Estimation and diagnosis of analysis/background errors using ensemble assimilation

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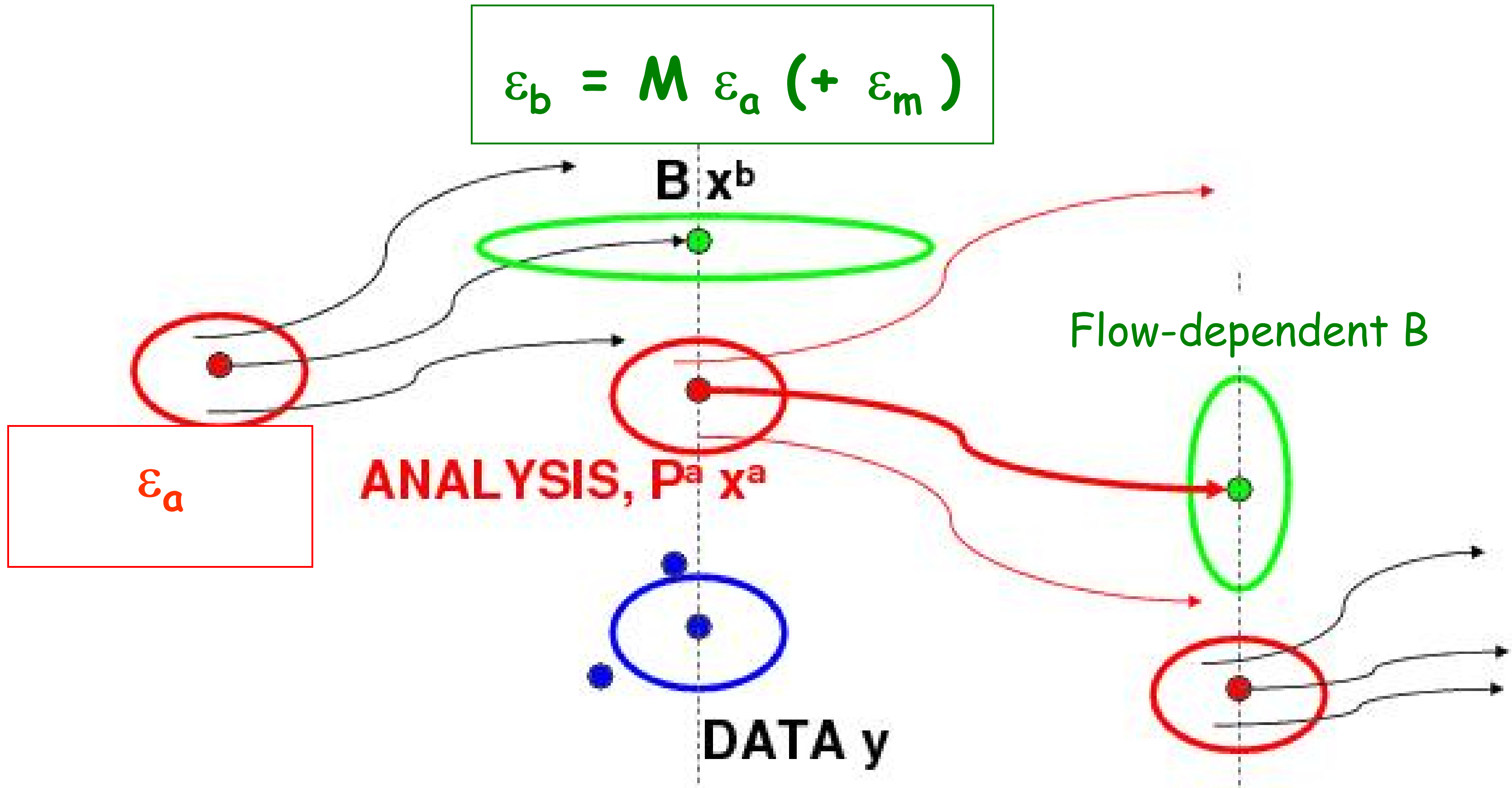
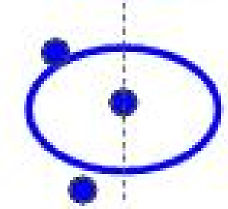
Thanks to Gérald Desroziers

Outline

1. Simulation of the error evolution
2. The operational MF ensemble variational assimilation
3. Diagnostics of analysis and background errors
4. Combined use of innovation-based and EnDA estimates

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





Explicit observation perturbations, and
implicit (but effective) background perturbations.

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

The analysis error equation

(e.g. Daley 1991, Berre et al 2006)

Analysis state : $x_a = (I-KH)\, x_b + K\, y$

True state (with $y^* = H\, x^*$): $x_* = (I-KH)\, x_* + K\, y_*$

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

with $e_a = x_a - x_*$

This is true even if K is suboptimal. NL case ok too.

The analysis perturbation equation

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

Unperturbed analysis : $x_a = (I-KH)\,x_b + K\,y$

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

with $\varepsilon_a = x'_a - x_a$

Formal comparison with NMC method
(Bouttier 1994, Berre et al 2006)

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

Analysis perturbation (EnDA) : $\varepsilon_a = (I-KH)\, \varepsilon_b + K\, \varepsilon_o$

Analysis increment (NMC) : $dx = -KH\, e_b + K\, e_o$

with I-KH ~ high-pass filter, whereas KH ~ low-pass filter.

⇒ Sharper correlations in EnDA than in NMC
(e.g. Belo Pereira and Berre 2006, Fisher 2003).

⇒ Better simulation of the analysis error equation in EnDA than in NMC.

Simulation of the error evolution : open issue(s)

Ex: reference 4D-Var and +/- high resolution model.

Possible approximations in the ensemble :

- reduce horizontal resolution of the model.
- approximate reference 4D-Var gain matrix K, with :
  3D-Fgat,
  4D-Var and fewer outer loops,
  ETKF/EnKF : by deriving K from the ensemble « only ».

⇒ What is the best approach (for a given computation cost) ?

EnKF-Var hybrid approaches : the « hybrid K » is not accounted for in the analysis perturbation update (in contrast with « consistent EnVar »).

- (model error representation…)

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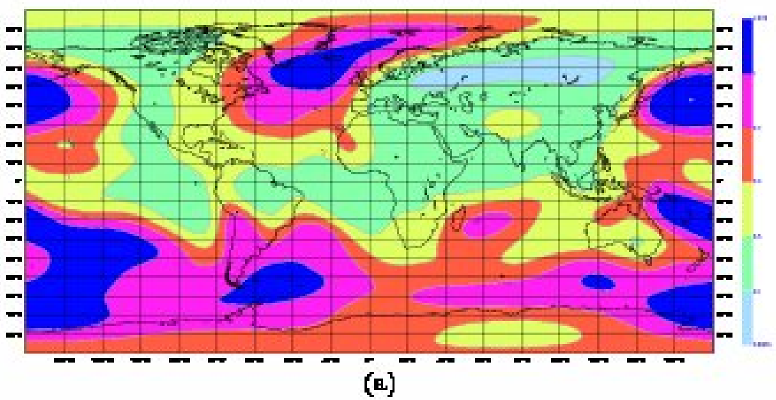
The operational MF ensemble Var assimilation

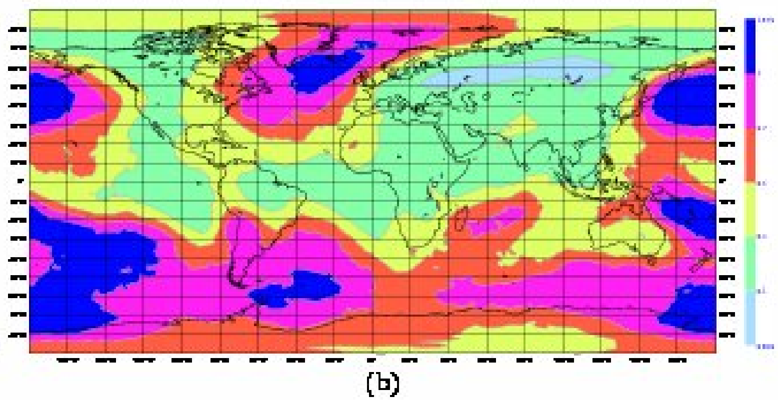
- 6 perturbed global members T359 L60 with 3D-Fgat (Arpege).
- Spatial filtering of error variances (see later), to further increase sample size and robustness (~90%).
- Inflation of ensemble B (by 1.3^2), as in the static approach, to represent model error contributions.
- The Arpege 4D-Var uses these « σ_b's of the day ». ⇒ operational since July 2008.
- Off-line coupling with six LAM members, with both Aladin (10 km) and Arome (2.5 km).

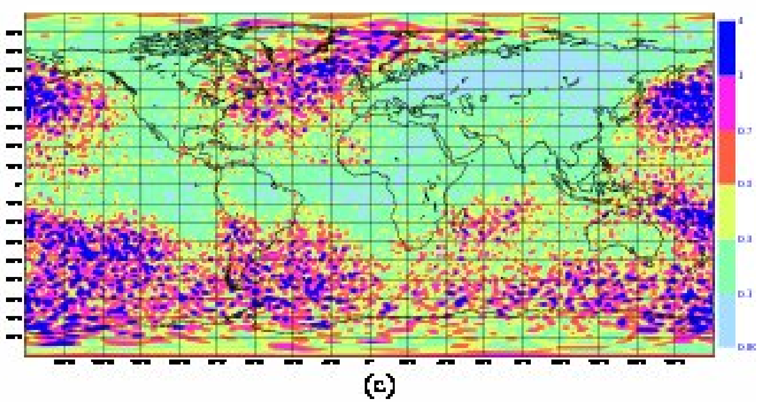
"OPTIMIZED" SPATIAL FILTERING
OF THE SIGMAB FIELD

« TRUE » SIGMAB'S



FILTERED SIGMAB's (N = 6)





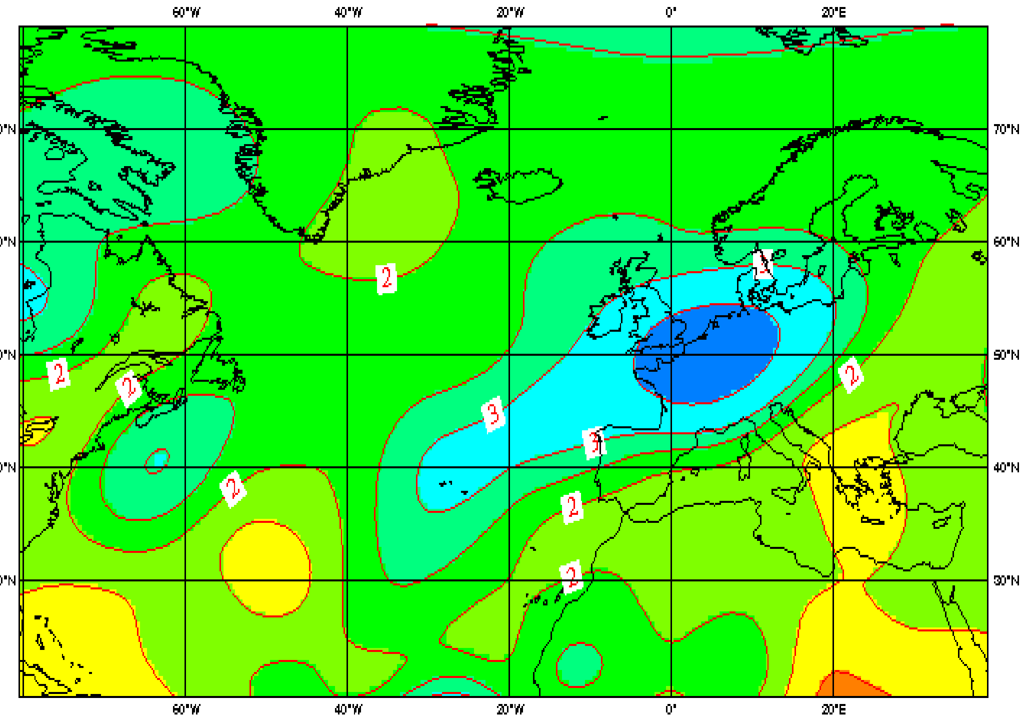
RAW SIGMAB's (N = 6)

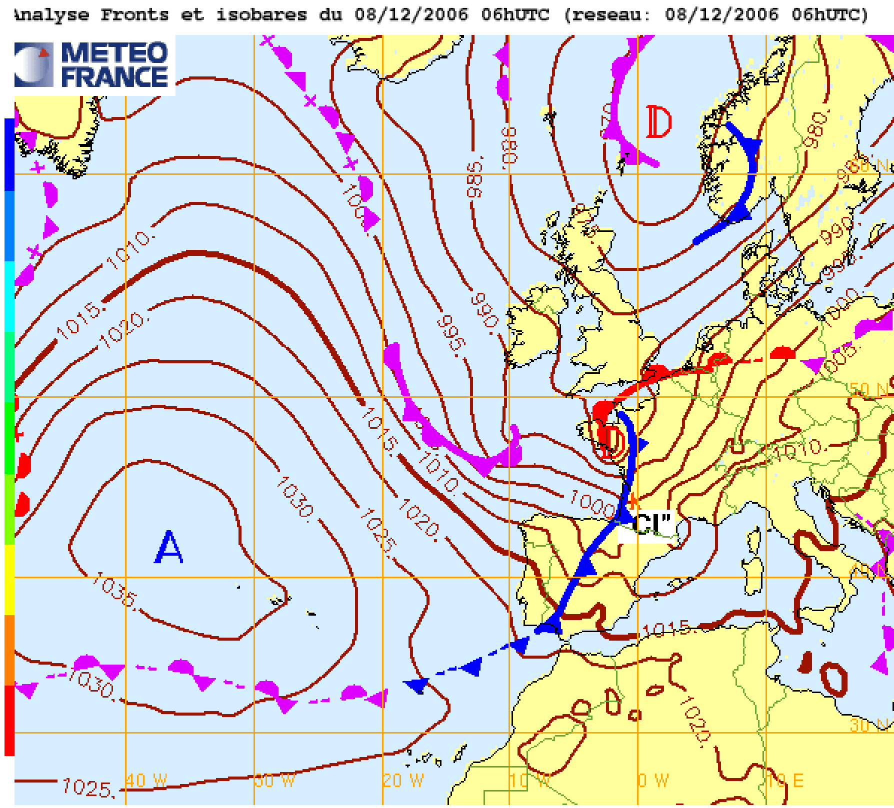
$$\varepsilon_b = B^{1/2}\,\eta$$

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

(Raynaud et al 2008)

Connection between large sigmab and intense weather
(08/12/2006 , 03-06UTC)





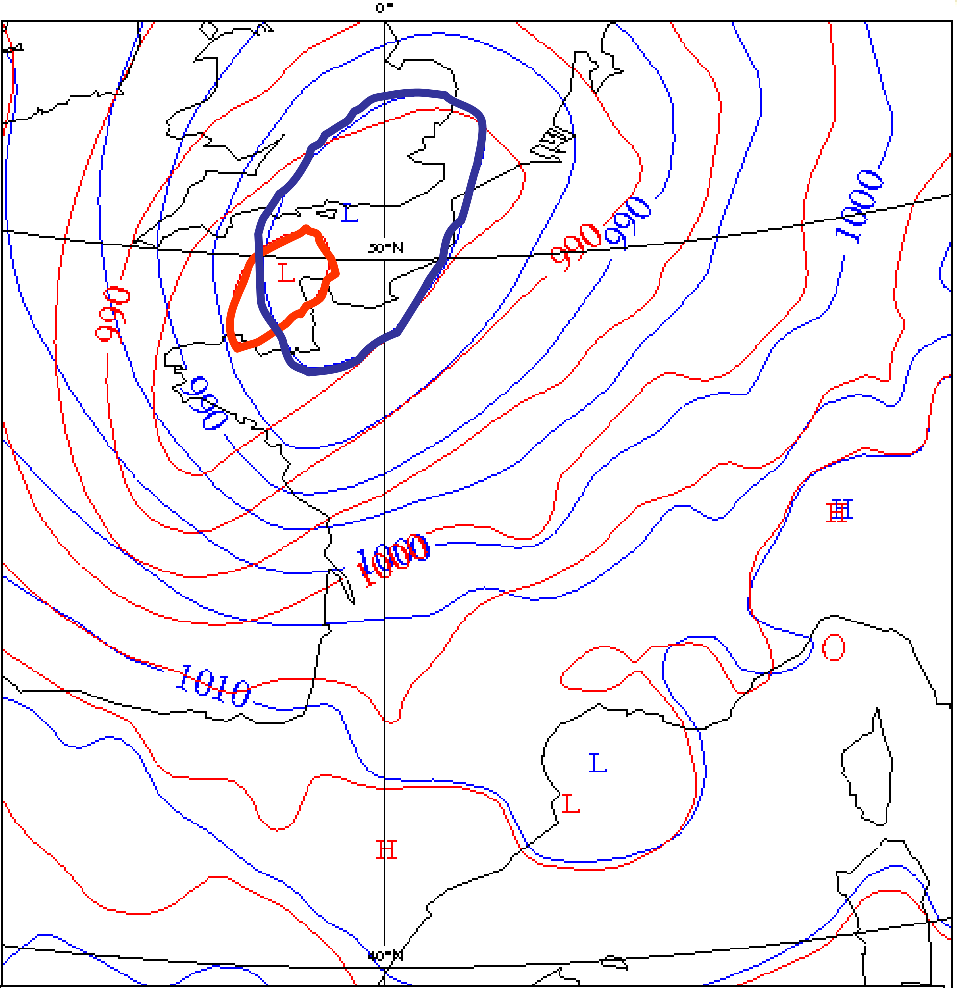
Ensemble spread:

large sigmab over France

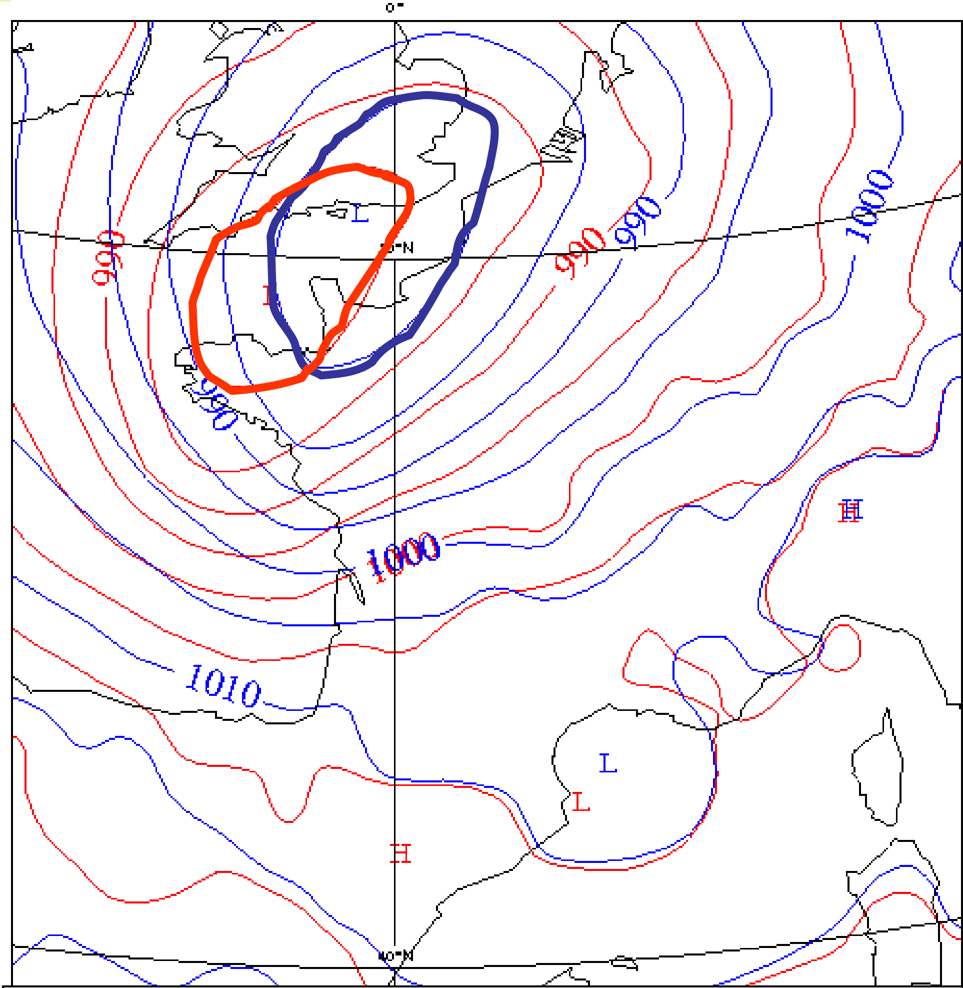
Mean sea level pressure :

storm over France

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



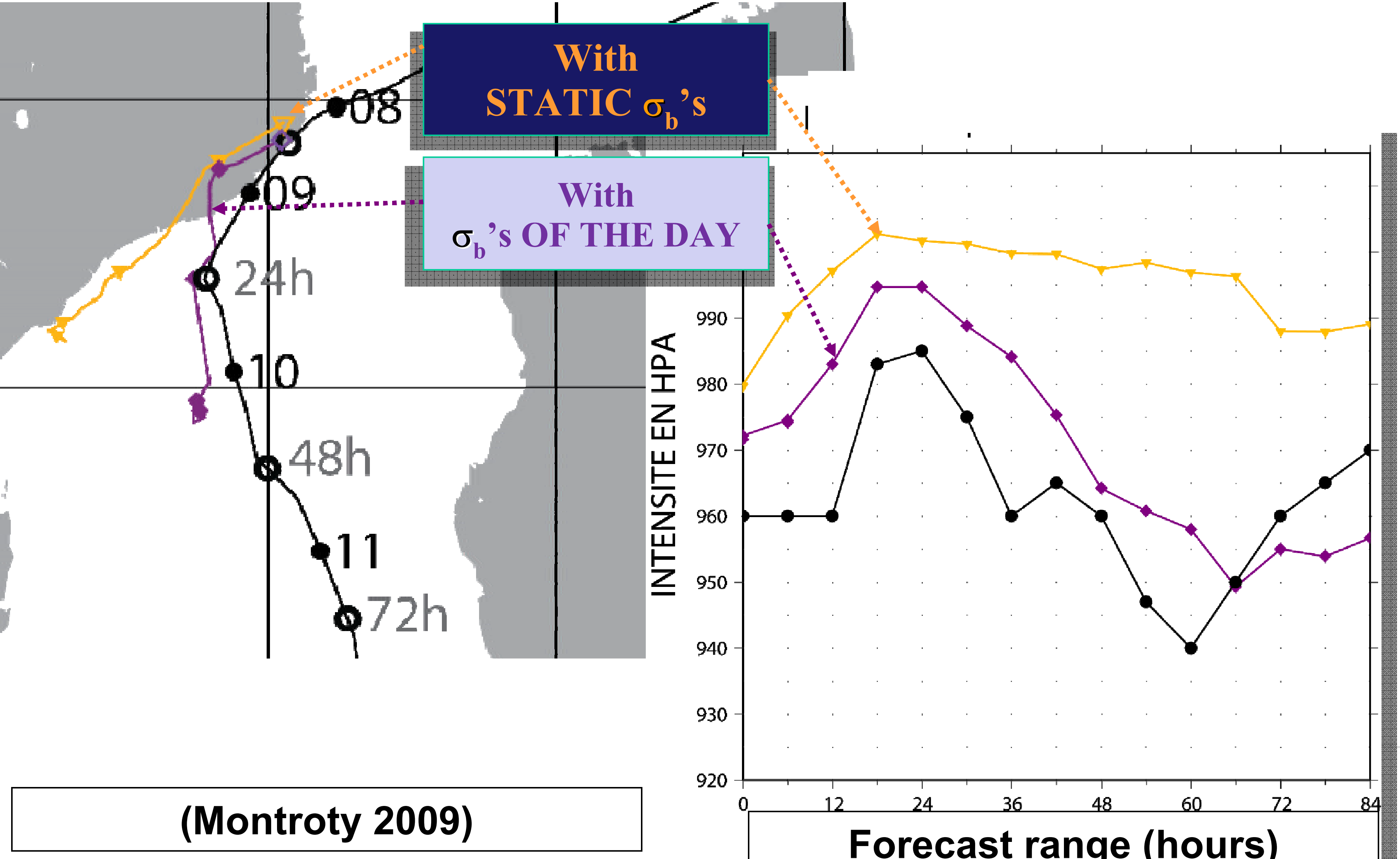
With **climatological σb's**



With **σb's « of the day »**

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

Impact of σ_b « of the day » on the forecast of cyclone *Jokwe*



(Montroty 2009)

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Analysis and background errors

- Analysis error estimate in the optimal case :

$$A = (I-KH)\,B$$

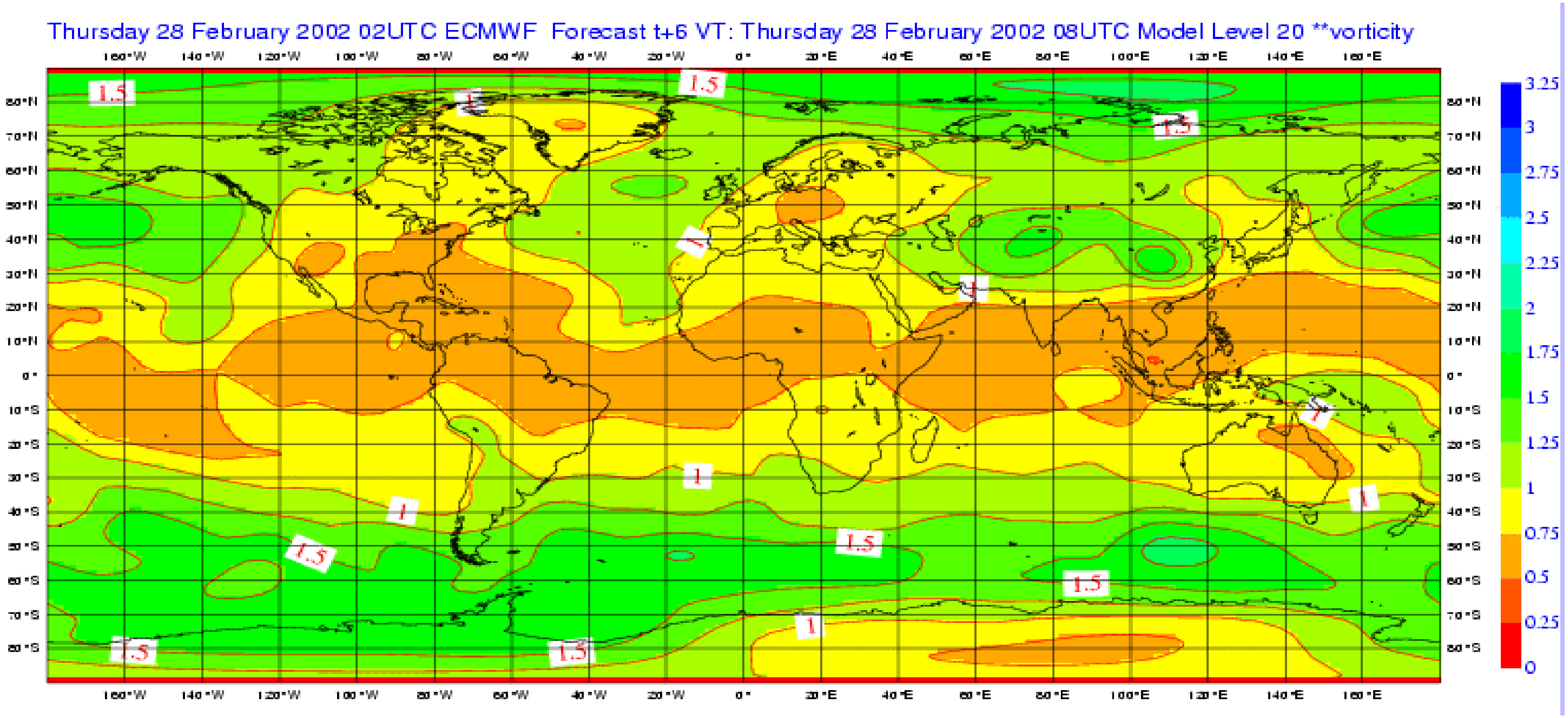
⇒ Analysis errors expected to be smaller than background errors.

- Analysis error estimate in the more general case (suboptimal), with EnDA :

$$A = (I-KH)\,B\,(I-KH)^T + K\,R\,K^T$$

⇒ Compare ensemble-based estimates of A and B to diagnose analysis effects.

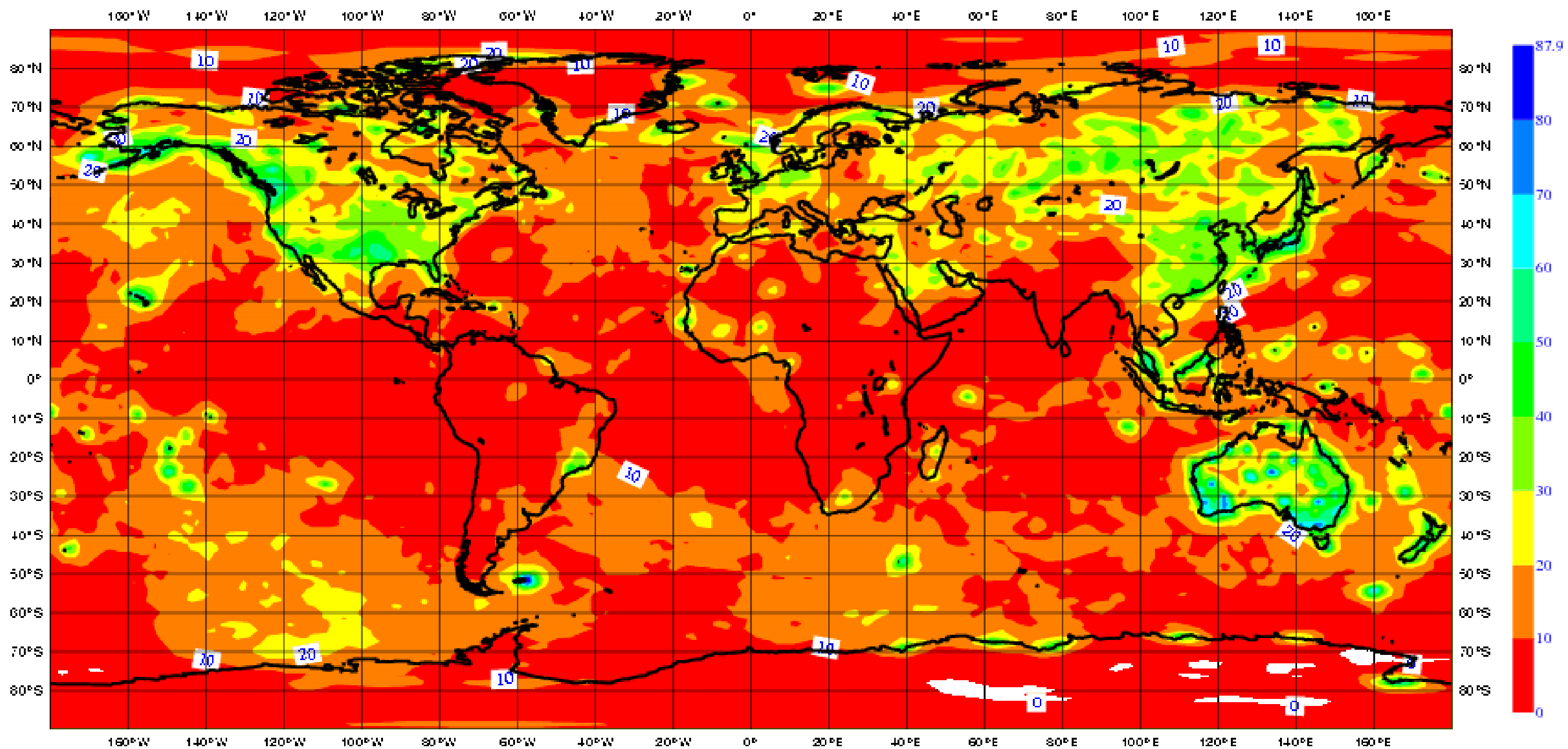
Background error standard deviations (vorticity, 500 hPa)



One month-averaged standard deviations (February 2002)

(Belo Pereira and Berre 2006)

Ensemble $\sigma^b - \sigma^a$ with energy norm



One month statistics (January 2007) at 00UTC

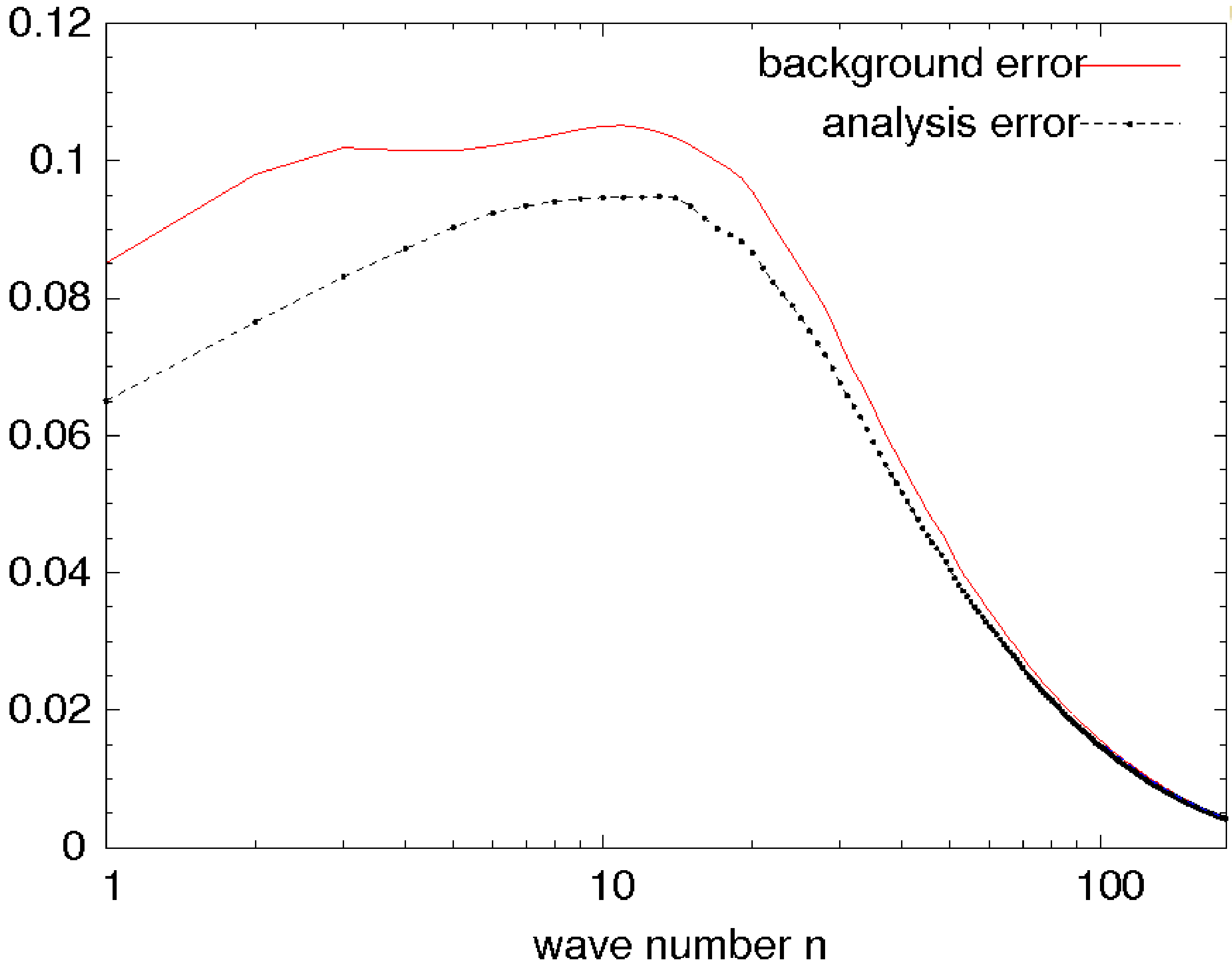
(Desroziers, pers. comm.)

Power spectra of error variances

(Stefanescu et al 2006, Belo Pereira and Berre 2006)

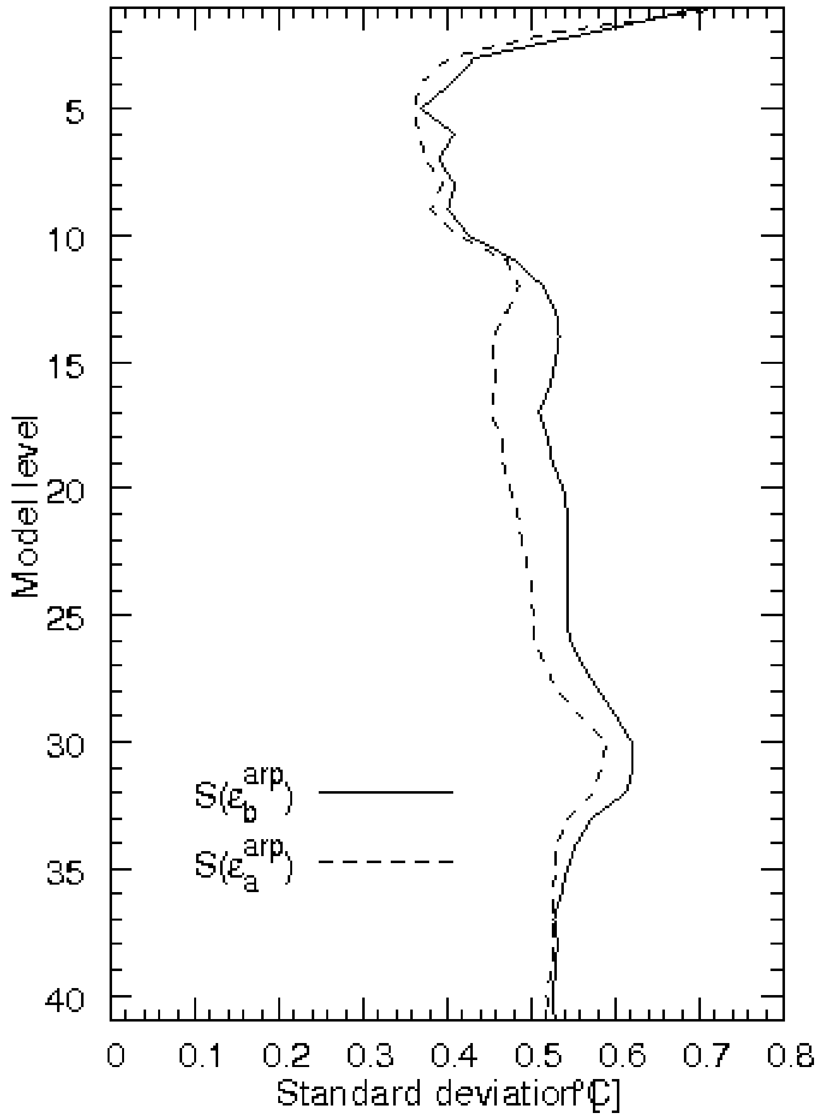
ERROR

STD DEVIATION



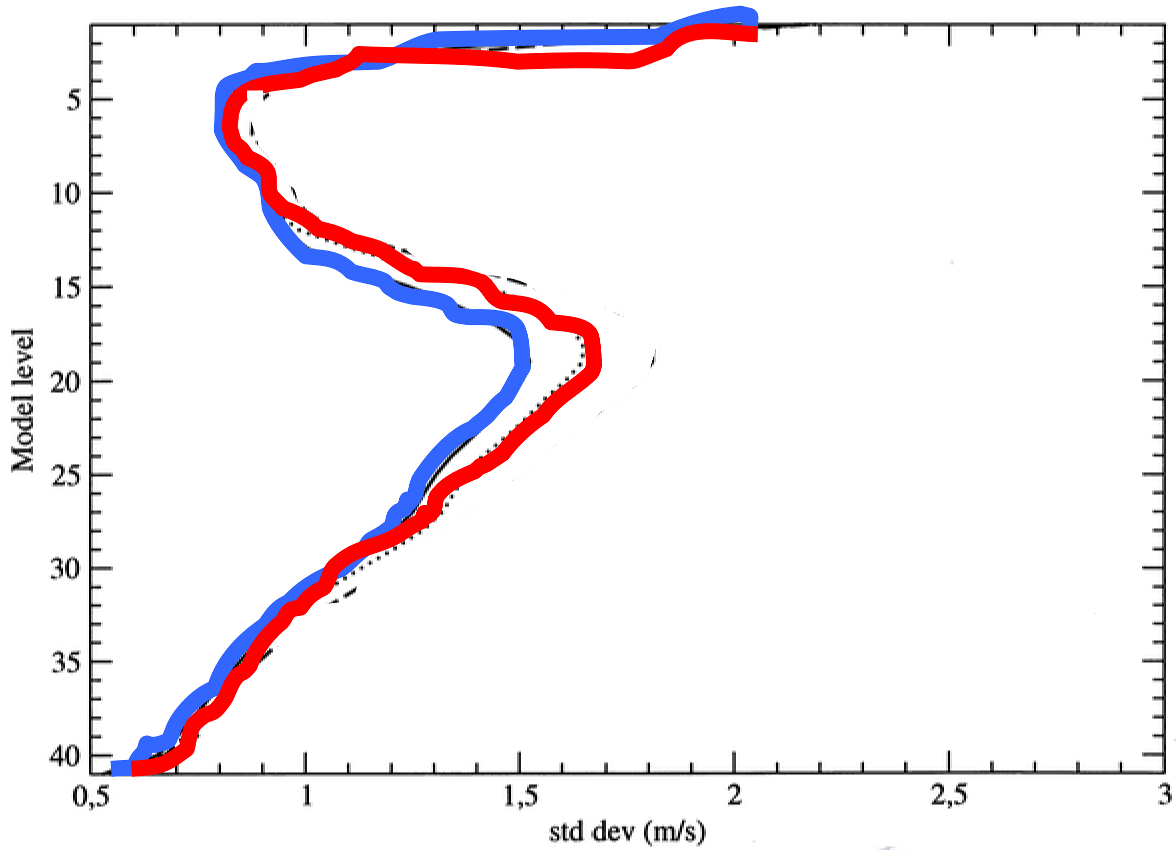
Analysis effect:
reduction of large-scale component of background errors, in particular in data-rich regions.

Vertical profile of temperature error standard deviations

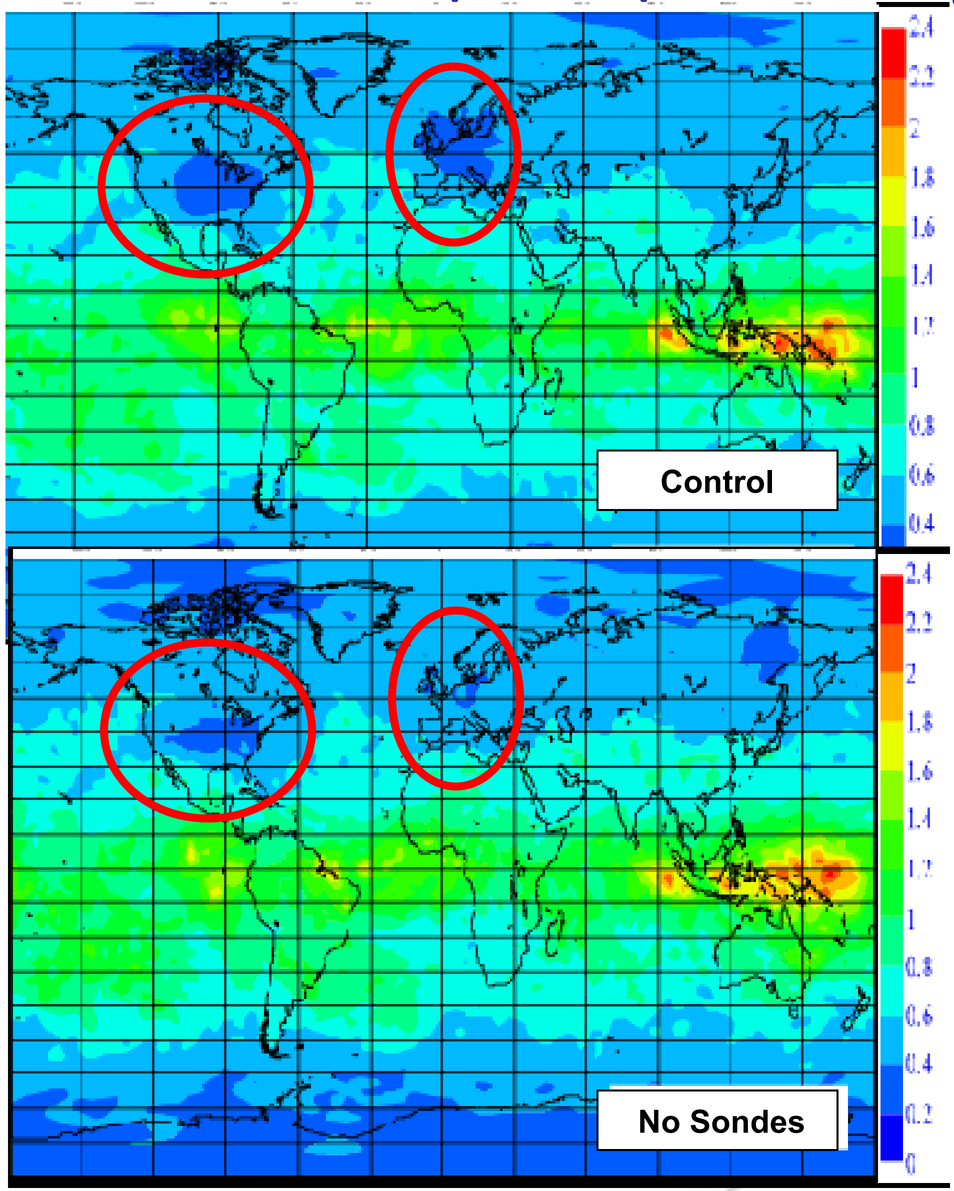


Analysis errors and forecast errors

(Belo Pereira and Berre 2006)



Impact of radiosondes on ensemble analysis spread (σ_a)



(Andersson, Tan et al 2005)

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Innovation-based sigmab estimate (Desroziers et al 2005)

$$\mathrm{cov}(\, H\, dx \,,\, dy\,) \sim H\, B\, H^T$$

⇒ This can be calculated for a specific date,

to examine flow-dependent features, but then the

local sigmab is calculated from a single error realization (N = 1) !

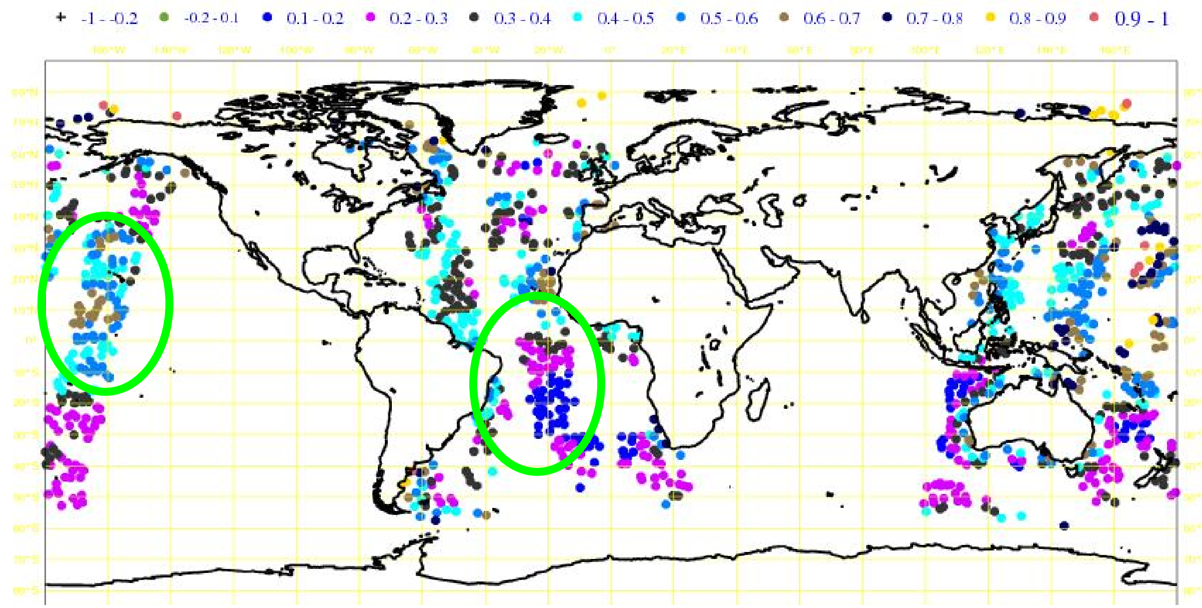
⇒ Conversely, if we calculate local spatial averages of these sigmab's,

the sample size will be increased, and

comparison with ensemble can be considered.

Validation of ensemble sigmab's « of the day »
HIRS 7 (28/08/2006 00h)

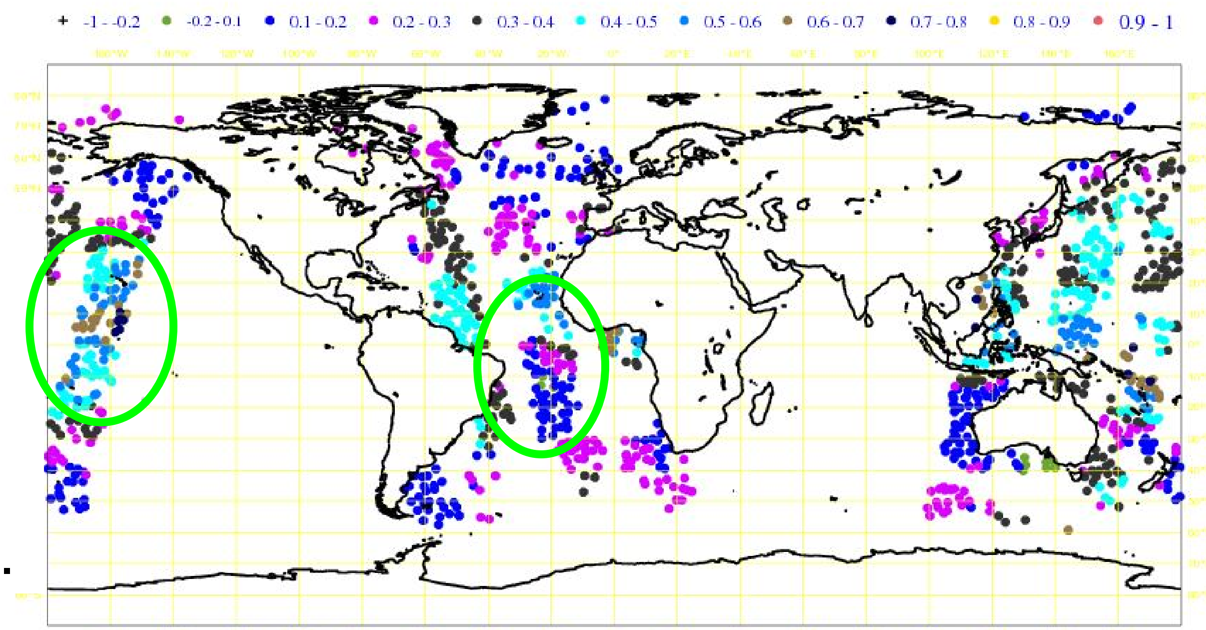
Ensemble sigmab's



« Observed » sigmab's

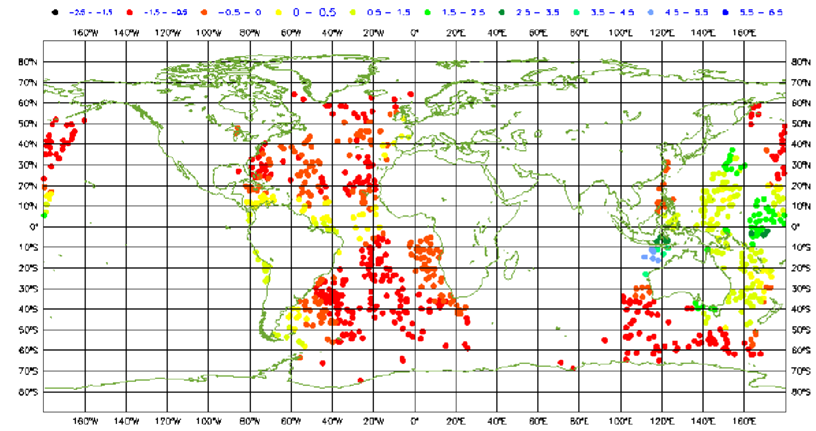
cov(H dx , dy) ~ H B H^T

(Desroziers et al 2005)



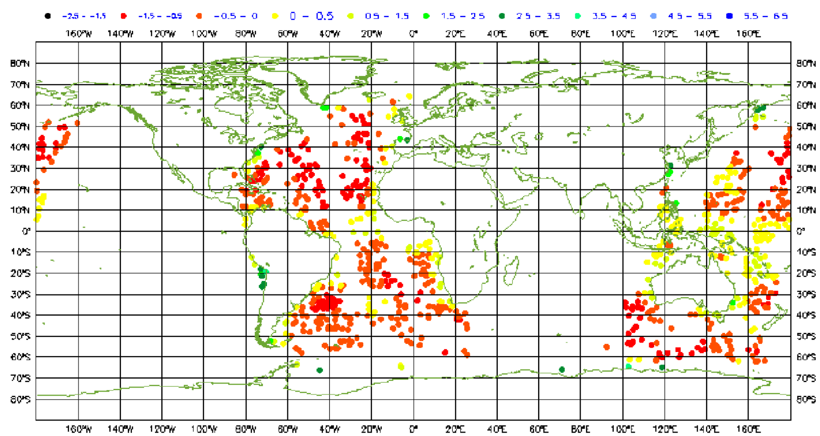
=> model error estimation.

Estimates of σ_b of the day, in HIRS 7 space



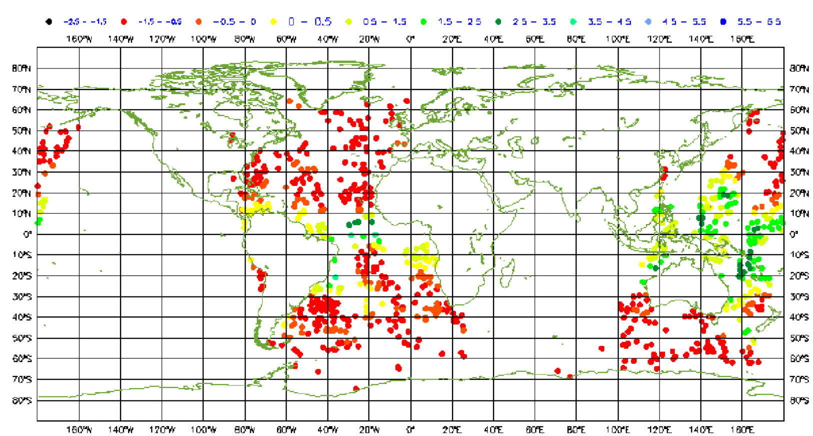
(a) HIRS7-diagnostic

cov(H dx , dy) of 4D-Var



(b) HIRS7-63HE-HR

Ensemble 3D-Fgat



Ensemble 4D-Var

(from Gibier, 2009)

Method(s) for estimating model error covariances (Q)

$$B = MAM^T + Q$$

- Use EnDA to estimate « MAM^T ».
- Use innovation diagnostics to estimate « B » (or at least HBH^T).
- Estimate Q as :

$$Q \sim B - MAM^T$$

(e.g. Daley 1992)

Conclusions

- EnDA allows analysis/background error cycling to be simulated and diagnosed.
- Diagnostic comparison between analysis and background spread provides information about analysis effects.
- Comparisons with innovation diagnostics : for validation, and for estimation of model error covariances.
- Flow-dependent covariances can be estimated, with a positive impact on intense/severe weather events.
- Open issues : optimization of error simulation, covariance estimation/filtering, and implementation techniques in 3D/4D-Var.

Thank you

for your attention

Background, analysis and forecast errors

(Belo Pereira and Berre 2006)