A new land surface assimilation scheme for AAA Part 2: description and preliminary results

Jean-François MAHFOUF

Météo-France/CNRM/GMME
Toulouse (France)

November 2007

Proposal

- Framework : offline version of SURFEX (suitable for HAAA)
- Method : Simplified Extended Kalman Filter [SEKF] (short assimilation window 6-h with evolved **B** matrix for unfrequent satellite observations)
- Most of the deficiencies of the OI previously mentioned are gone
- Possibility to accomodate for various domains, observation types, improved radiative and precipitation forcings
- This system could evolve towards EnKF or Var approaches

Summary of recent activities

- Concept developed at the Meteorological Service of Canada (2004-2006) in preparation of the HYDROS mission (Balsamo et al., 2006; 2007, *J. of Hydromet.*) following the online *simplified 2D-Var* of Balsamo et al. (2004) (ALATNET)
- Evaluation at local scale using simulated observations with a prototype version (Mahfouf, 2007)
  - For the assimilation of T_{2m} and RH_{2m} the soil analysis behaves very similarly for the OI approaches and the SEKF
  - The SEKF can assimilate microwave brightness temperatures in combination with screen-level observations
  - The SEKF has a similar behavior as a more expensive EnKF (less tuning parameters)
- The SEKF has been coded within SURFEX by K. Bergaoui (Tunisia) in spring 2007 and is currently under scientific evaluation at Météo-France and IRM (Belgium)

Description of a Simple LDAS prototype

The assimilation system runs in stand-alone mode (land surface forced at 50m) for a single point

- Land surface scheme : ISBA 2L (Mahfouf and Noilhan, 1996)
- Assimilation methods
  - Optimum interpolation (ECMWF, Météo-France) [operational schemes]
  - Extended Kalman filter (EKF)
  - Simplified 2D-Var
  - Ensemble Kalman filter (EnKF)
- Observation operators
  - Vertical interpolation in the surface boundary layer (air temperature and humidity at screen level)
  - L-band microwave radiative transfer (surface brightness temperatures)

Results from the SLDAS prototype

Description of the "twin experiments" framework.

Three step approach :

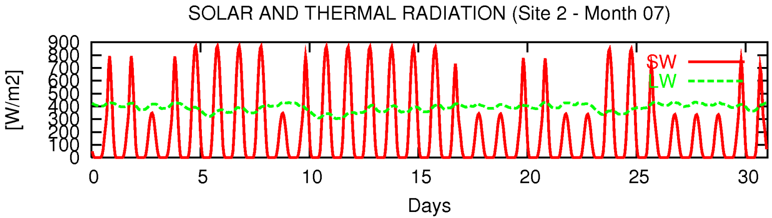
1. Define a reference simulation from which "perfect observations" are generated (REF).
2. Perturb the soil initial conditions (and also the forcing) in order to run an "open loop" simulation (OL)
3. Start from the perturbed soil initial conditions, and assimilate the "perfect observations" (ASSIM)

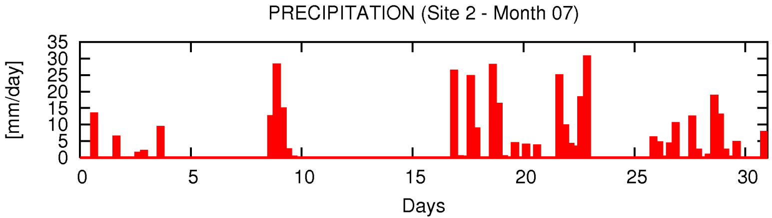
If the assimilation scheme works properly, the system should get away from the "open loop" simulation and get closer to the "reference simulation".

Experimental set-up

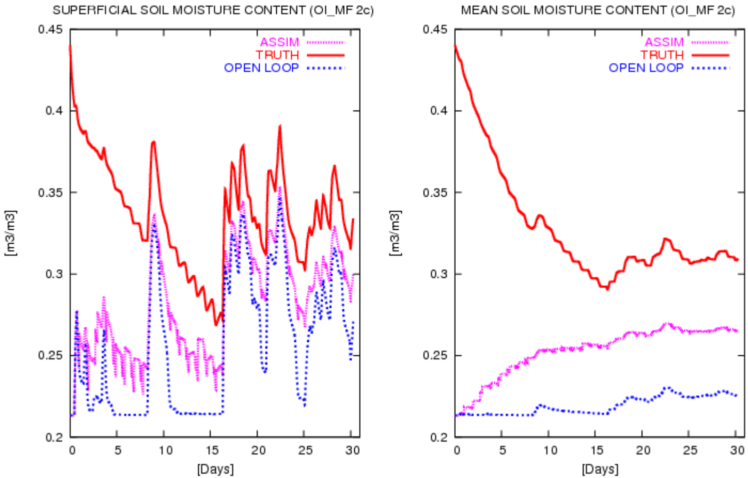
- Reference simulation : saturated soils
- Perturbed simulation (open loop) : initial conditions at wilting point + precipitation forcing reduced by a factor of two
- Period : July 2002
- Forcing : Central US over grassland (85 % vegetation cover) taken from ERA-40
- Observations : T_{2m}, HU_{2m} every 6 hours and T_b (2 polarizations) every 3 days
- Observation errors : $\sigma_{T2m} = 1$ K, $\sigma_{HU2m} = 10\%$, $\sigma_{Tb} = 2$ K
- Background errors : $\sigma_{ws} = 0.1$ SWI, $\sigma_{w2} = 0.1$ SWI, $\sigma_{Ts} = 1$ K, $\sigma_{T2} = 1$ K
- EnKF : Ensemble size = 100, inflation factor = 1.5 % every 6 hours, model errors (standard deviation = 0.01 m3/m3/day, correlation time scale = 3 days)

Atmospheric forcing

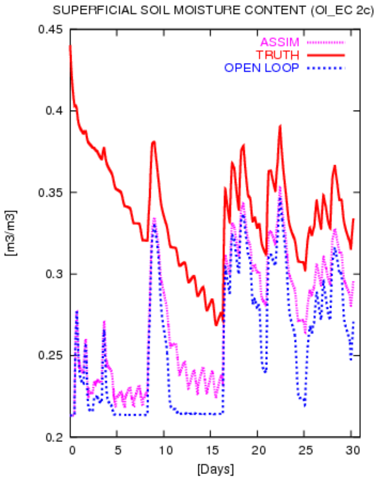


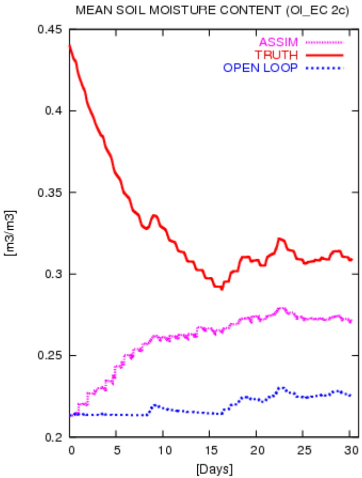


OI MF with T2m HU2m

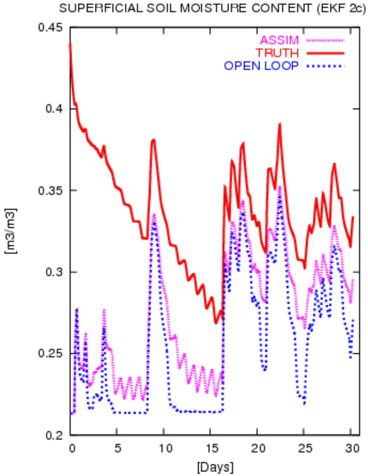


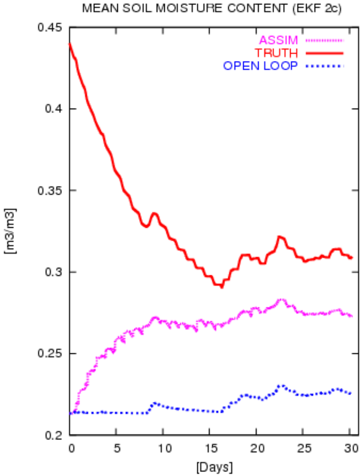
OI EC with T2m HU2m



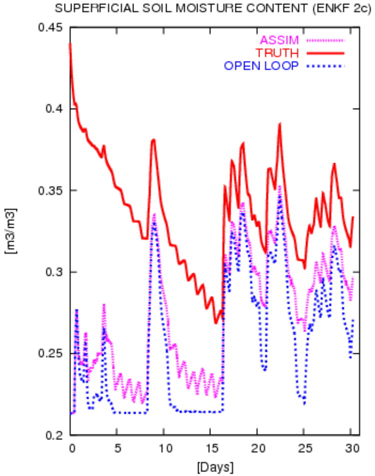


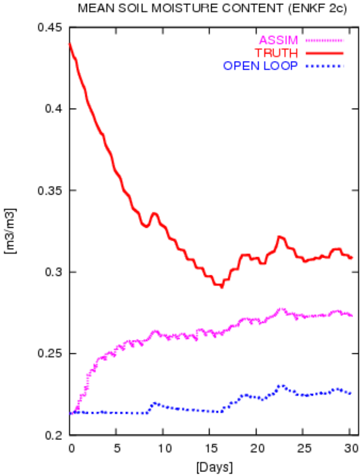
EKF with T2m HU2m



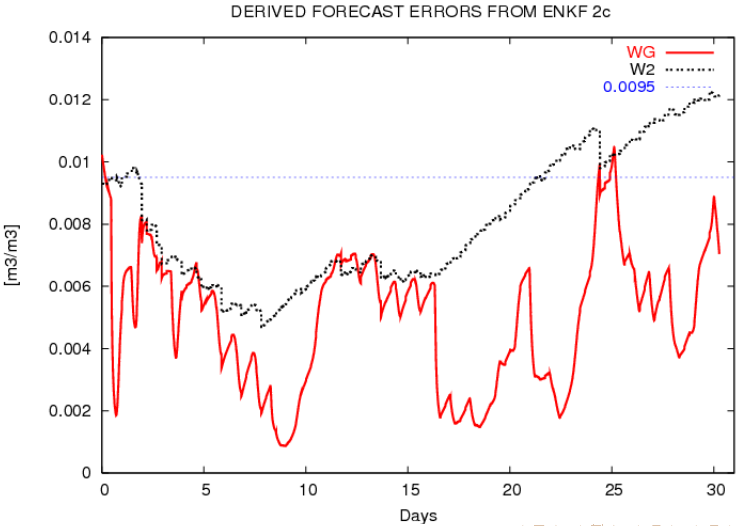


ENKF with T2m HU2m

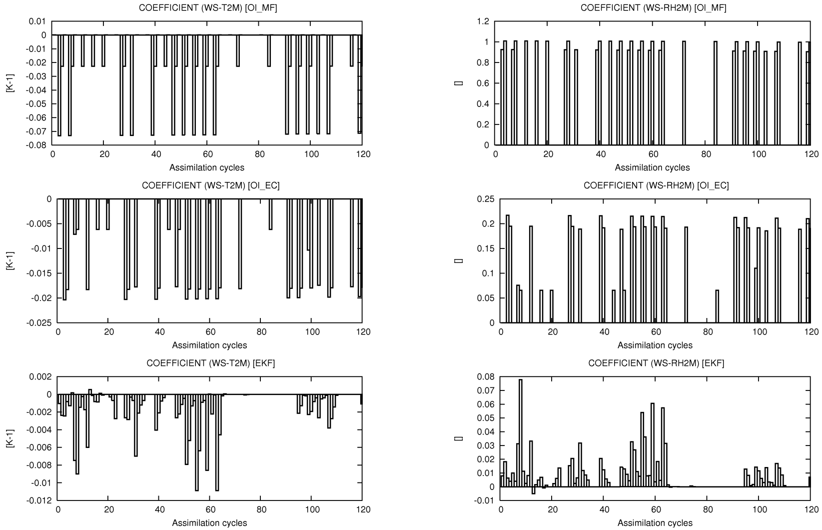




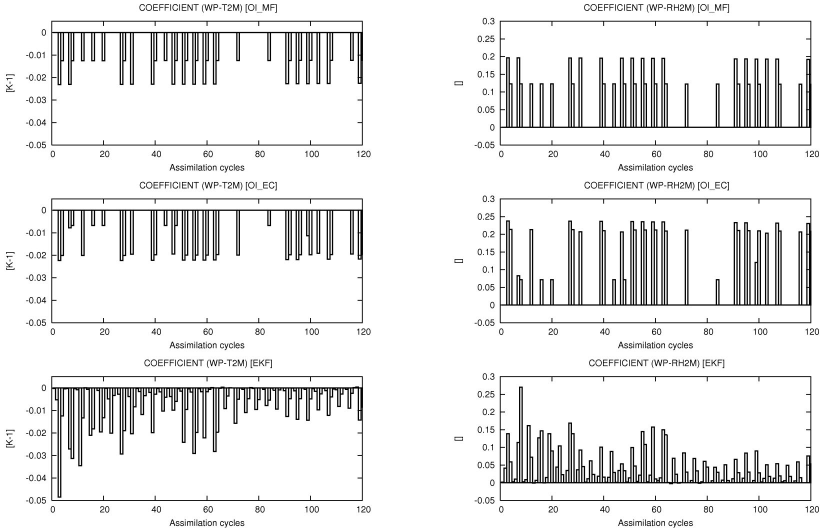
Evolution of forecast errors with an ENKF



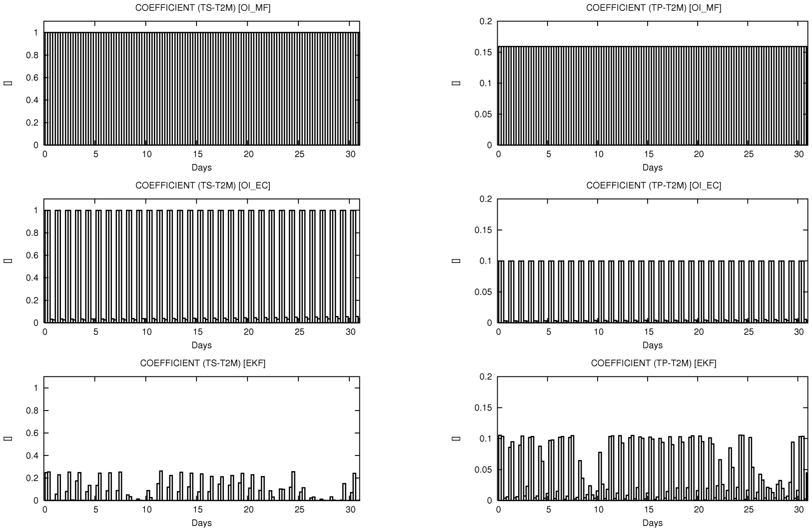
α_1 and α_2 OI coefficients



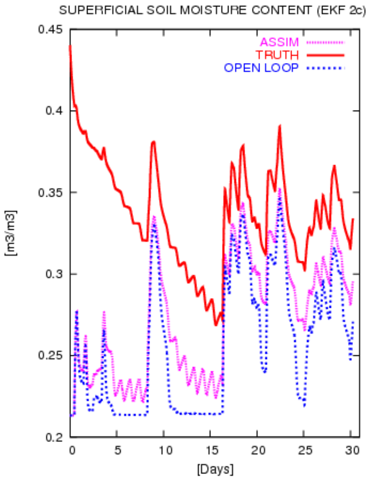
β_1 and β_2 OI coefficients

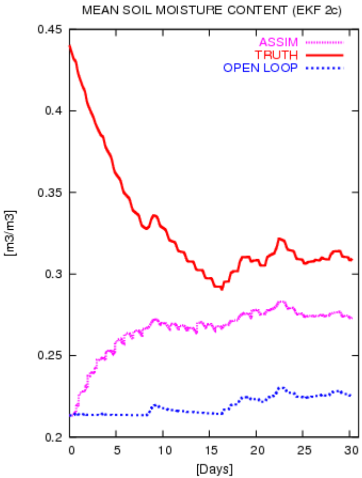


μ_1 and μ_2 OI coefficients

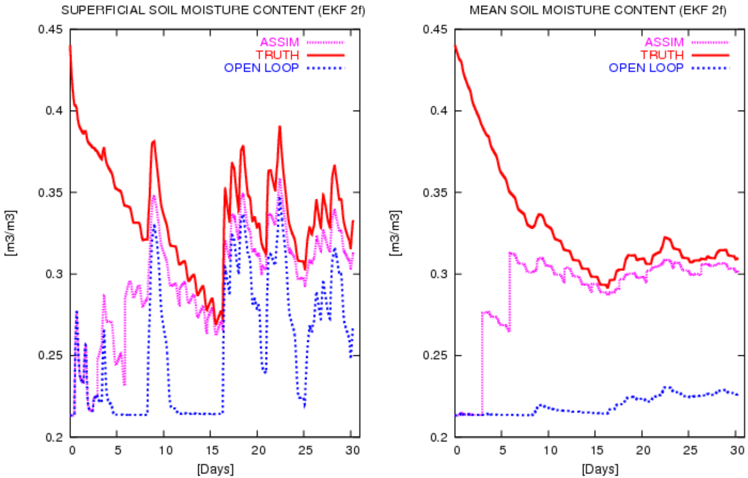


EKF with T2m HU2m

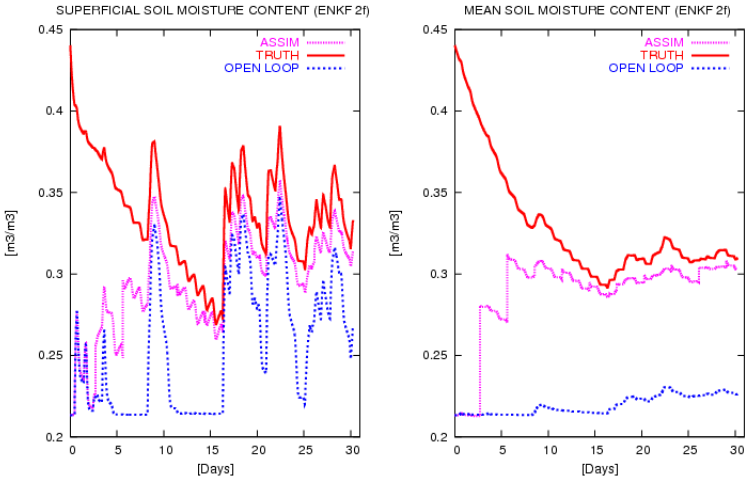




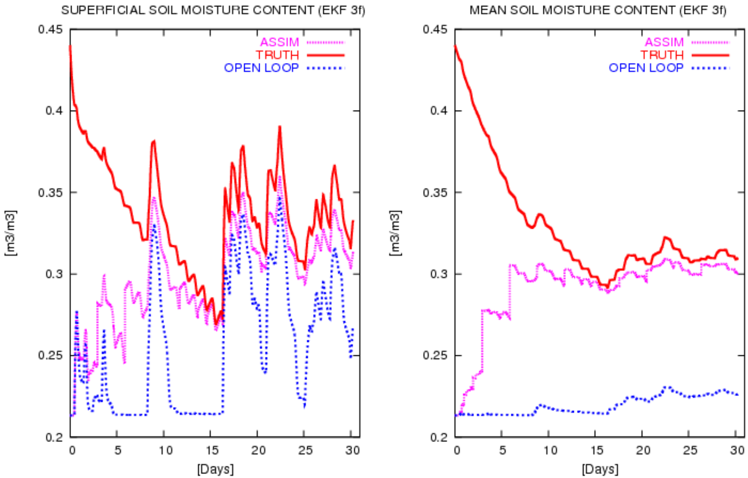
EKF with Tb


SUPERFICIAL SOIL MOISTURE CONTENT (EKF 2f)
ASSIM
TRUTH
OPEN LOOP
[m3/m3]
0.45
0.4
0.35
0.3
0.25
0.2
0 5 10 15 20 25 30
[Days]
MEAN SOIL MOISTURE CONTENT (EKF 2f)
ASSIM
TRUTH
OPEN LOOP
[m3/m3]
0.45
0.4
0.35
0.3
0.25
0.2
0 5 10 15 20 25 30
[Days]

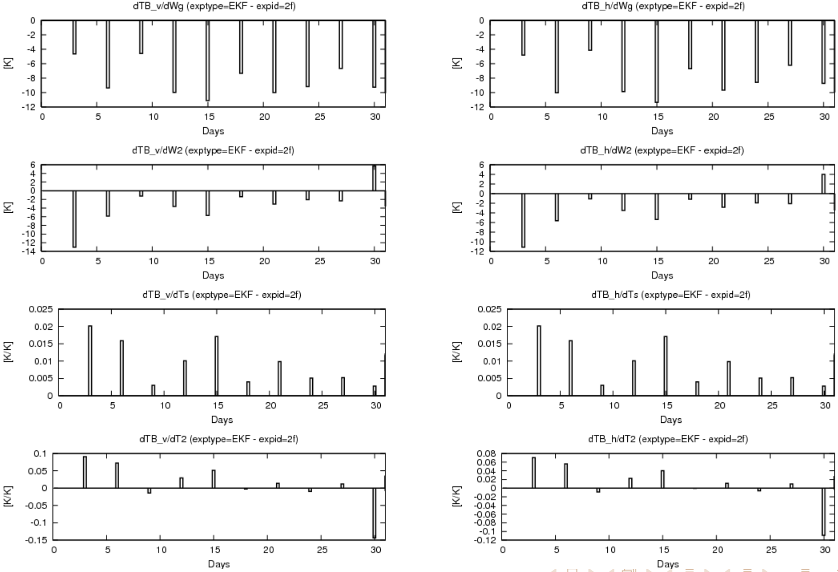
ENKF with Tb


SUPERFICIAL SOIL MOISTURE CONTENT (ENKF 2f)
ASSIM
TRUTH
OPEN LOOP
[m3/m3]
0.45
0.4
0.35
0.3
0.25
0.2
0 5 10 15 20 25 30
[Days]
MEAN SOIL MOISTURE CONTENT (ENKF 2f)
ASSIM
TRUTH
OPEN LOOP
[m3/m3]
0.45
0.4
0.35
0.3
0.25
0.2
0 5 10 15 20 25 30
[Days]

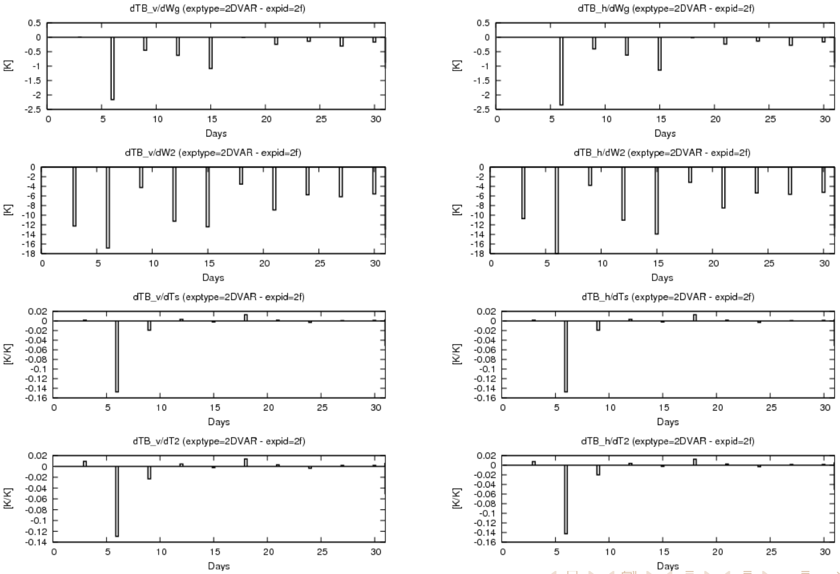
EKF with Tb and screen-level observations



Jacobian of observation operator $\partial T_b^t / \partial x^{(t-6)}$



Jacobian of observation operator $\partial T_b^t / \partial x^{(t-72)}$

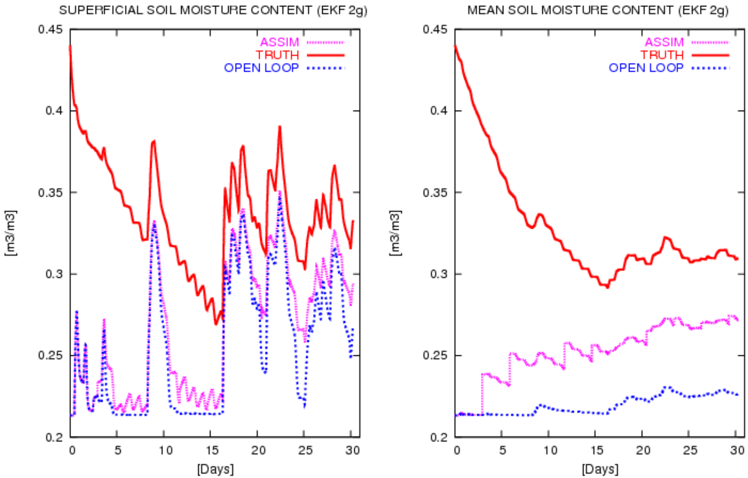


Discussion about errors

- Importance of cycling the **B** matrix to produce off-diagonal elements, that induce correlation errors between the surface soil moisture content (directly linked to observations) and the mean soil moisture content (variable of interest for surface water and energy exchanges).
- SMOS accuracy for surface moisture retrievals = 0.04 m3/m3
- Tb accuracy with $\partial Tb / \partial w_g = 100$, thus

$$\sigma_{Tb} = \frac{\partial Tb}{\partial w_g} \times \sigma_{wg} = 4K$$

EKF with Tb with 4 K accuracy

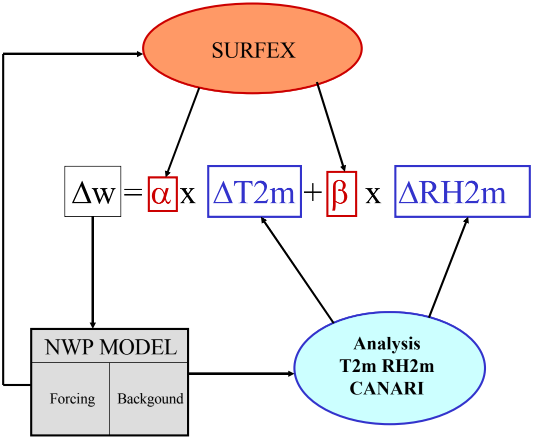


Feasibility study within SURFEX

Experimental set-up

- Period : July 2006
- Domain : ALADIN-France (273x273 pts)
- Analysis : mean soil moisture content w_2
- Observations : CANARI T_{2m} and RH_{2m} analysis every 6 hours over the ALADIN-France domain
- Atmospheric forcing : hourly short-range forecasts (0-6h) over the ALADIN-France domain
- SURFEX set-up :
  - Physiographic data bases (soil-vegetation) *as close as possible* from the current ALADIN operational fields
  - Options of ISBA *as close as possible* to the ALADIN configuration
  - Initial soil conditions : ALADIN analysis (01 July 2006 00Z)

Coupling between atmospheric model and offline surface scheme



Optimum interpolation

Analytical coefficients obtained from Monte-Carlo experiments (Bouttier et al, 1993; Giard and Bazile,2000)
Strong reduction in the presence of rain, clouds, strong wind, low radiative forcing (empirical thresholds)

Simplified EKF

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

where **B** and **R** are prescribed
The Jacobian of the observation operator **H** is obtained in finite differences (instead of adjoint code).

$$\mathbf{H} \approx \frac{\mathbf{y}(w_2 + \Delta w) - \mathbf{y}(w_2)}{\Delta w}$$

Kalman gain

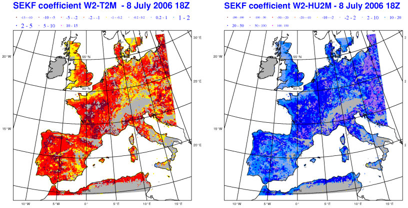


Figure: Extended Kalman Filter

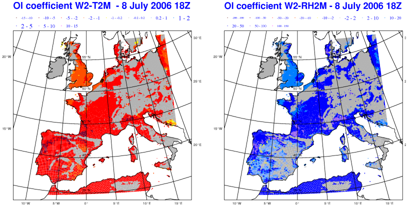


Figure: Optimum interpolation (MF)

Kalman gain comparison from Balsamo et al. (2004)

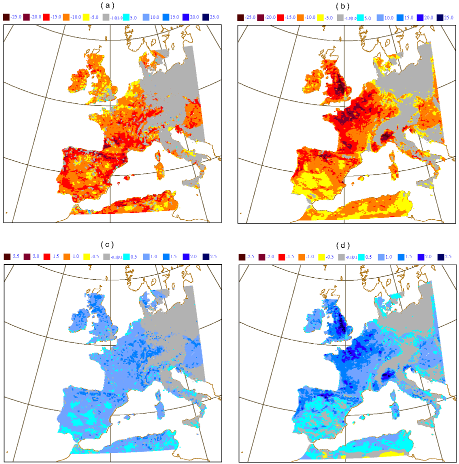
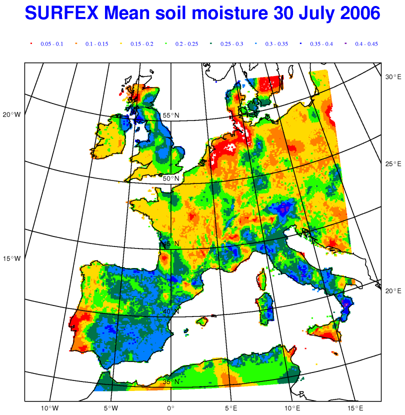
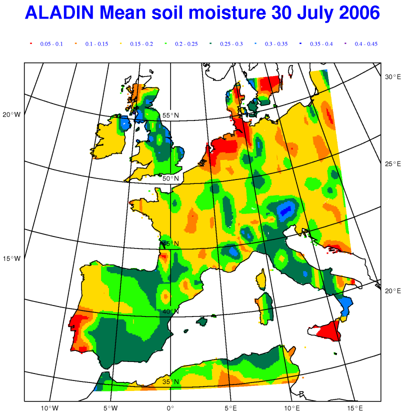


Figure 7. Components of the gain matrix for 2 m temperatures, (a) from 2D-VAR, obtained with a single estimate on a 6-hour forecast window and (b) the OI coefficient currently used in the ARPEGE operational analysis. Both methods use the masking of low-sensitivity grid points. (c) and (d) as (a) and (b), but for 2 m relative humidity. Units: (a) and (b) (10^{-3} m K^{-1}), (c) and (d) (10^{-3} m).

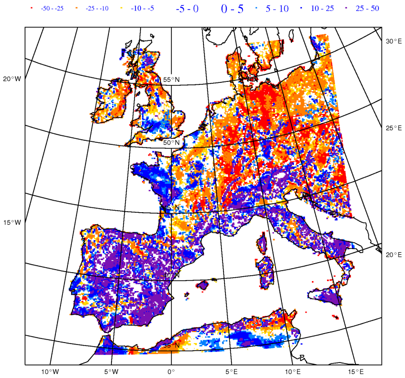
Soil moisture after 1 month of assimilation



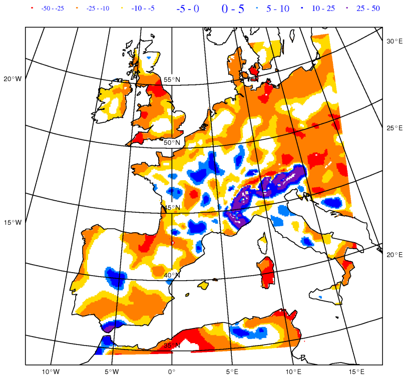


Soil moisture variations

SURFEX Soil moisture variations 30 - 01 July 2006 00Z

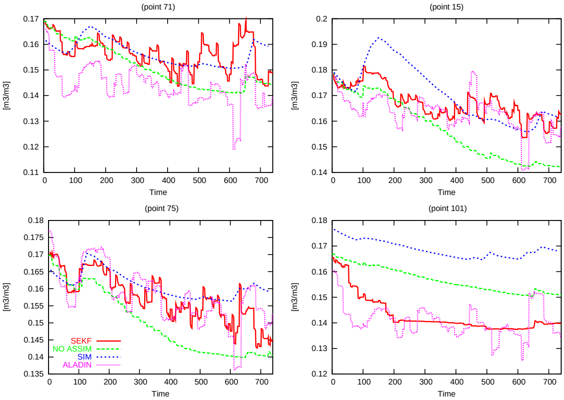


ALADIN Soil moisture variations 30 - 01 July 2006 00Z



Comparison with ALADIN, SIM and NO ASSIM

ALADIN = interpolation of ARPEGE analyses
SIM = ISBA scheme forced by observed precipitation forcing over France
NO ASSIM = ISBA scheme forced by ALADIN short-range forecasts



Conclusions

- Development of a flexible tool for land data assimilation within ALADIN (geographical domain, observations to be assimilated, variables to be analysed, land surface scheme version)
- A SEKF is now available within SURFEX for the analysis of soil moisture (but needs analysis increments from a 2D spatial interpolation tool like CANARI)
- The first results over the ALADIN-France for summer 2006 are encouraging (proof of concept)
- Work to be done (in collaboration with HIRLAM/ALADIN partners) :
  - Reduce remaining inconsistencies between SURFEX and ALADIN-ISBA
  - Perform assimilation of surface soil moisture contents (satellite, offline hydrological model SIM)
  - Couple the soil analysis with the atmospheric analysis (to allow feedbacks)
  - Improve the efficiency of offline SURFEX version

Important remaining issues

- Soil temperature analysis (including frozen soils)
- SBL vertical interpolation operators (definition, surface patches, forested areas)
- Specification of soil forecast errors (dependency with precipitation forcing)
- Inclusion of improved radiative and precipitation forcings
- Accuracy of (new) satellite measurements in well observed regions