Model-error representation in Météo-France ensemble NWP systems

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- At the global scale, Météo-France is operationnally running both EDA and EPS, based on the Arpège model
  - Arpège EPS operational since 2004
  - Arpège EDA operational since 2008
- At the convective scale, Météo-France is currently developing both EDA and EPS, based on the NH Arome-France model :
  - Arome EPS currently pre-operational (officially operational by the end of 2016)
  - Arome EDA currently under development (operational ∼ by the end of 2017)
- Representation of model error in these systems is essential, and it is accounted for with specific methods.

Plan

1. Model error in global ensemble systems
2. Model error in convective-scale ensemble systems
3. Diagnostic of model error in Arpège
4. Conclusions and future works

▷ **Goal**

- Provide flow-dependent **B**-matrix to the deterministic Arpège 4D-Var assimilation (both for minim and obs. quality control)
- Provide perturbed initial states to the Arpège EPS.

▷ **Configuration**

- 25 members with 4D-Var, T479 (40 km) L105, minim T149
- Perturbations of 4D-Var analyses : obs perturbs. (drawn from **R**) and background perturbs (cycling of analysis perturbs and model perturbs).
- Model error accounted for with a multiplicative inflation (cycled) of forecast perturbations, based on innovation estimates.

1 - Model error in Arpège EDA : methodology

- **In a perfect-model framework, EDA provides an estimate of predictability error variances $\mathbf{v}[\mathbf{M}e^a]$, while forecast error variances correspond to $\mathbf{v}[\mathbf{M}e^a + e^m]$**

- From Desroziers and Ivanov (2001), Chapnik *et al.* (2004),

$$\mathbf{v}[\mathbf{M}e^a + e^m] \simeq \frac{E[J^b_{exp}(\mathbf{x}^a)]}{E[J^b_{theo}(\mathbf{x}^a)]}\ \mathbf{v}_{specified}.$$

  - $E[J^b_{exp}(\mathbf{x}^a)]$ directly available from the deterministic 4D-Var run,
  - $E[J^b_{theo}(\mathbf{x}^a)] = Tr(\mathbf{HK})$ can be calculated directly from the EDA (Desroziers *et al.*, 2009)

- Inflation factor is computed as

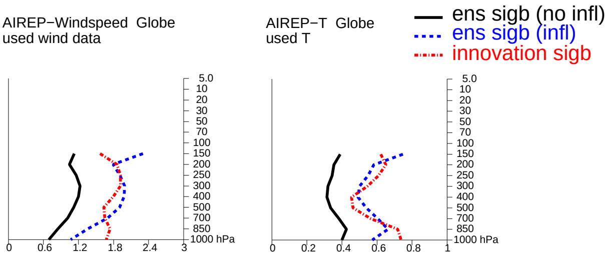
$$\alpha_t = \sqrt{\frac{\overline{\mathbf{v}[\mathbf{M}e^a + e^m]}^{xy}}{\overline{\mathbf{v}_t[\mathbf{M}e^a]}^{xy}}},$$

  - $\mathbf{v}_t[\mathbf{M}e^a]$ is the EDA variance at time t
  - $\mathbf{v}[\mathbf{M}e^a + e^m]$ is a tuned climatological forecast variance.

1 - Model error in Arpège EDA : results

Effect of the inflation on the ensemble spread

- $\mathbf{x}_k^b \rightarrow \overline{\mathbf{x}^b} + \alpha \left(\mathbf{x}_k^b - \overline{\mathbf{x}^b}\right)$
- $\alpha \approx 1.1$ at each EDA cycle
- Ens. spread $\times 2$ compared to a perfect model assumption
- This larger spread is validated by comparison with *a posteriori* diagnostics (Desroziers *et al.* (2005) ; $E[\mathbf{d}_b^a \mathbf{d}_b^{o\,T}] = \mathbf{HBH}^T$).



1 - Model error in Arpège EDA : results

Other impacts of the inflation

- Local modifications of ensemble variances (e.g. increase in dynamically active regions)
- Better representation of analysis effect
- Positive impacts on analysis and forecast scores.

Reference

L. Raynaud, L. Berre and G. Desroziers, 2012 : Accounting for model error in the Météo-France ensemble data assimilation system. *Q. J. R. Meteorol. Soc.*, 138, 249-262.

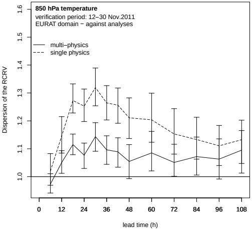
1 - Arpège EPS

- 34 perturbed members + control run
- Running at : 06UTC (90h range) and 18UTC (108h range)
- Forecasts resolution : T798C2.4L90 (≈10km over Europe, 60km on the opposite side of the globe)
- Initial conditions : combination of Arpège EDA perturbed states with singular vectors
- Model error accounted for with the multiphysics approach, considered to provide a valuable flow-dependent sampling of the uncertainty in the physical parametrizations :
  - 10 different physical parametrization sets, including the Arpège deterministic physical package
  - different schemes for turbulence, shallow convection, deep convection and for the computation of oceanic fluxes.

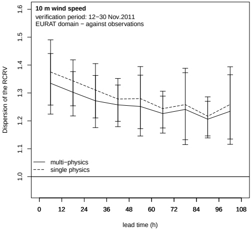
Reference

L. Descamps, C. Labadie, A. Joly, E. Bazile, P. Arbogast and P. Cébron, 2015 : PEARP, the Météo-France short-range ensemble prediction system, *Q. J. R. Meteorol. Soc.*, 141, 1671-1685.

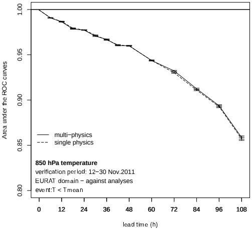
1 - Model error in Arpège EPS



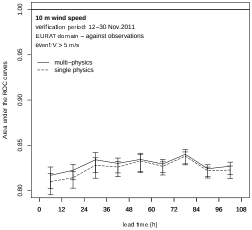
(a) RCV T850



(b) RCV FF10m



(c) ROCA T850



(d) ROCA FF10m

- ▷ Multiphysics increases the spread of the EPS
- ▷ Weaker but positive impacts also seen in the AROC score.

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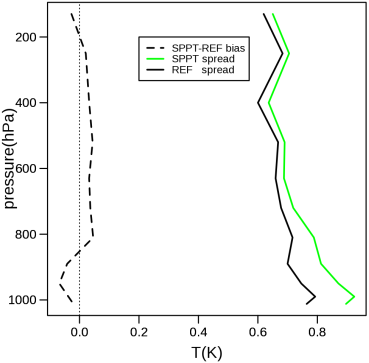
- Based on the non-hydrostatic convective-scale Arome-France model with a 2.5km horizontal resolution
- 12 perturbed members
- Running at 09UTC and 21UTC up to 45h
- Initial perturbations and lateral boundary conditions provided by selected runs of the Arpège EPS (through a clustering technique)
- Random perturbations added to some surface variables (including SST, soil temperature and humidity)
- Model error represented with stochastic physics, using a limited-area version of ECMWF's SPPT scheme.

Reference

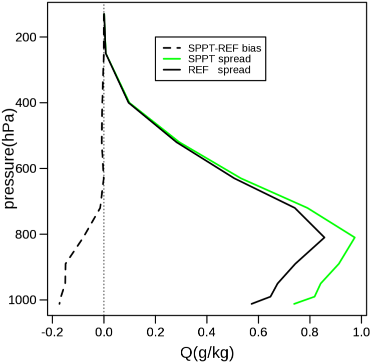
F. Bouttier, O. Nuissier, B. Vié and L.Raynaud, 2012 : Impact of stochastic physics in a convection-permitting ensemble, *Monthly Weather Review*, 140, 3706-3721.

2 - SPPT in Arome EPS

▷ SPPT enhances ensemble spread throughout the troposphere, and this effect is strongest near the surface.



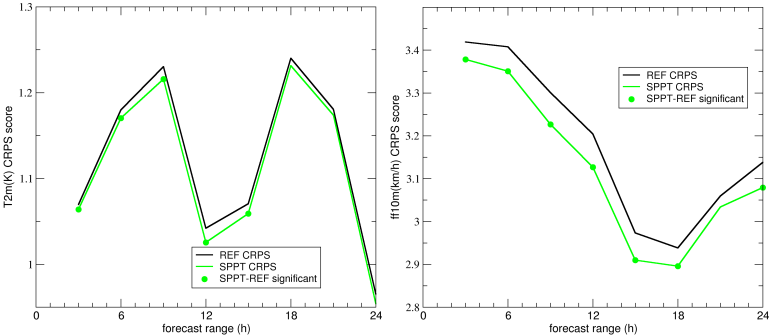
(a) Temperature +24h



(b) Humidity +24h

2 - SPPT in Arome EPS

▷ SPPT generally improves the ensemble performance



(a) CRPS T2m (b) CRPS FF10m

▷ Statistically significant improvement of the CRPS of temperature and wind speed at all lead times.

▷ Reliability of precipitation is improved

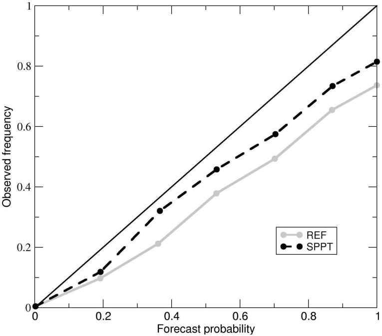
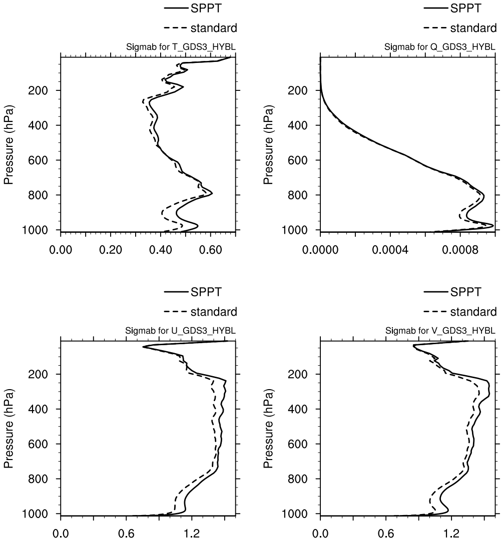


FIGURE : rr3h > 2mm

- **Goal**
  - Provide flow-dependent **B**-matrix to the deterministic Arome 3D-Var assimilation
  - Provide perturbed initial states to the Arome EPS.
- **Configuration** (preliminary because not operational yet ...)
  - Ensemble of 3D-Vars from perturbed observations
  - Based on the Arome-France model at 4km resolution
  - 25 members
  - Lateral boundary conditions from Arpège EDA
  - Model error : multiplicative inflation and SPPT scheme (same as in Arome EPS) are currently in test.

2 - SPPT in Arome EDA

▷ SPPT increases the spread of the ensemble throughout the troposphere



2 - Inflation in Arome EDA (without SPPT)

▷ Computation of inflation factor based on spread/skill relationship

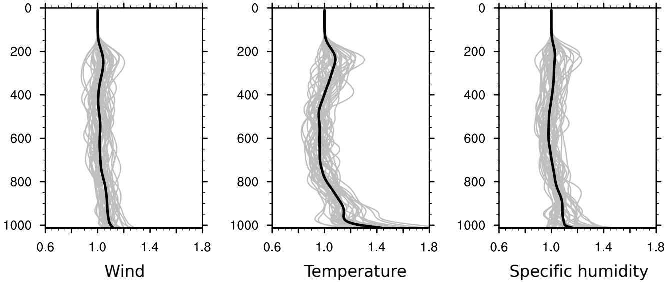


FIGURE : Inflation factors

Plan

3 - Diagnostic of model errors

From Daley (1992),

$$\mathbf{P}^f_{n+1} = \mathbf{M}_n \mathbf{A}_n \mathbf{M}_n^T + \mathbf{Q}_n$$

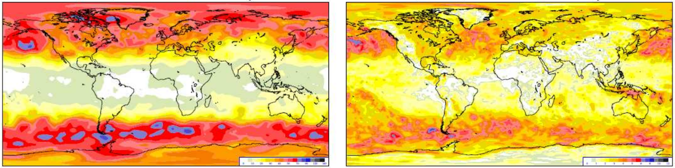
- Predictability error $\mathbf{P}^p_{n+1} = \mathbf{M}_n \mathbf{A}_n \mathbf{M}_n^T$
  $\Rightarrow$ can be estimated from an EDA : $\mathbf{P}^p_{n+1} = \frac{1}{N-1} \sum_{i=1}^{N} (x_i^f - \overline{x^f})^2$
- Forecast error $\mathbf{P}^f_{n+1} = (\overline{x^f} - x^{TRUE})^2$, where $x^{TRUE} = x^a_{ECMWF}$
- Boisserie *et al.* (2014) estimated the diagonal (variances) of $\mathbf{Q}_n$, using the Arpège EDA over a winter and a summer season.

Reference

Boisserie *et al.*, 2014 : Estimating and diagnosing model error variances in the Météo-France NWP model, *Q. J. R. Meteorol. Soc.*, 140, 846-854.

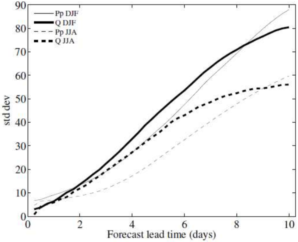
3 - Diagnostic of model errors in Arpège

b) Z500, forecast lead time= +5 days　　e) Ws850, forecast lead time= +5 days



⇒ Large-scale model error patterns in mid-latitude storm track.

a) Z500, NH



⇒ Linear growth of model error until saturation

⇒ After ∼ 2 days model errors start playing the dominant role.

4 - Conclusions and future works

- Model error is a key point in current EPS and EDA systems.
- Accounting for model error significantly improves EPS scores and modifies background-error covariances derived from EDAs.
- Future works :
  - preliminary applications of SPPT and inflation in Arome EDA need to be continued
  - tests of SPPT and SKEB schemes in Arpège EPS for comparison with the operational multiphysics
  - evaluation of additional representations of model error in Arome EPS (e.g., perturbations of the microphysical scheme, perturbations affecting the atmospheric boundary layer)
  - take benefit from the diagnostics of model error to tune some aspects of model error schemes (e.g., amplitude and structure of error patterns).
  - Unified representation of model error in our ensembles ?