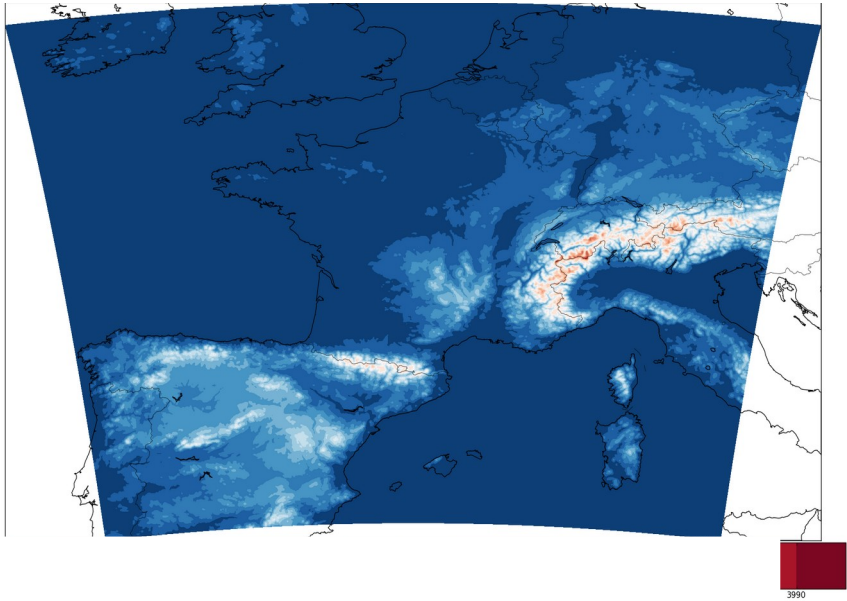
A 3DEnVar scheme for the operational convective scale NWP system Arome-France

Pierre Brousseau, Valérie Vogt, Etienne Arbogast, Loïk Berre (speaker) and colleagues ...
(Météo-France)

ISDA 2023 (Bologna)

Arome-France

- Spectral limited area non-hydrostatic model with explicit moist convection ; operational since December 2008.
- Resolution : 1.3 km and 90 vertical levels since 2016
- LBCs : hourly forecasts from global model ARPEGE



- Initial Conditions : 3D-Var at the model resolution, in a 1-h continuous assimilation cycle :
  - U, V, T, q and P_s analyzed
  - Hydrometeors, TKE and non-hydrostatic fields copied from the background
  - Conventional data + satellite observations (as in ARPEGE)
    + radar data (doppler winds and reflectivities) + screen-level measurements (T2m, Hu2m)
  - Climatological B matrix (horizontally homogeneous and isotropic)
    estimated from an « off-line » AROME EDA.

Towards a 3DEnVar scheme, using the OOPS framework

Plan

- Introduction
- Tuning of the selected configuration
- Impacts on scores and case studies
- Conclusions and prospects

3D-Var & 3DEnVar cost functions

- The variational scheme is based on the minimization of a cost function :

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

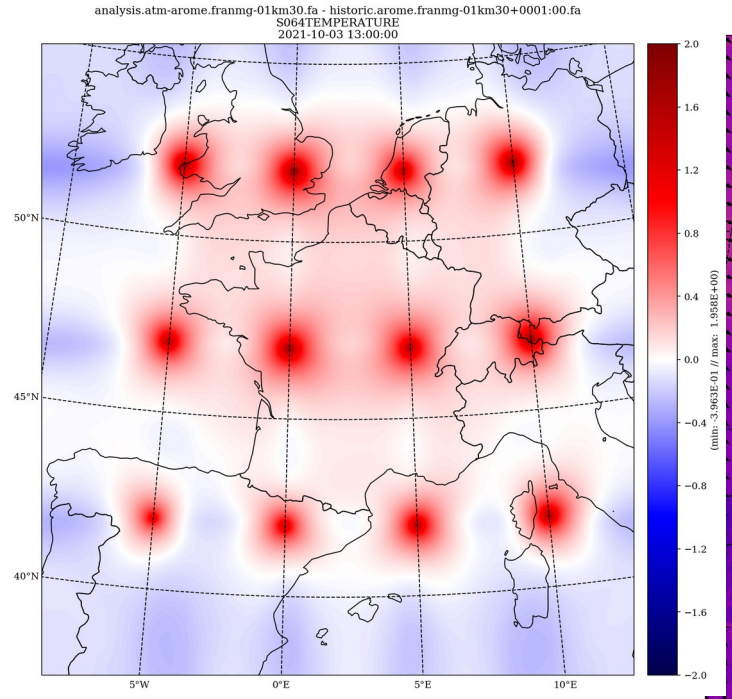
$$\epsilon_l^b = \frac{1}{\sqrt{N_e-1}}(\tilde{\mathbf{x}}_l^b - \langle\tilde{\mathbf{x}}^b\rangle)$$

$$\mathbf{X}^b = \left[\epsilon_1^b, \ldots, \epsilon_{N_e}^b\right]$$

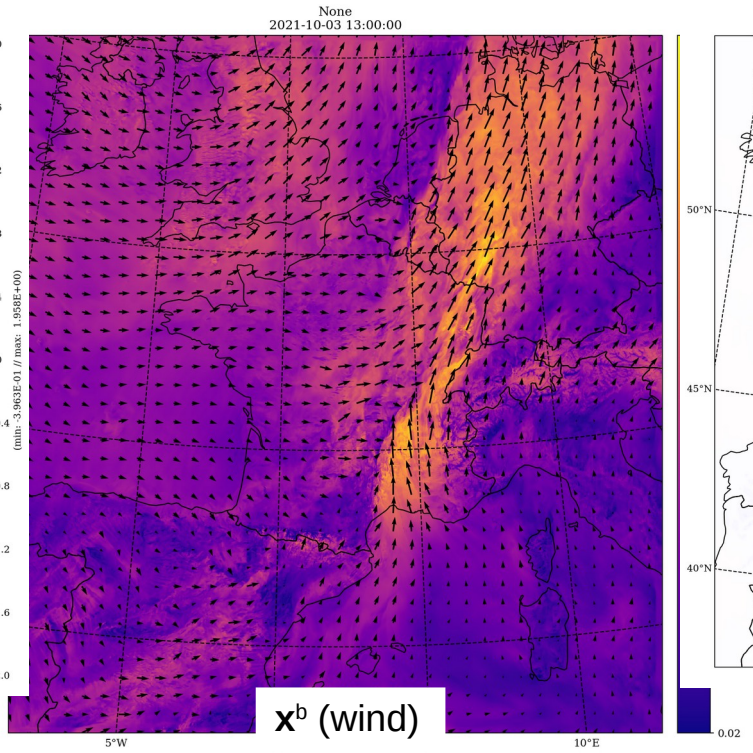
$$\mathbf{B} = \overline{\mathbf{B}} = \mathbf{K}\mathbf{B}_\mathbf{u}\mathbf{K}^\mathbf{T} \qquad \mathbf{B}_\mathbf{u} = \begin{pmatrix} \mathbf{C}_\zeta & 0 & 0 & 0 \\ 0 & \mathbf{C}_{\eta_\mathbf{u}} & 0 & 0 \\ 0 & 0 & \mathbf{C}_{(T,P_s)_\mathbf{u}} & 0 \\ 0 & 0 & 0 & \mathbf{C}_{q_\mathbf{u}} \end{pmatrix}$$

$$\mathbf{K} = \begin{pmatrix} I & 0 & 0 & 0 \\ \mathcal{M}\mathcal{H} & I & 0 & 0 \\ \mathcal{N}\mathcal{H} & \mathcal{P} & I & 0 \\ \mathcal{Q}\mathcal{H} & \mathcal{R} & \mathcal{S} & I \end{pmatrix}.$$

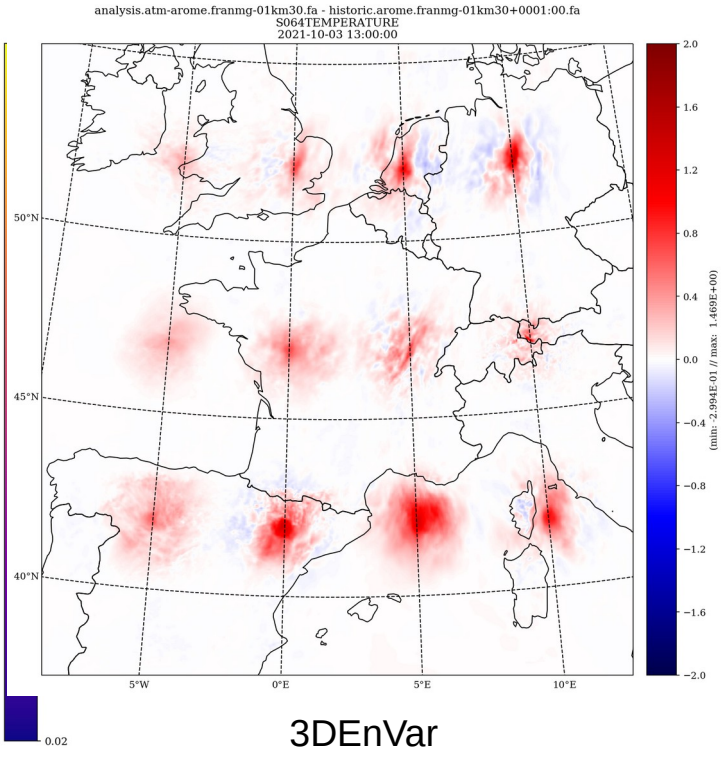
$$\mathbf{B} = \tilde{\mathbf{B}}_e = \mathbf{C} \circ \mathbf{X}^\mathbf{b}\mathbf{X}^{\mathbf{b}\mathrm{T}}$$



3D-Var



$\mathbf{x}^b$ (wind)



3DEnVar

3D-Var & 3DEnVar cost functions

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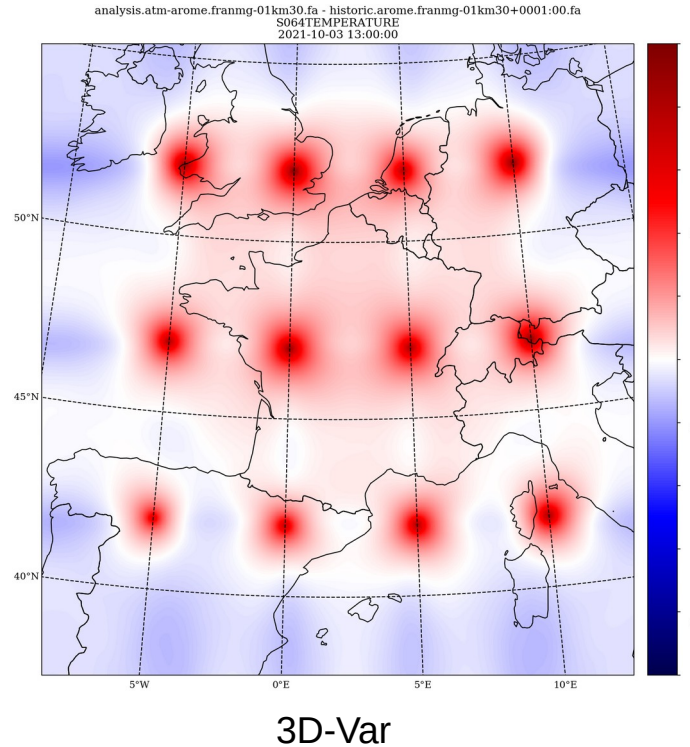
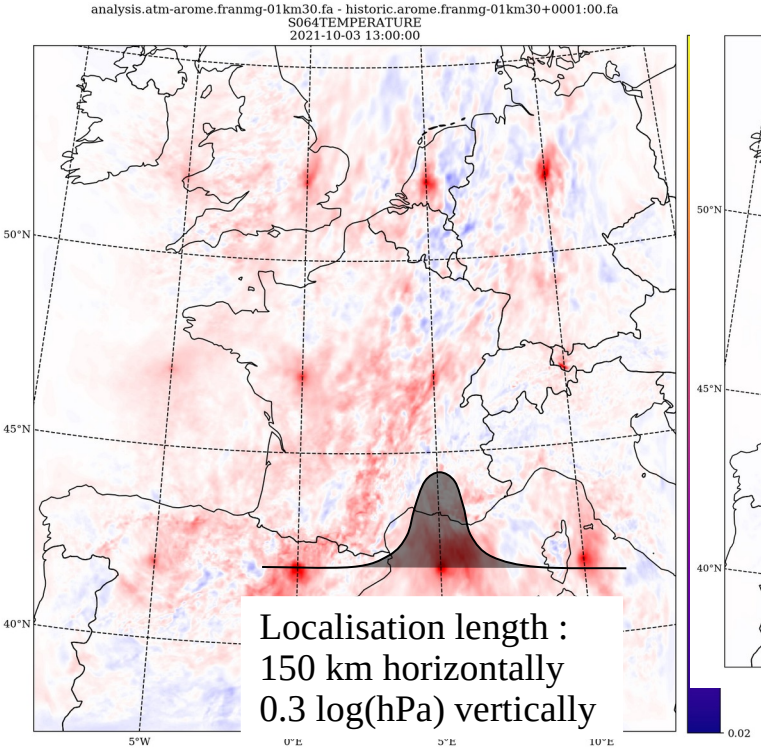
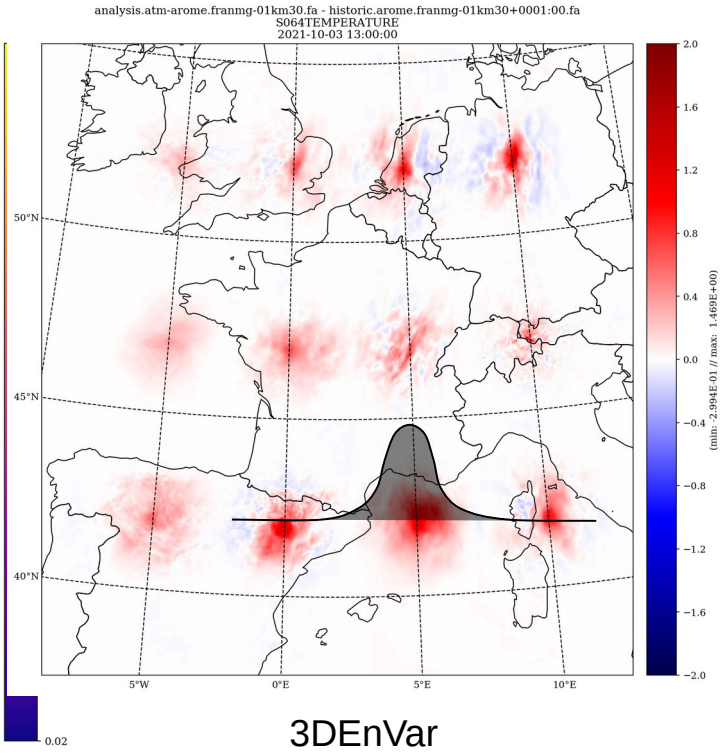


3D-Var





3DEnVar

Searching for an optimal 3DEnVar configuration

- Preliminary studies on 3DEnVar in Arome-France framework

Study	dx / cycle	Scheme	H. Loc. (km)	V. Loc log(hPa)	Software	Performance
Montmerle Et al. 2018	3.8 km/3h	3DEnVar and Hyb.	150	0.3	OOPS	3DEnVar better 5 wk. Winter period
Michel and Brousseau 2021	1.3 km/1h (3.2km/3h EDA)	Hyb. only	25	0.3	ARPEGE /IFS	Hyb . Better 3 m. Summer period

- Different configurations and different sensitivity results.
- Need for :
  - harmonisation
  - performance confirmation over a long period
- Preference for a pure EnVar formulation, in order to facilitate future developments (4DEnVar, extension to hydrometeors,…) in the OOPS software framework

Numerous new experiments, in order to build
a performant and robust configuration for operations.

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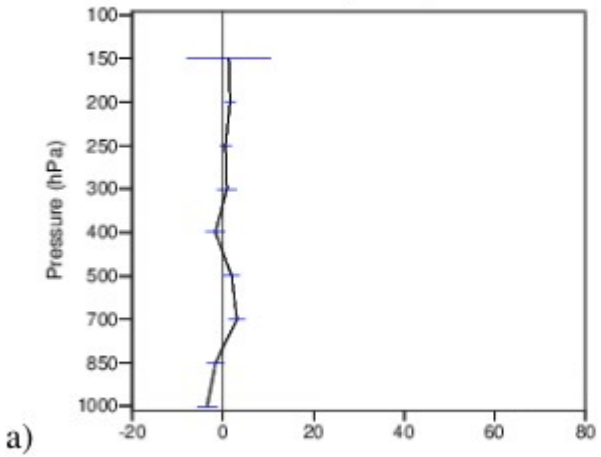
Searching for an optimal 3DEnVar configuration : Localisation length scale

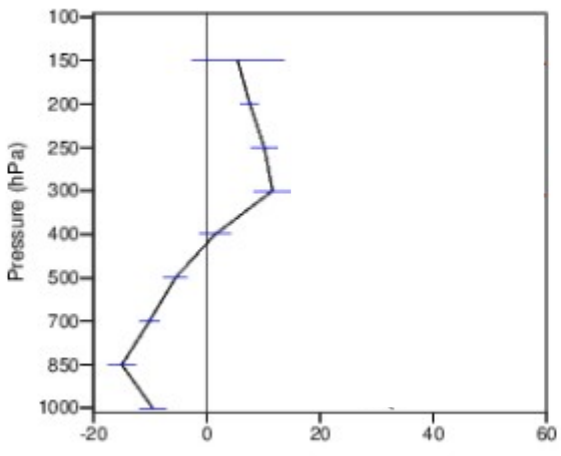
1 month period : 16/09/2020-15/10/2020

Loc 150 km



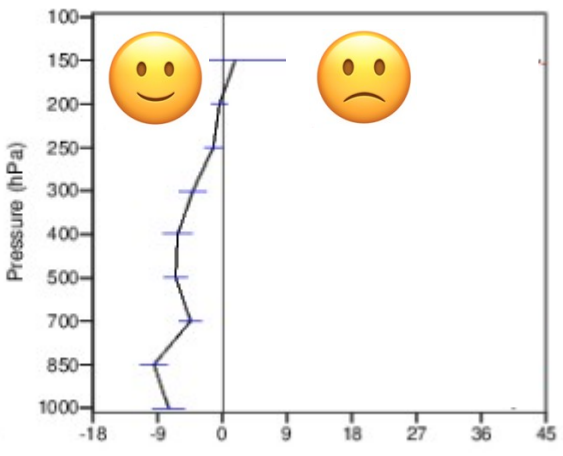
a)

Loc 25 km



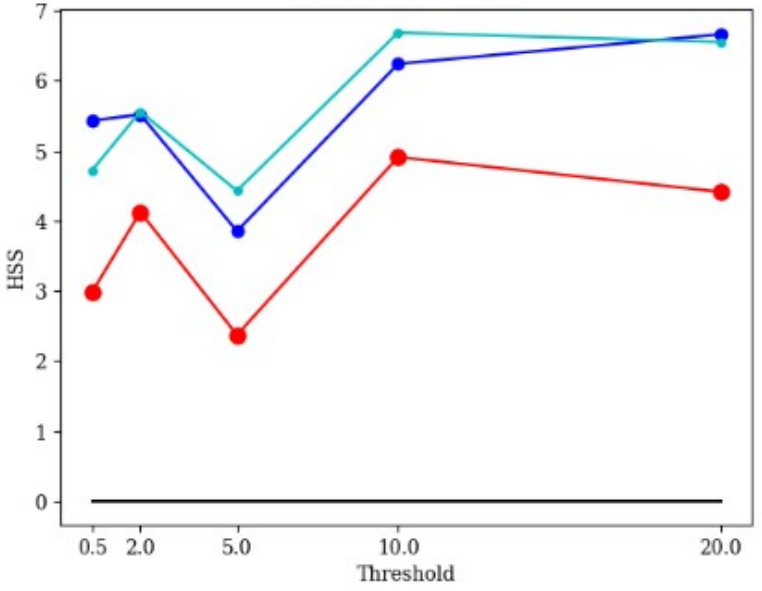
b)

Loc 25 – 150 km



c)

% of Obs-Guess RMS difference
for aircraft winds (3DEnVar vs 3D-Var)



Comparison between
24h precip. observed by radars and raingauges
& 24h precip. from accumulated 1h forecasts of DA cycle

Relative difference (%) of HSS values
for different precipitation thresholds

Loc 25 - 150 km
Loc 25 km
Loc 150 km
3D-Var

Searching for an optimal 3DEnVar configuration : other sensitivity experiments

Parameter	Impact on the DA system	Impact on previous diagnostics
Vert. Loc = 0.2 to 0.4 ln(hPa)	« Thinner/broader » filtering of background error vertical correlations	neutral/slightly negative
Inflation = 0.8 to 1.2	Smaller/Higher sigmab => the analysis fits less/more the observations	neutral/slighly negative
Hybridisation = 0.8 ens / 0.2 clim	Lesser flow dependency and lesser sampling noise	negative
Incremental Analysis Update (IAU)	Filtering of higher spin-up related to 3DEnVar	neutral/slighly positive

- And numerous combinations …

AROME 3DEnVar at Météo-France : selected configuration

- Same resolution as operational configuration :

  1.3 km, 90 vertical levels
- Ensemble of Data Assimilations (EDA) Arome :

  50 members, 3.25 km, 90 vertical levels, 3D-Var, 3-hourly cycling
- Horizontal localisation scale :

  varying between 25 km at low levels and 150 km near the model top
- Vertical localization : 0.3 log[hPa]
- Pure 3DEnVar (no hybridisation)

  => facilitates further developments, such as the

  extension of the control variable to hydrometeors for example,

  since background error covs for these variables are directly available from the EDA.

  => allows pure 4DEnVar (without TL/AD models): especially attractive for complex physics.
- Incremental Analysis Update (IAU)

  => to cope with 4 numerical explosions during the heatwaves of summer 2022

  (no other numerical problems reported during more than 1 year of experiments,

  including numerous storms)

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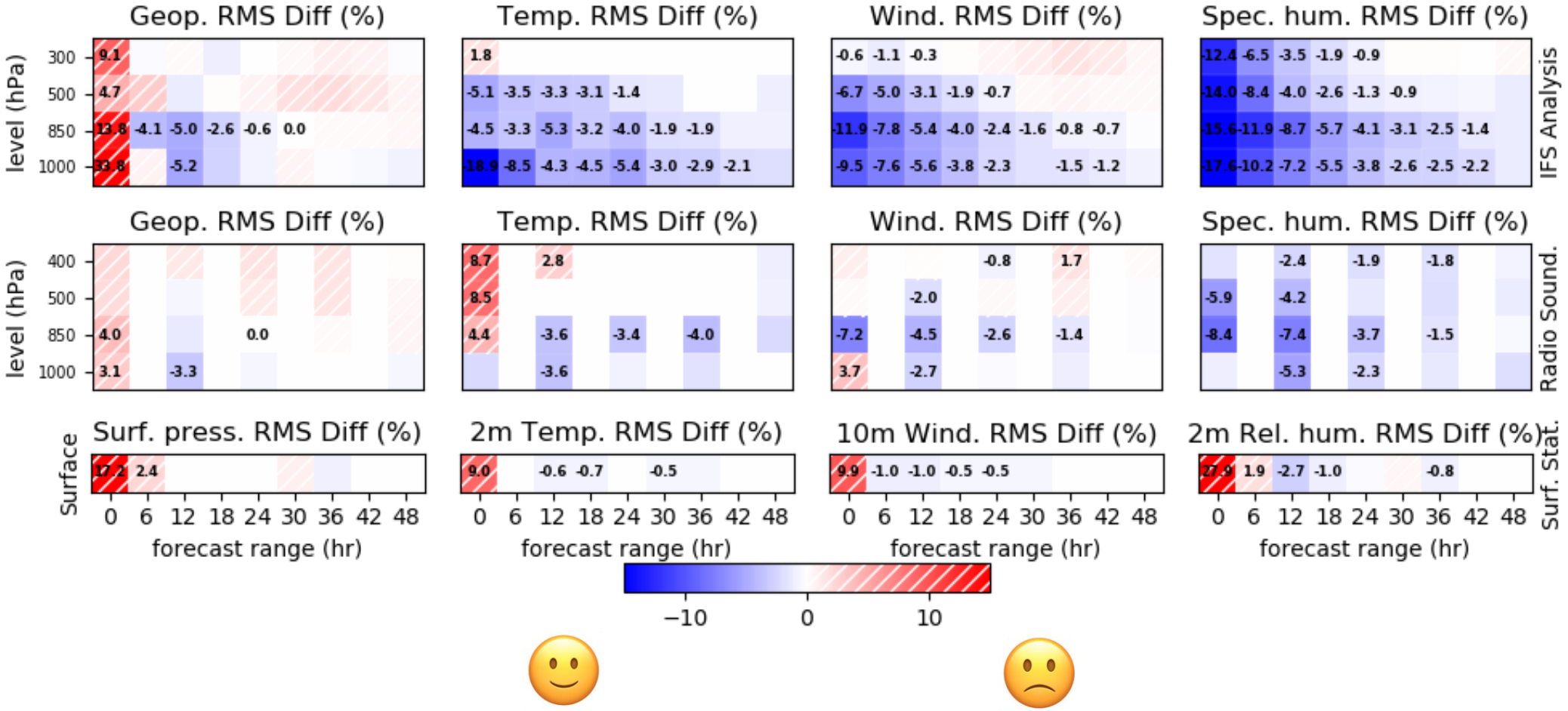
Score-card over 6 months : general parameters



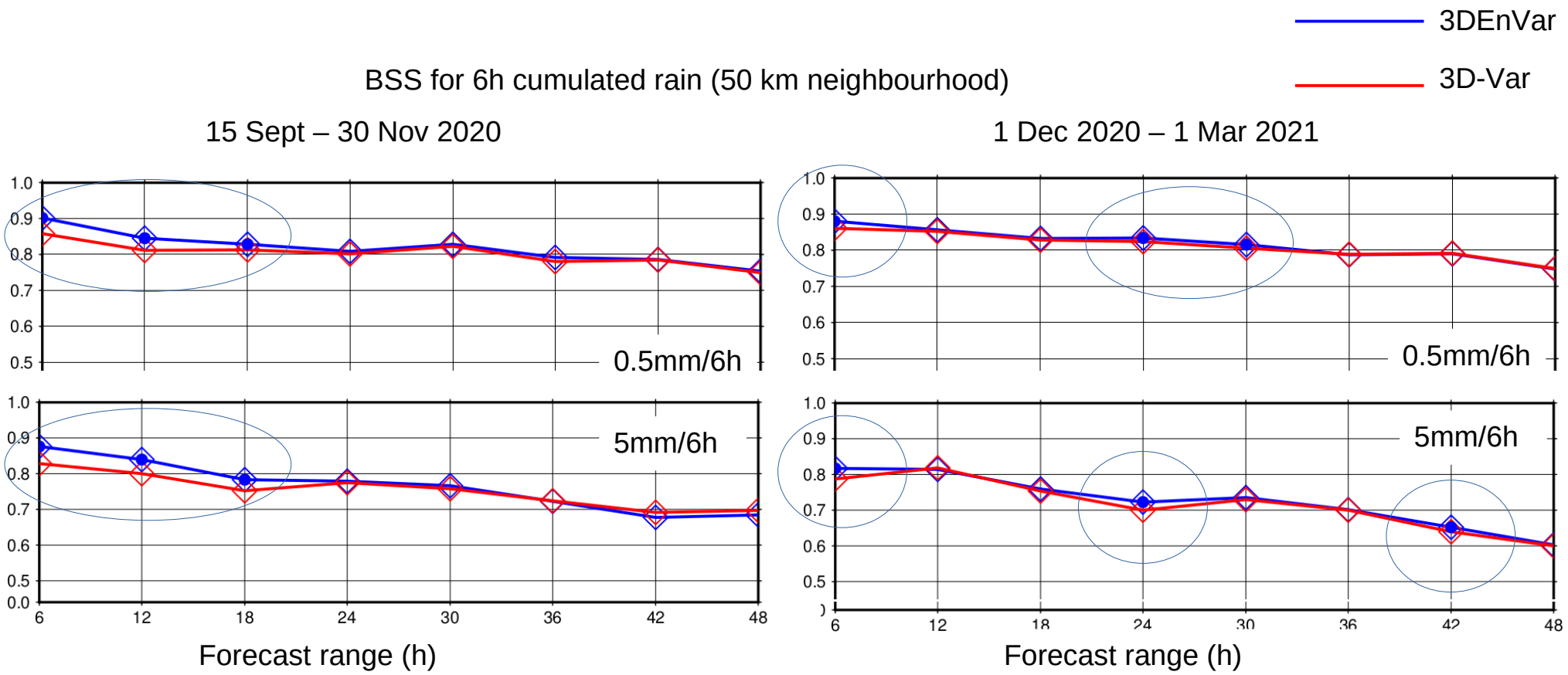
% of reduction of RMSE

for different parameters over 6 months (16/09/2020-01/03/2021) ;

ref = IFS analysis (top), radiosondes (middle), surface stations (bottom)

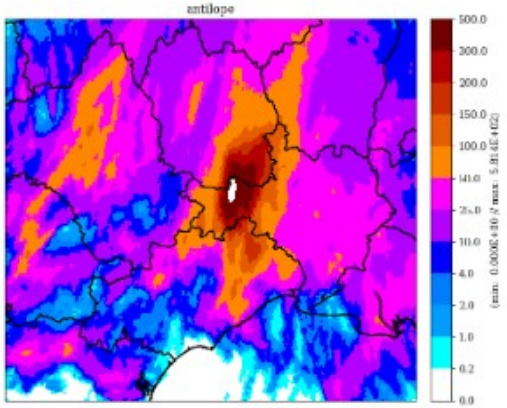
Pre-operational AROME 3DEnVar at Météo-France with OOPS : impact on precipitation

General performances over a **6-month period** (stronger during convective season) :



Pre-operational AROME 3DEnVar at Météo-France with OOPS : impact on HPE

Positive impacts on HPE events (8 cases investigated) :



19 september 2020 case :

- 16 successive long forecasts from the hourly cycle simulating the event

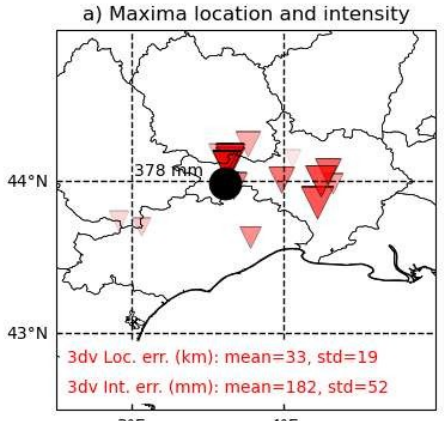
- triangle size proportional to the maximum of precipitation

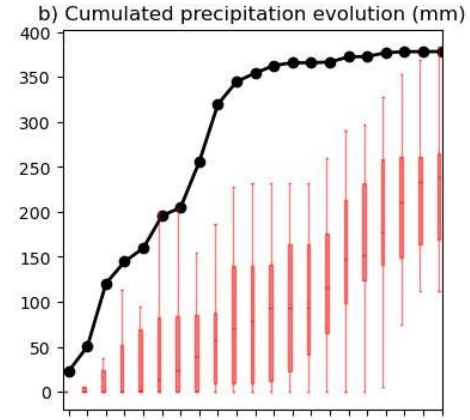
- color shade depends on the forecast starting hour (darker for more recent forecast)

Results :

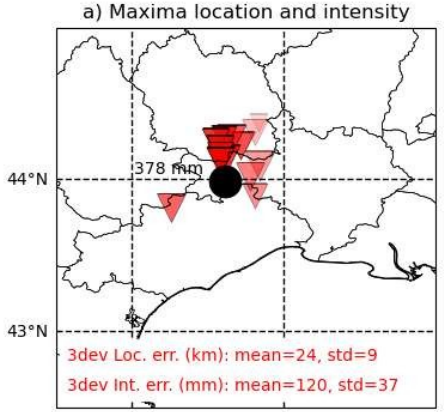
- better with 3DEnVar : location of the maxima, intensity, temporal evolution, consistency between the forecasts ; also improved when adding IAU.

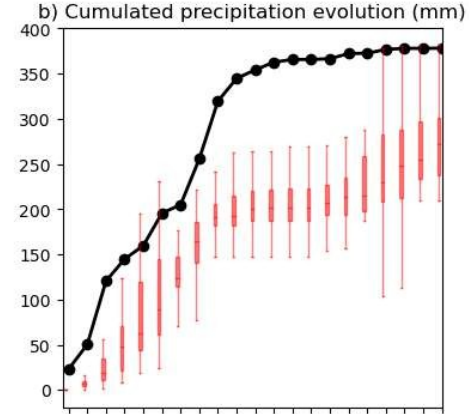
3D-Var



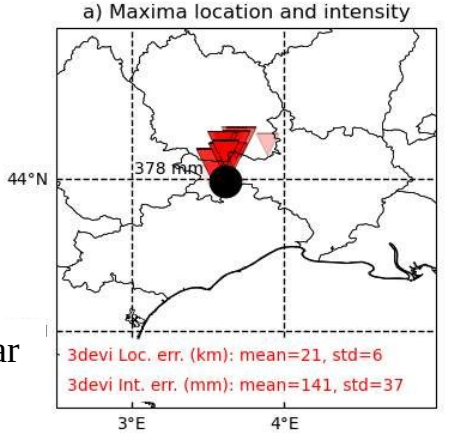


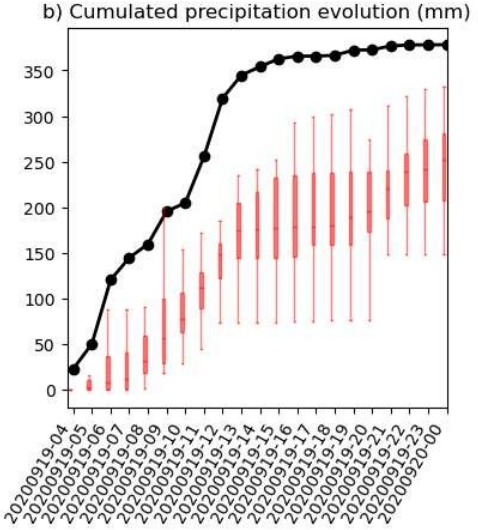
3DEnVar





3DEnVar + IAU



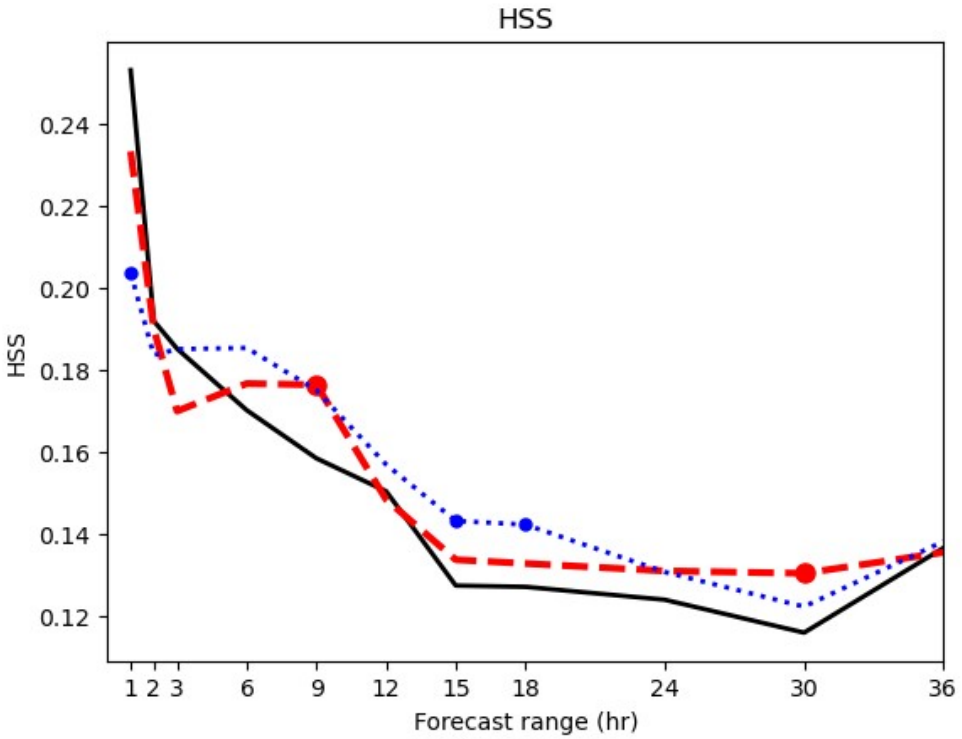


Pre-operational AROME 3DEnVar at Météo-France with OOPS : impact on storms & fog

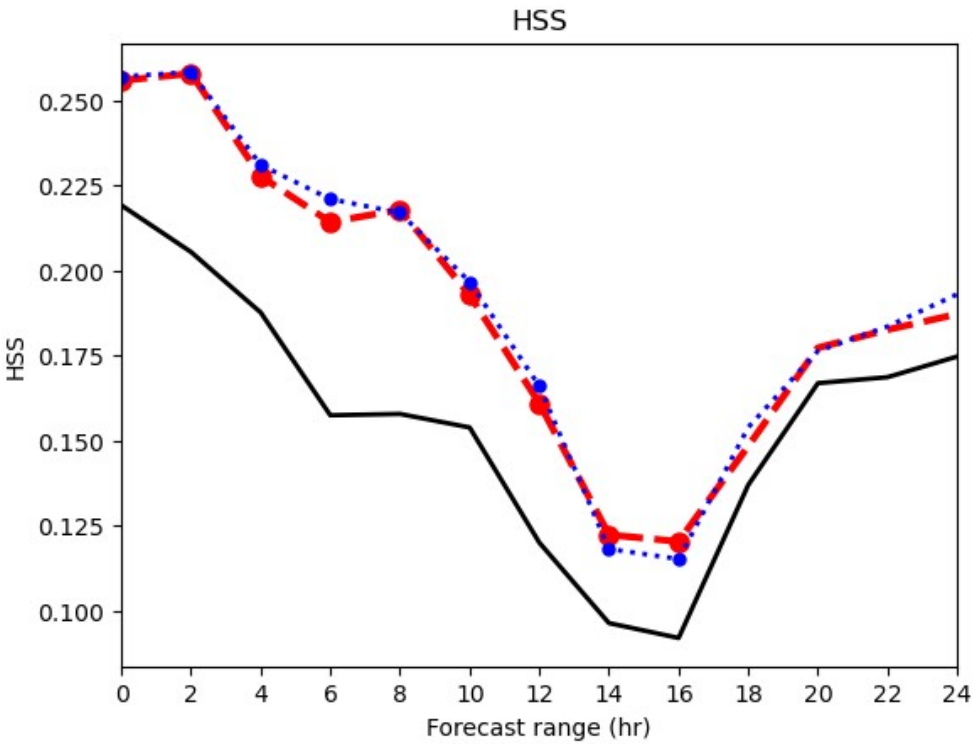
Impacts on :

3D-Var
3DEnVar
3DEnVar + IAU

6 winter storms (Daniel, Fabien, Jorge, Alex, Barbara and Bella) :
HSS for wind gust exceeding 90km/h, using
surface stations and 192 hourly forecasts (lagged-ensemble)



18 winter fog cases :
HSS for visibility lower than 1000m, using
surface stations and 126 forecasts (lagged-ensemble)



As expected :

- weak impact on storms that are mainly driven by large scale conditions
- strong impact on fog simulations, sensitive to local conditions and to vertical background error covariances adapted to the meteorological conditions

Conclusions and prospects

- Numerous investigations allow to build a robust and performant 3DEnVar configuration for operations.

  => Paper to be submitted

- Arome 3DEnVar is now part of the current real time E-suite

  at Météo-France with OOPS.

- It also leads to improved performances of AROME nowcasting (through corresponding backgrounds) and EPS (through corresponding analyses).

- The move to the OOPS framework and to a pure EnVar scheme

  facilitates the implementation of further developments :

  — Hydrometeors in the control variable and direct assimilation of radar reflectivities or lightning observations (see M. Martet's talk)

  — NH variables in the control vector

  — Scale Dependent Localisation

  — 4DEnVar : assimilation of 15-min observations

  (radar, SEVIRI, ground based GNSS and surface stations)

Thanks for listening !

References

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