Recent advances on land surface modelling & data assimilation at ECMWF in preparation for SMOS mission

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With the help of several colleagues

OUTLINE

- SMOS satellite mission will be remotely sensing the Earth surface at L-band (1.4GHz) frequency
  - It will be highly sensitive to all water surfaces & soil moisture
- At ECMWF both modelling and data assimilation are preparing to assimilate SMOS
- From the model point of view:
  - Revised soil and snow schemes
  - Vegetation seasonality
  - Lake modelling
- From data assimilation point of view
  - Community Microwave Emission Model (CMEM)
  - Extended Kalman filter
  - Structure of the surface analysis in the Integrated Forecasting System
  - Synergy with active microwave activities (ASCAT)

Passive MW remote sensing of soil moisture:

Skylab, NASA, L-band, 1973-1974 (but only 9 overpasses available)

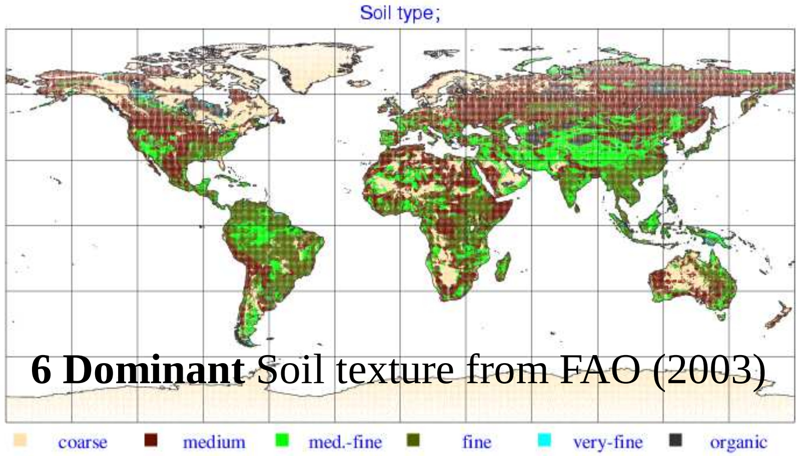
AMSR-E (Advanced Scanning Radiometer on Earth Observing System), NASA, C-band (6.9GHz), 2002-now

SMOS (Soil Moisture and Ocean Salinity Mission): ESA Earth Explorer, L-band (1.4 GHz), launch November 2009

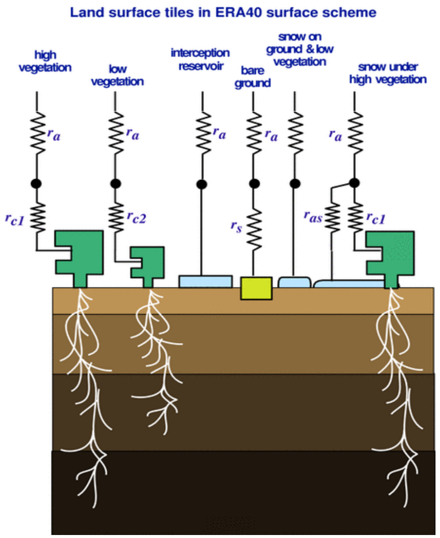
SMAP (Soil Moisture Active and Passive), NASA, L-band, launch 2014

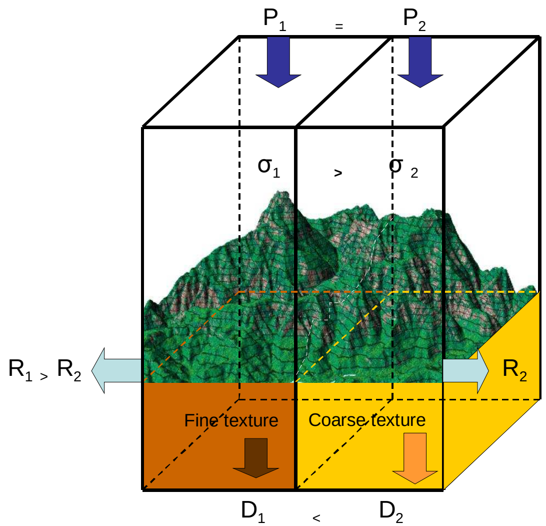
SMOS: will be the first satellite mission specifically devoted to soil moisture remote sensing. ECMWF actively prepares SMOS data assimilation activities.

A new soil hydrology (11/2007)



- **HTESSEL (Improved Hydrology: validation at monthly scales over 41 large World basins and daily scales only on Rhone basin**
- **HTESSEL became operational Nov. 2007**





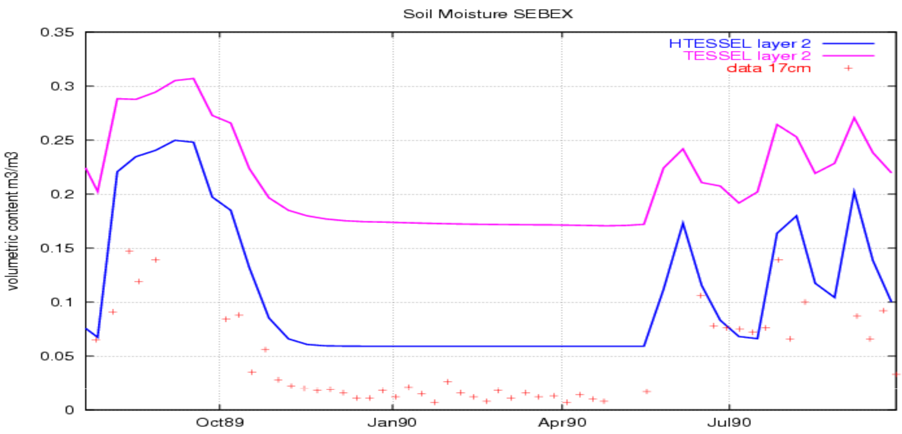
Hydrology-TESSEL

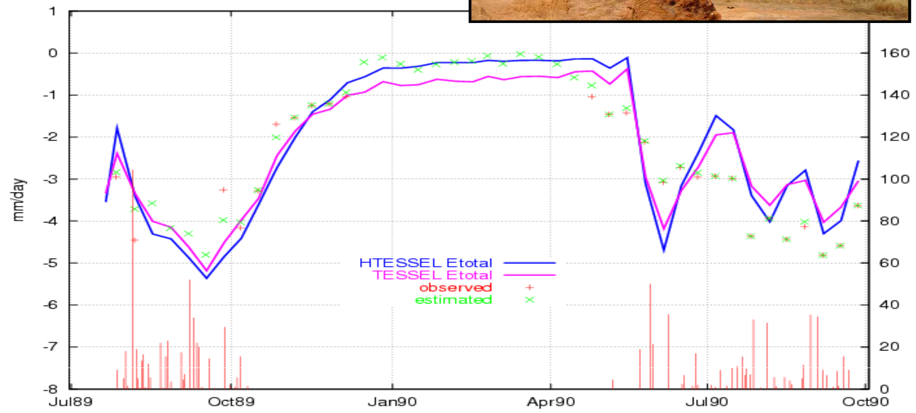
- Global Soil Texture Map (FAO)
- New formulation of Hydraulic properties
- Variable Infiltration capacity (VIC) surface runoff

- Balsamo et al. 2009 (*J. of Hydromet.*), van den Hurk et al. 2003, Viterbo and Beljaars 1996

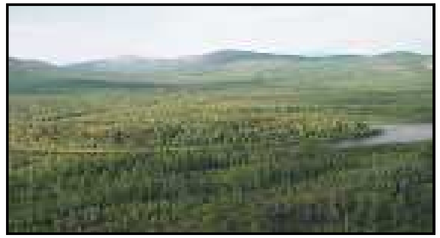
Improved soil moisture and evaporation

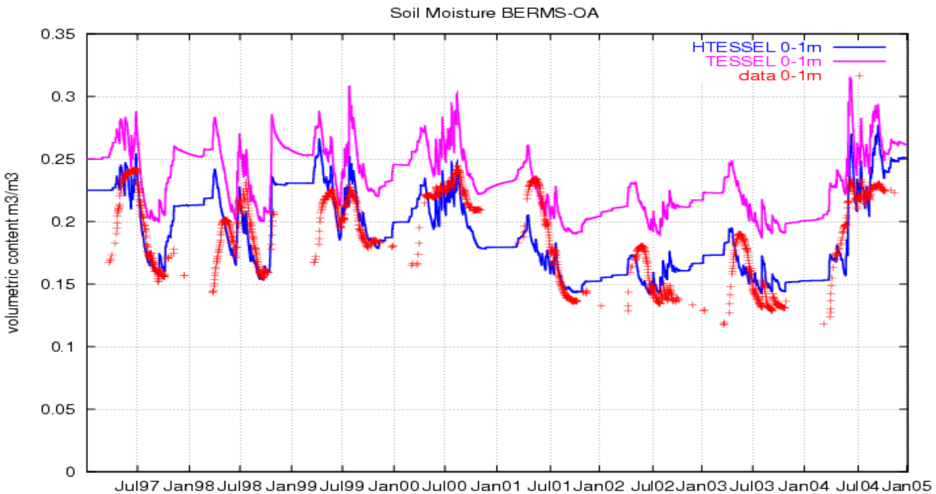
SEBEX (Savannah, Sandy soil)





BERMS (Boreal Forest)



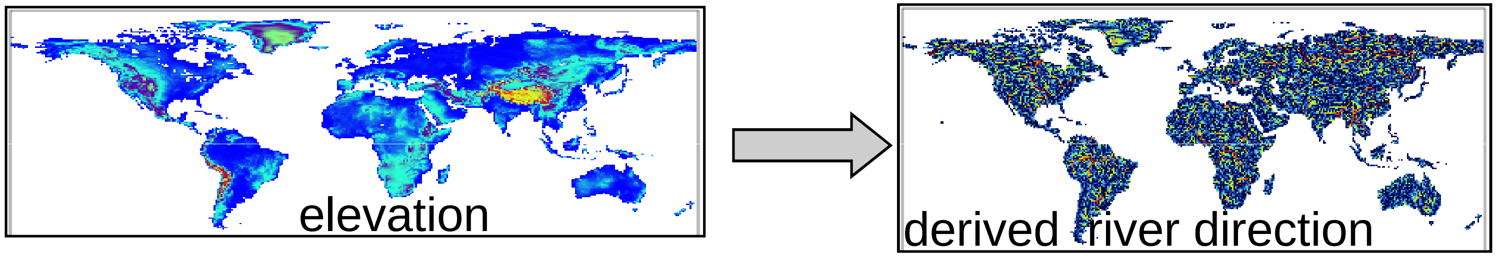


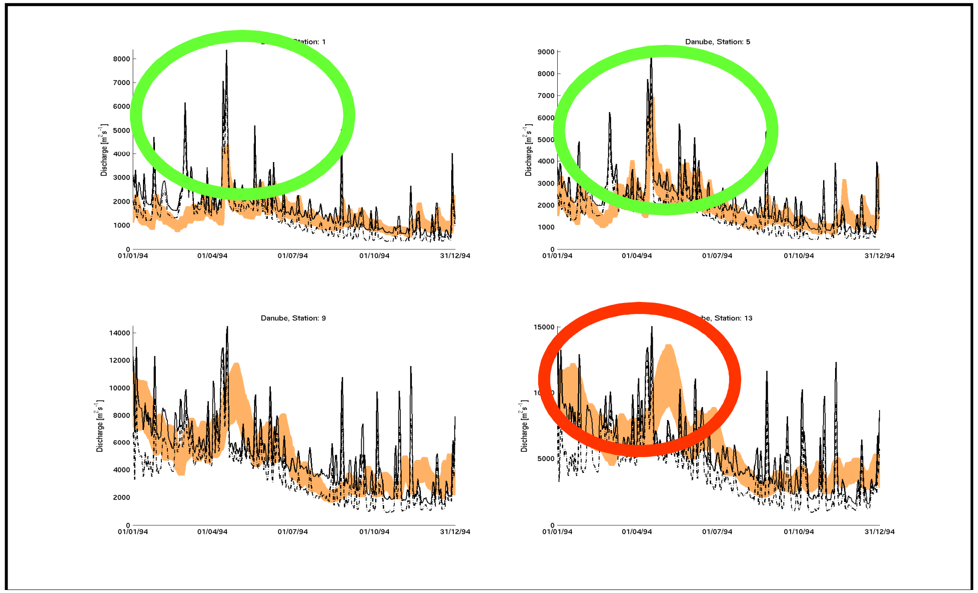
HTESSEL improves soil moisture and evaporation with respect to TESSEL in dry climates and leads to a better represented soil moisture inter-annual variability in continental climate

HTESSEL and hydrological applications

F. Pappenberger, H. Cloke, G. Balsamo, N.D. Thanh, T. Oki
(2009, *Int. J. of climatol., under revision*)

- **A routing scheme [TRIP2 evolution of TRIP , Oki and Sud, 1998)] is coupled to HTESSEL to account water path into rivers.**
- **The aim is to assess skill of the land surface models water output (Runoff) for river discharge modelling**





GSWP2+HTESSEL+TRIP2

Figure 10: Observed and modelled hydrographs (using HTessel) for four stations on the Danube river for the year 1994. The orange area indicates the observed data with its uncertainties. The dotted black line represents the 5th and 95th percentiles of the modelled flow.

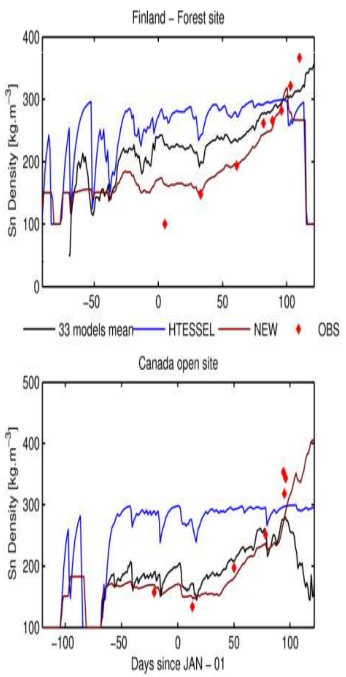
A new snow model (09/2009)

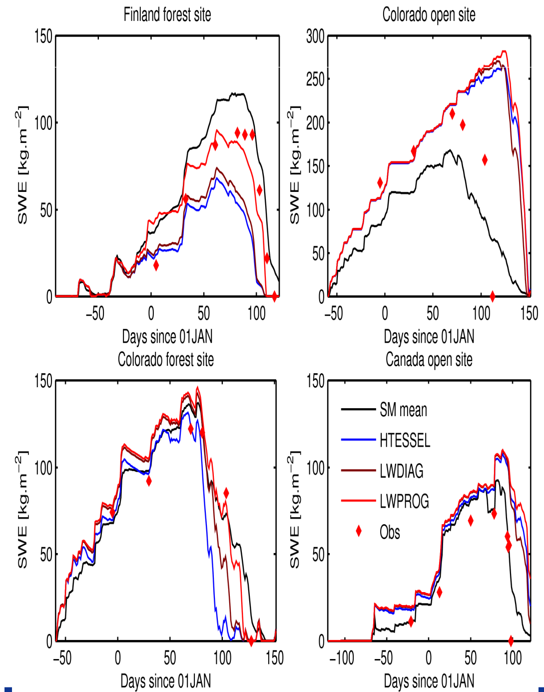
- The snow scheme from Douville et al. (1995) had few shortcomings shown on SNOW-MIP2 (Rutter et al. 2009) and highlighted by the ERA-40 analysis increments
- A revised snow scheme has been developed by E. Dutra et al. (2009) in collaboration with IM (P. Viterbo) and Univ. of Lisbon (P. Miranda)
- The revised snow scheme has been tested in cycle 33R1 and implemented in cycle 31R2(ERA-Interim) / 35R2 / 35R3(operational on the 10^{th} of September 2009).
  - Vegetation-dependent roughness (CY31R2)
  - Liquid water in the snow-pack (CY35R2)
  - Snow density (CY35R2)
  - Interception of rainfall (CY35R3)
  - Forest-Snow albedo revision
  - Open-area snow albedo revision
  - Snow fraction (depth dependent)

Impact of snow model (SnowMIP2/EC-Earth) and in ECMWF long integrations (13-month)

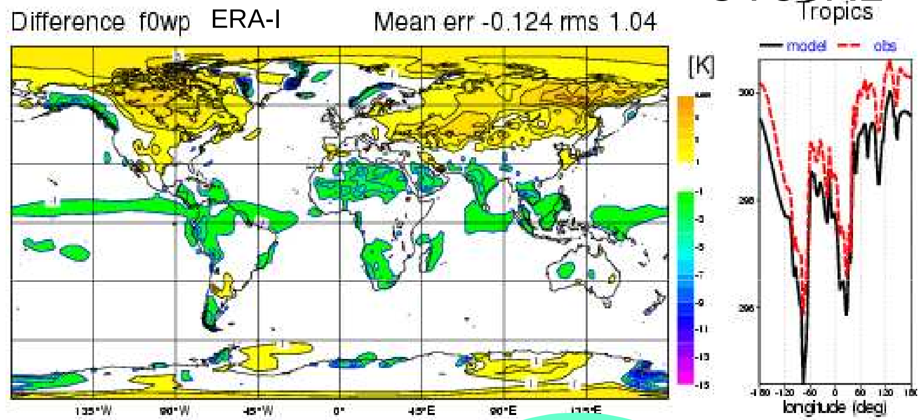
Dutra et al. (2009)

- **A new treatment of snow density**
- **Diagnostic liquid water in the snow-pack**

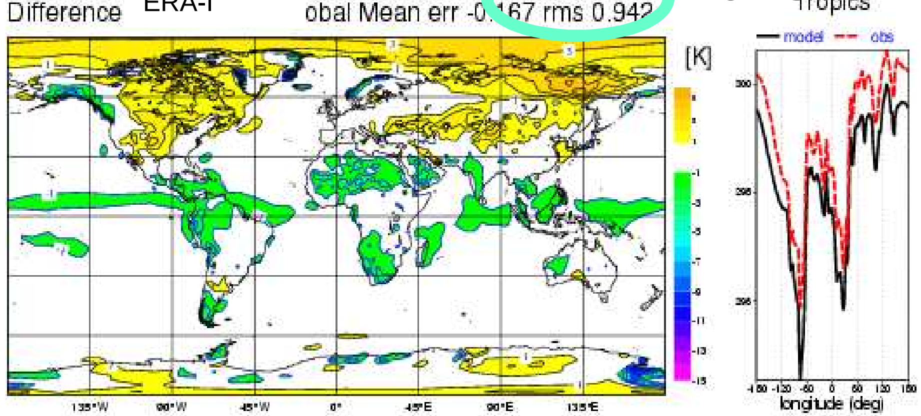




CY33R1



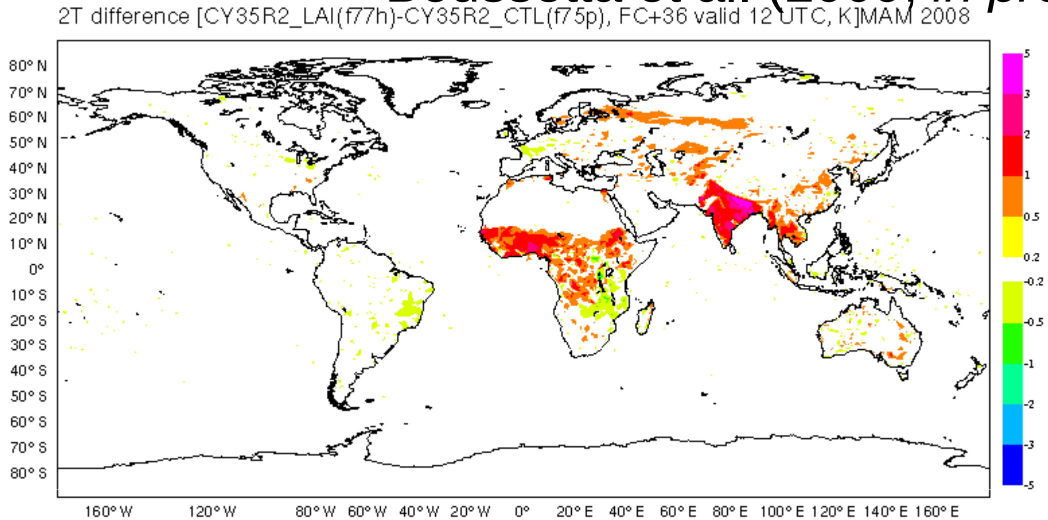
Rev Snow

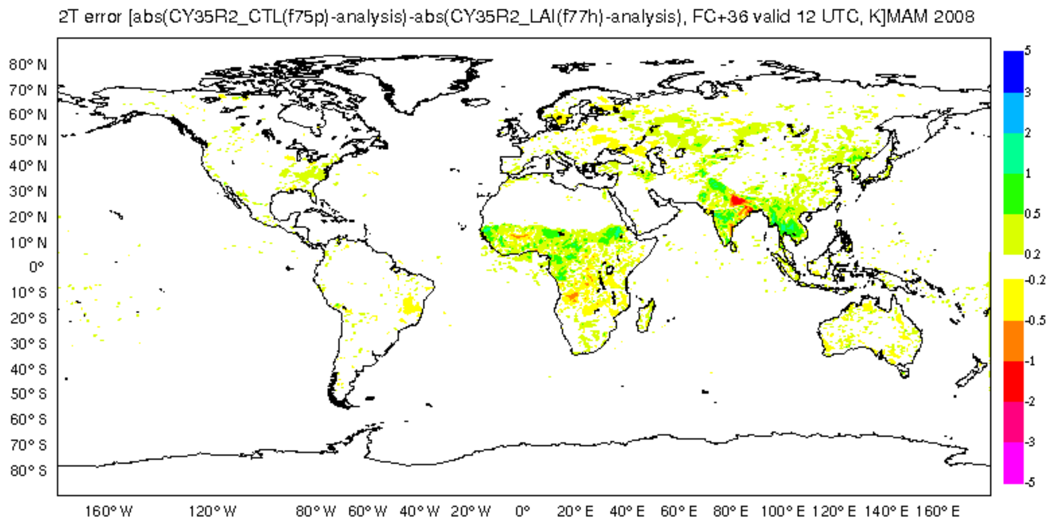


ECMWF

Vegetation Seasonality (11/2009)

Boussetta et al. (2009, *in preparation*)





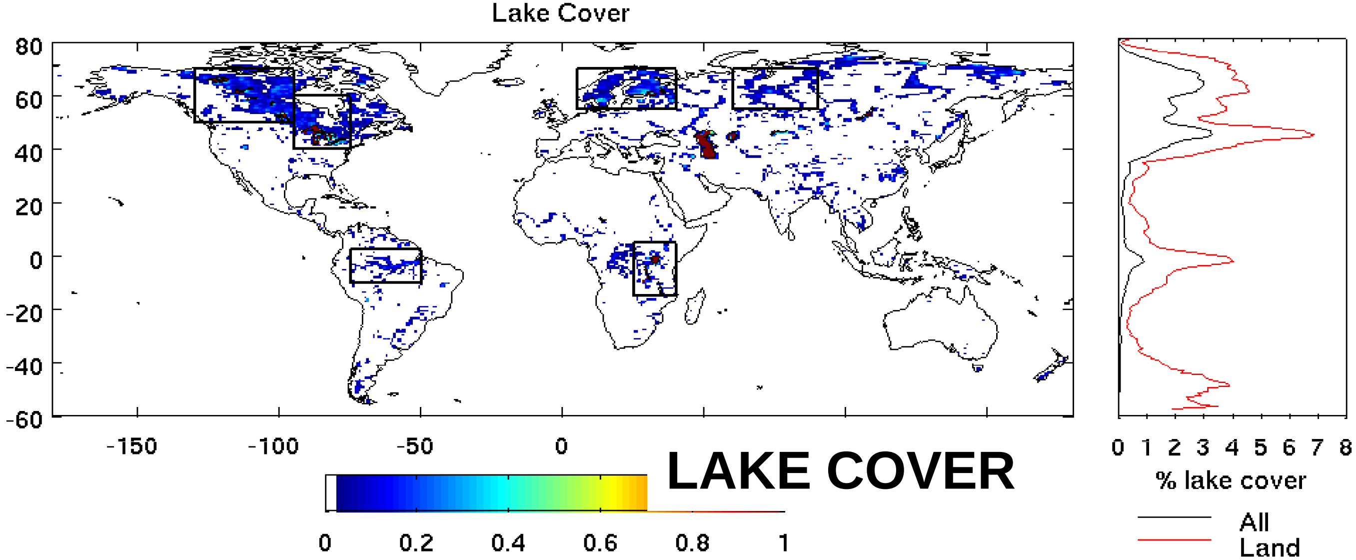
GEOLAND-2 activities

- **ECOCLIMAP/MODIS LAI are substituting the constant LAI in operations**
- **This seems to introduce a consistent warming**
- **This is due to reduction of LAI in spring, which increases the vegetation resistance to Evaporation Flux.**
- **Less Latent Heat Flux and more Sensible Heat Flux**
- **This has beneficial impact on near surface temperature forecast (green being positive impact in reducing t2m bias by ~0.5degree)**

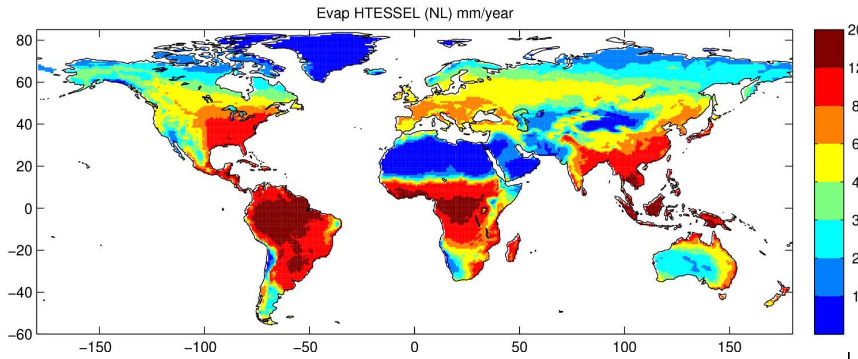
ECMWF

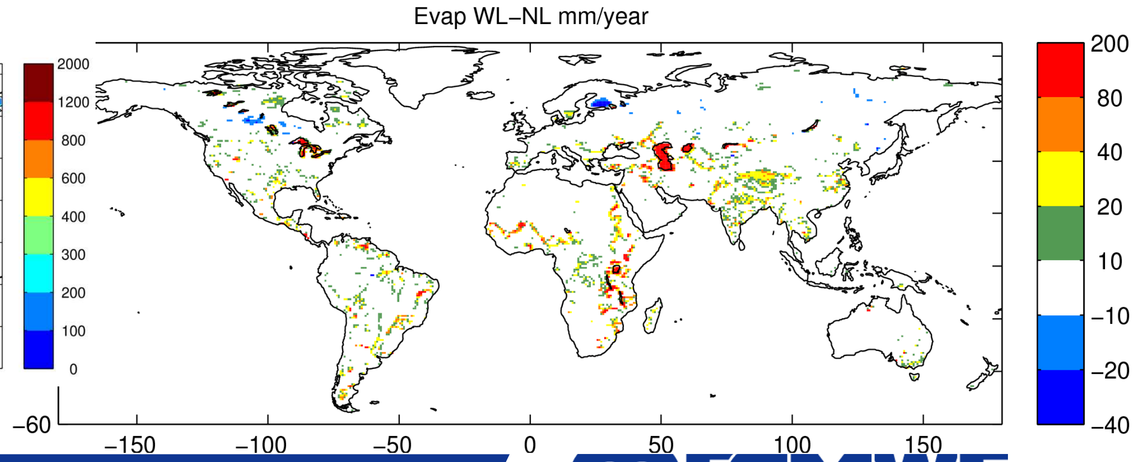
Lake modelling (2010)

Dutra et al. (2009), Balsamo et al (2009), *Boreal Env. Res.*



- FLAKE Lake model is implemented in CY35R3.
- Evaporation rates are greatly increased in temperate climate
- L-band peak even stronger on lakes than SM!





ECMWF

ECMWF activities in SMOS

•**Global Monitoring**

- Passive microwave forward operator CMEM,
- SMOS pre-processing data in the Integrated Forecasted System,
- Implementation of passive monitoring,

• **Data assimilation study**

- EKF surface analysis,
- Development of a bias correction scheme in C-band and L-band,
- Assimilation experiments.

In NWP, Near Real Time constraint imposes to use the brightness temperatures (TB)
→ Importance of the forward operator to transform model variable (soil moisture temperature…) to observable variable (TB)

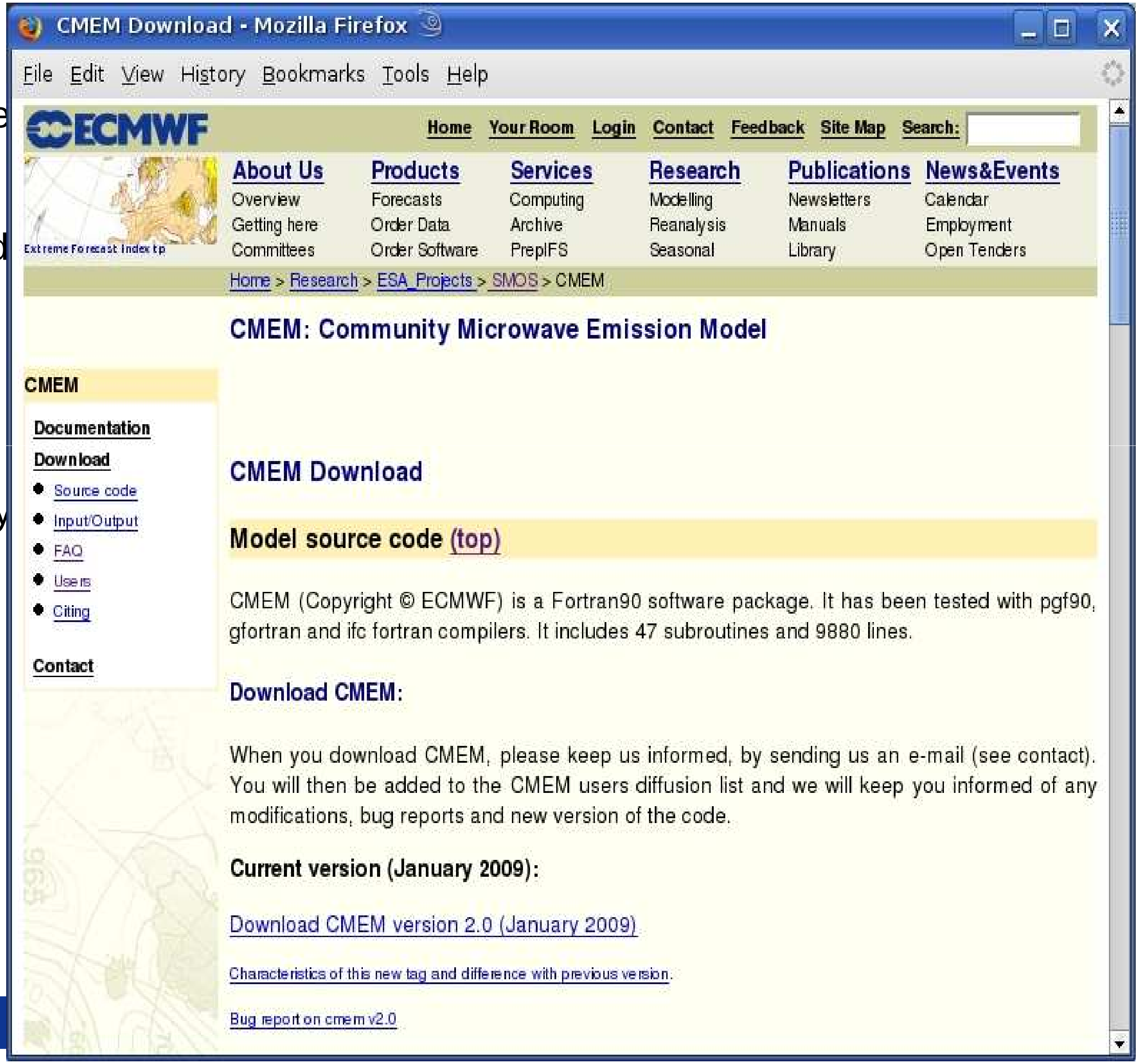
Community Microwave Emission Model (CMEM)

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

Land surface MW emission mode
developed at ECMWF for NWP.

Specifically developed as forward
Operator for SMOS, but also
Suitable at higher frequencies
(C-Band and X-Band).

Currently being implemented in
IFS CY35R3 (following the all-sky
Radiances processing).



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

ALMIP-MEM

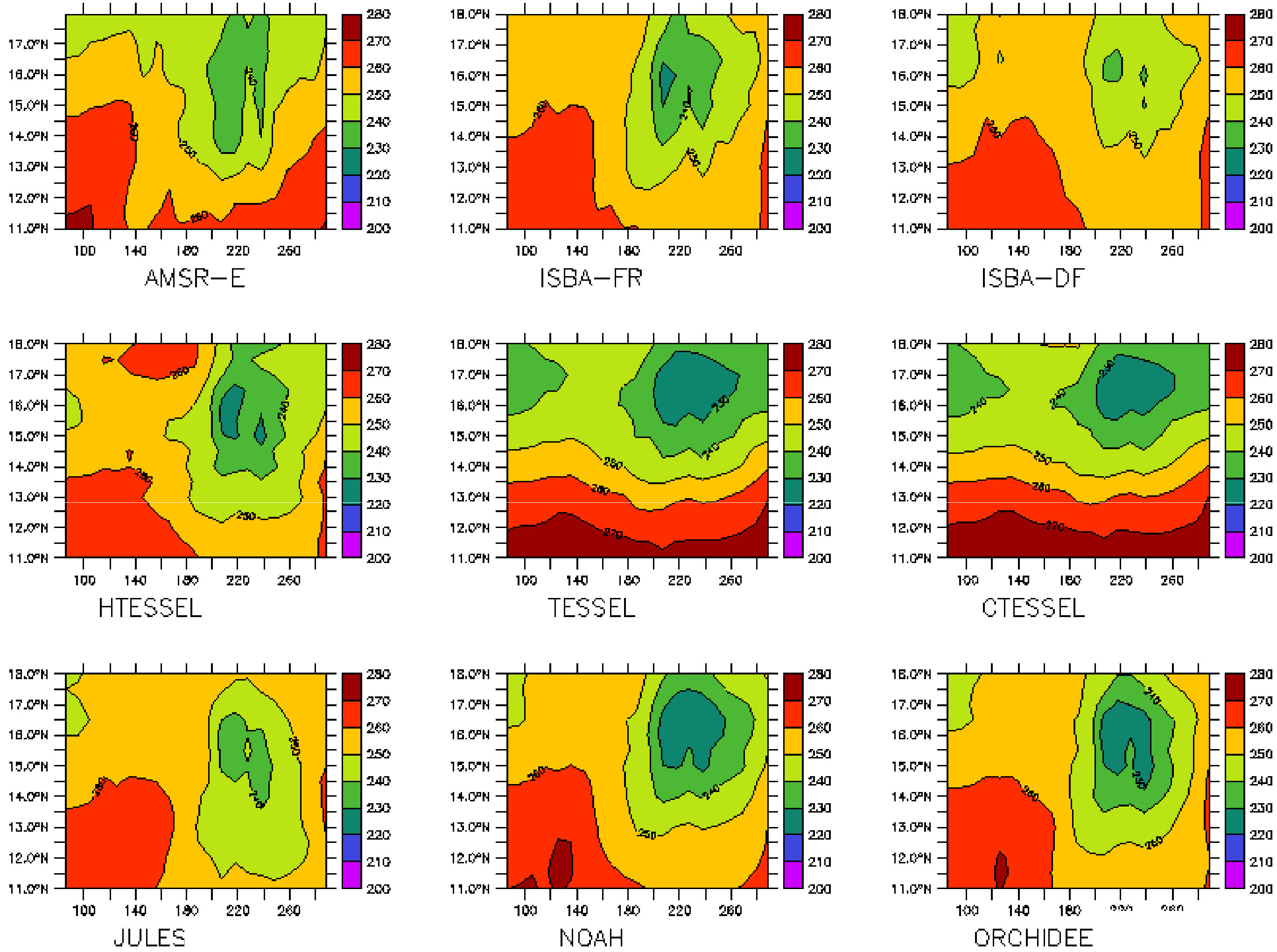
AMMA Land Surface Model Intercomparison Project – Microwave Emission Model
(de Rosnay et al., JGR 2009)

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

AMSR-E
8 ALMIP-MEM LSM

CMEM configuration 10
(Wang&Schmugge
+ Kirdyashev)

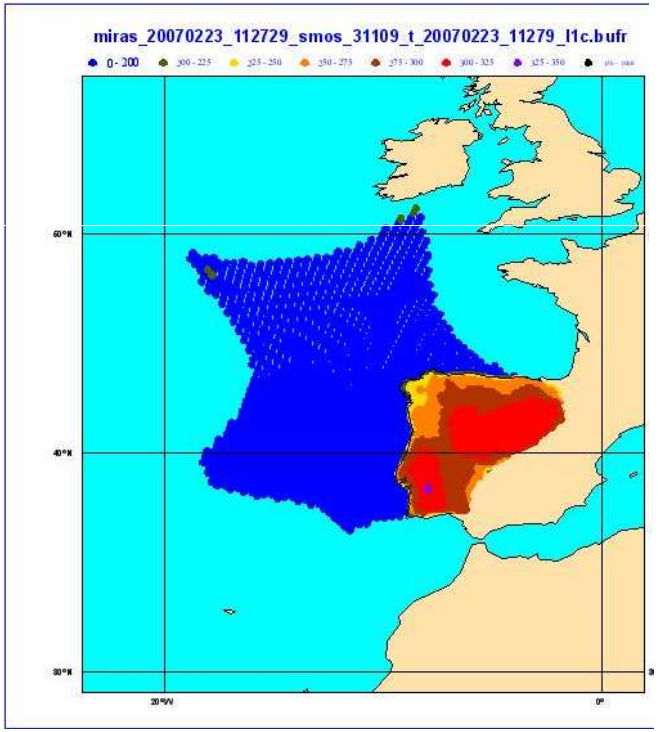
Bias correction
Applied for each LSM
- Time-latitude wet Patch
Well captured by most
of the LSMS



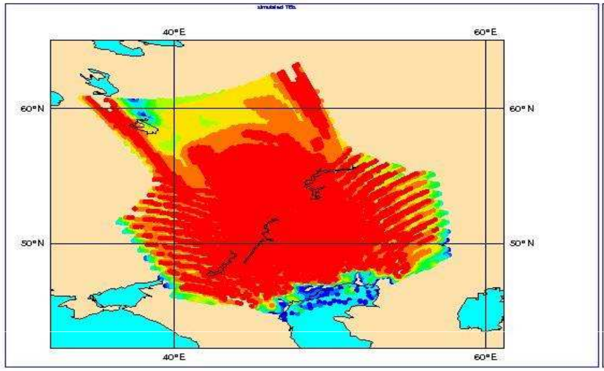
Implementation of SMOS data in IFS (J.Munoz Sabater)

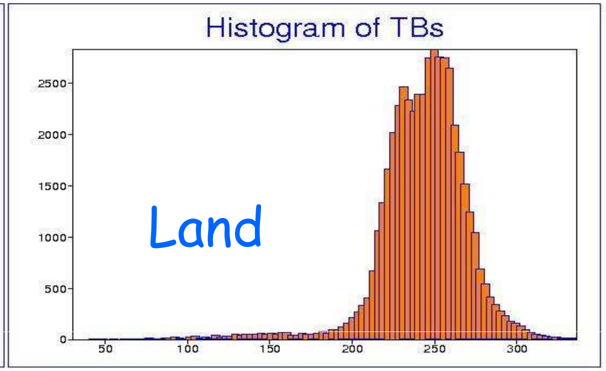
- Technical implementation to transform raw SMOS bufr data in IFS internal format + filtering jobs,
- Testing data:

2 demonstration files (19 bufr messages, 54 sec.)

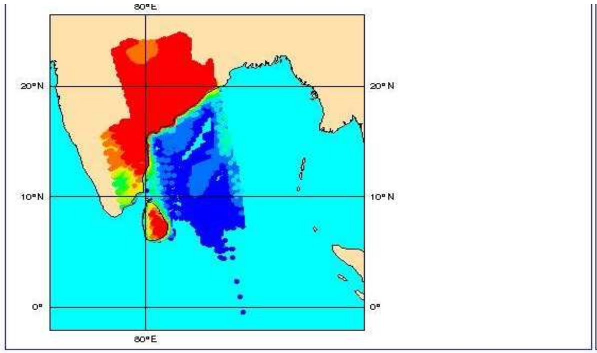


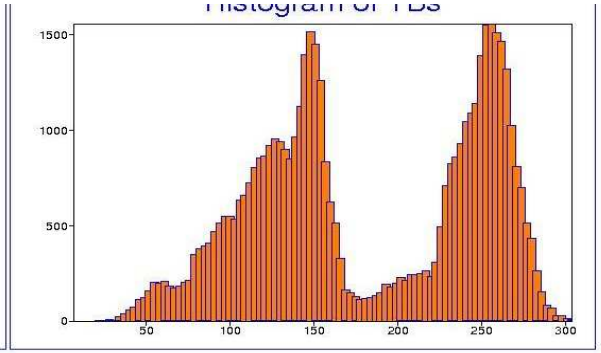
24h of pre-processed (simulated) bufr data for 2010





Sea and Land

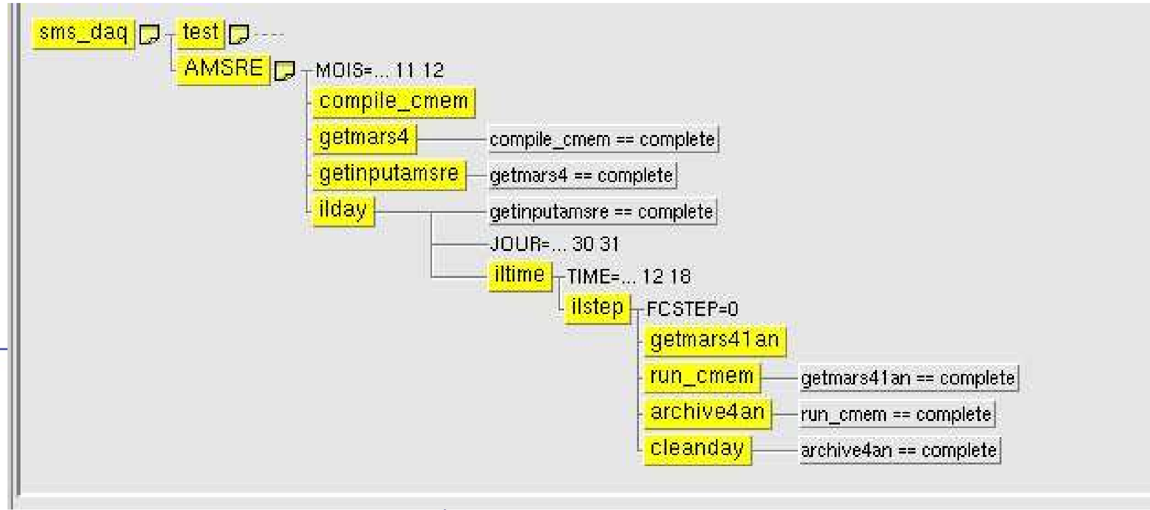




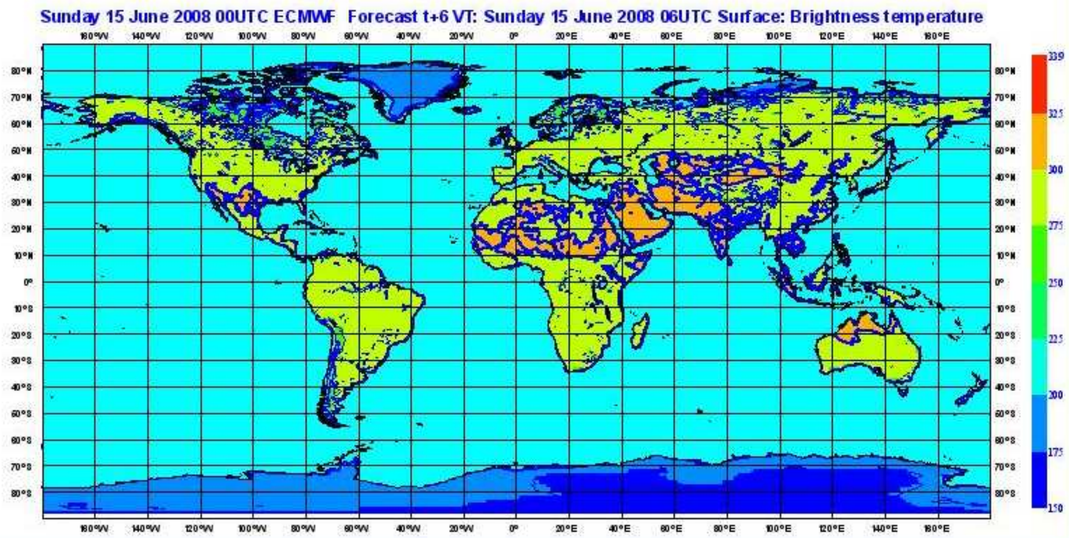
AMSR-E C-band background departures

(Muñoz Sabater et al)

Investigation of the simulated TB bias based on AMSR-E C-band data



Offline monitoring suite using CMEM



Simulated TB at C-band (K)

Current developments of soil moisture analysis: Extended Kalman Filter surface analysis

(Drusch et al. GRL 2009)

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. sensitivity as been conducted to find the optimum perturbation δx_j.

EKF surface analysis structure

Operational implementation (de Rosnay et al. 2009)

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

• When using satellite data it is even more consuming (x 20000 in CPU at T799 in 35R2 when using ASCAT data).

• UP TO cy35r2 surface analysis is performed after the 4D-VAR in very short time slot (a few minutes).

→ In order to make the EKF surface analysis affordable in operation we need to:

- **Allow more time for the surface analysis: new structure of the analysis.**
- **Reduce the cost of the EKF surface analysis to be able to use satellite data.**

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

→ cost reduction relies on decoupling the Jacobian computation from the atmosphere.

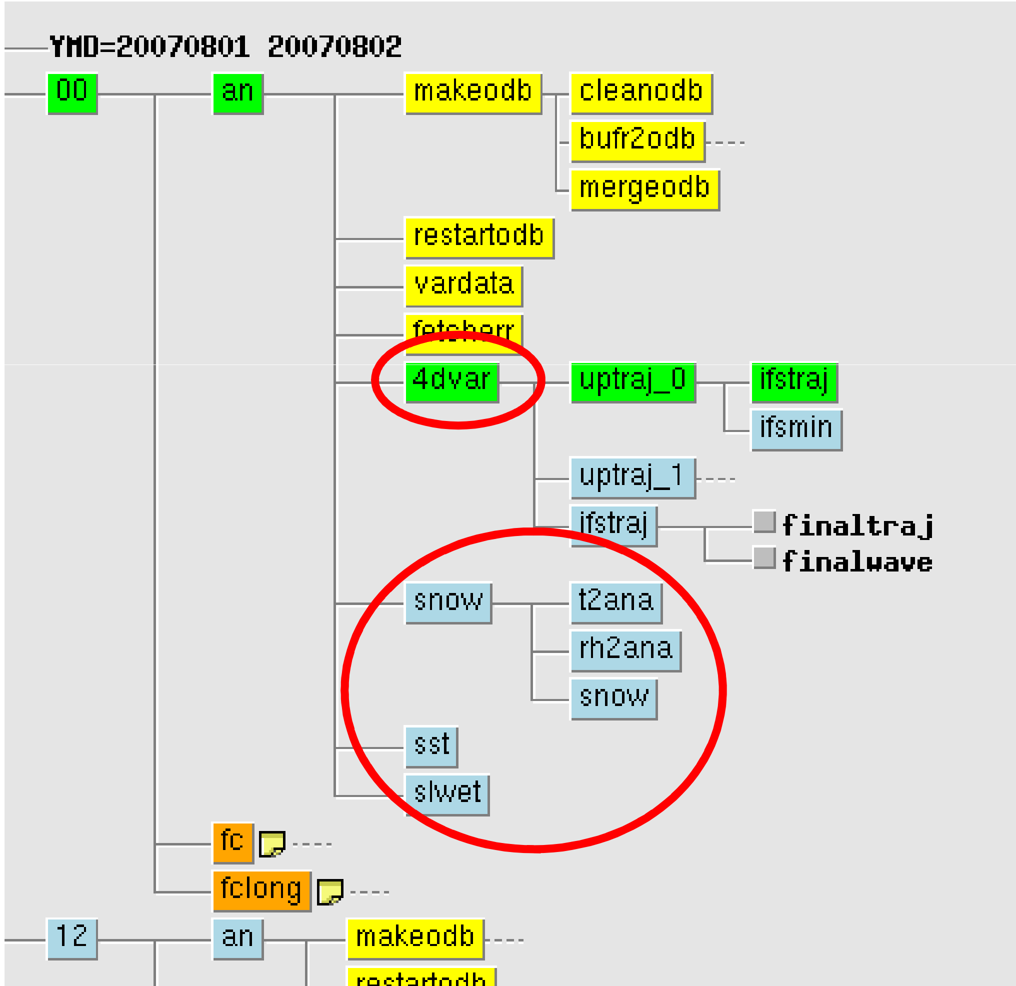
Done by reorganizing the EKF perturbing loops at low level in the model (under test) in 35R3.

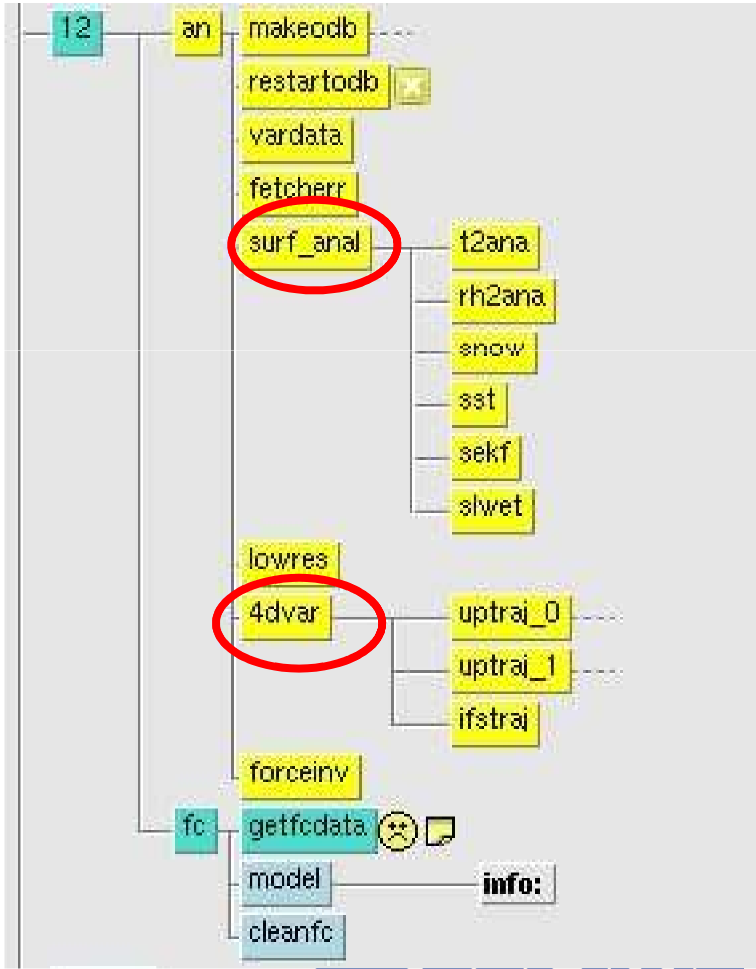
Surface Analysis

organisation within the ECMWF Integrated Forecasting System (IFS)

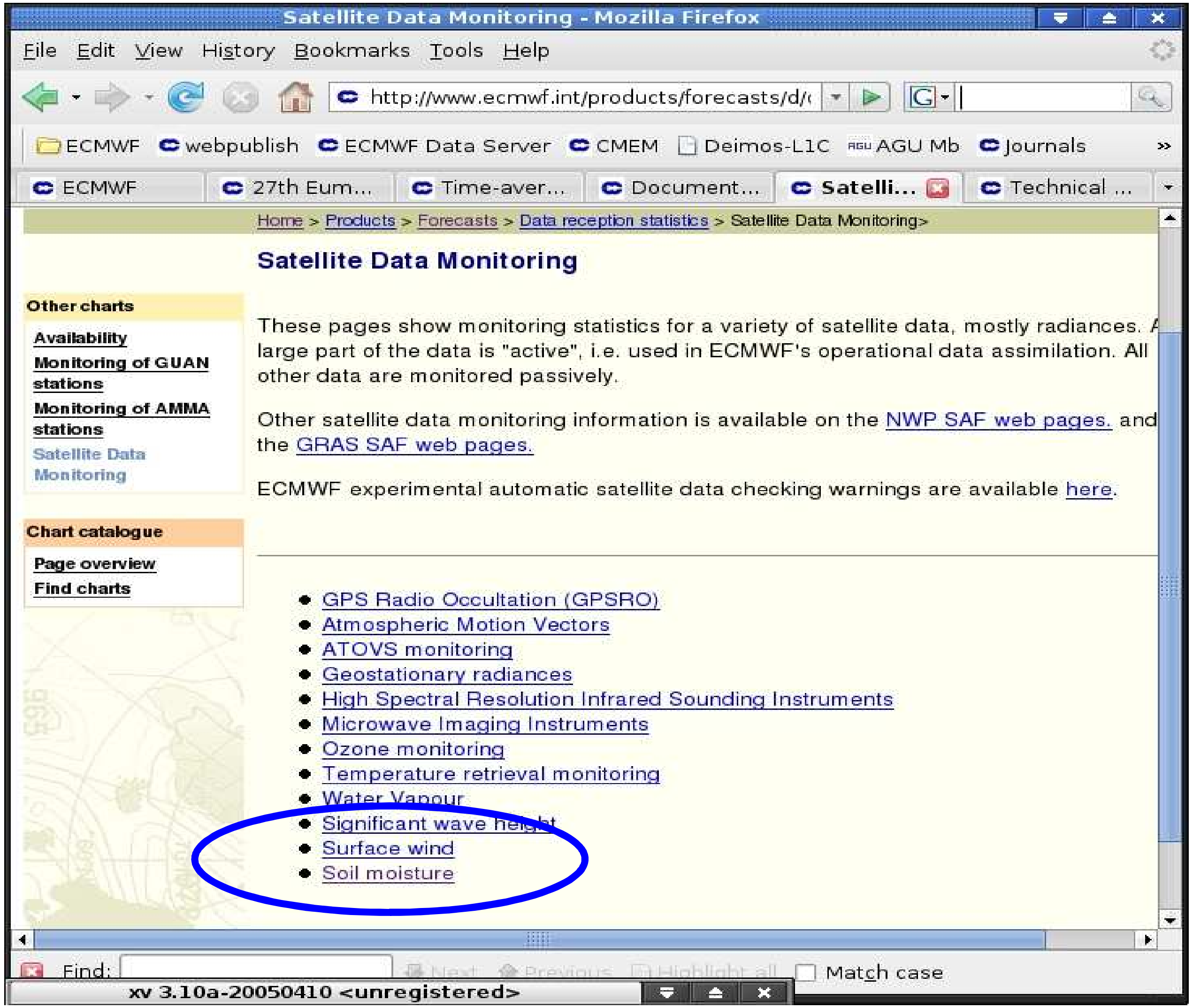
IFS cycle 35r2:
- Surface analysis after 4D-VAR

IFS cycle 35r3:
- Surface analysis before 4D-VAR
- EKF soil moisture analysis using offline Jacobians (under test)
(de Rosnay et al. 2009)





ASCAT monitoring

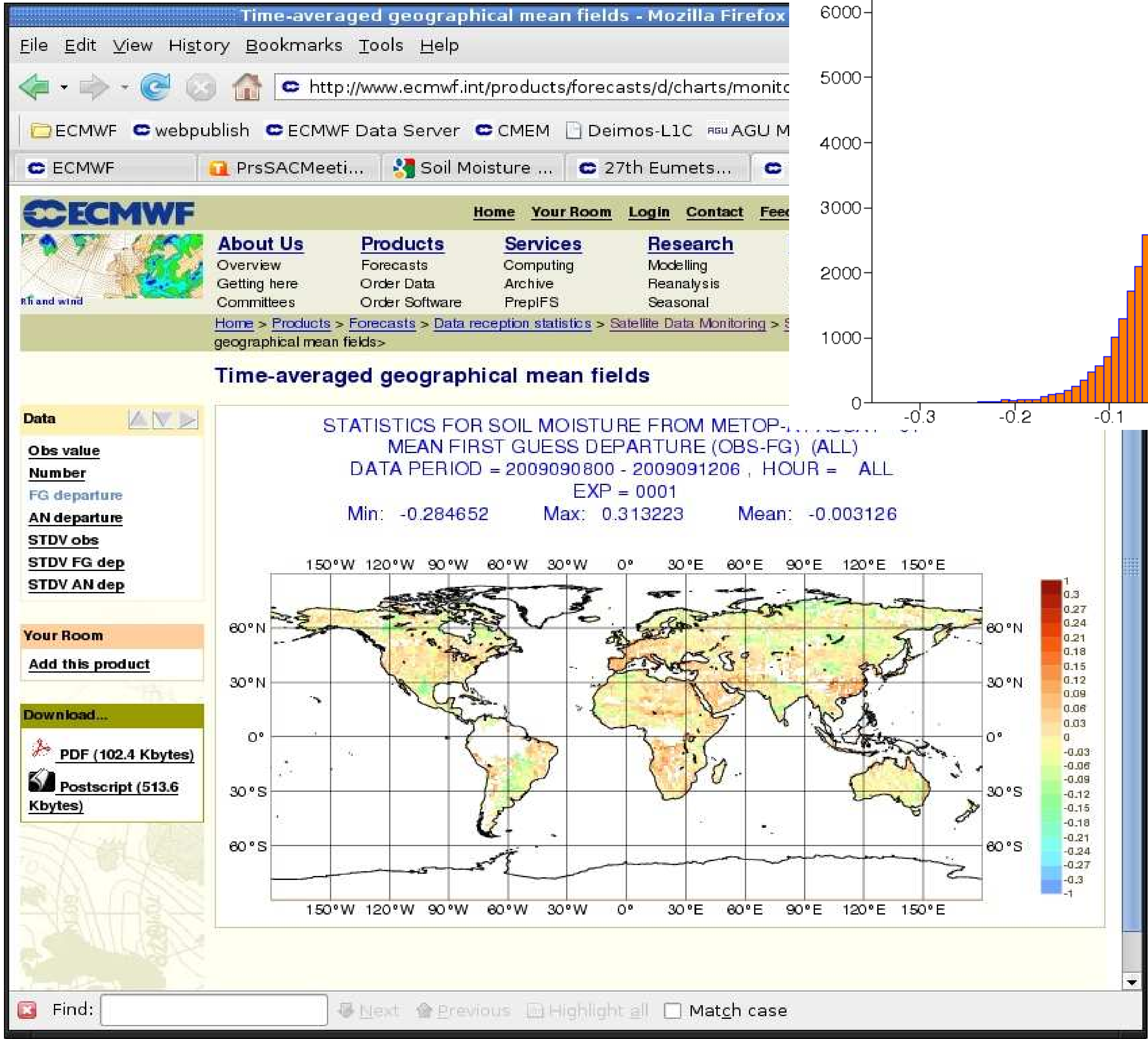


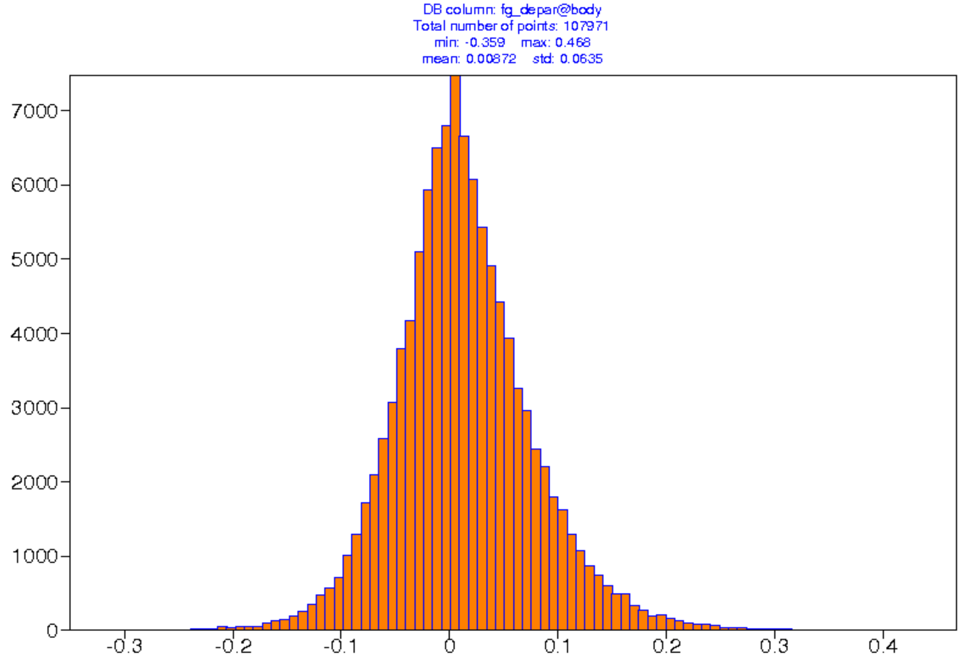
New Soil Moisture item on the ECMWF monitoring page

E-suite: July 2009

Operation:
since 8 September

ASCAT operational monitoring (cycle 35r3)





Unbiased departures

ASCAT monitoring:
FG departure
in m3/m3

Summary

- ECMWF is preparing to the imminent launch of SMOS
- Developments in the HTESSEL LSM (soil, snow, lakes)
- Developments in GEOLAND-2 context (vegetation, carbon)
- New structure of the surface analysis from CY35R3
- EKF land surface analysis ready for implementation. It will replace the OI in the next cycle after the resolution cycle (36R1 → 36R2).

- EUMETSAT H-SAF project: ASCAT (active microwave); monitoring and assimilation of soil moisture data. Preparation of the CDOP for 2010-2017 http://www.ecmwf.int/research/EUMETSAT_projects/SAF/HSAF/ecmwf-hsaf/index.html

- ESA SMOS (passive microwave): preparation of the monitoring: implementation of the SMOS preprocessing chain and implementation of the forward operator, investigate bias using AMSR-E C-band data http://www.ecmwf.int/research/ESA_projects/SMOS/index.html