FINAL REPORT PROGRAM LEFE

Program LEFE/ MANU	Project Title *« Localisations de covariances d'erreur d'ébauche dans un système d'assimilation hybride à échelle convective »*	Years 2015- 2016

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***Context**:* Development of a new data assimilation algorithm for the operational Numerical Weather Prediction (NWP) model AROME at convective scale. This algorithm makes use of ensemble of forecasts in order to sample the background error covariances and to use them in a variational context, in a so-called EnVar scheme. This project focuses on the filtering of the sampling noise of the covariances due to the small size of the ensemble, which is limited by the computational time.

Objectives / scientific questions: As in EnKF methods, such filtering is in practice performed with a localization procedure, which consists in the damping of the spatial correlations with distance. The first objective was to find an objective way to determine the localization lengths, which depend on the ensemble size, on the weather types that are sampled by the ensemble and on the vertical levels. The second objective was to develop and compare different formulations for the localization functions applied to spectral fields within a limited area and to quantify their impact in cycled EnVar assimilation experiments.

***Main results**:* A 3DEnVar has been firstly set up for the AROME model at 3.8 km horizontal resolution. This deterministic algorithm uses background error covariances sampled from an Ensemble of Data Assimilation (EDA) of 25 members, based on the same system and with the same spatial resolutions. To filter some of the sampling noise, two different localization schemes have been implemented, one in spectral space and one in grid-point space. Hybrid formulations, where the background error covariances are a weighted linear combination of the sampled covariances with climatological ones, have also been evaluated.
The original theory of Ménétrier et al (2015), which is based on the optimal linear filtering and on the centered moment theories, has been firstly used to objectively diagnose horizontal and vertical localization lengths for all control variables (horizontal wind components, temperature, humidity and surface pressure). It has been found that such horizontal lengths increase with height at least by a factor of two in a comparable way for all variables, except for humidity in the high troposphere, which is characterized by very dry conditions. Common profiles of localization lengths have been deduced both for the horizontal and the vertical (figure 1). This methodology has been also extended for non-continuous fields such as the different hydrometeors types. For such variables, the computations of the centered moments have been restricted to masked areas that correspond to cloudy or rainy regions. Much shorter localization lengths have been found for e.g. liquid clouds and rain, and the vertical stratification of hydrometeors within those regions directly reflects on the vertical localization values.
As displayed in figure 2, the increment structures that result on the 3DEnVar assimilation are of much smaller scales and are more noisier than those of the 3DVar, which is the data assimilation algorithm used operationally. Cycled experiments have then been performed over a five-week time period with 3 h updates at this 3.8 km horizontal resolution. Different localization lengths with or without dependencies to vertical level, along with different localization function formulations, have been tested. It has been found that 3DEnVar scheme largely outperforms standard 3D-Var in terms of forecast scores over a 5 weeks time period. The best experiment uses a grid-point localization scheme based on recursive filters and constant localization lengths for both directions. The best constant values correspond to the ones that have been deduced by vertically averaging the objectively diagnosed lengths. It has been found that adding vertical dependencies to the localization generally degrades the initial balance between the control variables, leading to spin-up issues typically in the first hour of the resulting forecast.
The hybrid configuration with 80 % of ensemble covariances and 20 % of climatological ones performs also significantly better than the 3D-Var but to a lesser extent than the best 3DEnVar configuration. The rank increase of the background error covariance matrix used in the latter configuration allows however to retrieve much better balanced initial fields.

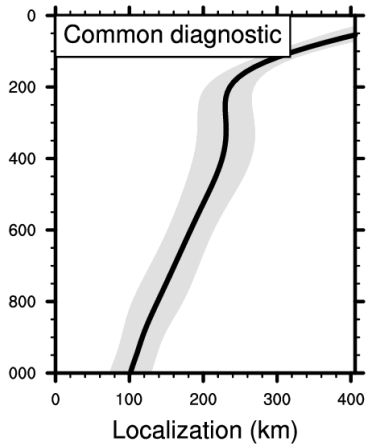

Figure 1: Profile computed from the averaged horizontal localization lengths for the different control variables deduced from 25 members of the EDA AROME between the 6 th to the 21 th of February 2016.

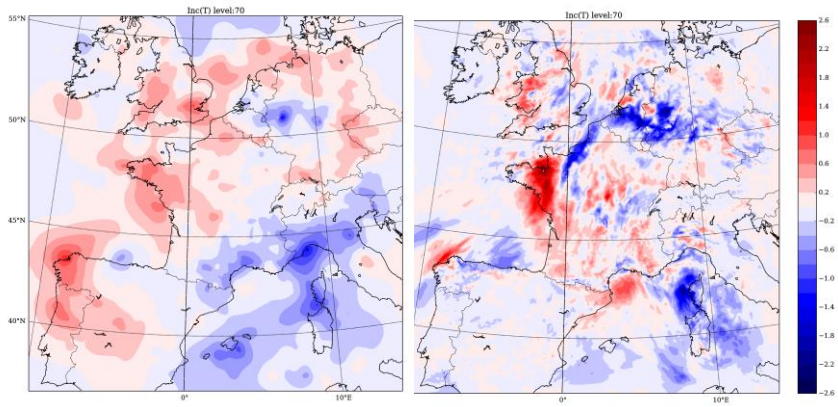

Figure 2: Horizontal cross-sections around 900 hPa of temperature increments (in K), computed the 6th of February 2016 at 00 UTC, for the 3DVar (left) and the 3DEnVar (right)

Future of the project: As the replacement of the current 3DVar by an EnVar for AROME is hopefully planned in a couple of years, many studies are ongoing at CNRM/GMAP on this particular topic. As a first step, an AROME EDA with 25 members at 3.25 km horizontal resolution is nowadays under evaluation in a pre-operational configuration. Amongst other applications, such EDA aims to supply ensemble perturbations to the deterministic EnVar in quasi-real time. Recent experiments have been conducted at the same resolution that of the operational suite (1.3 km), using interpolation operators allowing to keep on using background perturbations at a lower resolution while retrieving analyses at high resolution. Different configurations of EnVar and Hybrids, based on this multi-scale approach, are currently under evaluation. Study on the relation between spin-up issues and covariance localization is also being pursued.

Work is also ongoing on 4DEnVar, which is particularly interesting for convective scale models as the linearization of highly non-linear parameterizations is avoided by modeling the time evolution of errors within each assimilation window by localized linear combination of ensemble trajectories. Such 4DEnVar also permits to make a more optimal use of observations with high temporal resolutions, such as those from geostationary satellites, ground based and Doppler radar data. Advection of the localization functions within the assimilation window is considered in the first trials.

In parallel, a PhD thesis about the inclusion of hydrometeors in the EnVar control variables has started in 2017. The methodologies that have been developed in this « LOCA » project are directly exploited in this new project, which is also supported by LEFE-MANU (« HYDRE » project). Localization of non-continuous fields and of complex cross-covariances are two of its main challenges.

Publications, actes de communications

Articles :

- Montmerle, T., Michel Y. , Arbogast E., Ménétrier B. and P. Brousseau, 2018: A 3D Ensemble Variational Data Assimilation Scheme for the limited area AROME model: formulation and preliminary results. *Accepted for publication in Q.J.R. Met. Soc*.
- Michel, Y, Ménétrier B and Montmerle T., 2016 : Objective Filtering of the Local Correlation Tensor. *Quart. J. Roy. Meteor. Soc.*,142, 2314-2323.
- Legrand, R., Michel Y., and Montmerle T., 2016 : Diagnosing non-Gaussianity of forecast and analysis errors in a convective scale model. Nonlin-Processes-Geophys-Discuss., 2, 1061-1090.
- Ménétrier B, Montmerle T, Michel Y, Berre L. 2015a. Linear filtering of sample covariances for ensemble-based data assimilation. part i : Optimality criteria and application to variances filtering and covariances localization. Monthly Weather Review : 143, Issue 5, 1622-1643.
- Ménétrier B, Montmerle T, Michel Y, Berre L. 2015b. Linear filtering of sample covariances for ensemble-based data assimilation. part ii : Application to a convective-scale NWP model. Monthly Weather Review : 143, Issue 5, 1644-1664.

Communications :

- Montmerle T., Y. Michel, E. Arbogast, P. Brousseau and B. Ménétrier, 2017 : Implementation of En-Var data assimilation systems for the AROME NWP system at convective scale. WMO Data Assimilation Symposium, Florianopolis, Brésil.
- Montmerle, T., , E. Arbogast , P. Brousseau, G. Desroziers, B. Ménétrier, Y. Michel, 2016 : Dvt d'une assimilation variationnelle ensembliste pour le modèle météorologique à échelle convective AROME. Colloque National d'Ass. de Données, Grenoble, France.
- Montmerle T., E. Arbogast, P. Brousseau and Y. Michel, 2015: Preliminary test of an EnVar for the operational AROME-France NWP system at convective scale. 4th International Symposium on Data Assimilation, Kobe, Japon.