Recent research on AROME-France data assimilation

22nd ALADIN workshop / HIRLAM All-Staff Meeting
Marrakech, 7 may 2012

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METEO FRANCE
Toujours un temps d'avance

Outlines

- Diagnosis of the impact of observations on AROME-France analysis

- increase of the assimilation cycle frequency

Observation impact

- Usually estimated with :
  - Observing System Experiments (OSE).
  - Diagnosis : Degrees of Freedom for Signal (Chapnik et al. 2004, Fourrié et al. 2005), the observation sensitity (Doerenbecher et al. 2001), the reduction of the estimation error variance (Desroziers et al. 2005a).

- The linear estimation theory is based on the minimization of the variance of the estimation error.
  - The BLUE is : $$x^a = x^b + K\left(y^o - H\left(x^b\right)\right)$$
  - And the analysis error covariance matrix when **B et R** are correctly specified (optimal case) is :

$$A = B - \mathbf{KHB}$$

- The reduction of the estimation error variance can be written :

$$r = Tr\left(B\right) - Tr\left(A\right) = Tr\left(\mathbf{KHB}\right)$$

- If **R** is block diagonal, *r* can be estimated for an observation subset *i* :

$$r_i = Tr\left(K_i \mathbf{HB}\right) \qquad K_i = K\Pi_i^T \Pi_i$$

- *r* can also be transformed by an operator **L** (projection on a geographic area, an atmospheric level, an analyzed model field, a wave number…)

$$r = Tr\left(\mathbf{LKHBL}^T\right)$$

Estimation of tr(KHB) using randomization

- Problem : in a variational system, **K** and **B** are not explicitly known
- Estimation of a matrix trace using Girard's method (1989) : $Tr(C) = \eta^T C \eta$

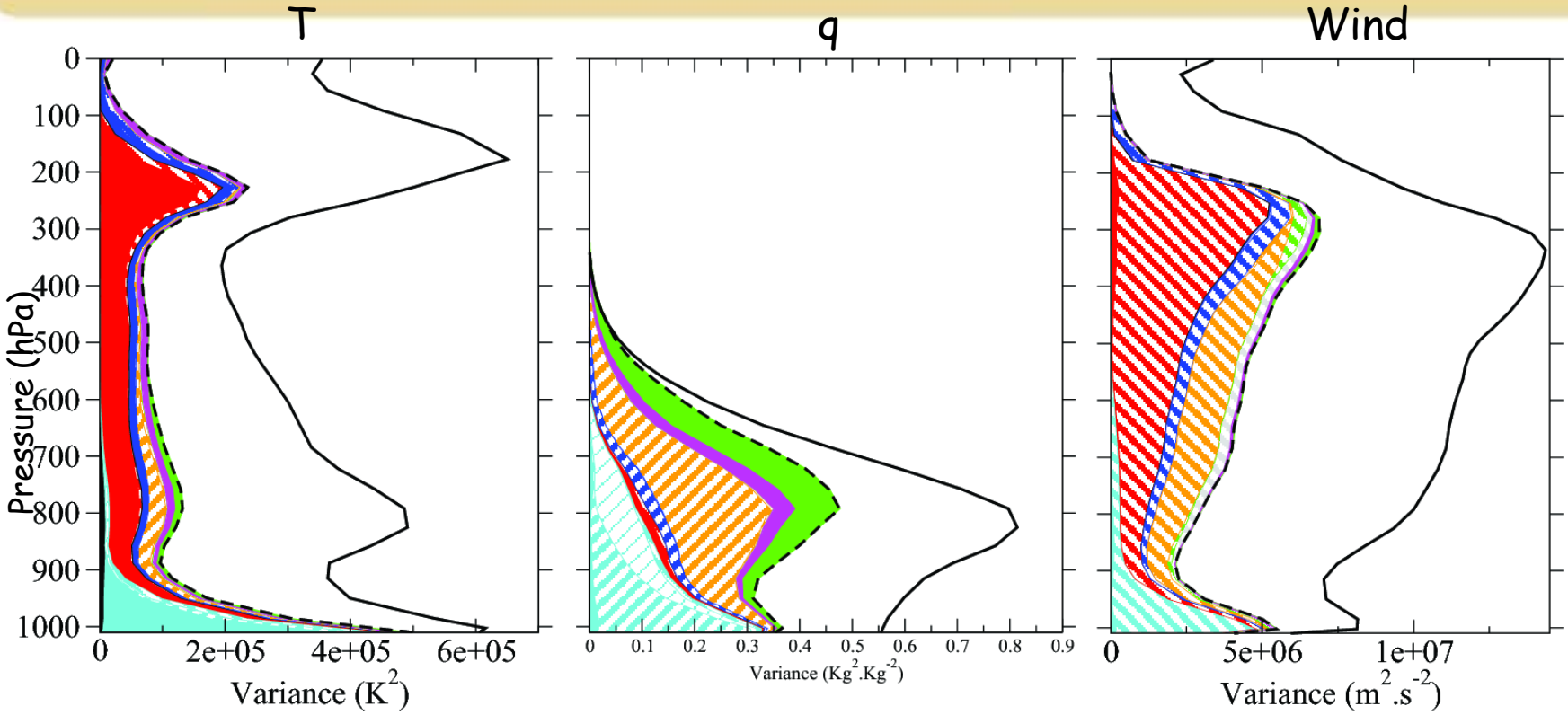
  with η a vector of numbers with a standard Gaussian distribution
- Using $\eta = \delta y^o$ of perturbations on the whole set of observations :

$$r_i = \delta y_i^{oT} R_i^{-1} \Pi_i \mathbf{HBL}^{\boldsymbol{T}} \underbrace{\mathbf{LK}\, \delta y^o}_{= \delta x_{ap}}$$

  difference betwen the analysis and the perturbed analysis
- Calculation :
  - Perform two analyses, one with the complete set of unperturbed observations and another one with the same complete set of perturbed observations,
  - Compute the difference and apply **L**, **L**$^{\mathrm{T}}$ and **B**
  - Evaluate the resulting field at the locations and for the variables contained in observations subset i, normalyse by the corresponding observation errors and perturbations

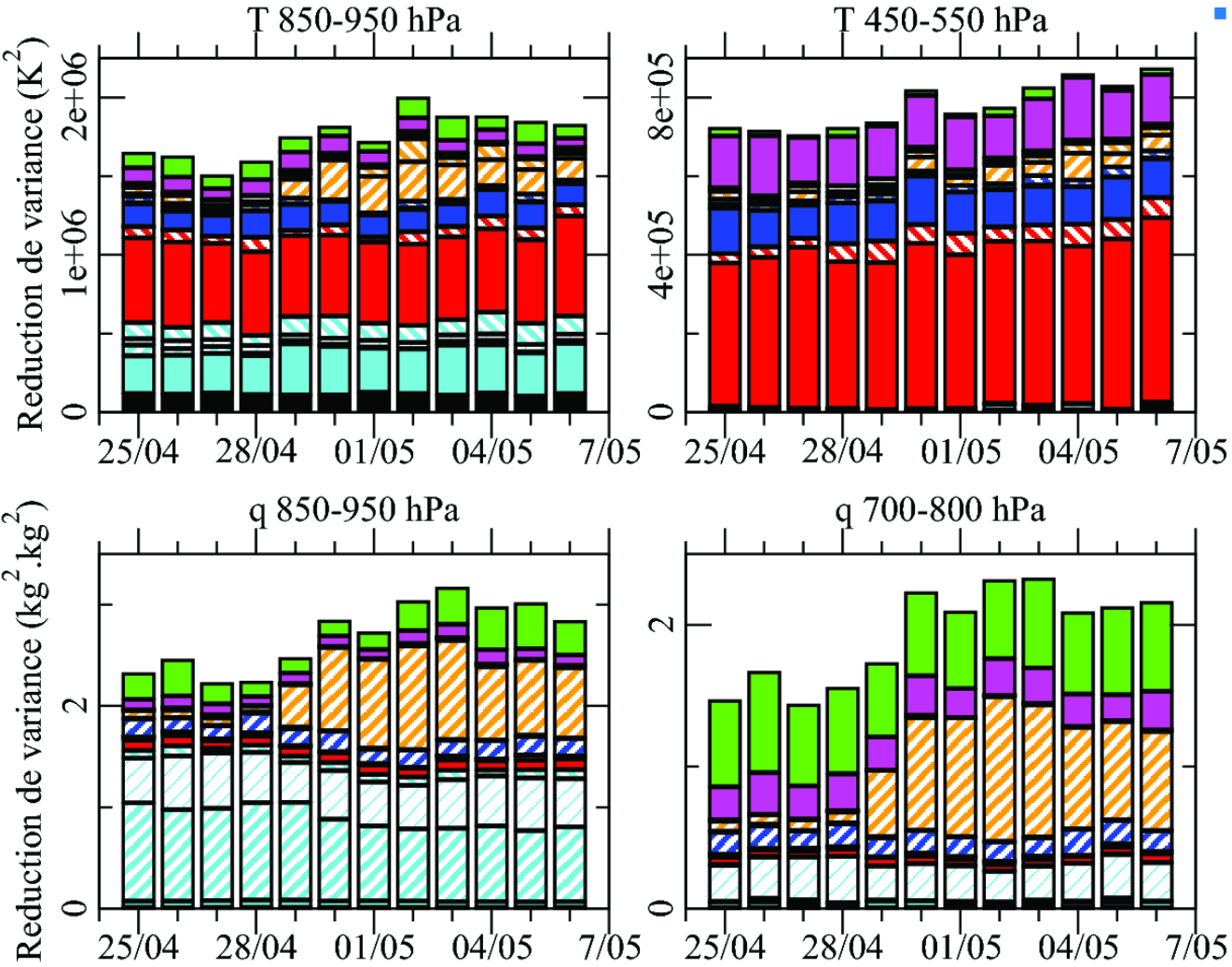
→ Can be a product of an ensemble assimilation

Daily mean reduction

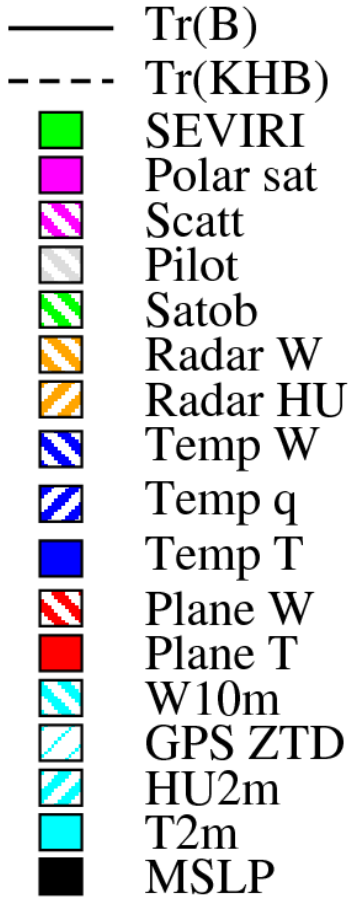


- Most important parts of *r* are provided by :
  - Surface observations
  - Plane
  - Radar

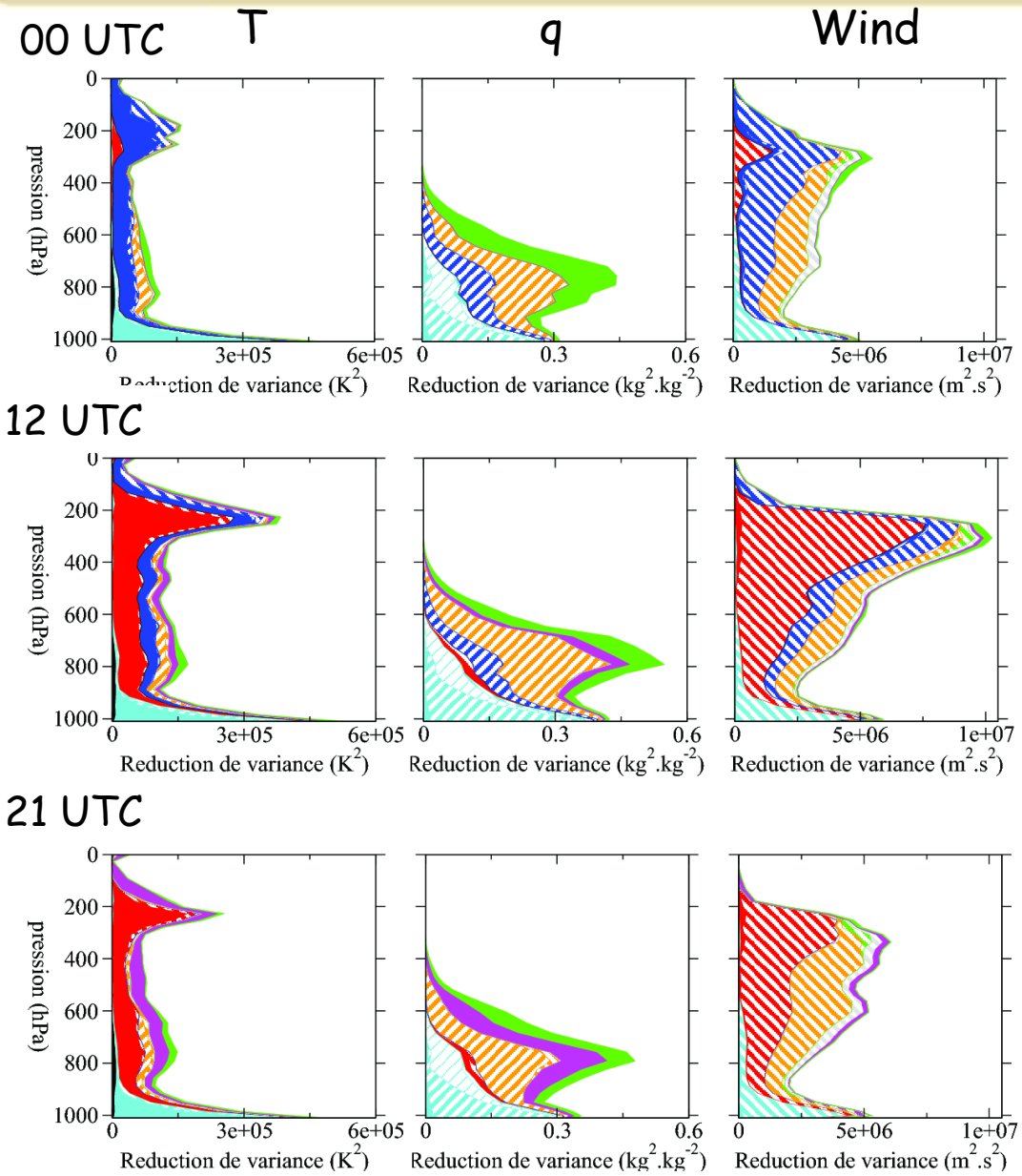
Daily variability



- The total reduction is higher when it is raining : reduction provided by radar measurements is added

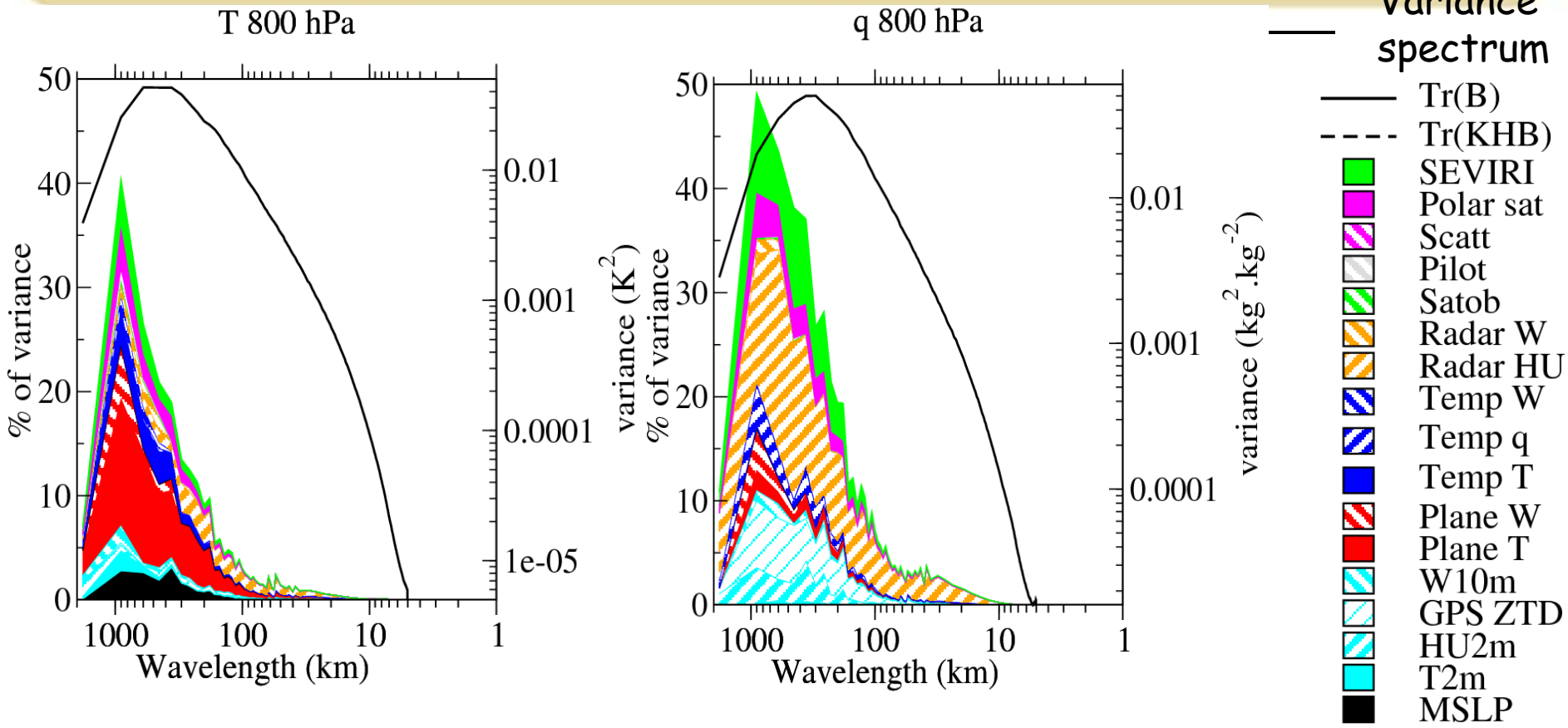


Assimilation time variability



- Depending on the number of available observations at the analysis time, the total reduction can vary.
- The same value of variance reduction can be provided by two different observation subsets : temp at 00 and plane at 21 UTC.
- Two observations subsets can be redundant : at 21 UTC IASI observations reduce the part of variance reduction provided by SEVIRI compared to 00 UTC.

Spectral decomposition



- Higher reduction of variance error for wavelengths corresponding to the higher values of variance spectra
- For wavelengths shorter than :
  - 200 km, only radar and plane measurements for temperature (GPS for specific humidity) contribute to the variance reduction
  - 100 km, the variance reduction reach only 5% of the error variance and it is only provided by radar observations

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- increase of the assimilation cycle frequency

Why

- Weakness of the representation of the temporal dimension in AROME-France data assimilation system (3D-Var) : inefficient use of observations with high temporal and often spatial coverage (radar measurements), which are quite very informative at meso-scale.

- Scheme as 4D-Var or EN-Var could solve this problem but : difficult implementation, important numerical costs.

- 3D-FGAT has been evaluated : allows to compare the observation with the background at the observation time (as in 4D-Var) but assumes the innovation vector to be constant both in time and space during the minimization (as in 3D-Var) :
  - Useful for observations far from the center of the assimilation window
  - Not adapted for static stations with numerous observations along the assimilation window : the different innovations are averaged.

- At short term, increase of the cycle frequency in order to assimilate more observations.

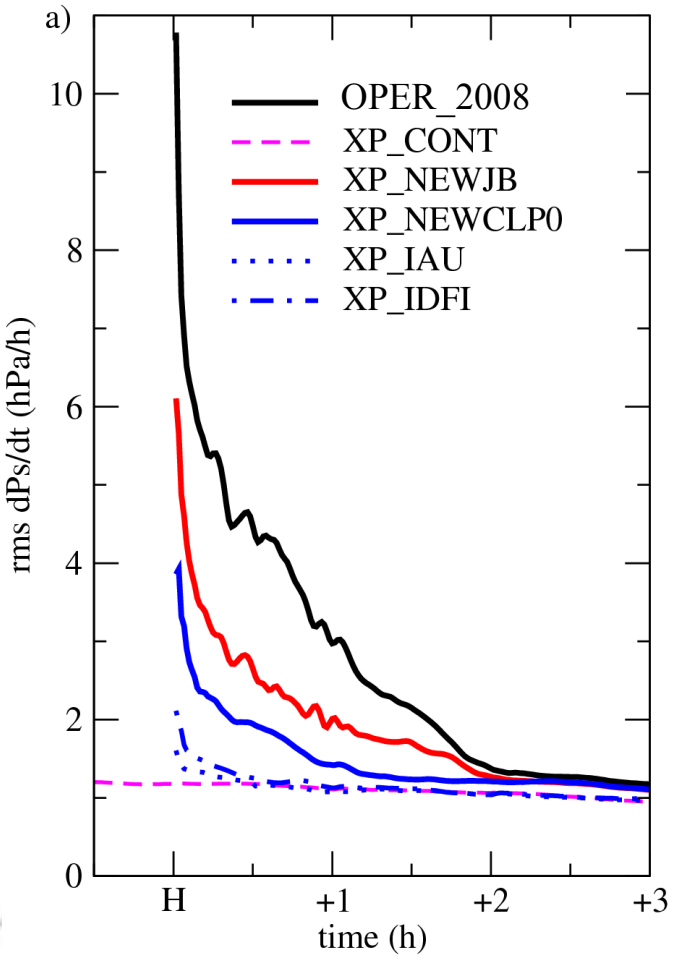
Problem of spin-up

- Spin-up : numerical noise in the first ranges of a model integration.
- Risk of accumulating noises and imbalances through the assimilation cycle decreasing system performances : choice of a 3-h period for the AROME-France operational cycle.
- Some sources of imbalance have been identified and reduced

  - Imbalances in the 3D-Var increment : the use of a new B matrix (Brousseau et al. 2011) more representative of small scales allows to reduce it substantially (XP_NEWJB). This B is estimated with forecast differences from an AROME-France assimilation ensemble instead of forecast obtained in dynamical adaptation (operational since April 2010).

  - Inconsistency at initial time between LBC (ARPEGE analysis) and the initial state (AROME analysis) : the use of the AROME analysis as LBC also allows to reduce spin-up in the first hour (operational since November 2011).

- Residual spin-up can be reduced using filtering methods as Incremental Digital Filter Initialization or Incremental Analysis Update

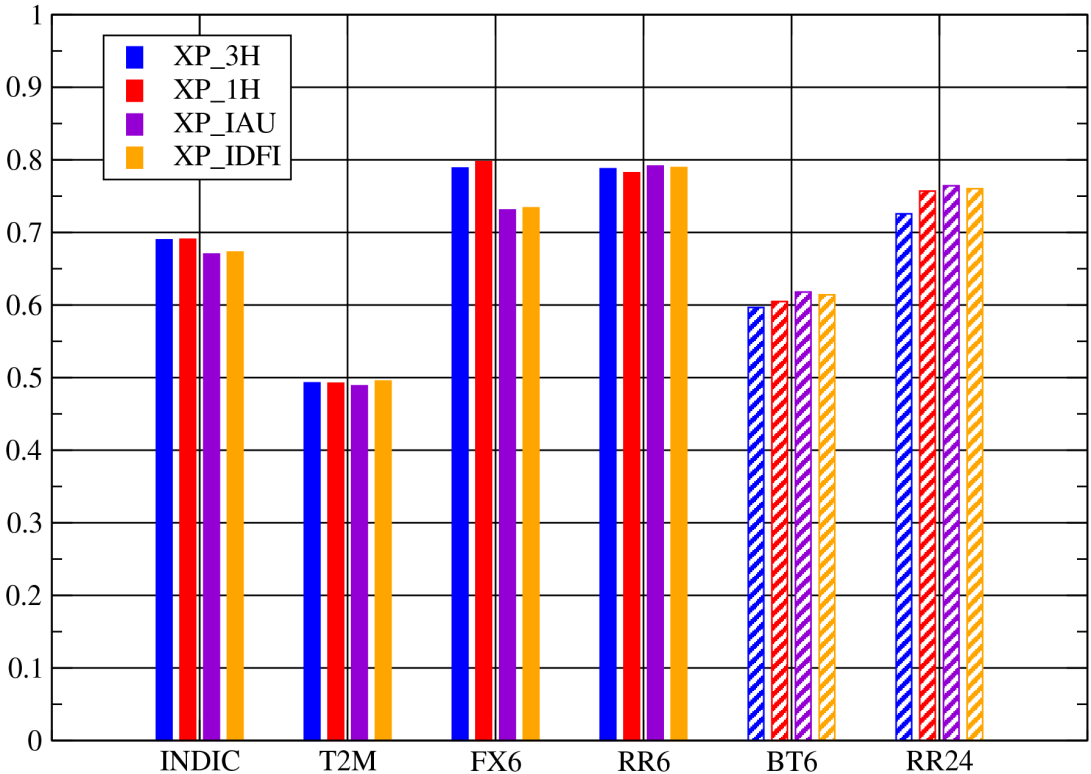


1-h/3-h cycle comparison : composite indicator

- 1 month experiment
- Composite score composed by normalized RMSE of T2m and Brier Skill Scores of maximal wind gust and 6h cumulative precipitations with a tolerance of 50 km averaged
  - for 6, 12, 18 and 24-h forecast ranges
  - For different excess thresholds
- BSS of brightness temperature of 10.8 μm SEVIRI channel
- BSS of 24-h cumulative precipitation (6-30h ranges)

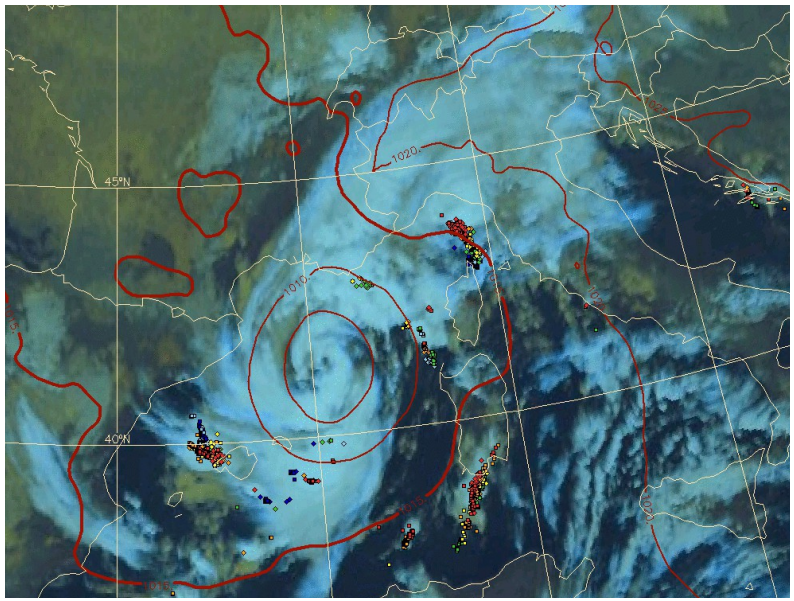
- Improvements, except for T2m (neutral) and RR6 (deterioration at 6 and 12-h forecast ranges, while other ranges are improved).

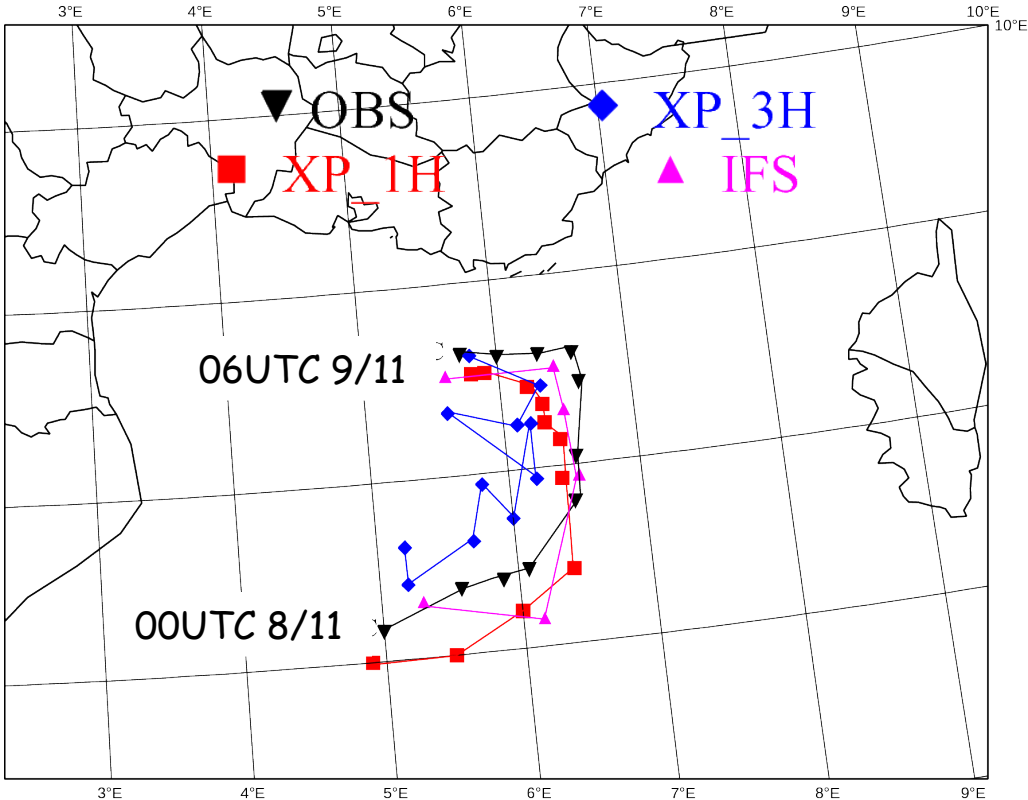
- The use of the 2 filtering methods do not correct this problem and leads to a deterioration of wind scores



7-9 November 2011 case study

- Tropical-like Mediterranean Storm
- Location of the pressure minimum estimated from MSG images and analyzed by AROME-France 3-h and 1-h assimilation cycle (each 3-h from 00UTC the 8/11 to 06 UTC the 9/11) and IFS (each 6-h) :
  - Both data assimilation systems using more observations (IFS with 4D-Var and AROME-France with a 1-h assimilation cycle) are able to analyze a trajectory spatially and temporally consistent with the observation
  - The 3-h cycle analyzed trajectory is more erratic.





Conclusion

- Observation impact on analysis :
  - The reduction of the estimation error variance is a very informative diagnosis
  - Observations providing the most important variance reduction are : surface stations under 900 hPa, radar and plane measurements above
  - Only radar observations contribute for shorter length scale.

- Spin-up reduction
  - Imbalances in the analysis state are reduced by the use of the new B matrix
  - The use of AROME-France analysis as LBC at initial time avoid inconsistencies between lateral and inner domain state
  - The use of a filtering method (IDFI, IAU) allows to reduce the residual spin-up

- 1-h assimilation experiments :
  - Results are slightly better except for 6-h cumulative precipitation at 6 et 12-h forecast ranges
  - Both IDFI and IAU do not allow to compensate this and strongly deteriorate wind scores.

Future plans

- Before an operational use, understand :
  - The RR6 score degradation due to 1-h cycle
  - The wind score degradation due to filtering methods

- Use of more informative observations
  - X-Band radar observations.
  - Radar from others countries (ex : Spanish radars in the framework of the HYMEX experiment) .

- Specification of flow-dependant background error covariances.

Thank you for your attention…

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