

Model error representation in Météo-France ensemble NWP systems

A variety of ensemble systems are currently operationally running or under development at Météo-France. At the global scale, operational ensemble data assimilation (EDA) and ensemble prediction systems (EPS) are based on the Arpège model, while at the convective scale EDA and EPS are being developed based on the non-hydrostatic limited-area Arome-France model. Experiments with these different systems have shown that the representation of model errors is a key aspect, hence appropriate strategies have been implemented in order to account for their contribution. We provide in the following paragraphs a short description of the methods used in each system.

The Arpège EDA is an ensemble of perturbed 4D-Var assimilations primarily developed to compute flow-dependent background-error covariances for the deterministic 4D-Var assimilation. A methodology has been proposed to estimate model-error global contribution from diagnostics relative to the minimum of the variational cost function (Raynaud *et al.*, 2012). This information is then used to implement a flow-dependent adaptive multiplicative inflation of background perturbations after each forecast step. This leads to an increase of the ensemble spread by roughly a factor of 2, which improves the consistency of ensemble variance estimates with innovation-based estimates. Positive impacts of inflated ensemble covariance estimates on the analysis and forecast scores are also observed.

Perturbed states from the global EDA also provide initial conditions for the Arpège EPS (Descamps *et al.*, 2015), which is currently running on a stretched grid with a 10km resolution over France. Model error in the EPS is accounted for with the multiphysics approach, which is considered to provide a valuable flow-dependent sampling of the uncertainty in the physical parametrizations. It is based on ten different physical parametrization sets, including the Arpège deterministic physical package, designed from different schemes for turbulence, shallow convection, deep convection and for the computation of oceanic fluxes. Scores indicate that the multiple parametrization set increases the ensemble spread, especially for 850hPa temperature, and also slightly improves the ensemble resolution.

To complement the global systems, convective-scale ensembles for both assimilation and forecasts are currently under development at Météo-France. The near-operational Arome-EPS is running with a 2.5km horizontal resolution, and model error is represented with the SPPT scheme (Bouttier *et al.*, 2012), which is a limited-area version of the ECMWF scheme. As expected, SPPT enhances ensemble spread, especially in the lower troposphere, and it generally improves the ensemble performance for the prediction of surface weather variables, as measured by the spread-skill relationship and various other probabilistic scores. The SPPT scheme is also shown to have a significant impact on rain forecasts, although it does not directly perturb condensed water species. On the other hand, the SPPT is shown to produce a drying of the lower atmosphere that should be further investigated.

Finally, preliminary versions of the Arome EDA, running with a 4km horizontal resolution, combines this SPPT scheme with a multiplicative inflation of background states to represent model error contribution. The impact of this EDA setting is currently being examined regarding both the initialization of the Arome-EPS and the estimated ensemble background-error covariances then used in the deterministic Arome analysis scheme.

The representation of model-error in the ensemble systems of Météo-France is an active area of research. While the currently used strategies have significant positive impacts on forecast scores there is still room for improvement. Future works will examine the application of the SPPT scheme in the Arpège EPS, as a potential replacement for the multiphysics approach which is typically difficult to maintain in an operational environment.

Going from the global SPPT to the independent SPPT scheme (iSPPT) in the Arome-EPS will also be considered, based on the preliminary promising results reported with this scheme. More generally, future developments regarding model error will focus on more physically-based strategies.