Current issues in atmospheric data assimilation and its relationship with surfaces

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1. Current atmospheric DA systems
2. Coupling surface/atmospheric DA
3. Trends & ideas

Current atmospheric Data Assimilation systems

Numerical Weather prediction: roughly half of past 20 years improvements are due to advances in data assimilation:

- data assimilation techniques: rise of the variational and Kalman filtering algorithms
- better data processing & quality control
- adaptation to new, valuable weather observations (mostly, radiances): asynoptic, with nonlinear link to model state
- (required enhanced prediction models & computing power)

The most spectacular global forecast performance gains are probably due to AMSU-A in the late 90s. Lower tropospheric radiances are still underused.

Regional NWP systems are sensitive to low-level analysis & surface properties.

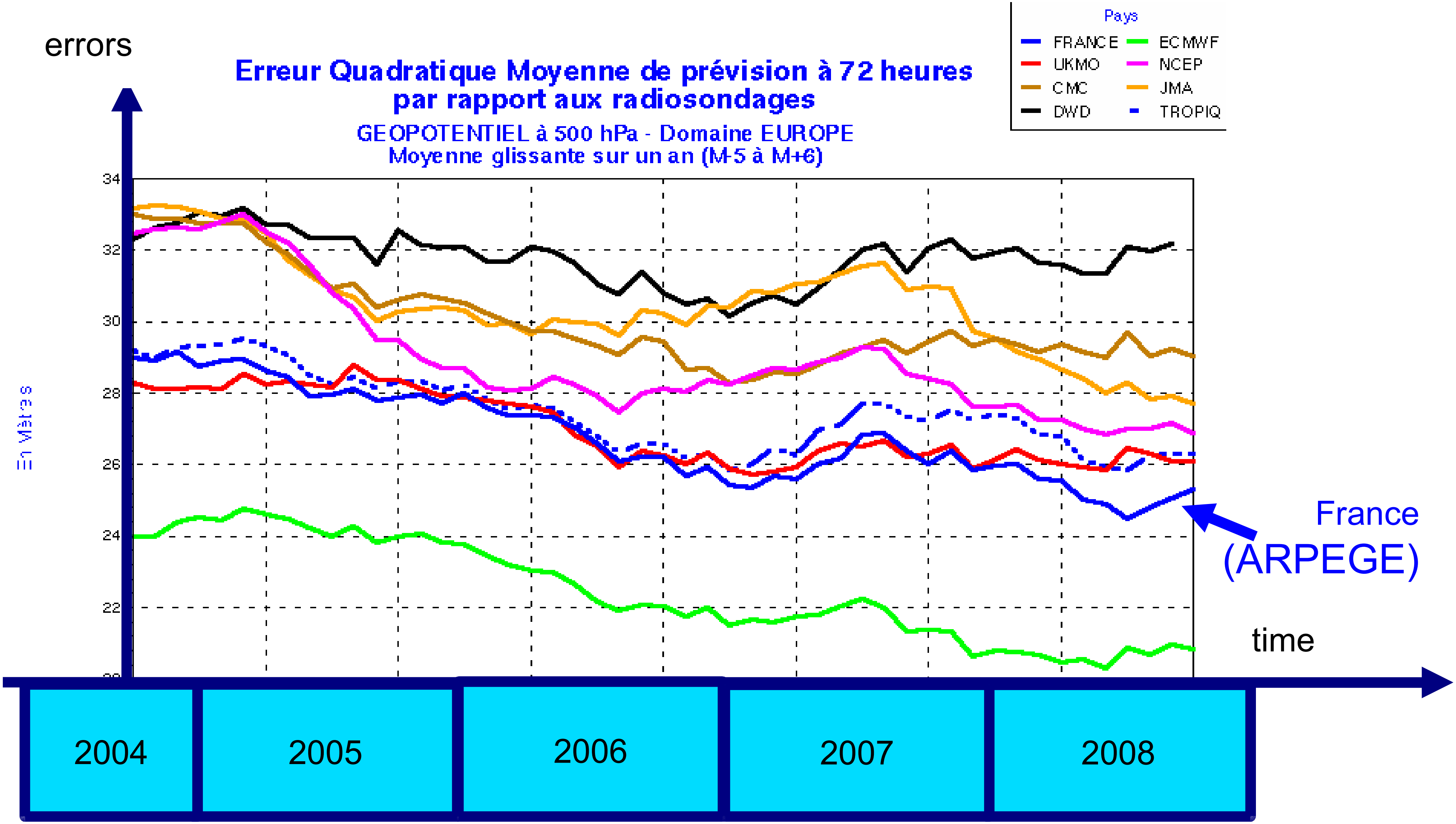
Spin-offs of NWP DA:

reanalysis - countless applications, increasingly used for climate studies

data assimilation for atmospheric research

observing system experiments (=observation network planning)

Continuous improvement of atmospheric Data Assimilation Systems



3D/4DVar Data Assimilation systems

3D or 4D variational algorithms dominate the major NWP centres:

- computationally efficient for what they do
- handles **weak nonlinearities** well

which means "effective at correcting errors when the forward model is weakly nonlinear in the vicinity of the previous forecast"

- well suited for **satellite data assimilation** (radiances)

They are not so good for 'messy' problems:

- strong **nonlinearities** (cloudy radiances)
- threshold physics (condensation, precip triggering, rain/snow)
- advection vs discontinuities (surface, fronts, cloud edges)

4D-Var

- is excellent for large-scale dynamics & instabilities (storms),
- copes with arbitrary obs times
- is limited by model & linearization errors
- **numerical cost** limits spatial resolution & time-critical applications

KF-like Data Assimilation techniques

Ensemble Kalman Filtering techniques: (ETKF, EnsKF...)

- numerical cost similar to 4DVar
- good for nonlinearities
- limited by **statistical sampling issues** ("ensemble size")
  which leads to complex algorithmic choices and to unsolved questions

Their use in operational weather prediction is limited, but increasing.
Clearly a good approach for :

- **stochastic DA** (for probabilistic prediction systems)
- **strongly nonlinear problems** (to be confirmed in practical applications)
- no need to "code an adjoint" (if that scares you :-)
- massively parallel computers

Variational vs EnsKF, in practice:

- Both make questionable assumptions in the analysis solver
- Both have background covariance modelling issues (error restriction to arbitrary subspaces)
- Eventually, they probably merge into a single hybrid algorithm.

Atmospheric impact of assimilating land surface data (T2m/HU2m)

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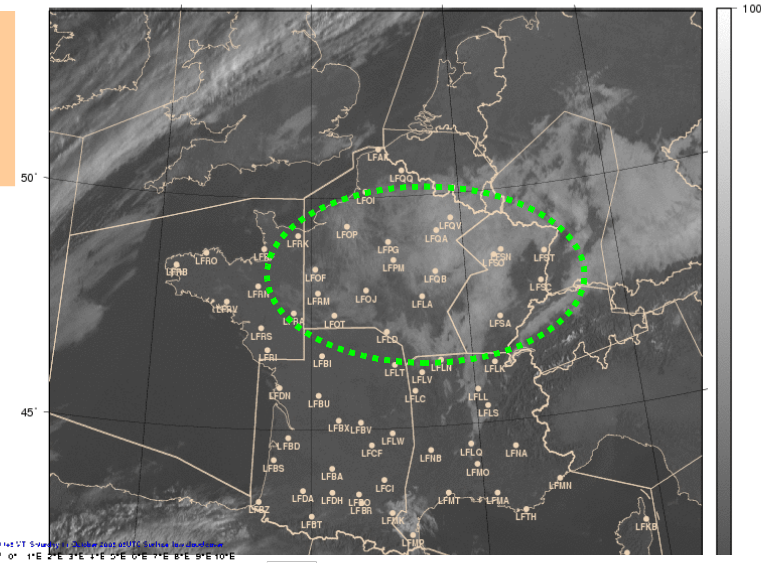
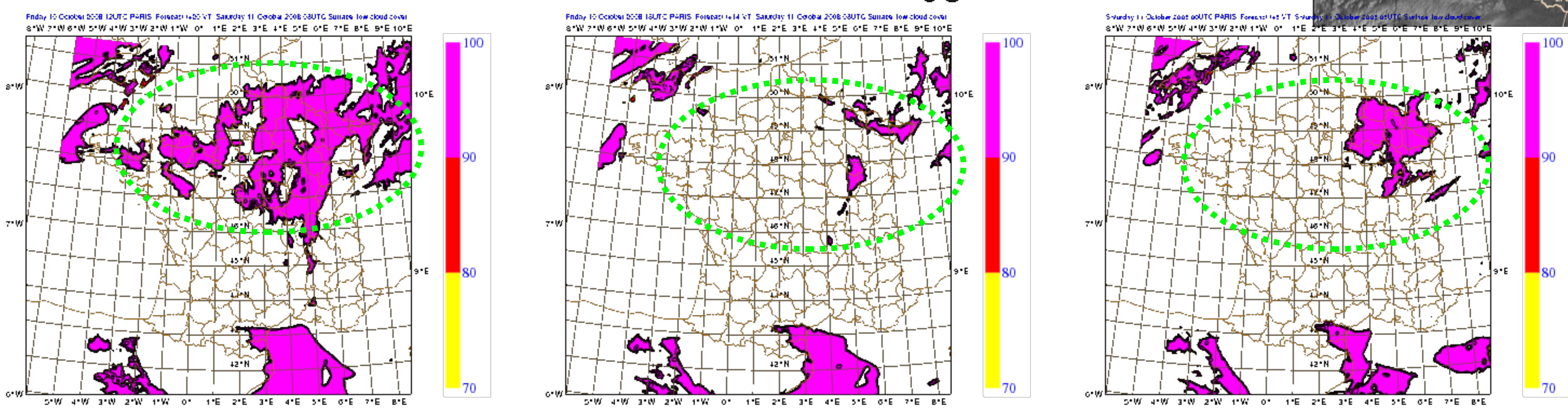


Low cloud successive forecasts by the mesoscale AROME model

all valid on 11 oct 08, 8hTU :

08



base 10 oct, 12h

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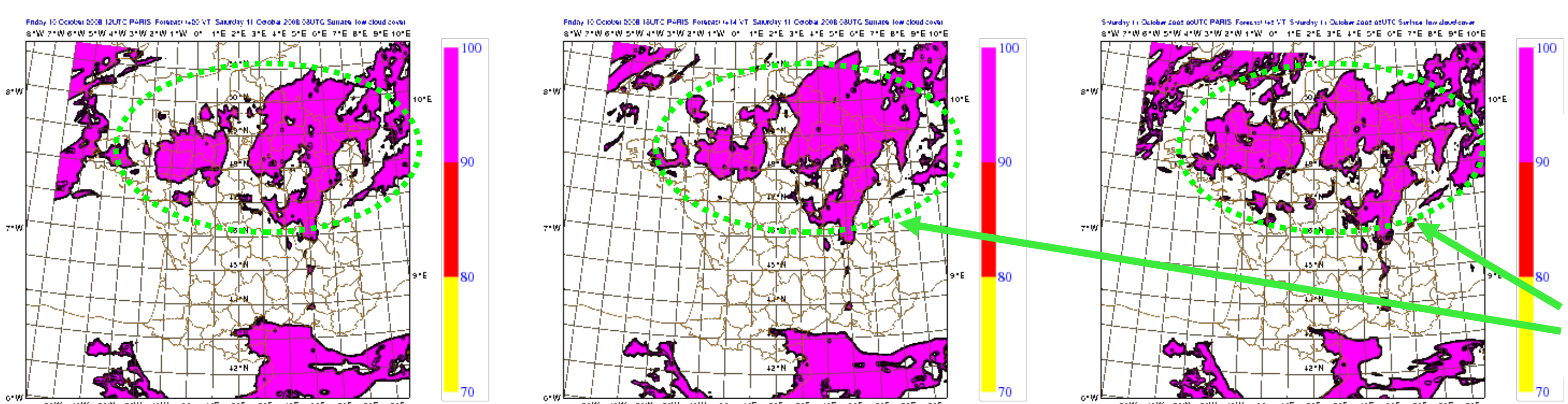
T2m HU2m not used in atmospheric 3DVar



atmospheric 3DVar assimilation of T2m HU2m

improved

The surface/atmosphere DA coupling problem

DA in the atmosphere:

- importance of the propagation of 3D waves
- horizontal homogeneity is a good starting hypothesis
- small-scales are usually forced by the larger scales
- error growth scales: a few hours, 100-200km (20km in convective-scale NWP)
- assimilation cycles of 3 to 12 hours

surface mostly is a *given boundary condition*:

(surf T, moisture, snow/ice cover → surface heat & moisture fluxes)

DA at/near the surface:

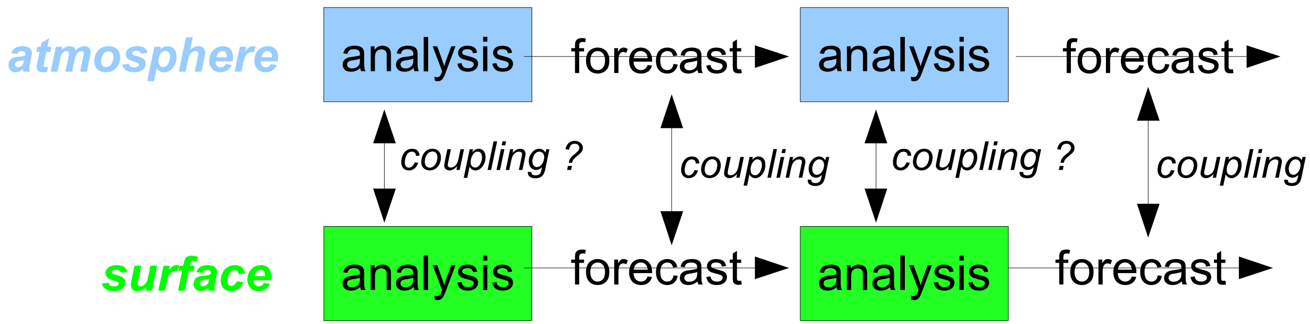
- horizontal propagation of surface properties is weak (if any)
- importance of small geographical features → inhomogeneous error structures
- importance of diurnal & seasonal cycles
- long memory of many processes (days to months)
- surface tends to accumulate fast atmospheric influences:

(radiation, precipitation, wind → soil, vegetation, ice cap, snow cover etc)

Difficulties:

- Obs relevant to surfaces may be very different from atmospheric ones
- 'Surface parameters' eg. Ts tend to be **memoryless**: they convey little information.

Surface/atmosphere assimilation coupling strategies



In forecast models:

- interactive coupling is a must (for PBL structuring) which implies exchange of information during data assimilation cycles
- the optimal extent of surface/atmosphere model coupling is a research topic (sea surface waves, ice, vegetation, snow properties, lakes, etc)

Existing DA coupling techniques:

- (initialize surface properties from climatology)

Update surface properties from offline analysis:

- satellite-derived products,
- **physical surface model forced by observations** (e.g. soil model with analyzed precip)
- physical surface model with own DA system

Compute surface properties as an 'atmospheric error sink':

- sequential (OI or KF) surface correction as a **function of low-level (T2m, HU2m) forecast errors**
- same idea with a variational algorithm (2D-Var = 1 column with time dimension)
- put surface properties (RTTOV Ts, ε...) at obs points into the control variable of atmospheric 3D/4DVar

Current trends in the NWP community

Ever-increasing horizontal resolution of **global models** & assimilated satellite data:

- Priority on reducing atmospheric analysis errors in cloudy/rainy areas (e.g. storm precursors)
- 'obs deserts': non-industrialised land, ice caps
- low levels (<5000m)

Growing priority on **convective scale meteorology**: emphasis on

- humidity data
- low levels (the PBL)
- detailed & reliable surface properties at sub-km resolution

The NWP field is expanding to **new user-required surface parameters** (road icing, aerosol fluxes, soil runoff for hydrology...)

Mesoscale ensemble prediction still a new field, a correct **modeling of the surface PDFs** (=uncertainty) will become an important topic.

A few ideas

Surface models with own DA may be unbeatable where there is good obs coverage:
the optimal way to couple surface/atmosphere DA coupling may depend on the location.

The 'atmospheric error sink' systems can be extended to use direct surface obs (for blending with atmospheric error information). *(see JF Mahfouf's talk)*

The relationship between observed **pixel properties & model gridbox variables** is complex and requires specific attention (cf the GRHSST work on defining the 'sea surface temperature' semantics)

Need to improve models of **surface-atmosphere error cross-covariances**:
- vertical correlations in PBL
- surface perturbations in EKF ensembles & background error statistics
- How can one model error covariances between different horizontal grids in surface and atmospheric models ?