moisture dynamics -> affects the simulated TB

AMSR-E C-band data show texture maps pbs



Diff of TBH Corr (FAO – Coarse)



Soil texture FAO (1 coarse, 2 med, 3 fine)