Use of SMOS data for Numerical Weather Prediction (NWP)

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Global Monitoring and Data Assimilation of SMOS data

- **1- Global Monitoring**
  - Objectives
  - The Community Microwave Emission Model (CMEM)
  - The ALMIP-MEM Study
  - SMOS monitoring
-
- 2- Data assimilation for soil moisture analysis
  - 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 simulated 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 (SSS, SM) into observed variables (TB).

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_v2.1 (March 2009)

CMEM Modular Physics

Modular physics <-> Modular code structure

Over Land, CMEM accounts for several 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 for TBocean:
- TB_flat in CMEM (Klein and Swift 1977)
- Tbrough: SMOS L2 algorithm
- Reflected Galactic Noise on rough surface

Tbrough + GN modules of the SMOS L2 OS processor to be interfaced with CMEM
Additional inputs (for SSS only): Wind components, SSS, Wave Height

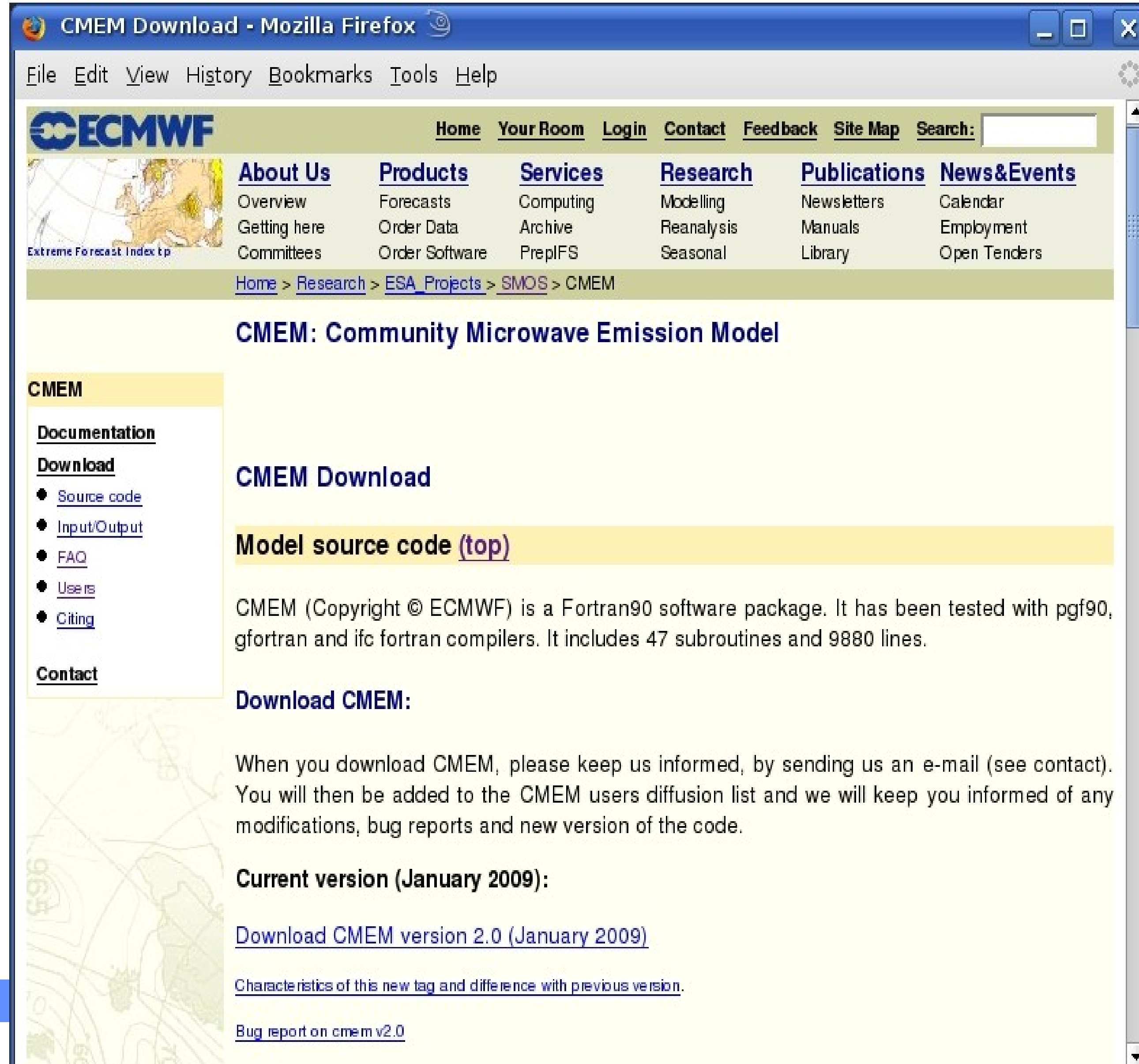
Roughness TB models: 3 different approaches
- Model-1(L2 default): 2-scale approach
  (Durden & Vesecky 1957,Dinnat et al., 2002)
- Model-2: foam contribution (Reul et al. 2003)
- Model-3: semi-empirical model (Gabarro et al.2008)

→ 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

(Poster XY 780)

ALMIP-MEM

AMMA Land Surface Model Intercomparison Project – Microwave Emission Model

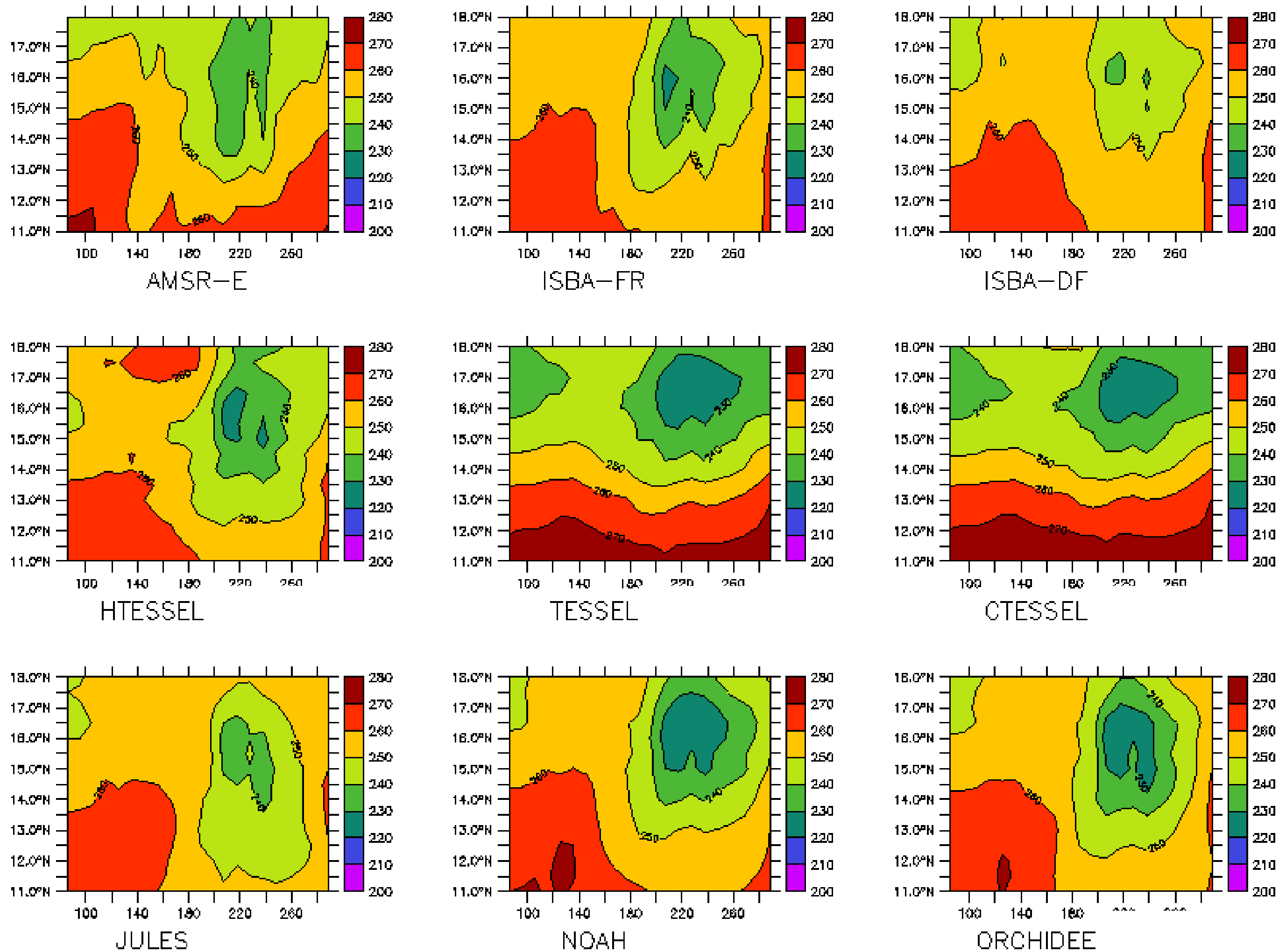
Time-latitude TB
(at horizontal Pol)
Average 10W-10E

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

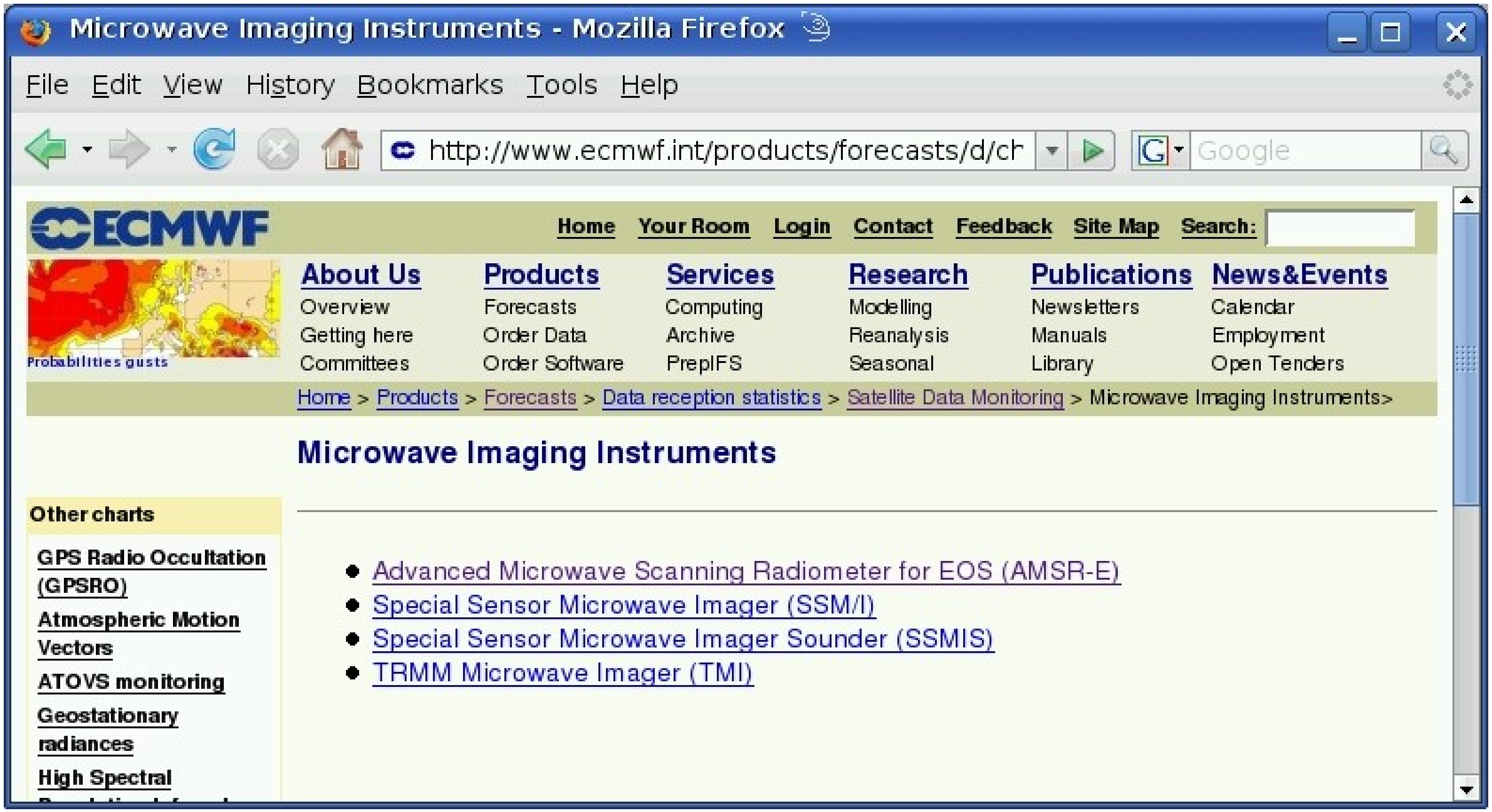


- ALMIP-MEM: First MEM intercomparison exercise, based on LSM community expertise
- Relative effects of LSM and MEM in the simulated TOA TB (evaluated with AMSR-E data)
- Identify key parametrisations for the SMOS data monitoring and assimilation

SMOS Data Monitoring

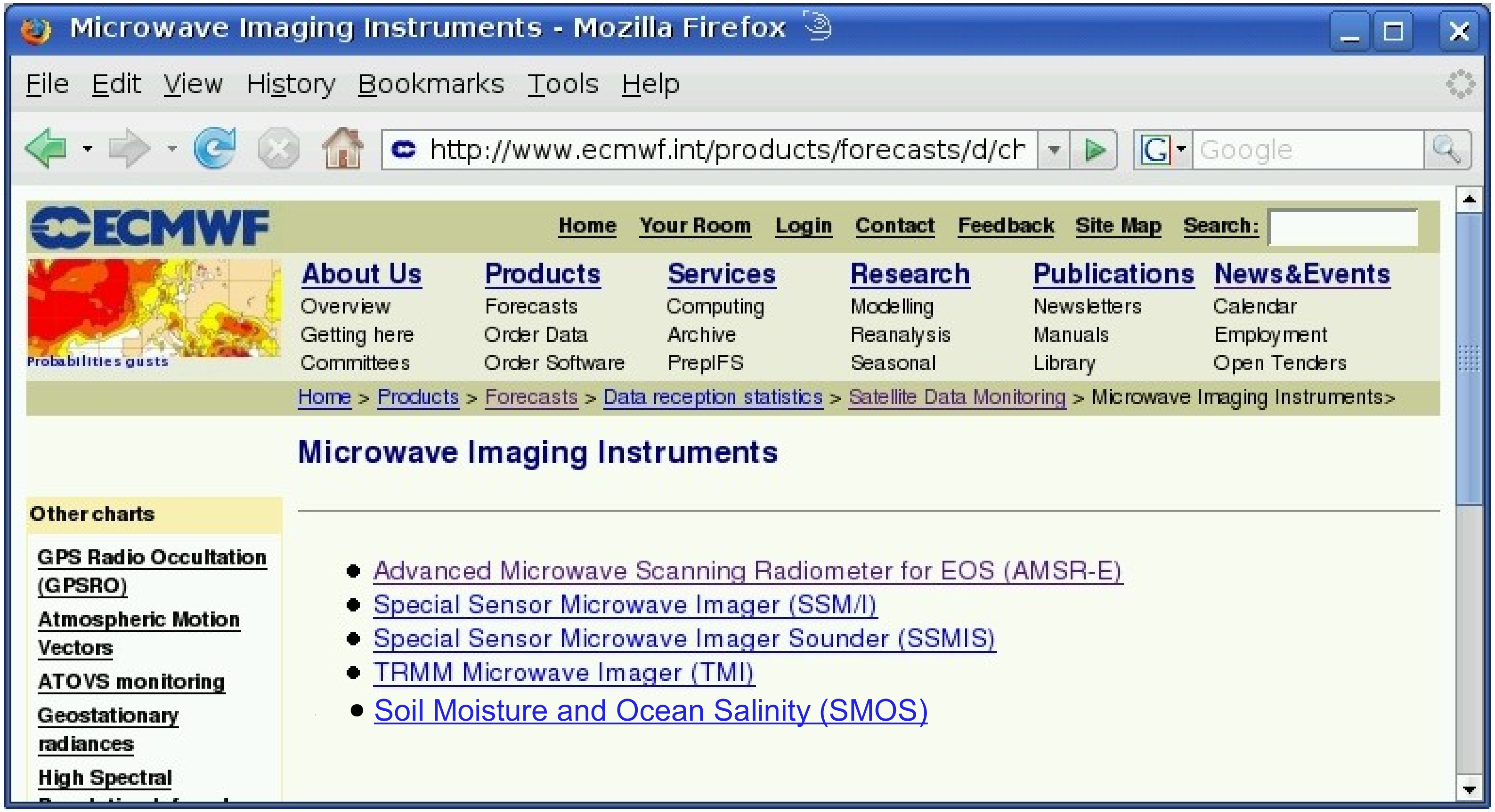
- Based on ECMWF IFS (Integrated Forecasts System) and using forward modelling

ECMWF monitoring page for microwave instruments

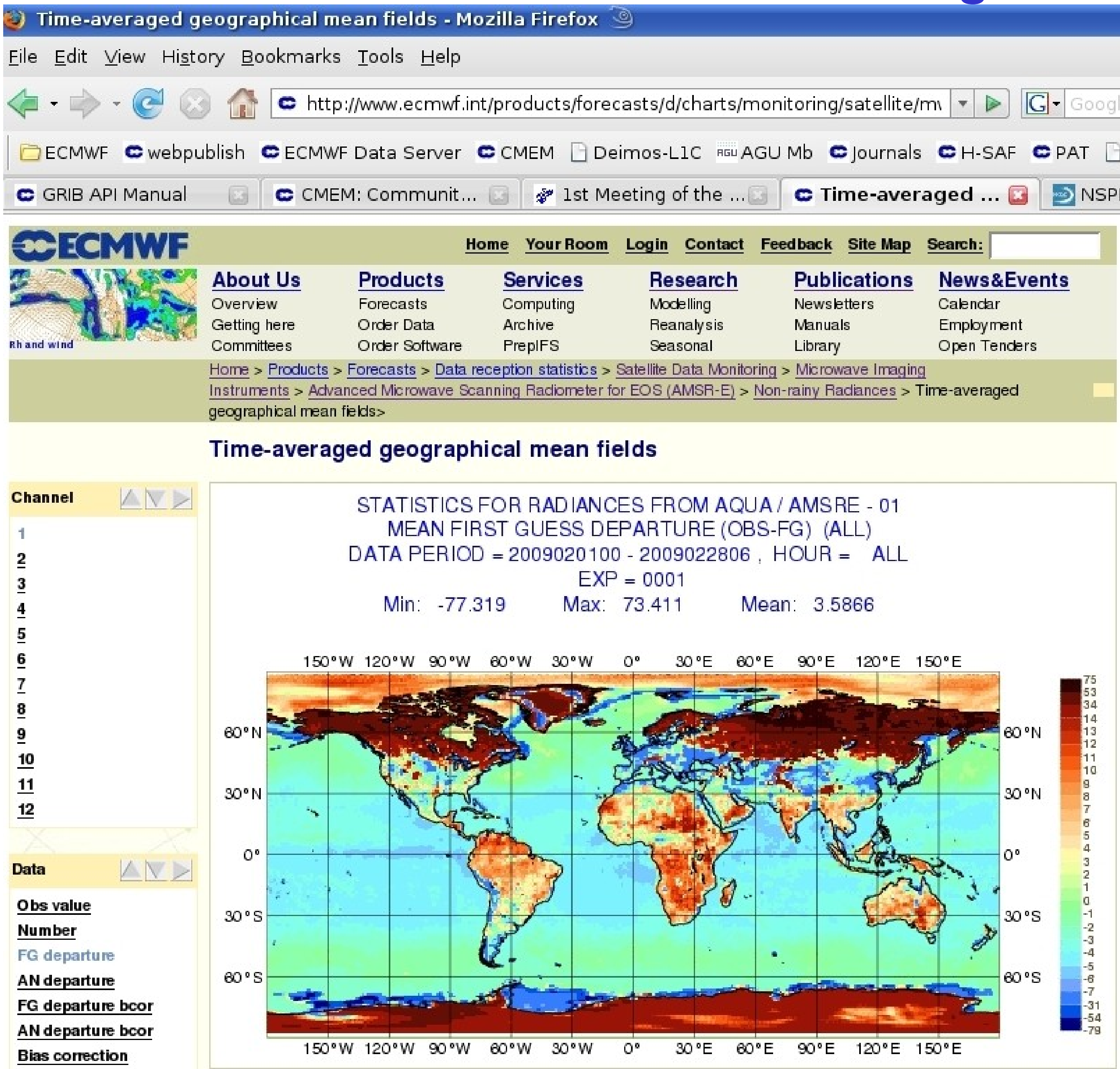


SMOS Data Monitoring

ECMWF monitoring page for microwave instruments



Data Monitoring



Example of AMSR-E Monitoring

SMOS: channel to be replaced by incidence angles

Global Monitoring and Data Assimilation Study

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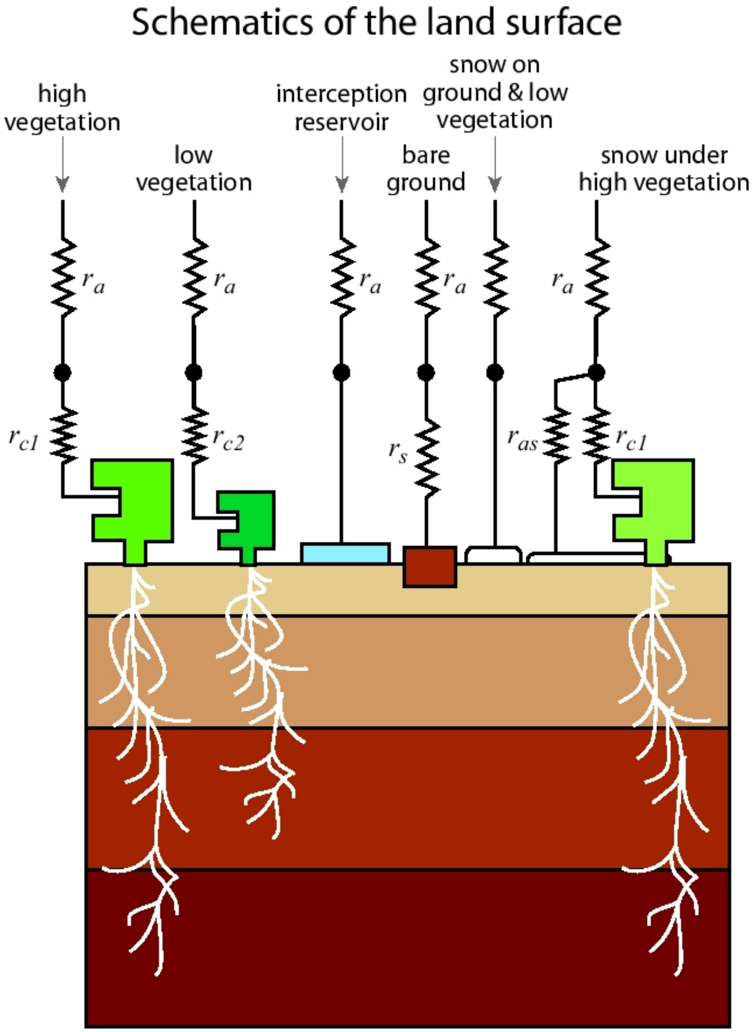
Current soil moisture analysis in operation at ECMWF
Optimum Interpolation (OI)

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 types 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:

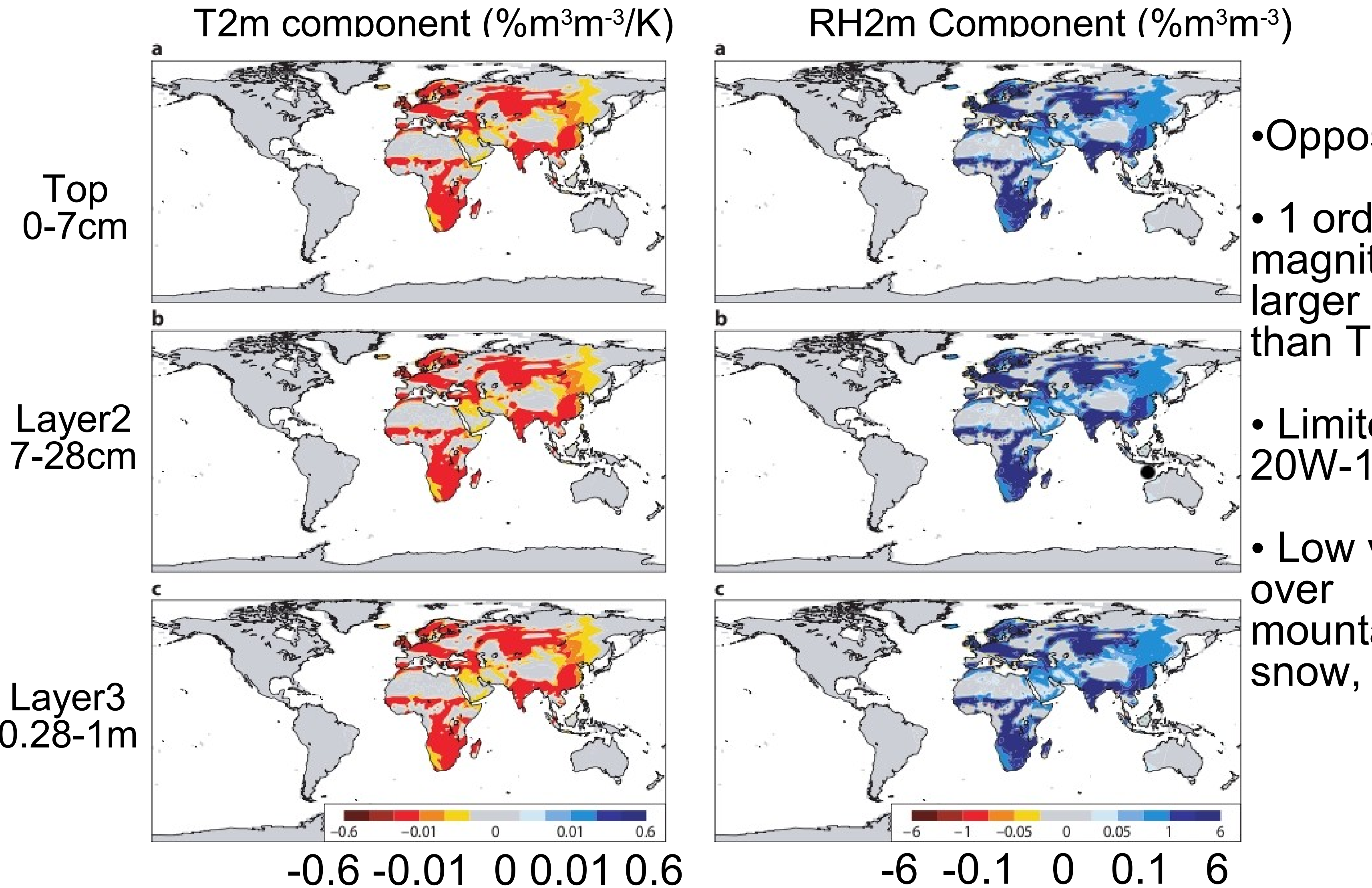
$$H_{ij} = \frac{\delta y_i}{\delta x_j} \simeq \frac{y_i\left(x + \delta x_j\right) - y_i\left(x\right)}{\delta x_j}$$

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



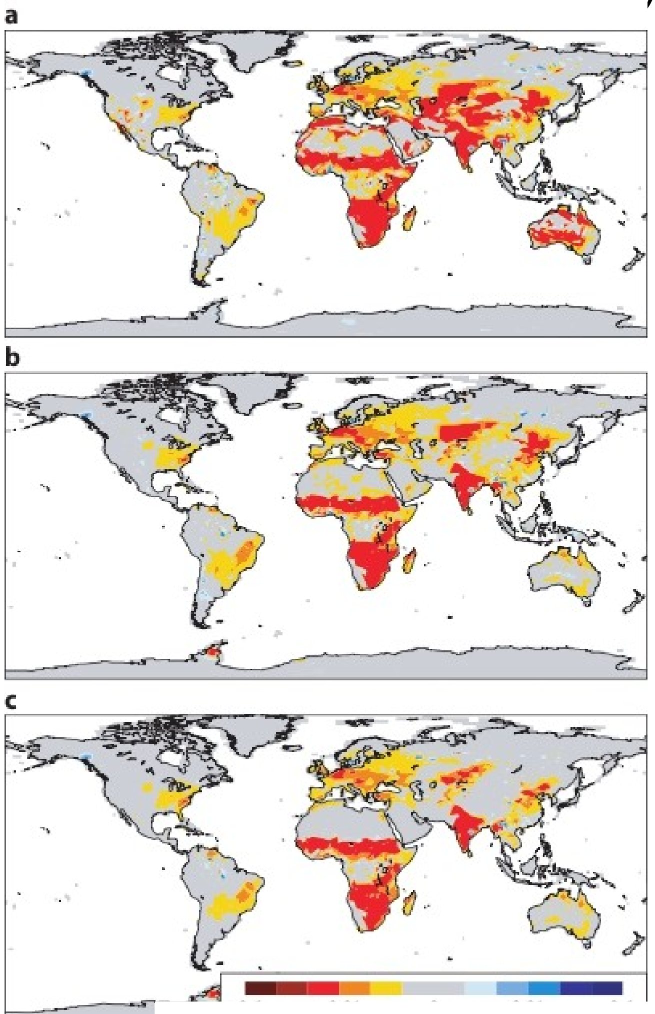
- Opposite sign
- 1 order of magnitude larger for RH than T2m
- Limited to 20W-130E
- Low values over mountains, snow, deserts

Comparison between OI and SEKF

SEKF Gain matrix coefficients

Case Study: 01 May 2007 12UTC

T2m component (%m³m⁻³/K)



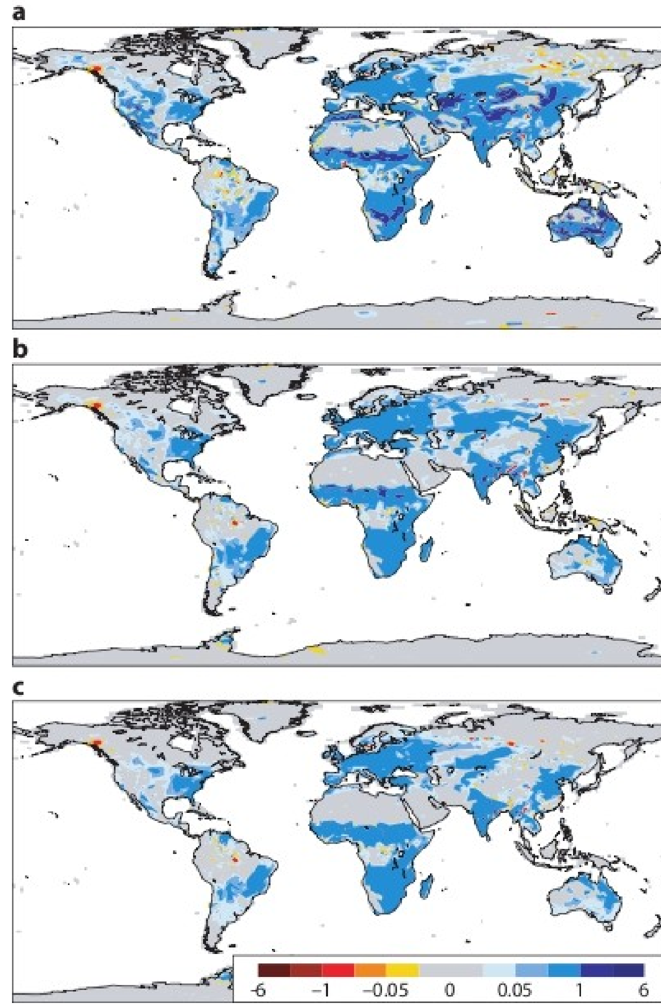
Top 0-7cm

Layer2 7-28cm

Layer3 0.28-1m

-0.6 -0.01 0 0.01 0.6

RH2m Component (%m³m⁻³)



-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

EKF surface analysis system

• Accounts for the complex and non-linear link between screen parameters (T2m RH2m).

• 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.

• EKF tested to assimilate ASCAT data (see Scipal et al, HS5.16, Room 32 - Friday)

Operational implementation:

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

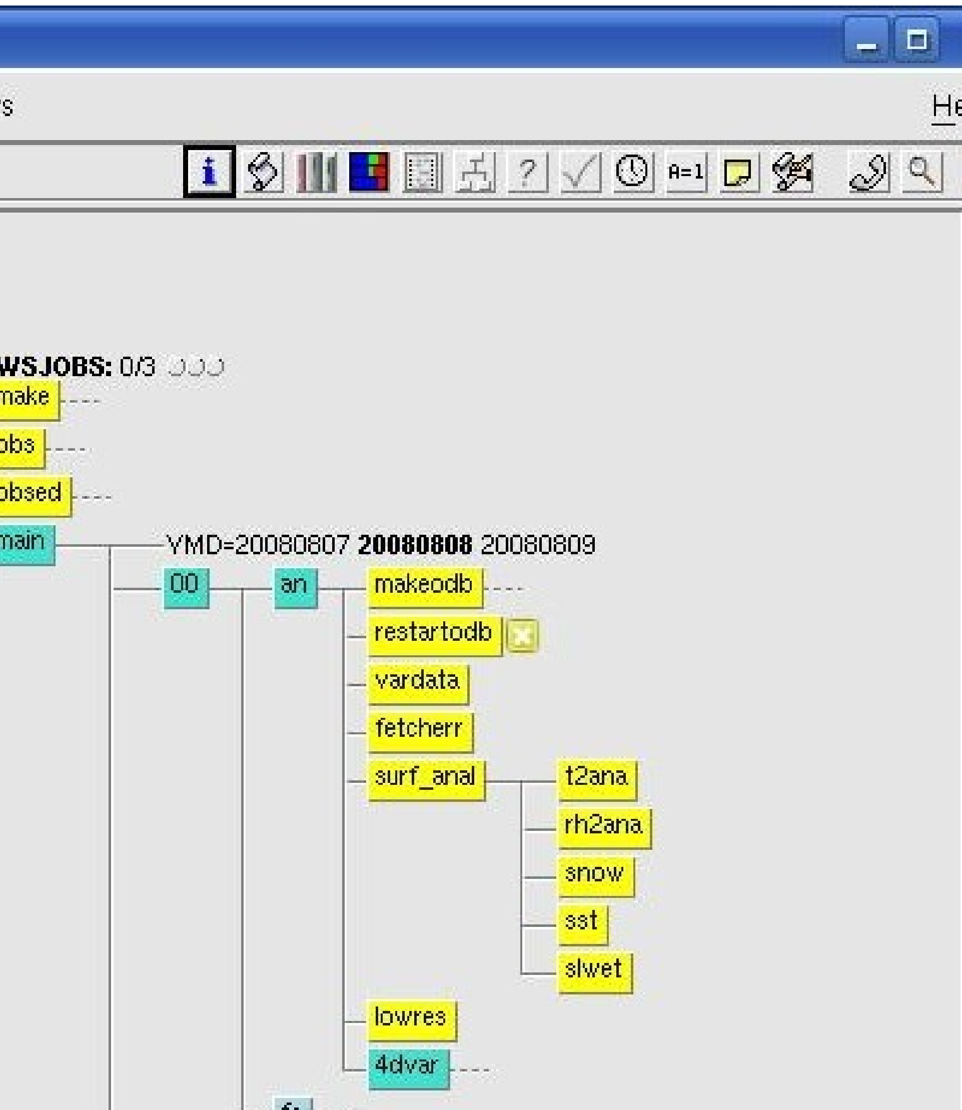
• The main costs is due to the perturbed coupled simulations required to estimate the Jacobian matrix (1 simulation per analysed layer)

• 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 included in the last IFS version (CY 35R3)

ECMWF

Summary

Use of SMOS data for NWP 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/