A land surface analysis scheme based on an Extended Kalman Filter for NWP models

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performed within ALADIN/LACE/HIRLAM consortia

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Scientific objectives (1)

- Improve the analysis of soil prognostic variables (temperature and soil moisture content) in NWP models (ALADIN, AROME, ARPEGE, HARMONIE)
- Current status in (most) ALADIN and HIRLAM models : Dedicated soil analysis based on optimal interpolation technique using screen-level temperature and relative humidity (Giard and Bazile, 2000)

Scientific objectives (2)

- Main weaknesses of the current soil analysis: difficult to assimilate new observation types and to initialize additional prognostic variables :
  - Satellite data informative about soil moisture state (AMSR-E, ERS, ASCAT, SMOS)
  - Precipitation analyses (raingauges, radars) and surface downward radiation fluxes derived from satellite measurements (LandSAF)
  - New versions of the land surface scheme ISBA (additional soil layers, inclusion of photosynthesis and plant growth)
- Proposal : Extended Kalman Filter (EKF) (*Simplified 2D-Var of Balsamo et al. (2004)*) in the offline version of the externalized surface platform SURFEX with a 6-hour assimilation window.

Definitions

- Control vector $\mathbf{x}$ (dimension N_x) : prognostic variables of the land surface scheme ISBA $\mathbf{x} = (w_g, w_2, T_s, T_2)$ $[N_x = 4]$
- Forward model $\mathcal{M}$: land surface scheme ISBA (2-layer force restore method): $\mathbf{x}^t = \mathcal{M}(\mathbf{x}^0)$
- Observations $\mathbf{y}_o$ (dimension N_y) : T_{2m}, RH_{2m}, w_g with a covariance matrix of observation errors $\mathbf{R}$
- Observation operator $\mathcal{H}$: Model counterpart of observations : $\mathbf{y}^t = \mathcal{H}(\mathbf{x}^t)$ (e.g. vertical interpolation scheme in the SBL)
- Background state : short-range (6-h) forecast of $\mathbf{x}$ ($\mathbf{x_f}^t$) with a covariance matrix of background errors $\mathbf{B}$

EKF equations (1)

An analysis state ${\mathbf{x_a}}^t$ is given by an optimal combination (minimum variance) of the observations and the background (short-range forecast) :

$$ {\mathbf{x_a}}^t = {\mathbf{x_f}}^t + \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}(\mathbf{y}_o^t - \mathcal{H}({\mathbf{x_f}}^t)) \tag{1} $$

whre $\mathbf{H}$ is the Jacobian matrix $(N_y \times N_x)$ of the observation operator $\mathcal{H}$:

$$ \mathbf{H}_{ij} = \frac{\partial \mathbf{y}_i}{\partial \mathbf{x}_j} \tag{2} $$

<u>Remark:</u> in SURFEX, we use a finite difference approach where the input vector $\mathbf{x}$ is perturbed N_x times to get for each model integration a column of the matrix $\mathbf{H}$:

$$ \mathbf{H}_{ij} \simeq \frac{\mathbf{y}_i(\mathbf{x} + \delta x_j) - \mathbf{y}_i(\mathbf{x})}{\delta x_j} \tag{3} $$

where δx_j is a small increment value added to the j-th component of the $\mathbf{x}$ vector.

EKF equations (2)

The analysis state in characterized by an analysis error covariance matrix:

$$\mathbf{A} = (\mathbf{I} - \mathbf{K}\mathbf{H})\mathbf{B} \tag{4}$$

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

The analysis is cycled by propagating the time the two quantities $\mathbf{x_a}$ et $\mathbf{A}$ up to next time where observations are available :

$$\mathbf{x_f}^{t+1} = \mathcal{M}(\mathbf{x_a}^t) \tag{5}$$

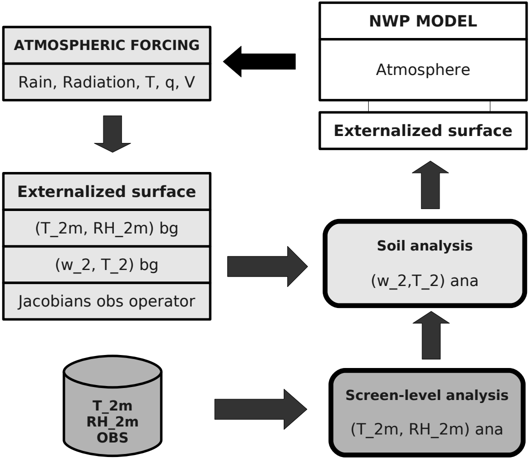
$$\mathbf{B}^{t+1} = \mathbf{M}\mathbf{A}^t\mathbf{M}^T + \mathbf{Q} \tag{6}$$

Jacobian matrix $\mathbf{M}$ of the forward model $\mathcal{M}$, between time t and time $t = 0$ (obtained like $\mathbf{H}$):

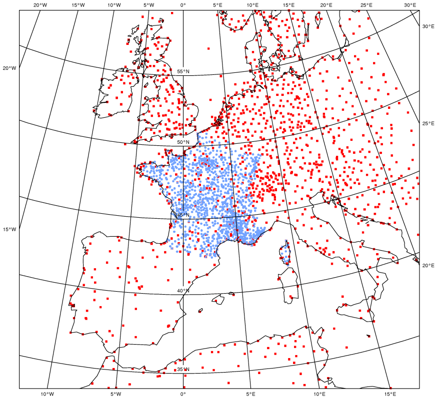
$$\mathbf{M}_{ij} = \frac{\partial x_i^t}{\partial x_j^0} \tag{7}$$

A new matrix $\mathbf{Q}$, representing the model error covariance matrix, needs to be defined.

Coupling between surface and atmospheric analyses

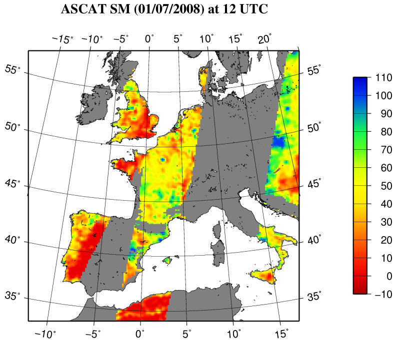


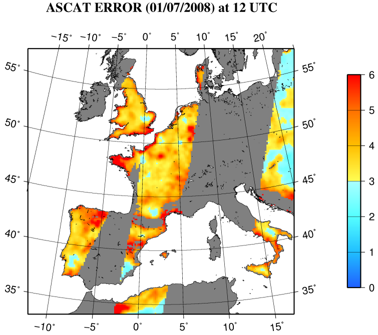
Surface network over ALADIN-France domain



blue = RADOME (1000) - red = SYNOP (1000)

ASCAT superficial soil moisture (2007-present)





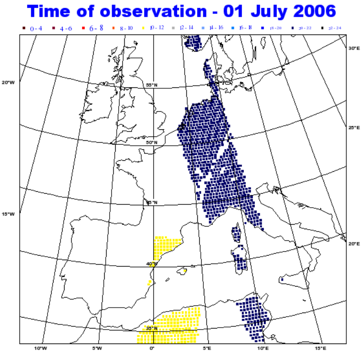
Assimilation of ERS superfical soil moisture retrievals

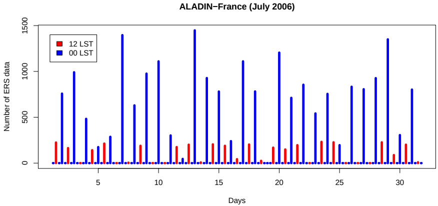
- Period : July 2006
- Data : w_g derived from C-band scatterometer ERS2 (change detection method) - available on a 27 km grid
- Technique : Simplified Extented Kalman Filter
- Assimilation window : 6h
- Control variables : w_2
- Numerical model : ALADIN-France with ISBA 2-L (9.5 km resolution)

Important steps to consider

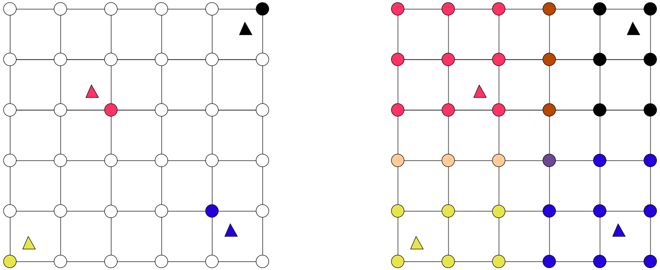
- Interpolation of observations on model grid
- Bias correction of observations
- Observation error specification
- Definition of the data assimilation system

ERS superficial soil moisture availabilty (1993-present)



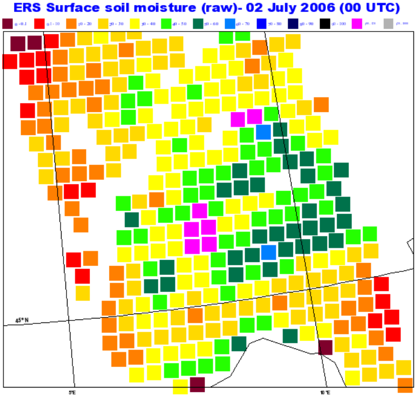


Projection on model grid

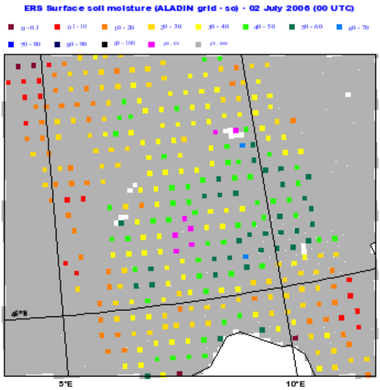


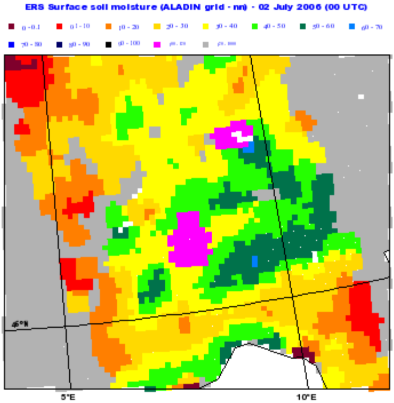
Nearest neighbour (nn) - Oversampling (os)

Raw data



Projected data

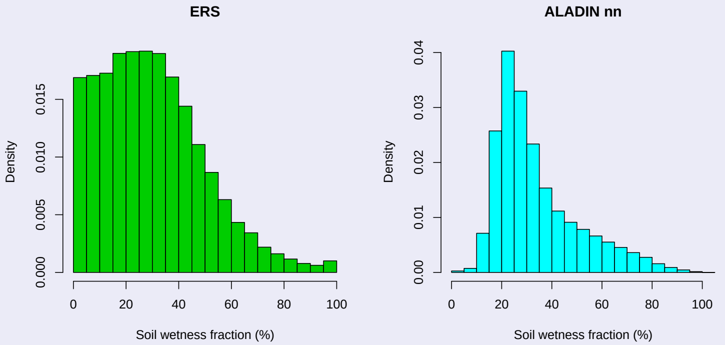




Nearest neighbour (nn) - Oversampling (os)

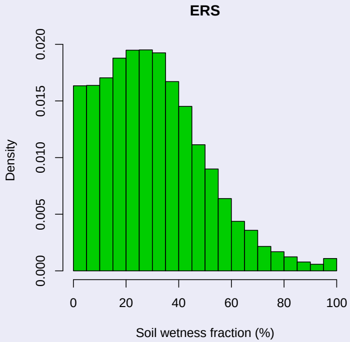
Comparison w_g/w_{sat} ERS vs. w_g/w_{sat} ALADIN (nn)

Raw observations without bias correction



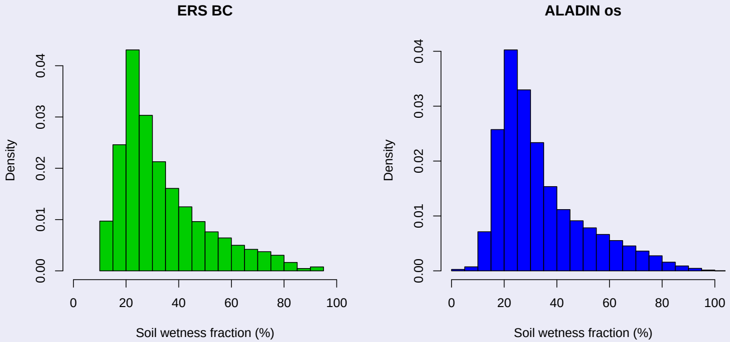
Comparison w_g/w_{sat} ERS vs. w_g/w_{sat} ALADIN (os)

Oversampled observations without bias correction

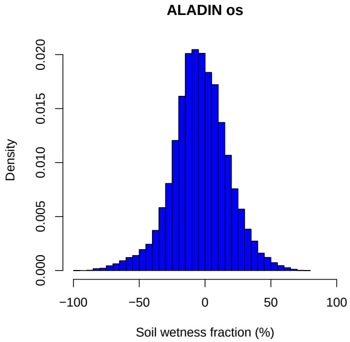


Comparaison w_g / w_{sat} ERS vs. w_g / w_{sat} ALADIN (os)

Bias corrected observations using CDF matching

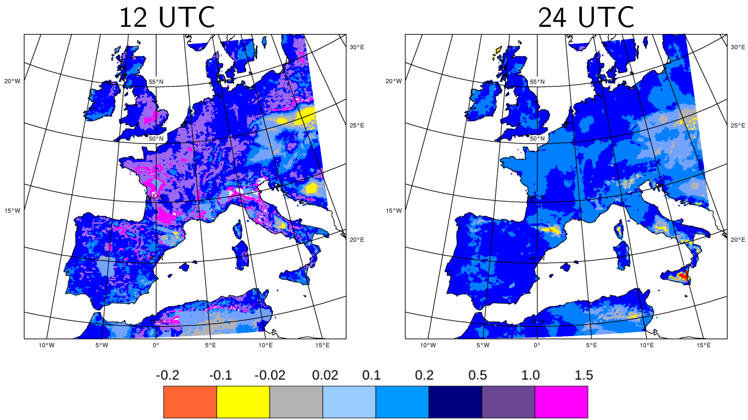


Distribution of innovations



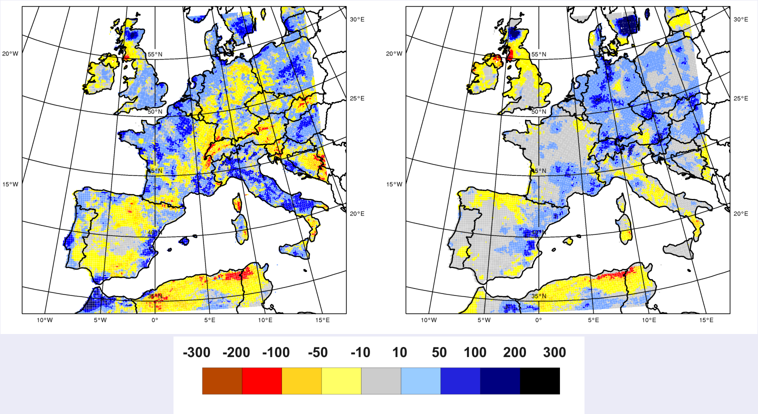
$\sigma_o = \sigma_b = 13\ \%$

Jacobian $\partial w_g / \partial w_2$



Root-zone soil moisture increments (mm) July 2006

assimilation ($T_{2m}+RH_{2m}+w_g$) - assimilation (w_g)



Conclusions

- Development of an externalized land data assimilation system based on an EKF for the analysis of soil prognostic variables in numerical weather prediction models (ARPEGE, ALADIN, AROME, HARMONIE)
- This new system is more flexible than the current OI soil analysis regarding the choice of variables to analyze and observation to assimilate.
- Encouraging results over ALADIN-France domain for the assimilation of screen-level observations (Mahfouf et al., 2009; JGR), ERS and AMSR-E satellite soil moisture (Draper et al. 2009; JGR).

Perspectives

Ongoing activities

1. Coupling of soil analysis with atmospheric analysis
2. Develop a specific soil analysis for the 2.5 km resolution model AROME
3. Examine winter situations with the EKF
4. Assimilation of ASCAT data (collaboration with ZAMG)
5. Improve the bias correction for w_g
6. Develop and validate an assimilation of LAI within SURFEX (GEOLAND2 project)
7. Prepare the assimilation of SMOS data (coupling with the radiative transfer model CMEM)