AROME Ensemble-Variational 3D/ 4D-EnVar under OOPS

Pierre BROUSSEAU, E. ARBOGAST, L. BERRE, Y. MICHEL, T. MONTMERLE, and colleagues

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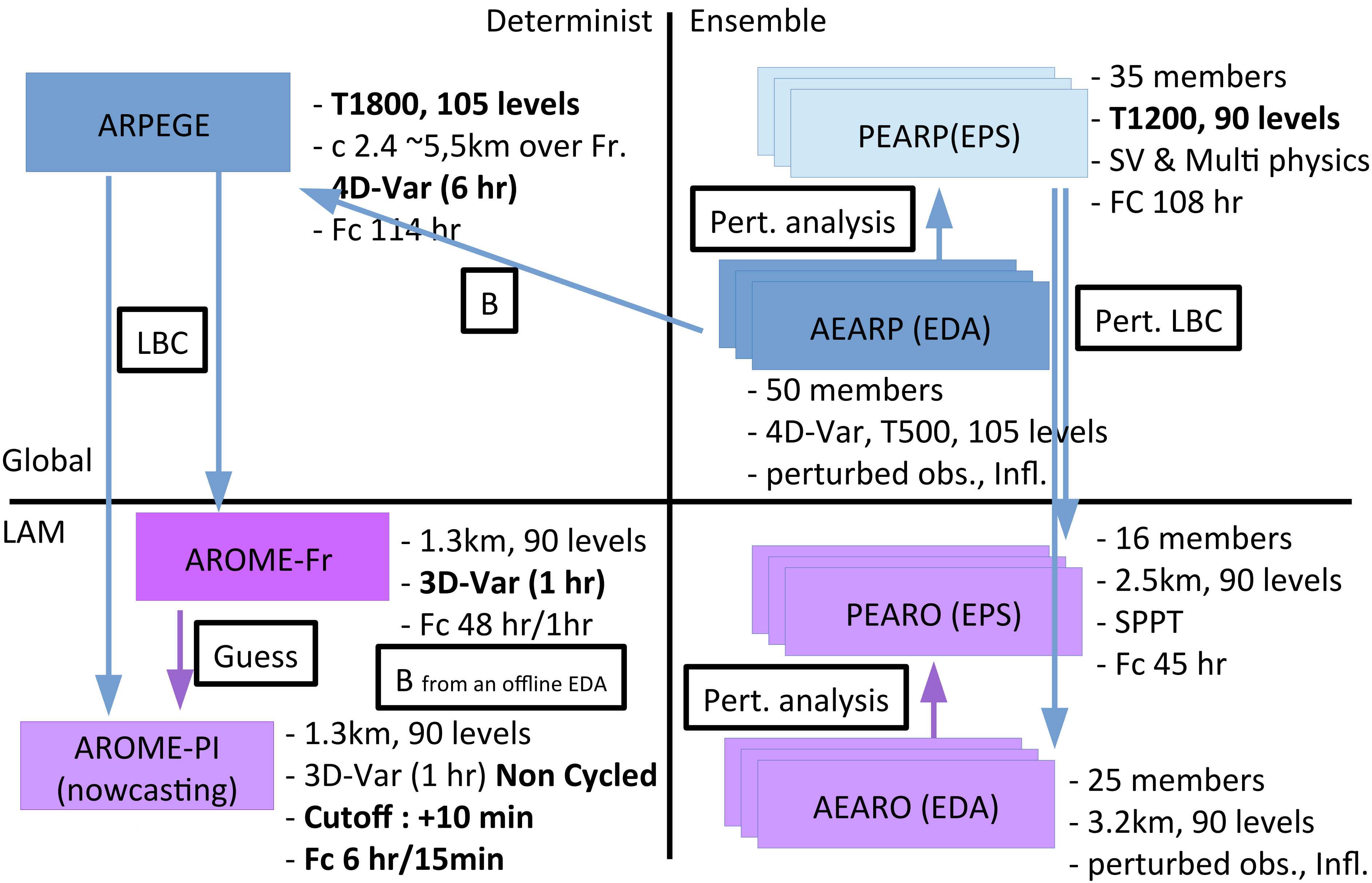
plan

- Introduction

- Summary of 3D-envar developments

- 4D-envar ongoing works

Meteo-France NWP system



OOPS : Object -Oriented Programing System

Next major evolution of the DA systems : towards Envar scheme

Using OOPS :

- project done at ECMWF in collaboration with Météo-France and LAM partners

- renovation of common data assimilation codes in order to enable the development of new algorithms and ease maintenance

- object-oriented design, upper level code in C++

- important refactoring of the IFS-Arpege-LAM FORTRAN codes

- main part of the coding effort now completed

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Prototype Envar sous OOPS

DA in AROME is performed using an incremental VAR formulation in 3D

$$J(\delta x) = \frac{1}{2}\delta x^T \mathbf{B}^{-1}\delta x + \frac{1}{2}(d - \mathbf{H}\delta x)^T \mathbf{R}^{-1}(d - \mathbf{H}\delta x)$$

- **Operationaly, hourly-cycled 3DVar are performed with :** Brousseau et al. 2016

$\mathbf{B} = \overline{\mathbf{B}}$ is climatological and modelized following Berre (2000)

$\delta x = \overline{\mathbf{B}}^{1/2}\chi$ with $\chi = (\zeta\ , \eta_u, (T, P_s)_u\ , q_u)$

⇒No flow dependencies : Homogeneous correlations, static variances

- **EnVar configurations have been implemented in OOPS :**

  - Full ensemble : $\mathbf{B} = \widetilde{\mathbf{B}}_e$
  - Hybrid : $\mathbf{B} = \beta_c \overline{\mathbf{B}} + \beta_e \widetilde{\mathbf{B}}_e$

$$\delta x = \mathbf{B} g$$

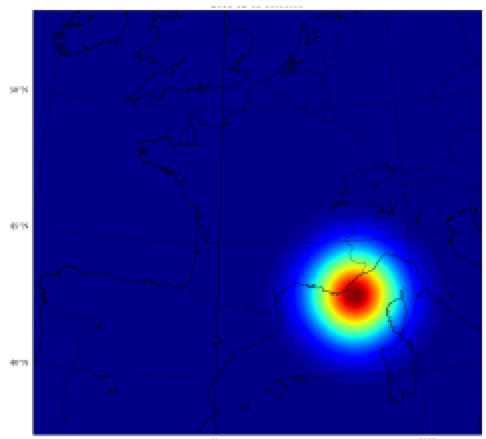
with a B-preconditioning : $g = (U, V, (T, P_s)\ , q)$

3DEnvar : Montmerle et al. 2018

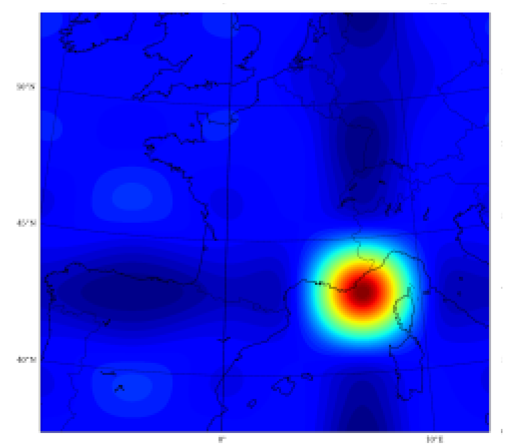
Experiments at 3,8km in a 3h cycle :

- comparison of spectral/spacial localisation

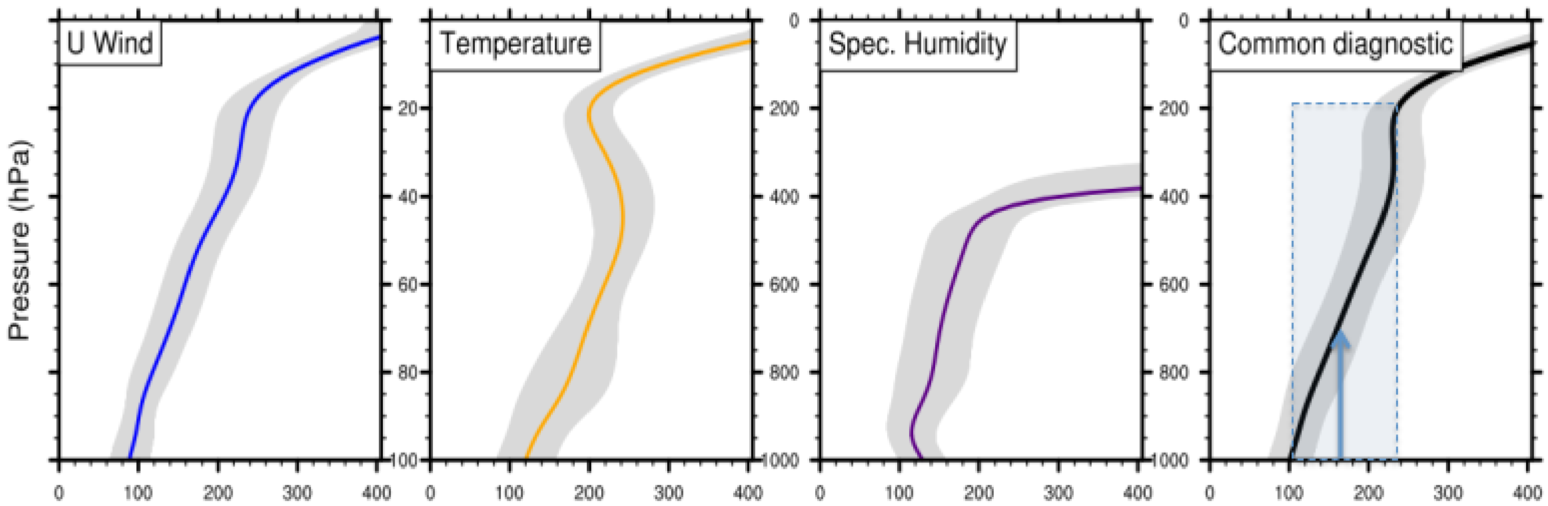
Spatial (michel 2012) :recursive filters of (Purser, 2003)



Spectral : inverse bi-Fourier transforms



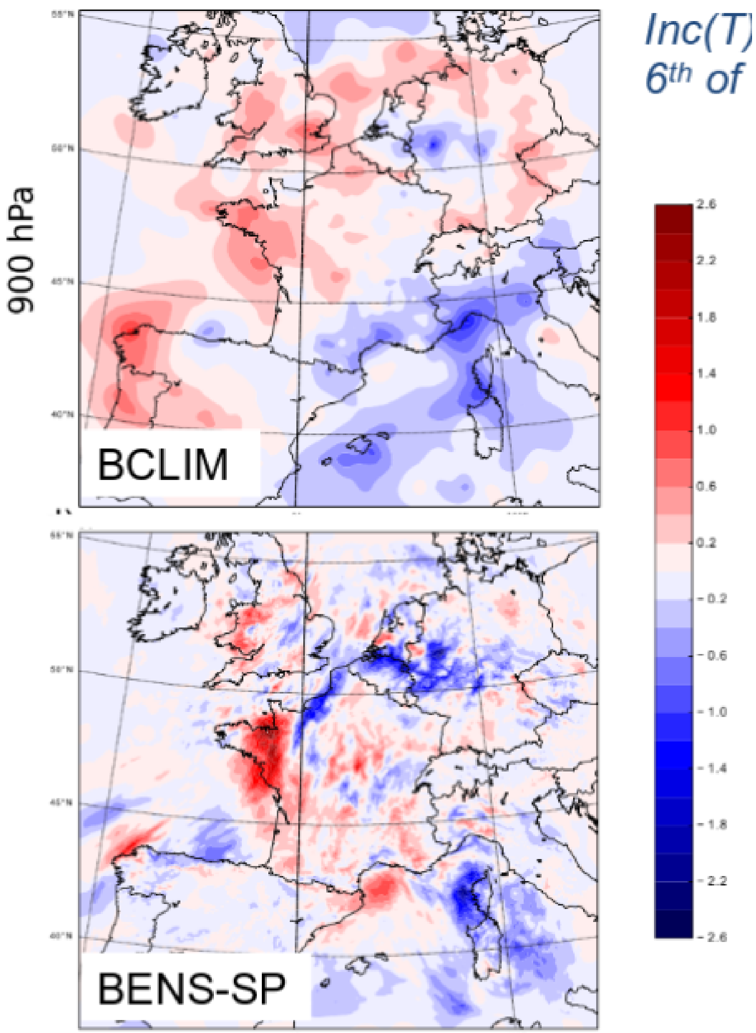
- diagnostic (Ménétrier 2015) and investigation on localisation length-scales

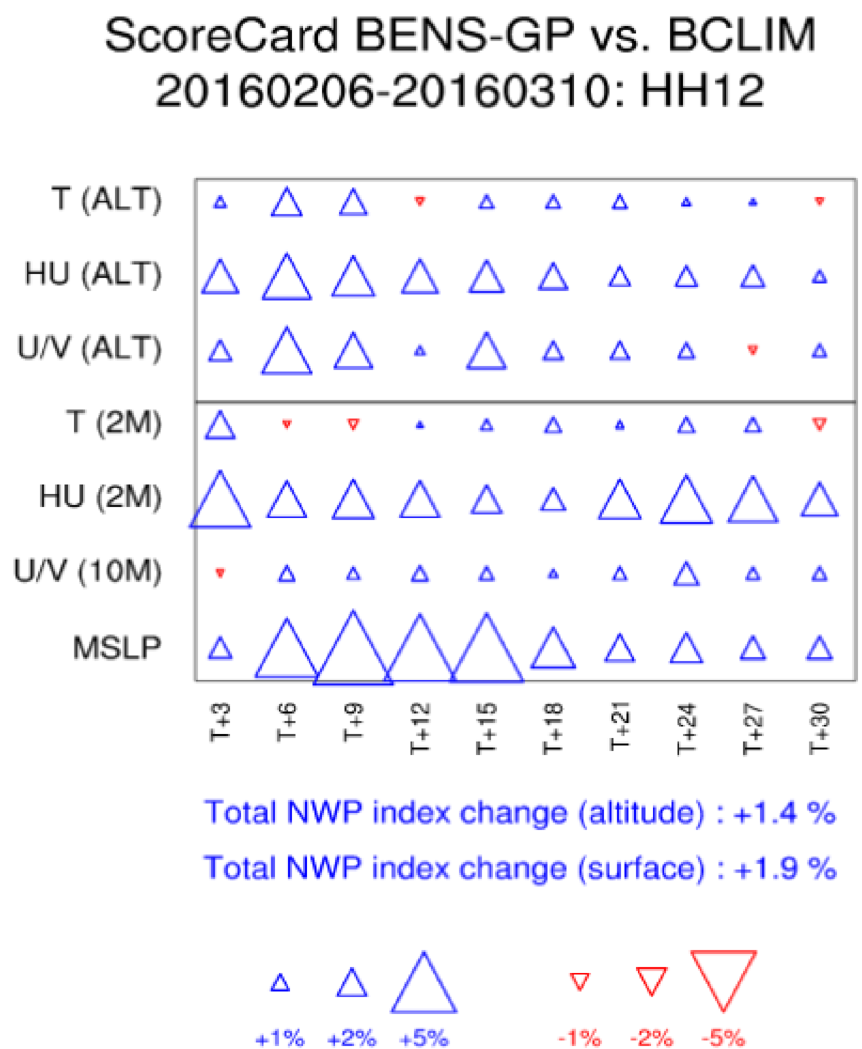


3DEnvar : Montmerle et al. 2018

(by Thibaut M.)

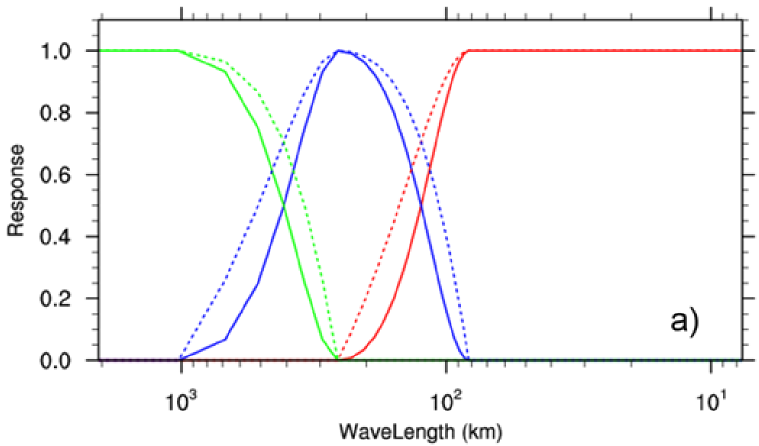
- Montmerle et al. 2018 QJRMS : 3,8km in a 3-h cycle : encouraging results

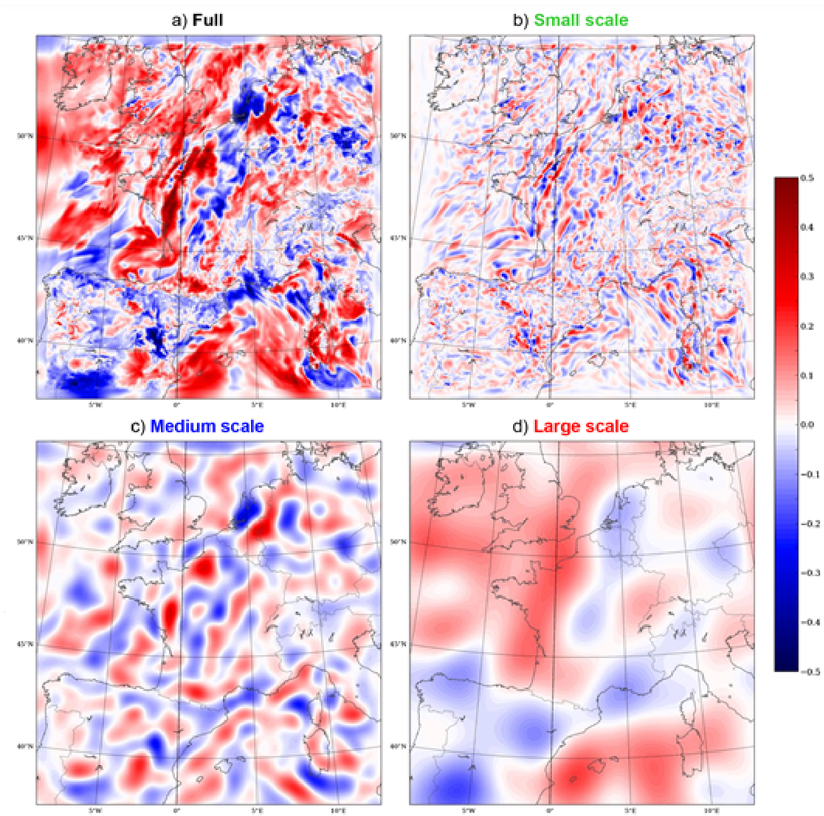


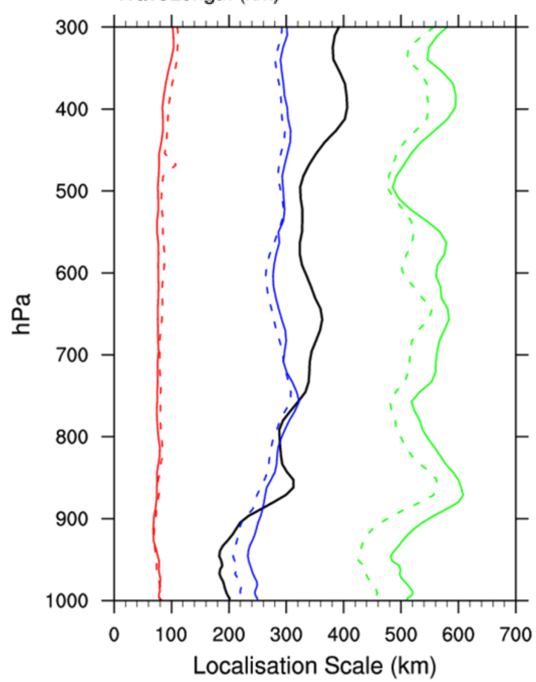


Scale-dependent localisation (Caron et al. 2019)

Wave band decomposition of the background error covariances :







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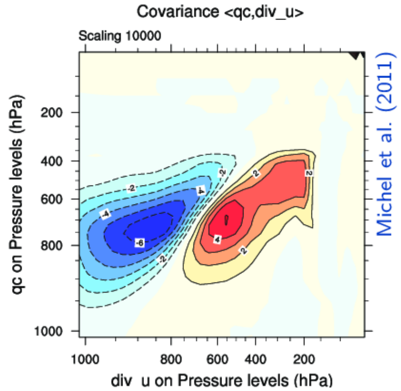
Scale dependent localisation

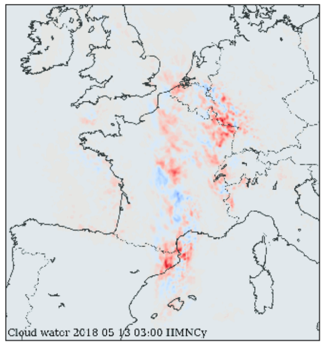
hydrometeors analysis (M. Destouches PhD)

Increments in standard variables

↓

Cross-covariances with hydrometeors → Hydrometeor increments

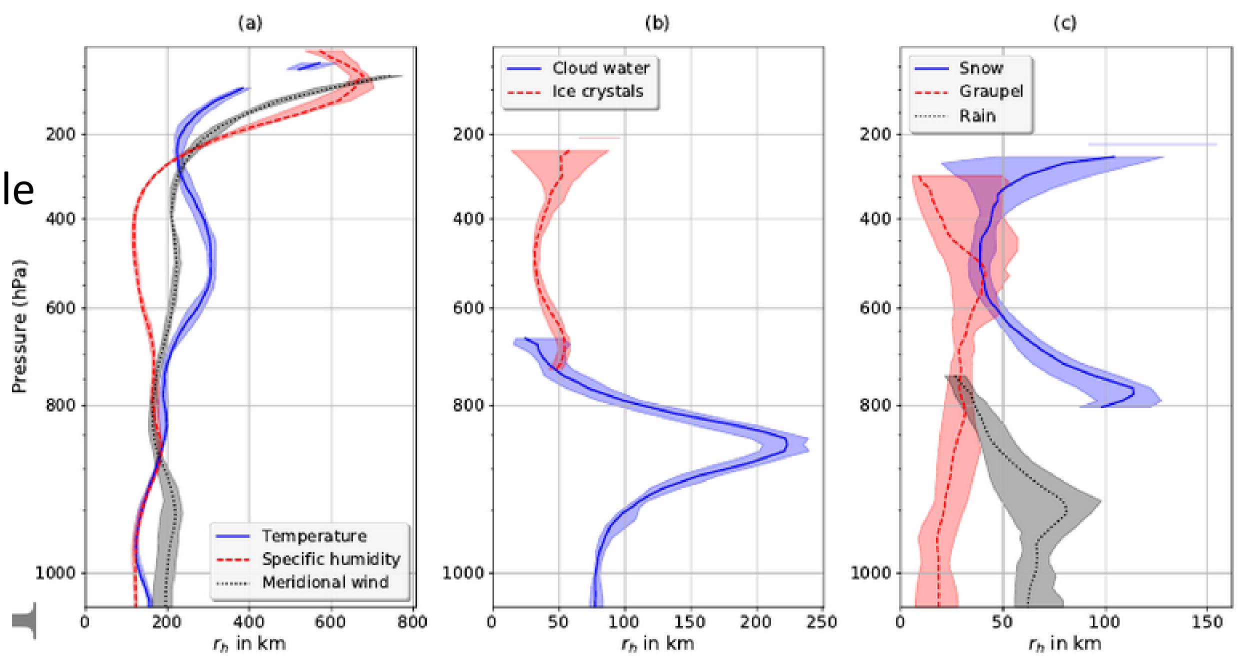




- allows standard observations to modify the hydrometeors fields according to the background error cross-correlations deduced from the EDA :

Hydrometeors localisation Scale

Destouches et al. 2020



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4DEnvar

- toward a full 4Denvar system :

3D-Var :
$$J(\delta\mathbf{x}) = \frac{1}{2}(\delta\mathbf{x})^T\mathbf{B}^{-1}(\delta\mathbf{x}) + \frac{1}{2}(\mathbf{d}-\mathbf{H}\delta\mathbf{x})^T\mathbf{R}^{-1}(\mathbf{d}-\mathbf{H}\delta\mathbf{x})$$

4D-Var :
$$J(\delta\mathbf{x}) = \frac{1}{2}(\delta\mathbf{x})^T\mathbf{B}^{-1}(\delta\mathbf{x}) + \frac{1}{2}\sum_{i=0}^{K}(\mathbf{d}_i-\mathbf{H}_i\mathbf{M}_{0\rightarrow i}\delta\mathbf{x})^T\mathbf{R}_i^{-1}(\mathbf{d}_i-\mathbf{H}_i\mathbf{M}_{0\rightarrow i}\delta\mathbf{x})$$

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4DenVar :
$$J(\underline{\delta\mathbf{x}}) = \frac{1}{2}(\underline{\delta\mathbf{x}})^T\underline{\mathbf{B}}^{-1}(\underline{\delta\mathbf{x}}) + \frac{1}{2}(\underline{\mathbf{d}}-\underline{\mathbf{H}}\underline{\delta\mathbf{x}})^T\underline{\mathbf{R}}^{-1}(\underline{\mathbf{d}}-\underline{\mathbf{H}}\underline{\delta\mathbf{x}})$$

Desroziers et al. 2014

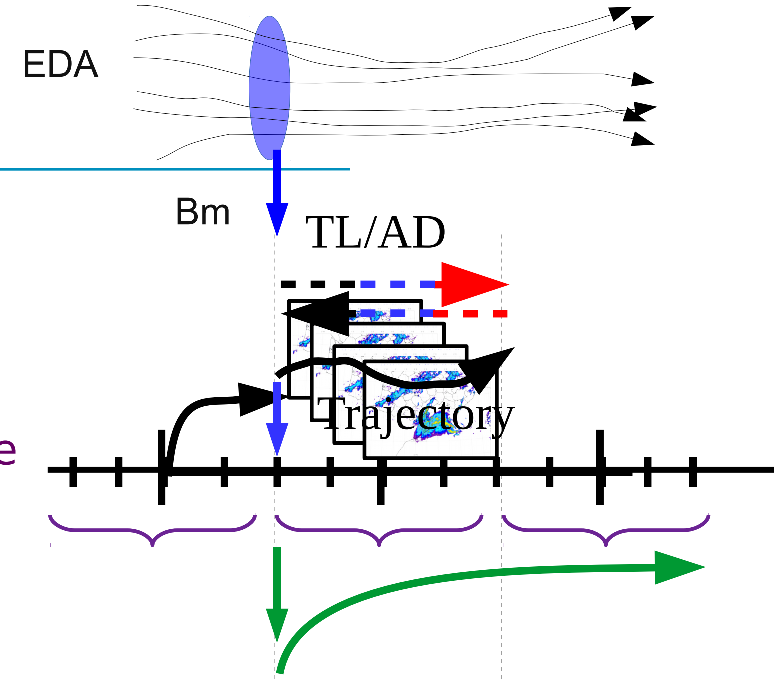
$$\underline{\delta\mathbf{x}} = \begin{pmatrix} \delta\mathbf{x}_0 \\ \delta\mathbf{x}_1 \\ \vdots \\ \delta\mathbf{x}_K \end{pmatrix}$$

$$\underline{\mathbf{B}} = \underline{\widetilde{\mathbf{B}}}^e = \begin{pmatrix} \widetilde{\boldsymbol{B}}^e_{0,0} & \widetilde{\boldsymbol{B}}^e_{0,1} & \cdots & \widetilde{\boldsymbol{B}}^e_{0,K} \\ \widetilde{\boldsymbol{B}}^e_{1,0} & \widetilde{\boldsymbol{B}}^e_{1,1} & & \widetilde{\boldsymbol{B}}^e_{1,K} \\ \vdots & & \ddots & \\ \widetilde{\boldsymbol{B}}^e_{K,0} & \cdots & & \widetilde{\boldsymbol{B}}^e_{K,K} \end{pmatrix}$$

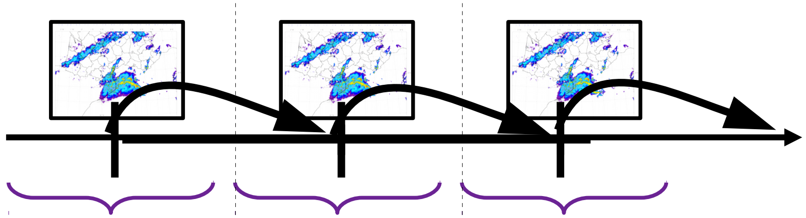
4DEnvar

- Operational AROME-Fr resolutions 1,3 km L90
- perturbations from an AROME-Fr EDA (Y.michel):
  3D-var / 50 members / 3.2 km / 3h DA cycle
- DA 1h Cycle with 5 timeslots : 3*15min + 2*7min

4D-Var, 1-h Cycle

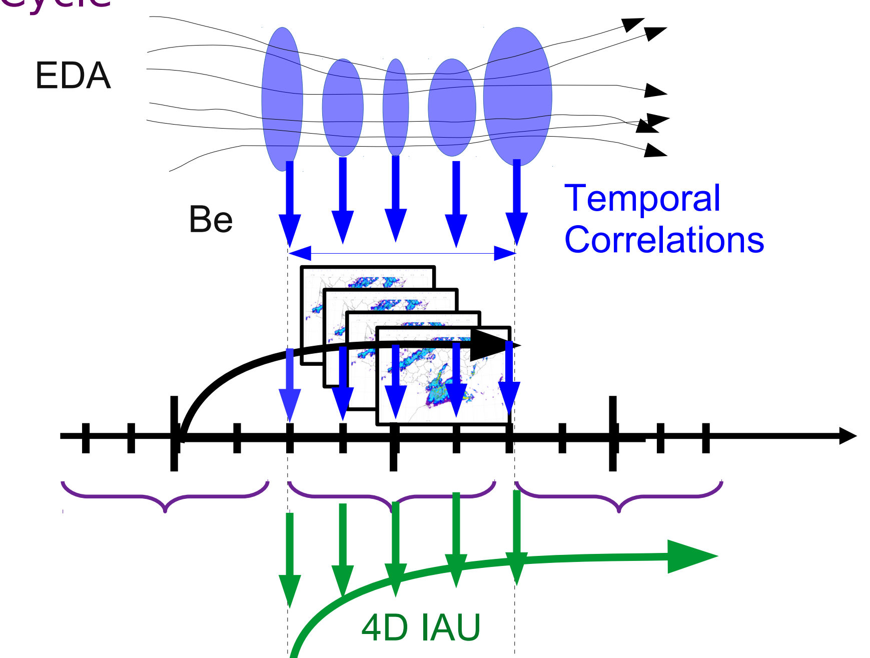


3D-Var, 1-h Cycle



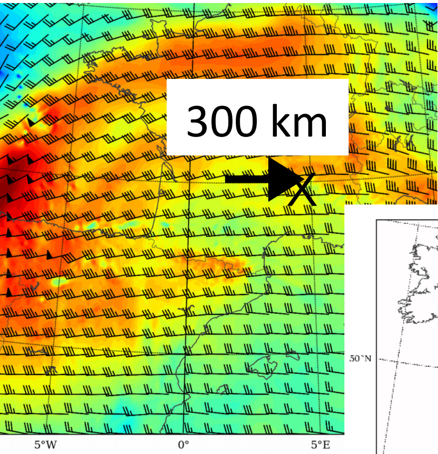
1-h assimilation window

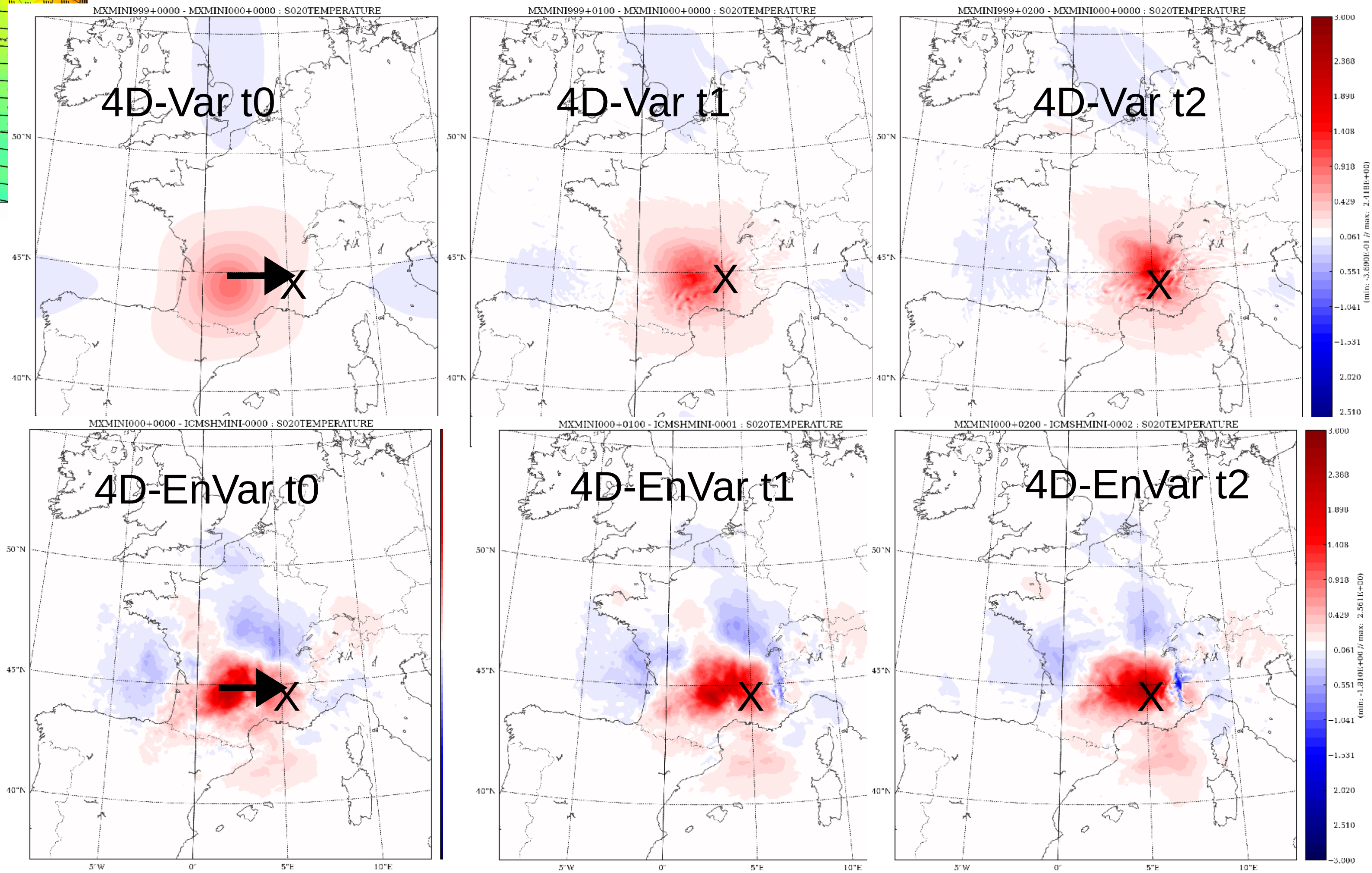
4DEnvar, 1-h Cycle



4DEnvar: single obs in a 3h cycle : hourly increments

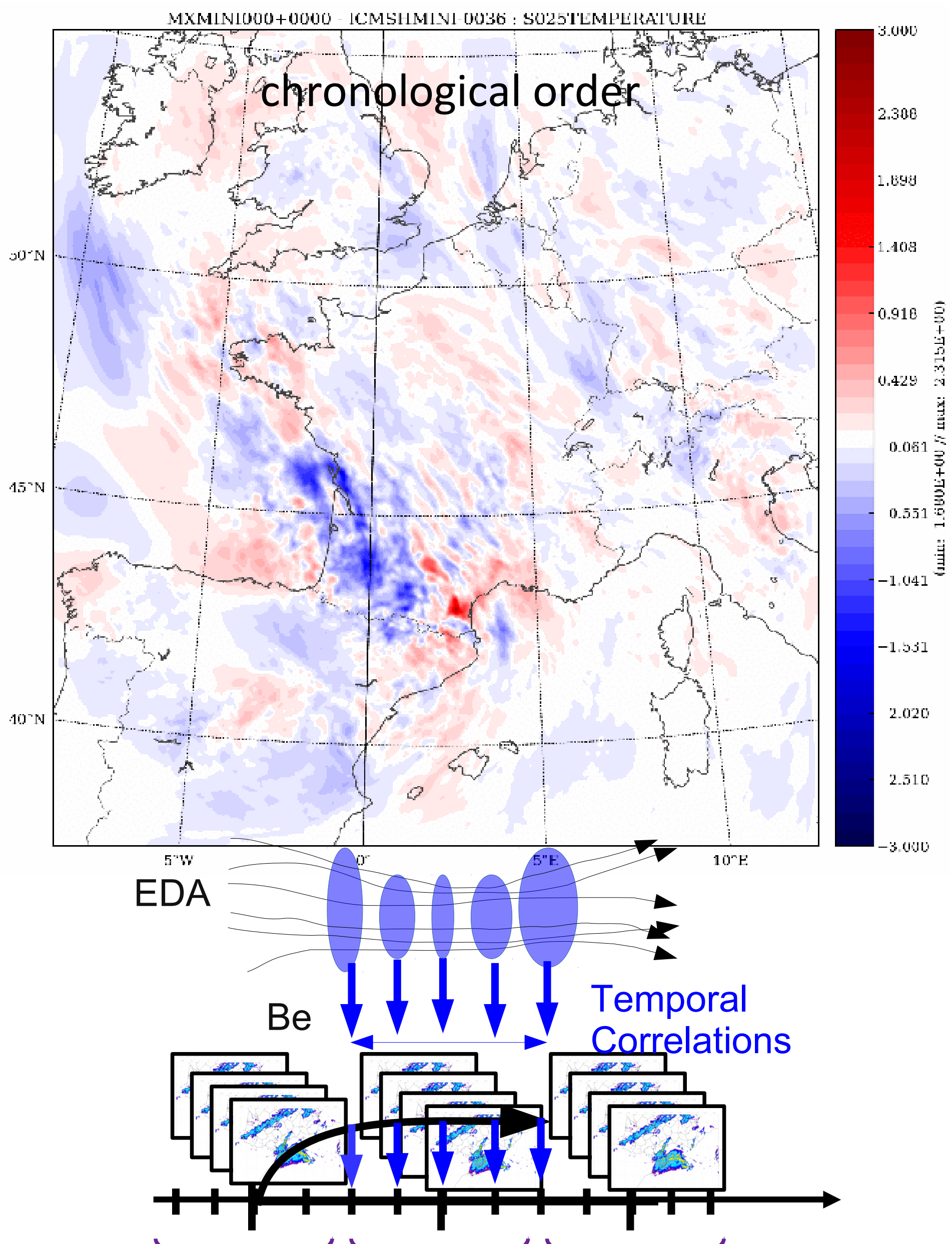
4° temperature innovation at 350 hPa at t+2h





4D Temperature increment

- temporal consistency



4D Temperature increment

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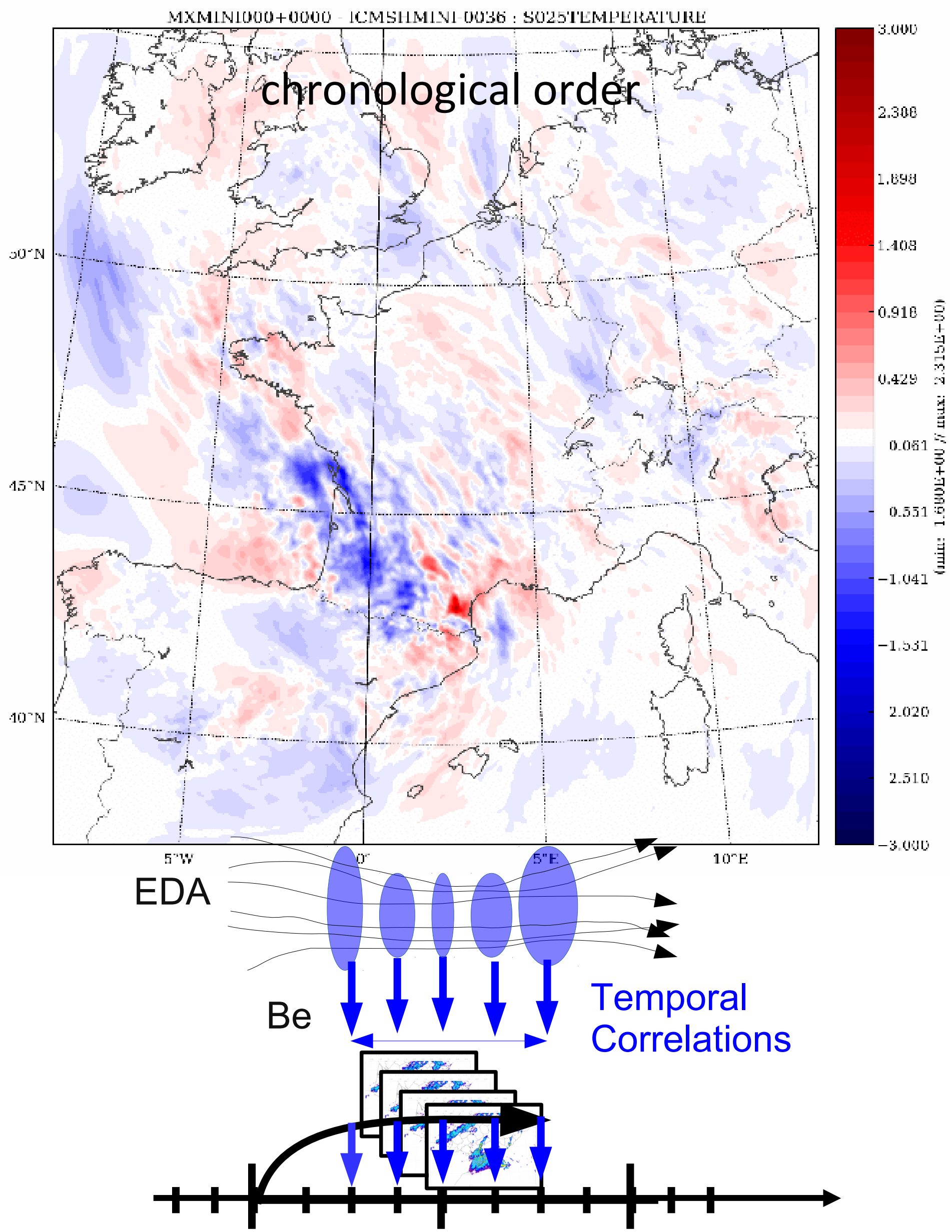

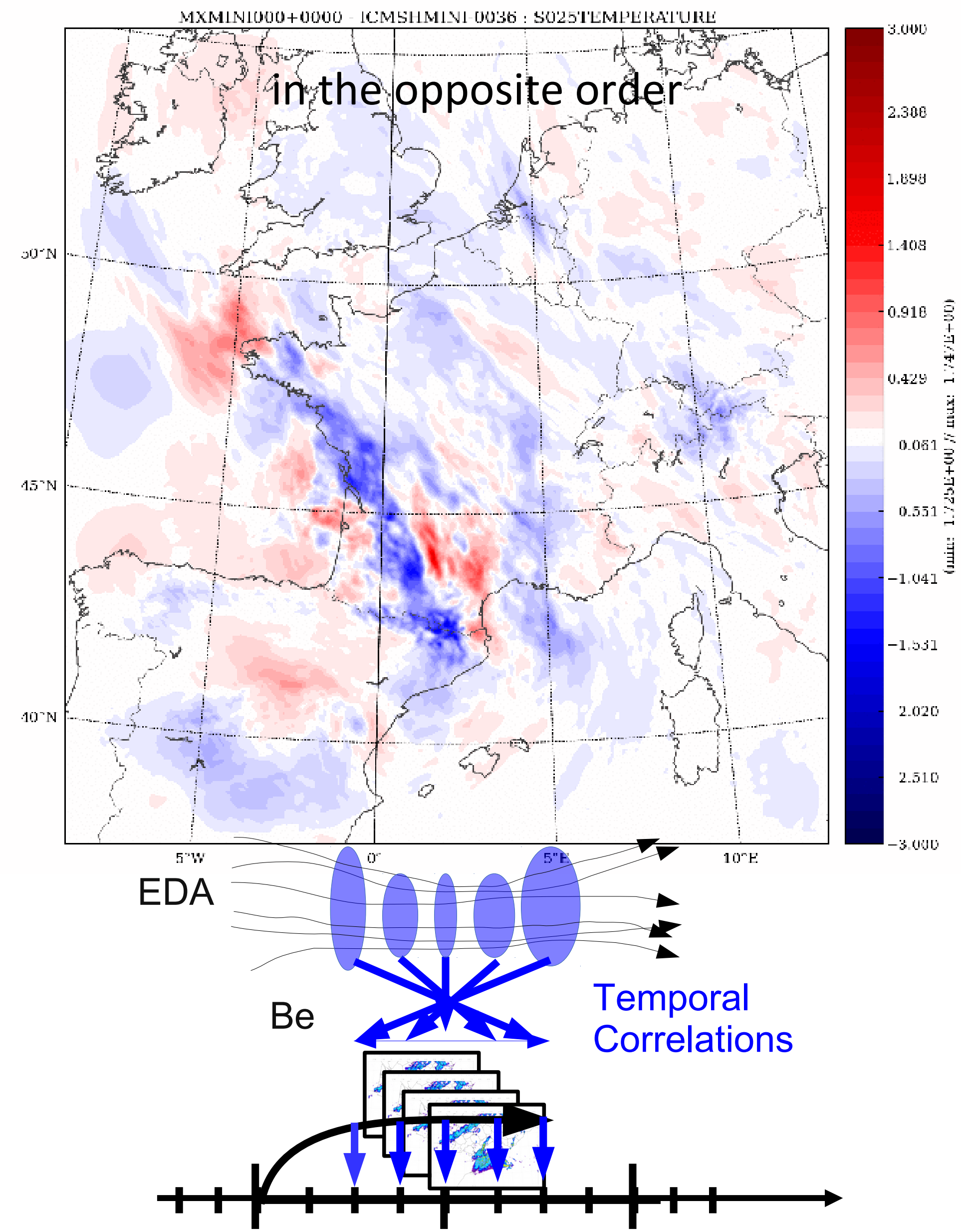

4D Temperature increment

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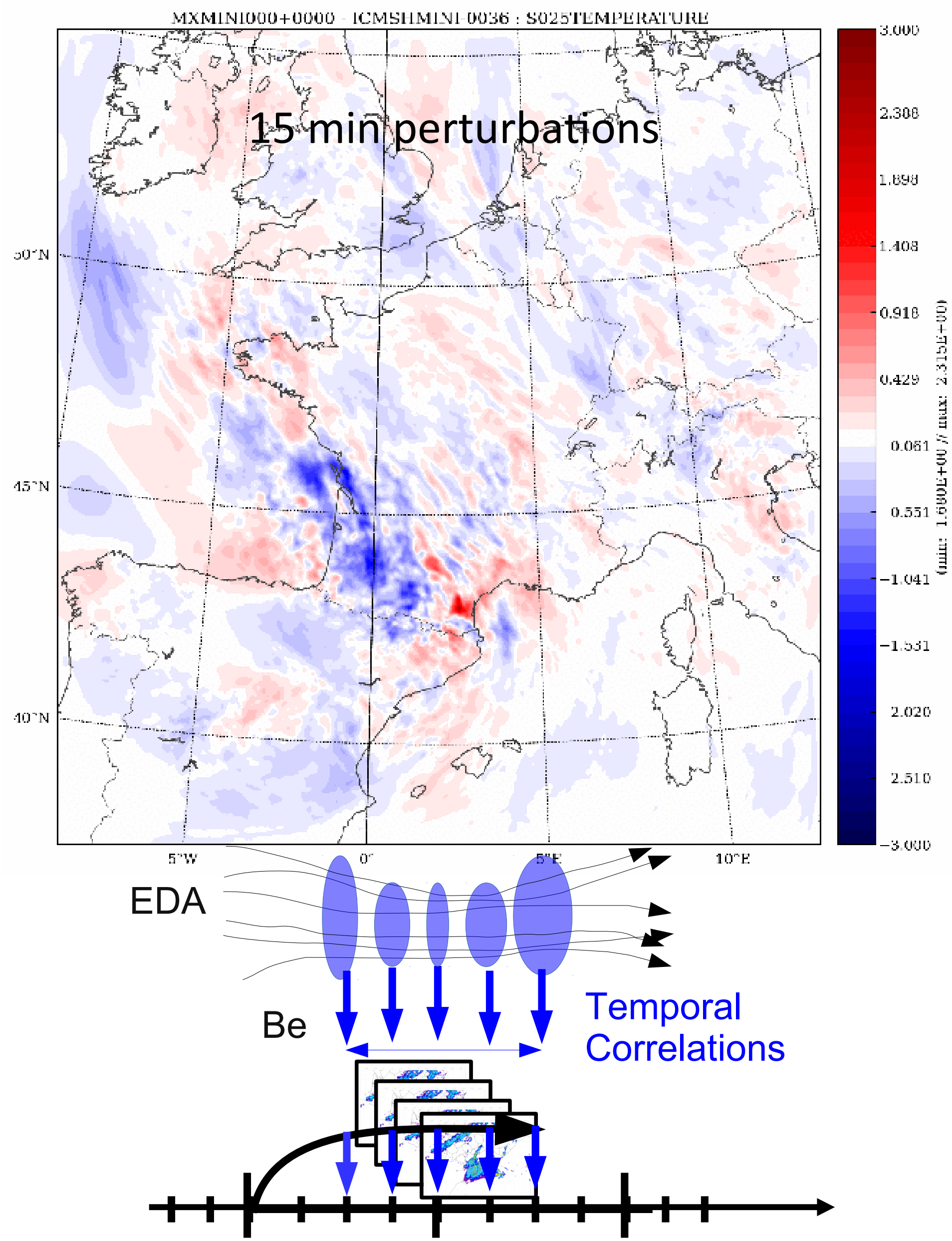
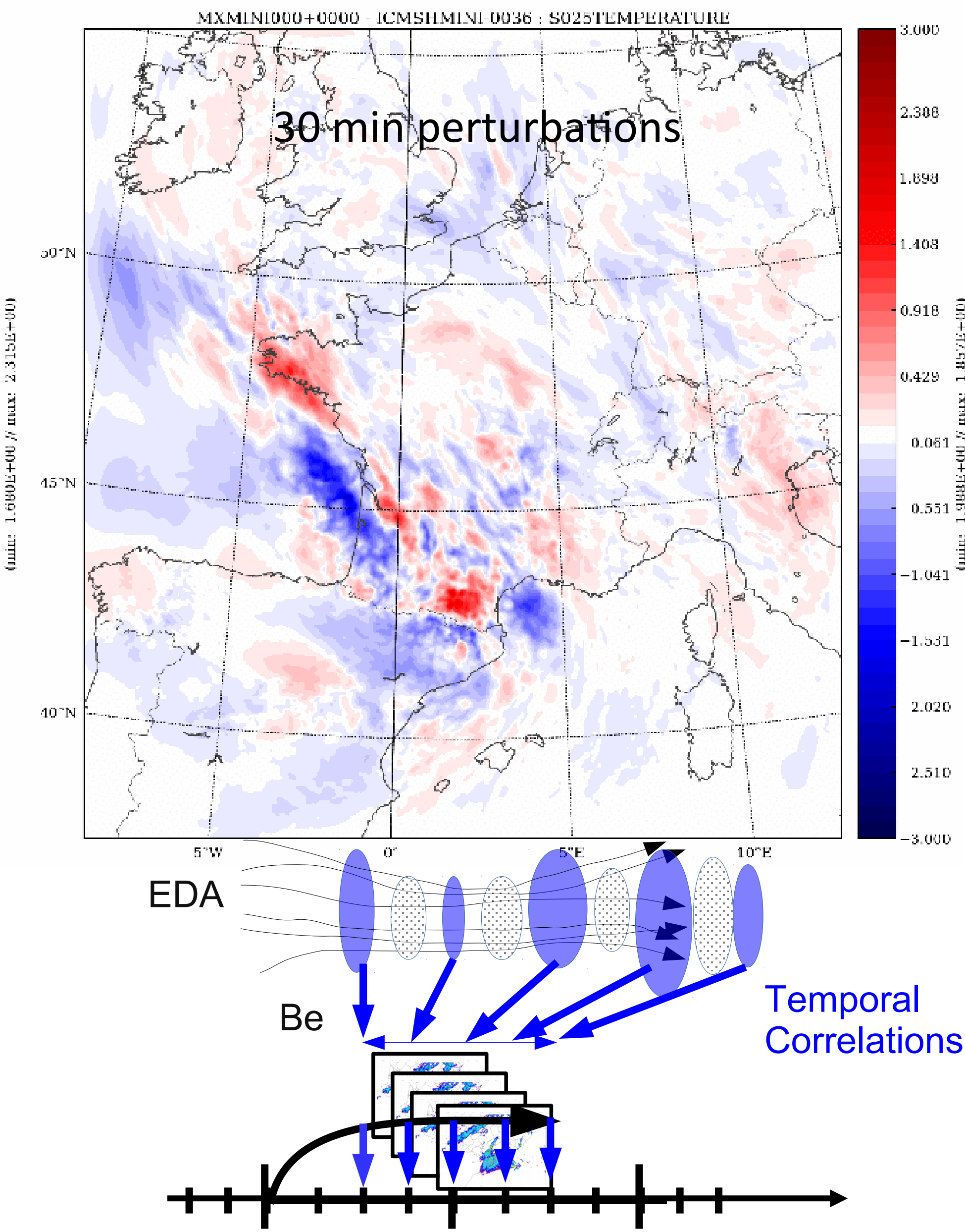
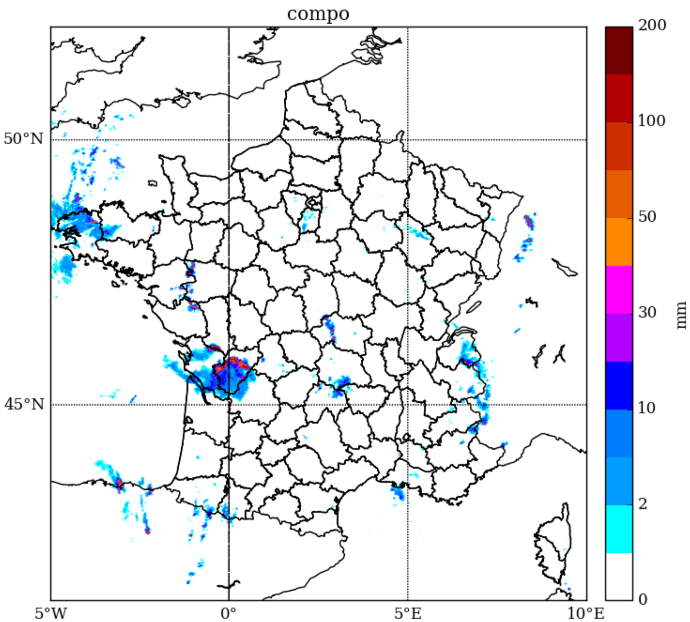
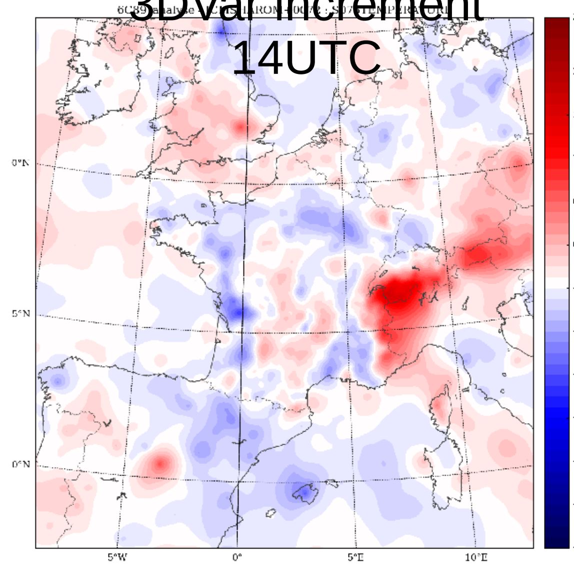




4DEnvar: 15 minutes increments



3DVar increment
14UTC



3DEnvar increment
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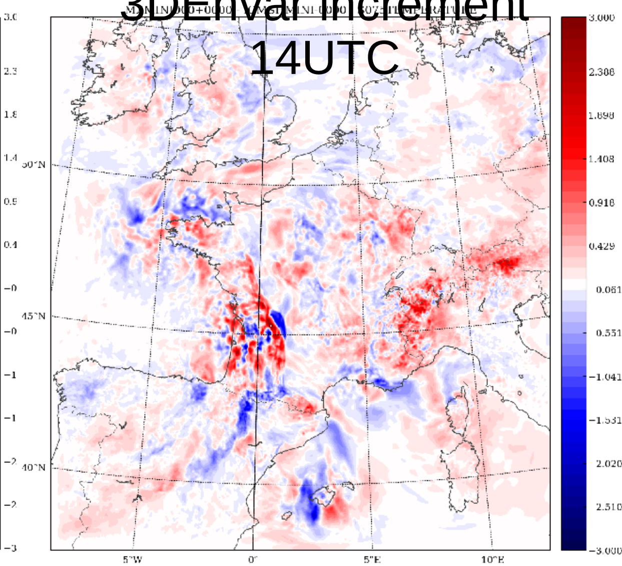
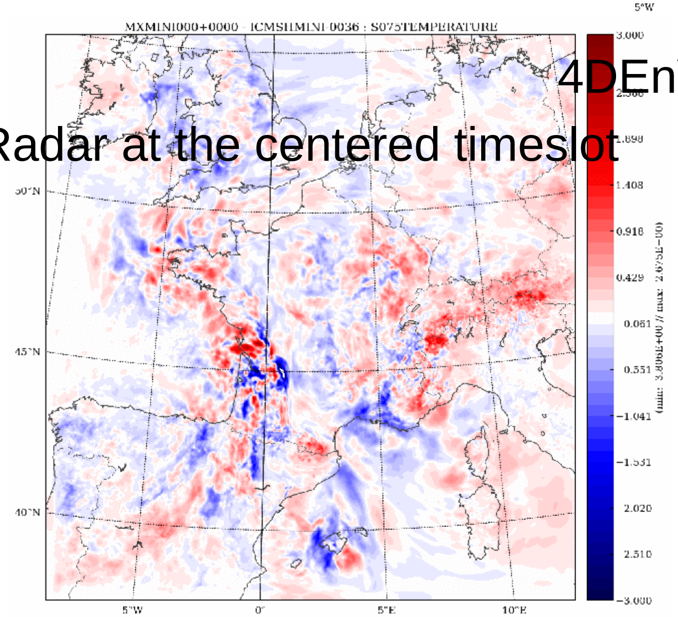
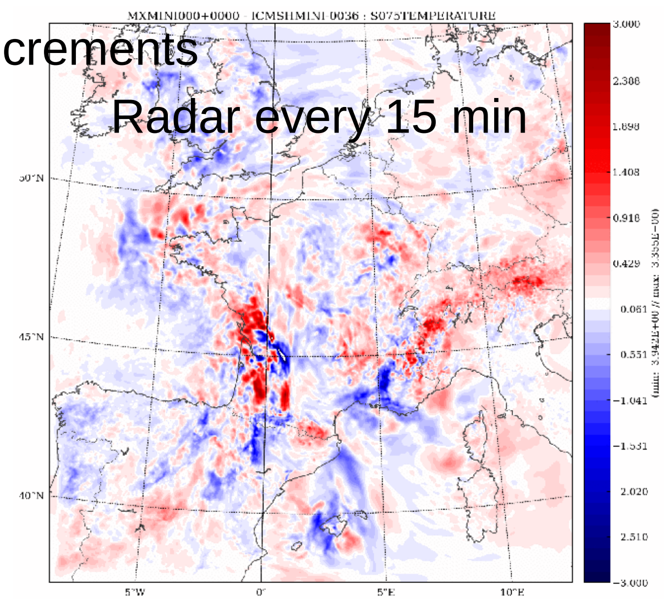


4DEnVar increments

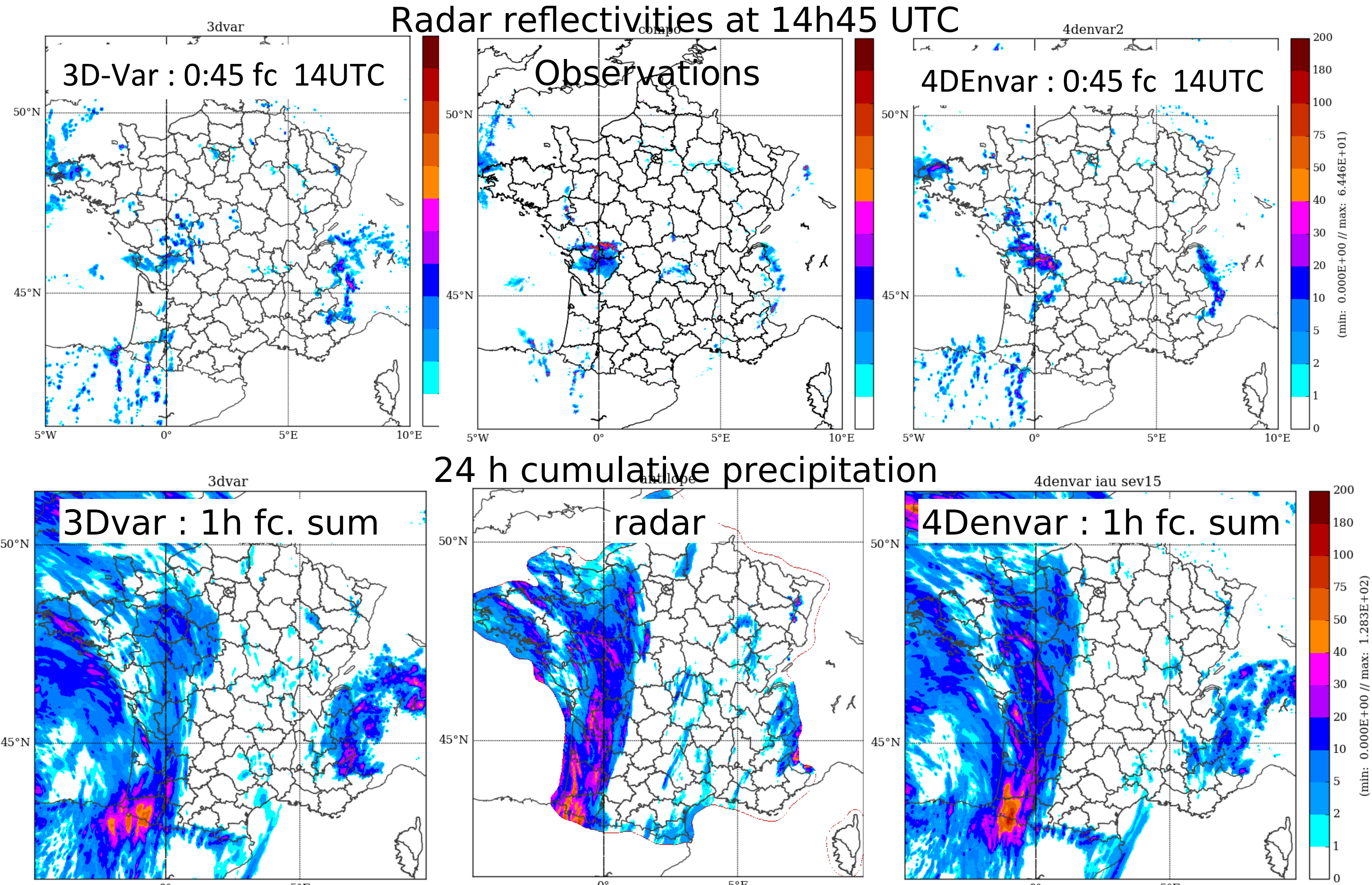
Radar at the centered timeslot



Radar every 15 min



4DEnvar case study 26/05/2018



Conclusion : towards Envar systems at Météo-France

- towards Envar (3D and 4D) scheme under OOPS :

- Numerous ingredients already available and validated :

- B or B1/2 pre-conditioning
- control variable extending
- spectral/spatial localisation
- localisation length-scale dependent on the variable, height, scale
- advection of the localisation (4D)
- resolution changes
- variational bias correction (recent development)

- Validation :

3Denvar :

- Encouraging results using a low resolution configuration
- To be confirmed with the full system over a long period

4Denvar :

- Encouraging results on case studies
- Validation over a long period to be done (new HPC)

In operations in 2022 ?

References

Brousseau, P., Seity, Y., Ricard, D., & Léger, J. (2016). Improvement of the forecast of convective activity from the AROME-France system. Quarterly Journal of the Royal Meteorological Society, 142(699), 2231-2243.

Caron, J. F., Michel, Y., Montmerle, T., & Arbogast, É. (2019). Improving background error covariances in a 3D ensemble–variational data assimilation system for regional NWP. Monthly Weather Review, 147(1), 135-151.

Desroziers, G., Camino, J. T., & Berre, L. (2014). 4DEnVar: link with 4D state formulation of variational assimilation and different possible implementations. Quarterly Journal of the Royal Meteorological Society, 140(684), 2097-2110.

Desroziers, G., Arbogast, E., & Berre, L. (2016). Improving spatial localization in 4DEnVar. Quarterly Journal of the Royal Meteorological Society, 142(701), 3171-3185.

Destouches, M., Montmerle, T., Michel, Y., & Ménétrier, B. Estimating optimal localization for sampled background error covariances of hydrometeor variables. Quarterly Journal of the Royal Meteorological Society.2020 doi.org/10.1002/qj.3906

Ménétrier, B., Montmerle, T., Michel, Y., & Berre, L. (2015). Linear filtering of sample covariances for ensemble-based data assimilation. Part I: Optimality criteria and application to variance filtering and covariance localization. Monthly Weather Review, 143(5), 1622-1643.

Montmerle, T., Michel, Y., Arbogast, E., Ménétrier, B., & Brousseau, P. (2018). A 3D ensemble variational data assimilation scheme for the limited-area AROME model: Formulation and preliminary results. Quarterly Journal of the Royal Meteorological Society, 144(716), 2196-2215.