

The new AROME-France E-suite : data assimilation aspects and general performances

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Outlines

1) Introduction

2) Content of the E-suite

4DEnVar

Scale dependent localisation

Direct assimilation of reflectivities

Other modifications

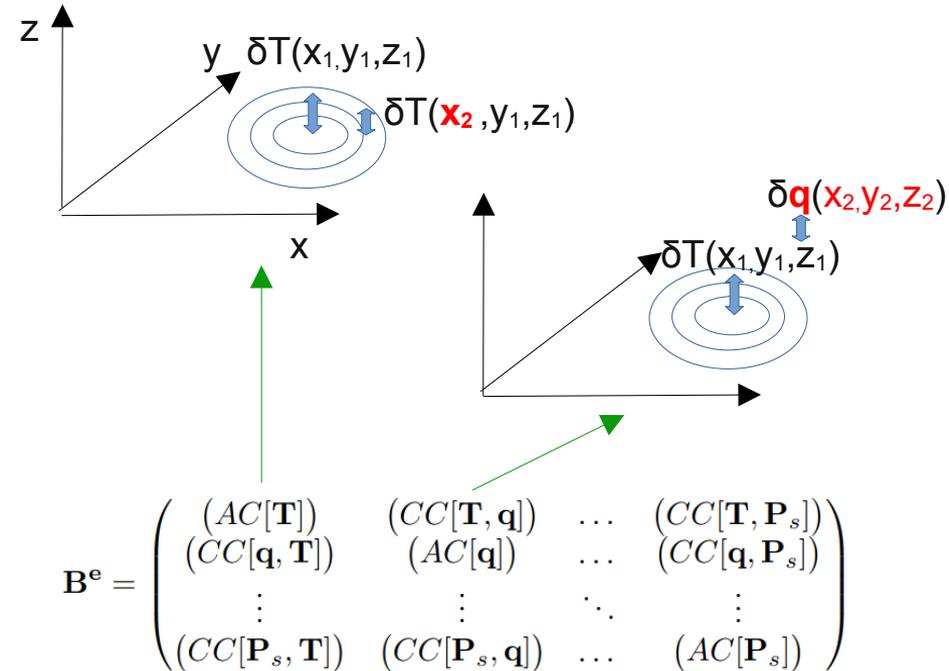
3) Scores and case study

4) Conclusion

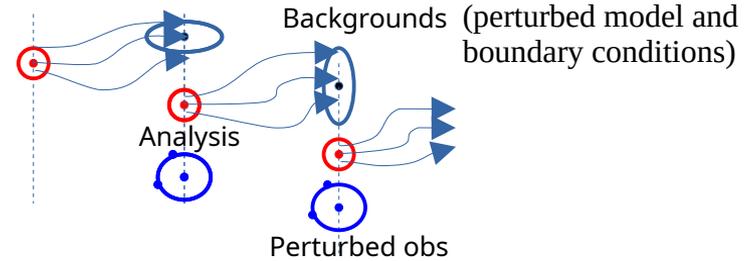
Introduction : 3DEnVar operational at Météo-France since October 2024

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

Control Variable : $\mathbf{Cv}=(\mathbf{T},\mathbf{q},\mathbf{U},\mathbf{V},\mathbf{P}_s)$



- **Estimation of \mathbf{B}^e in EnVar** : at Météo-France, \mathbf{B}^e is estimated using forecasts from a 50-member EDA to sample uncertainties of the assimilation cycle



- **Flow dependent perturbations** are deduced from this ensemble :

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

N_e nb of members
 $\tilde{\mathbf{x}}_l^b$ Forecast of member l
 $\langle \tilde{\mathbf{x}}^b \rangle$ Mean of the forecasts

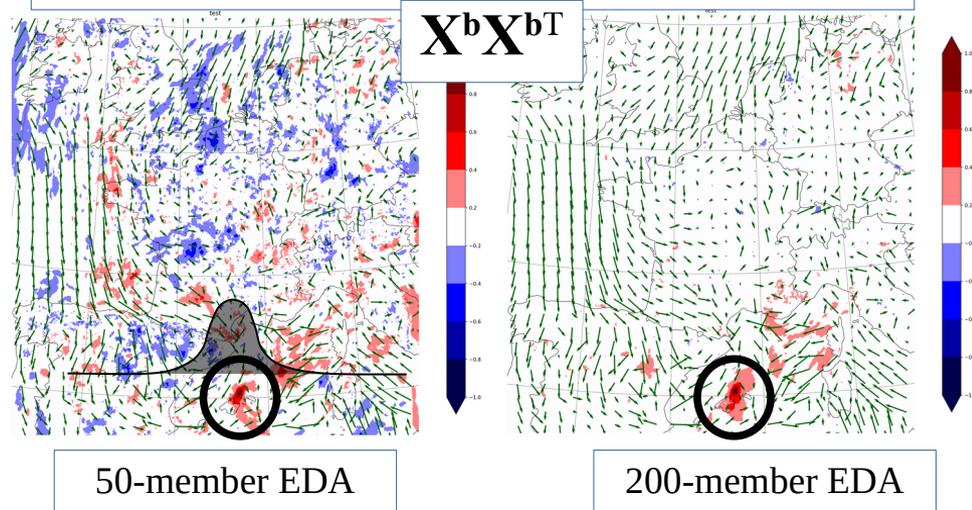
- Background error covariances are directly sampled from forecast perturbations, with a **localisation step**

$$\mathbf{X}^b = [\epsilon_1^b, \dots, \epsilon_{N_e}^b] \quad \mathbf{B}^e = \mathbf{X}^b \mathbf{X}^{bT} \circ \mathbf{C}$$

Introduction : need for localisation

- 50-member EDA: covariances affected by sampling noise
=> localisation : covariance filtering which ensures a gradual cancellation of covariances with distance
- Constraint of uniqueness of the localisation length, which is the same for all parameters and at all points in the domain :
 - surface pressure over sea,
 - temperature in valleys ...
- Compromise after sensitivity experiments :
 - Height dependent localisation : bottom 25km – top 150 km
 - fixed vertical localisation : $0.3 \log(h\text{Pa})$

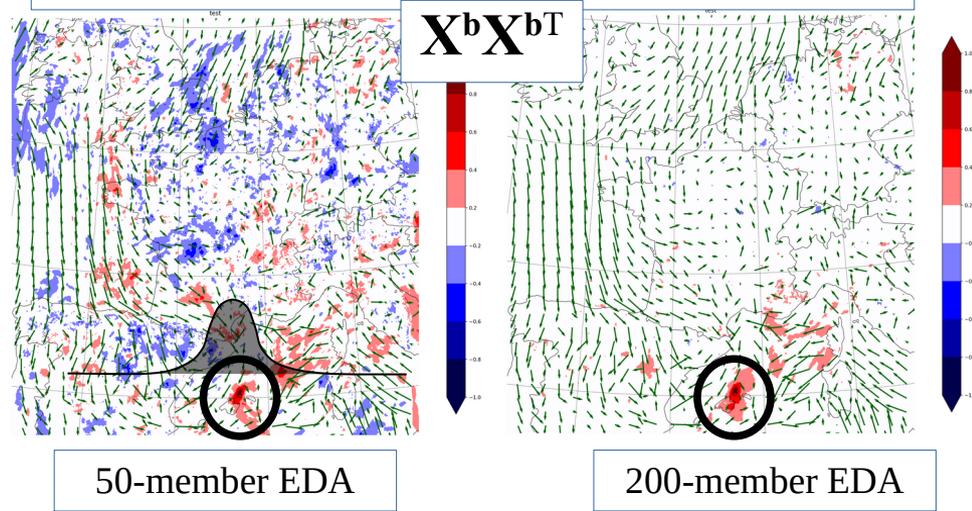
Raw correlations issued from Arome EDA forecasts
between temperature at level 70 at a point in the North
of the Balearic Islands and the other points of the same
field 17/08/2022 12h



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EnVar is a new kind of DA scheme which allows numerous new developments, facilitated by the use of the OOPS framework, such as the extension of the control variable to new parameters (ex : hydrometeors) or to the temporal dimension (4DEnVar)

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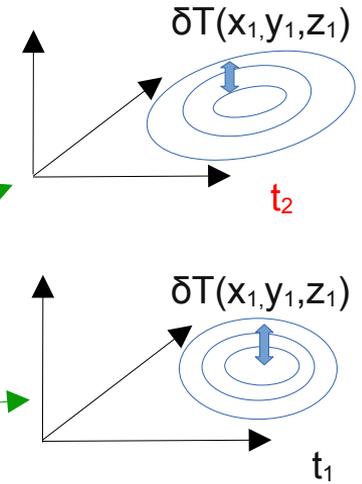
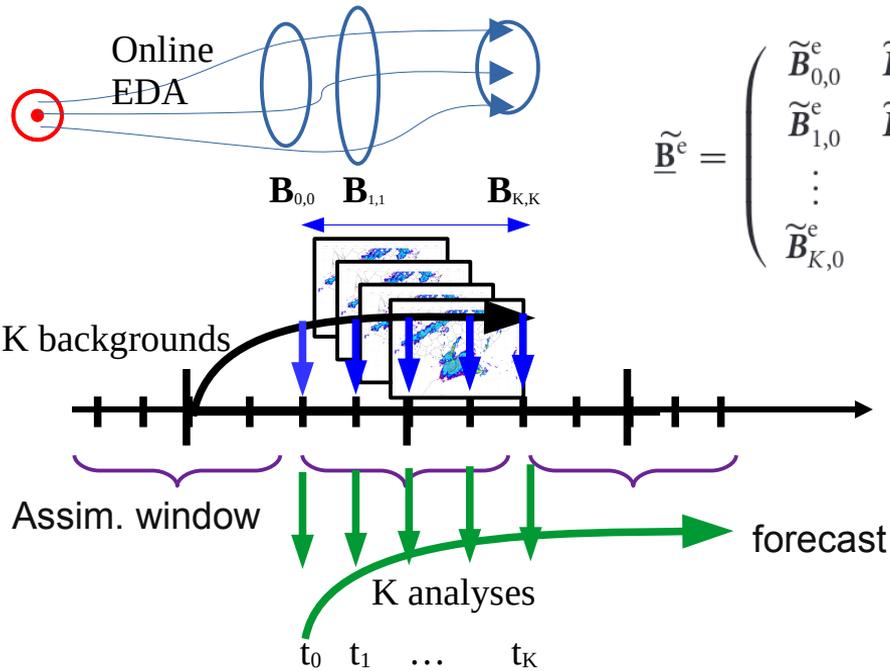
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4DEnVar : minimization of a 4D state without any TL/AD forecast models

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

4D Control Variable : $\mathbf{Cv} = (\mathbf{T}_0, \mathbf{q}_0, \mathbf{U}_0, \mathbf{V}_0, \mathbf{P}_{s0}, \mathbf{T}_1, \mathbf{q}_1, \mathbf{U}_1, \mathbf{V}_1, \mathbf{P}_{s1}, \dots, \mathbf{T}_K, \mathbf{q}_K, \mathbf{U}_K, \mathbf{V}_K, \mathbf{P}_{sK})$



The temporal dimension is managed by temporal background error cross-covariances, which are directly estimated from an EDA (perturbed non-linear model forecasts)

4DEnVar : retained configuration

- 1hour cycle with 5 timeslots : 3*15min + 2*7min
- Perturbations calculated every 15 minutes based on perturbed forecasts from Arôme-France EDA 3.2km hydrostatic (forecasts : 4h30-5h30-00h15, 5h30-6h30-00h15 and 6h30-7h30-00h15 depending on the assimilation time)
- All 5 increments are used to initialise the new forecast using 4D IAU (20 % of each)
- Localisation : no tuning (=> SDL)
- 4DEnVar allows for the assimilation of 15-min frequency observations in the 1 hr cycle
=> all operational observations with 15 min frequency are assimilated : radar, ground-based GNSS, SEVIRI radiances (geostationary platforms) and surface stations

Scale Dependent Localisation (SDL)

[Caron et al 2019](#)

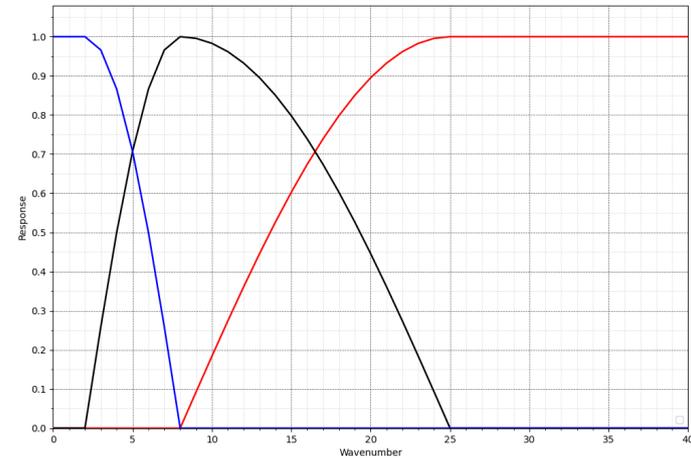
The principle of SDL is to perform a decomposition in spectral space of the Arome-EDA fields used to estimate the B matrix.

This produces several ensembles, representative of different spatial scales, to which different localisation lengths are applied :

- shorter for the smallest scales
- longer for the largest scales

In practice: decomposition into 3 frequency bands

Filters response functions

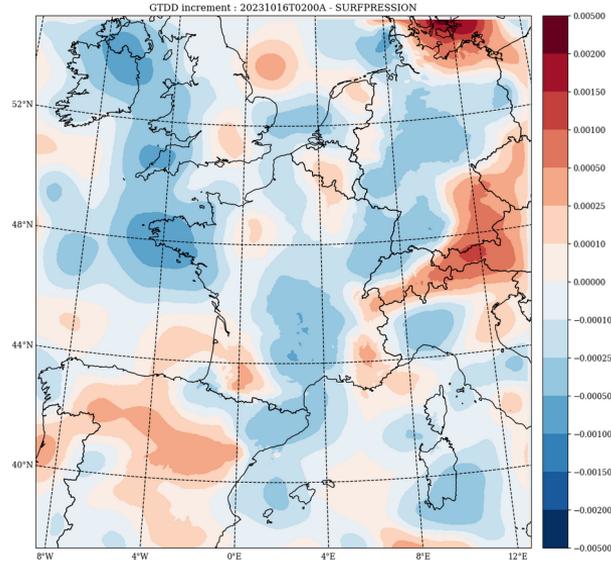
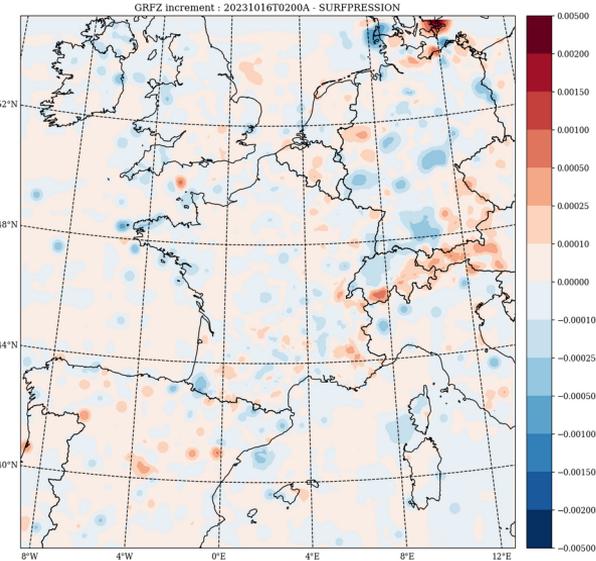
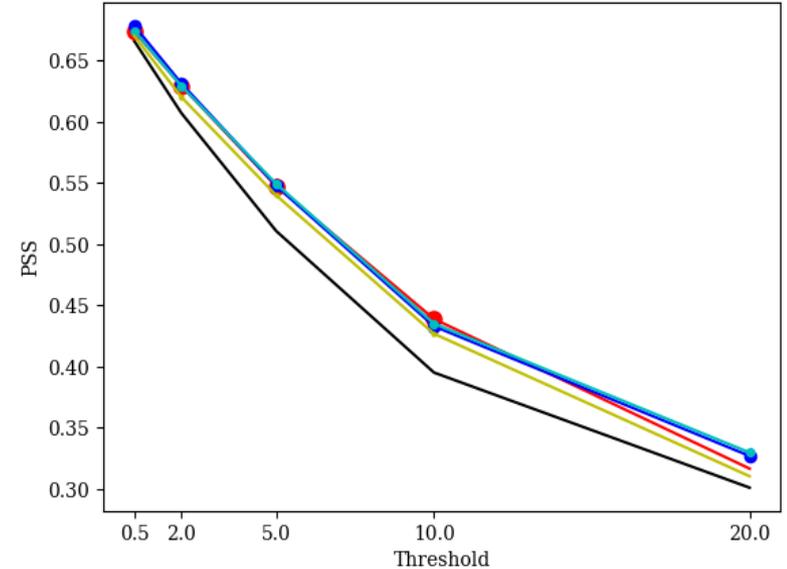


Scale Dependent Localisation (SDL)

Surface pressure

— arome 3denvar — arome sdl 15/100/200
 — arome sdl 25/75/150 — arome sdl 50/125/200
 — arome sdl 15/50/120

Scores PSS moyen



REF 3DEnVar
 height dependent localisation
 bottom 25km – top 150km

3DEnVar + SDL
 scale dependent localisation
 25/75/150km

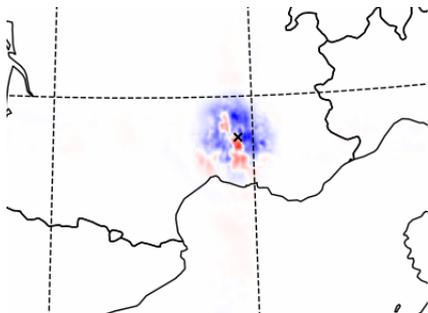
Pierce skill score computed on 12-hour accumulations from 0 and 12h runtimes
 Cycled experiments
 for several triplets of localisation
 28/08/2022-31/10/2022

=> Implicit adaptation of the localisation length to parameters and points in the domain
 => SDL reduces the need for localisation retuning (hydrometeors, 4D, ...)

Direct assimilation of reflectivities

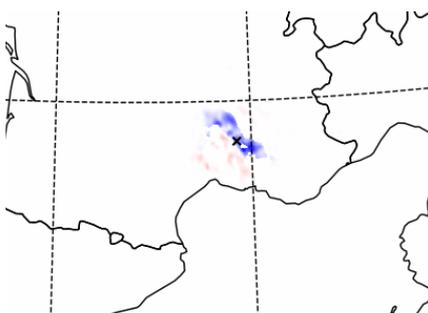
Bayesian inversion

Specific humidity level 70



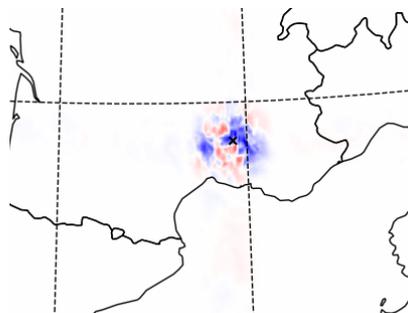
↓ Cross-covariances

Rain content level 70



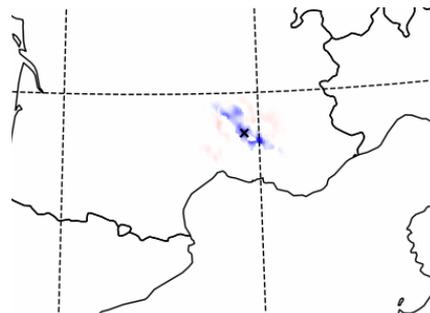
Reflectivity assimilation

Specific humidity level 70



↑ Cross-covariances

Rain content level 70

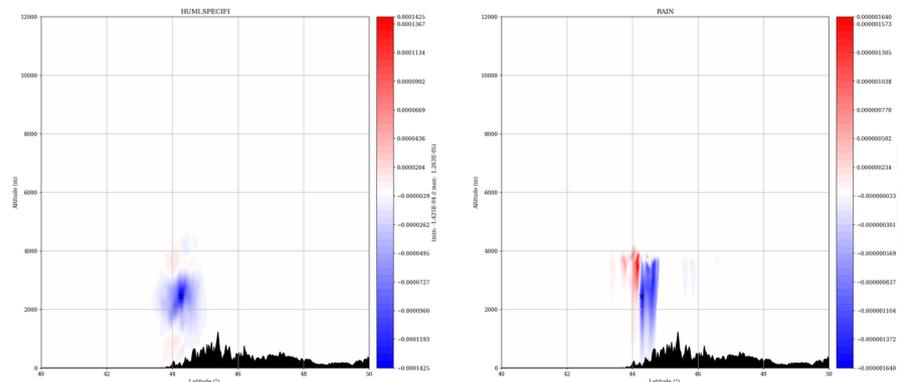


Hydrometeors in the control variable of a 3D-EnVar assimilation system with OOPS allows to directly assimilate reflectivity, provided you have **TL and AD** versions of observation operator.

Assimilation of one observation with two different methods :

- pseudo-observation of humidity calculated by Bayesian inversion
- direct assimilation of reflectivity

Reflectivity assimilation



Specific humidity

Rain content

Other modifications (observations and model)

Observations (V. Pourret C. Payan) :

- Modes-S data assimilation optimisation :
 - ▶ 4km Adaptive Weighting (AW) to avoid overfitting over Mode-S high density locations (triggered after QC and thinning)
 - ▶ New whitelist based on 2024 operational monitoring with 11007 selected aircraft over 14235 (~77 %)

- Revision of AMV quality control and error scheme :
 - ▶ Use of a prescribed observation error scheme that takes into account uncertainty in data altitude as a function of vertical wind shear, developed and applied at the MetOffice, then at ECMWF and EMC. This scheme applies to vertical model wind profiles combining a tracking error and a vertical positioning error, by satellite, by channel and by AMV height calculation method.
 - ▶ Revised AMV quality control based on the use of producer IQs (reducing dependence on model information), on orographic-type criteria (instead of geographical criteria), or on the tropopause level.
 - ▶ The specified computed error is also used as an additional thinning criterion.*

Model (S. Antoine) :

The deposition of cloud droplets on vegetation is now taken into account, with a constant deposition speed (2cm/s) - Antoine et al. 2023 Expected impact: reduction of liquid water content in the first model levels.

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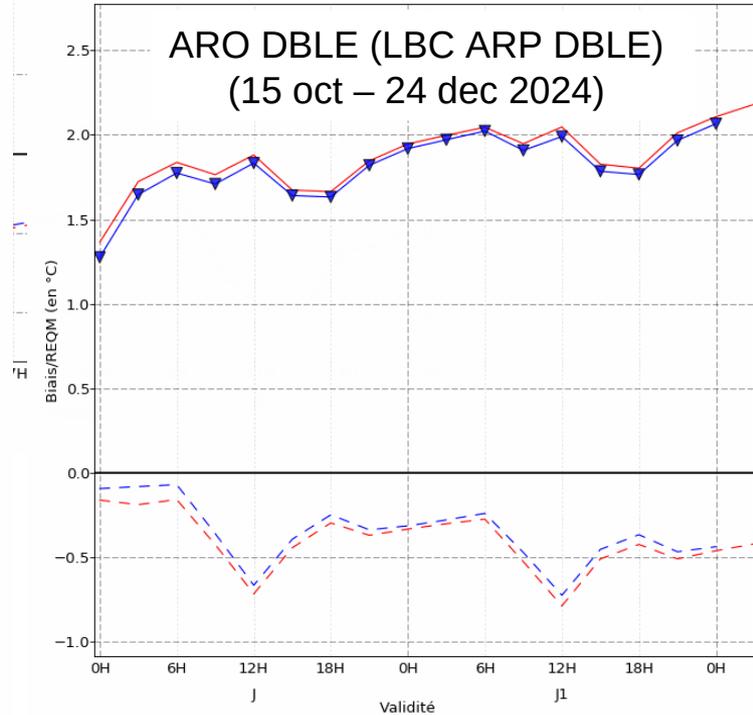
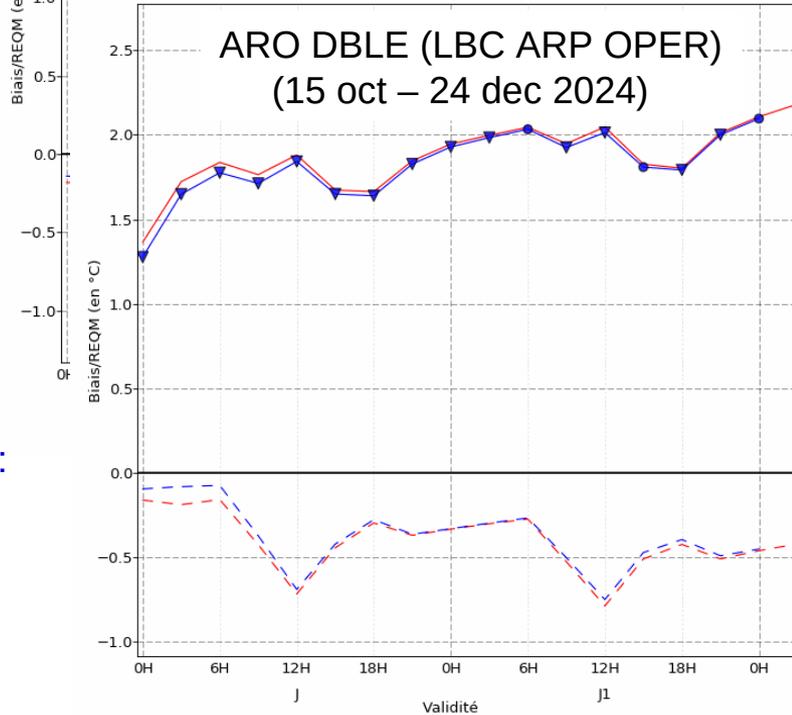
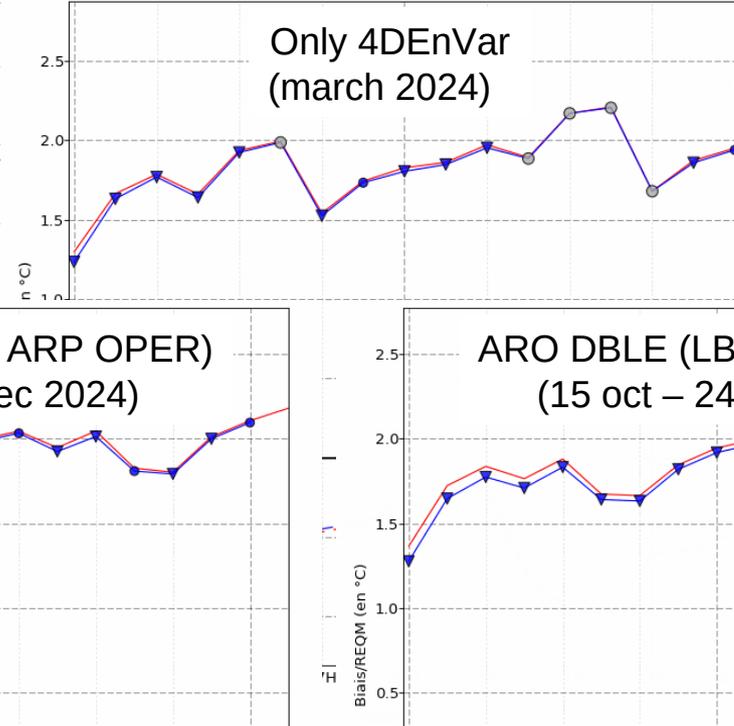
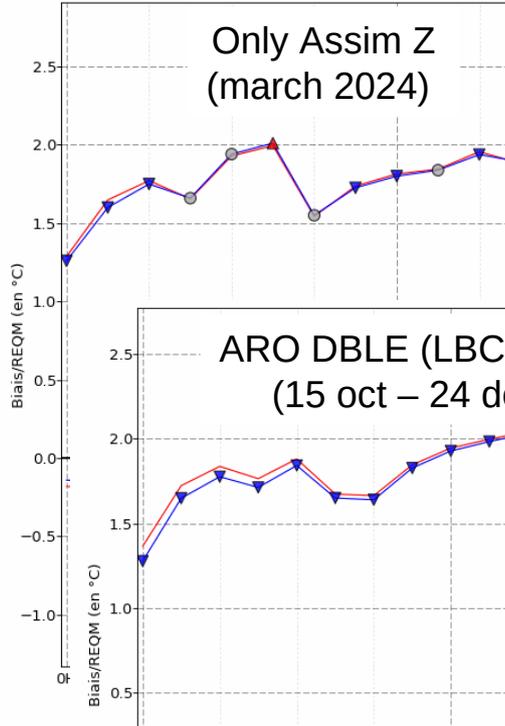
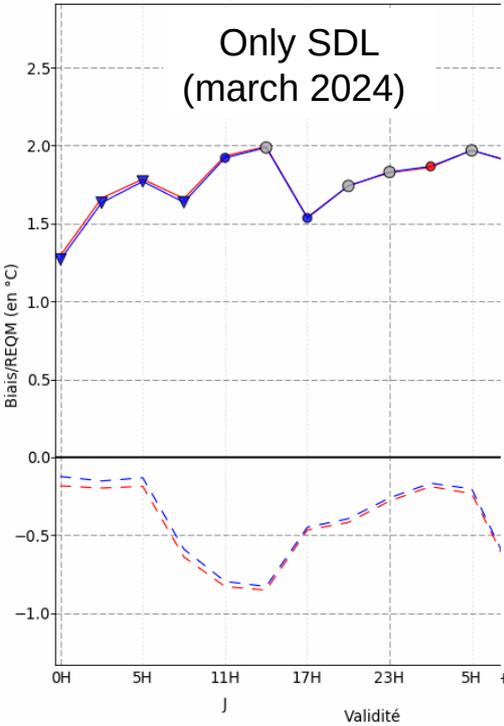
4) Conclusion

Impact of the different contributions on T2m scores Versus 3DEnVar oper

Experiment

Reference (oper)

— RMSE
 - - - BIAS

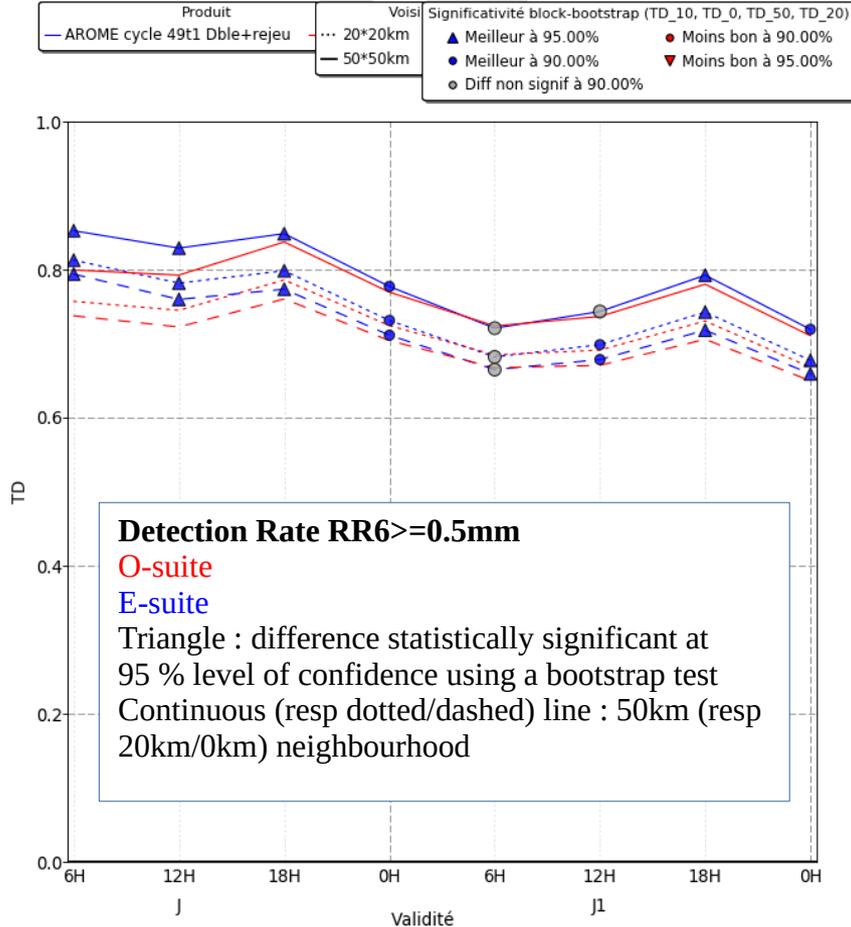


Bootstrap Significancy :
Xp better

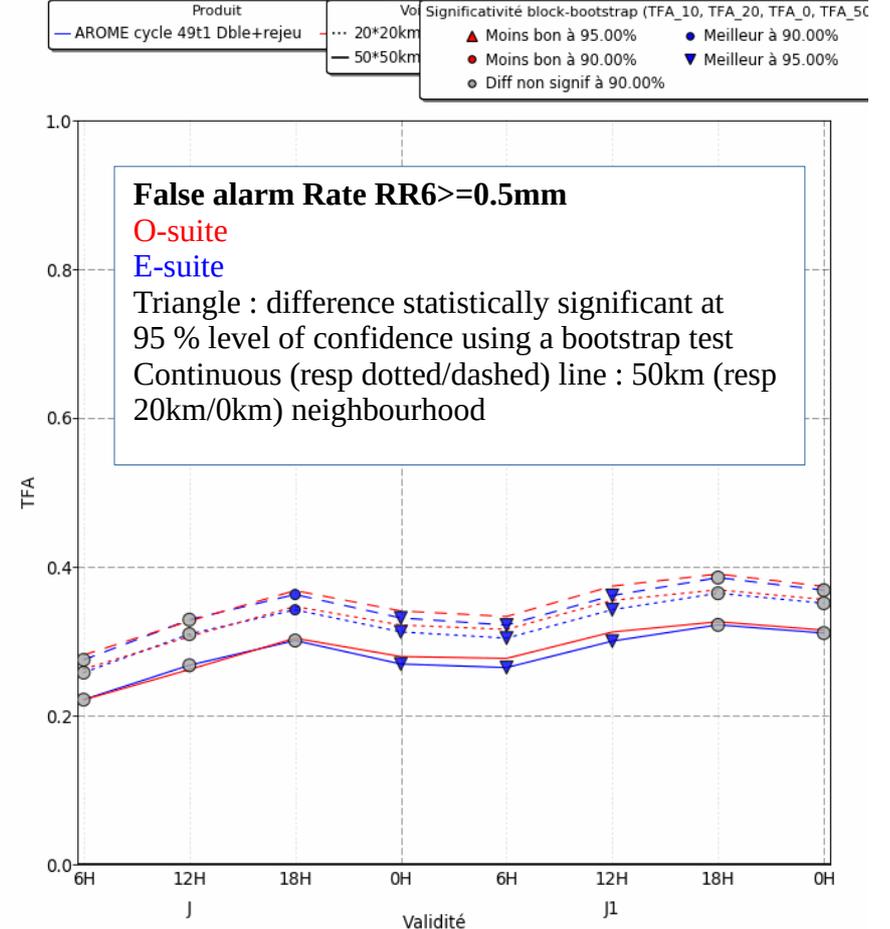
- ▲ At 95 %
- At 90 %
- Not significant

Scores of RR6 : 03/09/2024 - 18/09/2025

le détection RR6 $\geq 0.5\text{mm}$ -- du 03 sept. 2024 au 18 sept. 2025 (367 Prod type AROME 0H , réf. BDCLIM, contr. FRANXL



fausse alarme RR6 $\geq 0.5\text{mm}$ -- du 03 sept. 2024 au 18 sept. 2025 (30 Prod type AROME 0H , réf. BDCLIM, contr. FRANXL



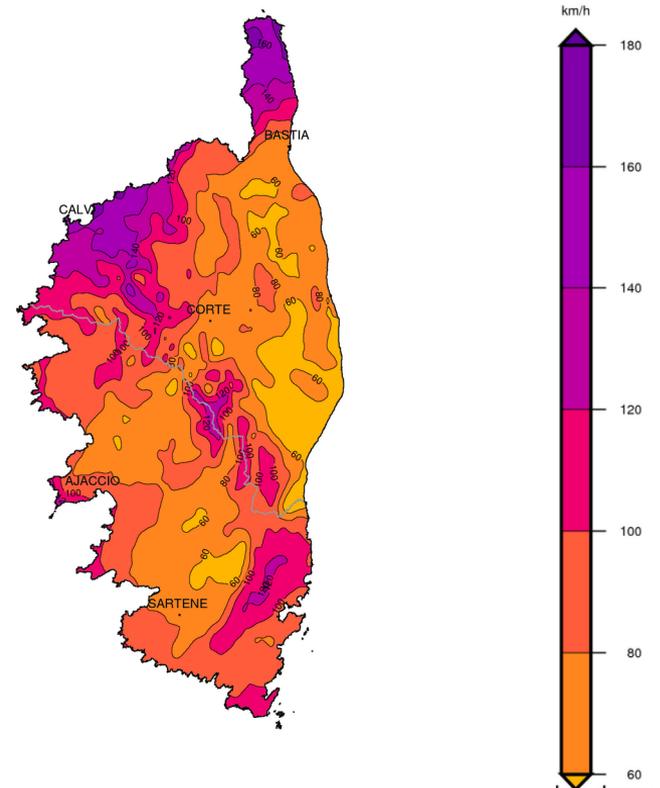
Case study : strong winds in Corsica 28 August 2025



- 100-120 km/h generalized wind gusts
- 150-160 km/h maximal wind gusts
- Orange warning

Maximum spatialised daily gust

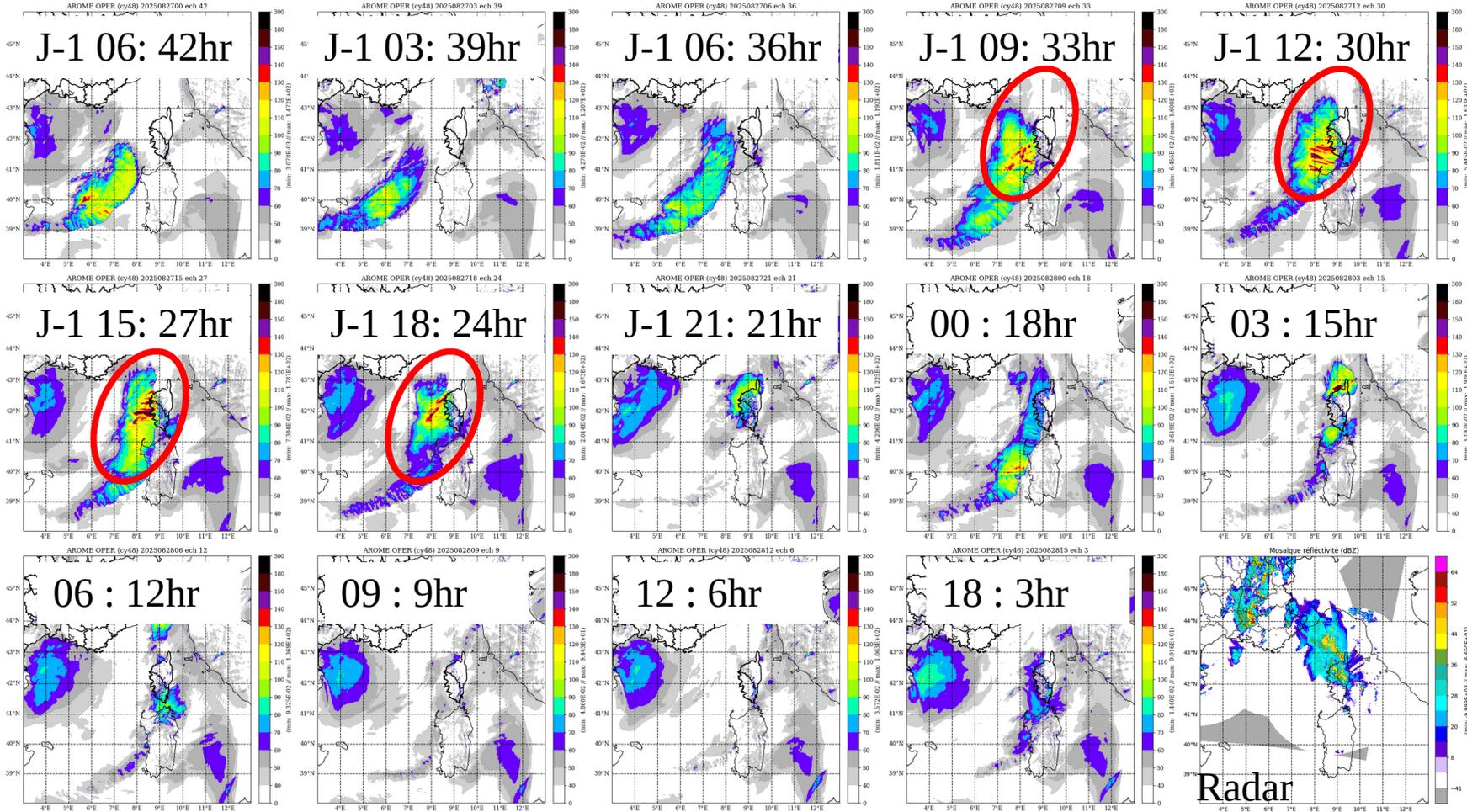
28 August 2025



o-suite

20250828

Wind gusts simulated by the different Arome-France o-suite forecasts valid at 18 UTC the 20250828 : 10 forecasts simulate an interesting signal, but the 4 last ones miss the event (Yellow > 110 Km/h)



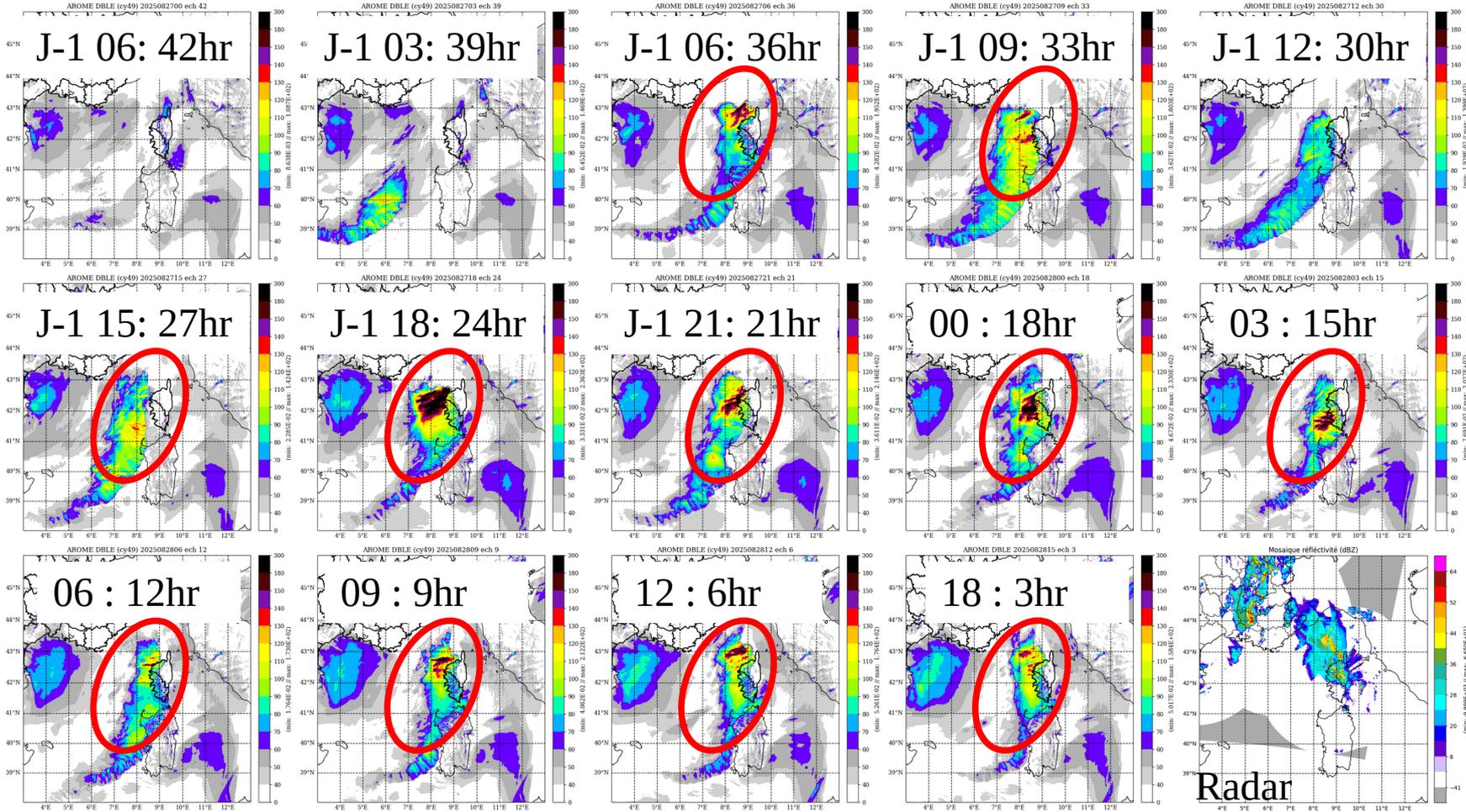
Radar
 reflectivities
 observed at 18
 UTC the
 20250828

e-suite

20250828

Wind gusts simulated by the different Arome-France e-suite forecasts valid at 18 UTC the 20250828 :

The event is well anticipated from 36hr before it occurs and by all the forecasts (Yellow > 110 Km/h)



Radar
 reflectivities
 observed at 18
 UTC the
 20250828

Conclusion

Thanks to the OOPS framework and the move towards EnVar schemes, a new AROME-France E-Suite based on cy49 has been developed, including :

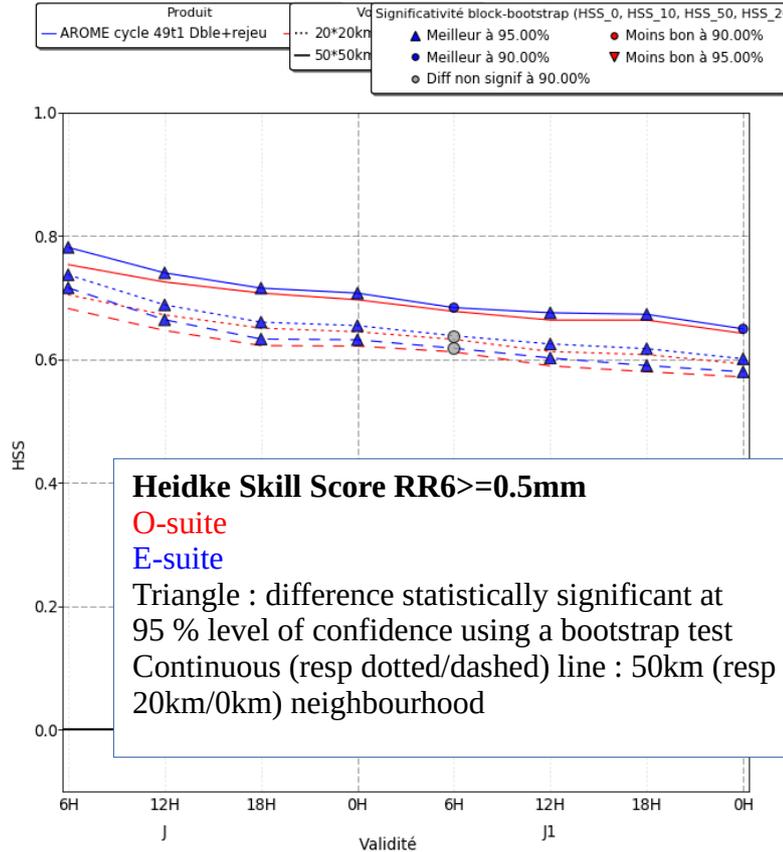
- 4DEnVar (instead of 3DEnVar) in Arome-France : 4DEnVar allows the assimilation of 15 minute observations (radar, Ground GNSS, SEVIRI, surface stations),
- Scale Dependent Localisation in EnVar scheme : performances are improved and the need for localisation retuning is reduced,
- direct assimilation of radar reflectivities (and the use of hydrometeors in the control variable) instead of the 1D pseudo observation retrieval of relative humidity,
- optimisation of assimilation of Mode-S and AMV observations.

This new version presents improved general performances and better simulations of severe meteorological events (HPE, fog, strong winds ...)

Thank you for your attention

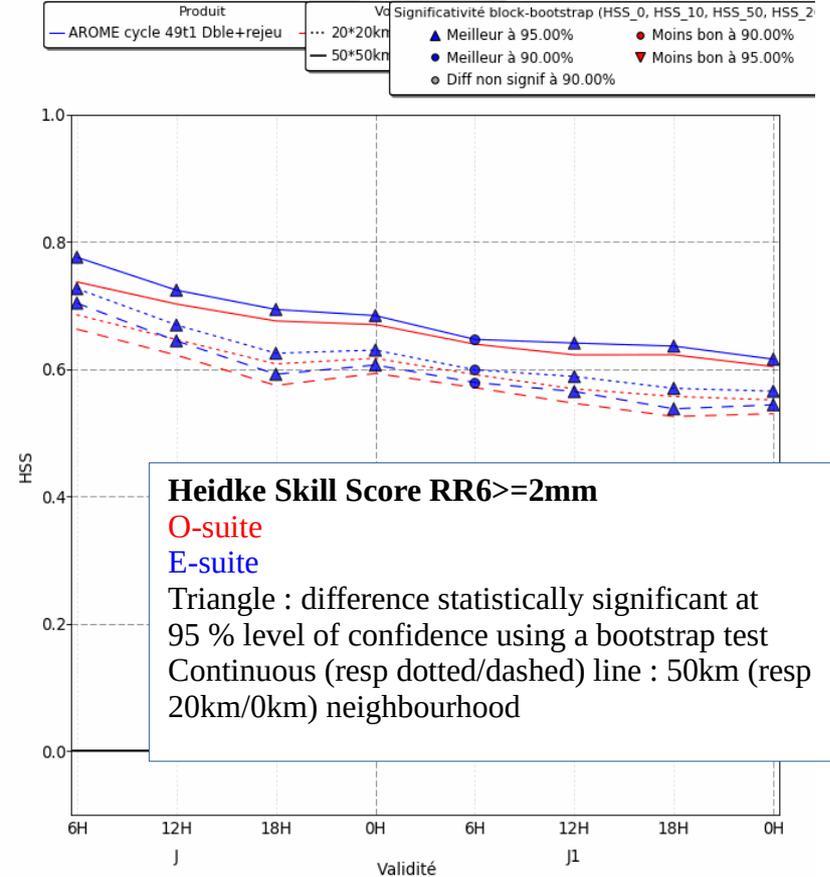
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Prod type AROME 0H , réf. BDCLIM, contr. FRANXL



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Skill Score RR6 $\geq 2.0\text{mm}$ -- du 03 sept. 2024 au 18 sept. 2025 (367
Prod type AROME 0H , réf. BDCLIM, contr. FRANXL



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