EnVar scheme for AROME : preliminary results at 3.8 km resolution

Thibaut MONTMERLE, Yann MICHEL, Etienne ARBOGAST, Benjamin MENETRIER and Pierre BROUSSEAU

CNRM, Toulouse, France

2018/04/16
Joint 28th ALADIN workshop

OUTLINES

1. EnVar in OOPS for LAM

2. Experimental Set-ups

3. Trial results

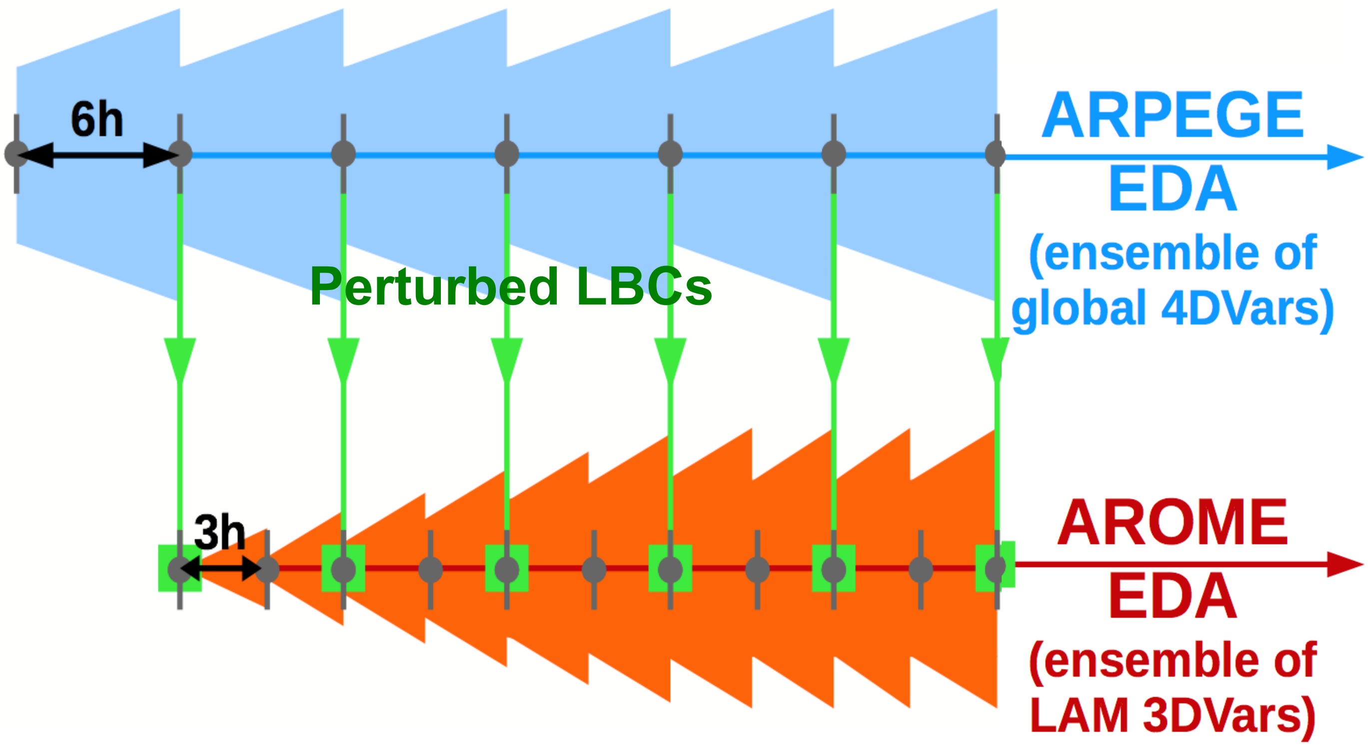
4. Conclusions

EnVar for LAM

EnVar (Lorenc 2003) make use, in the variational formalism, of background error covariances computed from background perturbations :

$$\widetilde{\mathbf{B}} = \frac{1}{N_e - 1} \sum_{l=1}^{N_e} \left(\widetilde{\mathbf{x}}_l^b - \langle\widetilde{\mathbf{x}}^b\rangle\right)\left(\widetilde{\mathbf{x}}_l^b - \langle\widetilde{\mathbf{x}}^b\rangle\right)^{\mathbf{T}} \quad \text{with} \quad \langle\widetilde{\mathbf{x}}^b\rangle = \frac{1}{N_e}\sum_{l=1}^{N_e} \widetilde{\mathbf{x}}_l^b$$

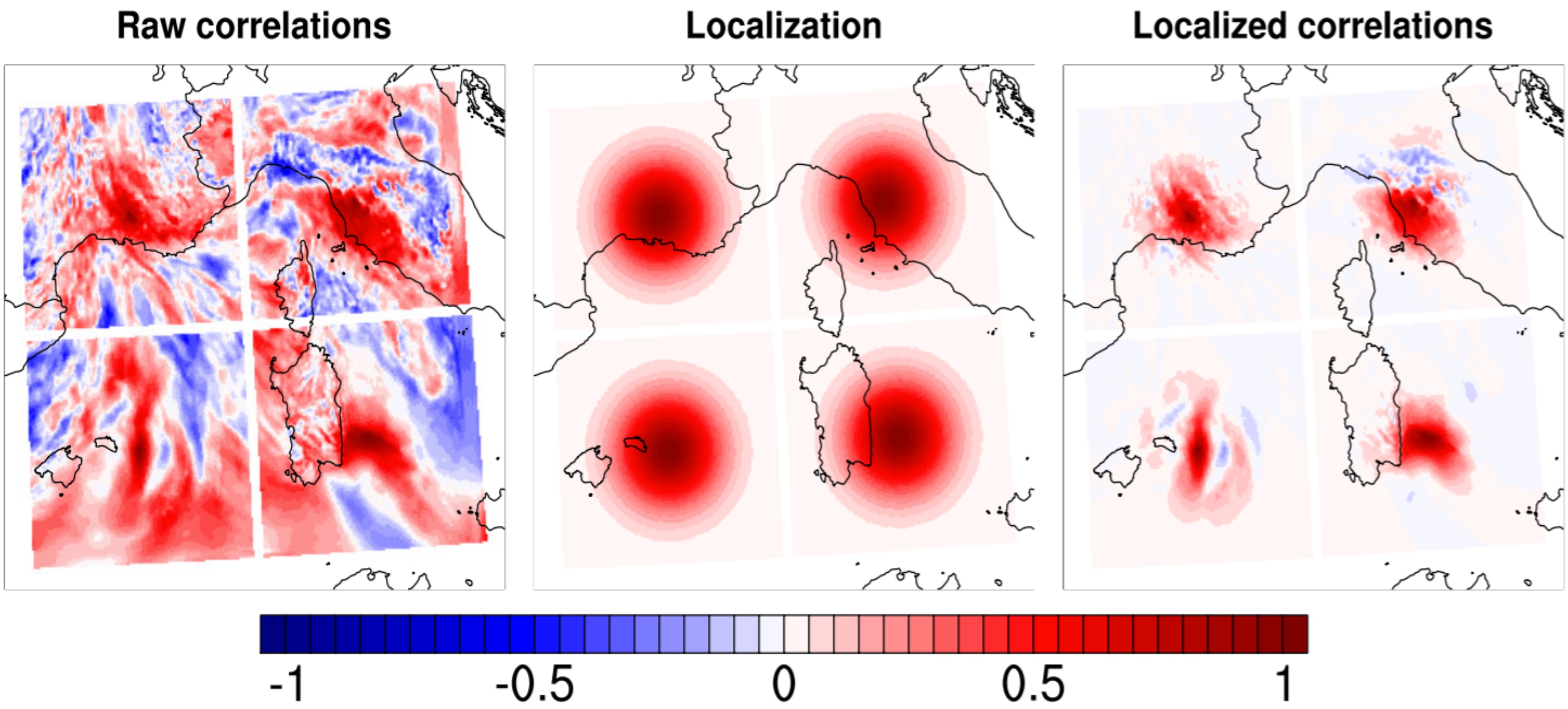
Perturbations are drawn from an EDA AROME which is run independently of the deterministic model (cf. Y. Michel's talk)



Localization

To filter some of the sampling noise, $\widetilde{\mathbf{B}}$ is localized by applying a correlation matrix through a Shur product (Houtekamer and Mitchell, 2001) :

$$\widetilde{\mathbf{B}}_e = \widetilde{\mathbf{B}} \circ \mathbf{C}$$



DA in OOPS for LAM

In the OOPS framework, different flavors of DA algorithms for LAM have been implemented :

- Regular 3DVar using a modeled $\overline{\mathbf{B}}$ validated against MASTERODB's version with all obs (but still without varbc)
- En3DVar and En4DVar with : $\mathbf{B} = \widetilde{\mathbf{B}}_e$ (resp.3D or 4D)
- Hybrids $\mathbf{B} = \beta_c \overline{\mathbf{B}} + \beta_e \widetilde{\mathbf{B}}_e$
- (EnVar can make use of spectral or spatial localization)

Main differences with DA in MASTERODB :

- the preconditioning is based on B instead of $B^{1/2}$ (more details in Desroziers 2014)
- in the EnVar, the control variables are (U, V, T, q, Ps) instead of (vor, div, T, q, Ps), especially because (U, V) have comparable localization lengths that of (T, q)

Experimental set-up

To save computational time, all experiments discussed here have been obtained **with a common analysis and forecast resolution of 3.8 km and a 3h assimilation/forecast cycle**

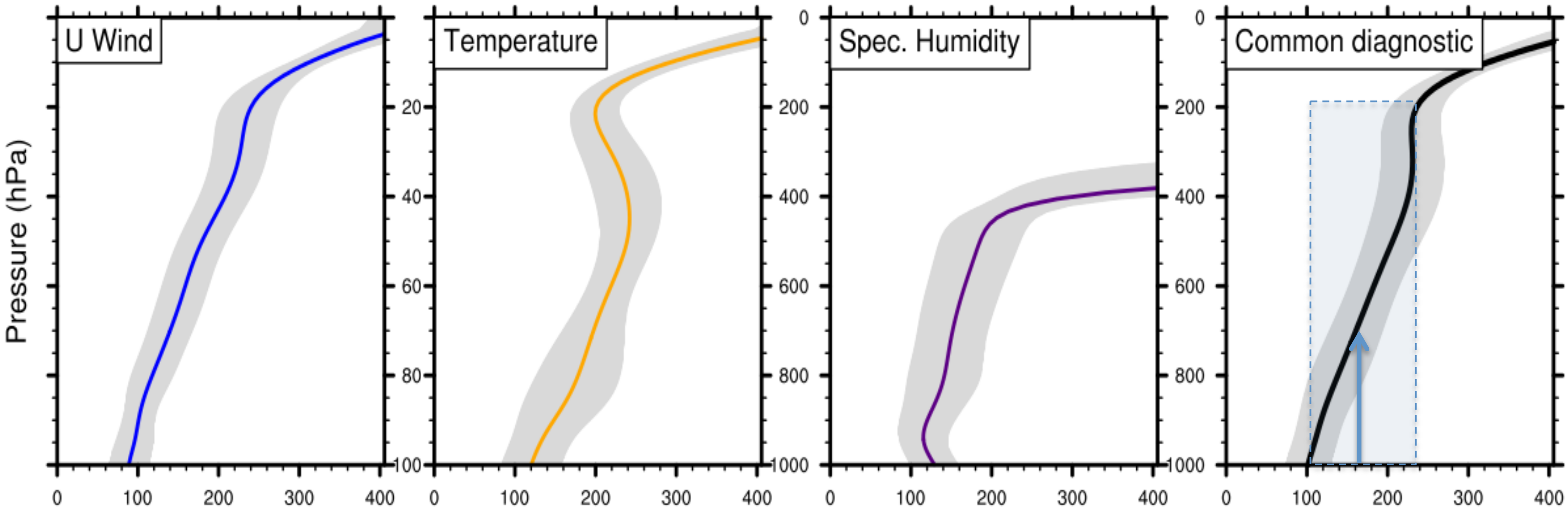
⇒ Not comparable yet to AROME-France, which uses a 1.3 km resolution and a 1h cycle (Brousseau et al. 2016)

Shared characteristics :

- Cycled experiments over 5 weeks (Feb./March 2016)
- EnVar make use of 25 perturbations from an EDA-AROME based on the same resolution of 3.8 km
- All observations of AROME-France are considered, except GPS stations, Geowind and interferometers
- Radar data are thinned at a 30 km resolution (instead of 8 km)

Diagnosed localization lengths

Objective computation of horizontal and vertical localization length-scales from the EDA, following Ménétrier et al. (2015)



Profiles of horizontal localization length-scales (km, Daley's of Gaspari and Cohn (1999) function)

⇒ Retrieval of a common profile (excluding q)

⇒ Averaged value below 200 hPa : $L_h \approx 170$ km , $L_v \approx 0.2$ (log(P))

Trials

First set : basic configurations and hybrids vs. 3DVar

Name in the text	DA method	Loc: type / horiz/ vert	clim/ens weights
BCLIM	3D-Var		1 / 0
BENS-SP	3D-EnVar	Spectral / 170 km / 0.2 hPa	0 / 1
BENS-GP	3D-EnVar	Spatial / 170 km / 0.2 hPa	0 / 1
HYB0.5	Hybrid	Spatial / 170 km / 0.2 hPa	0.5 / 0.5
HYB0.8	Hybrid	Spatial / 170 km / 0.2 hPa	0.2 / 0.8

Second set : sensitivities to localization lengths

BENS-GP-100	3D-EnVar	Spatial / 100 km / 0.2 hPa	0 / 1
BENS-GP-350	3D-EnVar	Spatial / 350 km / 0.2 hPa	0 / 1
BENS-GP-Hz	3D-EnVar	Spatial / f(z) / 0.2 hPa	0 / 1

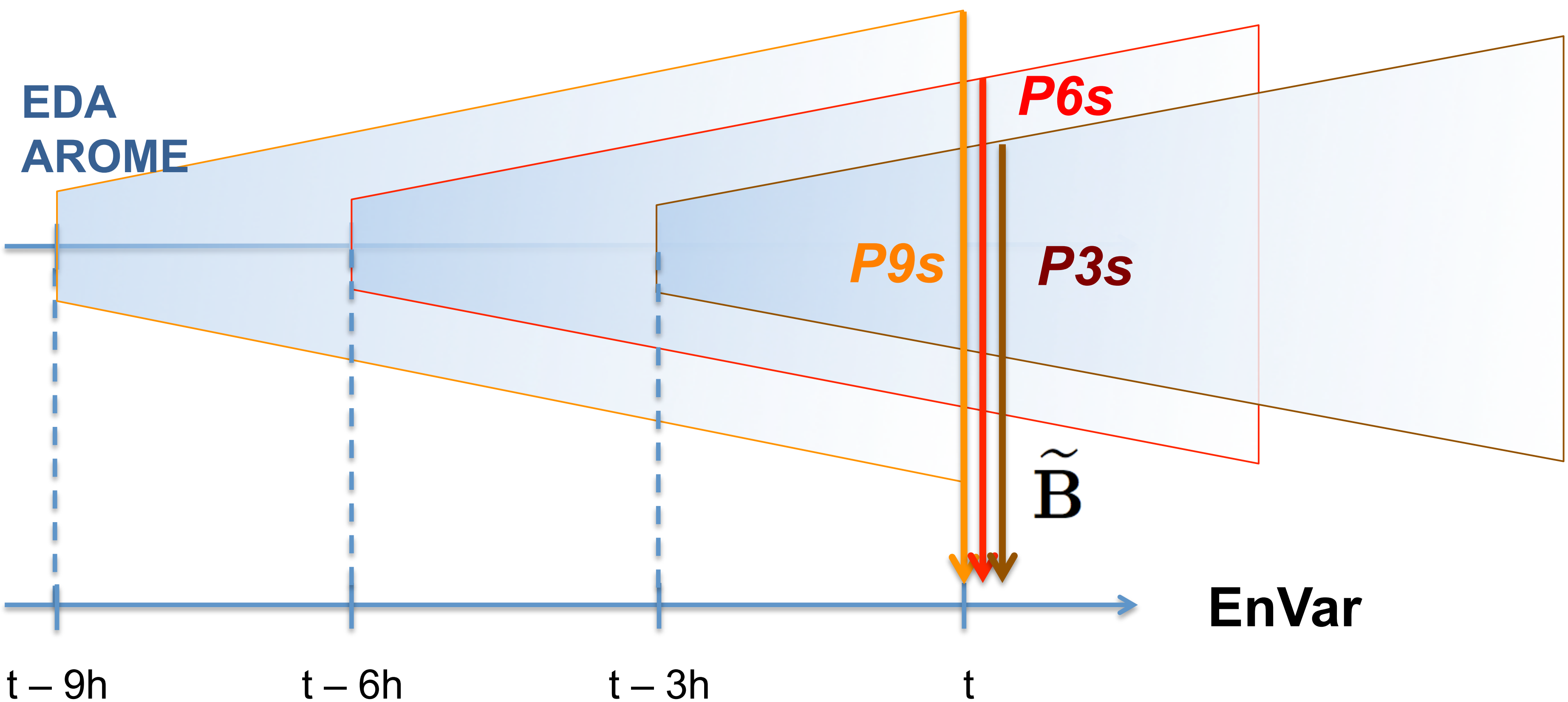
Third set : sensitivities to ensemble size using lagged forecasts

BENS-GP-L50	50m Lagged-3DEnVar	Spatial / 170 / 0.3	0 / 1
BENS-GP-L75	75m Lagged-3DEnVar	Spatial / 170 / 0.3	0 / 1

Time-lagged ensembles

Combines forecasts of different ranges, valid at the correct time, to make a larger ensemble (Hoffman and Kalnay, 1983)

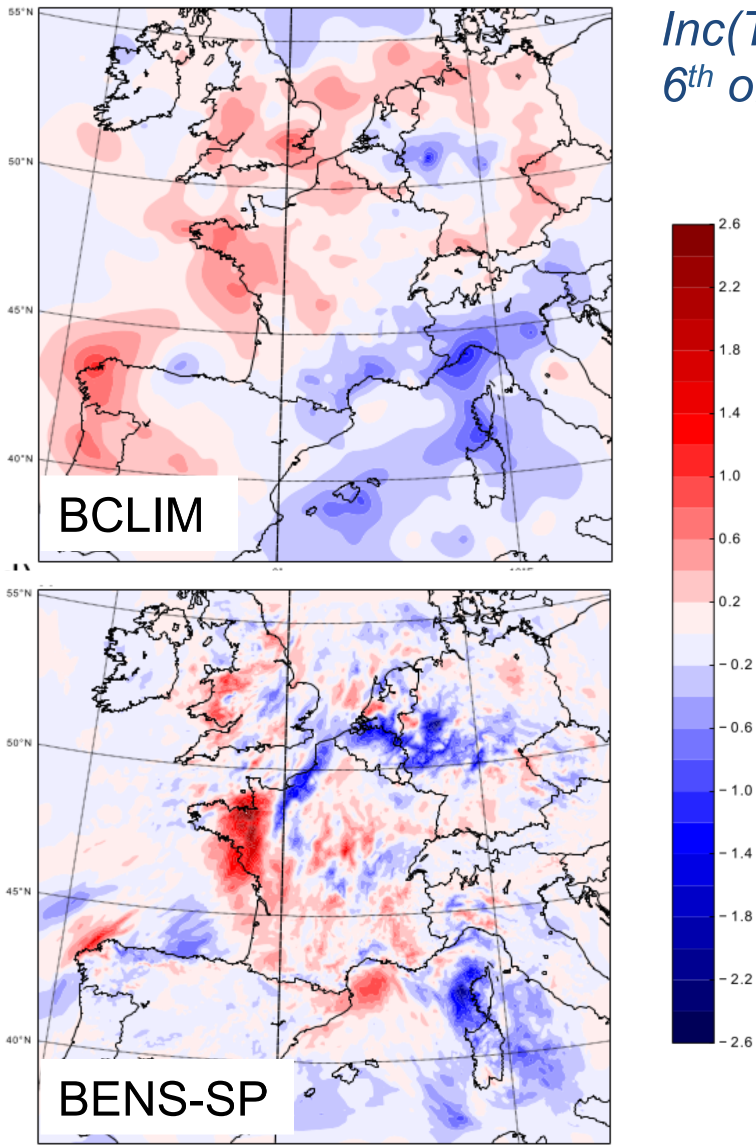
⇒ Extending forecast range of the EDA up to 9h allows to increase the ensemble size by 2 or by 3 :

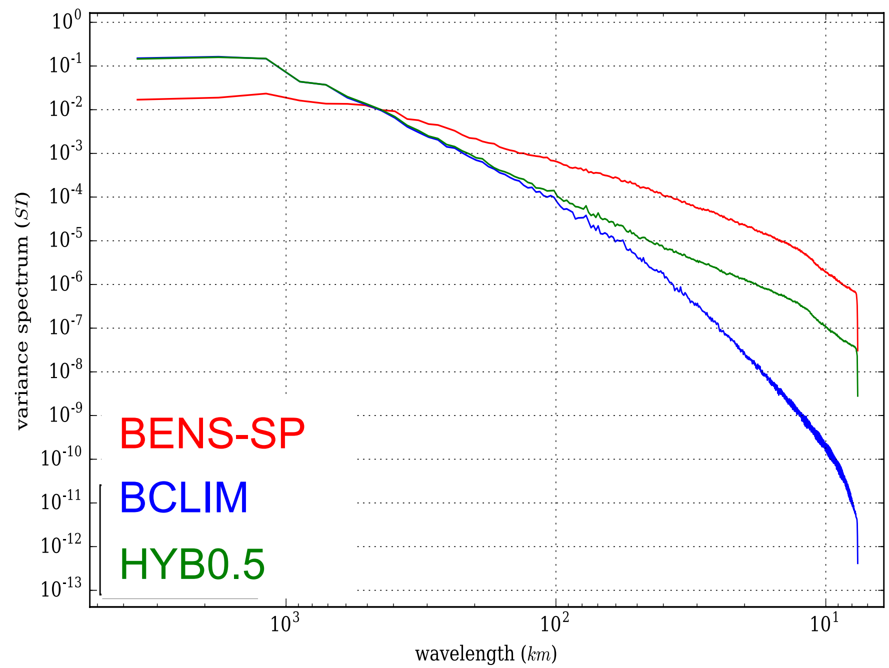


Analysis increments, first assimilation

900 hPa

Inc(T) (K) @900 hPa
6th of Feb. 2016 r0

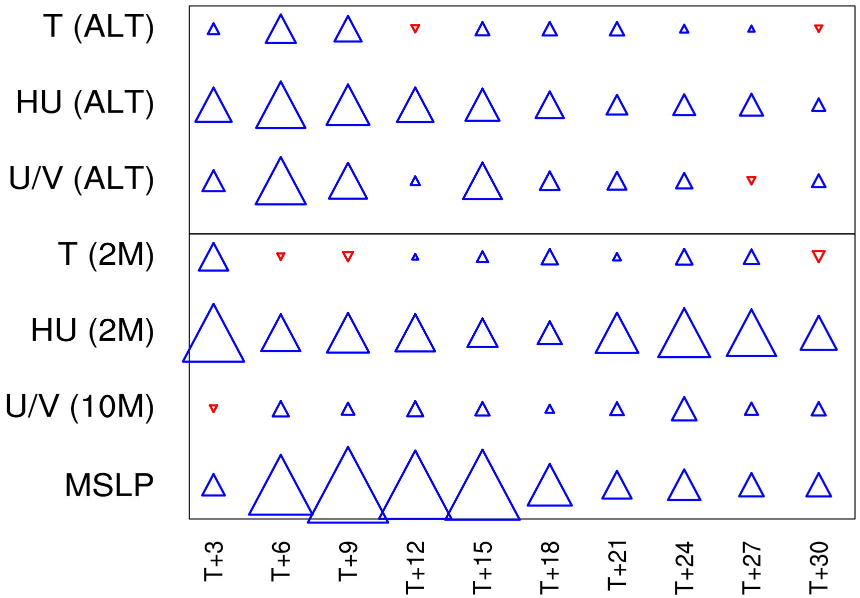




Vertically averaged spectra of T increments

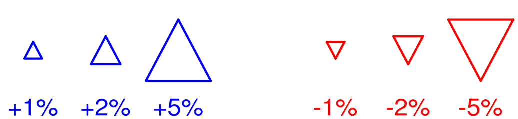
Forecast scores against 3DVar

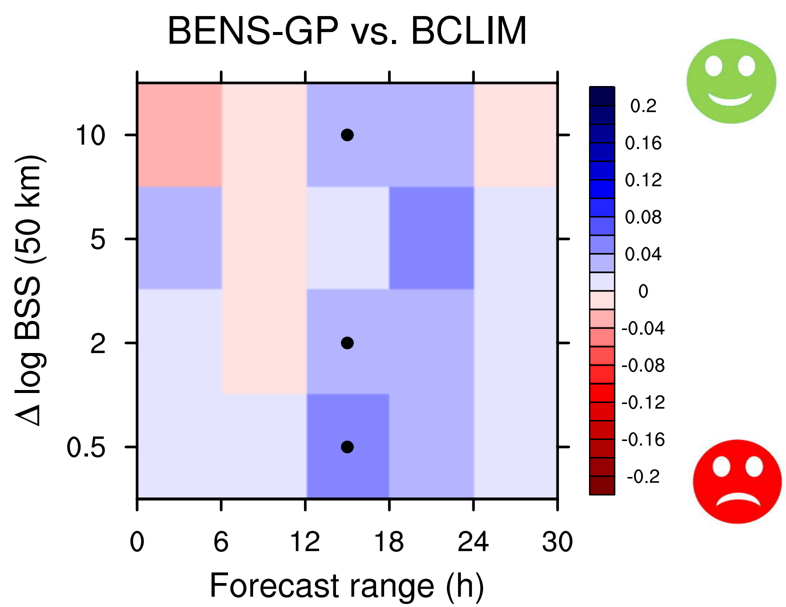
ScoreCard BENS-GP vs. BCLIM
20160206-20160310: HH12



Total NWP index change (altitude) : +1.4 %

Total NWP index change (surface) : +1.9 %





Relative Brier Skill Score for precipitations

Obs for verification :
T (ALT) : AIREP
HU(ALT) : SEVIRI, GPS
U/V (ALT) : AIREP, PILOT
SURFACE : SYNOP
BSS : raingauges

METEO FRANCE

Forecast scores against 3DVar

NWP index against BCLIM

Experiment	Altitude	Surface
BENS-GP	**+ 1.4 %**	**+ 1.9 %**
BENS-SP	+ 1.02 %	+ 1.64 %
HYB-0.5	- 0.02 %	- 0.02 %
HYB-0.8	+ 1.37 %	+ 1.26 %

- Using spectral localization is also efficient, but to a lesser extent than BENS-GP
- HYB-0.5 shows neutral scores
- Increasing the ensemble weight in HYB-0.8 is clearly beneficial, but not as much as using only B_e

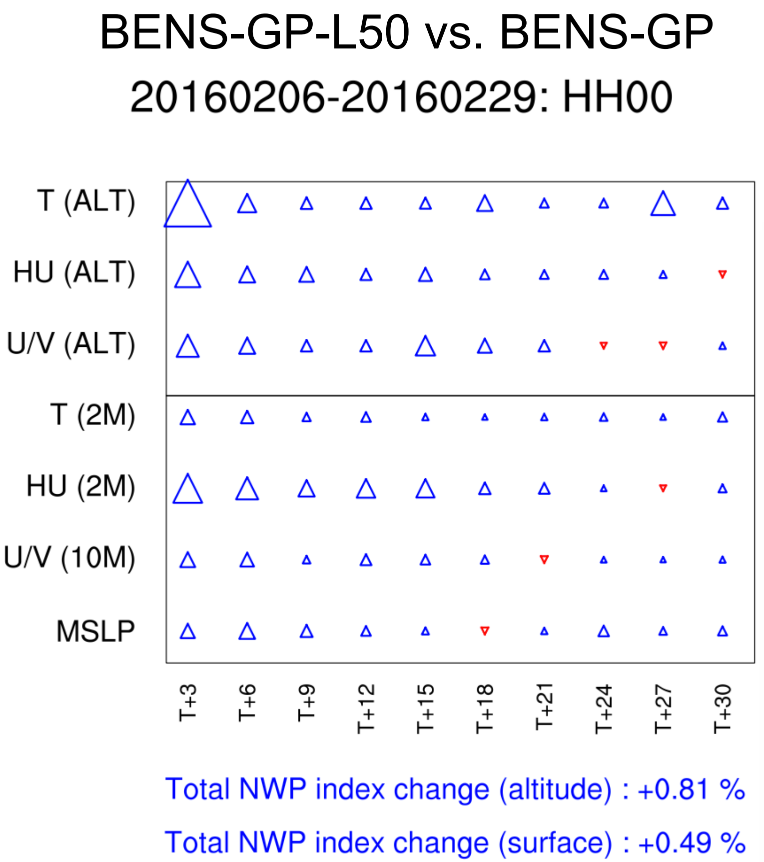
Sensitivities to localization lengths

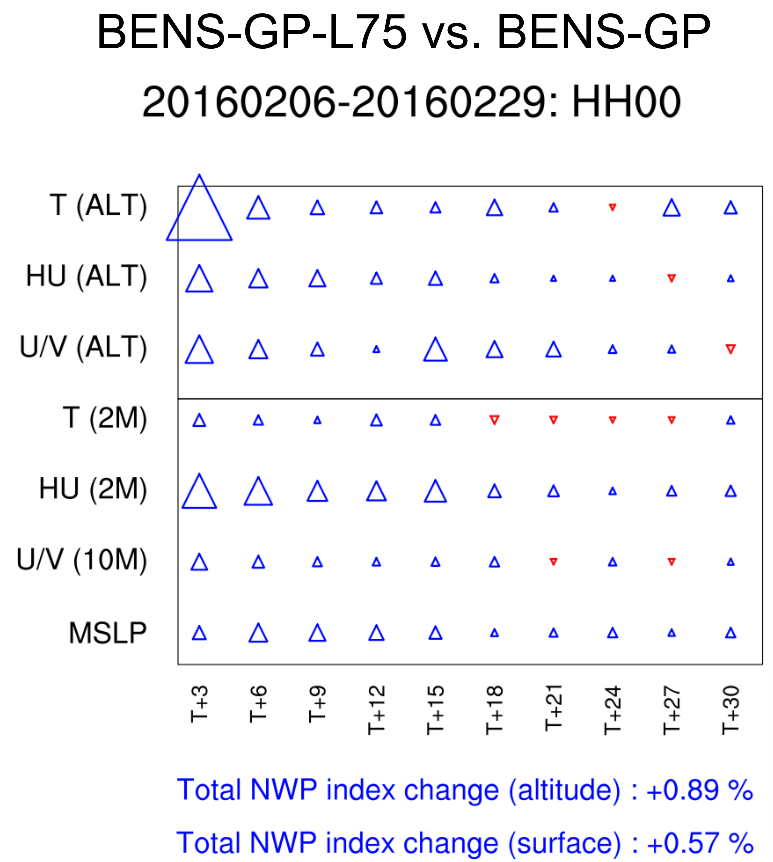
NWP index against BENS-GP

Experiment	Altitude	Surface
BENS-GP-100	- 0.23 %	- 0.09 %
BENS-GP-350	- 0.56 %	- 0.48 %
BENS-GP-Hz	- 0.02 %	- 0.1 %

$\Rightarrow$ Using homogeneous localizations with the objectively computed L_h is clearly the best configuration

Sensitivities to ensemble size

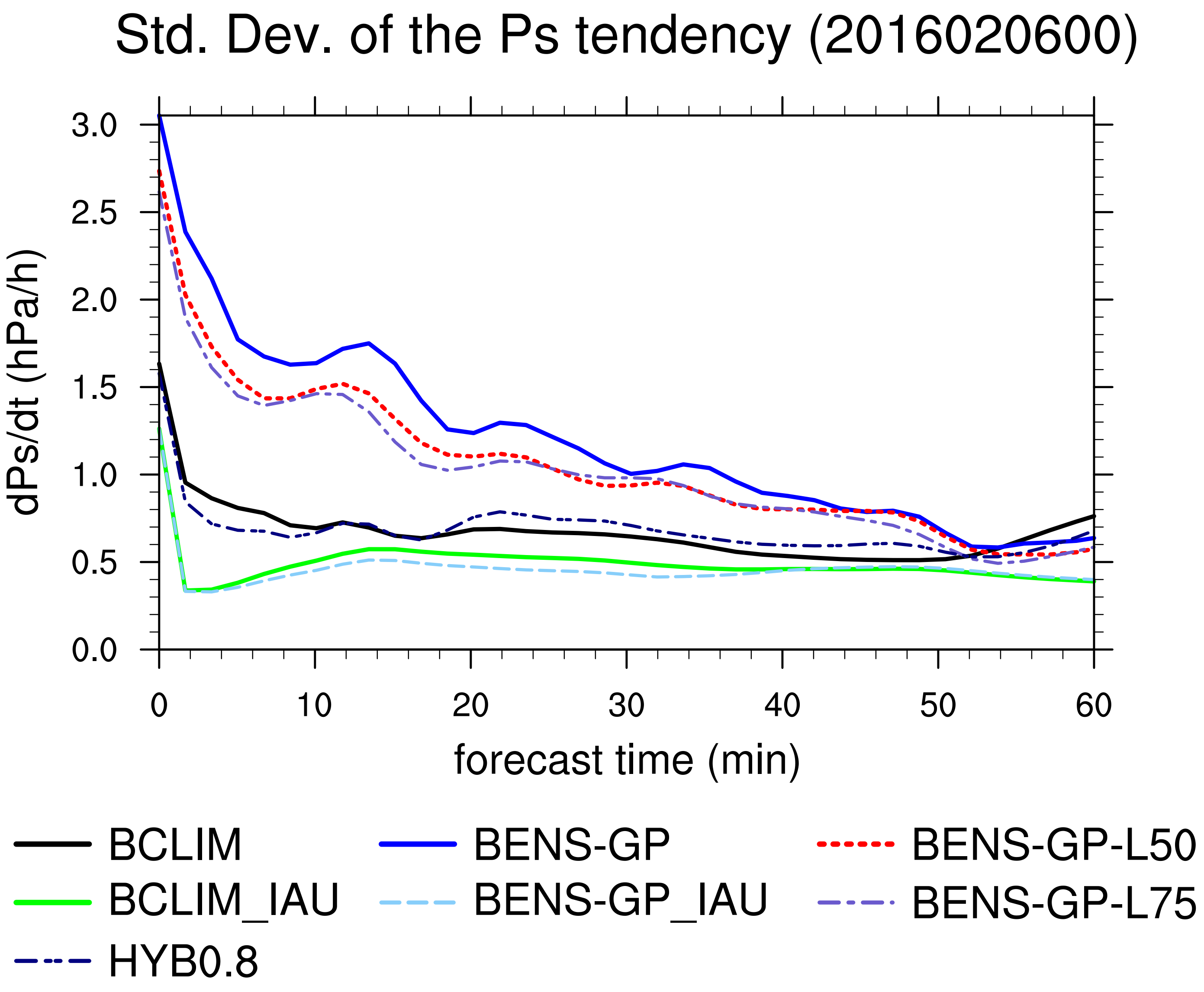




$\Rightarrow$ Considering Lagged forecasts to sample $\widetilde{\mathrm{B}}$ is clearly beneficial, thanks to lower sampling noise and to a larger rank

$\Rightarrow$ Biggest jump in score obtained when using both P3s and P6s

Effects on spin-up (1st assimilation)



Conclusions

B-preconditioned EnVar schemes, with different localization procedures, have been implemented for AROME in the OOPS framework

Considering a 3.8 km horizontal resolution for both EDA and deterministic EnVar analyses :

- Scores compared to 3DVar are clearly improved
- the best configuration uses entirely sampled covariances that are homogeneously localized, considering objective length-scales derived from the EDA in a spatial localization scheme
- Despite slightly negative scores compared to this configuration, Hybrids display much smaller spin-up thanks to the higher rank of the hybrid B and to the partial use of balance operators

Perspectives

- Paper about the results at 3.8 km in revision
- More work is needed to understand the interaction between localization and balance at convective scale
- Evaluation of cycled experiments at 1.3 km is ongoing, with perturbations from an EDA at 3.25 km
- 4DEnVar using an advection of the localization is tested
- Scale Dependent Localization successfully implemented by J.-F Caron with promising results
- PhD Thesis about the inclusion of hydrometeors in the control variable just started (M. Destouches)

Thank you for your attention !

References

Brousseau P, Seity Y, Ricard D, Le ́ger J. 2016. Improvement of the forecast of convective activity from the AROME-France system. *Quart. J. Roy. Meteor. Soc.* : 2231–2243doi: 10.1002/qj.2822.

Buehner, M., 2005: Ensemble-derived stationary and flow-dependent background-error covariances: Evaluation in a quasi-operational NWP setting. Quart. J. Roy. Meteor. Soc., 131, 1013–1043.

Desroziers et al, 2014:4DEnVar: link with 4D state formulation of variational asimilation and possible different implementation. QJRMS, in press.

Gaspari, G., and S. E. Cohn, 1999: Construction of correlation functions in two and three dimensions. Quart. J. Roy. Meteor. Soc., 125, 723–757.

Gustafsson N, Bojarova J, Vignes O. 2014. A hybrid variational ensemble 1084 data assimilation for the HIgh Resolution Limited Area Model (HIRLAM). 1085 *Nonlin. Processes Geophys.* 21: 303–323, doi:10.5194/npg-21-303-2014.

Hoffman and Kalnay, 1983: Lagged average forecasting, an alternative to Monte Carlo forecasting. Tellus, 35A.

Houtekamer P, Mitchell H. 2001. A sequential ensemble Kalman filter for atmospheric data assimilation. *Mon. Wea. Rev.* **129**: 123–137.

Legrand R, Michel Y, Montmerle T. 2015. Diagnosing non-Gaussianity of forecast and analysis errors in a convective scale model. *Nonlin. Proc. in Geoph. Disc.* 2(4): 1061–1090, doi:10.5194/npgd-2-1061-2015.

Lorenc AC. 2003. The potential of the ensemble Kalman filter for NWP - a comparison with 4D-Var. Q. J. R. Meteorol. Soc. 129: 3183–3203.

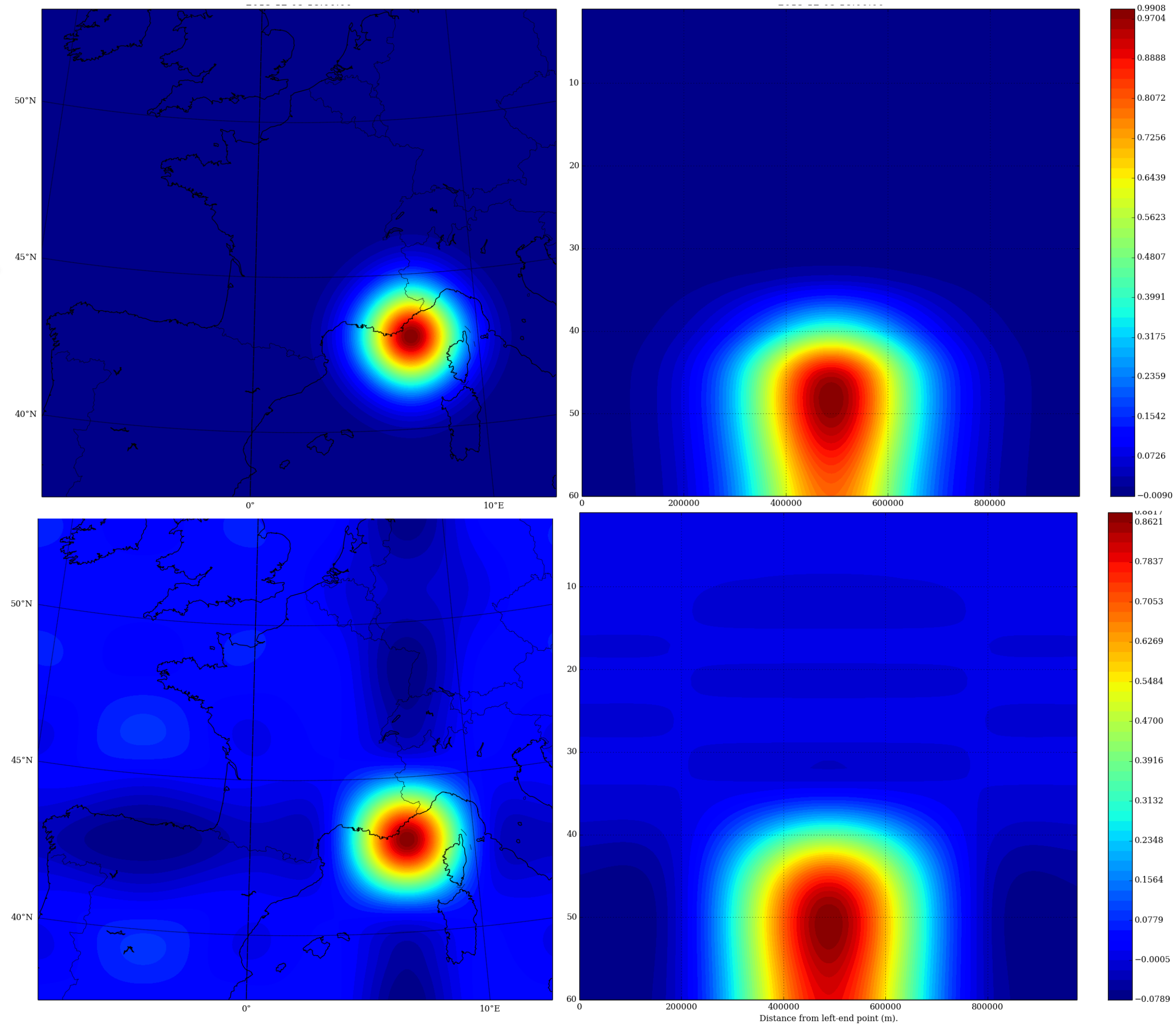
Ménétrier B, Montmerle T, Michel Y, Berre L. 2015b. Linear Filtering of Sample Covariances for Ensemble-Based Data Assimilation. Part II: Application to a Convective-Scale NWP Model. *Mon. Wea. Rev.* 143(5): 1644–1664.

Purser RJ, WuWS, Parrish DF, Roberts NM. 2003. Numerical aspects of the application of recursive filters to variational analysis. Part I: Spatially homogeneous and isotropic Gaussian covariances. Mon. Weather Rev. 131: 1524–1535.

Tested localization functions

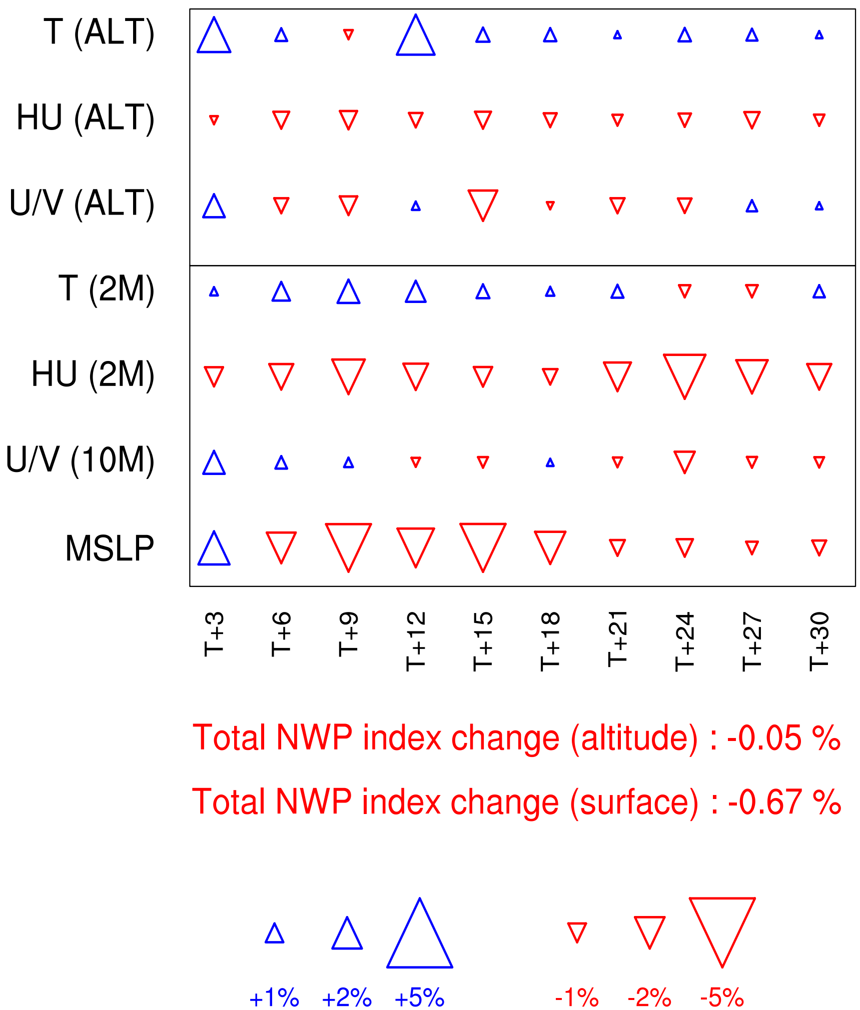
- **Spatial** : homogeneous recursive filters of (Purser, 2003) in both directions, applied to distorted grid for the vertical (Michel, 2012)

- **Spectral** : use of the inverse bi-Fourier transforms

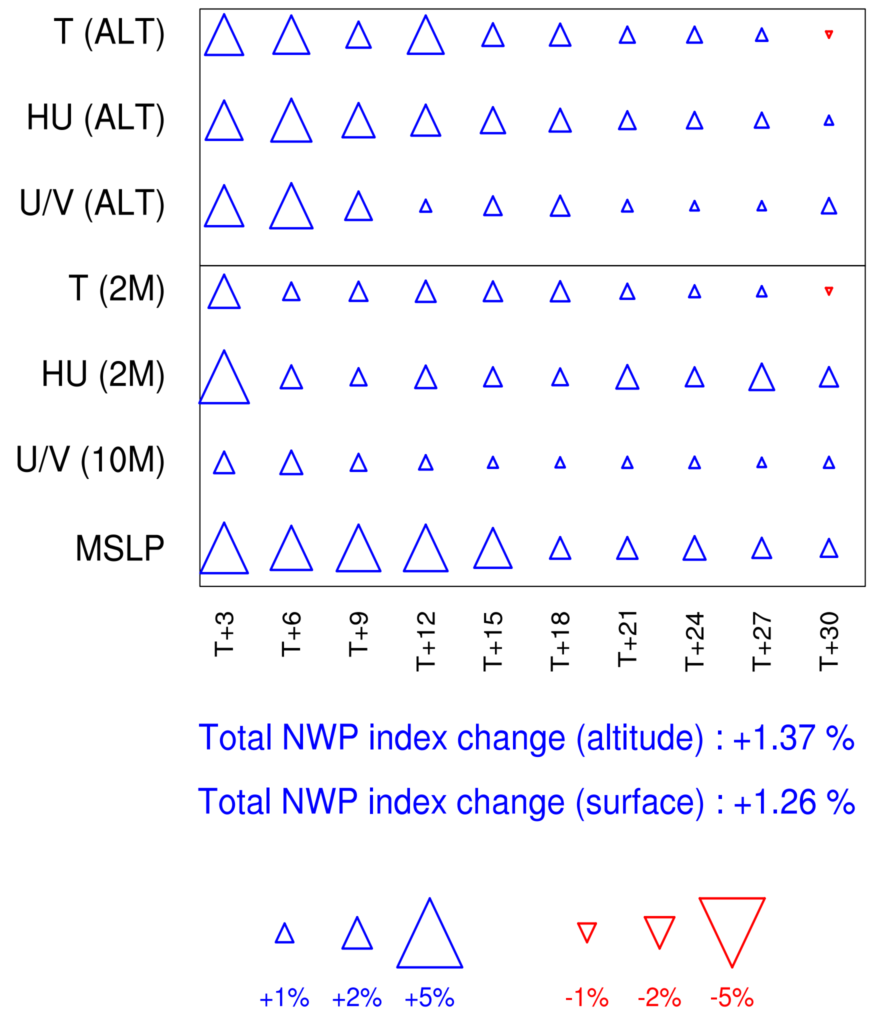


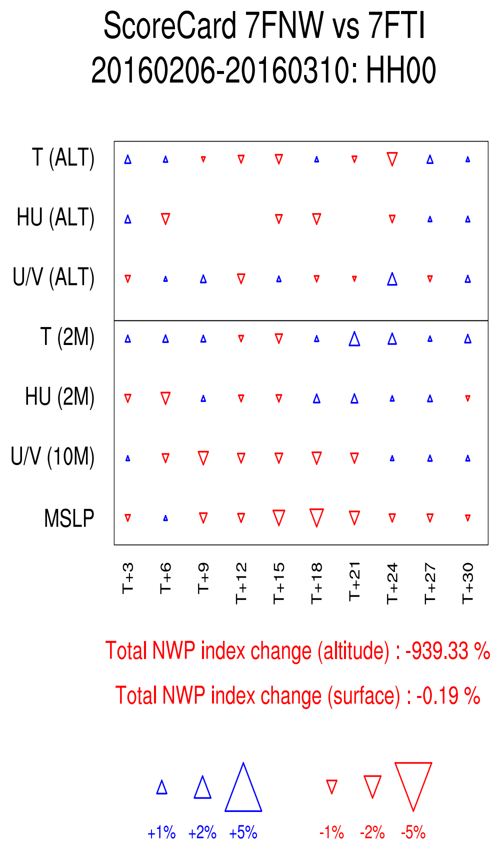
C $\delta^T_{i,j,k}$ *with* L_h *= 250 km and* L_v *= 0.2 (log(P))*

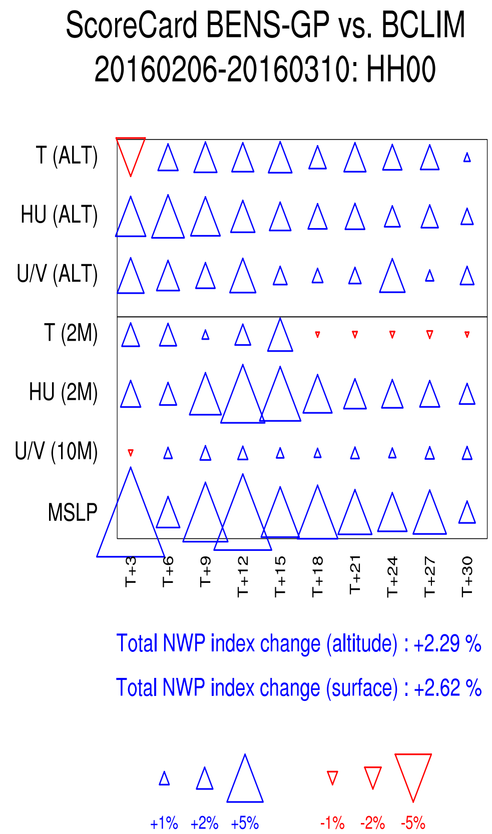
ScoreCard HYB0.8 vs. BENS-GP
20160206-20160310: HH12

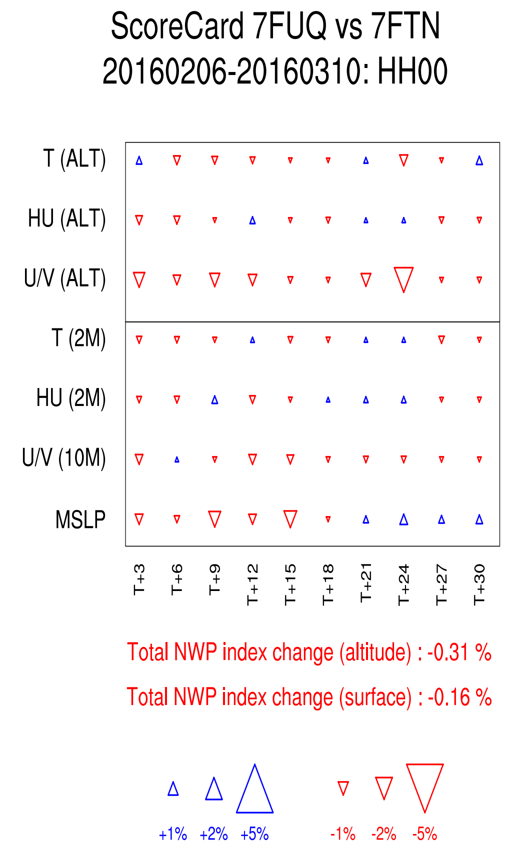


ScoreCard HYB0.8 vs. BCLIM
20160206-20160310: HH12




ScoreCard 7FNW vs 7FTI
20160206-20160310: HH00
T (ALT)
HU (ALT)
U/V (ALT)
T (2M)
HU (2M)
U/V (10M)
MSLP
T+3
T+6
T+9
T+12
T+15
T+18
T+21
T+24
T+27
T+30
Total NWP index change (altitude) : -939.33 %
Total NWP index change (surface) : -0.19 %
+1%
+2%
+5%
-1%
-2%
-5%

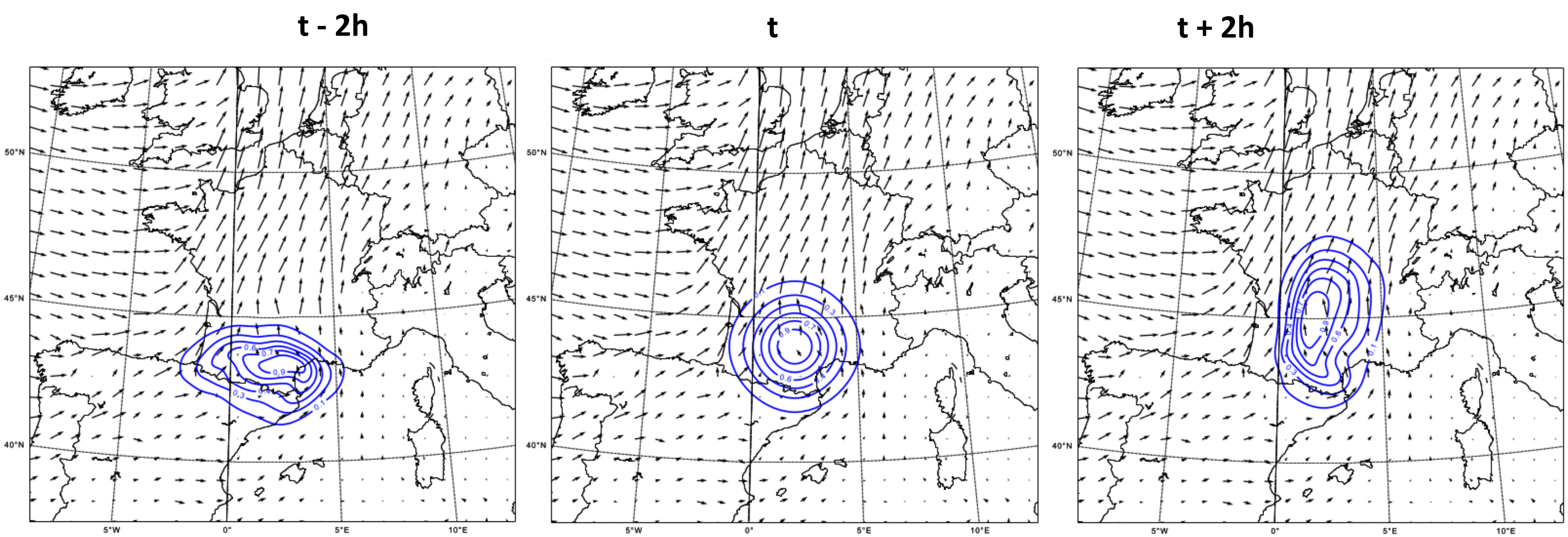

ScoreCard BENS-GP vs. BCLIM
20160206-20160310: HH00
T (ALT)
HU (ALT)
U/V (ALT)
T (2M)
HU (2M)
U/V (10M)
MSLP
T+3
T+6
T+9
T+12
T+15
T+18
T+21
T+24
T+27
T+30
Total NWP index change (altitude) : +2.29 %
Total NWP index change (surface) : +2.62 %
+1%
+2%
+5%
-1%
-2%
-5%


ScoreCard 7FUQ vs 7FTN
20160206-20160310: HH00
T (ALT)
HU (ALT)
U/V (ALT)
T (2M)
HU (2M)
U/V (10M)
MSLP
T+3
T+6
T+9
T+12
T+15
T+18
T+21
T+24
T+27
T+30
Total NWP index change (altitude) : -0.31 %
Total NWP index change (surface) : -0.16 %
+1%
+2%
+5%
-1%
-2%
-5%

Localisation : advection

Advection des perturbations dans le calcul du gradient pour le 4D-EnVar (Desroziers et al. 2016) :

$$h_k = \sum_{l=1}^{N_e} \sum_{k'=0}^{K} \delta\tilde{\mathbf{x}}^b_{l,k} \circ (\mathcal{A}\mathbf{C}\mathcal{A}^T(\delta\tilde{\mathbf{x}}^b_{l,k'} \circ g_{k'}))$$



Advection d'une fonction de corrélation horizontale par un vent filtré