Surface analyses for NWP model initialization at Météo-France

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Plan

- Introduction
- Soil moisture and soil temperature analysis
- Others analyses: snow, sea surface temperature, sea ice, ...
**Introduction**

- Surface fluxes: key role in the evolution of meteorological fields near the ground, in the boundary layer and in the troposphere.

- These fluxes depend strongly on surface variables which have strong variabilities in time and space (pronostic variables).

  \[ \Rightarrow \text{Necessity of same degree of sophistication between surface scheme, physiographic database, surface analysis} \]

- Surface analyses are performed separately from upper air analysis.

- Several surface analyses are used for different surface parameters (Soil temperature and Soil moisture, Snow, SST, Sea ice, ...)

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**Graphical Illustration**

- Points labeled with `+6hfcst` indicating forecasts at 00UTC, 06UTC, 12UTC, 18UTC, and 00UTC.
Soil moisture and soil temperature analysis
**Surface Parameterization scheme (ISBA)**


**Research versions:**
- Interactive vegetation module (Calvet et al. 1998),
- Sub grid-scale runoff and sub-root layer (Boone et al 1999),
- Explicit 3-layers snow scheme (Boone & Etchevers 2001), tiling,
- Multi-layer soil scheme, urban scheme

**Energy**
- $R_g$, $R_{at}$, $\alpha R_g$, $R_i$, $H$, $LE$

**Analysis**
- Surface temperature
- Mean soil temperature
- Superficial soil water content
- Total soil water content

**Water**
- $P_r$, $P_n$, $P_g$

~1-2 hours
- $T_s$

~1-2 days
- $T_p$

~6-12 hours
- $W_r$, $W_s$, $W_{si}$

~10 days
- $W_p$, $W_{pi}$

$G$, $Q_r$, $E_{r}$, $E_{tr}$, $E_{g}$, $W_{n}$, $D_{2}$, $K_{2}$
Importance of soil moisture and temperature analysis

- **Stable surface conditions**: Low surface fluxes. Influence of surface limited near the ground.

- **Neutral/instable surface conditions**: Strong surface fluxes. Influence on PBL evolution and sometimes more (trigger deep convection)

Soil moisture initialization is very important under strong solar radiation (determines Bowen ratio).

\[ Wr << Ws << Wp \]

According time scale evolution. Accumulation of model error may degrade significantly the forecast during long period
Optimum Interpolation method

1) Optimum Interpolation of $T_{2m}$ and $RH_{2m}$ using SYNOP observations
interpolated at the model grid-point (by a 2m analysis)

$$\Delta T_{2m} = T_{2m}^a - T_{2m}^b$$
$$\Delta RH_{2m} = RH_{2m}^a - RH_{2m}^b$$

2) Correction of surface parameters ($T_s$, $T_p$, $W_s$, $W_p$) using 2m increments
between analysed and forecasted values

Sequential analysis (every 6h)

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B} \mathbf{H}^T (\mathbf{H} \mathbf{B} \mathbf{H}^T + \mathbf{R})^{-1} (\mathbf{y} - \mathbf{H}(\mathbf{x}^b))$$

$$T_s^a - T_s^b = \Delta T_{2m}$$
$$T_p^a - T_p^b = \Delta T_{2m} / 2\pi$$
$$W_s^a - W_s^b = \alpha_{WST} \Delta T_{2m} + \alpha_{WSRH} \Delta RH_{2m}$$
$$W_p^a - W_p^b = \alpha_{WpT} \Delta T_{2m} + \alpha_{WpRH} \Delta RH_{2m}$$

OI coefficients
Optimum Interpolation coefficients

\[
\alpha_{Wp/T} = \frac{\sigma_{Wp}^a}{\Phi \sigma_{T2m}^b} \left[ 1 + \left( \frac{\sigma_{RH2m}^a}{\sigma_{RH2m}^b} \right)^2 \right] \rho_{T2m, Ws/p} - \rho_{T2m, RH2m} \rho_{RH2m, Ws/p}
\]

\[
\alpha_{Wp/RH} = \frac{\sigma_{Wp}^a}{\Phi \sigma_{RH2m}^b} \left[ 1 + \left( \frac{\sigma_{T2m}^a}{\sigma_{T2m}^b} \right)^2 \right] \rho_{RM2m, Ws/p} - \rho_{T2m, RH2m} \rho_{T2m, Ws/p}
\]

\[
\Phi = \left[ 1 + \left( \frac{\sigma_{T2m}^a}{\sigma_{T2m}^b} \right)^2 \right] \left[ 1 + \left( \frac{\sigma_{RH2m}^a}{\sigma_{RH2m}^b} \right)^2 \right] - \rho_{T2m, RH2m}^2
\]

Very strong dependency of these background error statistics to physiographic properties and meteorological conditions

MonteCarlo method under summer anticyclonic conditions to get the dependency to physiography (deriving analytical formulation of OI coefficients) + empirical additional dependency to meteorological conditions

\[
\alpha_{Wp/S/RH} = f(t, \text{ veg, LAI}/R_{s\min}, \text{ texture, atmospheric conditions})
\]

Long and difficult work (in principle should be redo with model or physiography evolutions!)
Optimum Interpolation method

- March 98:
  - Operational implementation with ISBA

- October 99:
  - Factor 3 reduction of OI coefficients on Wp
  - Continuous formulations for OI coefficients
  - Cloudiness is taken into account in OI coefficients

New with factor 3 reduction
OI Lonnberg-Holl. method
Optimum Interpolation method

- Spatial smoothing of Soil Wetness Index (SWI)
- Improved 2m background error statistics (smaller scales)
- Factor 2 reduction of OI coefficients on Wp
- Zenith solar angle is taken into account
- Remove temporal smoothing of Wp analysis increments
- No bias correction on T2m analysis increments

⇒ Improvements of SYNOP scores on T2m and H2m in winter
⇒ More realistic soil moisture

OPER / NEW
Illustration of problem with first implementation: 42h ALADIN forecast for 17th June 2000 at 18h UTC
Soil Wetness Index in SIM (left) and ARPEGE (right) on 11 July 2005.
Analysis increments (May-June 2006)

Daily mean of absolute analysis increments

|ΔT2m|

Cumulated analysis increments on Wp (in mm)

From 1st May 2006 to 11 July 2006 (in days)
Variational surface analysis

Mahfouf (1991), Callies et al. (1998), Rhodin et al. (1999), Bouyssel et al. (2000)

Formalism:

\[ J(x) = J^b(x) + J^o(x) = \frac{1}{2} (x - x^b)^T B^{-1} (x - x^b) + \frac{1}{2} (y - H(x))^T R^{-1} (y - H(x)) \]

- \( x \) is the control variables vector
- \( y \) is the observation vector
- \( H \) is the observation operator
- \( B \) is the background error covariance matrix
- \( R \) is the observation error covariance matrix

The analysis is obtained by the minimization of the cost function \( J(x) \)

For high dimensional problems: TL/AD models
For low dimensional problems: finite differences
Visualisation of cost function
Variational Analysis on MUREX experiment

![Graph showing SWI vs Julian days with different lines representing observations and model runs.](image-url)
**Dynamical optimal interpolation or Simplified 2D-Var**

Hess (2001), Balsamo et al. (2002)

- TL hypothesis: \( H(x+dx) \approx H(x) + H.dx \) (acceptable for Wp)

\[
x^a = x^b + BH^T(HBH^T + R)^{-1}(y - H(x^b))
\]

\[
W_p^a - W_p^b = \alpha_{WP}T \Delta T_{2m} + \alpha_{WP}RH \Delta RH_{2m}
\]

- “Normal” OI coefficient \( \alpha_{WP}T \) and \( \alpha_{WP}RH \) are evaluated statistically (once)
- Dynamical OI coefficients \( \alpha_{WP}T \) and \( \alpha_{WP}RH \) are evaluated dynamically (each time)
Comparison of statistical and dynamical OI

A comparison with OI (Gain Matrix and OI coefficients) is useful to point out some properties of the variational approach:

- masking of low sensitivity grid-points (coherence of masked areas)
- dependency from radiation rather than vegetation
- evaluation of the overall correction of the OI

K component (OI): 20000616 at 12 UTC [k1(T2m,Wp)]

K component (2D-VAR): 20000616 at 12 UTC [k1(T2m,Wp)]
Dyn OI tested in ELDAS (two 6 months assimilations)

the two cycles without and with Precipitation readjustment are compared

⇒ Differences of small scales: temporal and spatial
Soil Moisture Validation in France

- A national project (Météo-France / CNES)
- Soil moisture networks are needed
  Validation of Land Surface Models
  Assimilation: to help characterise/reduce the bias between SMOS products and the model wg
- A 12 station network in SW France
  Atlantic-Mediterranean RADOME operational network of Météo-France, delivering real-time data
Others analyses:
Sea surface temperature
Sea ice
Snow
...
**SST and Sea Ice cover analysis**

Optimal interpolation assimilating buoys and ships (~1300 obs by rXX)

Relaxation towards SST NESDIS analysis 0.5°*0.5° (~5 days time scale)

Use SSMI observations to determine Sea Ice (once a day). Temporal consistency in sea ice cover analysis.

No lake temperature analysis

**Snow correction**

Snow analysis developed in CANARI, but never operational

Research study to use either IFS or NESDIS snow cover analysis

Snow melting in case of warm T2m observations

**Frozen soil correction**

Melting of frozen soil in case of warm T2m observations
1D simulation over Sodankyla (Finland)

T2m juin 05

Eau du sol gelée
TEMPERATURE CORR.

28 cas, 01/08/2005_00UTC -> 02/07/2005_00UTC

- - - - Bias P A, r 0/SYNOP
- - - - Bias P 70NJ, r 0/S

* - * - Eqr P A, r 0/SYNOP
* - * - Eqr P 70NJ, r 0/S

BULGARIA

FINLAND

NORWAY

SUEDE
Conclusions

- Surface analyses implemented for ARPEGE, not yet in ALADIN or AROME (technically and scientifically working) -> CHMI
- Important effort on soil moisture analysis (including satellite obs)
- New algorithms (2D-Var, Dyn-OI) but two costly for the time being
- Importance of 2m observations
- Potential of better atmospheric forcings (radiation, precipitations)
- How to combine in a reasonable cost system analysed/observed forcings, 2m obs, satellite obs? Link with upper analysis? Is the spatialisation of observation a good solution?