ECMWF soil moisture analysis: use of active and passive microwave data

ECMWF
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This paper presents the European Centre for Medium-Range Weather Forecasts (ECMWF) soil moisture analysis system and its recent developments to use passive data from the future SMOS (Soil Moisture and Ocean Salinity) and active data from the ASCAT (Advanced SCATterometer) sensors.

Optimal Interpolation

The current operational Soil Moisture (SM) analysis used in the Integrated Forecast System (IFS), is based on an Optimal Interpolation (OI) scheme using proxy observations (2-m air temperature and relative humidity) (*Mahfouf et al.*, 2000). The OI soil moisture analysis relies on the link between soil variables and the lowest atmospheric level:

Too dry soil ➞ 2m air too dry and too warm

Too wet soil ➞ 2m air too moist and too cold.

Based on this, soil moisture increments are computed from the analysis increments for the T2m and RH2m:

$$\Delta\Theta_i = a_i\,(T^a - T^b) + b_i\,(rH^a - rH^b)$$

Superscripts a and b denote analysis and background respectively, i denotes the soil layer. Coefficients ai and bi are defined as the product of optimum coefficients αi and βi minimizing the variance of analysis error and of empirical functions.

Schematics of the land surface

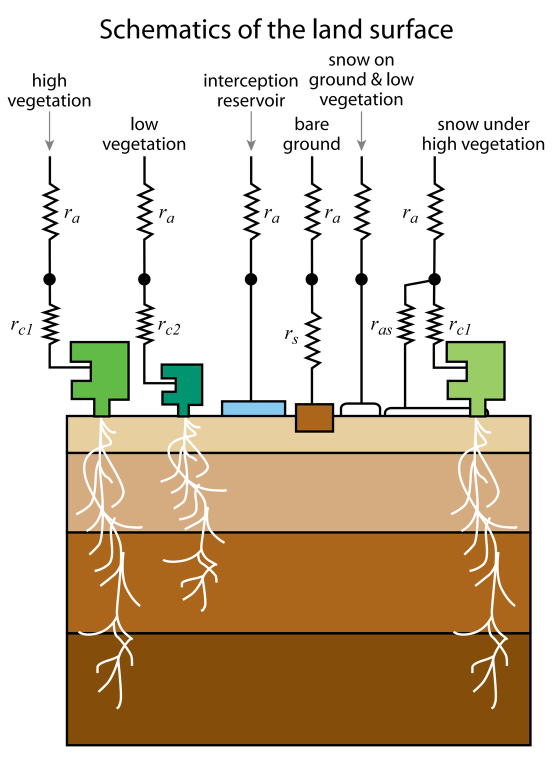


Figure 1 HTESSEL (Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land) Land Surface Model (*Viterbo et al.*, 1995, *Balsamo et al.*, 2009).

Limitations

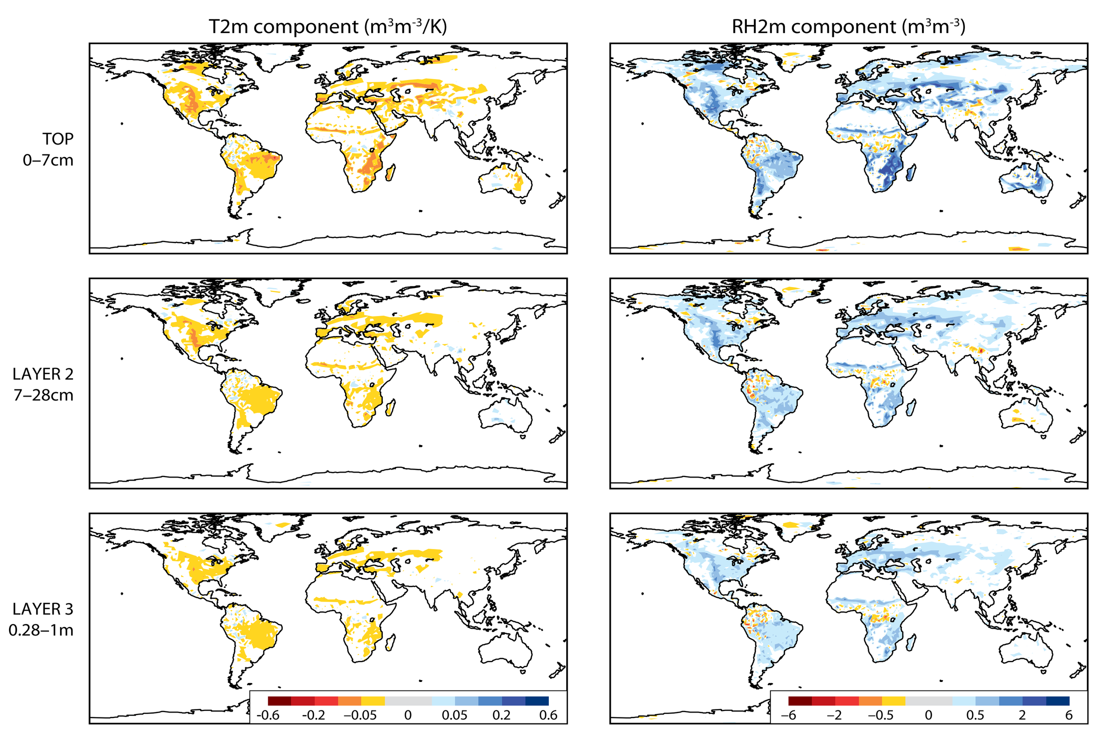
- The OI efficiently improves the turbulent surface fluxes and the weather forecast on large domains but root zone soil moisture is the variable in which errors accumulate.
- Link between screen parameters (T2m rH2m) and soil parameters relies on very complex and non-linear land-surface-atmosphere processes.
- Thresholds to switch off the OI in particular conditions: wind, freezing, snow, precipitation.
- Difficult to interface with new features of the Land Surface Model (HTESSEL).
- Difficult to include new types of observations directly linked to soil moisture or vegetation:
  - SM form active microwave (C-band ERS, ASCAT on MetOp, SMAP)
  - SM from passive microwave (L-band SMOS, C-band AMSR-E, SMAP)
  - Leaf Area Index (MODIS, SPOT-VEGETATION)
  - Snow (H-SAF, Land-SAF).

Extended Kalman Filter Soil Moisture Analysis

A new SM analysis scheme has been developed based on a point-wise Extended-Kalman Filter (EKF) for the global land surface. It is being implemented for operational Numerical Weather Prediction (NWP).

Preliminary tests where performed to validate the EKF approach at T159 (~125km): comparison between OI and EKF when the two assimilation systems are used in the same conditions (screen level parameters, 6h window, B matrix not cycled) (*Drusch et al.*, 2009).

For operational implementation, further tests were conducted at T799 (25km) in early delivery mode:



- Similar pattern than for the OI
- Same order of magnitude than OI gain
- Not limited to daylight areas
- Slightly reduced gain at depth: lower link with screen level variables

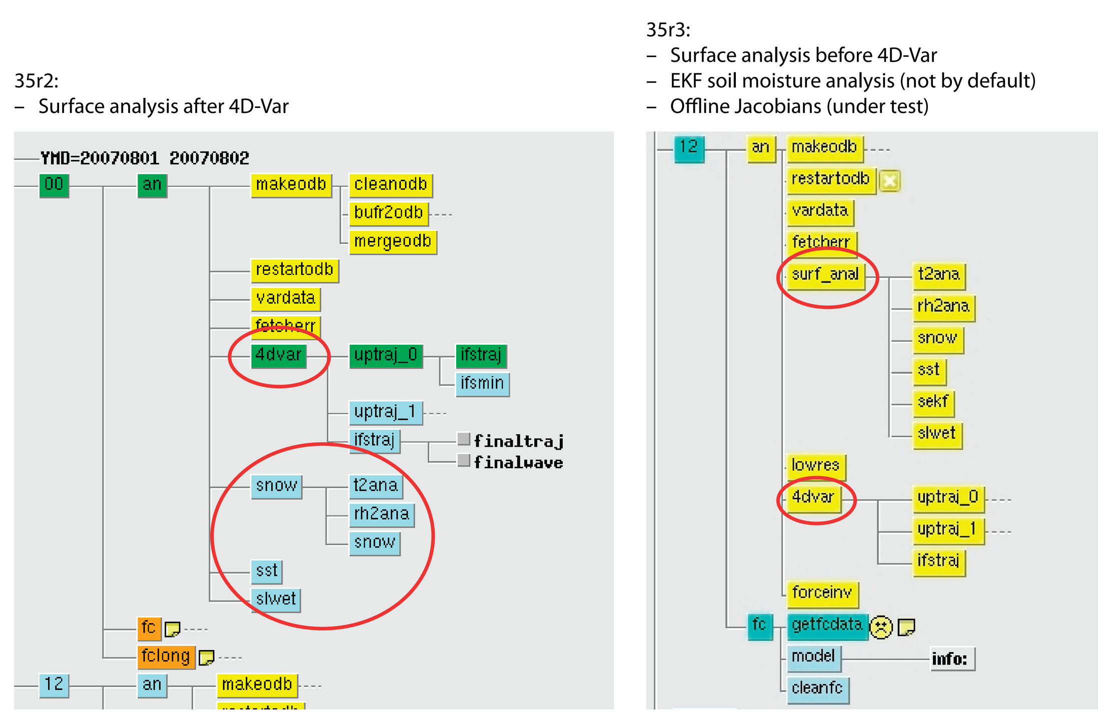
Figure 2 EKF in IFS cycle 35r3, at T799 (~25km): Gain matrix coefficients 01 August 2008 12 UTC.

Operational implementation: structure of the ECMWF surface analysis

The EKF surface analysis is far more expansive than the OI (x 1000 in CPU). Up to IFS cycle 35r2 the 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 needed to:

- Allow more time for the surface analysis: new structure of the analysis (*Vasiljevic et al.*, 2009).
- Reduce the cost of the EKF surface analysis to be able to use satellite data.

The main cost 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. It is done by reorganising the EKF perturbing loops at low level in the model (under test) in 35r3.



EKF soil moisture analysis is being implemented for operational Numerical Weather Prediction (NWP) and it will be activated in operation in winter 2009/2010. The new surface analysis system opens a range of further development possibilities, exploiting new satellite surface data and products, for initialisation of the land surface in NWP.

Figure 3 Organisation within the ECMWF IFS.

Summary

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).

Offline Jacobians will be implemented to enable the use of satellite data (SMOS and ASCAT) in the EKF surface analysis.

EUMETSAT H-SAF project: ASCAT (active microwave); monitoring and assimilation of SM data. Preparation of the CDOP for 2010-2017.

ESA SMOS (passive microwave): preparation of SMOS monitoring: implementation of the SMOS preprocessing chain and implementation of the forward operator, investigate bias using AMSR-E C-band data.

Use of satellite soil moisture from active microwave (ASCAT)

Context: ECMWF participation to the EUMETSAT Satellite Application Facility (SAF) on support to operational hydrology and water management (H-SAF).

Observation operator: Cumulative Distribution Function (CDF) matching between ERS and ERA-Interim data for 1992–2000 (*Scipal et al.*, 2008).

HSAF Continuous Development and Operational Phase (CDOP), 2010–2017.

Monitoring activities in cycle 35r3 (operational September 2009) at T799.

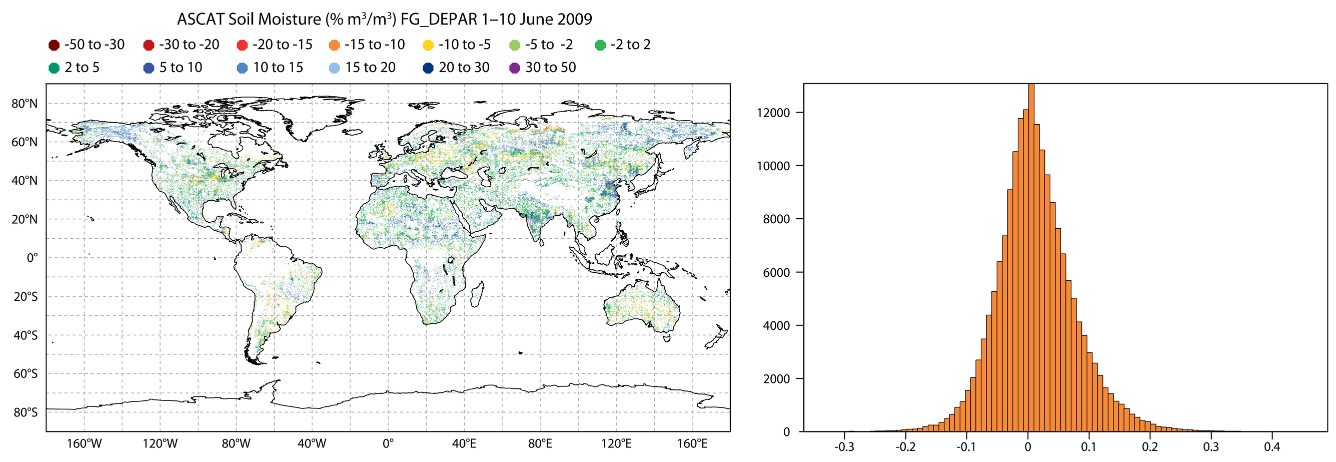
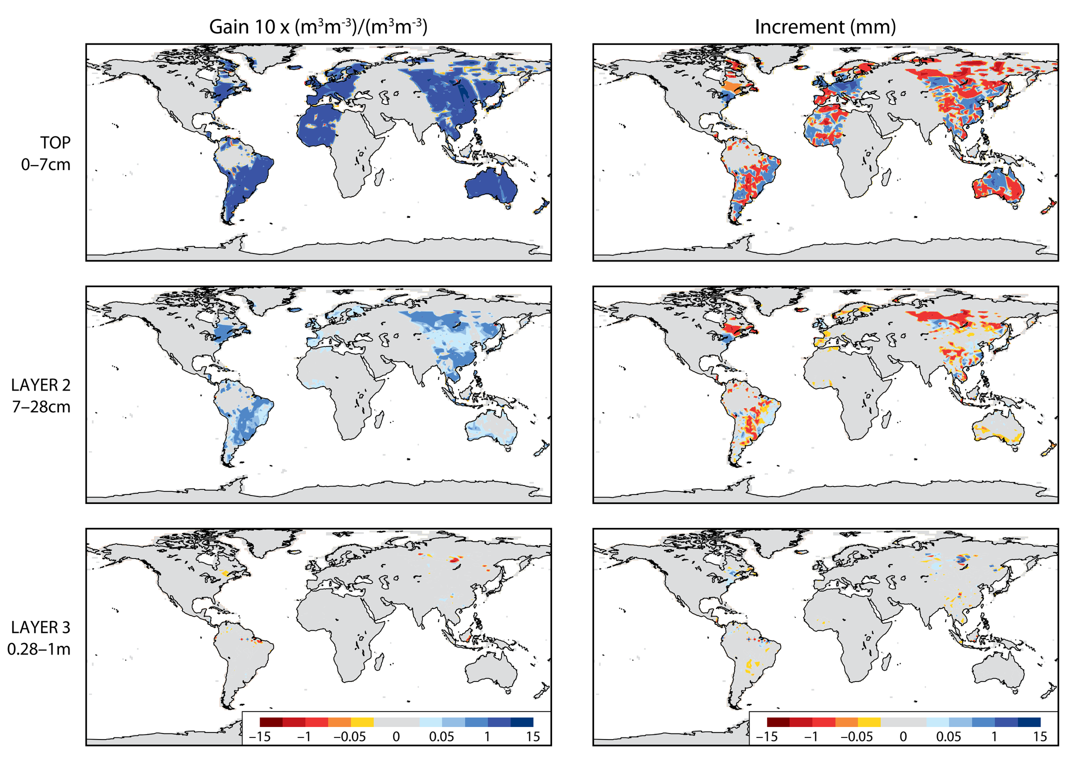


Figure 4 ECMWF surface soil moisture first guess departure in IFS cycle 35r3 (standard deviation = 0.06m³/m³).

ASCAT data Assimilation in the EKF surface analysis at T159:



- Low values at high latitudes
- No gain over tropical forest, desert
- Similar amplitude at night (America) and day (Europe)
- Low gain at depth

Figure 5 Gain and increments at T159 (~125km) when ASCAT data are assimilated. 01–03 May 2007 at 12 UTC.

Use of satellite brightness temperature from passive microwave (SMOS)

ECMWF contribution to SMOS (ESA-ECMWF)

- Global Monitoring (from SMOS + 2 months)
  - Passive microwave forward operator CMEM,
  - SMOS pre-processing data in the Integrated Forecasted System,
  - Implementation of passive monitoring,
- Data assimilation study (from SMOS + 8 month in research mode)
  - EKF surface analysis
  - Development of a bias correction scheme in C-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 (e.g. soil moisture, temperature) into observable variable (TB).

CMEM: Community Microwave Emission Model (*Holmes et al.*, 2008, *de Rosnay et al.*, 2009, *Drusch et al.*, 2009)

- Land surface MW emission model 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.

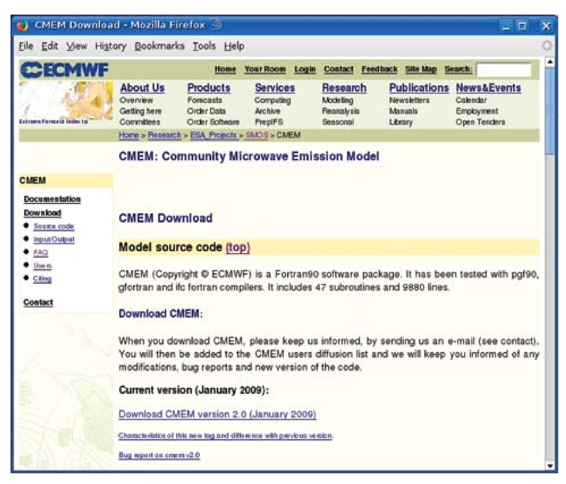


Figure 6 CMEM web page (under ECMWF SMOS page).

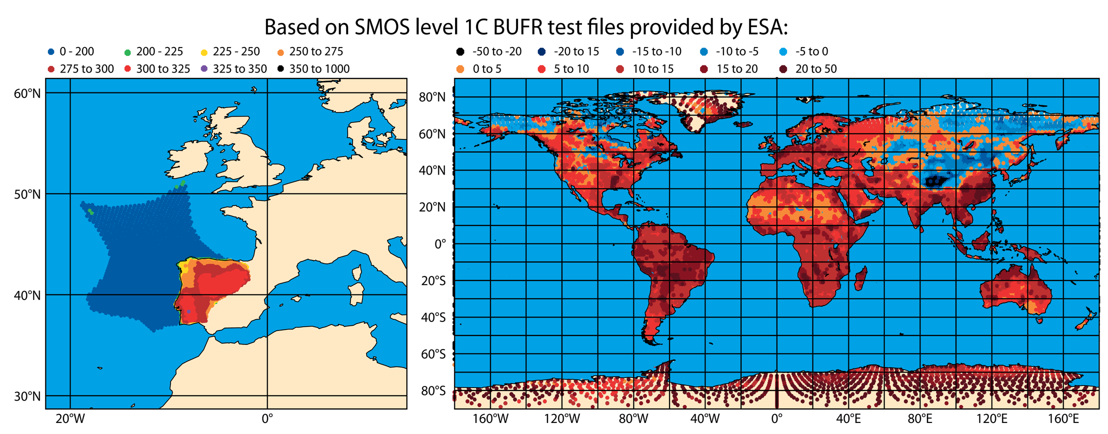


Figure 7 Implementation of SMOS data in IFS. Tests at C-band: AMSRE C-band background departures.

More information on the ECMWF surface analysis

IFS documentation: *http://www.ecmwf.int/research/ifsdocs/*

Data Assimilation training courses: *http://www.ecmwf.int/newsevents/training/meteorological_presentations/MET_DA.html*

ECMWF SMOS page: *http://www.ecmwf.int/research/ESA_projects/SMOS/index.html*

ECMWF H-SAF page: *http://www.ecmwf.int/research/EUMETSAT_projects/SAF/HSAF/*

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