Advances in land data assimilation at Météo-France

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Outline

- Main features of NWP models at Météo-France
- Short history and current status on land data assimilation at Météo-France
- Description of a new land data assimilation system within SURFEX
- Feasibility studies :
    - Assimilation of screen-level variables (T_{2m}, RH_{2m})
    - Assimilation of satellite derived superficial soil moisture (w_s)
    - Assimilation of satellite derived surface albedo and LAI
- List of perspectives and issues

Météo-France NWP models

- ARPEGE : Spectral global stretched model T538C2.4L60 (15 km resolution over France) - multi-incremental 6h 4D-Var assimilation system at (T107/T224) (90 km)
- ALADIN : Spectral limited area model E149x149C1L60 (9.5 km resolution) - 6h 3D-Var assimilation system
- AROME : Spectral limited area model E255x299C1L41 (2.5 km resolution) - 3h 3D-Var assimilation system
- Summary of physical parameterizations : TKE vertical diffusion scheme, *deep convection mass-flux scheme (Bougeault)*, cloud microphysical scheme (4/5 hydrometeors), shallow convection mass-flux scheme (Kain-Fritsch), ECMWF RRTM radiation scheme, **ISBA land surface scheme (externalized modelling platform SURFEX)**

Land data assimilation at Météo-France 25 years ago (1)

The force-restore equations (Deardorff, 1977; 1978) in the hemispheric model EMERAUDE :

$$\begin{aligned}
\frac{\partial T_s}{\partial t} &= C_T(R_n - H - LE) + \frac{2\pi}{\tau_1}(T_2 - T_s) \\
\frac{\partial T_2}{\partial t} &= \frac{2\pi}{\tau_2}(T_s - T_2) \\
\frac{\partial w_s}{\partial t} &= \frac{1}{\rho_w d_1}(P_g - E_g) - \frac{1}{\tau_1}(w_s - w_2) \\
\frac{\partial w_2}{\partial t} &= \frac{1}{\tau_2}(w_s - w_2)
\end{aligned}$$

with $w_{sat} \times d_1 = 10$ mm, τ_1=1 day and τ_2=5 days

Land data assimilation at Météo-France 25 years ago (2)

Soil analysis equations based on increments from a screen-level analysis of temperature T_{2m} and relative humidity RH_{2m} using SYNOP data :

$$\begin{aligned} T_s^a &= T_s^b + (T_{2m}^a - T_{2m}^b) \\ T_2^a &= T_2^b + \left[\frac{\tau_1}{\tau_2}(T_{2m}^a - T_{2m}^b)\right] \\ w_s^a &= w_s^b + w_{sat}(RH_{2m}^a - RH_{2m}^b) \\ w_2^a &= w_2^b + w_{sat}\left[\frac{\tau_1}{\tau_2}(RH_{2m}^a - RH_{2m}^b)\right] \end{aligned}$$

adapted from Coiffier et al. (1987)

Current land data assimilation at Météo-France (1)

Same methodology adapted to the ISBA-2L scheme with an emphasis on soil moisture (w_s, w_2) by using optimum interpolation (OI) coefficients (statistics of forecast errors derived from a set of Monte-Carlo experiments) [Mahfouf, 1991].

$$
\begin{aligned}
T_s^a &= T_s^b + \mu_1(T_{2m}^a - T_{2m}^b) + \mu_2(RH_{2m}^a - RH_{2m}^b) \\
T_2^a &= T_2^b + \nu_1(T_{2m}^a - T_{2m}^b) + \nu_2(RH_{2m}^a - RH_{2m}^b) \\
w_s^a &= w_s^b + \alpha_1(T_{2m}^a - T_{2m}^b) + \alpha_2(RH_{2m}^a - RH_{2m}^b) \\
w_2^a &= w_2^b + \beta_1(T_{2m}^a - T_{2m}^b) + \beta_2(RH_{2m}^a - RH_{2m}^b)
\end{aligned}
$$

Analytical formulation of the α_i and β_i coefficients (dependencies with solar time, soil texture and vegetation properties) [Bouttier et al. (1993); revised by Giard and Bazile (2000)].
For temperature : $\mu_1 = 1$, $\mu_2 = 0$, $\nu_1 = 1/2\pi$, $\nu_2 = 0$

Current land data assimilation at Météo-France (2)

Operational configuration :

- Soil analysis for ARPEGE (with climatological relaxation) (since 1998) and ALADIN (no climatological relaxation) (since 2009).
- AROME soil initial state = interpolation of ALADIN analysis

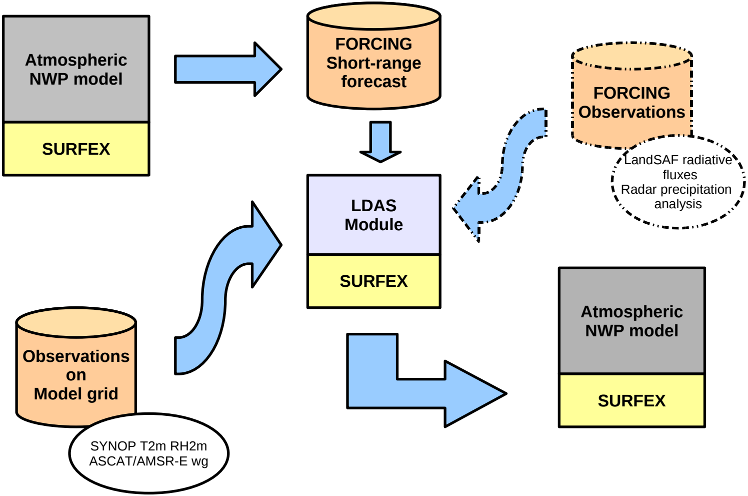
Also used operationally at Météo-France, ALADIN and HIRLAM partners, CMC, ECMWF, (DWD, UKMO)

- OI scheme lacks flexibility for new observation types and new surface prognostic variables :
  - Satellite observations informative about superficial soil moisture (AMSR-E, ERS, ASCAT, SMOS, SMAP)
  - Precipitation analyses (raingauges, radars) and satellite derived downward radiative fluxes (EUMETSAT LandSAF)
  - Multi-layer versions of the ISBA scheme or versions describing photosynthesis (biomass = prognostic variable)

Development of an offline land data assimilation system

- The surface models (ISBAs/Towns/Lakes/Oceans) have been externalized from the atmospheric models into a platform called SURFEX (SURFace EXternalized)
- SURFEX can be coupled to any atmospheric model used at Météo-France (ARPEGE, ALADIN, AROME, Méso-NH) [internal coupling using the strategy of Best et al. (2004)]
- SURFEX can be used in offline mode (e.g. validation studies against field experiments)
- New surface analysis schemes are being developed within SURFEX (offline version / semi-coupled) :
  - Optimum Interpolation
  - Extended Kalman Filter
  - Ensemble Kalman Filters and Particle Filters (collaborations with NILU/HIRLAM)

Coupling between the atmospheric model and the externalised soil assimilation



Comparaison of the OI and EKF soil analysis schemes in ALADIN

OI : Analytical coefficients used operationnally at Météo-France : Formulation of Giard and Bazile (2000) but β_1 and β_2 reduced by a factor of 6 (F. Bouyssel, personnal communication)

EKF : Dynamical coefficients :

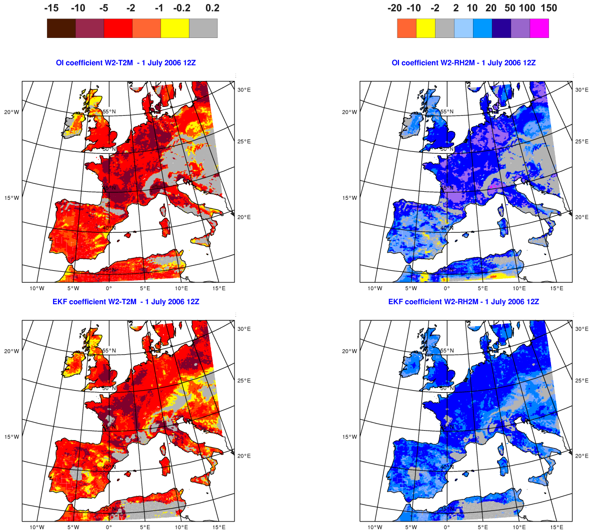
$$\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

where the matrices **B** and **R** are prescribed and the Jacobian of the observation operator **H** obtained in finite differences :

$$\mathbf{H} \approx \frac{\mathbf{y}^t(w_2^0 + \Delta w_2^0) - \mathbf{y}^t(w_2^0)}{\Delta w_2^0}$$

Affordable because the ISBA scheme is run in offline mode and soil columns are treated independently.

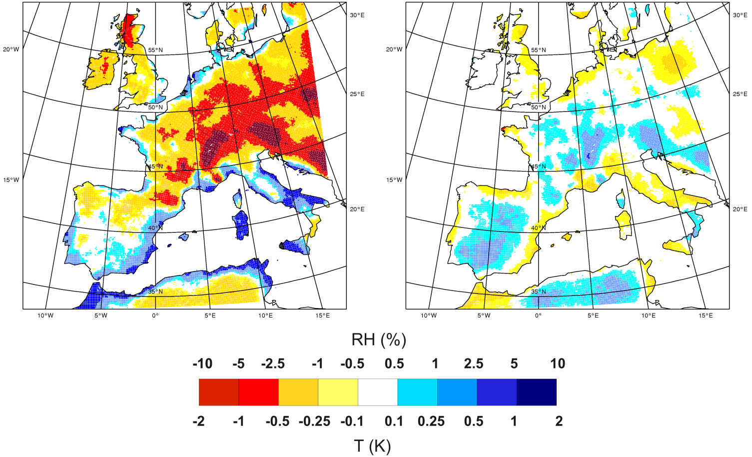
OI vs EKF coefficients : β_1 and β_2 (01/07/2006 at 12 UTC)



OI

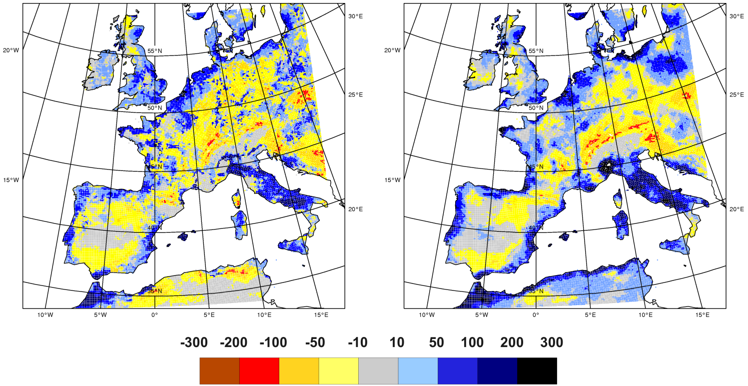
EKF

Analysis increments of T_{2m} and RH_{2m} (mean over July 2006)



Deep soil moisture increments in July 2006 (mm)

EKF increments - OI increments



With ISBA-2L, $\sigma^b_{w_2} \simeq 0.01 m^3/m^3$ leads to $\Delta w_2 \simeq 50 mm$

Preliminary studies on the assimilation of w_s satellite products

- Products currently evaluated : AMSR-E/Aqua, SCAT/ERS, ASCAT/MetOp
- These products have been easily introduced in the EKF
- Examination of the model Jacobians (i.e. link between w_s and w_2) : rather linear - (too) large in ISBA 2-L - simple enough for an analytical formulation
- Importance of a bias correction scheme
- The specification of the covariance matrix of background errors **B** is an issue with ISBA-2L for combined assimilation of conventional and satellite observations.

$$\sigma^b_{w_2} \simeq 0.01 m^3/m^3 << \sigma^o_{w_s} \simeq 0.06 m^3/m^3$$

Preliminary studies on the assimilation of satellite derived surface albedo and *LAI*

- Simple analysis schemes : slow evolution of the associated dynamics compared to availability of satellite observations (forward operator close to identity).
- Feasibility studies with a Kalman Filter for MSG surface albedo : Optimal combination between observations (climatological albedo and MSG daily surface albedo) and a priori bare soil and vegetation albedos. Positive impacts on forecast scores for T_{2m} in ALADIN.
- Use of ISBA-A-gs (describing photosynthesis and plant growth) for the assimilation of *LAI* in the EKF (local scale : SMOSREX ; France : FP7 GEOLAND 2 projet)

Current activities and remaining issues (1)

- Development of a soil analysis for AROME based on OI (initialisation of "town" temperatures)
- Analysis of snow depth from SYNOP observations (OI CANARI) [inclusion of snow extent information from MSG]
- Use of radar precipitation in the EKF for correcting soil moisture contents
- Assimilation of ASCAT soil moisture in the ALADIN 3D-Var (and then in ARPEGE 4D-Var)
- Improvement of background/model error statistics for soil variables (ensemble forecasts or assimilations)

Current activities and remaining issues (2)

- Assimilation of ASCAT soil moisture in the hydrometeorological system SIM (over France)
- Improvement of the screen-level analysis (FP7 EURO4M project)
- Intercomparison between EKF and EnKF (eventually PFs)
- GEOLAND 2 : combined assimilation of *LAI* and *SWI*
- Preparation of SMOS : coupling of SURFEX with microwave RTM (CMEM) - scaling issues

Important items for the assimilation of satellite w_s ?

- Improved land data assimilation system : not sure ! no strong non-linearities
- Improved land surface scheme : yes (root zone depth, soil textural properties, surface energy balance)
- Improved specification of errors : yes (diagnostics first)
- Improved bias correction schemes : yes (which one is right ?)
- Importance of other products over limited area domains : geostationnary satellites (albedo, radiative fluxes), radars, raingauges, screen-level variables - examine combined assimilations

Thank you for your attention !