Presentation of surface analyses (temperature and soil moiture over continental area, sea surface temperature, sea ice cover, snow)

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with inputs from G. Balsamo, E. Bazile, K. Bergaoui, D. Giard, M. Harrouche, S. Ivatek-Sahdan, M. Jidane, F. Taillefer, L. Taseva, ...

Plan

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

  ...

Introduction

Introduction

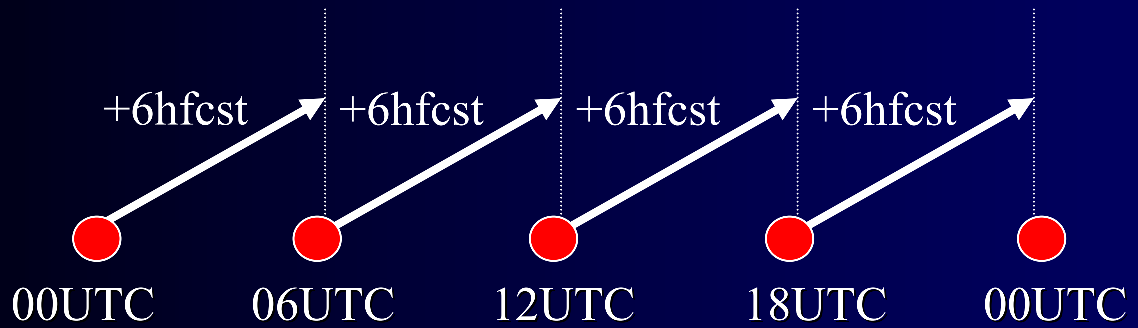
- Surface fluxes : key role in the evolution of meteorological fields near the ground, in the boundary layer and in the troposphere

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

  ⇒ Necessity of same degree of sophistication between surface scheme, physiographic database, surface analysis

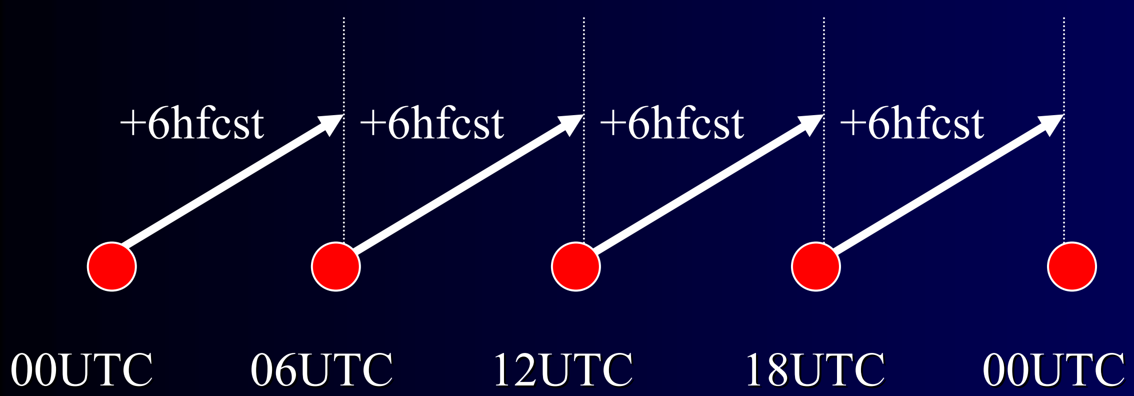
- Surface analyses are performed separately from upper air analysis

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



Surface analyses and upper-air analysis

- For the time being surface analyses are performed separately from upper air analysis. In theory a single analysis would be better but it is much more difficult implement: 1) definition of B between upper air and surface variables, 2) time scale evolutions may be different, ...
- For the time being several surface analyses are used for simplicity and because very different surface parameters (Soil temperature and Soil moisture, Snow, SST, Sea ice, ...)



Atmospheric analysis and several surface analyses are done separately and combined at the end to provide the final analysis for the forecast

(6h sequantial analysis is just an exemple)

Soil moisture and soil temperature analysis

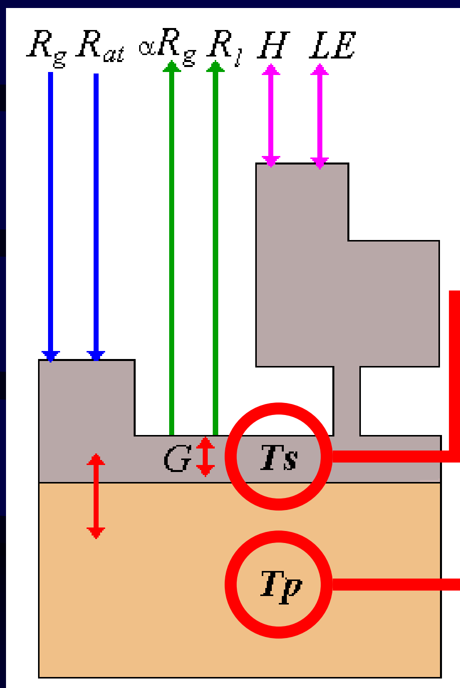
Surface Parameterization scheme (ISBA)

Operational version : Noilhan & Planton (1989), Noilhan & Mahfouf (1996), Bazile (1999), Giard & Bazile (2000)

Energy

~1-2 h

~1-2 day



Analysis

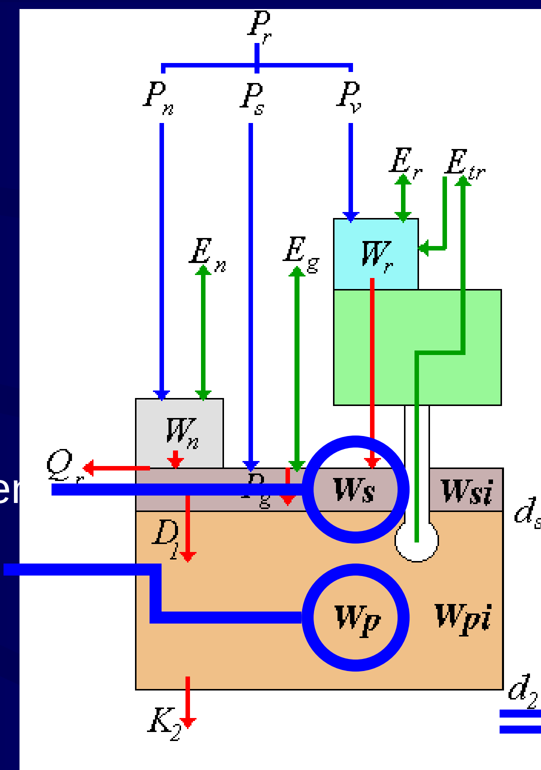
surface temperature

mean soil temperature

superficial soil water content

total soil water content

Water



~6-12 h

~10 days

Research versions : interactive vegetation module (Calvet et al. 1998),

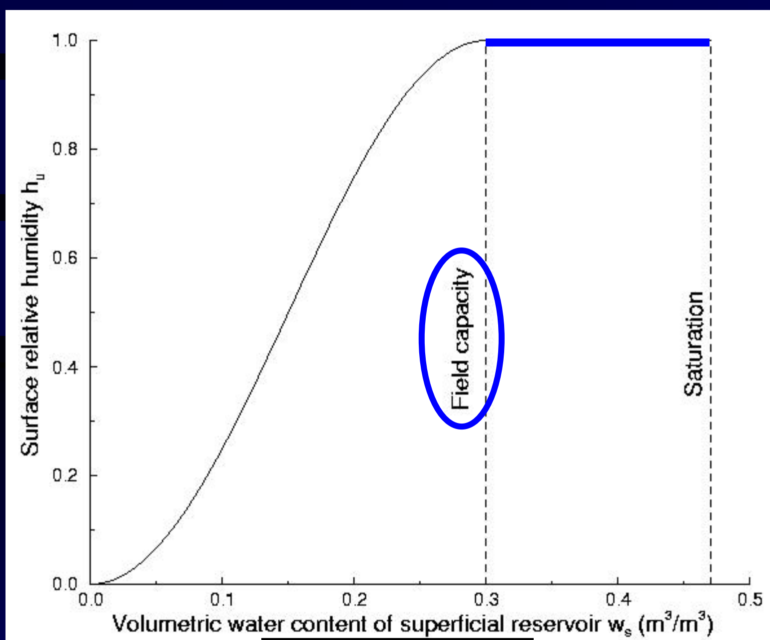
sub grid-scale runoff and sub-root layer (Boone et al 1999),

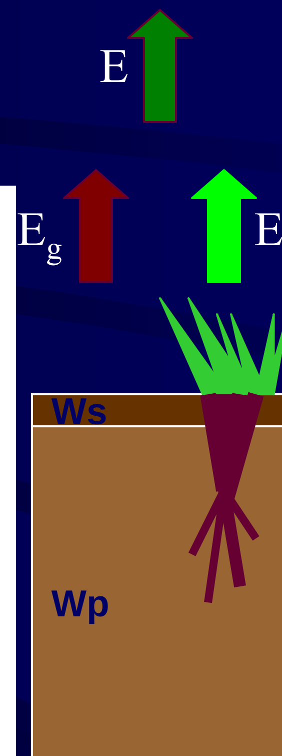
explicit 3-layers snow scheme (Boone & Etchevers 2001), tiling,

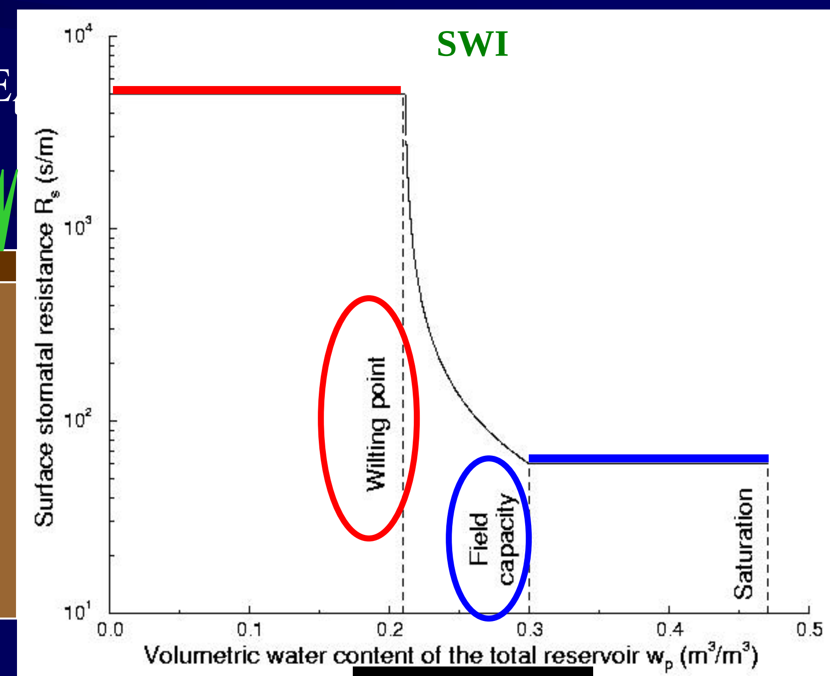
multi-layer soil scheme, urban scheme

The link between soil moisture and atmosphere

- The main interaction of soil moisture and atmosphere is due to evaporation and vegetation transpiration processes.







Ws
bare ground

Wp
vegetation

Importance of soil moisture and temperature analysis

- stable surface conditions : Low surface fluxes. Influence of surface limited near the ground
- instable surface conditions : Strong surface fluxes. Influence on PBL evolution and sometimes more (trigger deep convection)

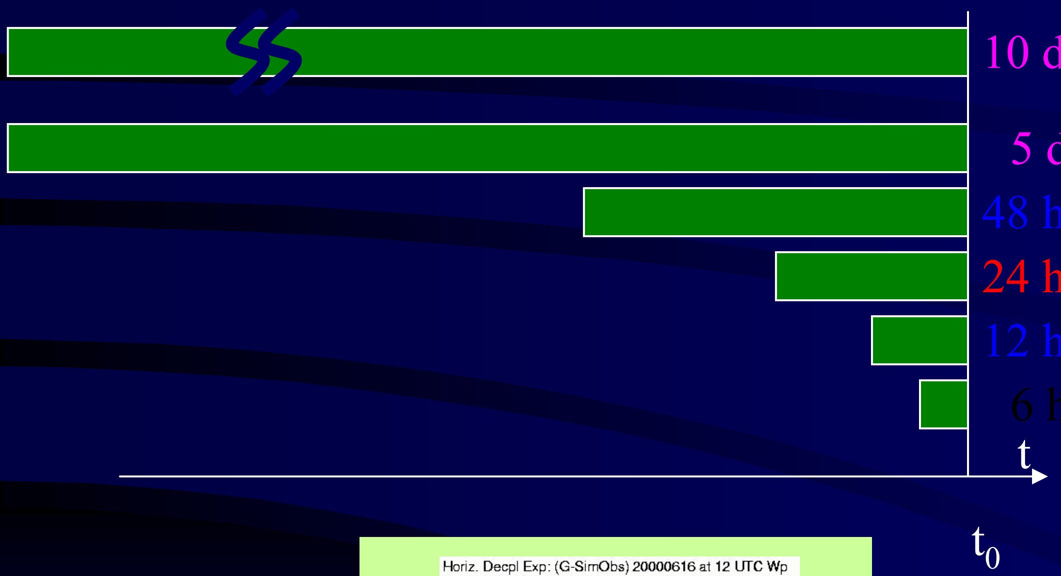
- Soil moisture is very important under strong solar radiation at the surface because it determines the repartition of incoming energy into sensible and latent heat fluxes.
  Importance of initialization: Wr << Ws << Wp according capacity and time scale evolution. Accumulation of model error may degrade significantly the forecast during long period.

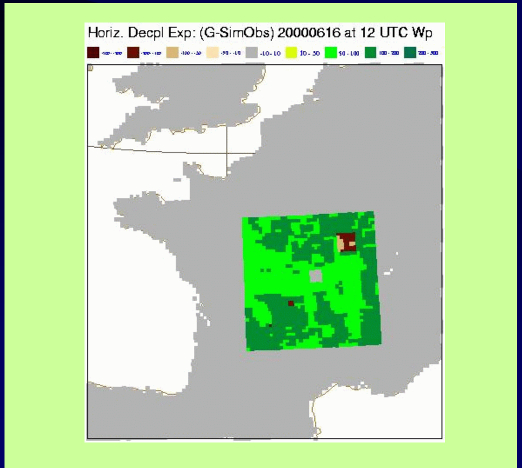
- Soil temperature is important in case of stable conditions because it affects low level temperature. Importance of initialization: Ts << Tp

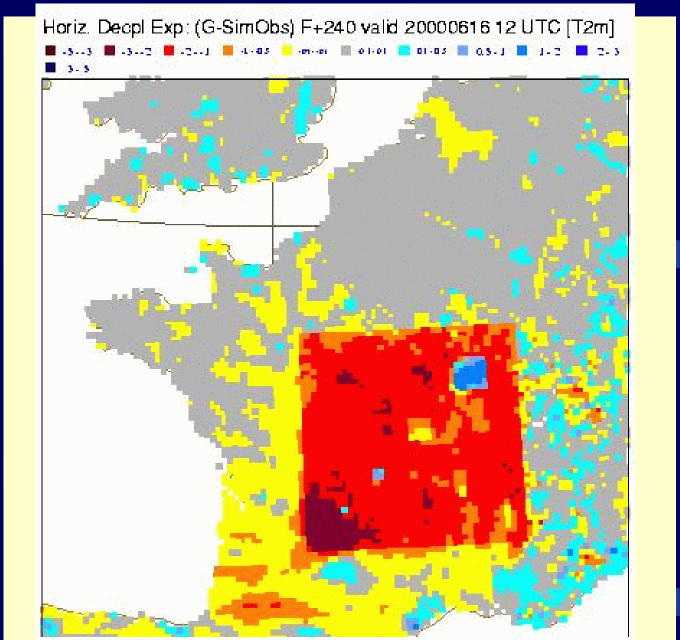
- Necessity of same degree of sophistication between surface scheme, physiographic database, surface analysis

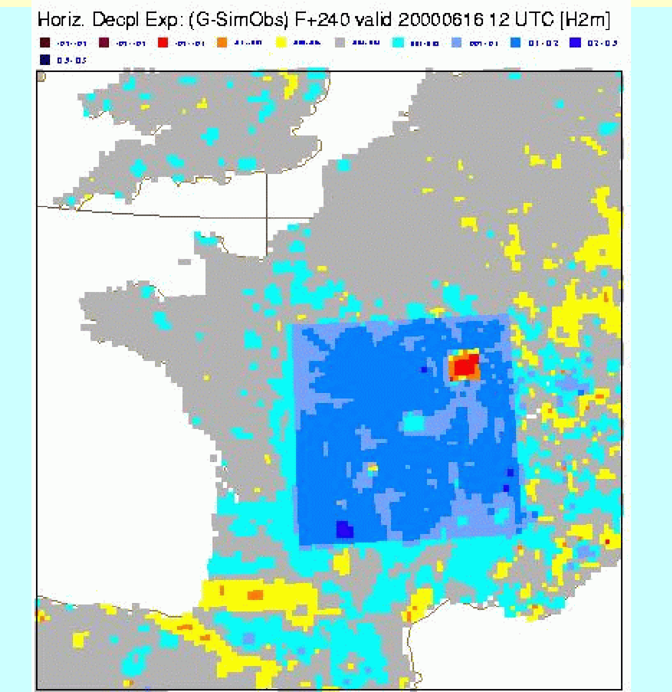
*But **strong sensibility** of surface fluxes (sensible and latent) to the soil temperature and moisture*

To illustrate the memory effect, the impact of a prescribed initial error in the soil moisture field is shown for different *forecast ranges* (T_{2m}, RH_{2m})



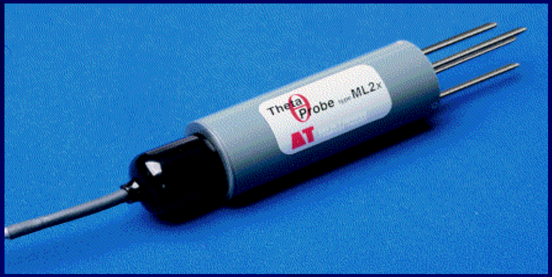


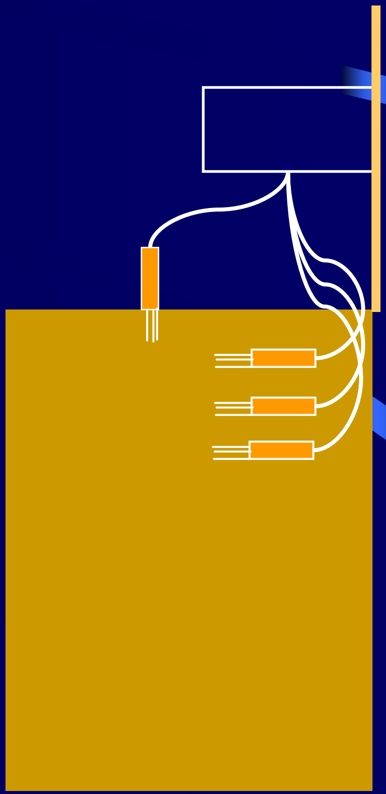




Specificities of soil moisture and temperature analysis

- Strong soil and vegetation spatial heterogeneities (mountains, coastal regions, forest, bare ground, various cultures, towns, lakes, ...)
- Strong spatial variability of soil moisture (linked with surface and soil properties and precipitations)
- Lack of direct observations (very expensive and problem of representativeness)
- Large variety of time scales in soil processes (up to several weeks or months)





Available observations for soil moisture analysis

- Precipitations observations (rain gauges, radars) :
  + direct link with the variations of soil water content

- Satellite observations:
  + global coverage
  + infrared: clear sky, low vegetation, geostationnary satellites : high temporal and spatial resolutions (energy budget), strong sensitivity to low level wind, surface roughness
  + microwave: active and passive instruments measure directly the soil moisture in the first few centimeters (scatterometer (ERS,ASCAT), passive or active radiameters (SMOS, HYDROS): resolution ~20/40km, frequency ~0.3/1 per day

- 2m observations (temperature et humidity):
  + good global coverage of existing network
  + close links with the fields in the ground in some meteorological conditions

Operational initialization methods

- Climatological relaxation of deep soil parameters (uncertainties in these climatologies (GSWP), interannual variability not taken into account)

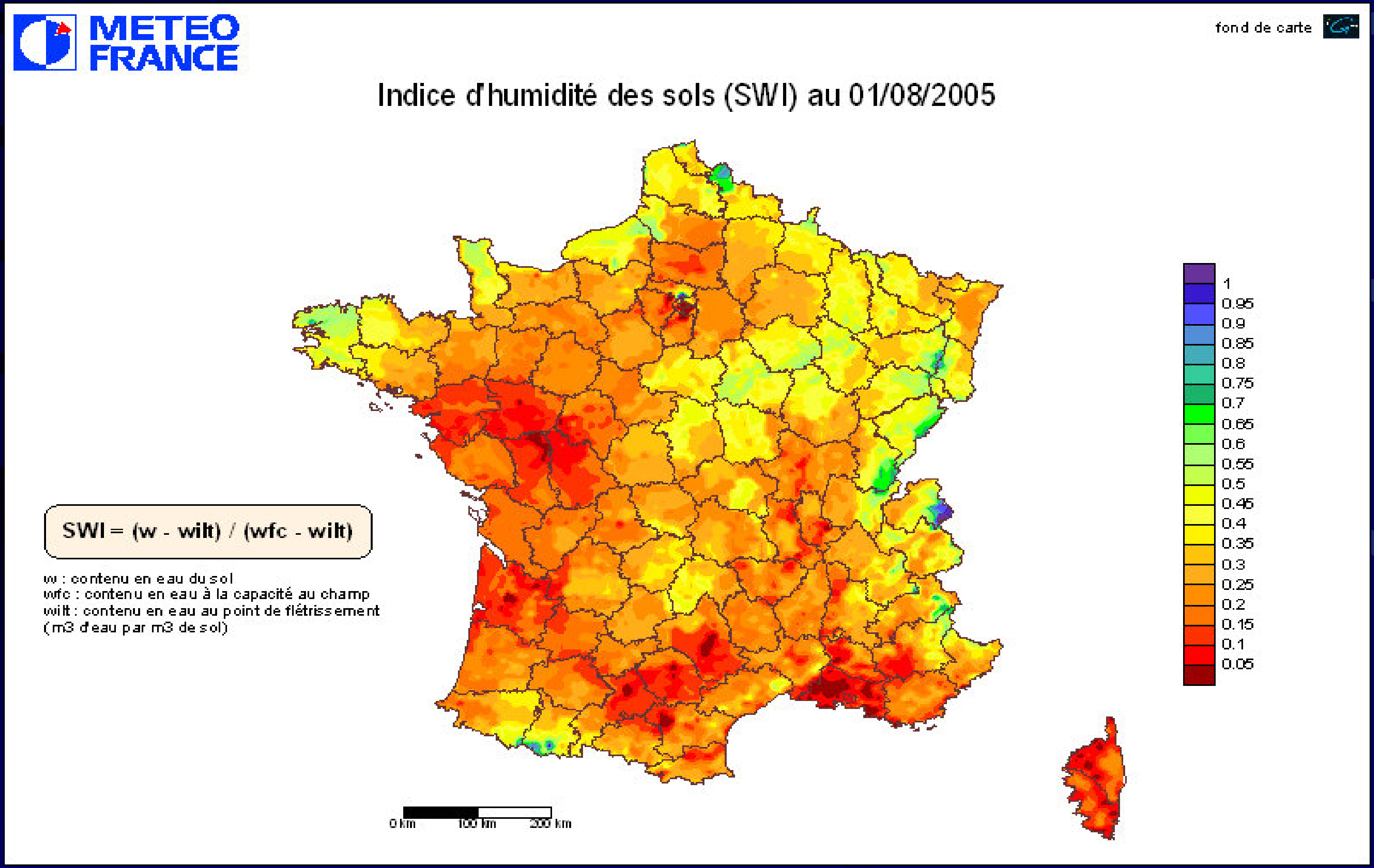
- Off line surface scheme driven by forecasted or analysed fields and fluxes (flux of precipitation, of radiation, fields near the surface T_{2m}, HU_{2m}, V_{10m}, P_s)
  Exemple: SAFRAN-ISBA-MODCOU

- Few operational use of satellite data for temperature and soil moisture analysis (near future)

- Assimilation of 2m observations of temperature and relative humidity

Off-line method (SIM exemple)

Run operationally over France at 8 km : SAFRAN (upperair analysis: Ta, qa, U, SW↓, LW ↓, RR, …) , ISBA, MODCOU Hydrological model

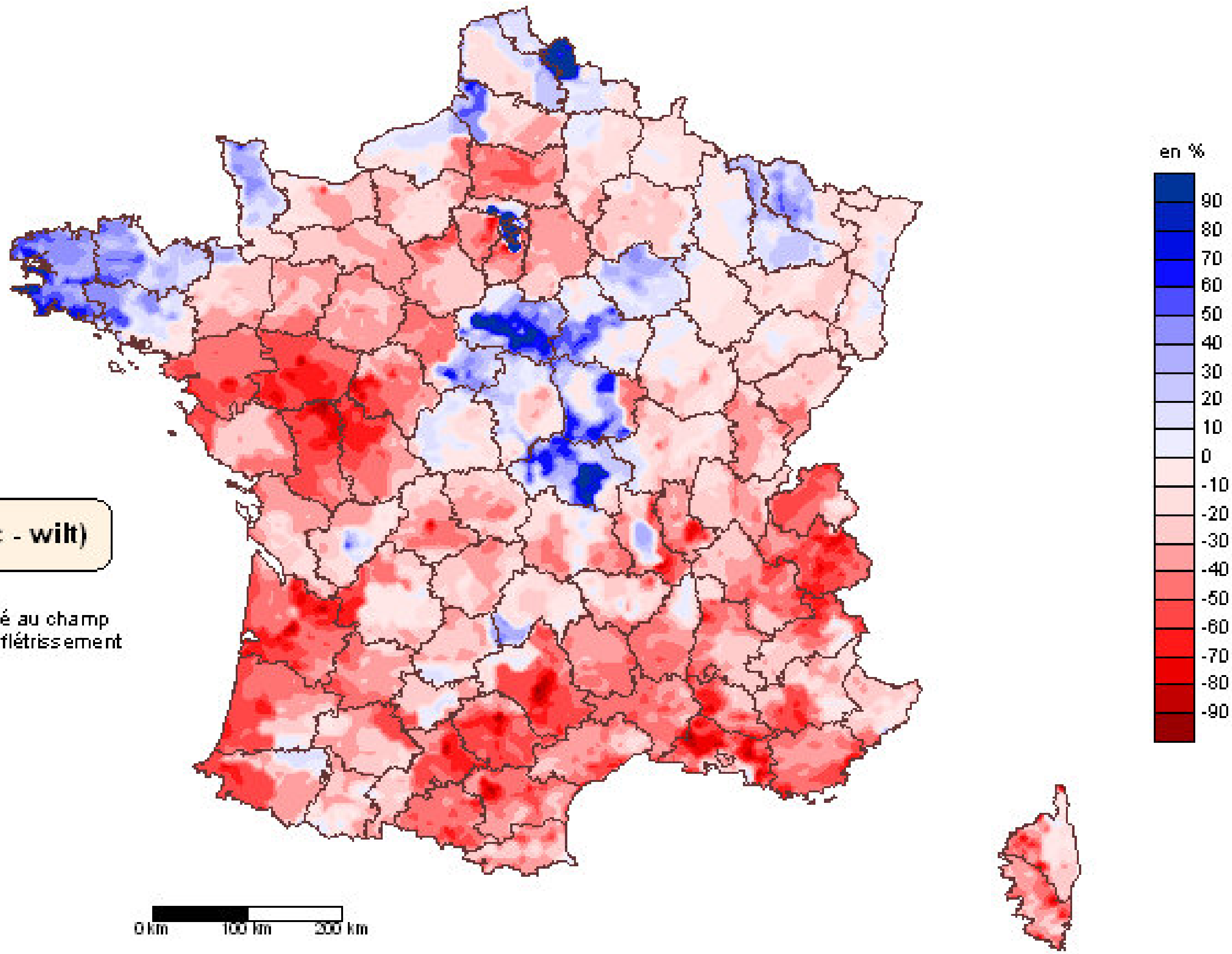


Off-line method (SIM exemple)

METEO FRANCE

fond de carte

Indice d'humidité des sols (SWI)
Ecart à la moyenne 1995-2003 pour le 01/08/2005



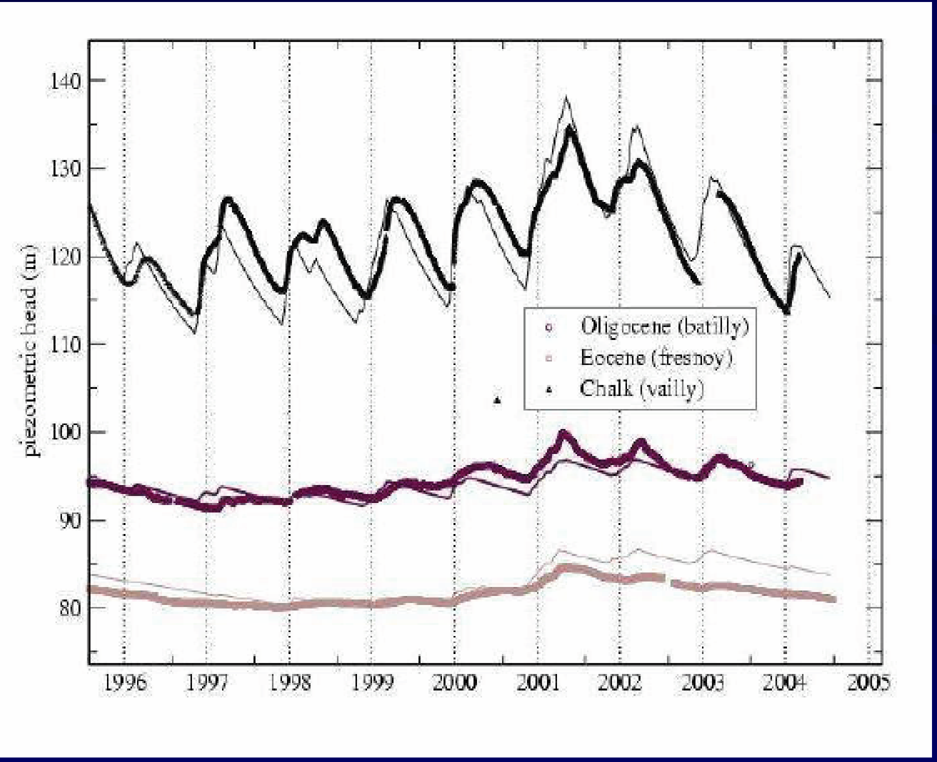
SWI = (w - wilt) / (wfc - wilt)

w : contenu en eau du sol
wfc : contenu en eau à la capacité au champ
wilt : contenu en eau au point de flétrissement
(m3 d'eau par m3 de sol)

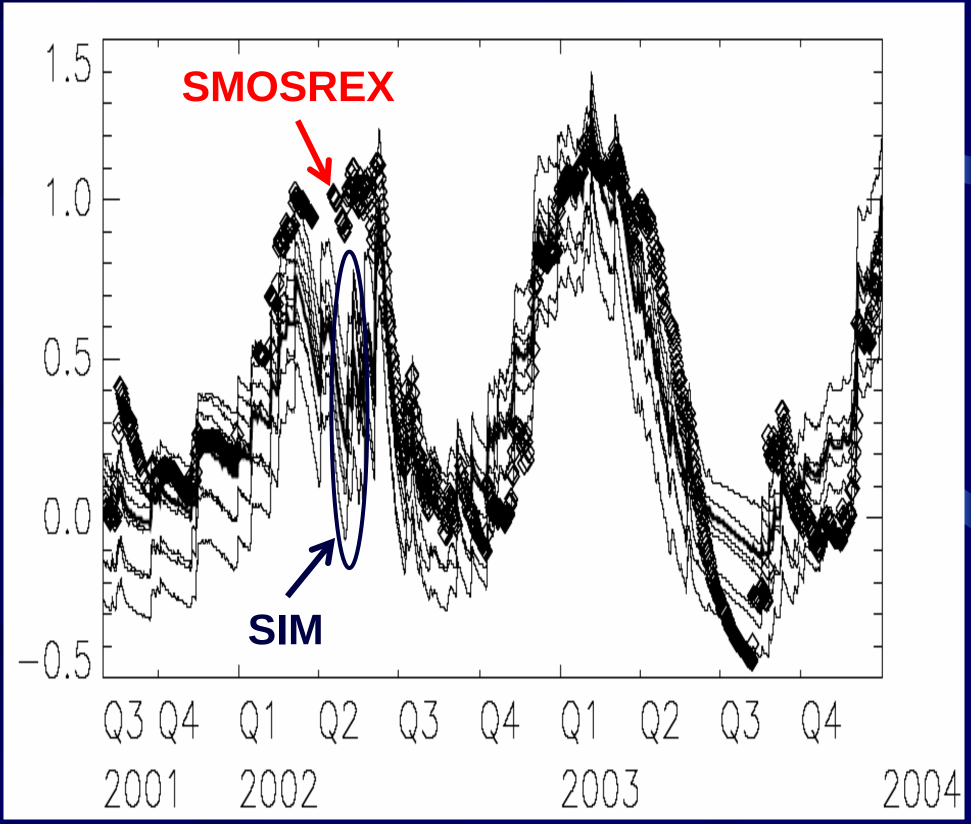
Off-line method (SIM exemple)

- Validation: river flow & snow depth & measurement site

water table (Seine)



Soil Wetness Index(SMOSREX)



Off-line method (pros & cons)

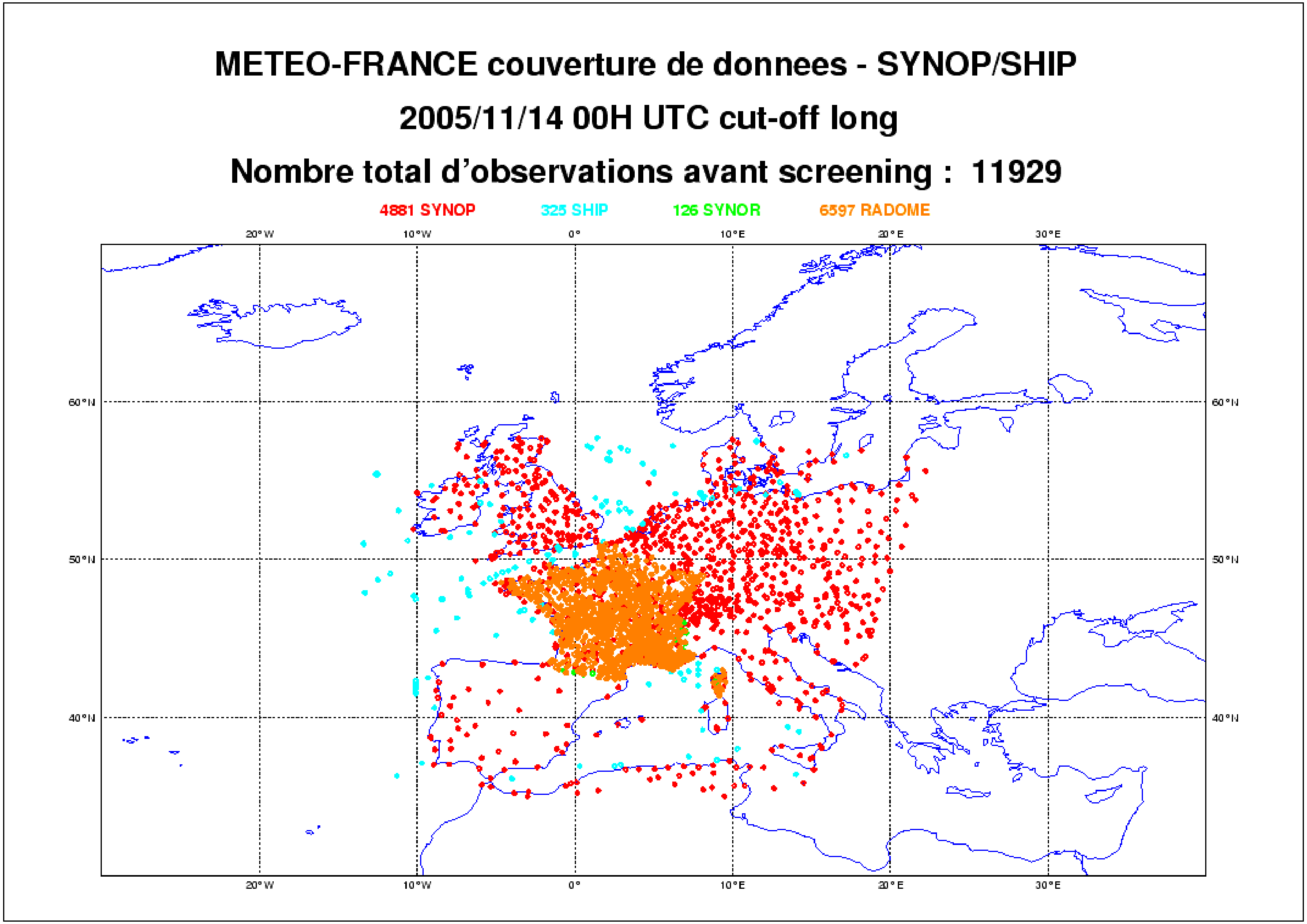
❑ Strengths:

+ with good precipitation, radiation and atmospheric forcings provides realistic soil moisture evolution even at high temporal evolution (useful for NWP, but also agriculture, water managment, ...)
+ cheap model (just the surface), work on PC, allows multi-years reanalysis
+ allows the use of complex surface model
+ high spatial resolution (RR analysis, MSG radiation fluxes)

❑ Limitations:

+ no analysis & perfect model hypothesis while surface processes are complex and physiographic database not perfect: model bias may exist on soil moisture and soil temperature and remain for a long period
+ restricted to some geographical areas (good obs coverage)

Assimilation of 2m observations



Optimum Interpolation method

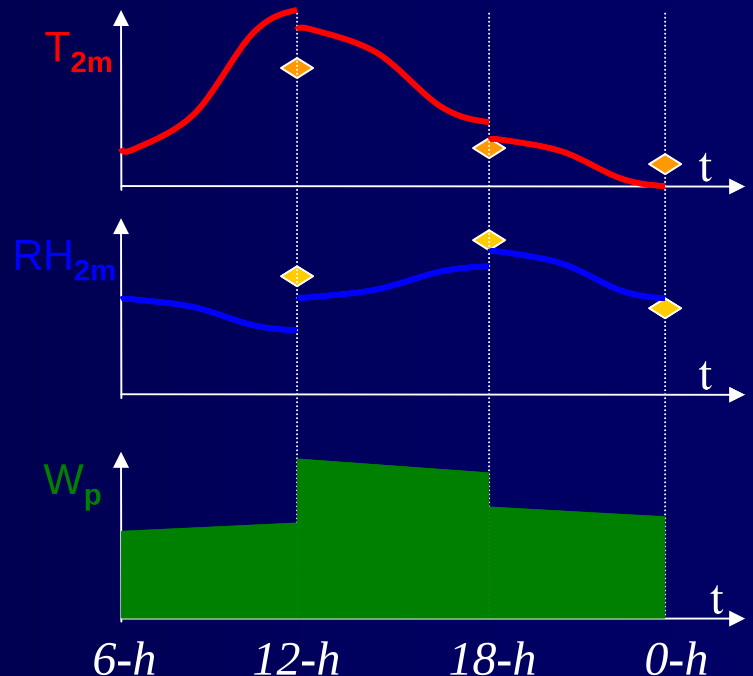
Coiffier 1987, Mahfouf 1991, Bouttier 1993, Giard and Bazile 2000

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

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

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)



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

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

$$T_p^{a} - T_p^{b} = \Delta T_{2m} / 2\pi$$

$$W_s^{a} - W_s^{b} = \alpha_{WsT} \Delta T_{2m} + \alpha_{WsRH} \Delta RH_{2m}$$

$$W_p^{a} - W_p^{b} = \alpha_{WpT} \Delta T_{2m} + \alpha_{WpRH} \Delta RH_{2m}$$

OI coefficients

Optimum Interpolation coefficients

$$\alpha_{Ws/pT} = \frac{\sigma^{b}_{Ws/p}}{\Phi\sigma^{b}_{T2m}} \left\{ \left[1 + \left(\frac{\sigma^{a}_{RH2m}}{\sigma^{b}_{RH2m}} \right)^{2} \right] \rho_{T2m,Ws/p} - \rho_{T2m,RH2m}\rho_{RH2m,Ws/p} \right\}$$

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

$$\Phi = \left[1 + \left(\frac{\sigma^{a}_{T2m}}{\sigma^{b}_{T2m}} \right)^{2} \right] \left[1 + \left(\frac{\sigma^{a}_{RH2m}}{\sigma^{b}_{RH2m}} \right)^{2} \right] - \rho^{2}_{T2m,RH2m}$$

Very strong dependency of these backgroung 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

$$\boxed{\alpha_{Wp/sT/RH} = f\,(t,\ veg,\ LAI/Rs_{min},\ texture,\ atmospheric\ conditions)}$$

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

Soil moisture analysis

$$\alpha_s^{T/H} = \frac{\delta\omega}{\delta\omega_r} \cdot B(C1) \cdot (1 - veg) \cdot \left[a_0^{T/H}(t^*) + a_1^{T/H}(t^*) \cdot veg + a_2^{T/H}(t^*) \cdot veg^2\right]$$

$$\alpha_p^{T/H} = \frac{\delta\omega}{\delta\omega_r} \cdot B(C1) \cdot \Big\{(1 - veg) \cdot \left[b_0^{T/H}(t^*) + b_1^{T/H}(t^*) \cdot veg + b_2^{T/H}(t^*) \cdot veg^2\right]$$

$$+ veg \cdot \frac{LAI}{R_{s\,\min}} \cdot \left[c_0^{T/H}(t^*) + c_1^{T/H}(t^*) \cdot veg\right]\Big\}$$

$\delta\omega_r$ is a reference value for $\delta\omega$, corresponding to loam. The local solar time t^*, expressed in hours, is a straightforward integer function of declination and absolute solar time (i.e., of date, latitude, and longitude). It is scaled according to the length of daylight, so that it is equal to 6 at dawn, 12 at midday, 18 at twilight, and 24 at midnight whenever possible. Also, B represents a simple potential weighting by the mean cloudiness over the past 6 h: $B(\mathrm{Cl}) = 1 - B_1\mathrm{Cl}^{B_2}$, where B_1 and B_2 are tunable parameters.

a simple sinusoidal function of the local solar time with period 24 h has been adjusted to each polynomial term, using values from $t^* = 6$ to $t^* = 18$ for the fit:

$$x(t^*) = x_s \sin(2\pi t^*/24) + x_c \cos(2\pi t^*/24) + x_m$$

$$(\text{where } x = a_n^{T/H},\ b_n^{T/H},\ \text{or } c_n^{T/H}). \qquad (22)$$

From Giard and Bazile 2000

Soil moisture analysis

- March 98:
  - Operational implementation with ISBA (Giard and Bazile, 2001)

- Characteristics:
  - OI coefficients according Bouttier et al. (1993)
  - Reduction of OI coefficients under specific meteorological conditions (see below)
  - Analysis is not allowed to make Wp/Ws jump outside the range :

    Veg.Wwilt < Wp < Wfc and 0 < Ws < Wfc (LIMVEG=T and LHUMID=T)
  - Temporal smoothing of total soil moisture increments (LISSEW=T)

    $\Delta Wp = 0.25* \{ \Delta Wp(HH) + \Delta Wp(HH\text{-}6) + \Delta Wp(HH\text{-}12) + \Delta Wp(HH\text{-}18) \}$
  - Removing bias on $\Delta T2m$ analysis increments

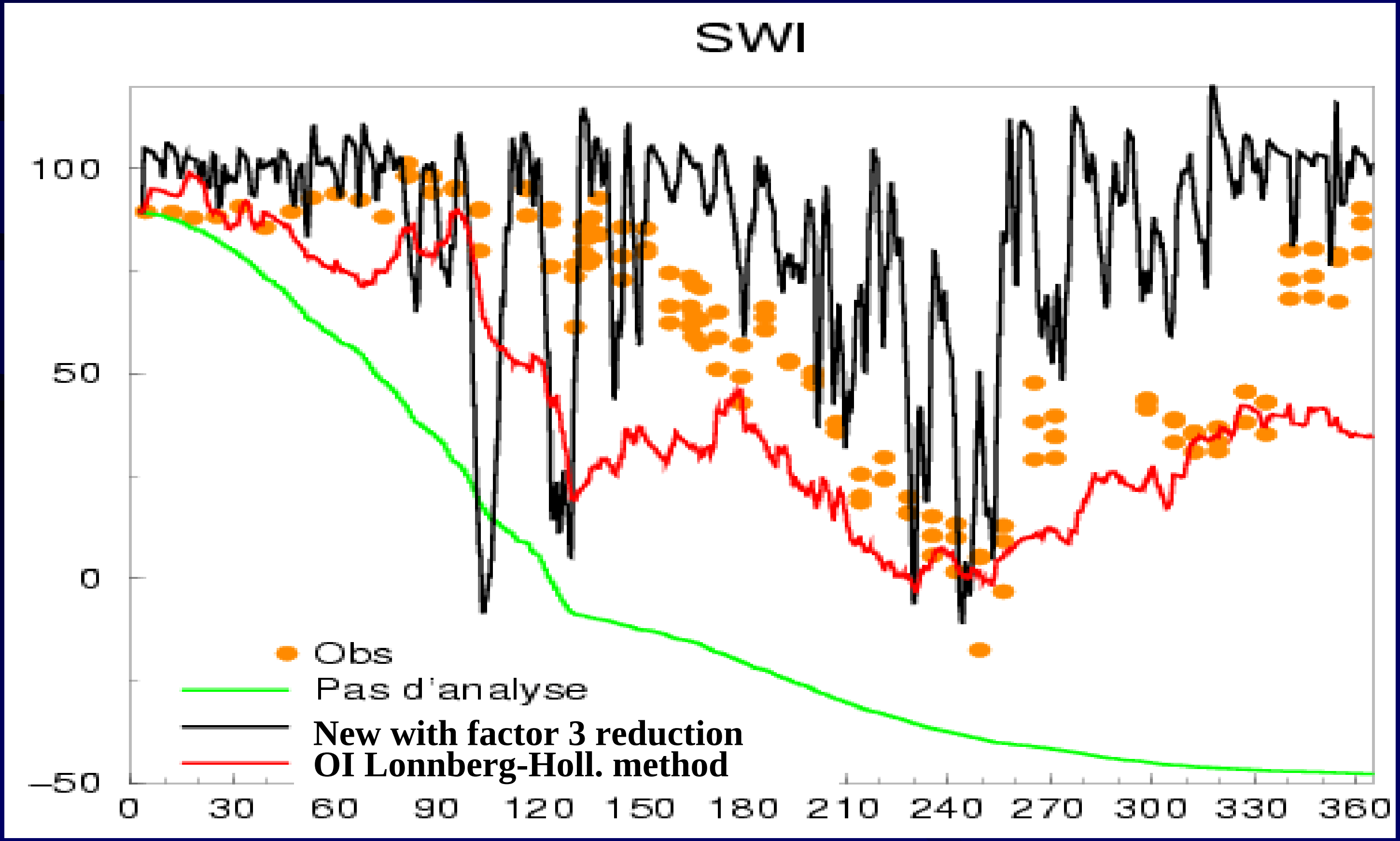
    $\Delta T2m^* = (1\text{-}SCOEFT).\Delta T2m^* + SCOEFT.\Delta T2m$ with SCOEFT=0.5

    $\Delta T2m = \Delta T2m - \Delta T2m^*$
  - Relaxation towards a climatology for Tp, Wp, Sn

Model Fields		Threshold
Min solar time duration	J_min	6 h
Max wind velocity	Vmax	10 ms^{-1}
Max precipitation	P_max	0.3 mm
Min surface evaporation	E_min	0.001 mm
Max soil ice	W_imax	5.0 mm
Presence of snow	Sn_max	0.001 kg/m2

Soil moisture analysis

- October 99:
  - Factor 3 reduction of OI coefficients on Wp because the initial OI coeff have been computed with an NMC method using initial Wp values ranging uniformly between $0 < SWI < 1$ but without any rescaling of $\sigma_{Wp} \sim 0.25.(Wp_{fc} - Wp_{wilt})$
  - Continuous formulations for OI coefficients
  - Cloudiness is taken into account in OI coefficients



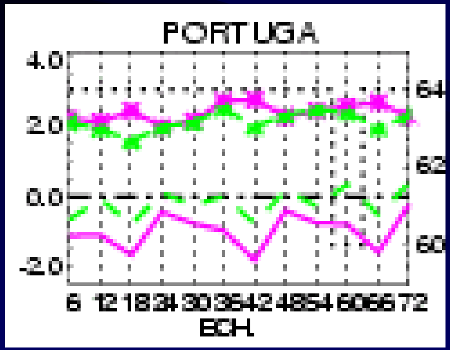
Soil moisture analysis

- May 03:
  - 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 smooting of Wp analysis increments
  - No bias correction on T2m analysis increments

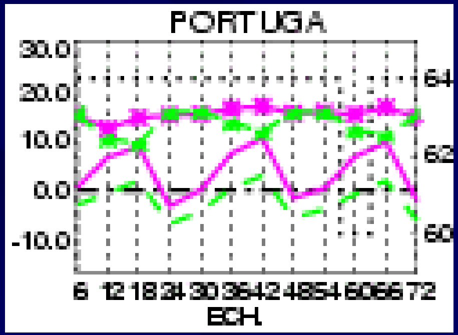
⇒ Improvments of SYNOP scores on T2m and H2m in summer

⇒ More realistic soil moisture

T2m

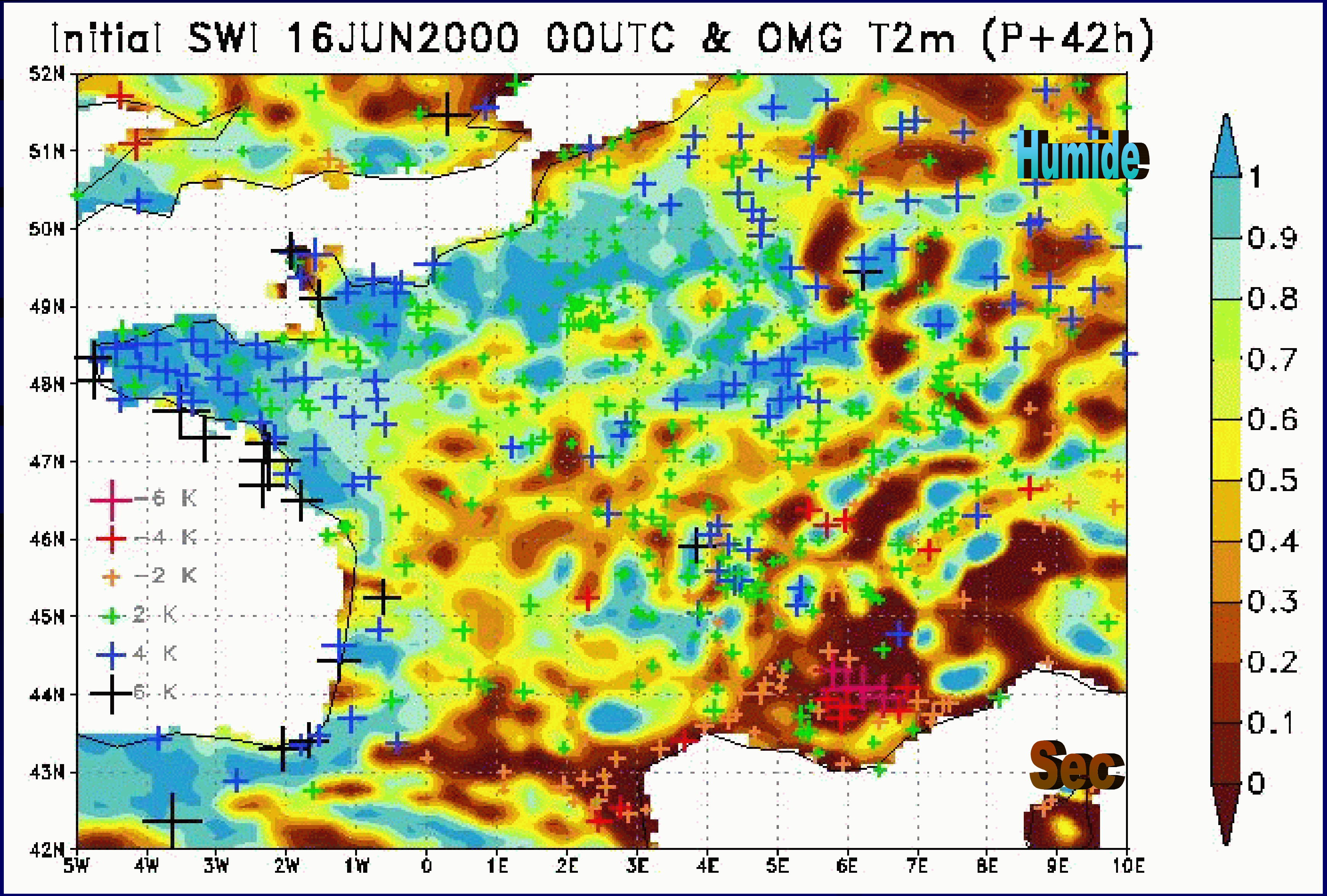


H2m



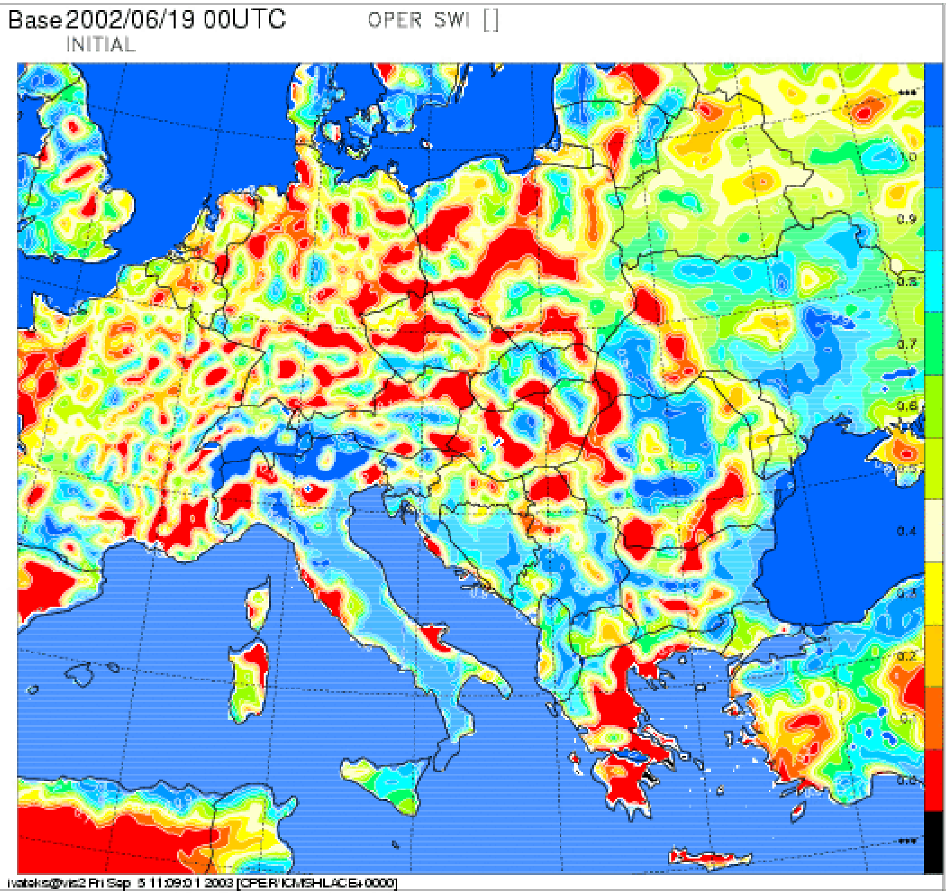
OPER / NEW

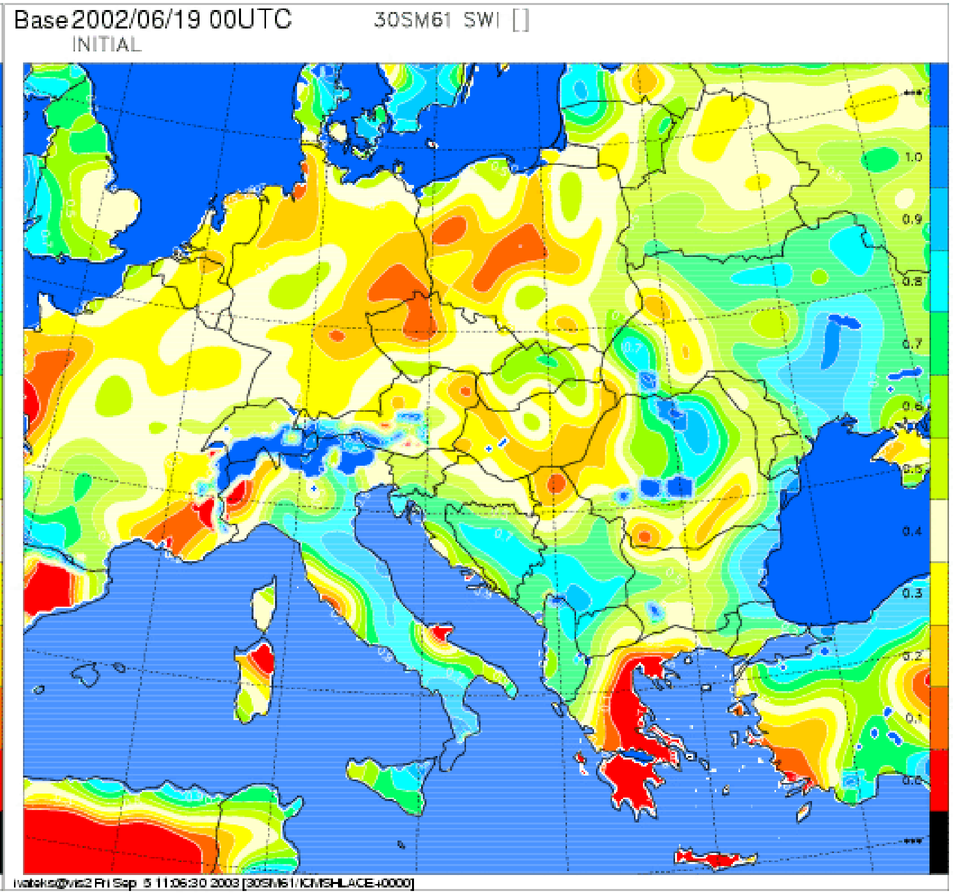
Illustration of problem with first implementation: 42h ALADIN forecast for 17th June 2000 at 18h UTC



Smoothing of Soil Wetness Index (SWI) - II

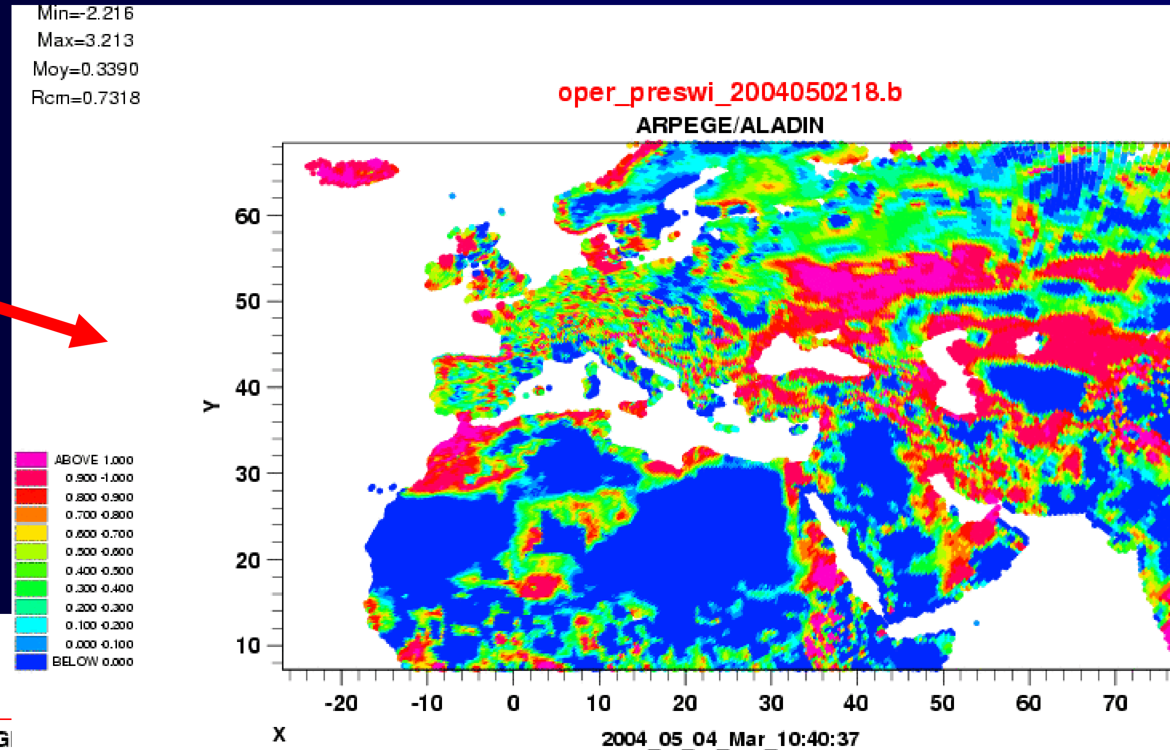
SWI for 19th June 2002 00 UTC - summer example

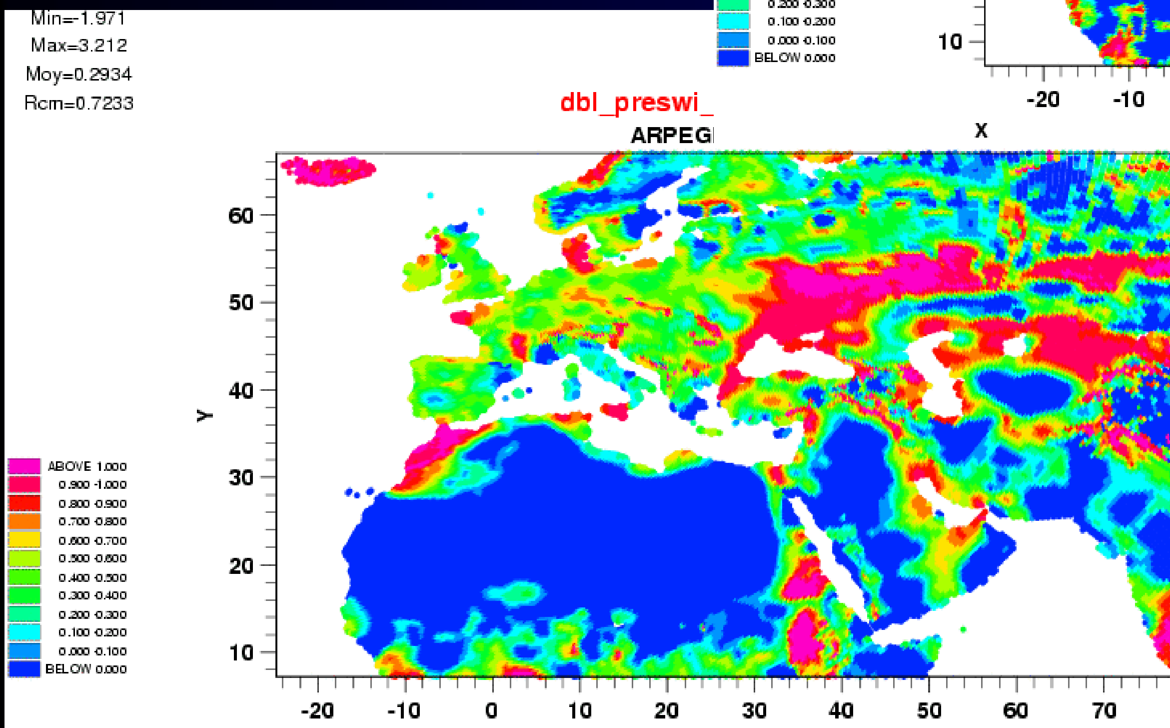




Soil wetness index (SWI) pour le 2 mai 2004

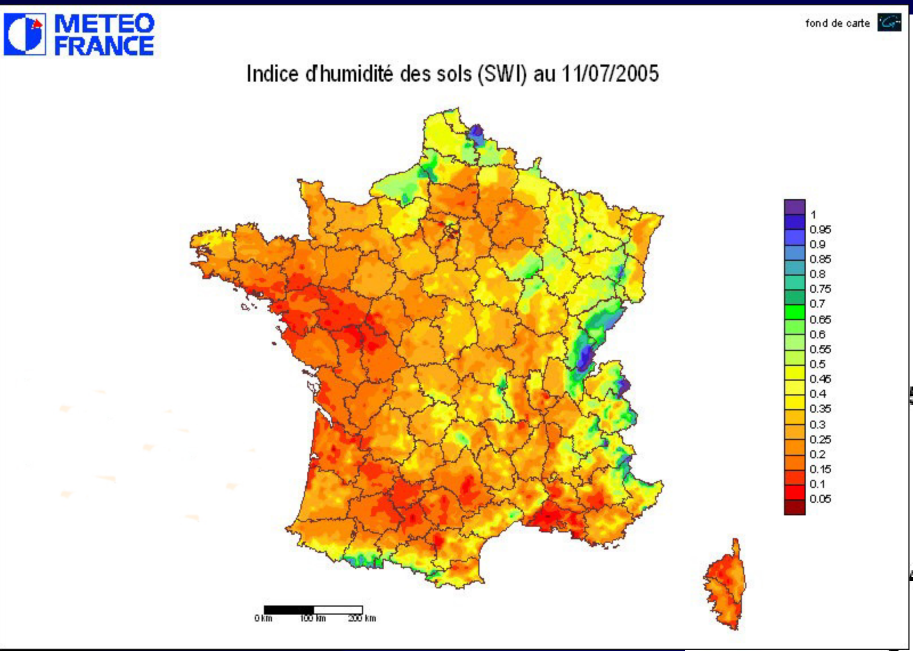
OPER

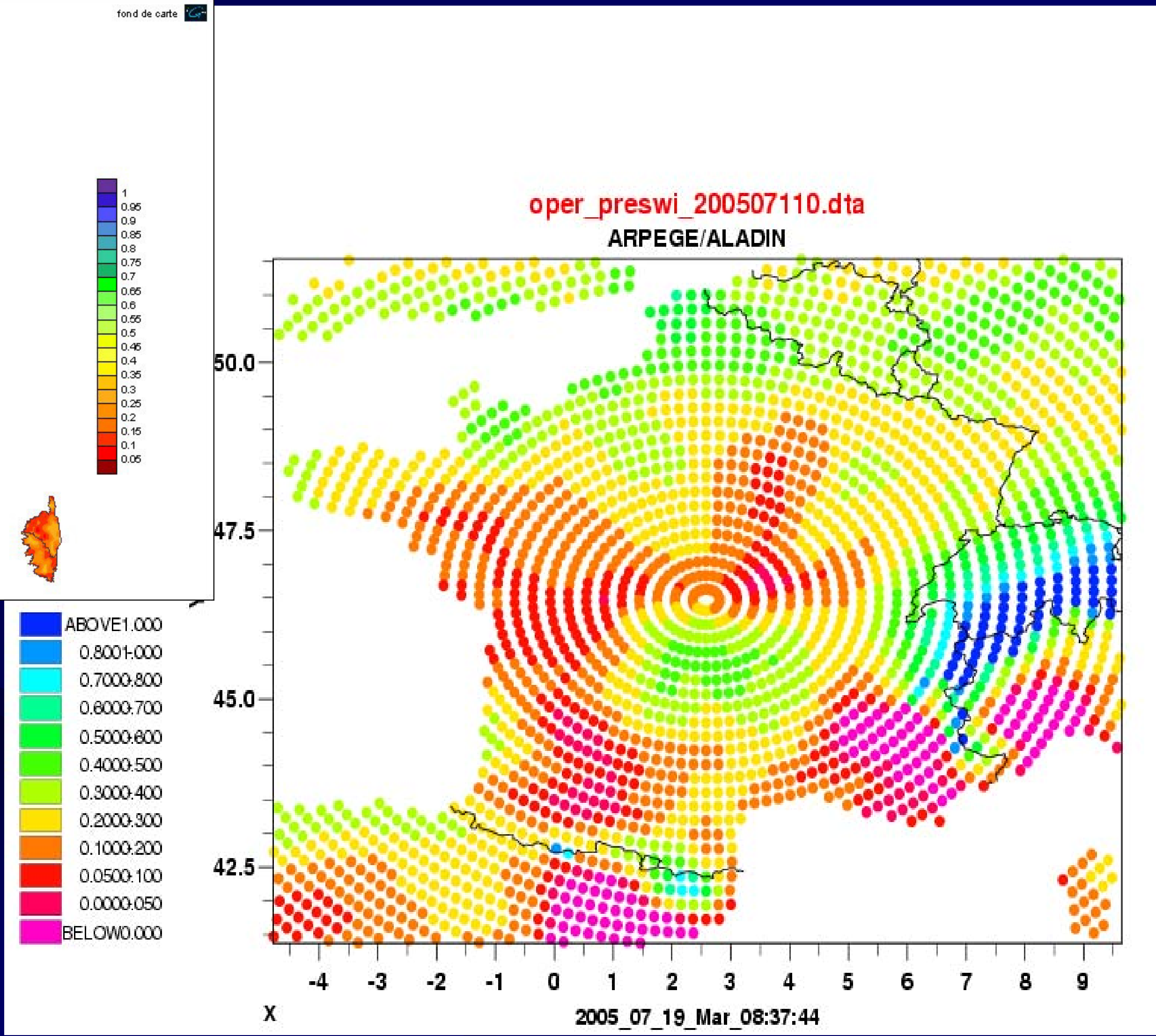




NEW

Soil Wetness Index in SIM (left) et in ARPEGE (right) 11 July 2005

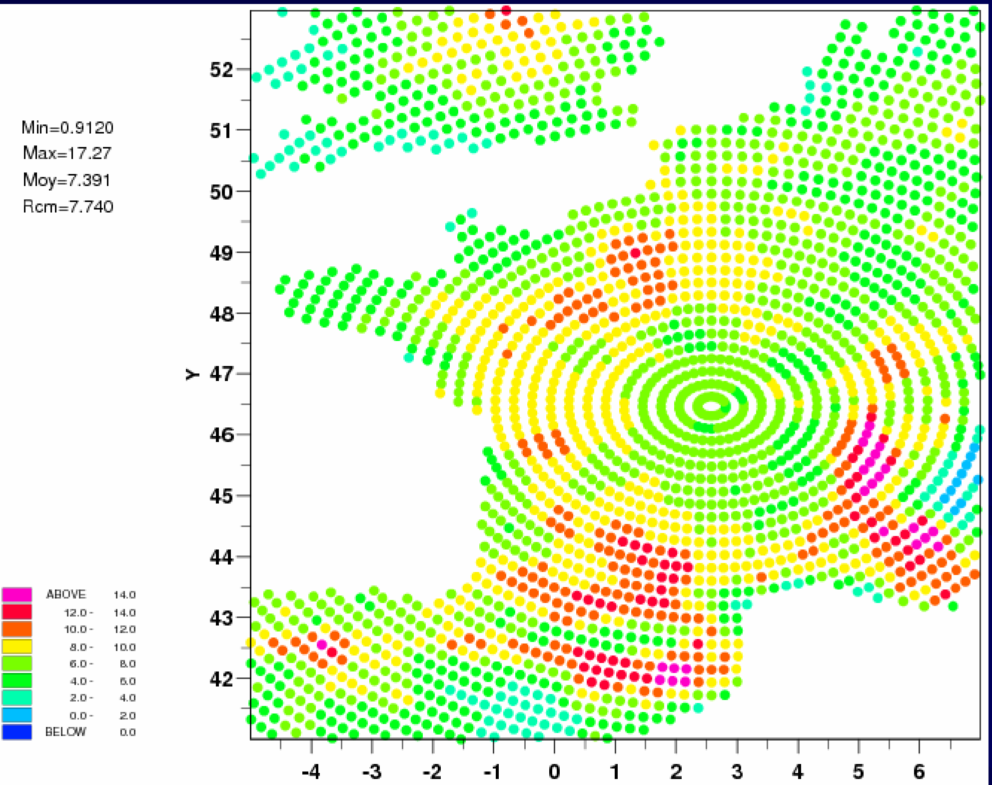




Analysis increments (May-June 2006)

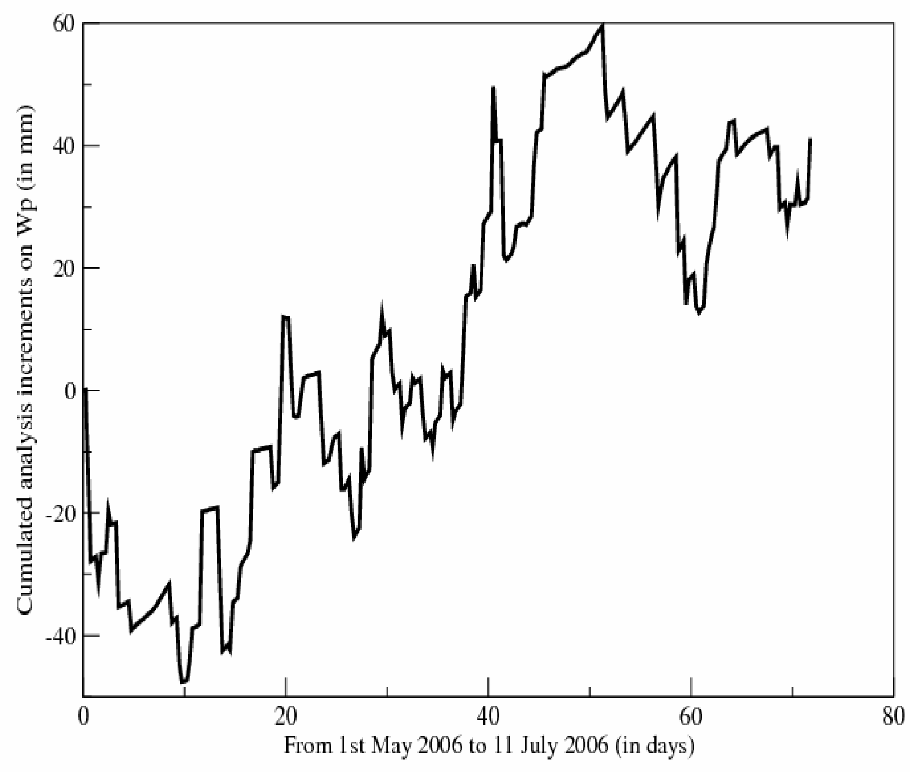
Daily mean of absolute analysis increments

|ΔT2m|



Cumulated analysis increments on Wp

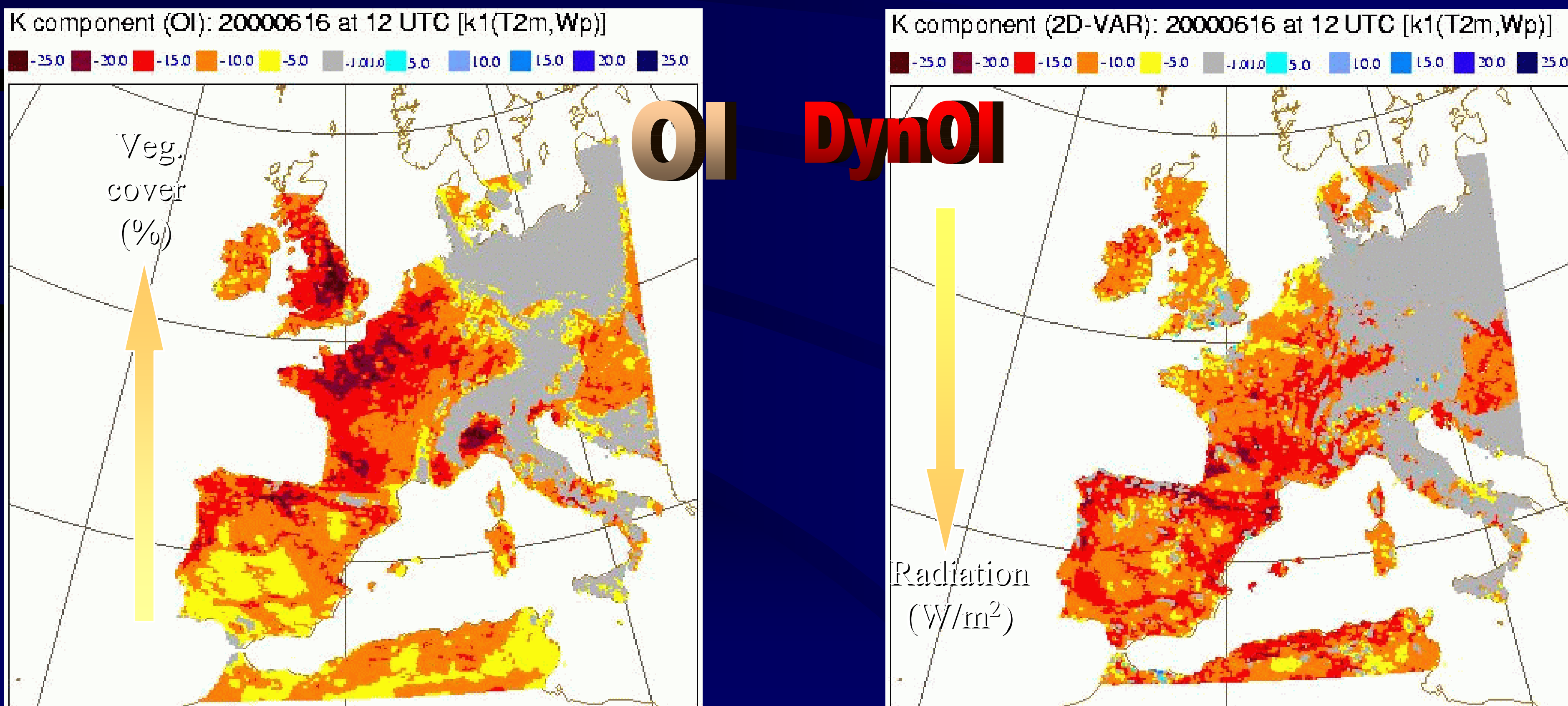
(in mm)



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



Optimal interpolation with 2m obs (pros & cons)

❑ Strengths:

+ suitable in most area in the world, quite cheap analysis
+ work for soil moiture and soil temperature
+ take into account model errors (surface model, physiographic database) to provide suitable soil moisture for fitting 2m observations (if no model error sensible and latent heat fluxes are correct).

❑ Limitations:

+ OI coefficients are climatological ones (empirical adjustment to climatological conditions, should be recomputed when model changes) $\Rightarrow$ dynamical OI or variational method
+ Instantaneous analysis (no assimilation of asynoptic observations)
+ Not suitable to analyse fast superficial soil moisture evolution $\Rightarrow$ use of precipitation observations (raingauges, radars)

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

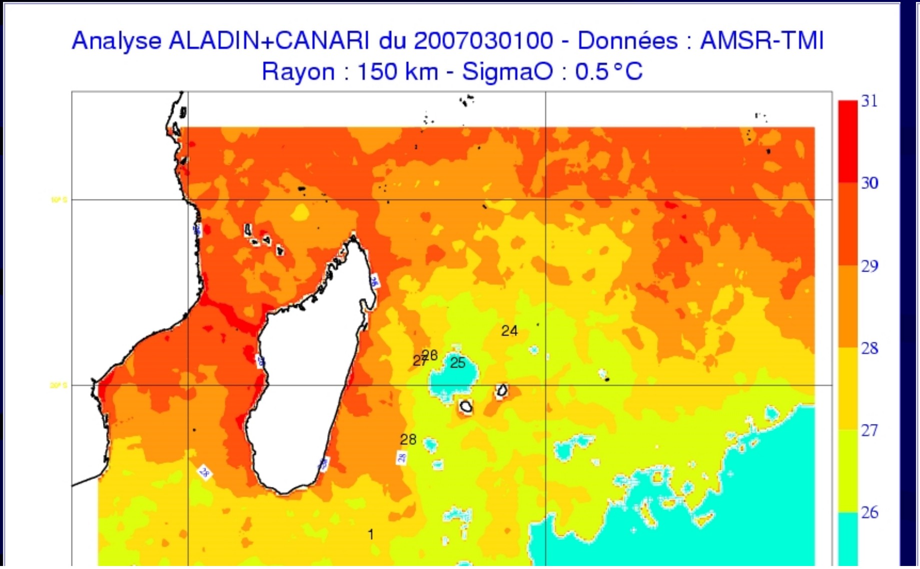
Research study to use either IFS or NESDIS snow cover analysis

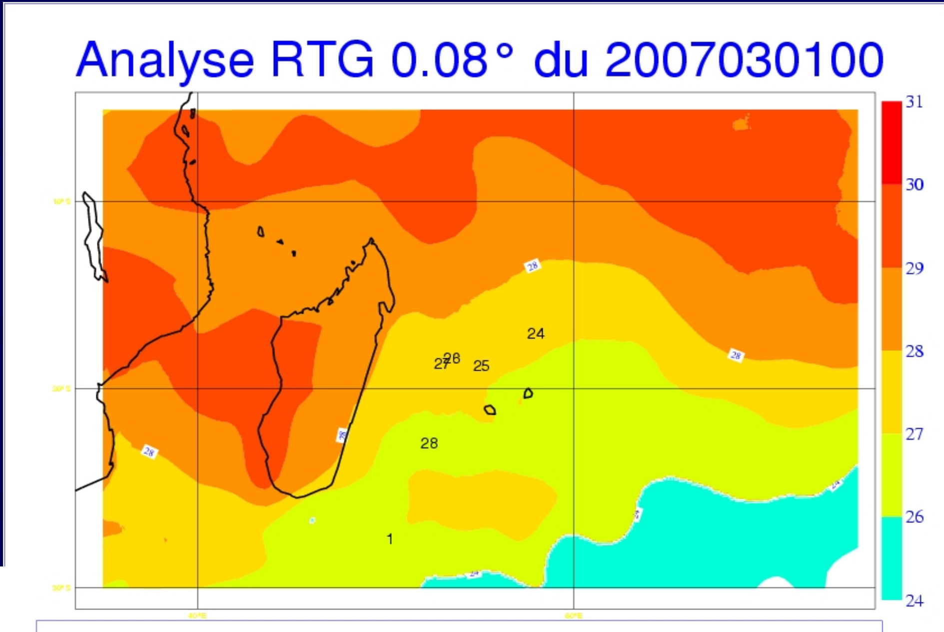
Snow melting in case of warm T2m observations

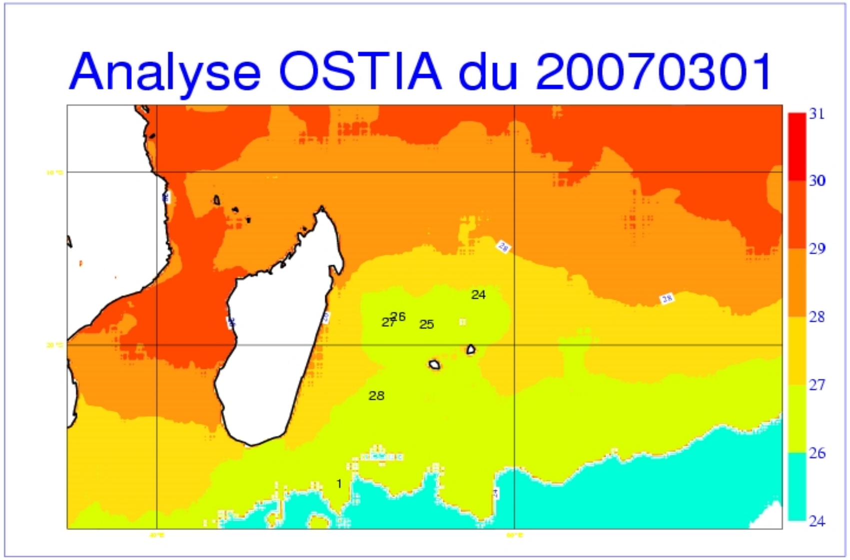
Frozen soil correction

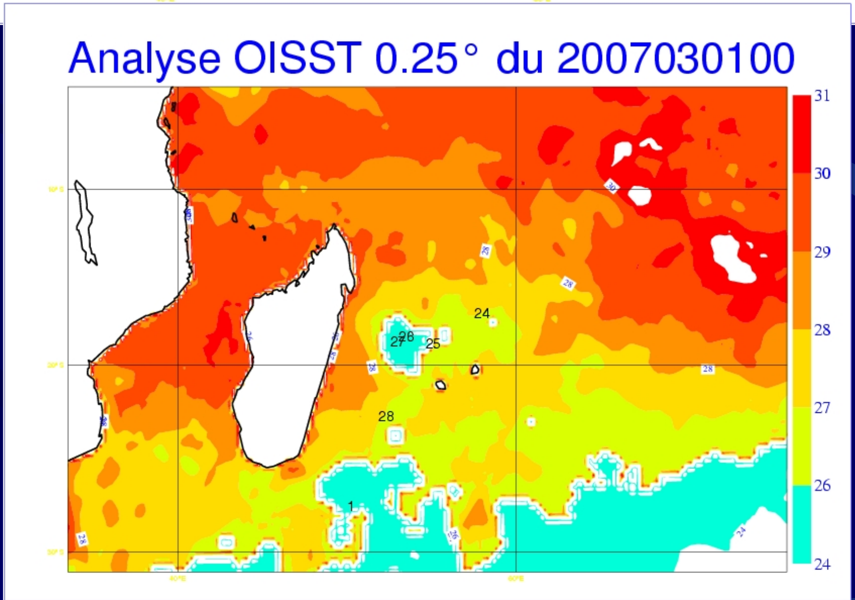
Melting of frozen soil in case of warm T2m observations

Assimilation of SST obs at higher resolution in CANARI

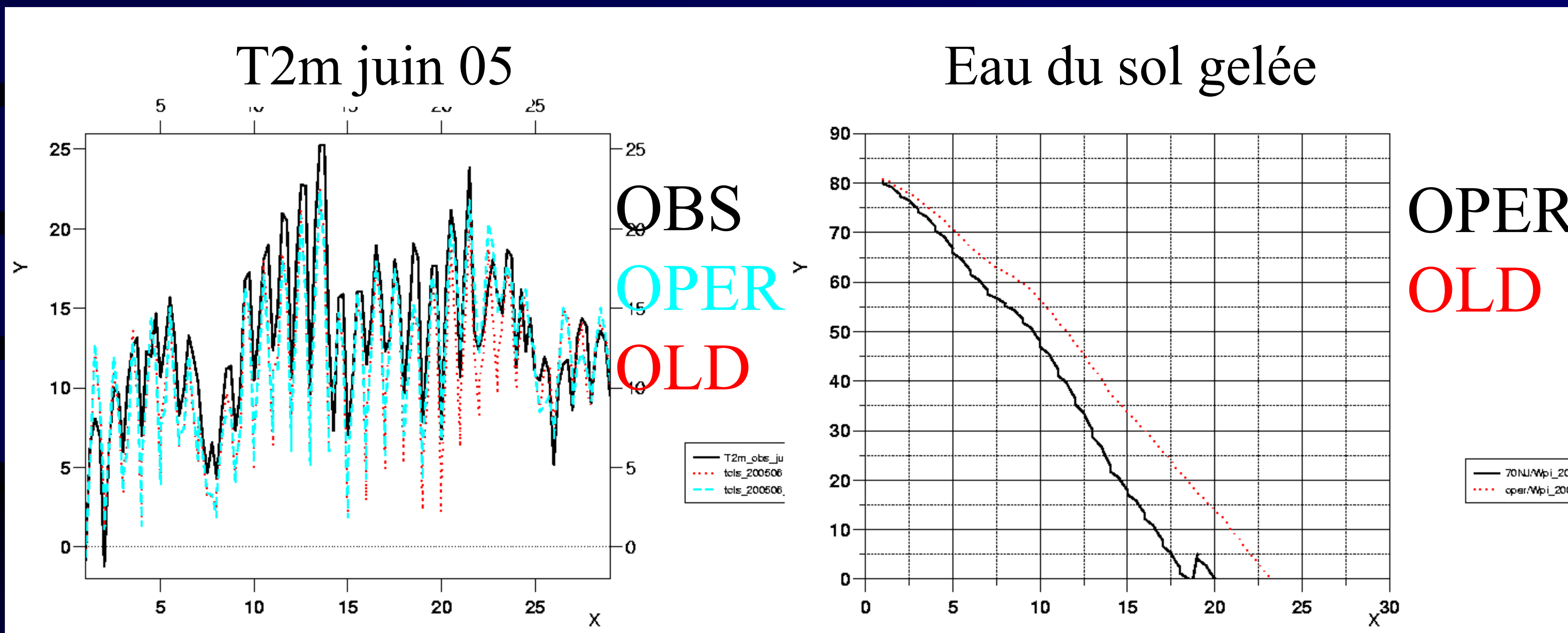






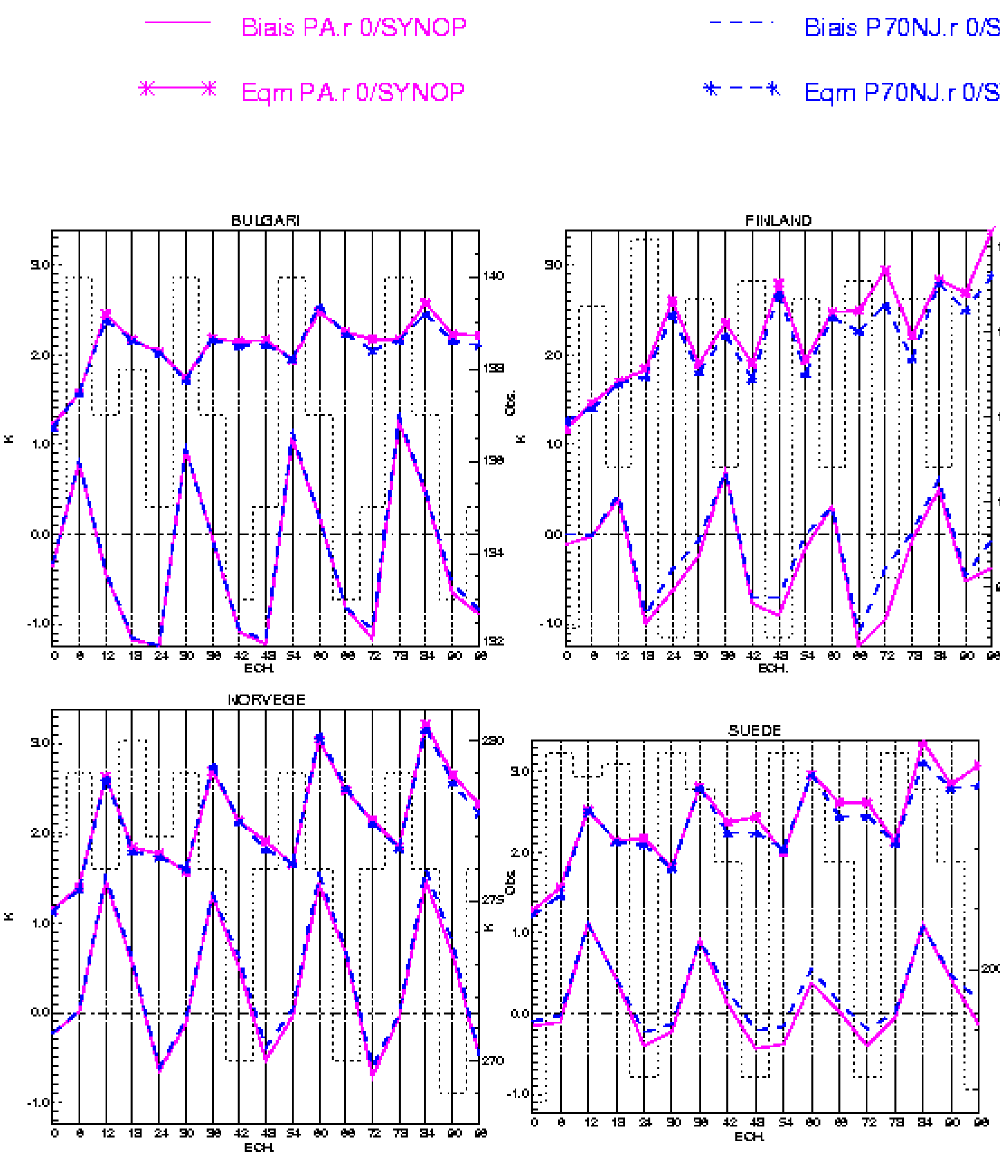


1D simulation over Sodankyla (Finland)



TEMPERATURE CORR.

28 cas, 01/06/2005_00UTC -> 02/07/2005_00UTC



Perspectives

- Surface analyses implementation in ALADIN (done at CHMI) and under development for AROME
- Soil moisture / Soil temperture:

  - Assimilation of satelite obs (ASCAT, SMOS, SEVIRI, ...)

  - How to use analysed atmospheric forcings (radiation, precip)

  - New algorithms (2D-Var, Dyn-OI, ...)

  - Better consistency with upperair analysis
- SST analysis at higher spatial and temporal resolution, Sea Ice Cover analysis, Develop a lake temperature analysis
- Need a snow cover analysis (HIRLAM, NESDIS, SAF-Land, ...)
- Development of analyses for LAI, VEG, albedo, ...