Variational ensemble DA at Météo-France

L. Berre, G. Desroziers, H. Varella,
L. Raynaud, C. Labadie and L. Descamps
Météo-France (CNRM/GAME)

dépasser les frontières

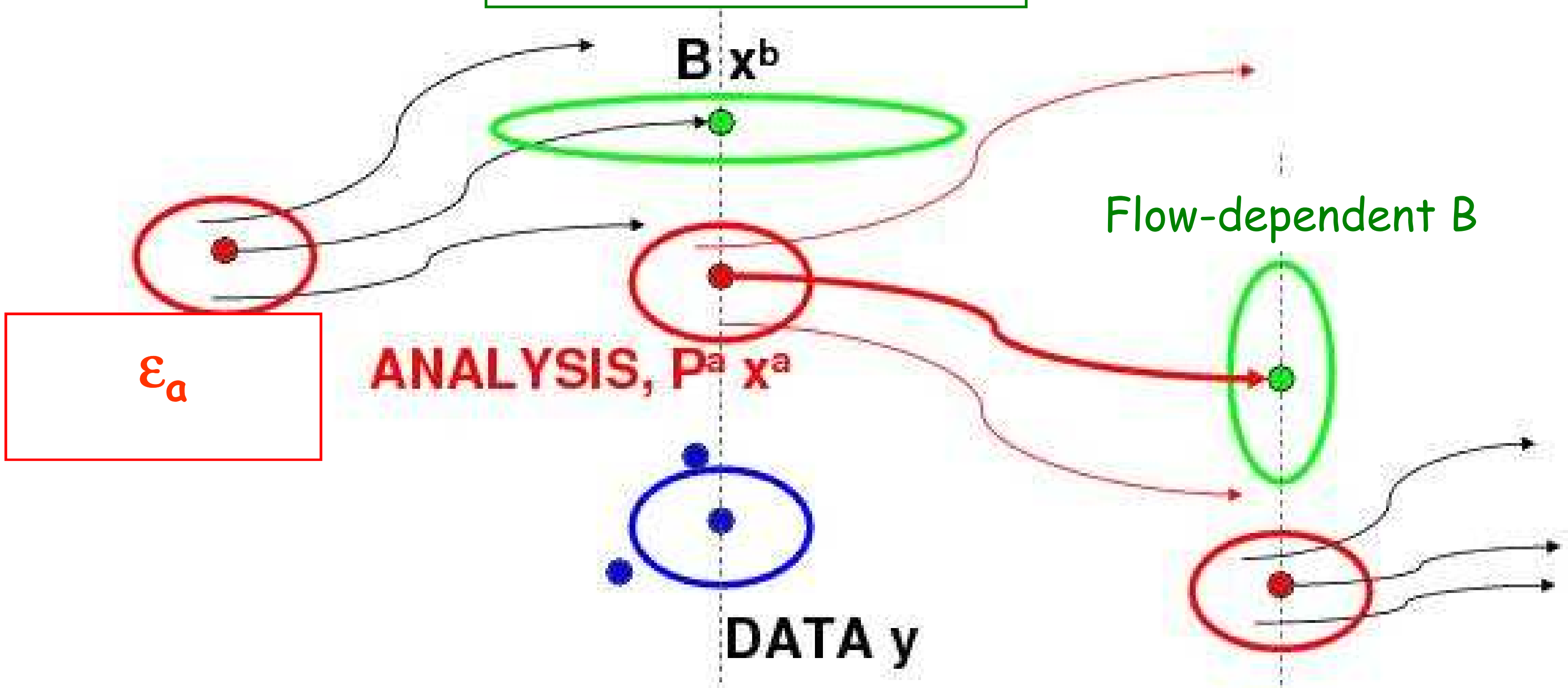
METEO FRANCE
Toujours un temps d'avance

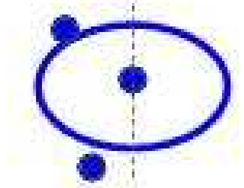
Plan of the talk

- Error equations and their simulation
- Filtering error variances
- Model error
- Wavelet flow-dependent correlations

Ensemble assimilation (EnDA = EnVar, EnKF, ...) :
simulation of the error evolution

$$\varepsilon_f = M\,\varepsilon_a + \varepsilon_m$$





Explicit observation perturbations, and
background perturbations (cycling + model error).

(Houtekamer et al 1996; Fisher 2003 ;
Ehrendorfer 2006 ; Berre et al 2006)

Analysis error equation

- Analysis state (BLUE, K = 4D-Var gain matrix) :

$$x_a = (I-KH)\, x_b + K\, y_o$$

- True state :

$$x_t = (I-KH)\, x_t + K\, Hx_t$$

- Analysis error :

$$e_a = x_a - x_t$$

i.e.

$$e_a = (I-KH)\, e_b + K\, e_o$$

Analysis perturbation equation

- Perturbed analysis :

$$x'_a = (I-KH)\, x'_b + K\, y'_o$$

- Unperturbed analysis :

$$x_a = (I-KH)\, x_b + K\, y_o$$

- Analysis perturbation :

$$\varepsilon_a = x'_a - x_a$$

i.e.

$$\varepsilon_a = (I-KH)\, \varepsilon_b + K\, \varepsilon_o$$

Simulation of analysis errors : « consistent ensemble 4D-Var » or « hybrid EnKF/Var » ?

A consistent 4D-Var approach is used at M.F.
in both ensemble and deterministic components :

- Simple to implement (perturbed Var ~ unperturbed Var).
- Full-rank flow-dependent B consistently used.
- Non-linear aspects of 4D-Var $\Rightarrow$ non Gaussianities / outer loop.
- Possible replacement of TL/AD by NL ensemble traj. (Buehner 2010).
- Synergic minimizations.

Additionally :

- Spatial correlations of obs. errors in obs. perturbations.
- Vertical localisation of correlations (if applied) in model space.
- Observation handling.

The operational M.F. variational EnDA

- Six perturbed global members, T399 L70 with 4D-Var Arpege.
- Spatial filtering of error variances.
- Inflation of forecast perturbations / model errors.
- The Arpege 4D-Var's use these « errors of the day ».
- Regional EnVar (LAM) is also experimented,
  with Aladin (10 km) and Arome (2.5 km).

Applications of EnDA at M.F.

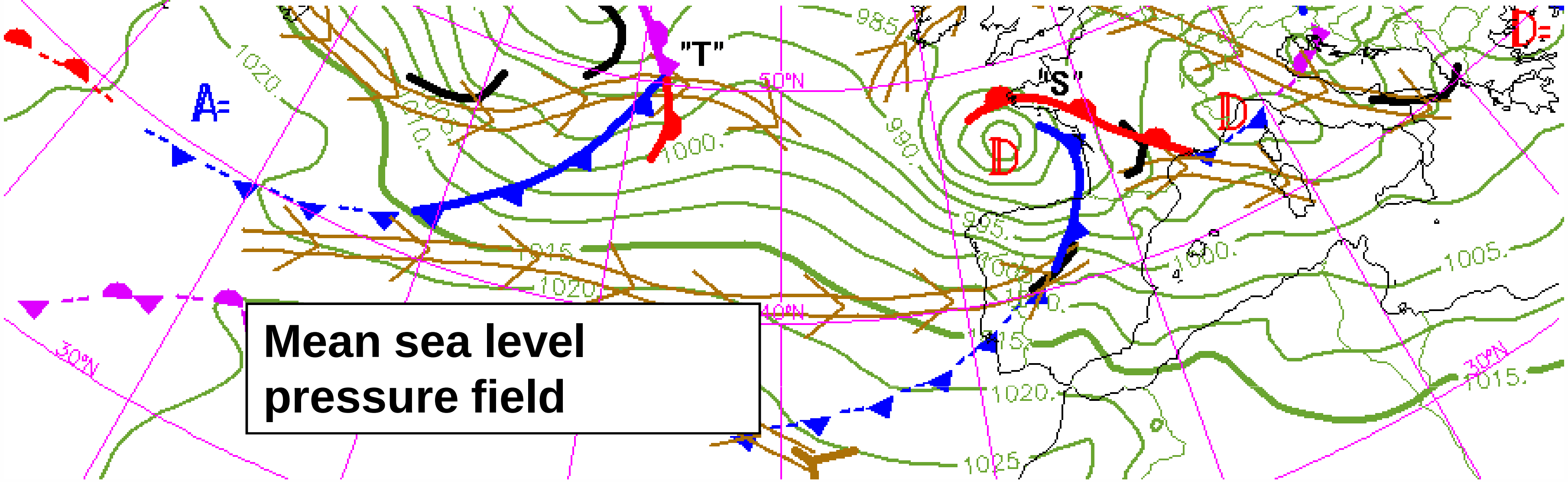
- Flow-dependent background error variances (oper 2008) (for all variables including humidity and unbalanced variables)

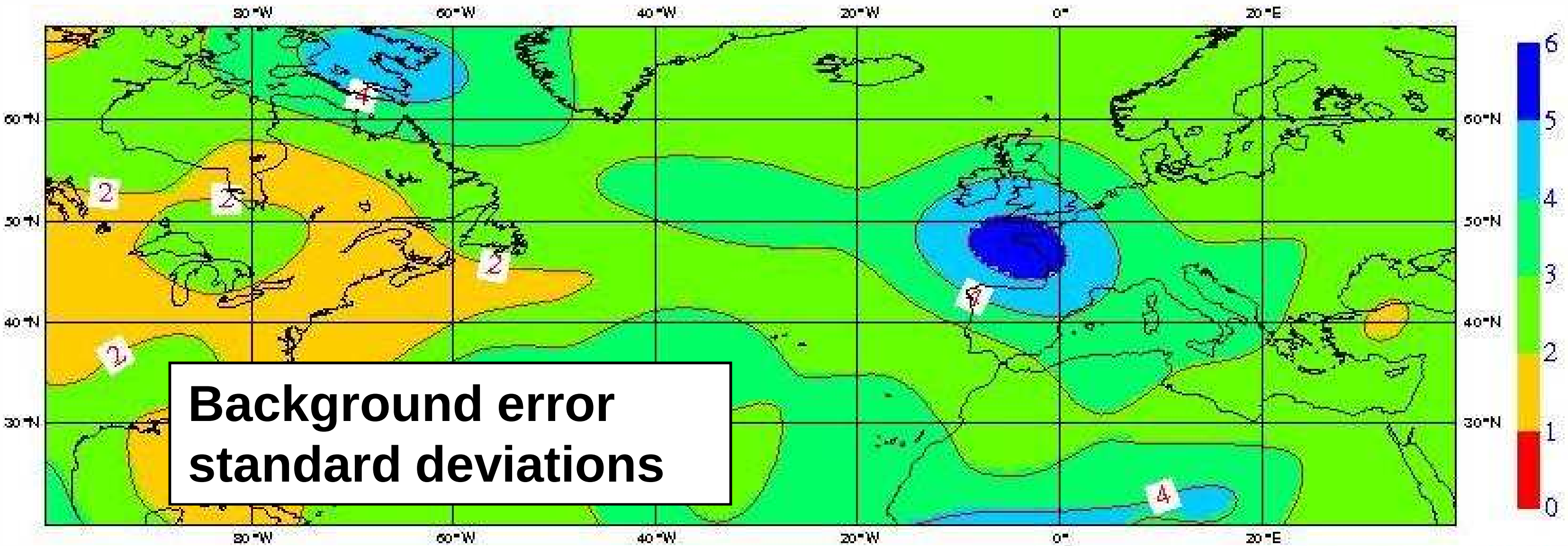
⇒ for **obs. quality control** and for **analysis (minimization).**

- Flow-dependent background error correlations experimented using wavelet filtering properties (Varella et al 2011, 2012).

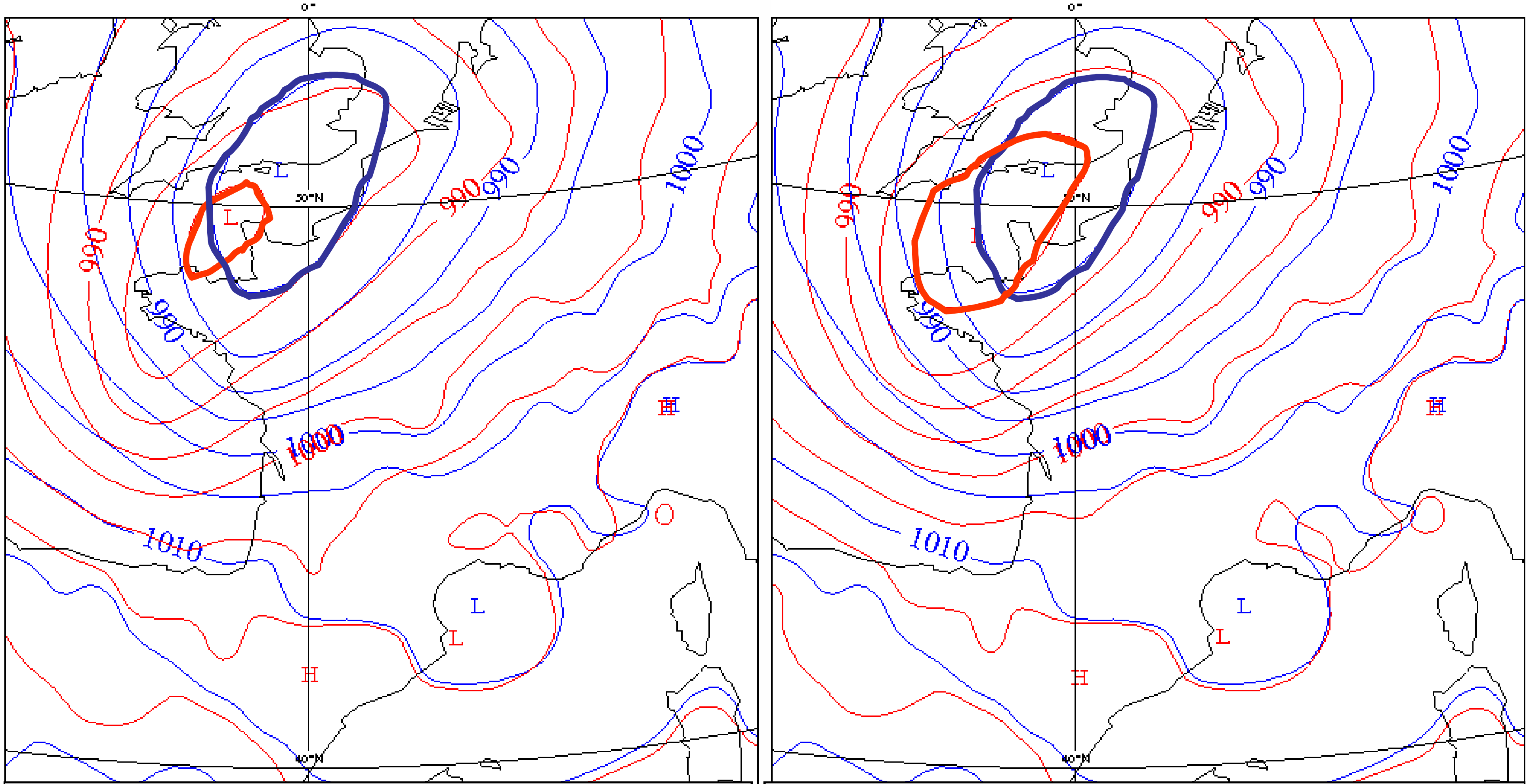
- Initialisation of M.F. ensemble prediction (PEARP) by EnDA (2009) : EnDA is now a major component of PEARP.

Connexion between large σb's and intense weather
(Klaus storm, 24/01/2009, 00/03 UTC)





Impact on a severe storm (10/02/2009) :
36h forecasts versus verifying analysis

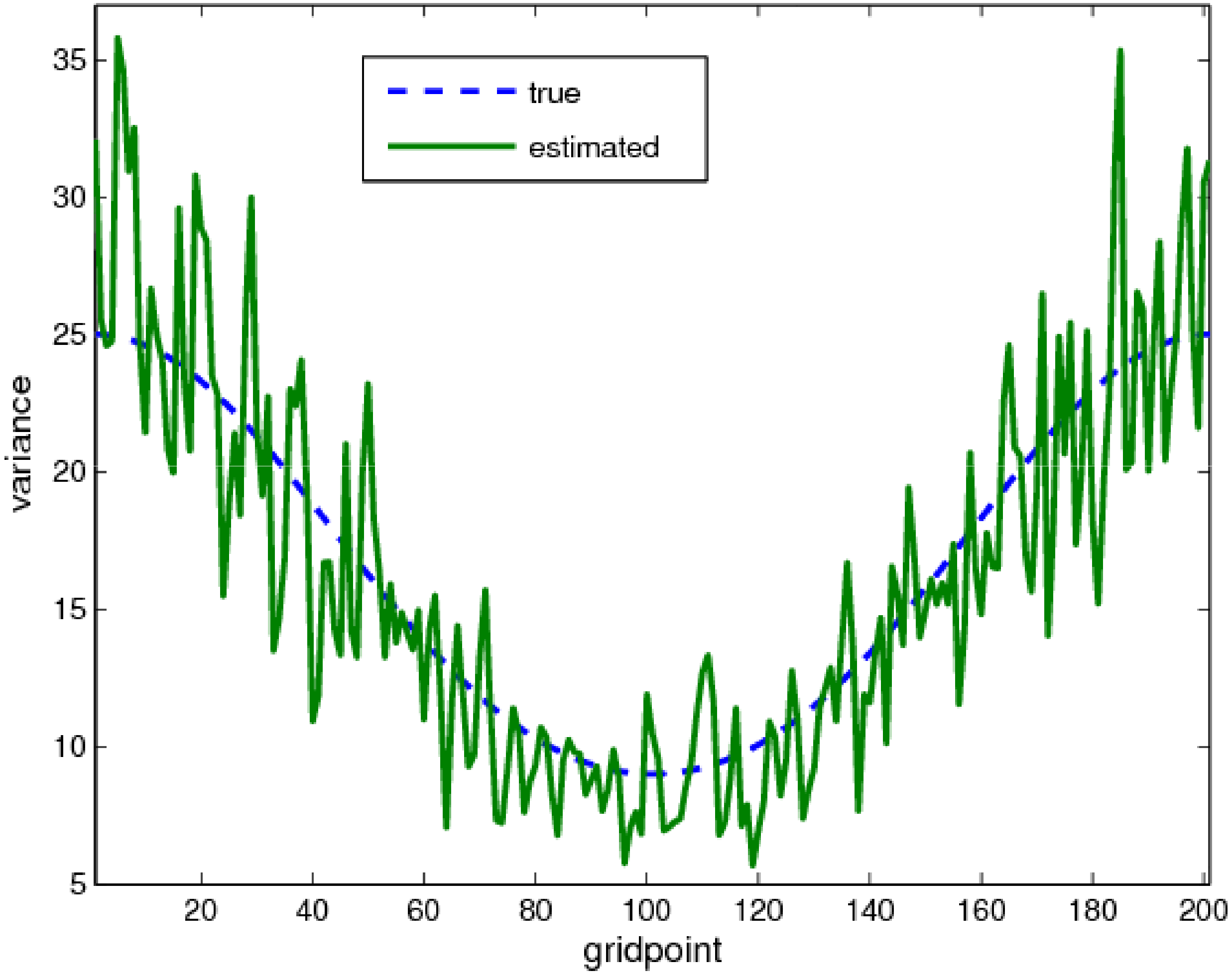


With static errors

With errors « of the day »

⇒ Positive impact on the depth of the low + gradient intensity

Spatial structure of sampling noise for variances (Raynaud et al 2008a)



N = 50

L(ε_b) = 200 km

$\Rightarrow$ While the signal of interest is large scale,
the sampling noise is small scale.

Spatial structure of sampling noise for variances (Raynaud et al 2009)

Spatial covariance of sampling noise $V^e = V(N) - V^*$:

$$\overline{V^e (V^e)^T} = 2/(N-1)\ B^* \circ B^*$$

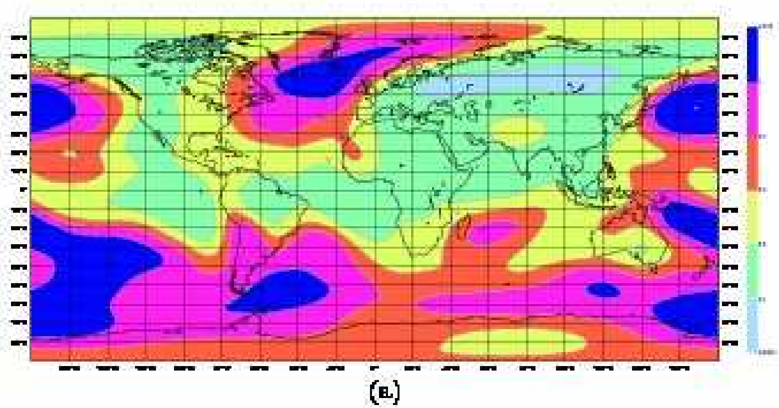
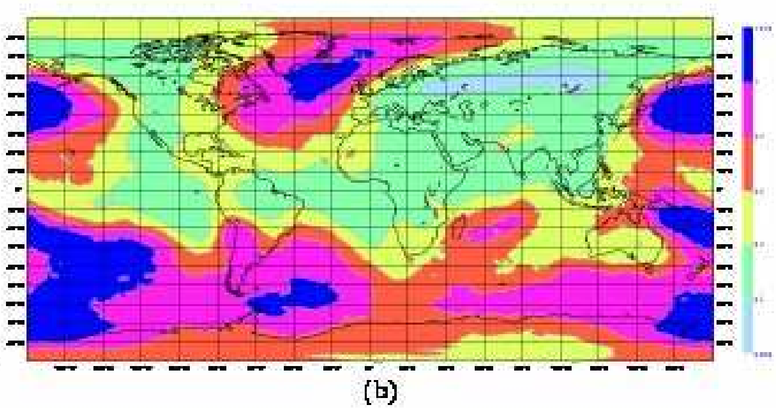
$B^* \circ B^*$ = Hadamard auto-product of $B^* = \overline{\varepsilon_b (\varepsilon_b)^T}$.

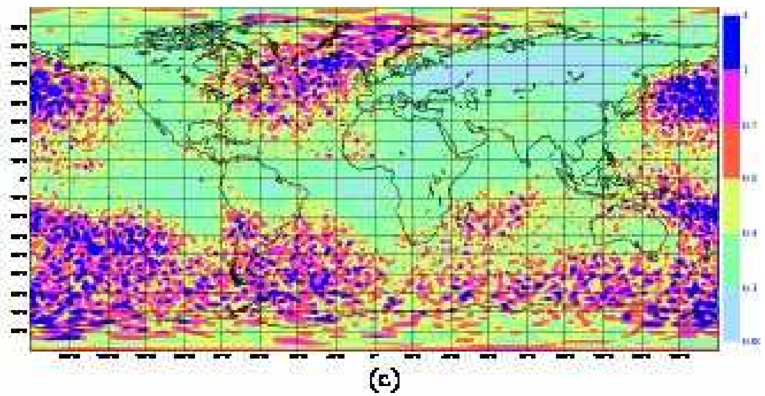
$\Rightarrow$ Structure of sampling noise V^e is closely connected to structure of background errors ε_b.

"OPTIMIZED" SPATIAL FILTERING

OF THE VARIANCE FIELD

« TRUE » VARIANCES | **FILTERED VARIANCES (N = 6)**



RAW VARIANCES (N = 6)

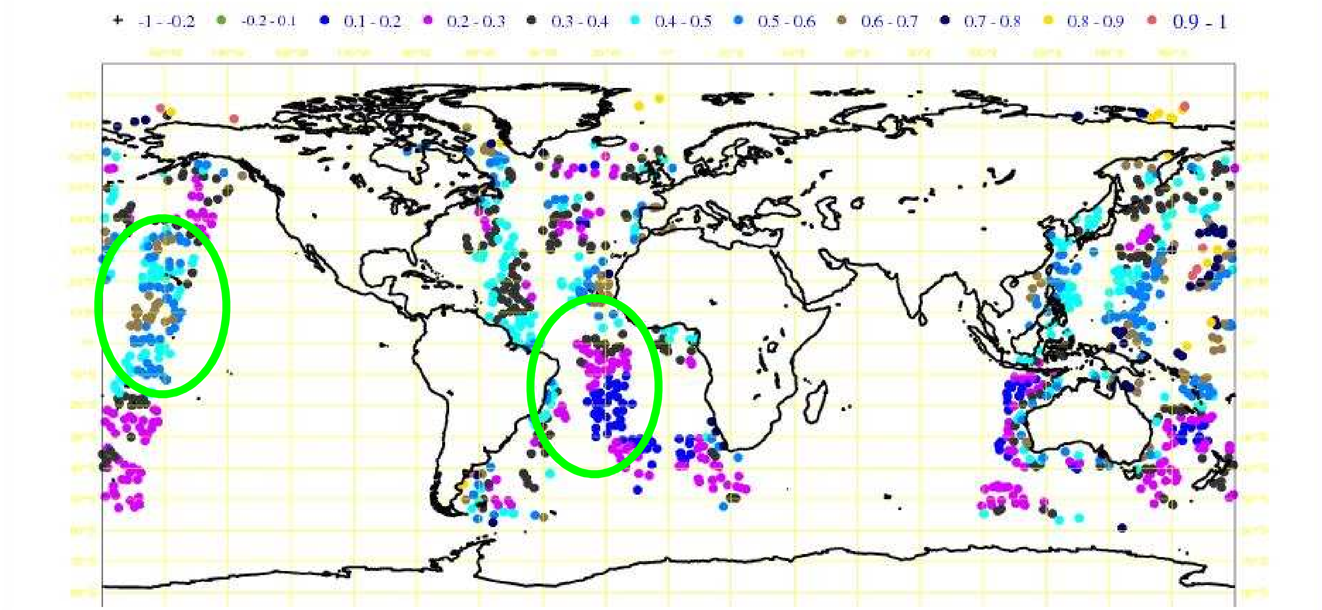
$$V_b^* \sim \rho \, V_b$$

where ρ = signal/(signal+noise)

(Berre et al 2007,2010, Raynaud et al 2008,2009,2011)

Validation of flow-dependent ensemble σb's
in HIRS 7 space (28/08/2006 00h) (Berre et al 2007, 2010)

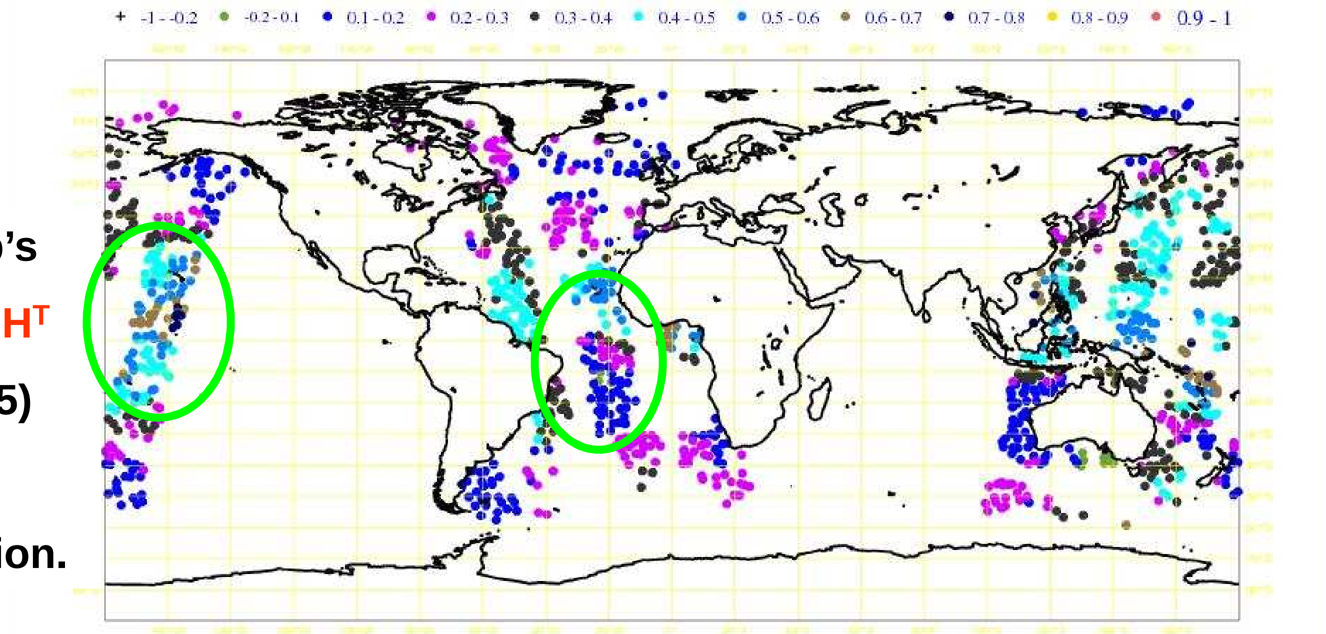
Ensemble sigmab's



« Observed » sigmab's

cov(H dx , dy) ~ H B H^T

(Desroziers et al 2005)



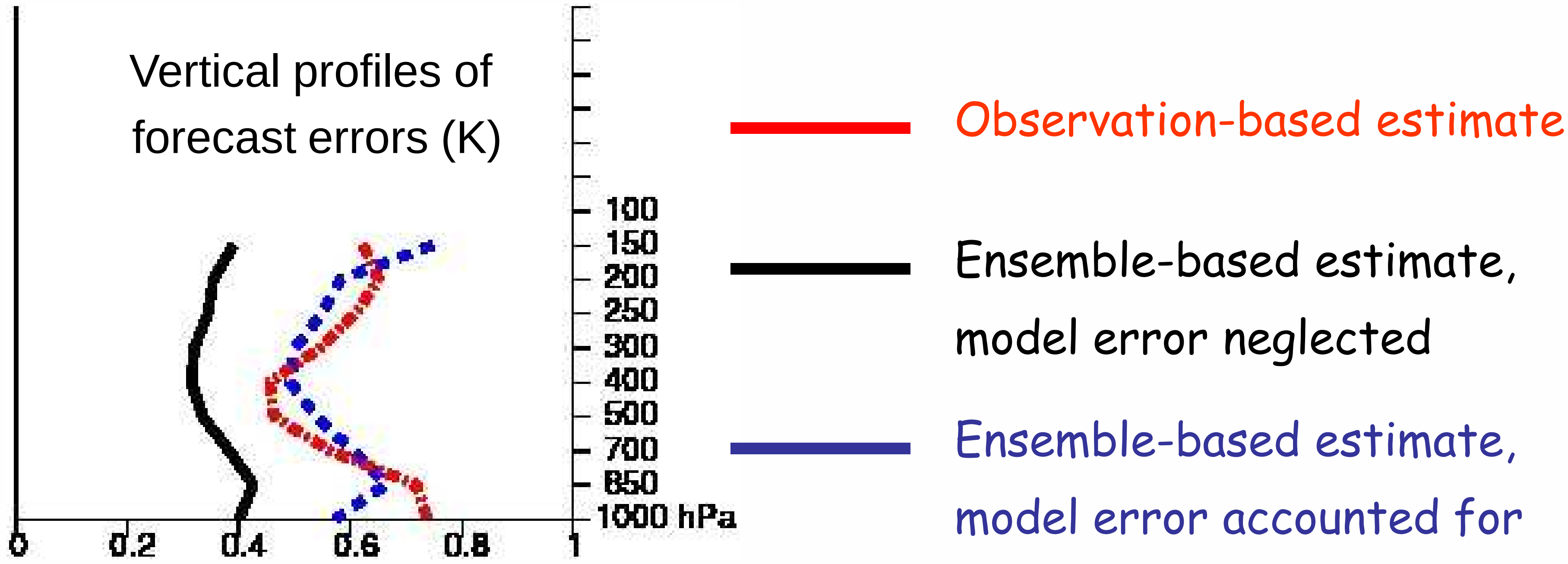
=> model error estimation.

Use of innovations
to estimate model errors (Q)

$$\varepsilon_f = M\,\varepsilon_a + \varepsilon_m$$

- Use ensemble assimilation to estimate « MAM^T ».
- Use innovation diagnostics to estimate « B »
  (or at least HBH^T).
- Estimate Q by comparing B and MAM^T (e.g. Daley 1992).
- Represent model error by inflating forecast perturbations
  in accordance with Q estimate.

Model error in M.F. ensemble 4D-Var
(Raynaud et al 2012, QJRMS)



Model error in M.F. ensemble 4D-Var

- Inflation of forecast perturbations by 15% every 6h.

- Much more realistic initial spread (by a factor 2-3) for ensemble prediction.

- A vertical and latitudinal dependence is needed w.r.t. high level tropical winds.

- Neutral impact of new variances on the forecast quality.

- Spectral block-diagonal approach :
  homogeneous correlations from EnDA.

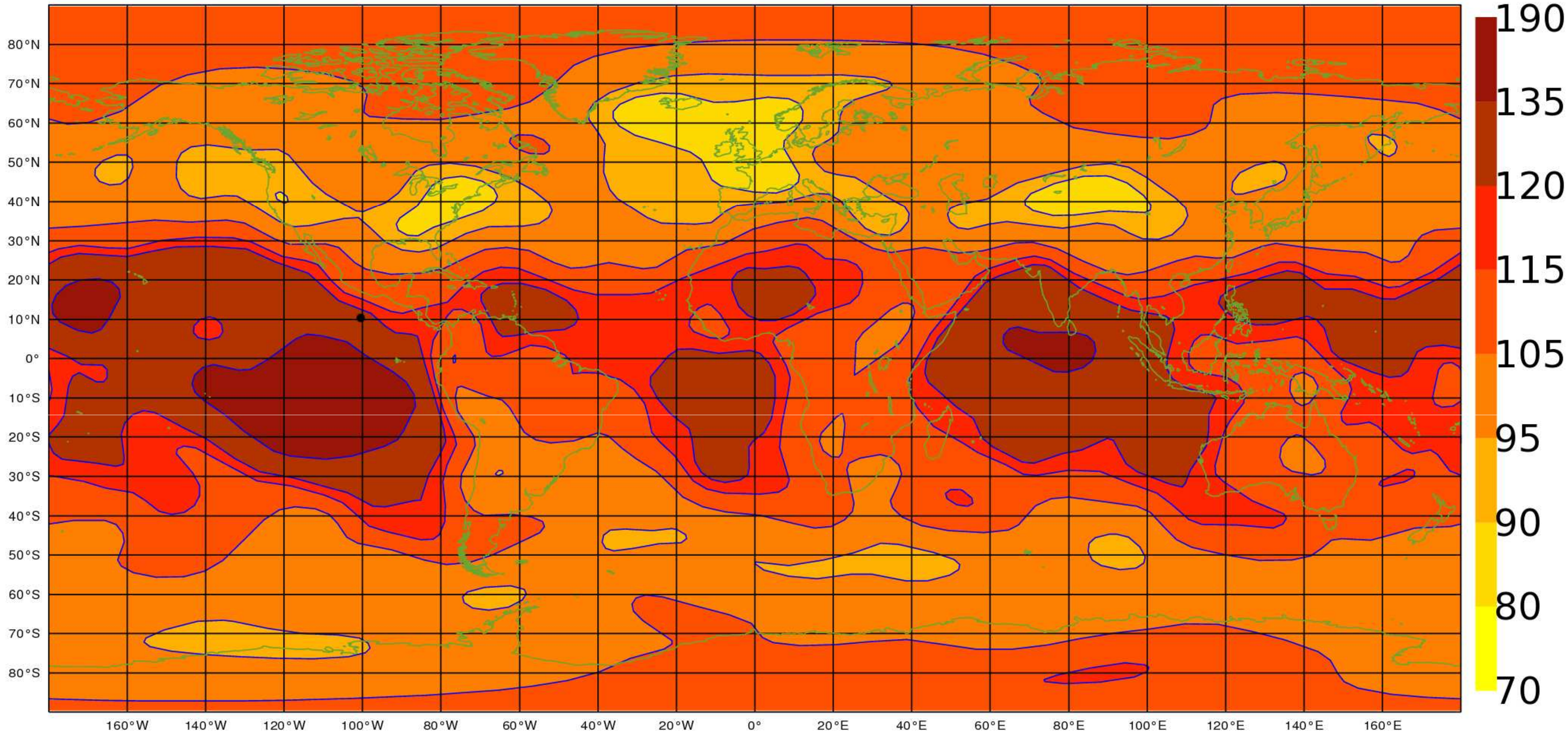
- Wavelet block-diagonal approach :

  heterogeneous correlations from EnDA.

⇒ Ecmwf : static heterogeneous correlations (Fisher 2003),
Météo-France : flow-dependent correlations (Varella et al 2011, 2012).

⇒ Implicit use of local spatial averages :
spatial filtering of sampling noise.

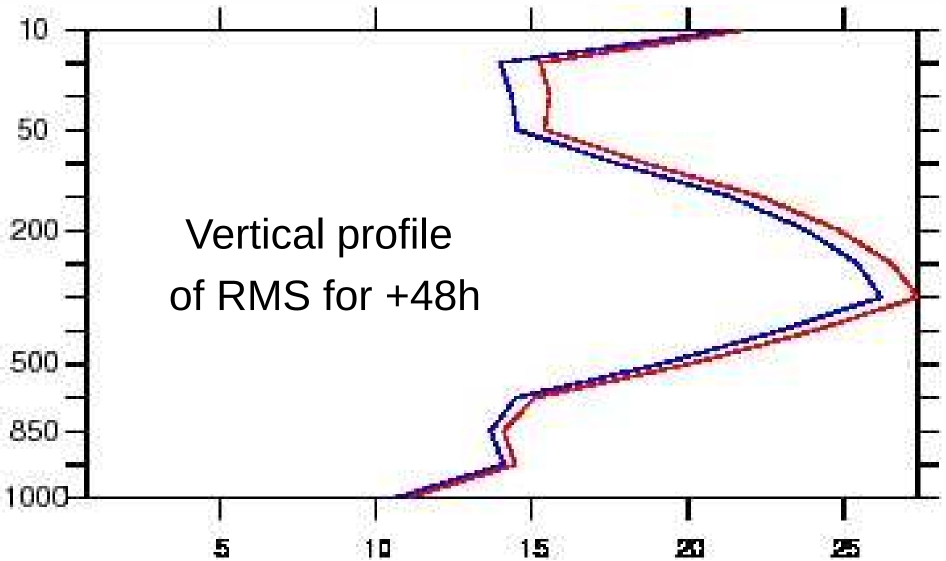
Background error correlations using EnDA and wavelets



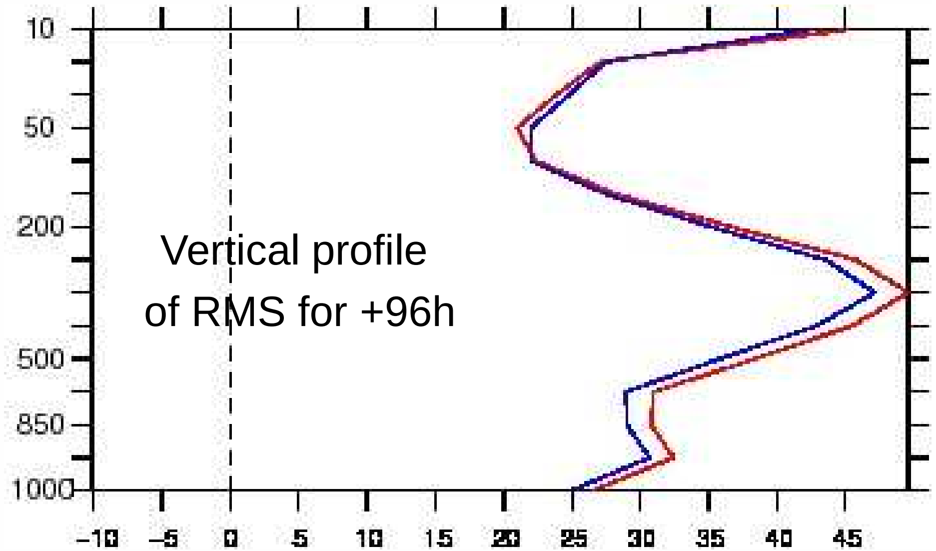
Wavelet-implied horizontal length-scales (in km), for wind near 500 hPa, averaged over a 4-day period.

(Varella et al 2012)

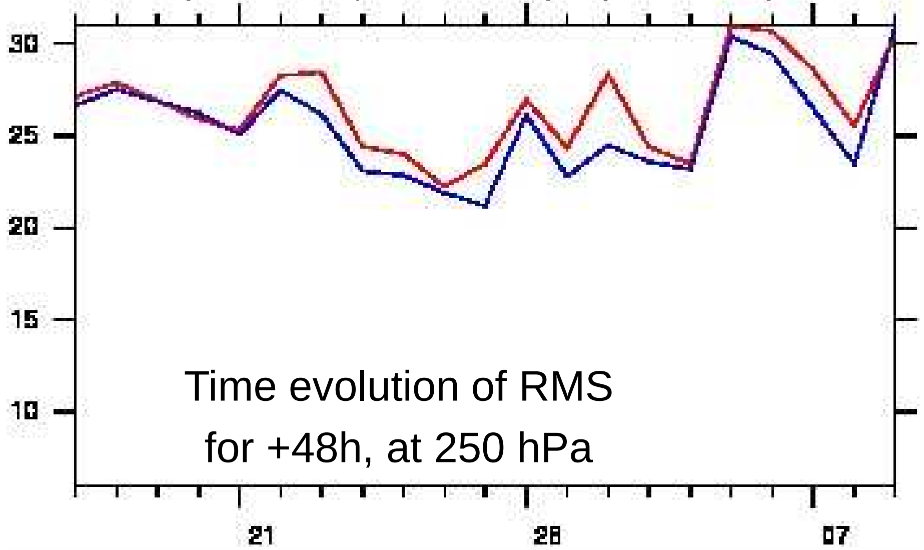
Impact of wavelet flow-dependent correlations against spectral static correlations (winter 2010, Varella et al 2012)

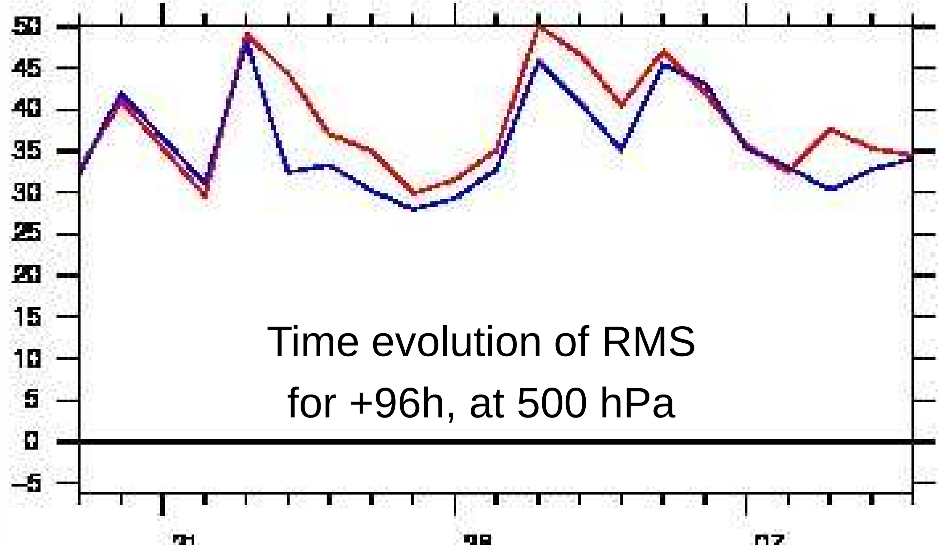


SOUTHERN HEMISPHERE
(3 weeks, RMS of geopotential)

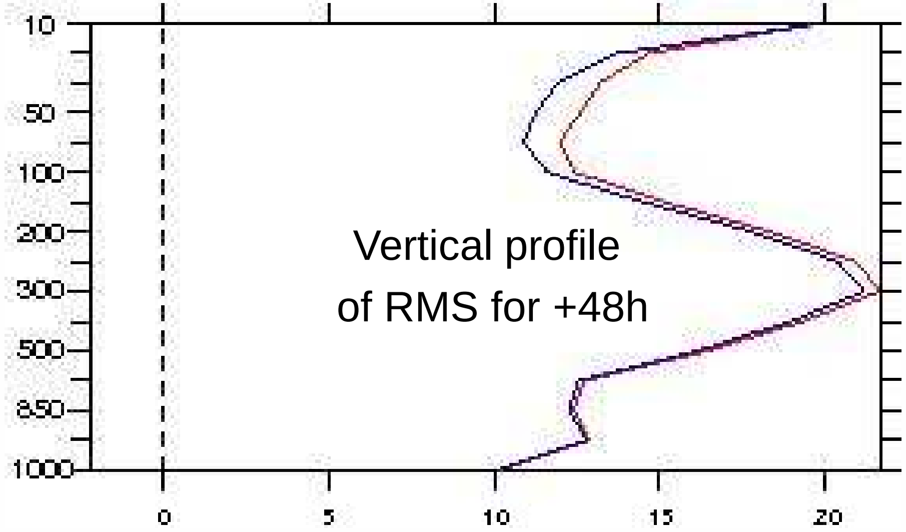


EUROPE AND N. ATLANTIC
(3 weeks, RMS of geopotential)

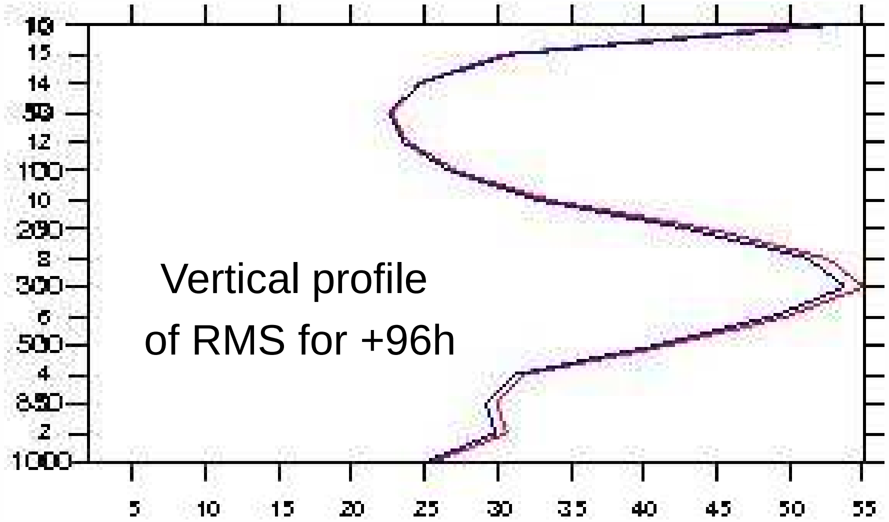




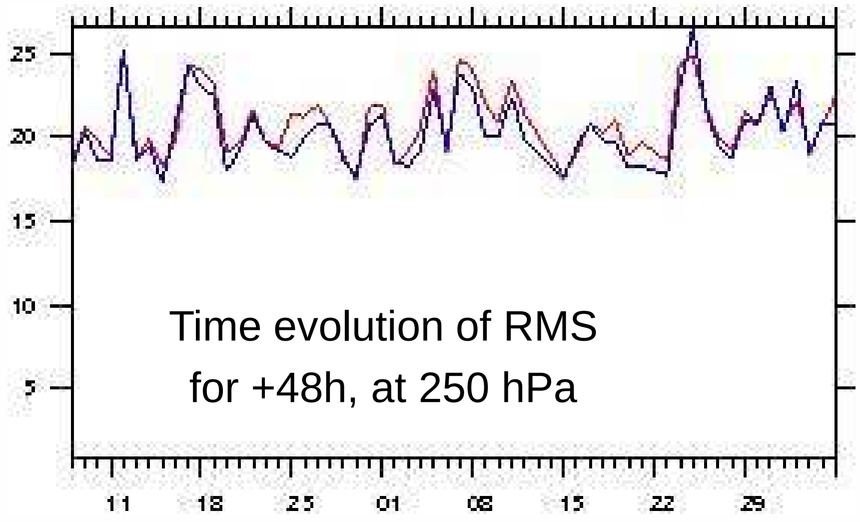
Impact of wavelet flow-dependent correlations against spectral static correlations (winter 2012, Varella et al 2012)

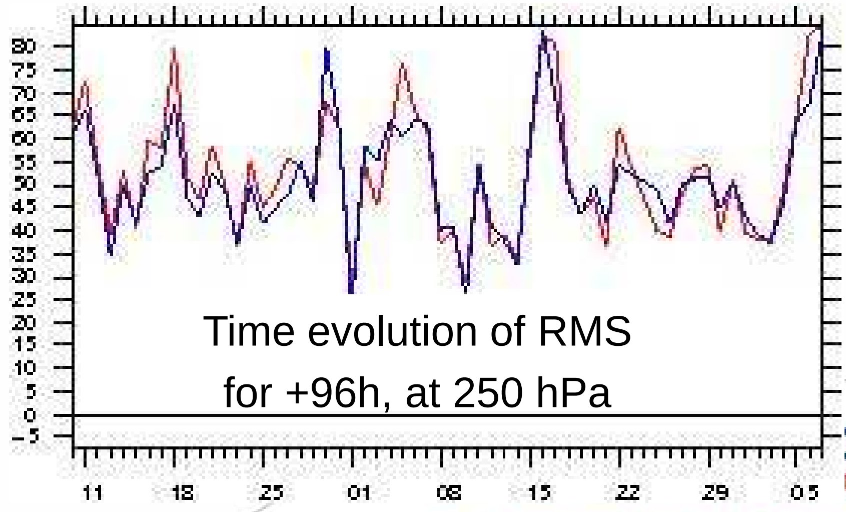


SOUTHERN HEMISPHERE
(8 weeks, RMS of geopotential)

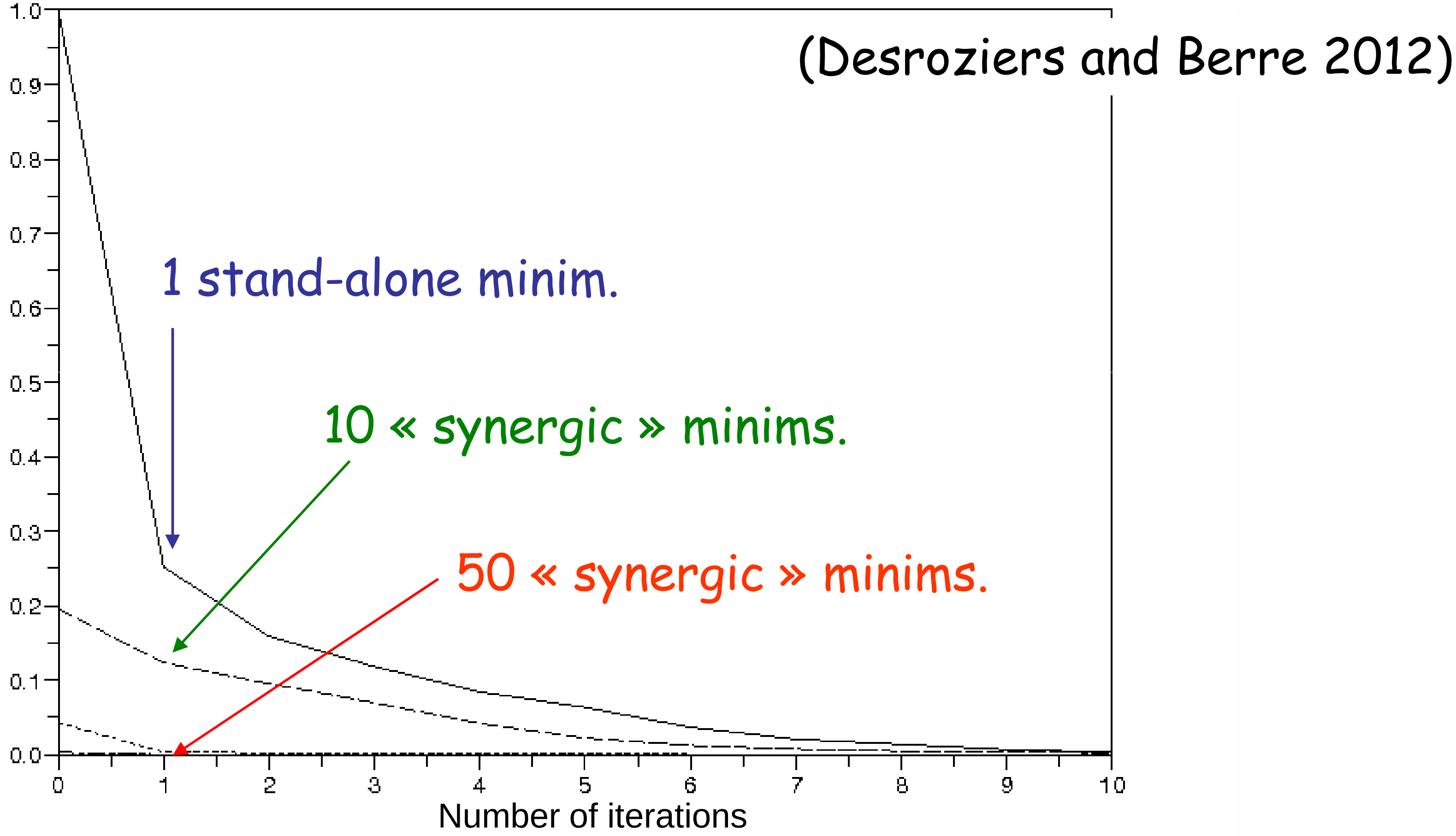


EUROPE AND N. ATLANTIC
(8 weeks, RMS of geopotential)





Accelerating and parallelizing
Ensemble/Deterministic Var minimizations
(proof of concept in 1D toy)



Decrease of cost function (for a given member)
when using shared Lanczos vectors
for starting point and preconditioning

METEO FRANCE
Toujours un temps d'avance

Conclusions

- Variational EnDA: error cycling simulated consistently with 4D-Var.
- Flow-dependent covariances for obs quality control and analysis.
- Sampling noise in covariances $\Rightarrow$ optimized spatial filtering.
- Innovation diagnostics : estimation of model error covariances.
- Positive impacts, e.g. for intense/severe weather events,
  from flow-dependent variances and correlations.
- EnDA is now a major component of the Météo-France EPS also.

Future work

Soon :

- Use of flow-dependent correlations, with wavelet spatial filtering.

In the mid-term :

- Increase of ensemble size.
- Towards 4D-En-Var.
- Acceleration and parallelisation of EnDA + Det. Var.
- High resolution regional variational EnDA.

Thank you

for your attention

METEO FRANCE
Toujours un temps d'avance