A 4DEnVar scheme for Arome-France : presentation and evaluation

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Météo-France, DESR/CNRM/GMAP

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- At Météo-France, a 3DEnVar scheme, utilising OOPS, will become operational for AROME-France next month in the current 1hr data assimilation cycle (instead of the historical 3D-Var one) : see V. Vogt's talk at 45th EWGLAM and 30th SRNWP Meeting 2023

-The next evolution planned for the next E-suite : 4DEnVar in the 1hr cycle in order to :

- assimilate 15min observations : radar, surface, ground GNSS and SEVIRI observations

- improve the comparison to the background for the others ones (polar satellites, …)

- the present talk aims :

- to introduce the 4DEnVar scheme

- to introduce the MF's AROME-France implementation

- to show some evaluation results against 3DEnVar

- **Introduction to a 4DEnVar DA system**

- **Proposal for the next AROME-France E-suite and evaluation.**

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

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

→ a LAM 4D-var is available in IFS/ARP/ARO/HAR code but relies on the ALADIN model

- direct model : hydrostatic dynamic, less sophisticated physic (only 4 hydrometeors without graupel), without surfex

- Tangent and adjoint model : hydrostatic, very simple simplified physic

→ In a 4DEnVar scheme :

4DEnVar :
$$J(\underline{\delta\mathbf{x}}) = \frac{1}{2}(\underline{\delta\mathbf{x}})^T\underline{\mathbf{B}}^{-1}(\underline{\delta\mathbf{x}}) + \frac{1}{2}(\underline{\mathbf{d}} - \underline{\mathbf{H}\delta\mathbf{x}})^T\underline{\mathbf{R}}^{-1}(\underline{\mathbf{d}} - \underline{\mathbf{H}\delta\mathbf{x}})$$ (Desroziers et al. 2014)
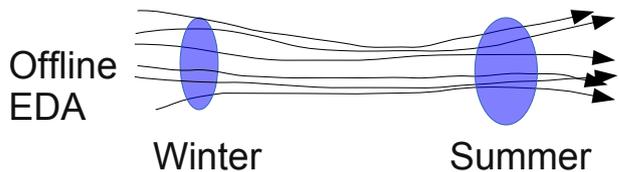
$$\underline{\delta\mathbf{x}} = \begin{pmatrix} \delta\mathbf{x}_0 \\ \delta\mathbf{x}_1 \\ \vdots \\ \delta\mathbf{x}_K \end{pmatrix} \qquad \underline{\mathbf{B}} = \widetilde{\underline{\mathbf{B}}}^e = \begin{pmatrix} \widetilde{\mathbf{B}}_{0,0}^e & \widetilde{\mathbf{B}}_{0,1}^e & \cdots & \widetilde{\mathbf{B}}_{0,K}^e \\ \widetilde{\mathbf{B}}_{1,0}^e & \widetilde{\mathbf{B}}_{1,1}^e & & \widetilde{\mathbf{B}}_{1,K}^e \\ \vdots & & \ddots & \\ \widetilde{\mathbf{B}}_{K,0}^e & \cdots & & \widetilde{\mathbf{B}}_{K,K}^e \end{pmatrix}$$ Provided by an EDA
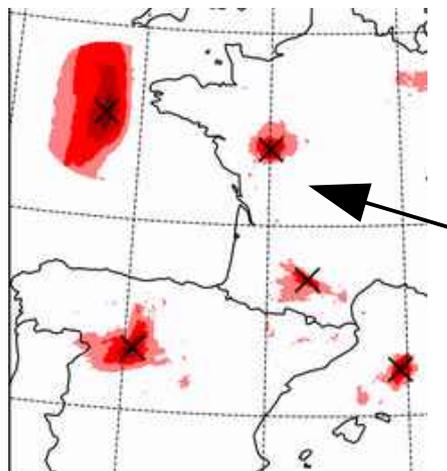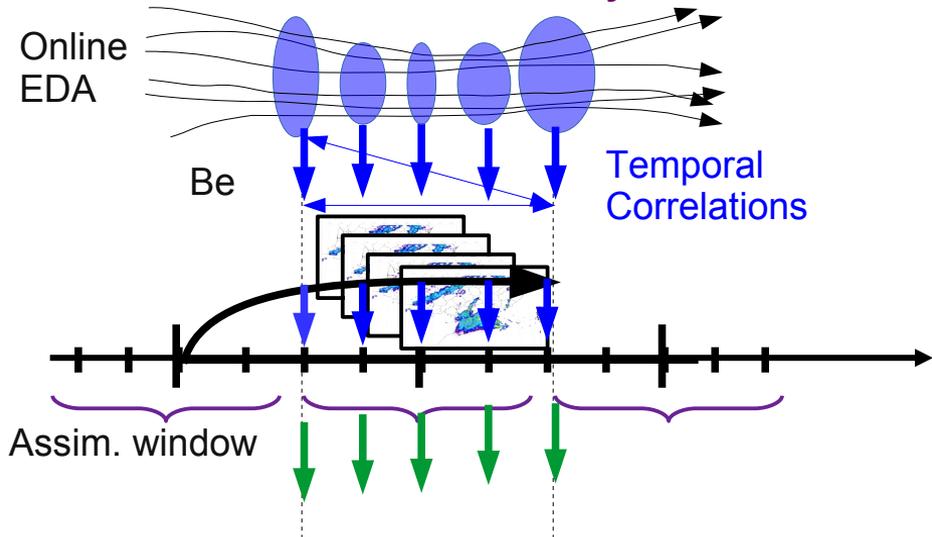
Towards a 4D scheme

AROME 4D-Var, 1-h Cycle

X

X

TL/AD

Trajectory

time
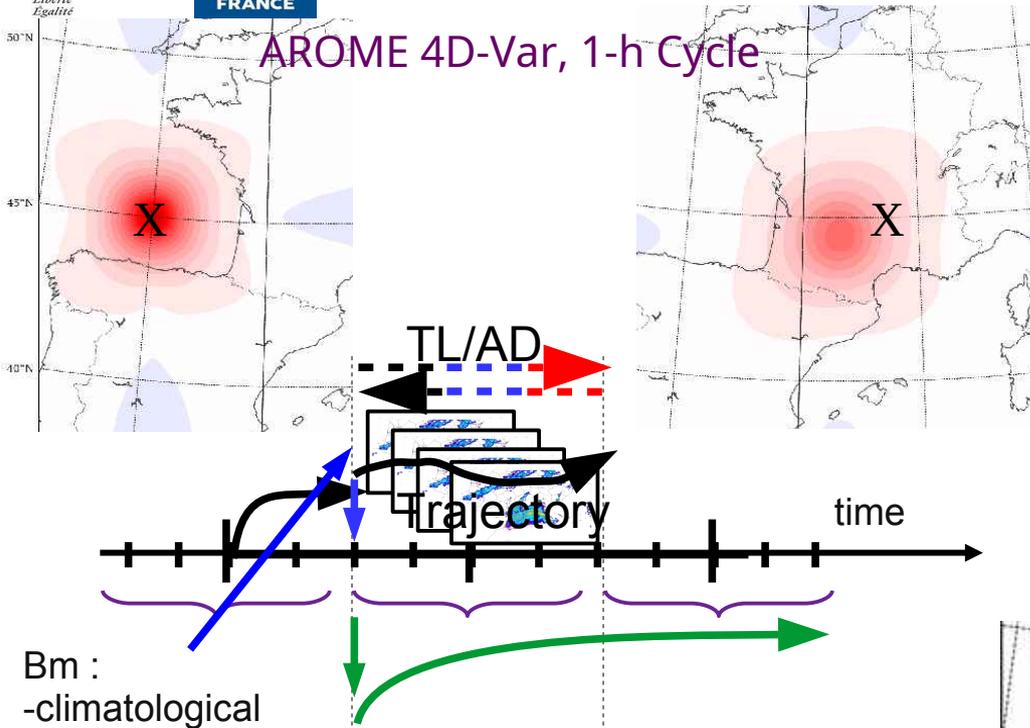
Bm :
-climatological
-spectral
-homogenous
(as in 3dvar)

Offline
EDA

Winter   Summer

AROME 4DEnvar, 1-h Cycle
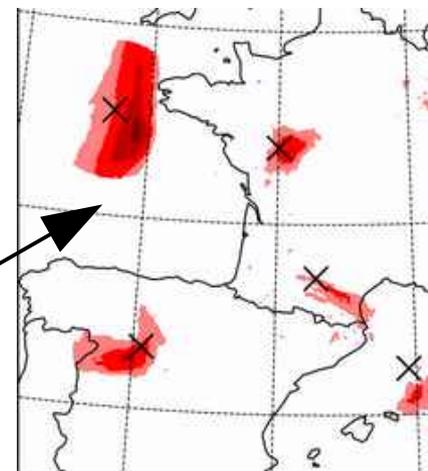
Online
EDA

Be

Temporal
Correlations

Assim. window
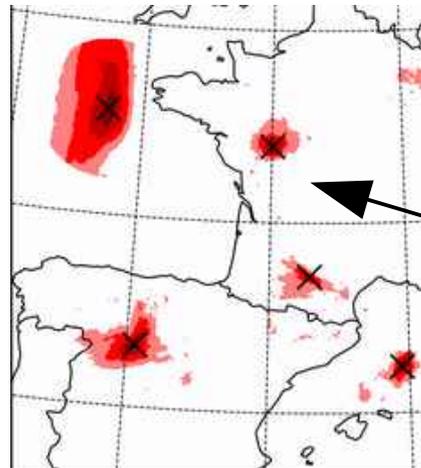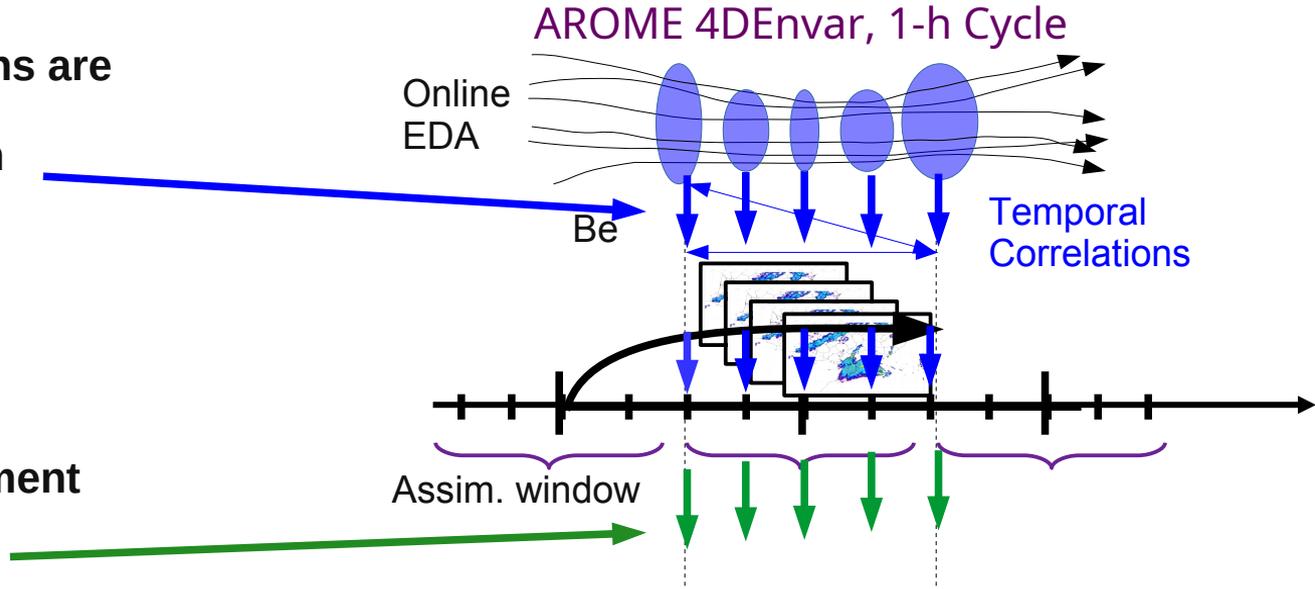
q 850hPa
error
correlation

at h-30m

between
h-30m and
h+30m

(V. Chabot)

Towards a 4D scheme : 2 challenges

How the temporal error correlations are able to manage the temporal information along the assimilation window ?

How should we use the 4D increment to start the new forecast ?

AROME 4DEnvar, 1-h Cycle

Online EDA

Be

Temporal Correlations

Assim. window

q 850hPa error correlation

at h-30m

between h-30m and h+30m

(V. Chabot)
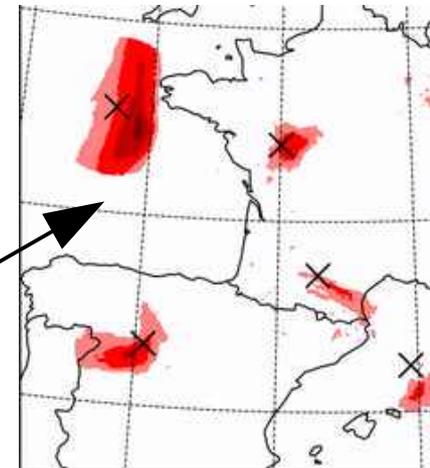
4D Temperature increment at 850 hPa

compo

3DVar increment
14UTC

3DEnvar increment
14UTC

4DEnVar increments
13h30-14h30
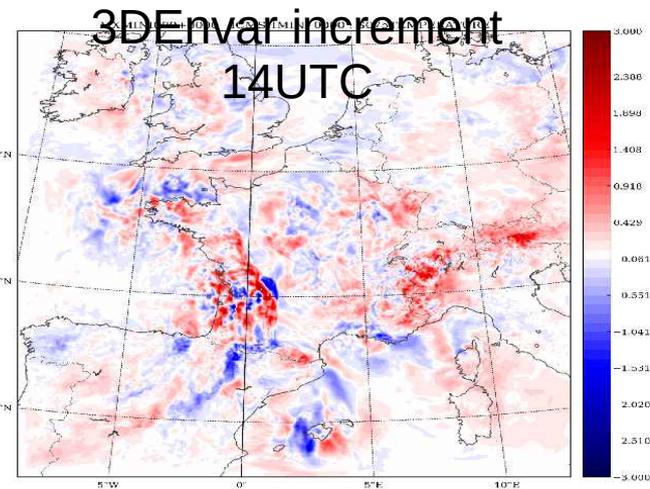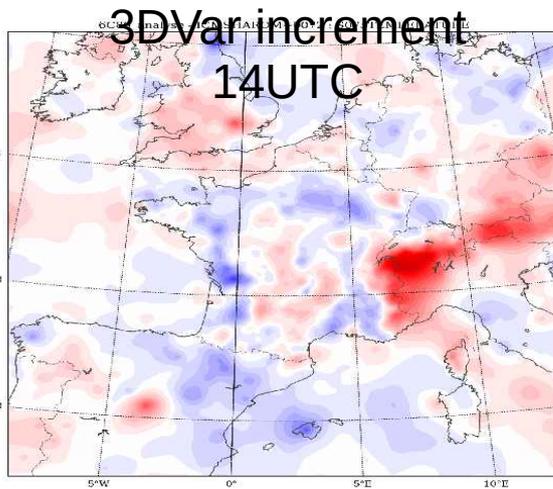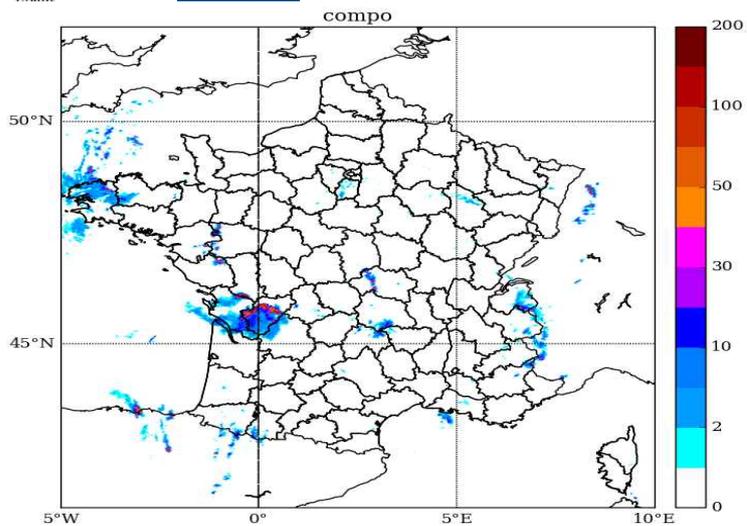
Using the same radar observations
only at the assimilation window center
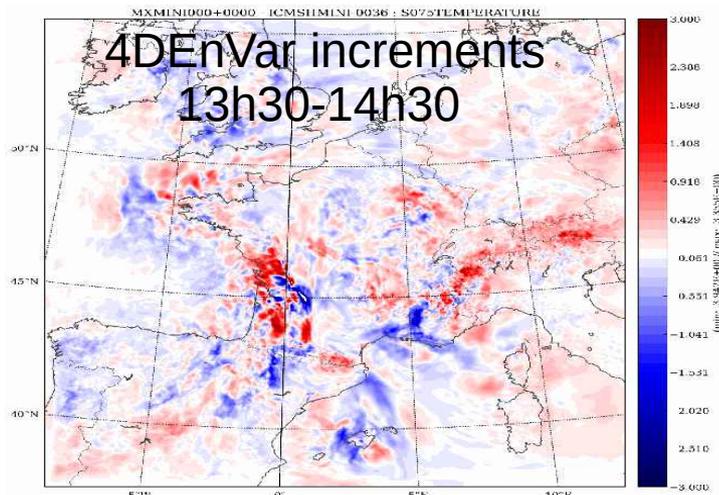
Temporal correlation highlight

One 4DEnVar minim compared to five 3DEnvar minims using :
- the same observations : only 15 minutes radar
- the same 15 min background states
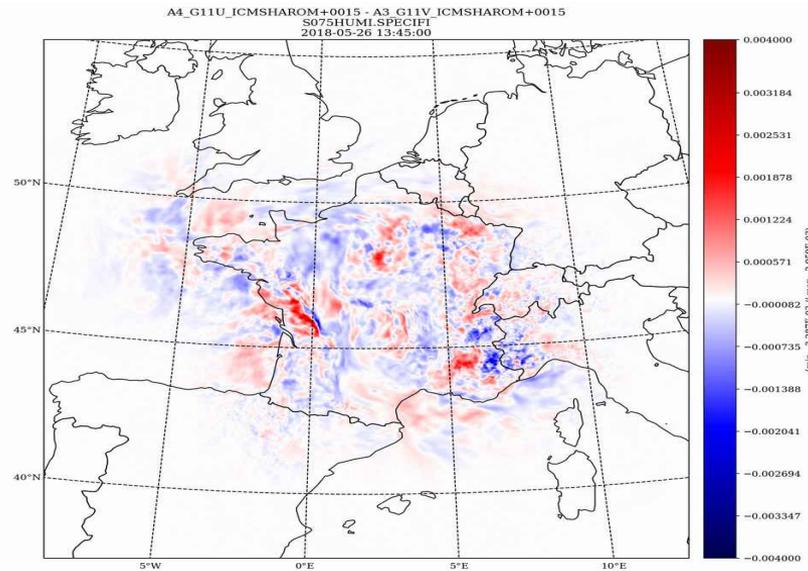- the same 15 minutes background covariances from the EDA

4DEnvar, 1-h Cycle

Multi 3DEnvar, 1-h Cycle

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

EDA

Be

Temporal Correlations

EDA

Be

4D inc.

Five 3D inc.
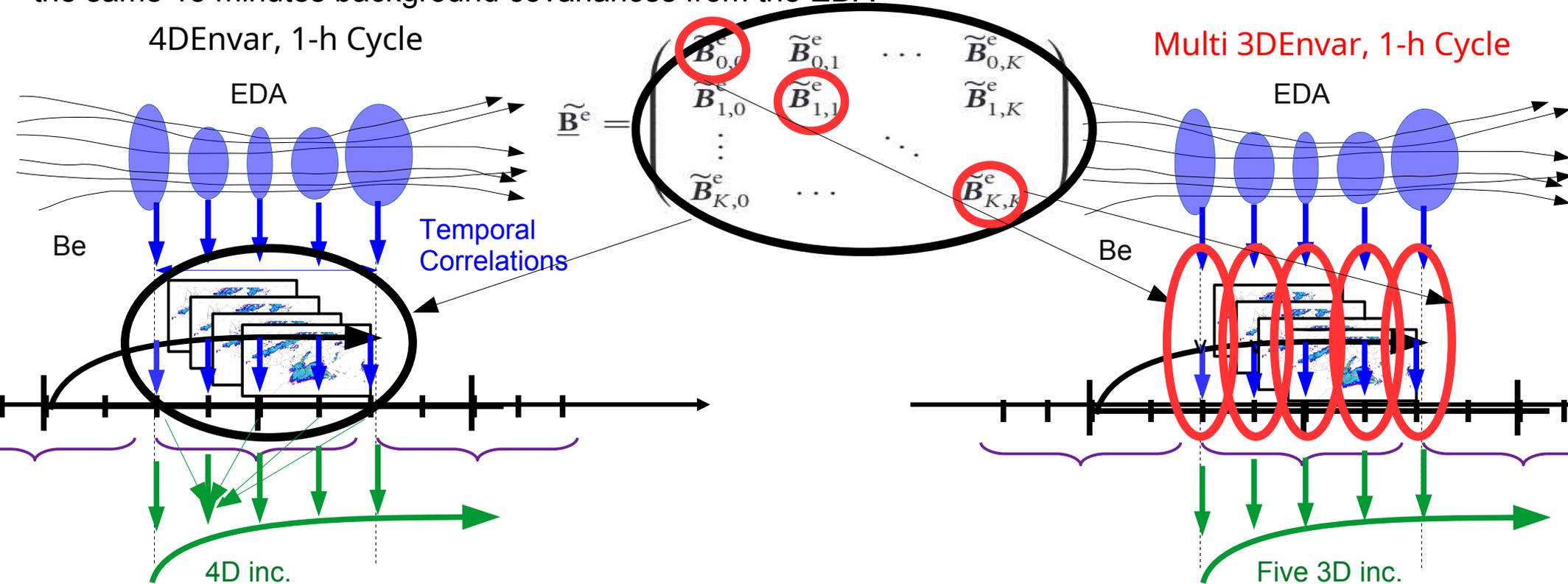
Temporal correlation highlight

15 min animation of the specific humidity analysis increment at 850 hPa : 14 UTC
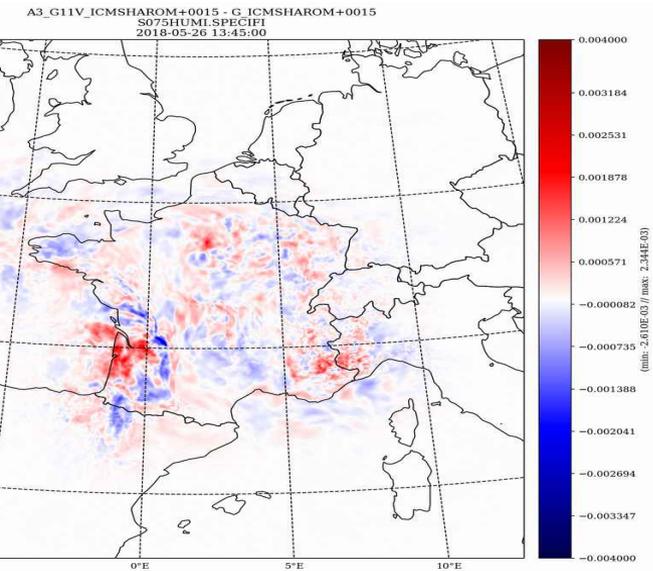
Multi 3DEnvar   4DEnvar-M3DEnvar   4DEnvar
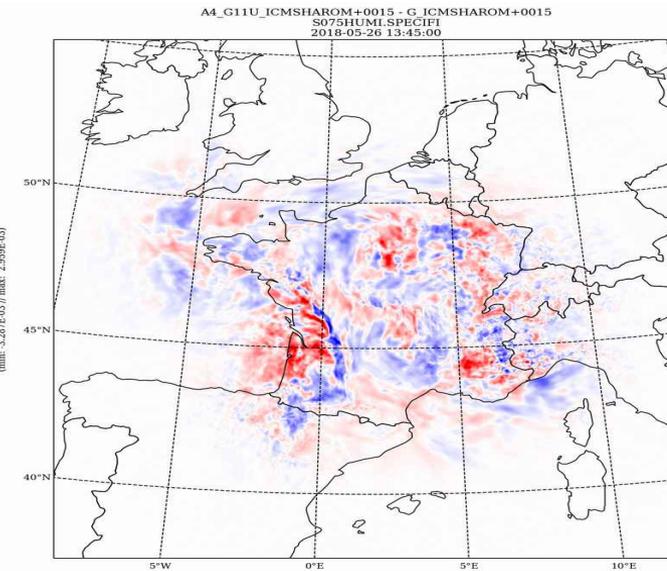
- increment and differences of the same magnitude
- 4DEnVar increment as a better temporal consistency

Temporal correlation of the increment

Temperature at 850 hPa
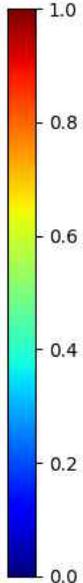
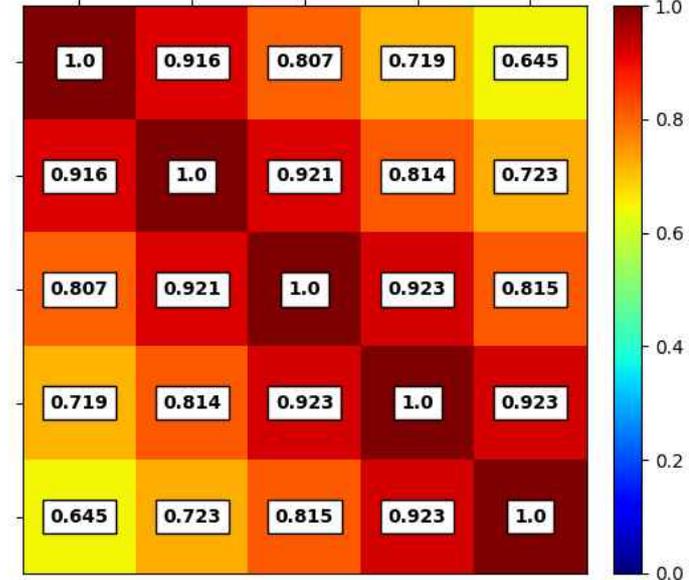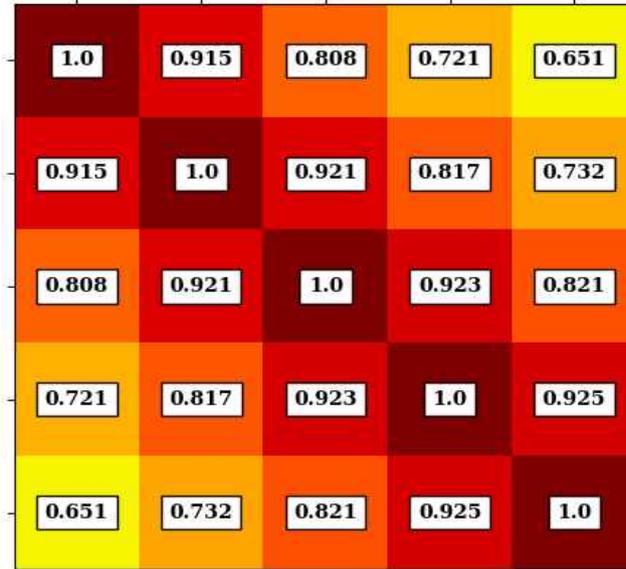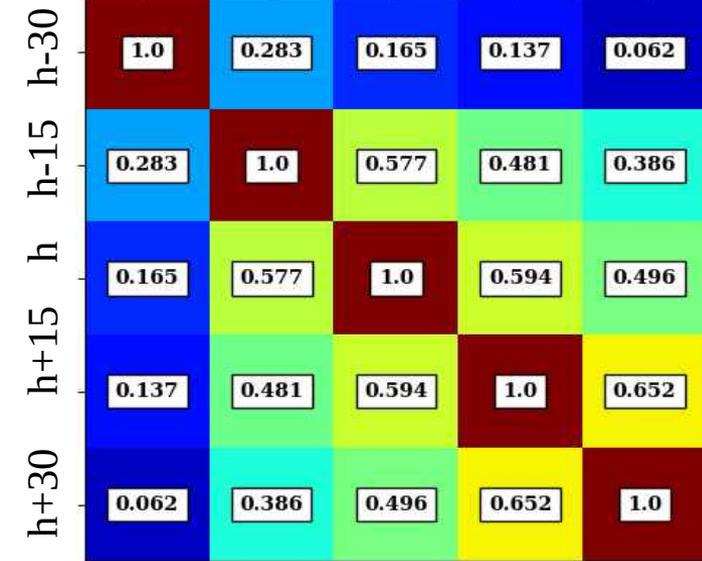- Non diagonal correlations higher in 4DenVar (~ x 2)
- the correlation between the farest timeslots in 4DEnvar is higher than between the nearest ones in Multi 3DEnVar

- **Introduction to a 4DEnVar DA system**

- **Proposal for the next AROME-France E-suite and evaluation.**

Implementation

* Based on the current 3DEnVar implementation :

   - 1,3km horizontal resolution

   - 1 hr assimilation window with 5 timeslots (2x 7 min + 3x 15 min)

   - same observations but radar, SEVIRI, ground-based GNSS and surface stations every 15min

   - perturbations from a 50 members EDA (3DVar in 3hr cycle at 3,2km) at each timeslot : every 15min

   - Localisation length : 25 km at the lowest level to 150km at the highest one

* Challenge : how to use the 4D increment ? In theory, all 3D states are statistically equivalent, and the new forecast can be initiated from any of them :

   - the first one (as in 4D-Var) ?

   - the central one (as in 3D-Var or 3DEnvar) ?

   - actually, better results are obtained by using 20% of all of them by 4D IAU

4D IAU (20 % of the 5 Inc.) —————— Obs-Guess

3D IAU of the Central Inc. (as in 3DEnVar) - - - - - - Obs-Analysis

EDA

Be

Temporal Correlations

4D IAU

RADAR Globe
Used RH

STD.DEV

Numerical cost

EDA

Be

Temporal Correlations

4D IAU
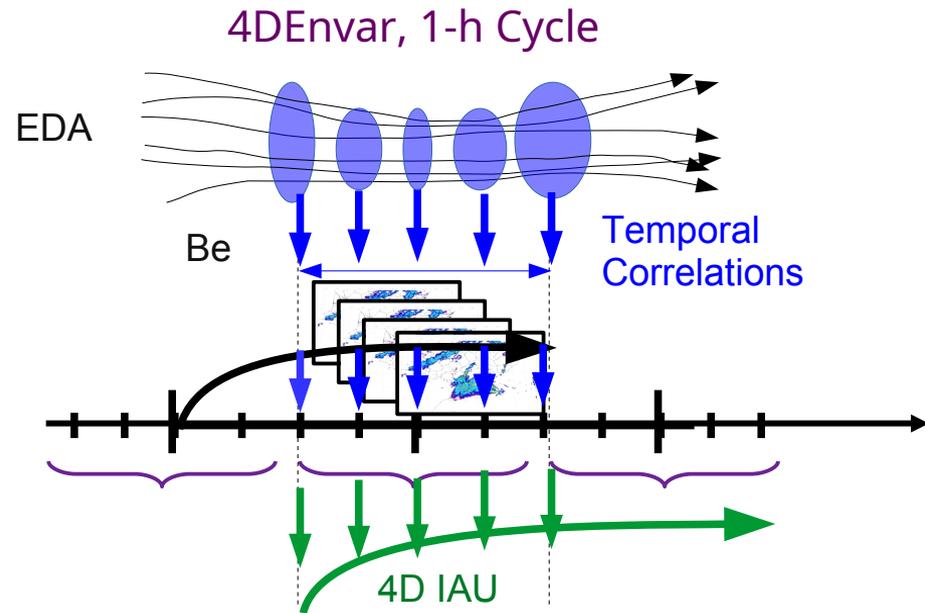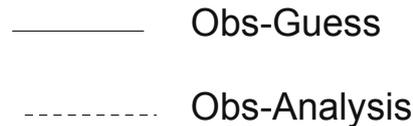
* Numerical cost Vs 3DEnVar :

- screening+minim : time x 2, memory x 5 :

=> need for 24 MF's HPC nodes to run screening+minim in 12 min (12 nodes for 3DEnvar in 10 min or 34 nodes to run a 24h arome forecat in 30 min).

- due to the use of 4D IAU : time x 2 due to the forecast to produce the next background : need for a 2 hr forecast range instead of 1 hr
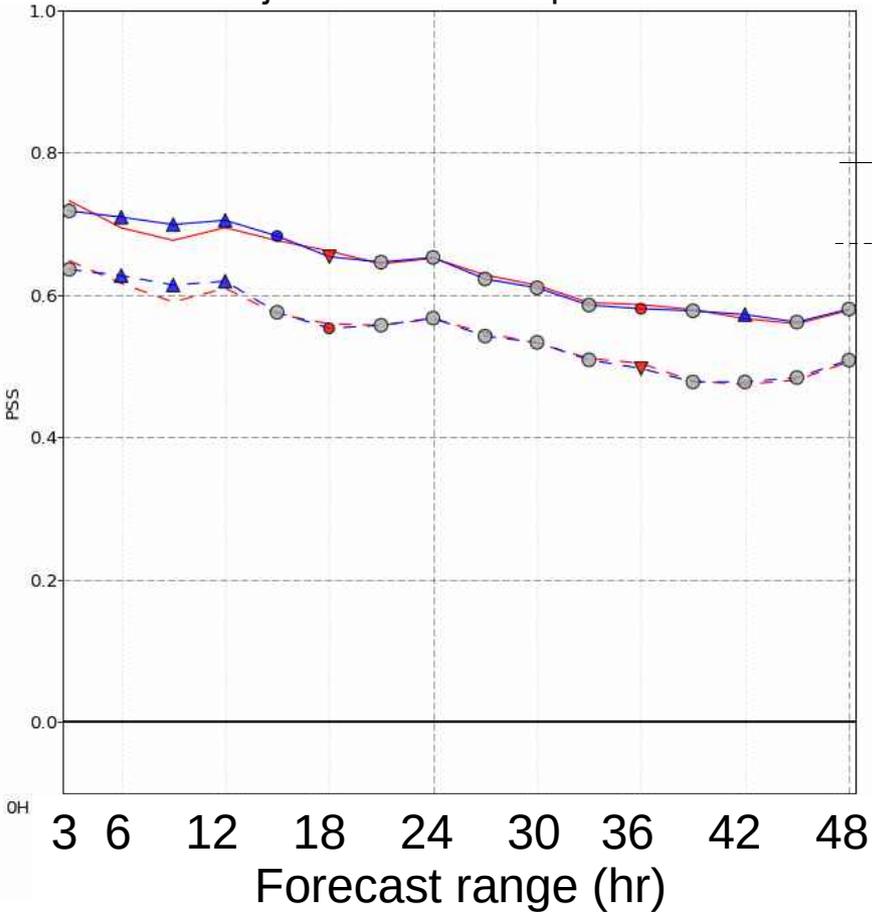
=> +5min on the current 12 nodes used for the DA background

All these additional numerical costs are affordable on the current MF's HPC
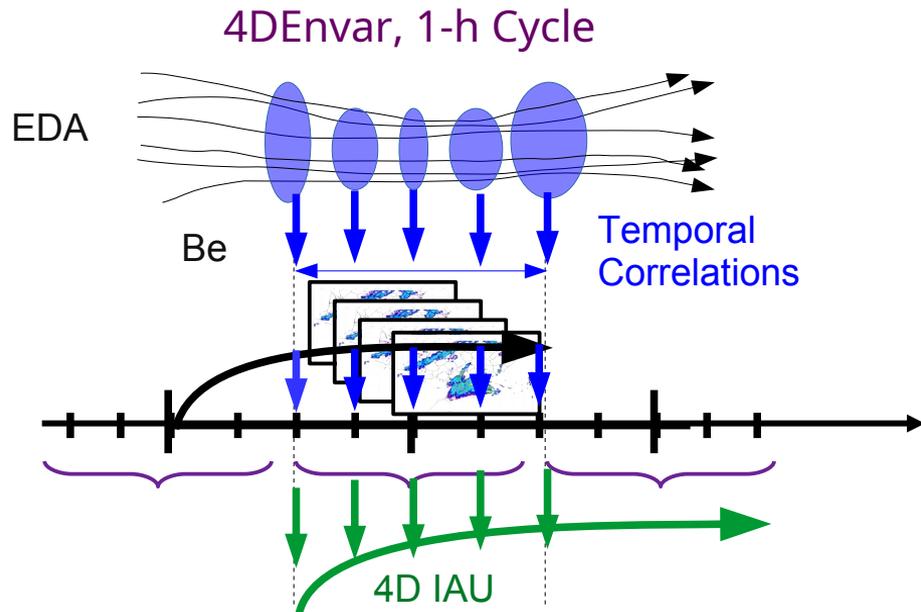
Long range forecast performances (00 UTC) : PSS for RR3h against raingauges : 2mm/3h threshold (but representative of other thresholds)

Oct 2023 – jan 2024 : winter period

May - Jun 2023 : convective period

4DEnVar

3DEnVar

——— 50Km neigh.

- - - - Without neighbourhood

Bootstrap Significancy : 4DEnvar better

At 95 %

At 90 %

Not significant
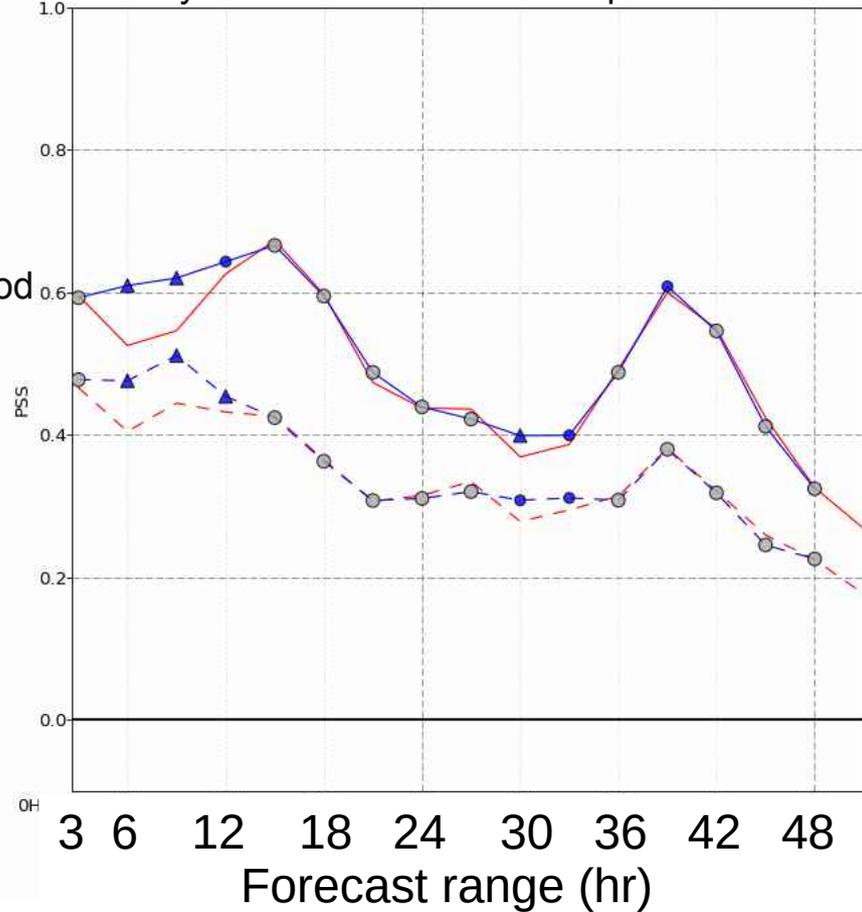
Case study : derecho over Corsica 18 Aug. 2022

- 100-120 km/h generalized wind gusts

- 200-225km/h maximal wind gusts

- 5 casualties

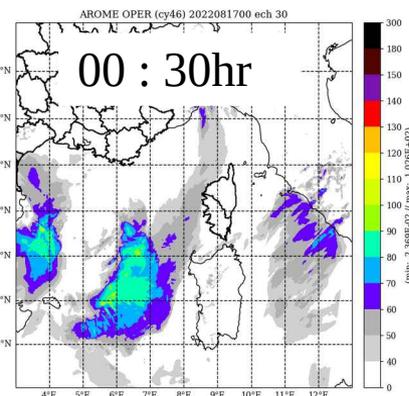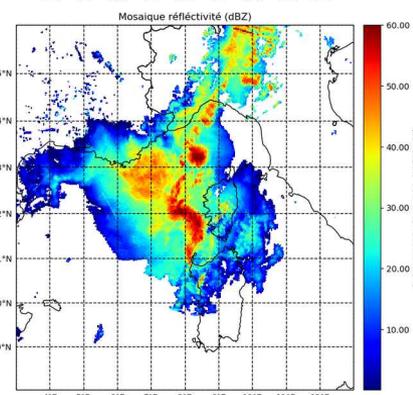- only an late orange warning !!
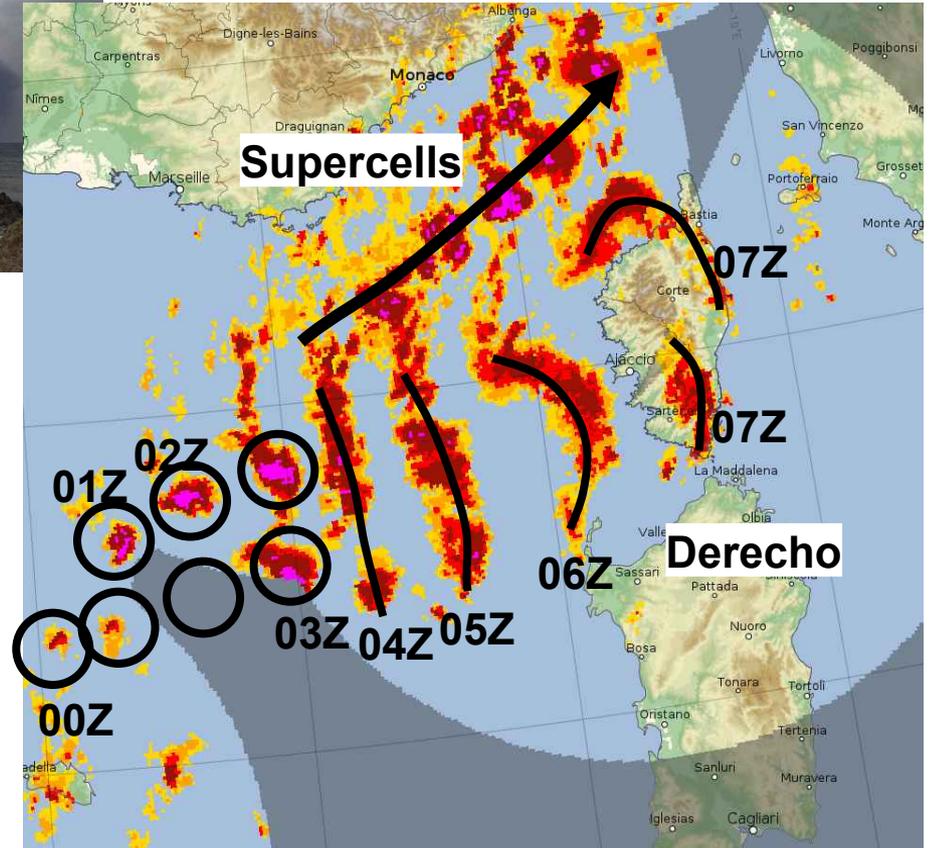
3D-Var

20220817

Wind gusts simulated by the different Arome-france forecasts valid at 06 UTC the 20220818 using 3D-Var : 3 forecasts simulate an interesting signal (Yellow > 110 Km/h)
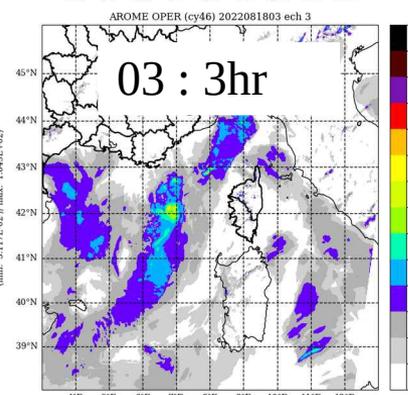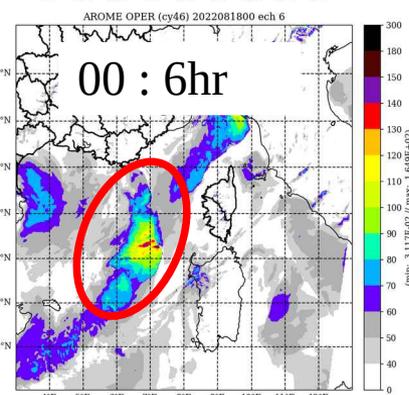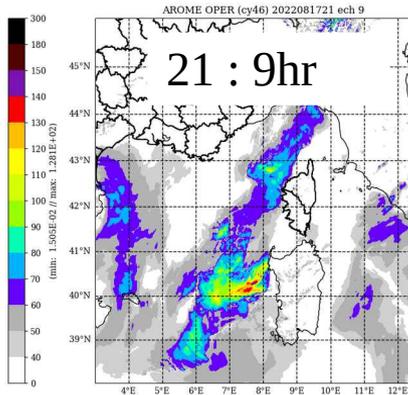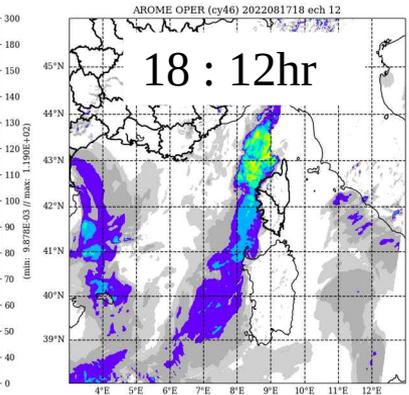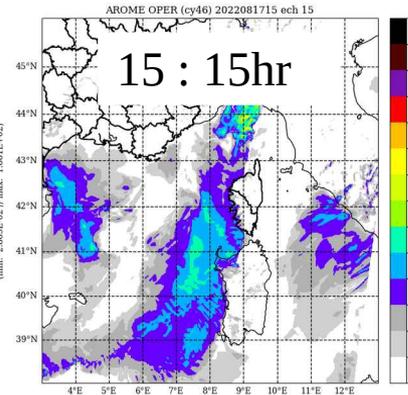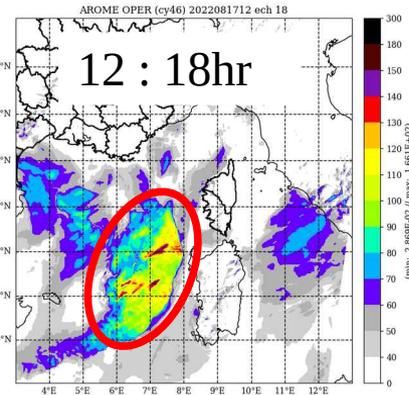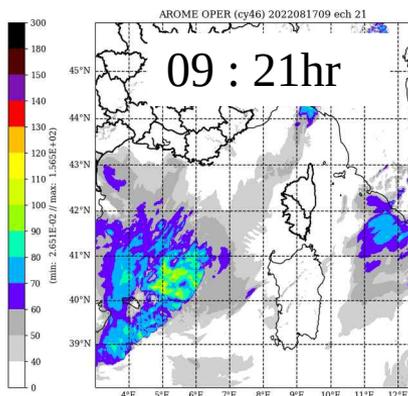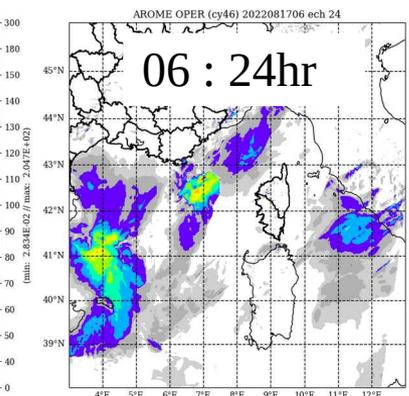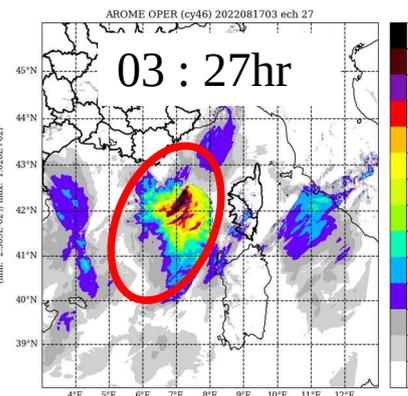
20220818

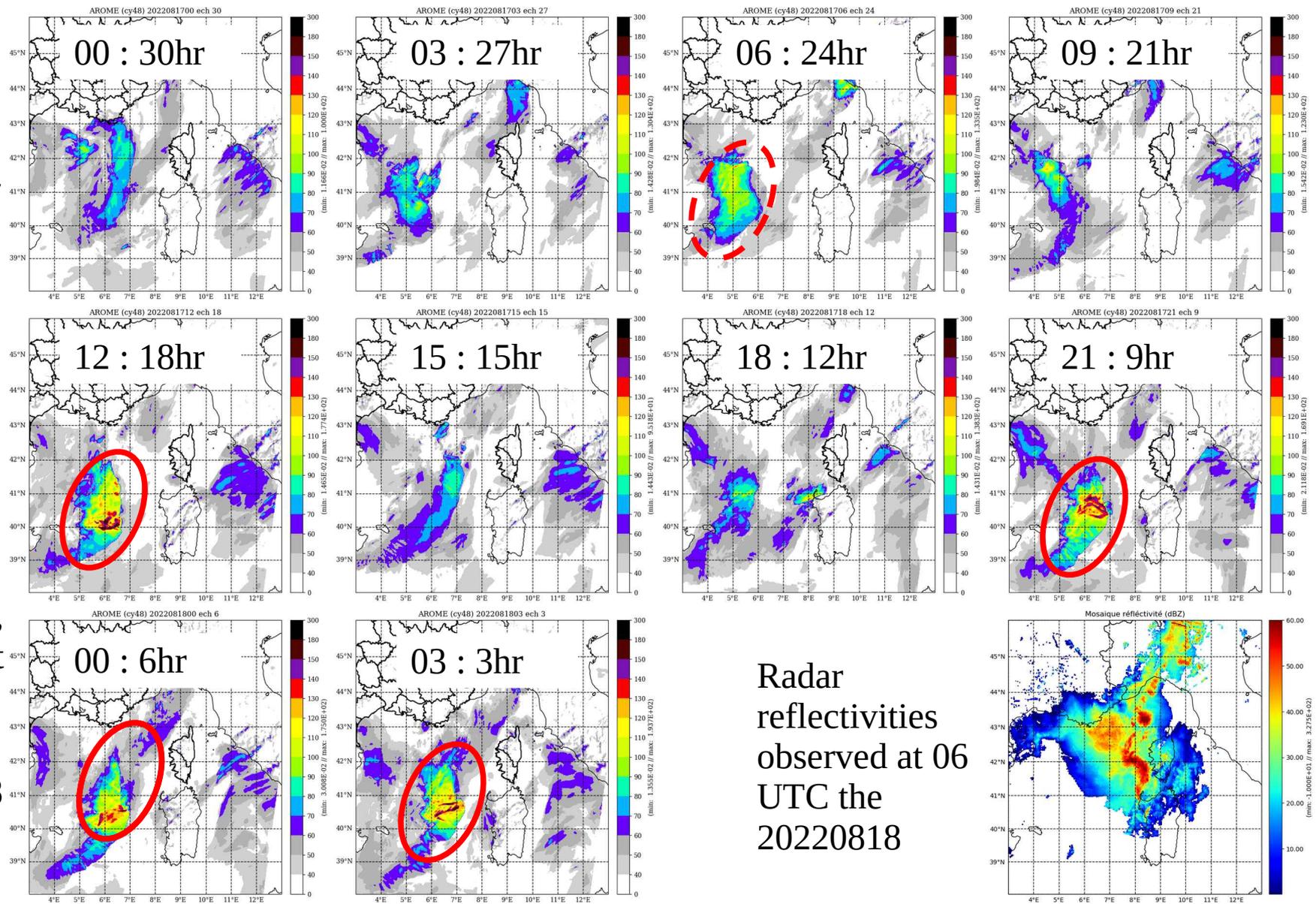Radar reflectivities Observed at 06 UTC the 20220818

3DEnVar

20220817

Wind gusts simulated by the different Arome-france forecasts valid at 06 UTC the 20220818 using 3DEnVar : 5 forecasts simulate an interesting signal, especially the last 3 ones (Yellow > 110 Km/h)
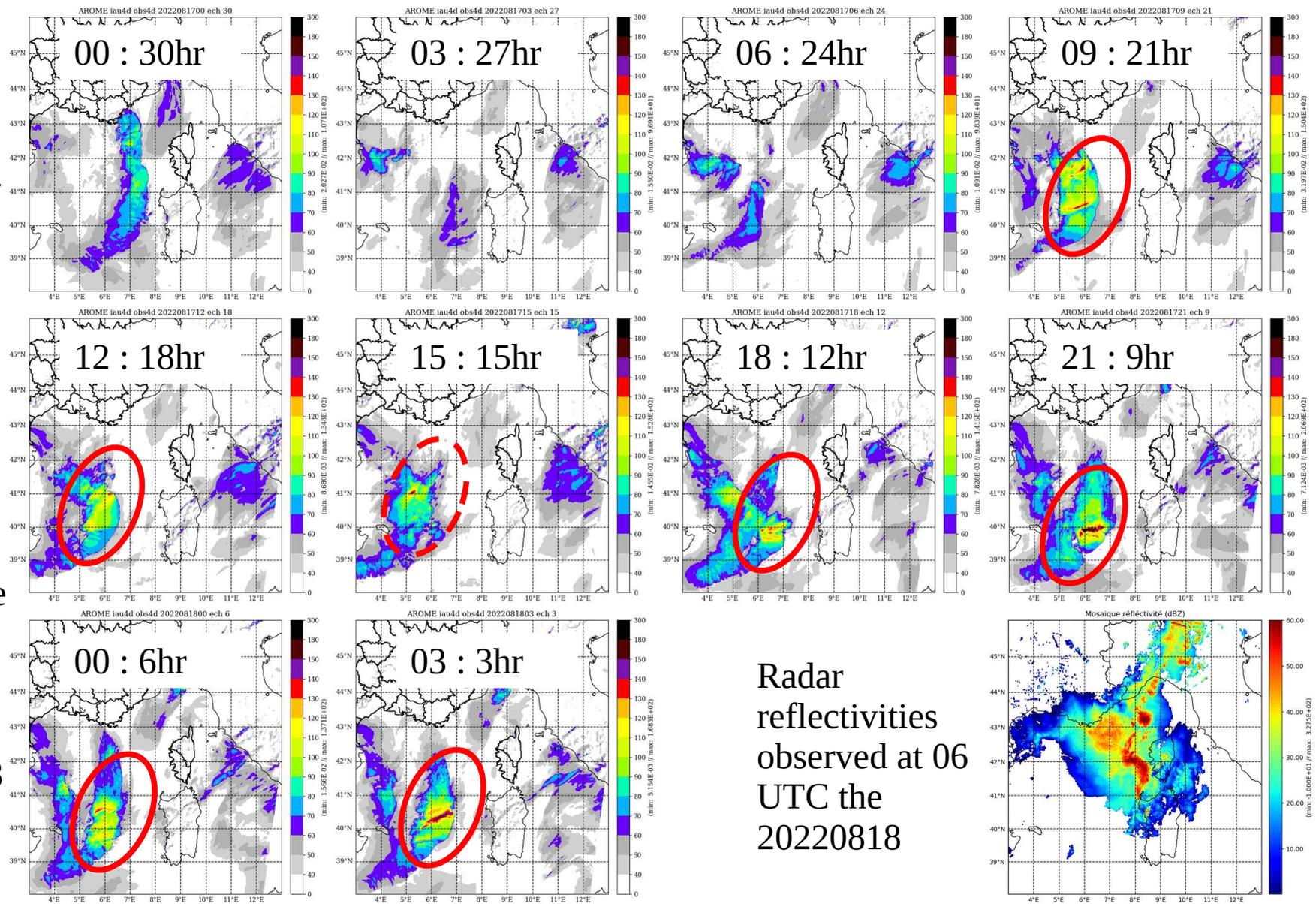
20220818

Radar reflectivities observed at 06 UTC the 20220818

4DEnVar

20220817

Wind gusts simulated by the different Arome-france forecasts valid at 06 UTC the 20220818 using 4DEnVar : the last 7 forecasts simulate an interesting signal (Yellow > 110 Km/h)

20220818

Radar reflectivities observed at 06 UTC the 20220818

Conclusion

A 4DEnVar scheme, utilising OOPS, has reached a sufficient level of maturity and has been well evaluated within the Arome-France framework :

– The temporal dimension is managed by the temporal background error cross-correlations, which are directly estimated from the AROME-France EDA (perturbed non-linear model forecasts)

– This allows for the assimilation of 15-min frequency observations in the 1 hr cycle

– Screening + minim run in 12 min on 24 MF's HPC nodes which is affordable operationally

– General performances (classical scores) are comparable to those of 3DEnVar, but precipitation scores (especially during convective periods) and the simulation of severe events have been improved.

– This 4DEnVar configuration is proposed for incorporation in the next MF E-suite, in addition to Scale Dependent Localisation (V. Vogt) and direct assimilation of radar reflectivities (M. Martet).
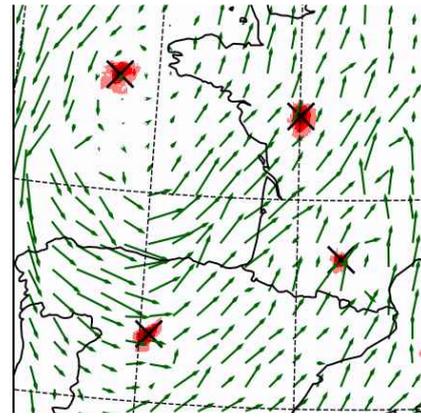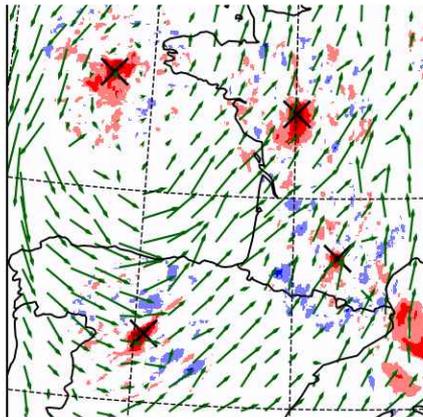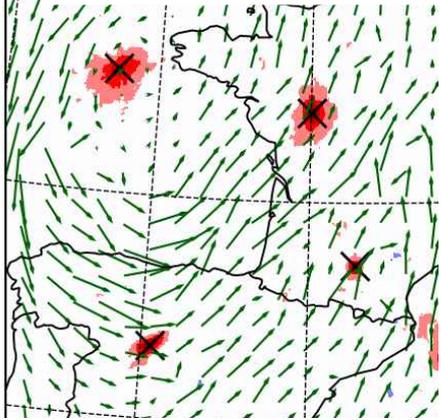
Thank you for your attention …

T+0 : auto-correlations

200 members   50 members   50 members + Loc 66km

T+60min : 1hr temporal correlations

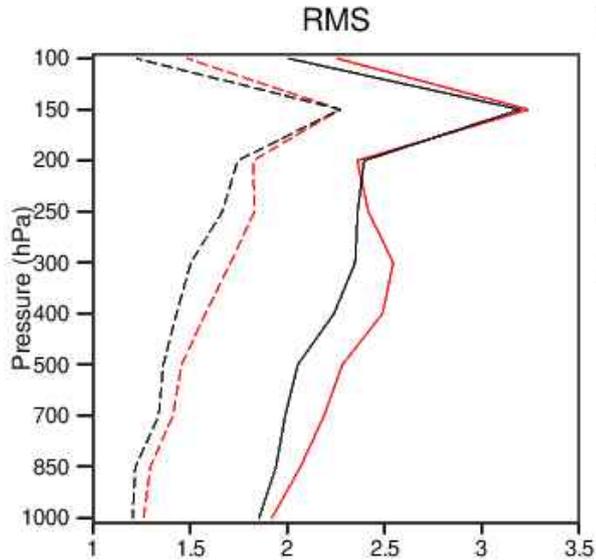200 members   50 members   50 members + Loc 66km
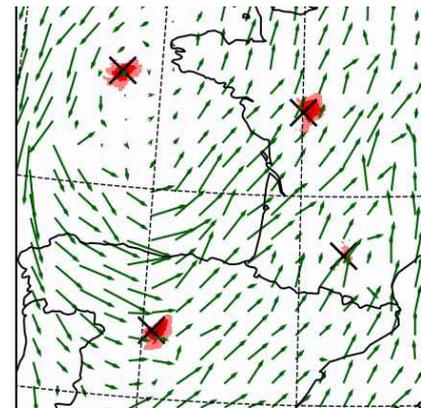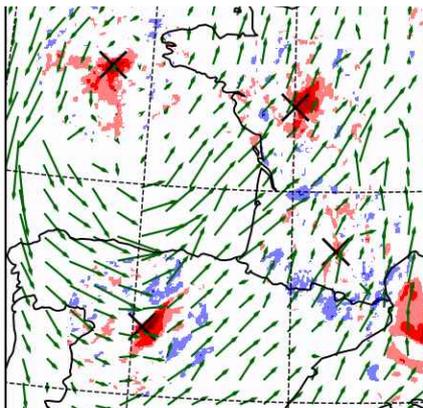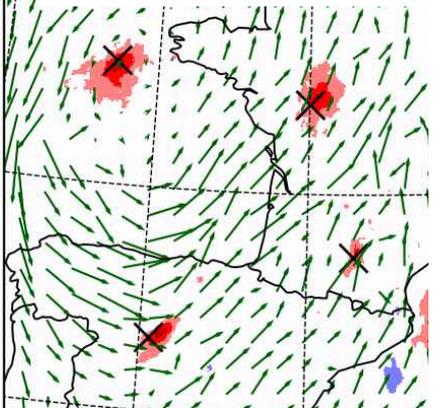
MODES wind :
- more consistent obs-guess comparison
- ~ obs number (+ 4 %)
- and reduced obs-guess and obs-analysis

Radar HU :
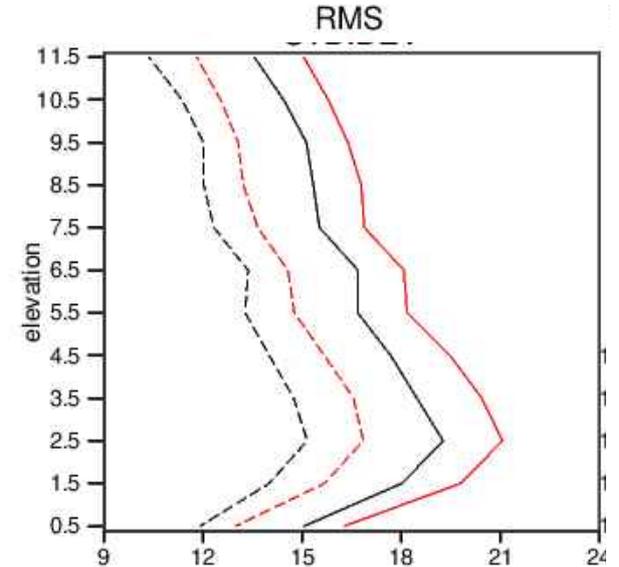- obs number x 4
- reduced obs-guess and obs-ana

3DEnVar => 4DEnVar + 4DIAU +4DOBS
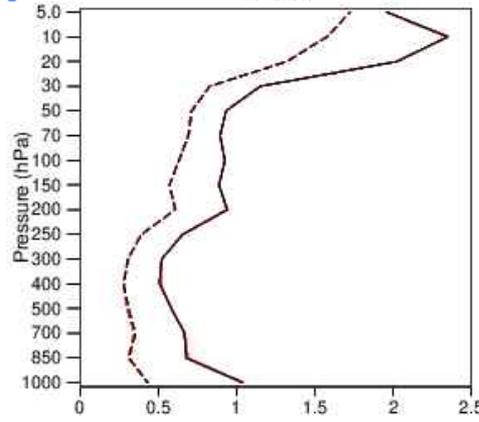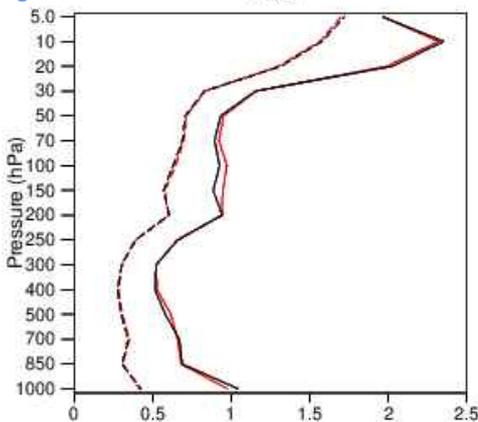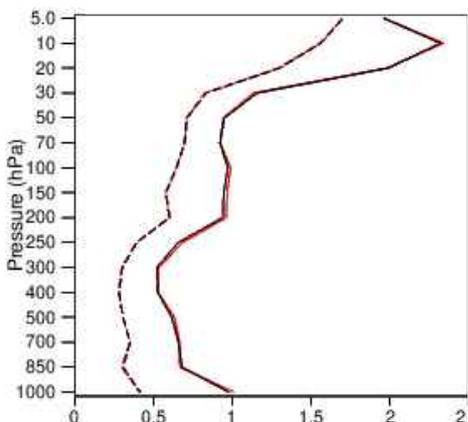

4DEnvar Vs 3DEnvar
IAU and Obs as
in 3DEnvar

+

4DEnvar Vs 4DENVar
+ 4DIAU + 3DIAU

+

4DEnvar Vs 4DENVar
+ 4DIAU   4DIAU
+ 4DOBS   3DOBS

4DEnvar Vs 3DENVar
+ 4DIAU
+ 4DOBS

TEMP-T
Used T
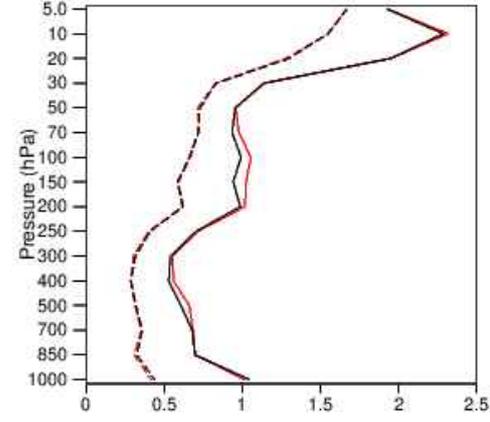
RADAR Globe
Used RH

——— Obs-Guess   --------- Obs-Analysis