EnVar developments with OOPS at Météo-France

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Plan

- Reminder about OOPS
- AROME 3DEnVar (LAM)
- AROME 4DEnVar (LAM)
- ARPEGE 4DEnVar (GLOBAL)
- Conclusions

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OOPS : Object-Oriented Programing System

Next major evolution of the MF DA systems : towards EnVar schemes

Using OOPS :

- project started in 2009 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.

- precursor of the JEDI project at JCSDA (US) also used now at MetOffice.

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AROME 3DEnVar with OOPS : experimental setup

3DEnVar is being experimented, in order to specify flow-dependent **B** for AROME :

- Same resolution as operational configuration (1.3 km).
- Use 50 ensemble members from AROME EDA (3.2 km).
- Horizontal localisation scale varying
  between 25km at low levels and 150km near the model top.
- Vertical localisation scale = 0.3.
- Pure 3DEnVar version (no hybridation in the next slides).

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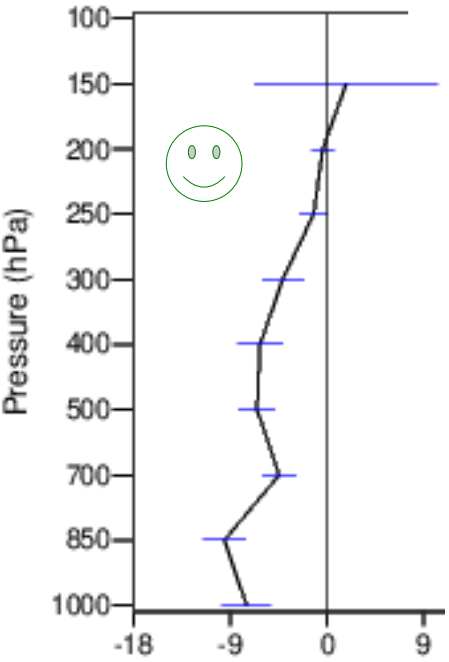
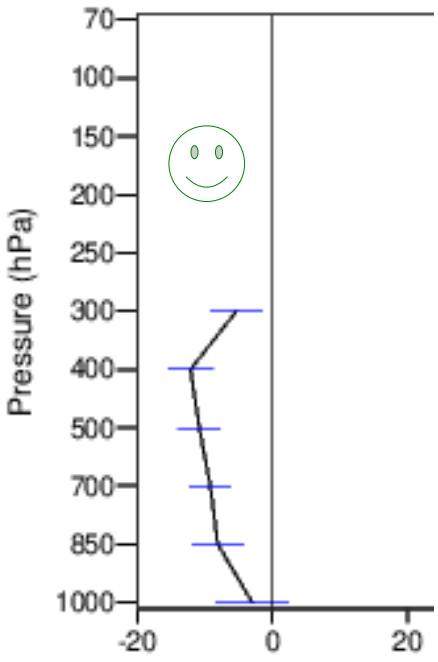
(V. Vogt and P. Brousseau)

Testing 3DEnVar for AROME with OOPS (vs 3D-Var) : obs-guess & scores over 27 days



%diff RMS(wind)
obs(airep)-guess



%diff RMS(q)
obs(temp)-guess

Domaine FRANGP (27 cas)

	Réf.	TEMPs	ECMWF analysis	SYNOPs
	Grille			EURW1S40
	Éch.	0H à 48H pas de 12H	0H à 48H pas de 6H	0H à 48H pas de 6H
Geopotential	100hPa	= = = = =	▼ ▲ = ▲ = = = = =	
	500hPa	= ▲ = = =	▲ ▲ = = = = =	
	850hPa	= ▲ ▲ = =	= ▲ ▲ ▲ ▲ ▲ = =	
	1000hPa	= ▲ ▲ =	▼ = ▲ ▲ ▲ ▲ ▲ ▲	
MSLP	Mer			▼ = ▲ ▲ ▲ ▲ ▲ =
Temperature	100hPa	▼ ▲ = =	= ▲ ▲ ▲ ▲ ▲ = =	
	500hPa	▼ ▲ = =	▲ ▲ ▲ ▲ ▲ ▲ = =	
	850hPa	▲ = ▲ =	▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲	
	1000hPa	▲ = =	▲ ▲ ▲ ▲ ▲ ▲ ▲	
T2m	2m			▼ ▲ ▲ ▲ ▲ = =
Wind	250hPa	= = =	▲ ▲ ▲ ▲ = = =	
	500hPa	= ▲ = =	▲ ▲ ▲ ▲ ▲ = =	
	850hPa	▲ ▲ ▲ = =	▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ =	
10m wind	10m			▼ ▲ ▲ ▲ ▲ ▲ ▲
Humidity	400hPa	= ▲ ▲ =	▲ ▲ ▲ ▲ = = = =	
	700hPa	▲ ▲ = =	▲ ▲ ▲ ▲ ▲ ▲ ▲	
	850hPa	= = = = =	▲ ▲ ▲ ▲ ▲ ▲ =	
	2m			▼ ▼ ▲ ▲ = = = =

Synthesis of score differences

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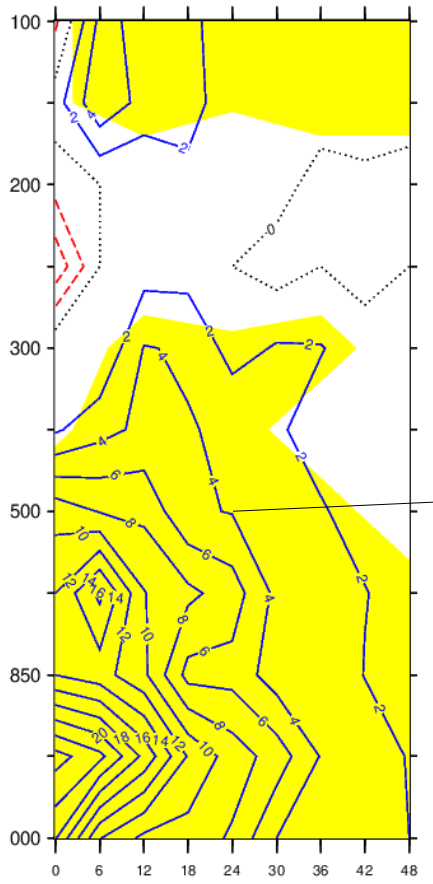
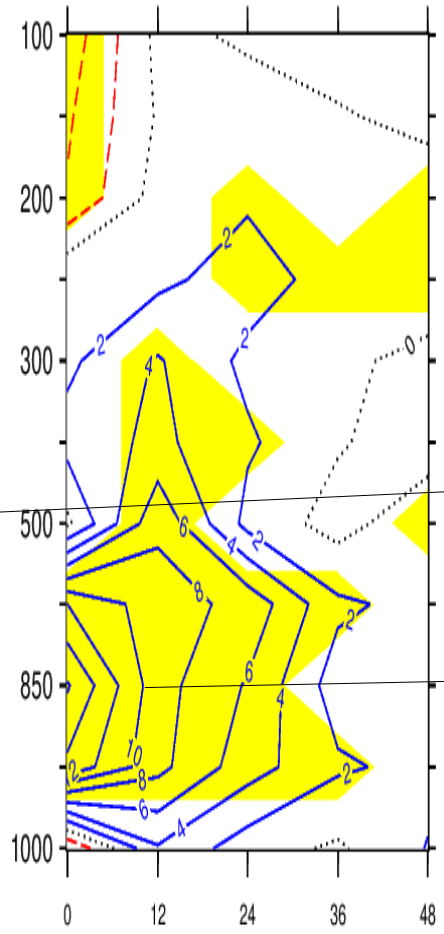
Testing 3DEnVar for AROME with OOPS (vs 3D-Var) : obs-guess & scores over 27 cases



%diff RMS(T)
Ref= analysis(ECMWF)



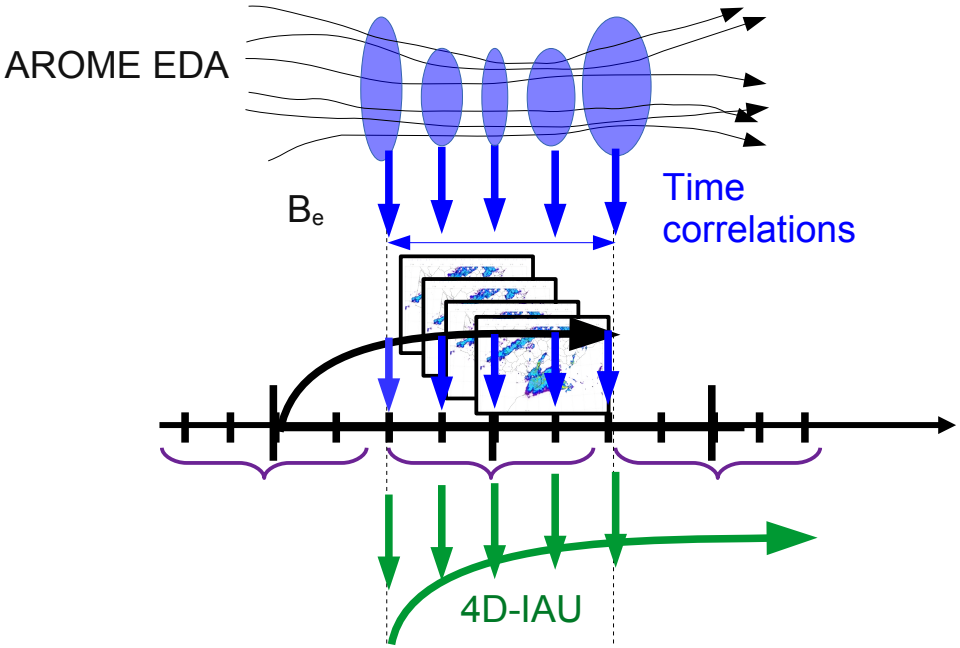
%diff RMS(wind)
Ref = radiosondes

Domaine FRANGP (27 cas)

	Réf.	Radiosondages	Analyses CEP	SYNOPs
	Grille	EURW1S40	FRANGP05	EURW1S40
	Éch.	0H à 48H pas de 12H	0H à 48H pas de 6H	0H à 48H pas de 6H
Géopotentiel	100hPa	= = = = =	▼ ▲ = ▲ = = = =	
	500hPa	= ▲ = = =	▲ ▲ = = = =	
	850hPa	= ▲ ▲ = =	= ▲ ▲ ▲ ▲ ▲ = =	
	1000hPa	= ▲ ▲ =	▼ = ▲ ▲ ▲ ▲ ▲	
Pression	Mer			▼ = ▲ ▲ ▲ ▲ ▲ =
Température	100hPa	▼ ▲ = =	= ▲ ▲ ▲ ▲ ▲	
	500hPa	▼ ▲ = =	▲ ▲ ▲ ▲ ▲ ▲ = =	
	850hPa	▲ = ▲ =	▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲	
	1000hPa	▲ = =	▲ ▲ ▲ ▲ ▲ ▲ ▲	
Température corrigée	2m			▼ ▲ ▲ ▲ ▲ = =
Vent	250hPa	= =	▲ ▲ ▲ ▲ = = =	
	500hPa	= ▲ = =	▲ ▲ ▲ ▲ ▲ = =	
	850hPa	▲ ▲ ▲ = =	▲ ▲ ▲ ▲ ▲ ▲ ▲ ▲ =	
FF	10m			▼ ▲ ▲ ▲ ▲ ▲ ▲
Humidité	400hPa	= ▲ ▲ =	▲ ▲ ▲ ▲ = = = =	
	700hPa	▲ ▲ = =	▲ ▲ ▲ ▲ ▲ ▲ ▲	
	850hPa	= = = = =	▲ ▲ ▲ ▲ ▲ ▲ ▲ =	
	2m			▼ ▼ ▲ ▲ = = = =

Synthesis of score differences

AROME 4DEnVar with OOPS

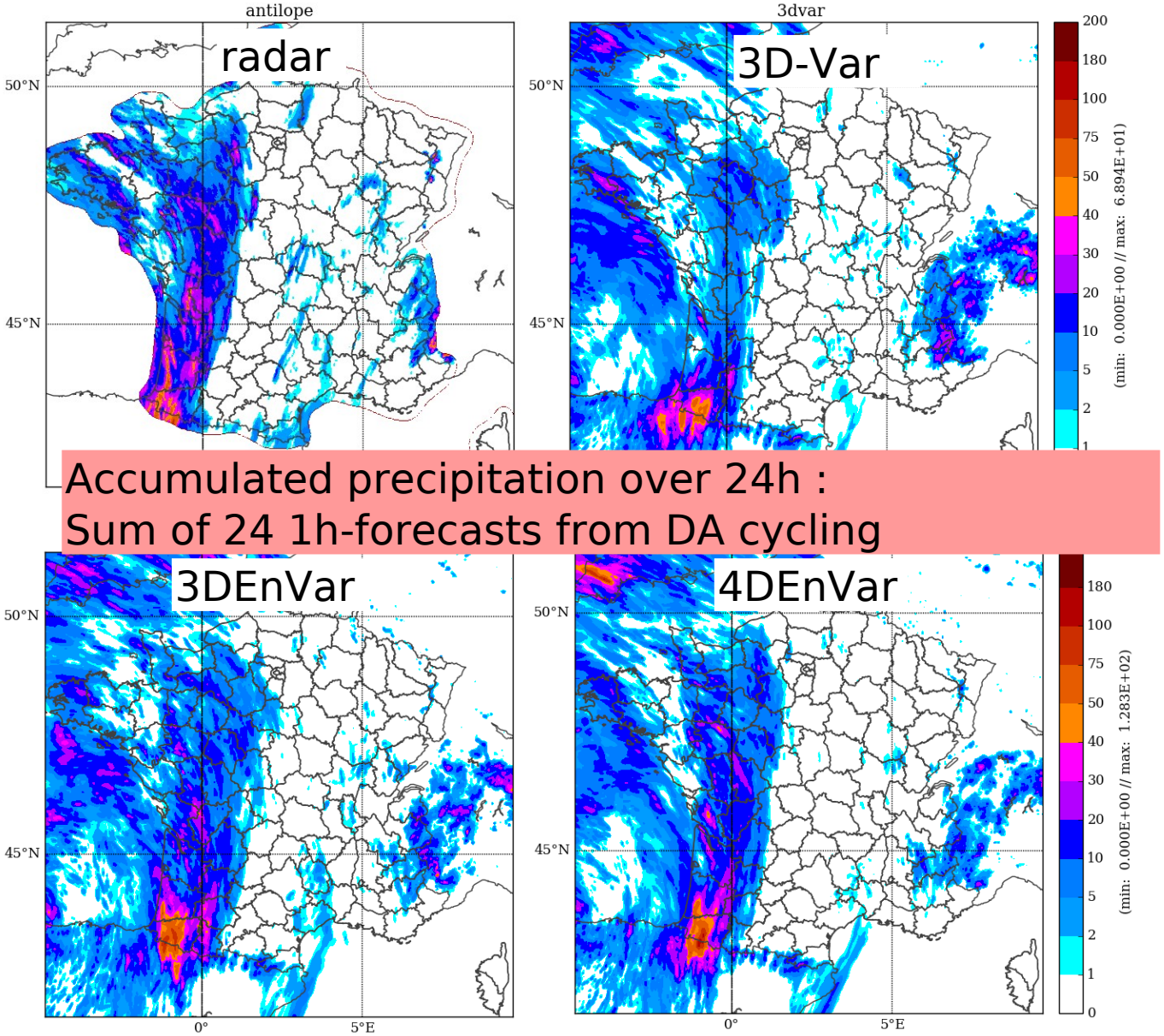


- 4DEnVar : 1h cycle with 5 timeslots : 3*15min + 2*7min
  => use 4D increment (e.g. 4D-IAU).

- 4D perturbations provided by AROME EDA : - resolution of 3.2 km
  - 3D-Var with 3h DA cycling
  - same observations as in deterministic AROME
  (but less dense thinning and lower time frequency)

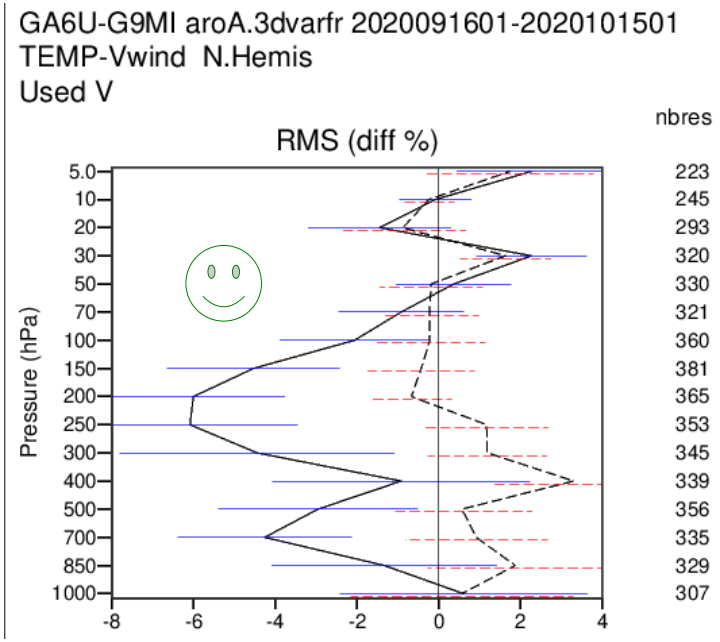
(P. Brousseau)

AROME 4DEnVar : case study 26/05/2018



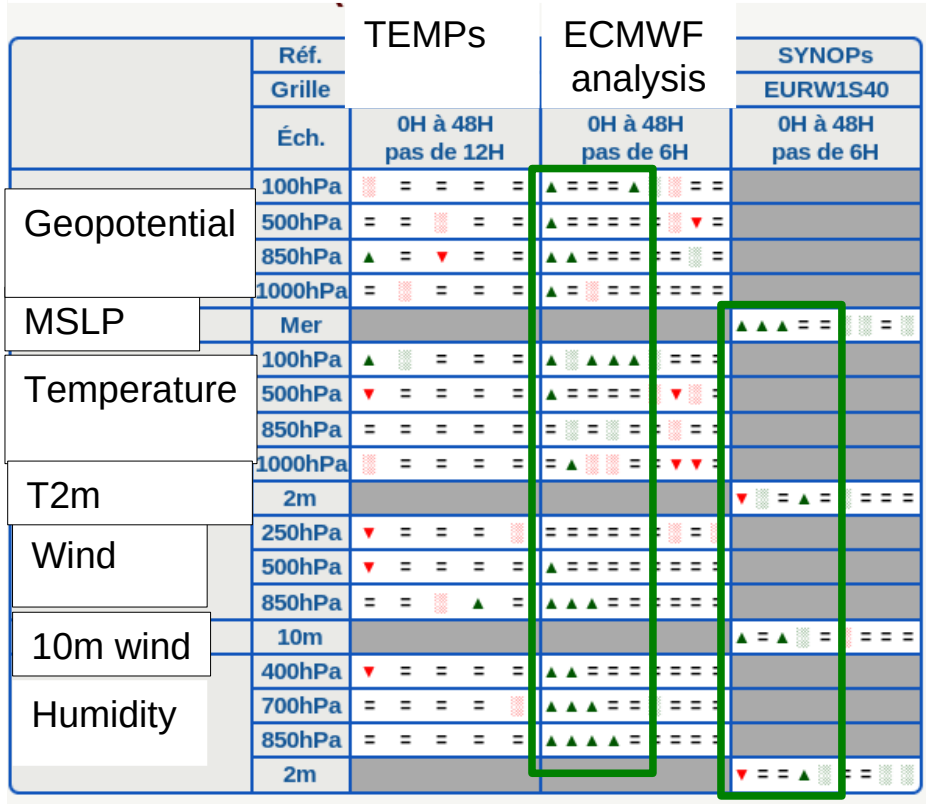
AROME 4DEnVar : experimental results

- Testing AROME 4DEnVar with OOPS over case studies,
  with radars, ground based GNSS & SEVIRI every 15 minutes : positive impact.
- Experimentation has started over long periods,
  with same settings & same observations as in 3DEnVar experiments.



Impact of 4D screening / TEMPs

Synthesis of scores : 4DEnVar vs 3DEnVar (47 cases)



- Usage of 4D increment :
  4D-IAU (progressive addition of 5 increments over 1h window) gives the best results.

4D-hybrid formulation of 4DEnVar for ARPEGE

3D-hybrid 4DEnVar : $\underline{\mathbf{B}} = w_e \, \underline{\mathbf{X}}^{b'} \underline{\mathbf{X}}^{b'T} \circ \underline{\mathbf{L}} + w_m \, \underline{\mathrm{I}} \, \mathbf{B}_0 \, \underline{\mathbf{I}}^T$ (hybrid with static $\mathbf{B}_0$)

4D-hybrid 4DEnVar : $\underline{\mathbf{B}} = w_e \, \underline{\mathbf{X}}^{b'} \underline{\mathbf{X}}^{b'T} \circ \underline{\mathbf{L}} + w_m \, \underline{\mathbf{M}} \, \mathbf{B}_0 \, \underline{\mathbf{M}}^T$ (hybrid with linearly propagated $\mathbf{B}_0$)

can be seen as **a unifying framework** :

w_e=0 : equivalent to 4D-Var ;

w_e=1 : non-hybrid 4DEnVar ;

w_e=0.5 : 4D-hybrid 4DEnVar (intermediate approach).

Allows « a smooth transition » from current 4D-Var towards 4DEnVar,

+ combination of features of the two 4D covariance models :

° **High resolution non linear processes** are represented by the 4D ensemble.

° **Flow-dependent large scale components** are represented through linearly evolved $\underline{\mathbf{M}}\mathbf{B}_0\underline{\mathbf{M}}^T$.

$\underline{\mathbf{M}}\mathbf{B}_0\underline{\mathbf{M}}^T$ can be computed at lower resolution than

the high resolution increments produced by the 4D ensemble.

(L. Berre and E. Arbogast)

Experimental setup for the global ARPEGE system

- 4D-hybrid formulation of 4DEnVar implemented for ARPEGE,
  thanks to **flexibility of OOPS framework**.

- Comparison between “4D-hybrid 4DEnVar” and “4D-Var” over 1 month.
  All conventional and satellite observations are assimilated.

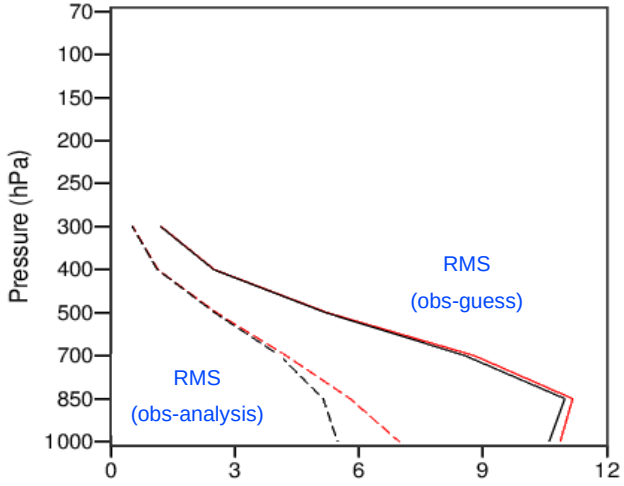
- Minimization at **truncation T499**, with operational TL/AD model,
  followed by HR non linear trajectory update and DFI (at T1798 c2.2).

- ARPEGE EDA provides ensemble information from **50 members** at truncation T499 ;
  $\mathbf{B}_0$ is the operational flow-dependent wavelet matrix (Berre et al 2015).

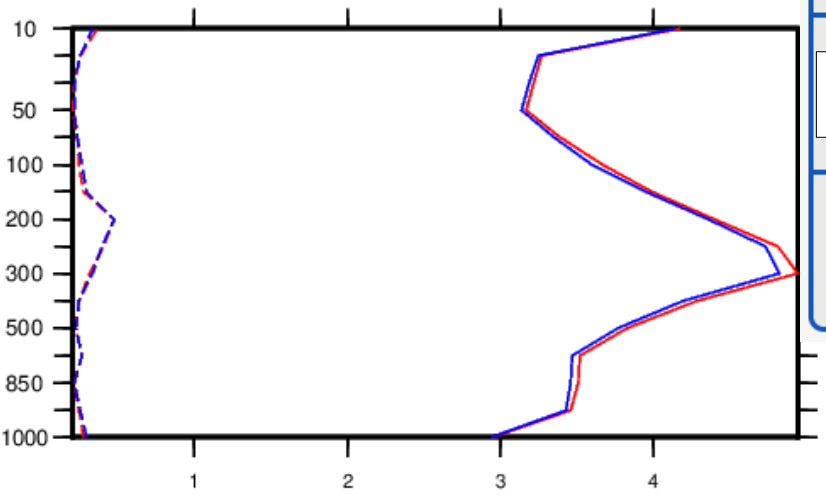
- Setting of covariance weights in the 4D-hybrid version of 4DEnVar :
  $\mathbf{w_m = w_e = 0.5}$ in the troposphere and low stratosphere (up to 150 hPa) ;
  $w_m = 1\text{-}w_e$ is increased from 0.5, at 150 hPa, to 1 at 25 hPa and above (high stratosphere).

- Relatively short localisation scales (~200 km) have been applied ; localisation is advected
  (Desroziers et al 2018) and applied to transformed variables for ln(Ps) and wind (Berre et al 2017).

«4D-hybrid 4DEnVar» vs «4D-Var» (ARPEGE, with OOPS) : results over 30 days



RMS(q) in dg/kg,
over N. Extratropics



RMS(wind) at +48h (TEMPs),
in m/s over N. Extratropics

	Réf.	TEMPs	ECMWF analysis
	Grille		
	Éch.	0H à 96H pas de 12H	0H à 102H pas de 6H
Geopotential	100hPa	▼ = ▼ ▼ = = = = =	▲▲▲▲ = = ▼ = = = = = = = = = = =
	500hPa	▒ ▒ ▲ = = = = ▲ =	▲▲▲▲ ▒ ▲ = = = = = = ▒ = ▒ ▒ = =
	850hPa	▲ = ▒ = = = ▒ ▒ =	▒ ▲ = = = = = ▒ = = = = ▒ = = = = =
	1000hPa	▒ = = ▲ = = = = =	▼ ▲ = ▲ ▒ = = ▒ ▒ ▒ ▒ = = = = = =
Temperature	100hPa	▼ ▲ ▲ ▲ ▲ ▲ = = =	▲▲▲▲▲▲▲▲▲▲▲▲▲ = = = = = =
	500hPa	▼ ▒ ▲ ▲ ▲ = ▒ = =	▲▲▲▲▲▲▲▲ ▒ = = = = = = = =
	850hPa	= = = ▒ = ▒ = ▒ =	▲▲▲▲▲▲▲▲▲▲▲▲▲▲ ▒ = = =
	1000hPa	= = = = = ▲ ▒ ▲ =	▲▲▲▲▲▲▲ = = ▲▲▲▲▲ = = = =
Wind	250hPa	▼ = ▲ = ▒ = = = =	▲▲▲▲▲▲ = ▲▲▲ = = = = = = =
	500hPa	▼ ▲ ▲ ▲ ▒ = = = =	▲▲▲▲▲▲▲▲ ▒ = = = = = = = =
	850hPa	▒ ▲ ▲ ▒ = = = = =	▲▲▲▲▲▲▲▲ ▒ = = = ▒ = = = =
Humidity	400hPa	▼ = = = = = ▒ = =	▲▲▲▲▲▲▲▲▲ = = = = = = = =
	700hPa	▒ ▲ ▲ = = = = ▒ =	▲▲▲▲▲▲▲▲▲▲ ▒ = = = = = = =
	850hPa	= ▲ = = ▲ ▲ = ▒ =	▲▲▲▲▲▲▲▲▲▲▲▲ ▒ ▒ ▲▲▲▲

Synthesis of scores RMS (bootstrap)
Over N. Extratropics

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Conclusions

- Development and testing **AROME 3DEnVar** with OOPS is well advanced, with positive results, and is thus considered for double E-suite in 2022.

- Development of **AROME 4DEnVar** is also progressing well thanks to OOPS, with encouraging results, to be pursued with high frequency observations (15 min), for possible double E-suite in 2023.

- A new **4D hybrid formulation** is proposed for **ARPEGE 4DEnVar with** OOPS, to combine high resolution ensemble with linearly propagated large scale covariances, with positive results compared to 4D-Var, leading 4DEnVar to be considered for double E-suite in 2022.

- **OOPS will also allow new approaches to be considered** : hydrometeors & NH variables in the control variable, better trajectory handling, observation error correlations, …

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Thanks for listening !