Data assimilation in AROME: Present status and ongoing work

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METEO FRANCE
Toujours un temps d'avance

Outlines

1. **The operational AROME 3DVar at MF**

   - B matrix

   - Observations (with focus on Doppler winds)

2. **Ongoing work**

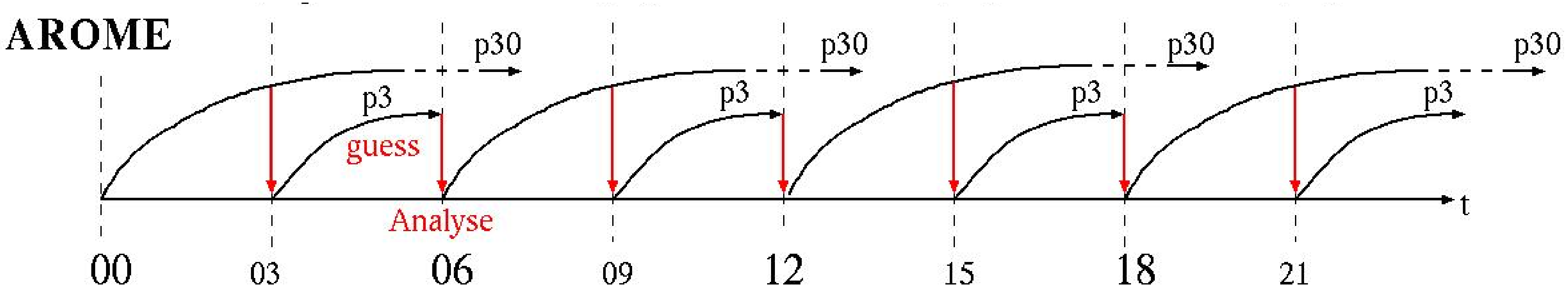
   - Jk, 3DVar-FGAT

   - Assimilation of objects

   - Use of a heterogeneous B matrix

AROME operational suite

- **Operational since December 2008 over France**
- Cycled 3DVar assimilations/forecast every 3 hours with a +/- 1h30 cut-off, coupled with ALADIN



- U, V, T, q and P_S analyzed, TKE, NH and microphysical variables cycled
- 30h forecasts launched every 6 hours
- Surface analysis interpolated from ALADIN's every 6 hours

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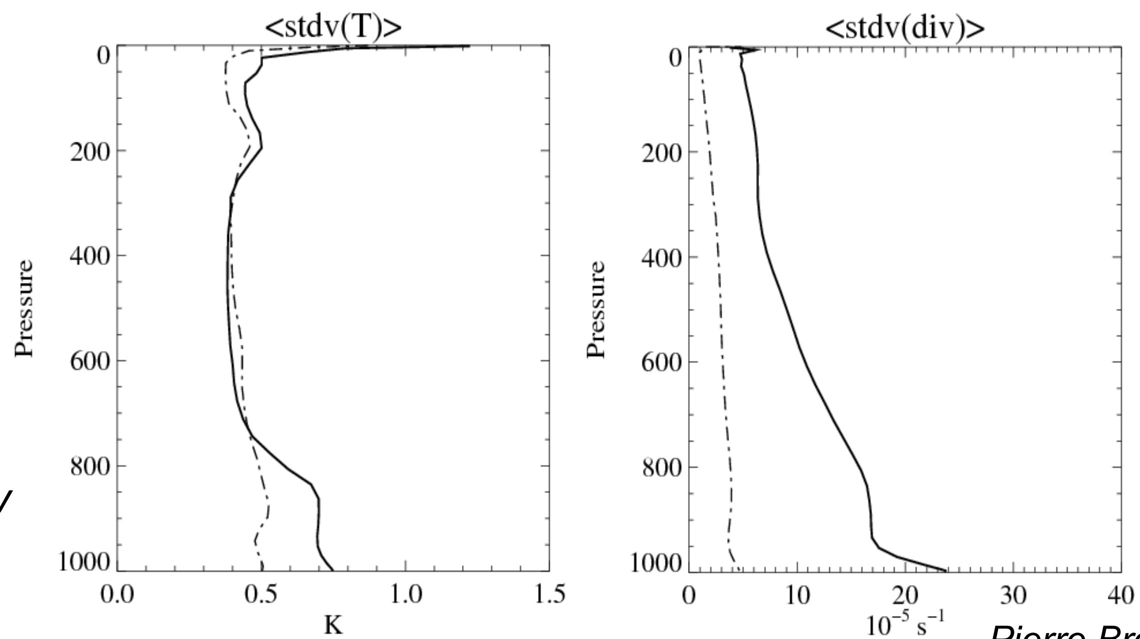
Background error covariance matrix

AROME uses a B matrix deduced from an ensemble of AROME 3h forecasts, coupled with an ensemble of ALADIN forecasts initialized from analyses that use perturbed observations.
This matrix follows the multivariate formalism of Berre (2000)

___ Arome

- - - Aladin

Spectral average of σ_b for T and div

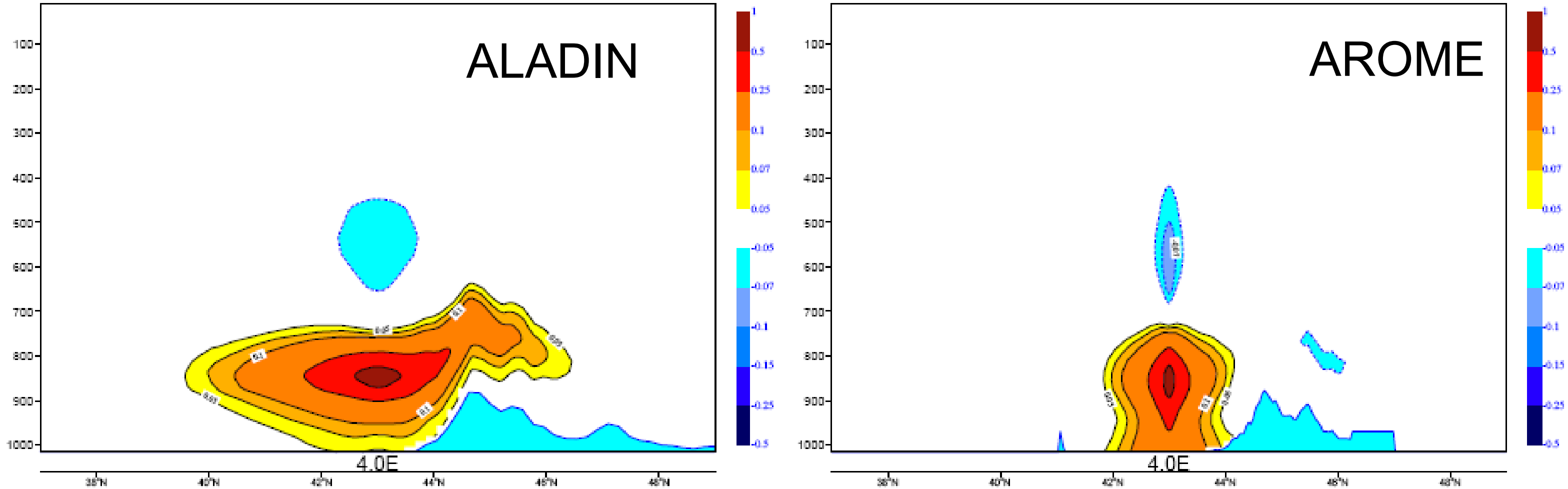


Pierre Brousseau

$\Rightarrow$ greater σ_b for AROME than for ALADIN : The background is less trusted, mostly in the boundary layers and for variables that are representative for small scales

Background error covariance matrix

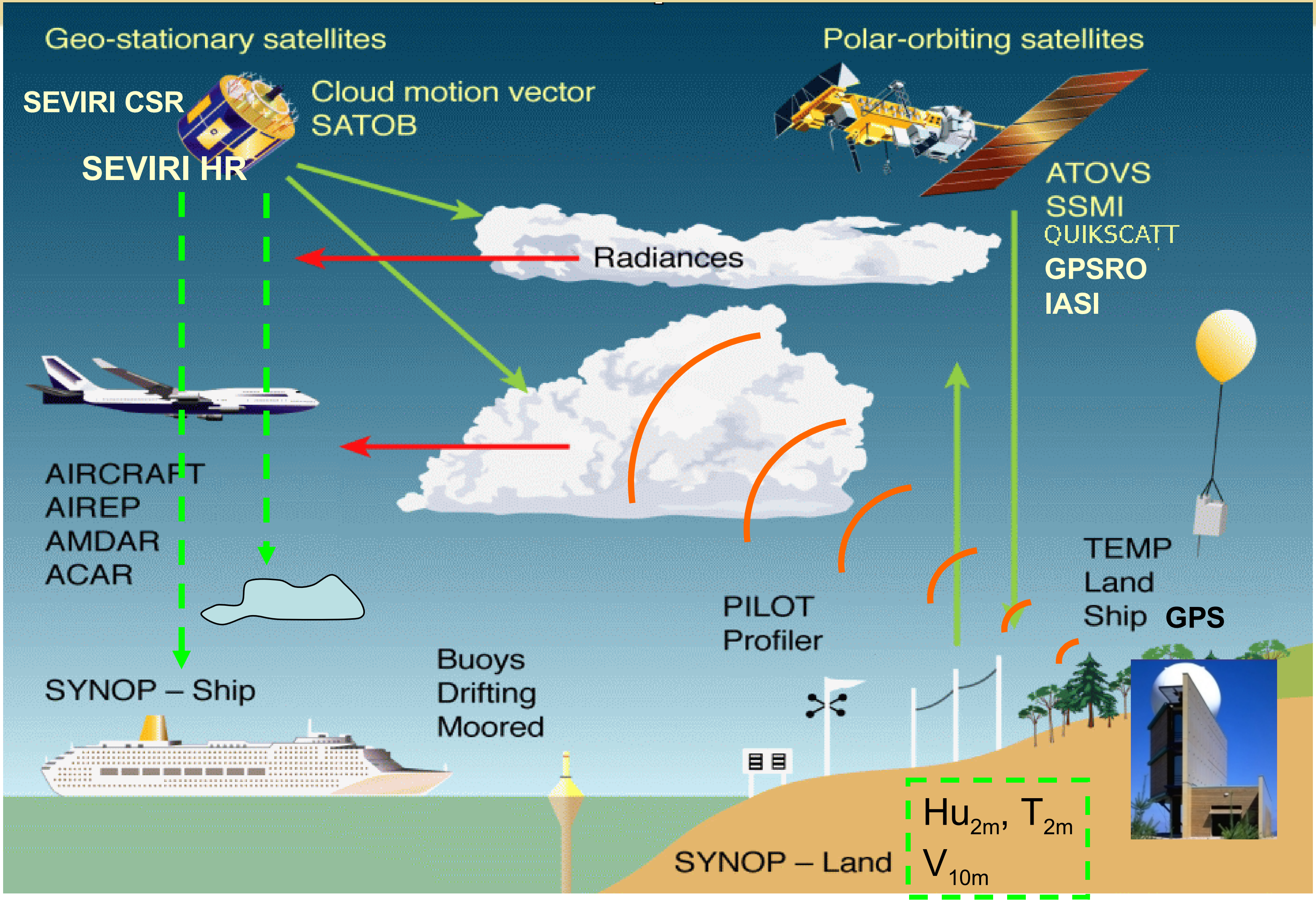
One obs experiment: 2K temperature innovation at 850 hPa



Shorter correlation lengths for AROME than for ALADIN, which is coherent with the smaller domain and smaller horizontal resolution.

⇒ the assimilation of one observation leads to more localized increments
⇒ dense observation networks (ground measurements, geostationary satellites, GPS, radars…) can be used with a higher horizontal resolution (by paying attention to correlations between observation errors)

Assimilated data



ARPEGE → **ALADIN** (SEVIRI HR instead of CSR, Hu_{2m},T_{2m},V_{10m}) → **AROME** (+ radars + more GPS)

Radar data in AROME

The ARAMIS radar network

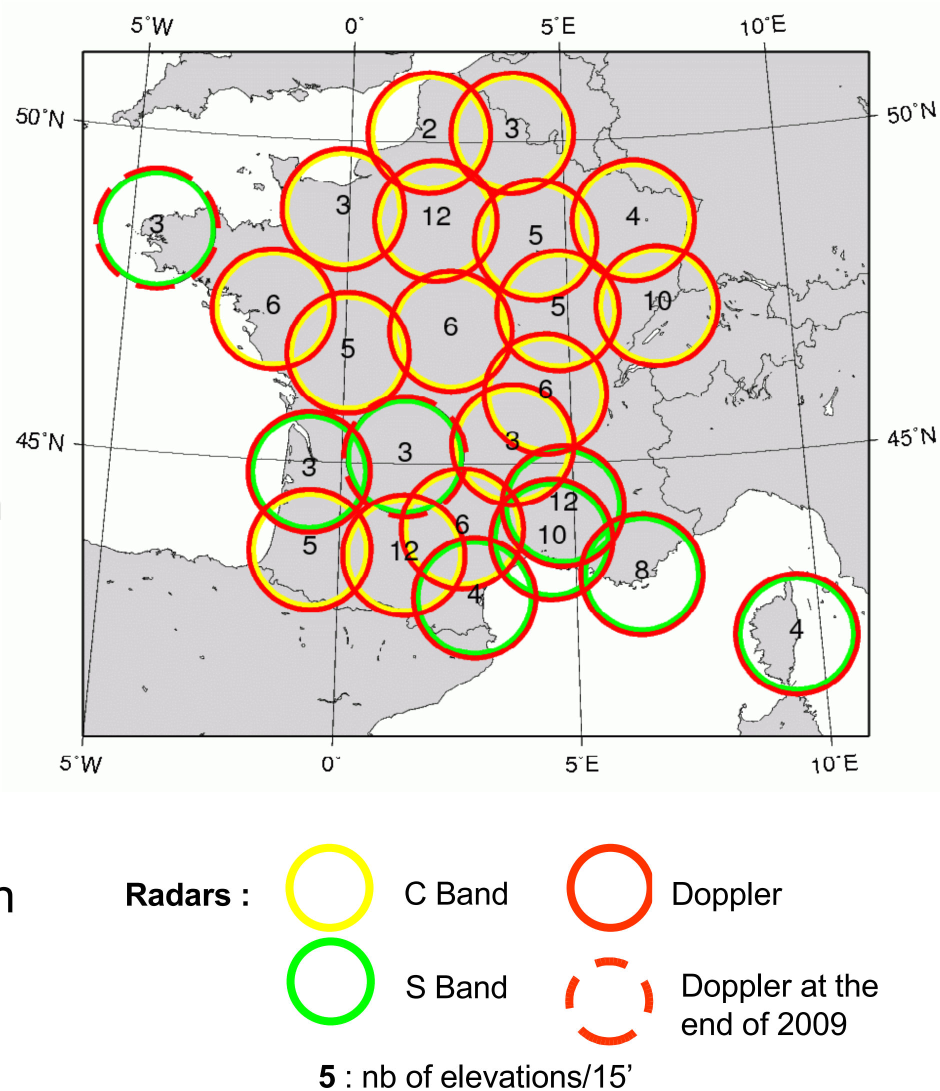
• 24 radars (incl.22 Doppler),
performing between 2 and 12 PPIs/15’

In AROME:

• **Radial velocities** of 15 Doppler radars currently assimilated operationally. The remaining 7 are often contaminated by non meteological targets, but should be included this summer thanks to the use of new detection algorithm.

(For details, see Montmerle and Faccani, 2009, MWR)

• **Reflectivity** of every radars assimilated in research mode (see Eric’s talk after), and hopefully in the parallel suite this summer.



Impact of Doppler winds 1/2

ex: 2007/11/08 case

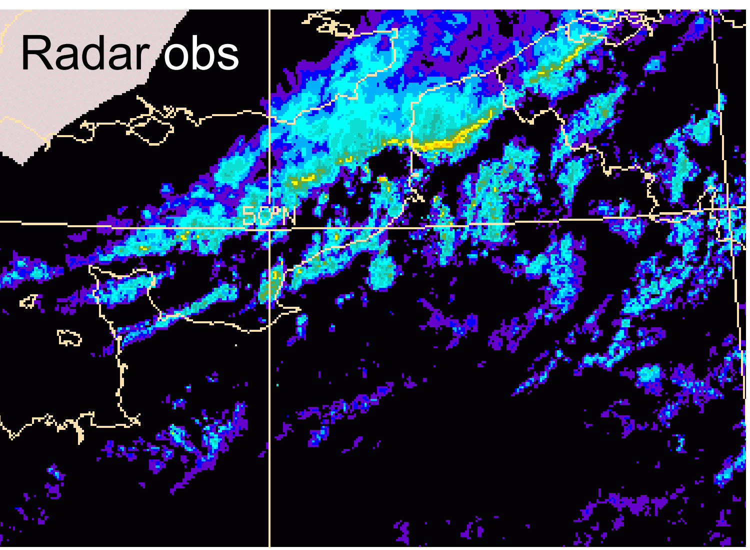
Convergence line associated to a cold front

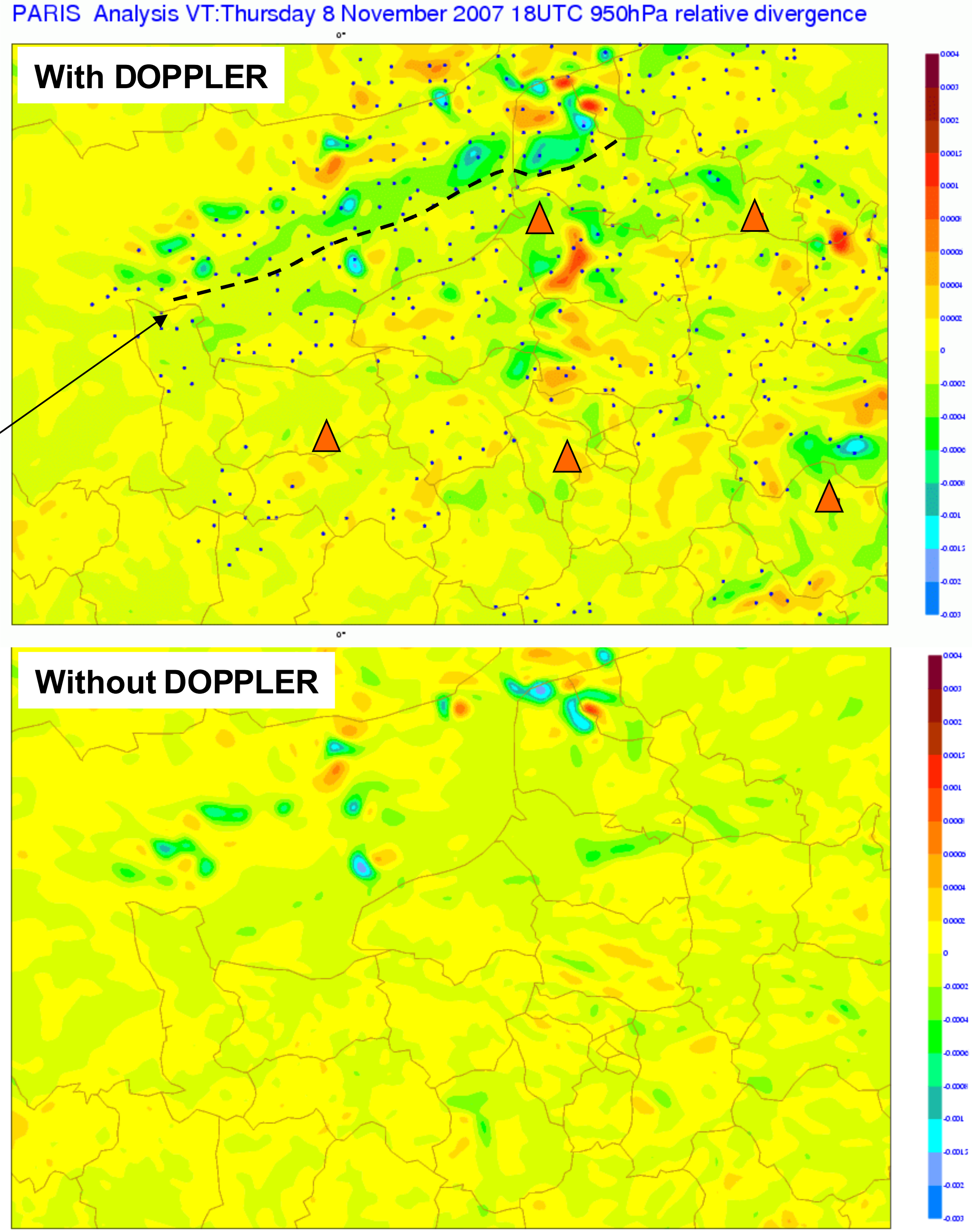
Divergence Analysis

(925 hPa)

(dots: active radar profile)

Main convergence line well analyzed
⇒ More realistic precipitation forecast up to 6 h

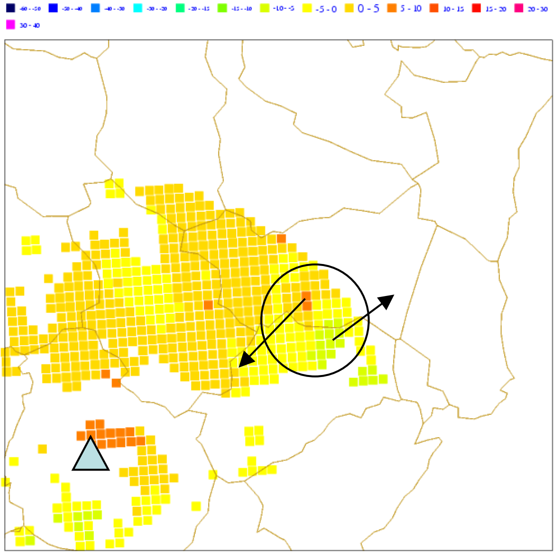




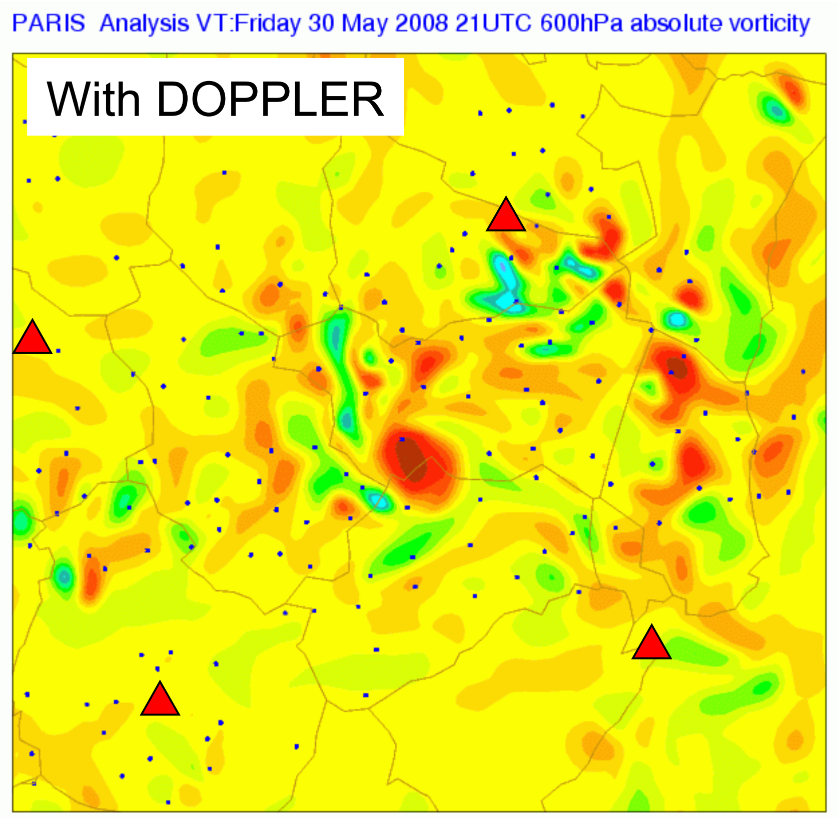
Impact of Doppler winds 2/2

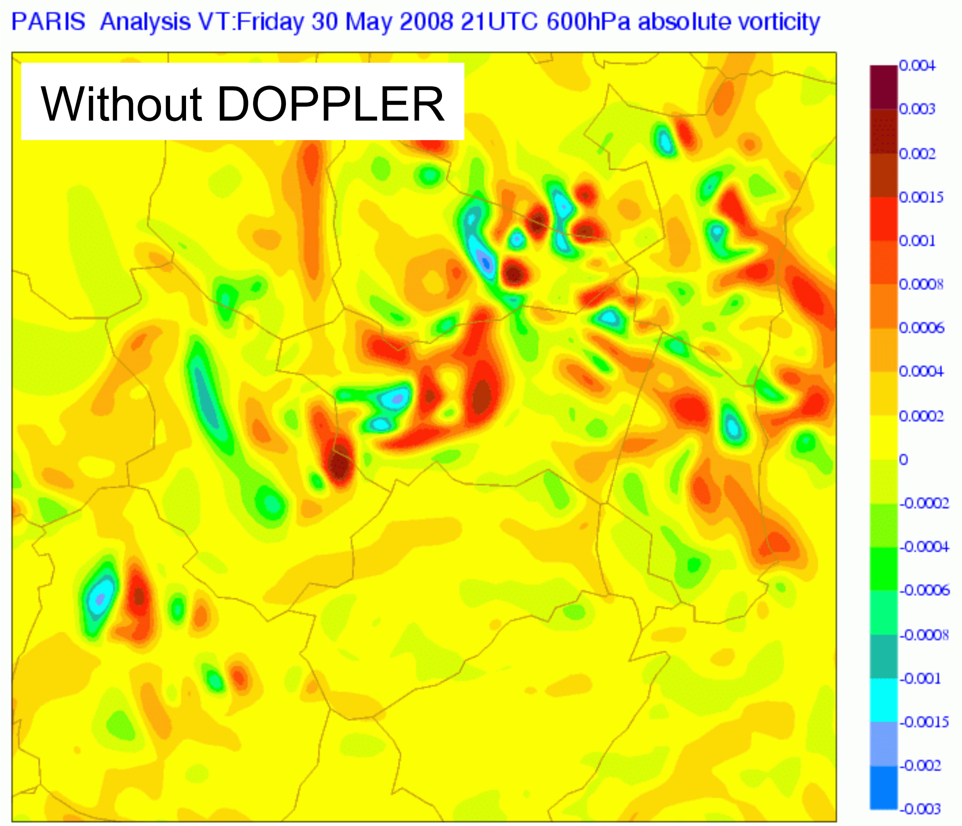
ex: 2008/05/30 case
Meso-vortex

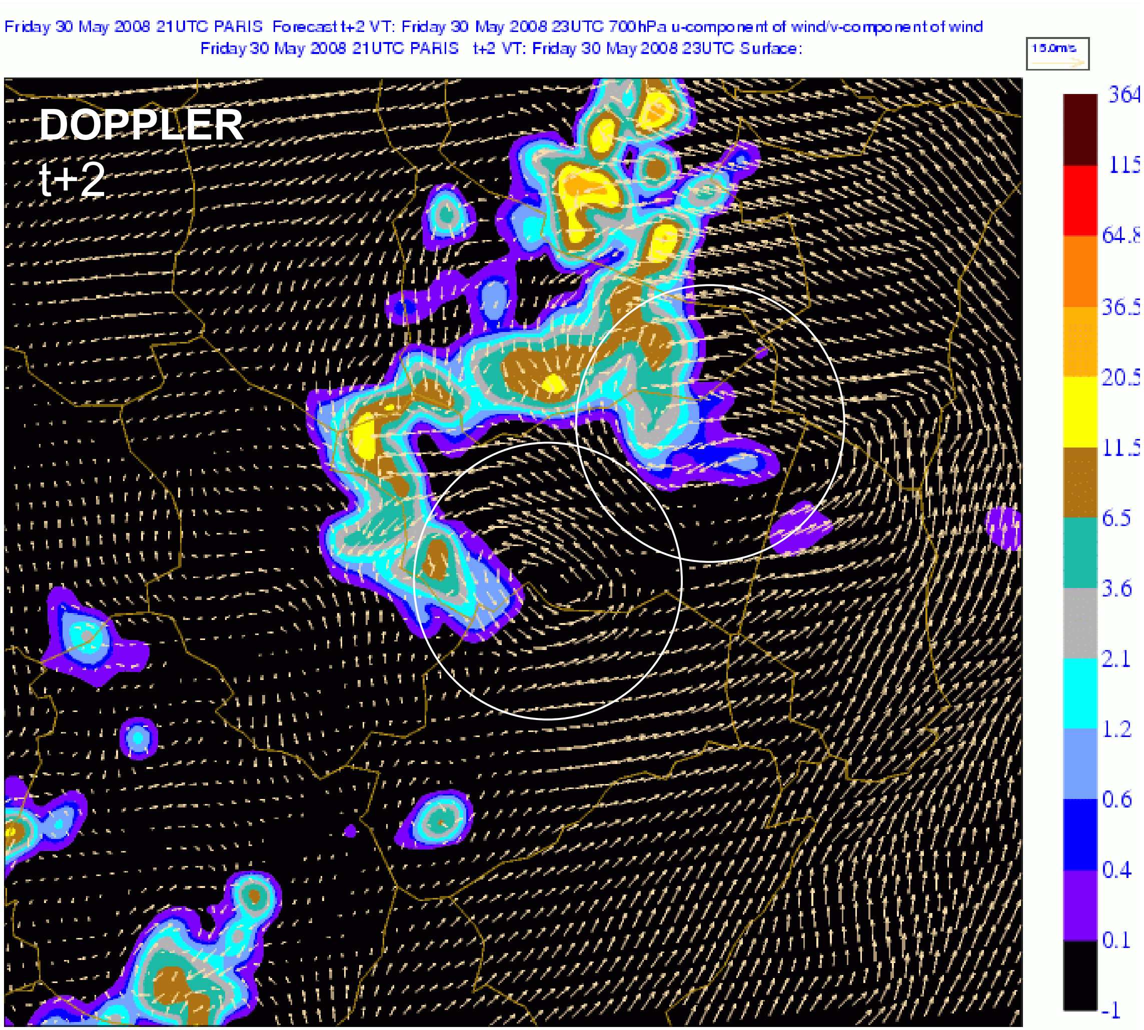
Vr Blaisy
1st elev

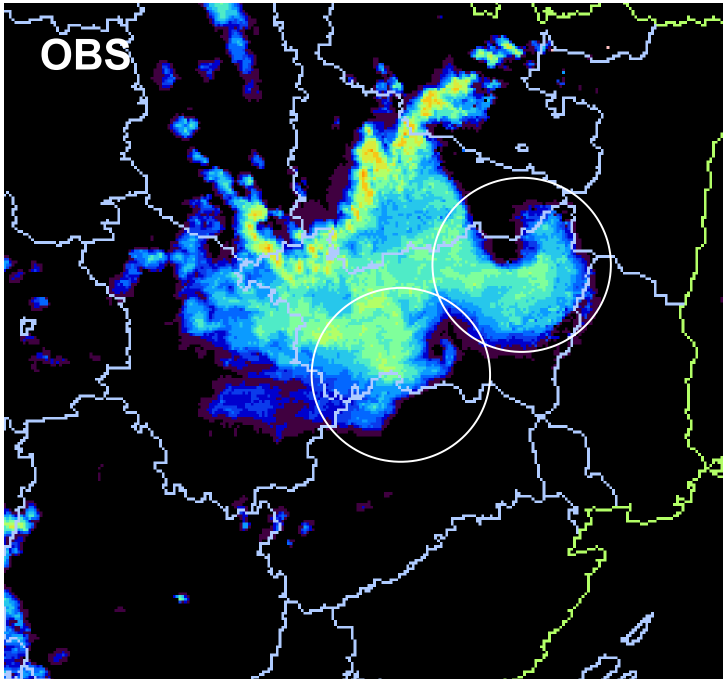


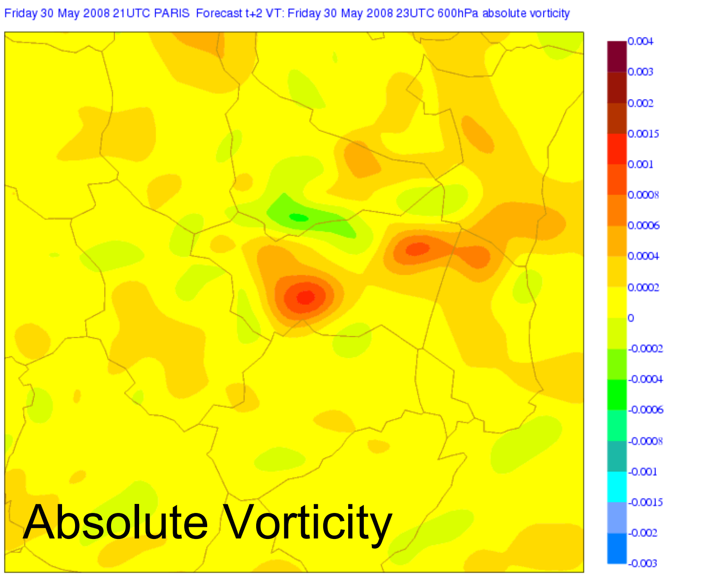
Vorticity Analysis (600 hPa)







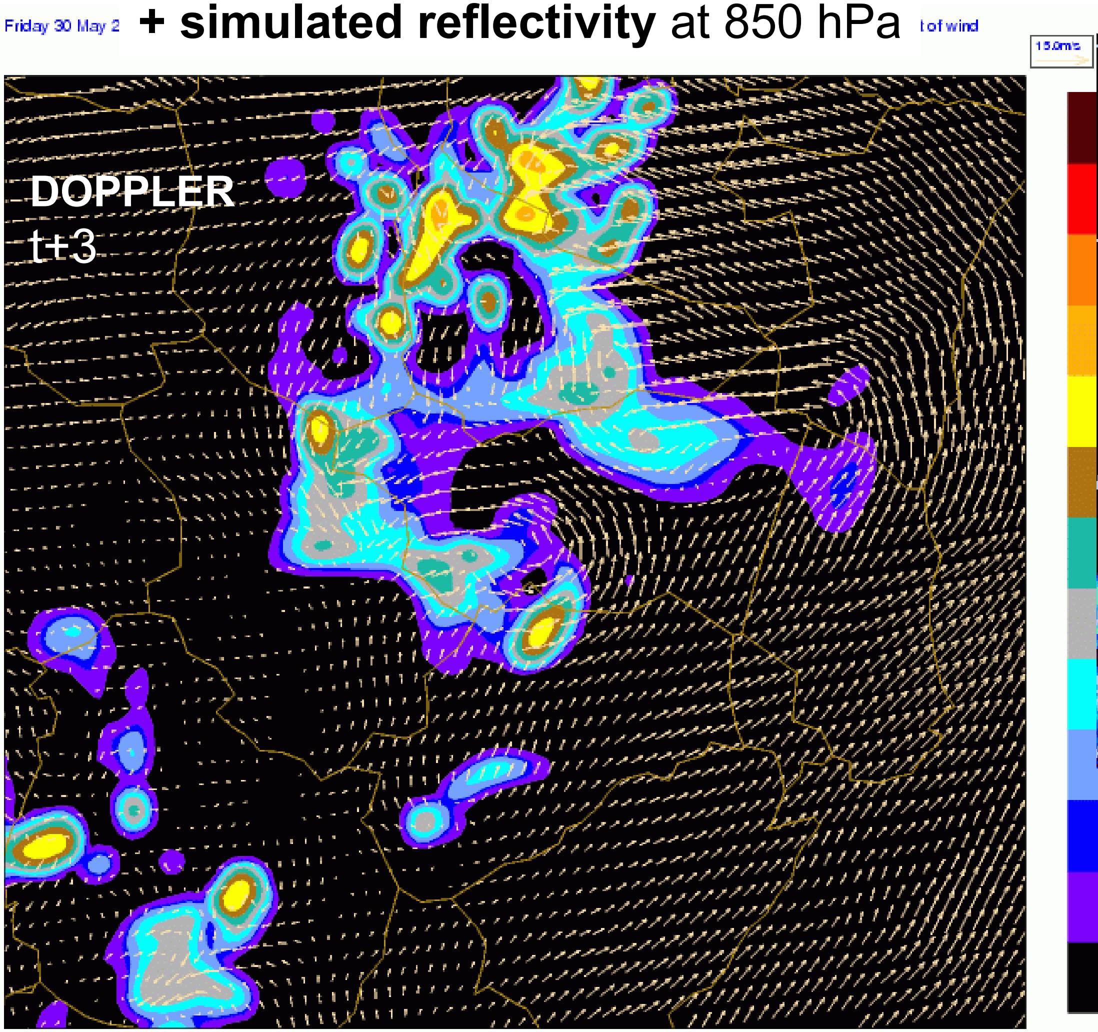


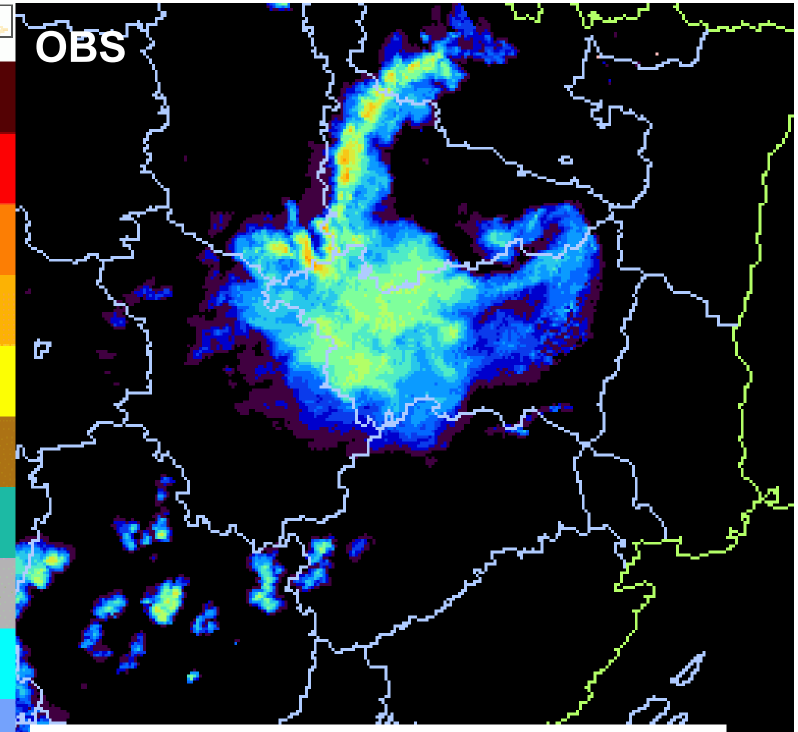


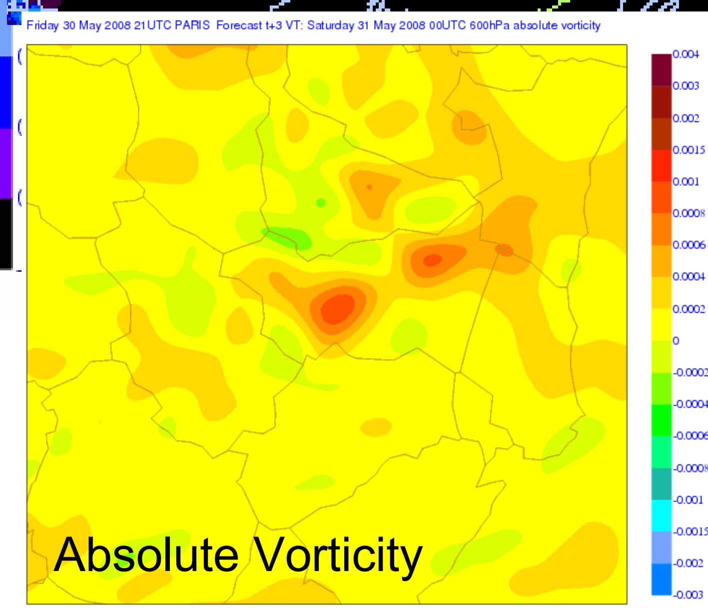
Wind at 700 hPa
+ simulated reflectivity at 850 hPa

Wind at 700 hPa

+ simulated reflectivity at 850 hPa







EW to NS Tilting of the main precipitating well forecasted with Doppler winds

Ongoing work

About observations:

- ALADIN/AROME directly benefit from studies performed in the ARPEGE framework (microwave radiances over continents, IASI, cloudy radiances…)

- **Specifically for AROME:**
  - radiances with higher horizontal resolution
  - radar reflectivity
  - assimilation of objects based on structure matching

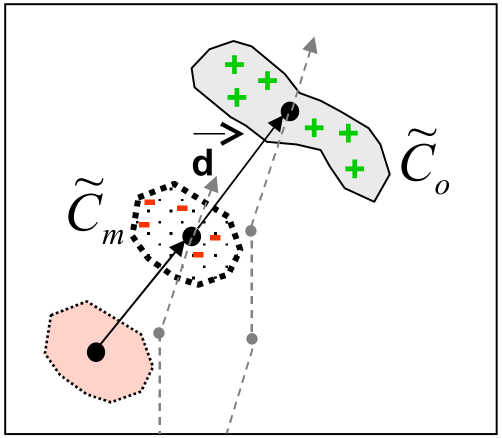
Assimilation of objects based on structure matching

- At first, structures, or “object”, are deduced from image processing applied on observed and simulated radar reflectivity over a certain time period previous to the analysis time.

- A misplaced simulated structure of heavy precipitations is then shifted towards the observed structure that is the closest in the structure space during a fixed time period, using pseudo-observations deduced from the background.

$$\begin{cases} y(\tilde{C}_o) = H_{RH}\left(x_b(\tilde{C}_m)\right) + \varepsilon_A \\ y(\tilde{C}_m) = H_{RH}\left(x_b(\tilde{C}_m) - \varepsilon_D\right) \end{cases}$$

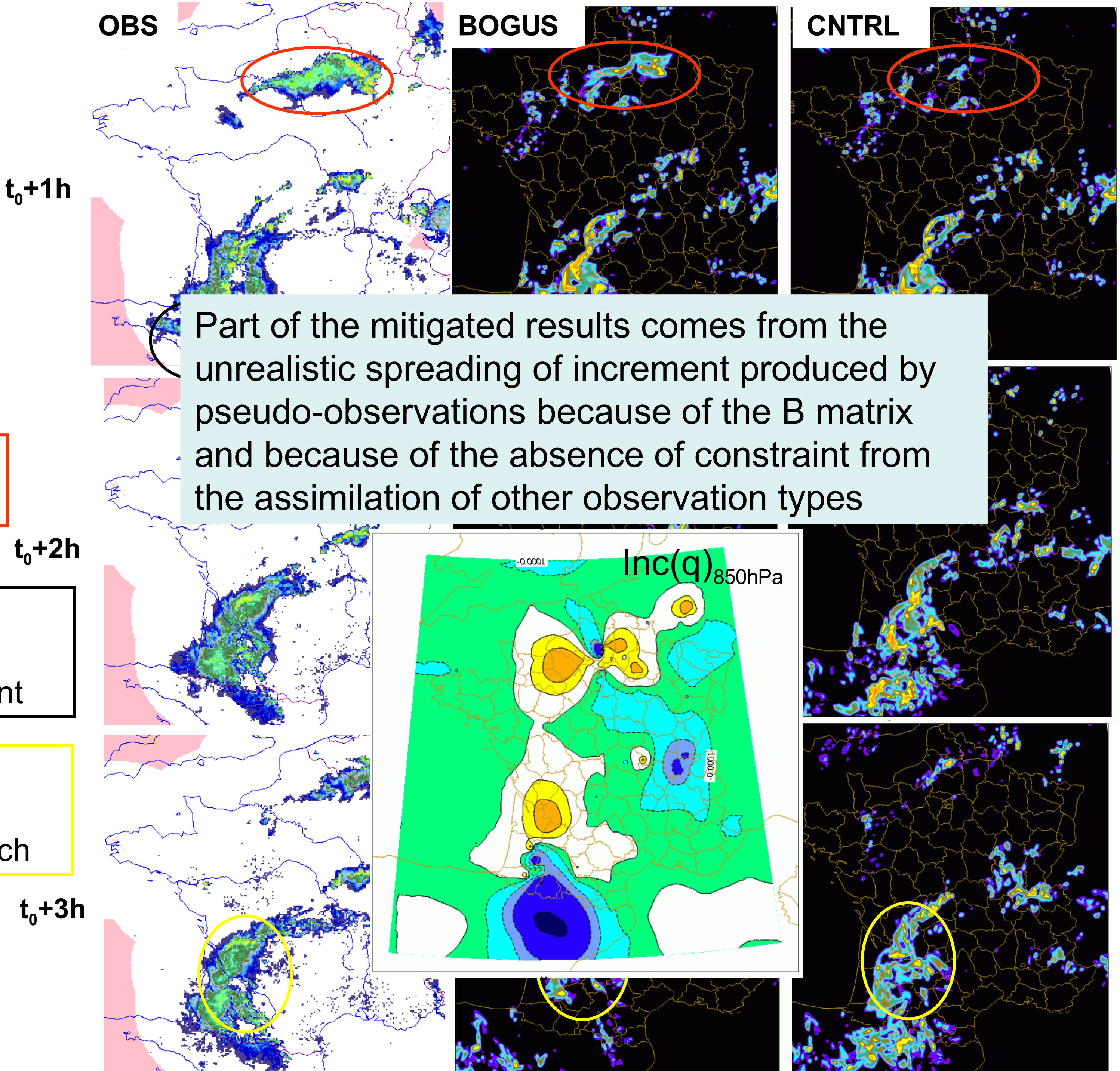
With H_{RH}=<RH>$_c$



Impact on precipitations

$Z_{850\ hPa}$

2007/05/25 r18



Main squall line more realistic

Drying based on background information efficient

In some areas, precipitations are increasing too much

Part of the mitigated results comes from the unrealistic spreading of increment produced by pseudo-observations because of the B matrix and because of the absence of constraint from the assimilation of other observation types

Ongoing work

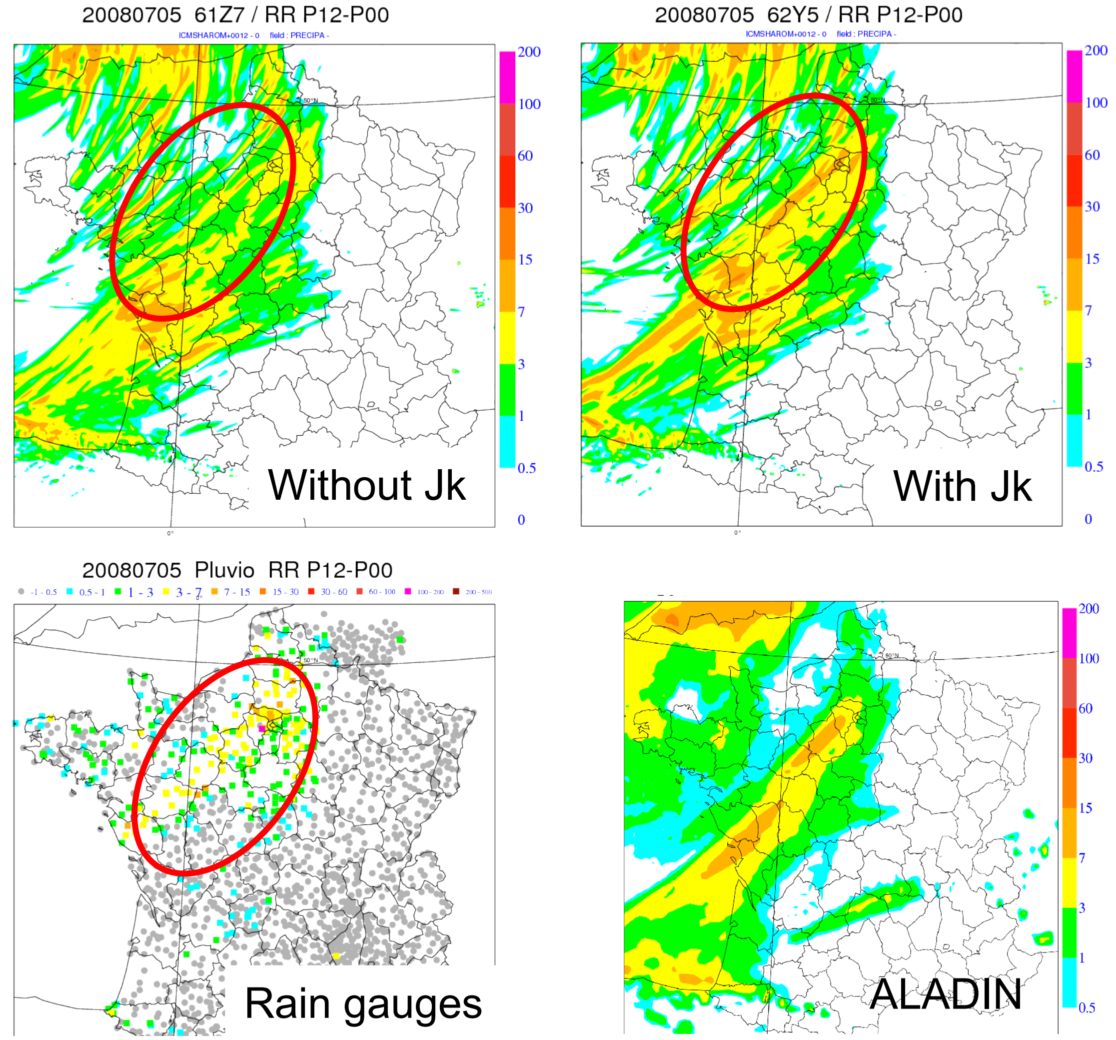
Optimisation of observation impacts

- **3DVar-FGAT:** technically ok, experiments are ongoing by Pierre Brousseau

- **Relaxation towards larger scales in Var (J_k)** (PB):

25 days experiment, relaxing toward large scale (>100 km) of ALADIN analyses above 250hPa:

- neutral scores against conventional data
- small improvements in QPF scores for small precipitating amount
- 1 case with significant improvement



- **Use of a heterogeneous B matrix**

Use of a heterogeneous B matrix

To use more suitable background error statistics in clear air and precipitating areas, we can write:

$$\mathbf{B} = \alpha \mathbf{B}_p + \beta \mathbf{B}_{np}$$

$$\mathbf{B} = \underbrace{\left(\alpha^{1/2}\mathbf{B}_p^{1/2} \quad \beta^{1/2}\mathbf{B}_{np}^{1/2}\right)}_{\mathbf{B}^{1/2}} \underbrace{\begin{pmatrix} \mathbf{B}_p^{T/2}\alpha^{T/2} \\ \mathbf{B}_{np}^{T/2}\beta^{T/2} \end{pmatrix}}_{\mathbf{B}^{T/2}}$$

With: $\alpha = \mathbf{FMF}^{-1}$ and $\beta = \mathbf{F(1\text{-}M)F}^{-1}$

M: grid point mask deduced from observed radar reflectivity.

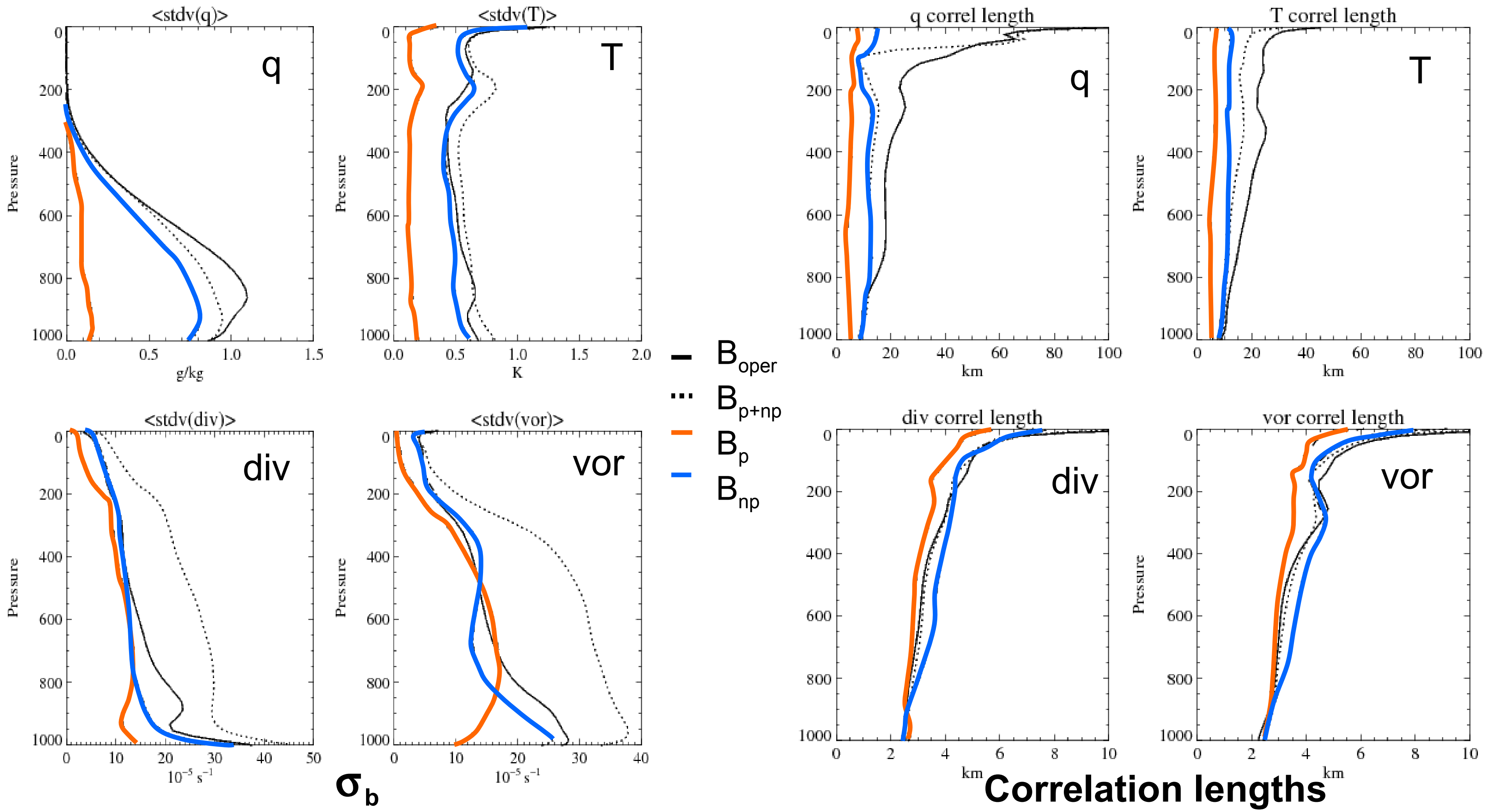
$\mathbf{B_p}$ and $\mathbf{B_{np}}$ are separately computed by performing statistics on an assimilation ensemble of precipitating cases, considering a mask based on simulated precipitations.

The increment writes:

$$\delta x = \mathbf{B}^{1/2}\chi = \left(\alpha^{1/2}\mathbf{B}_1^{1/2} \quad \beta^{1/2}\mathbf{B}_2^{1/2}\right)\begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix}$$

$\Rightarrow$ Which implies to double the control variable χ and the gradient $\nabla_\chi J$

Comparisons between structure functions



⇒ Smaller σ_b for q and T in precipitating areas because the statistics are performed using saturated profiles
⇒ Smaller horizontal correlations in precipitating areas
⇒ Precipitating observations can be used with a greater density

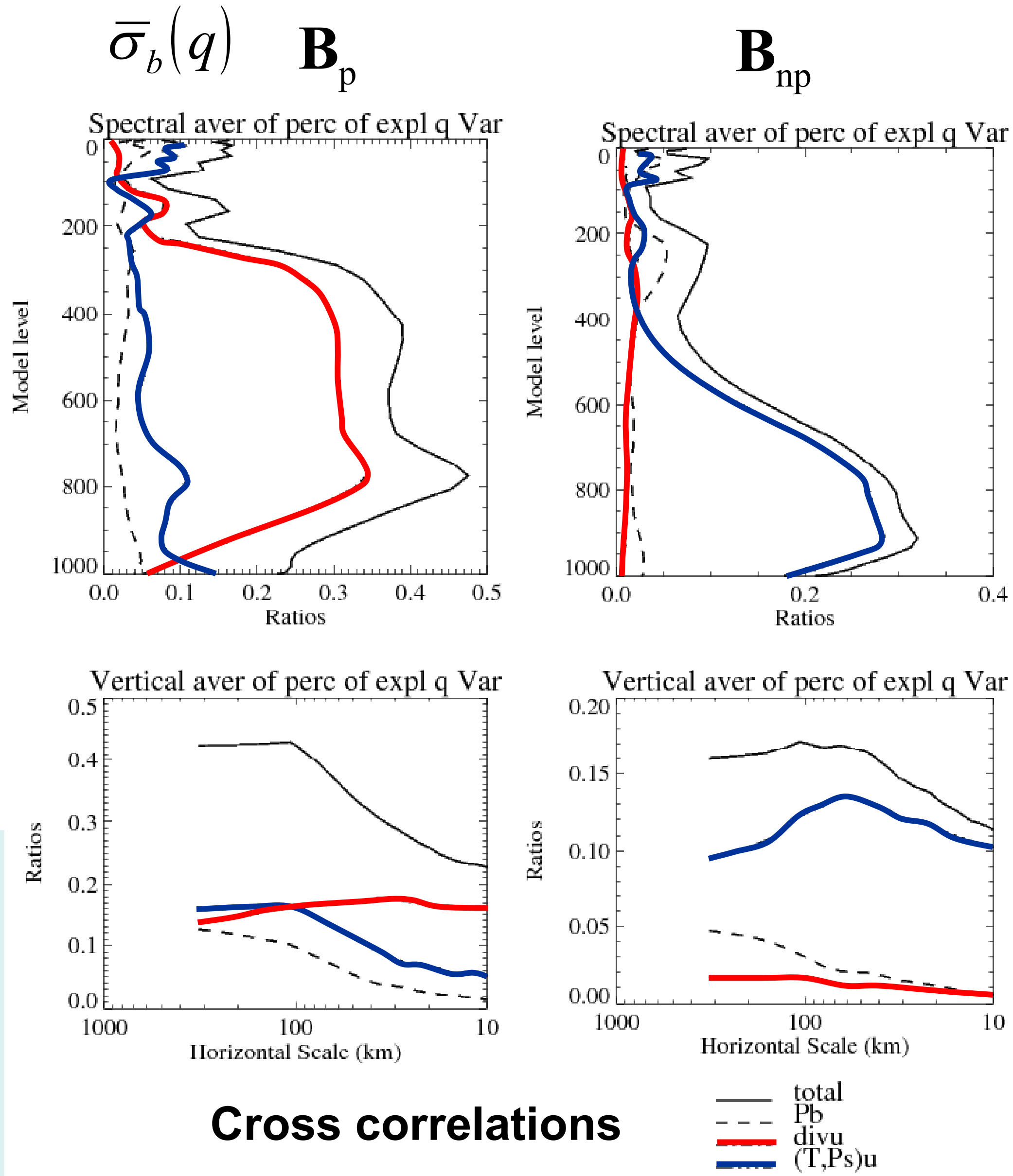
Comparisons between structure functions

Multivariate formulation of errors:

$$\zeta = \zeta$$
$$\eta = \mathcal{M}\mathcal{H}\zeta + \eta_{\mathrm{u}}$$
$$(T,\ P_{\mathrm{s}}) = \mathcal{N}\mathcal{H}\zeta + \mathcal{P}\eta_{\mathrm{u}} + (T,\ P_{\mathrm{s}})_{\mathrm{u}}$$
$$q = \mathcal{Q}\mathcal{H}\zeta + \mathcal{R}\eta_{\mathrm{u}} + \mathcal{S}(T,\ P_{\mathrm{s}})_{\mathrm{u}} + q_{\mathrm{u}}$$

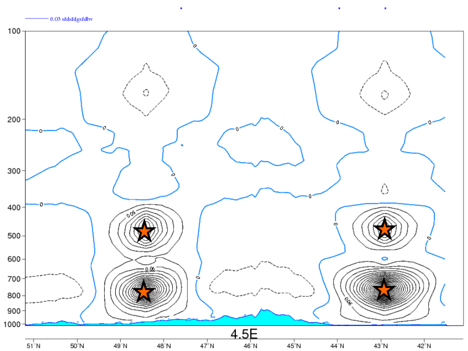
In precipitating areas, σ_b(q) is mostly explained by η_u at mesoscale, whereas it is almost univariate and linked to the mass field in clear air

$\Rightarrow$ B_p et B_{np} are characterized by very different structure functions that are coherent with the model's physic in precipitating and non-precipitating areas respectivelly

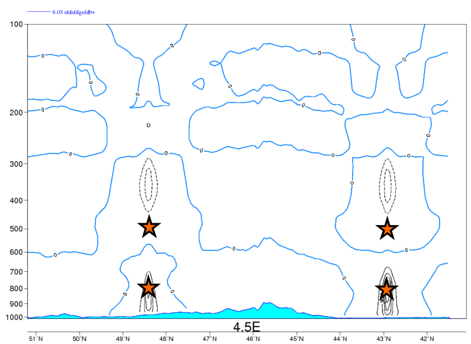


2 obs experiment

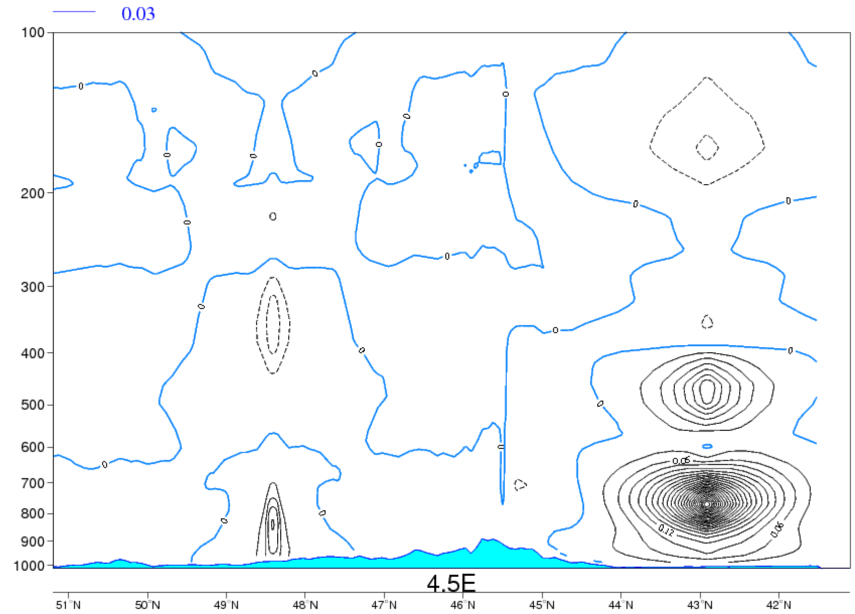
Innovations of – 30% RH
At 800 and 500 hPa



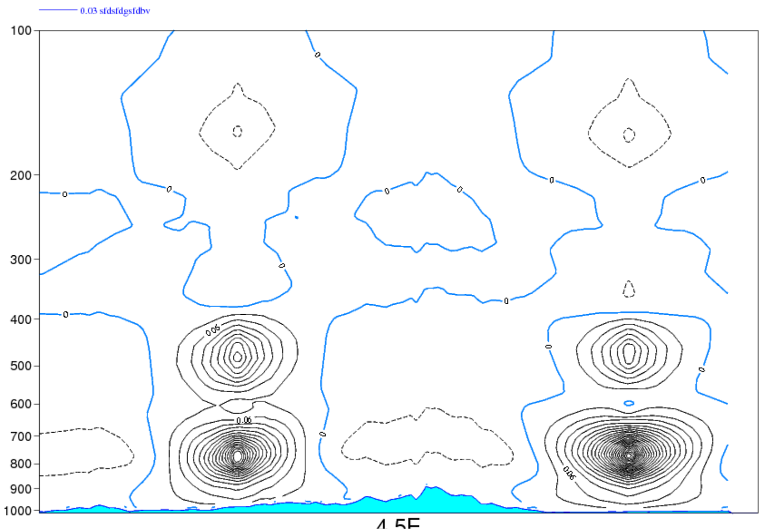
$$\delta x = B_{np}{}^{1/2}\chi$$



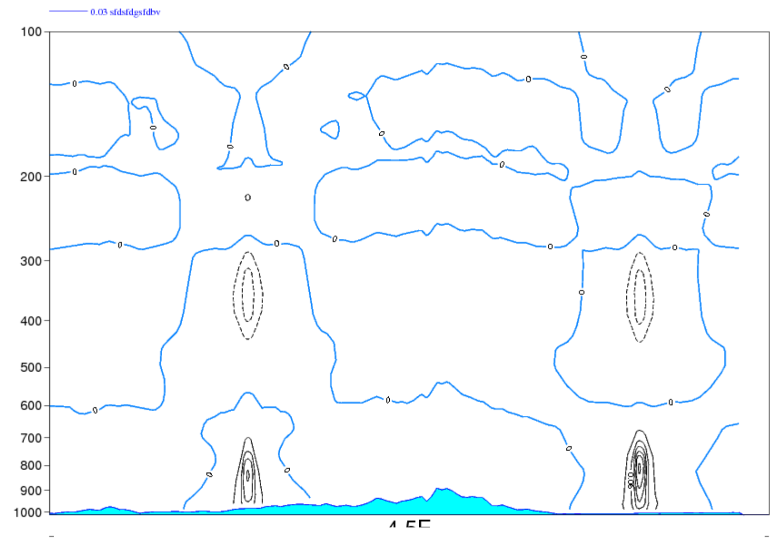
$$\delta x = B_{p}{}^{1/2}\chi$$



$$\delta x = \alpha^{1/2}B_{np}{}^{1/2}\chi_1 + \beta^{1/2}B_{p}{}^{1/2}\chi_2$$



$$\delta x = \beta^{1/2}B_{np}{}^{1/2}\chi_1 + \beta^{1/2}B_{np}{}^{1/2}\chi_2$$



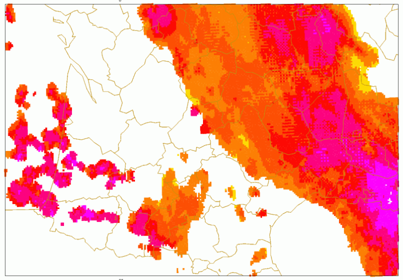
$$\delta x = \alpha^{1/2}B_{p}{}^{1/2}\chi_1 + \alpha^{1/2}B_{p}{}^{1/2}\chi_2$$

Real case experiment

CNTRL: AROME oper + Reflectivities

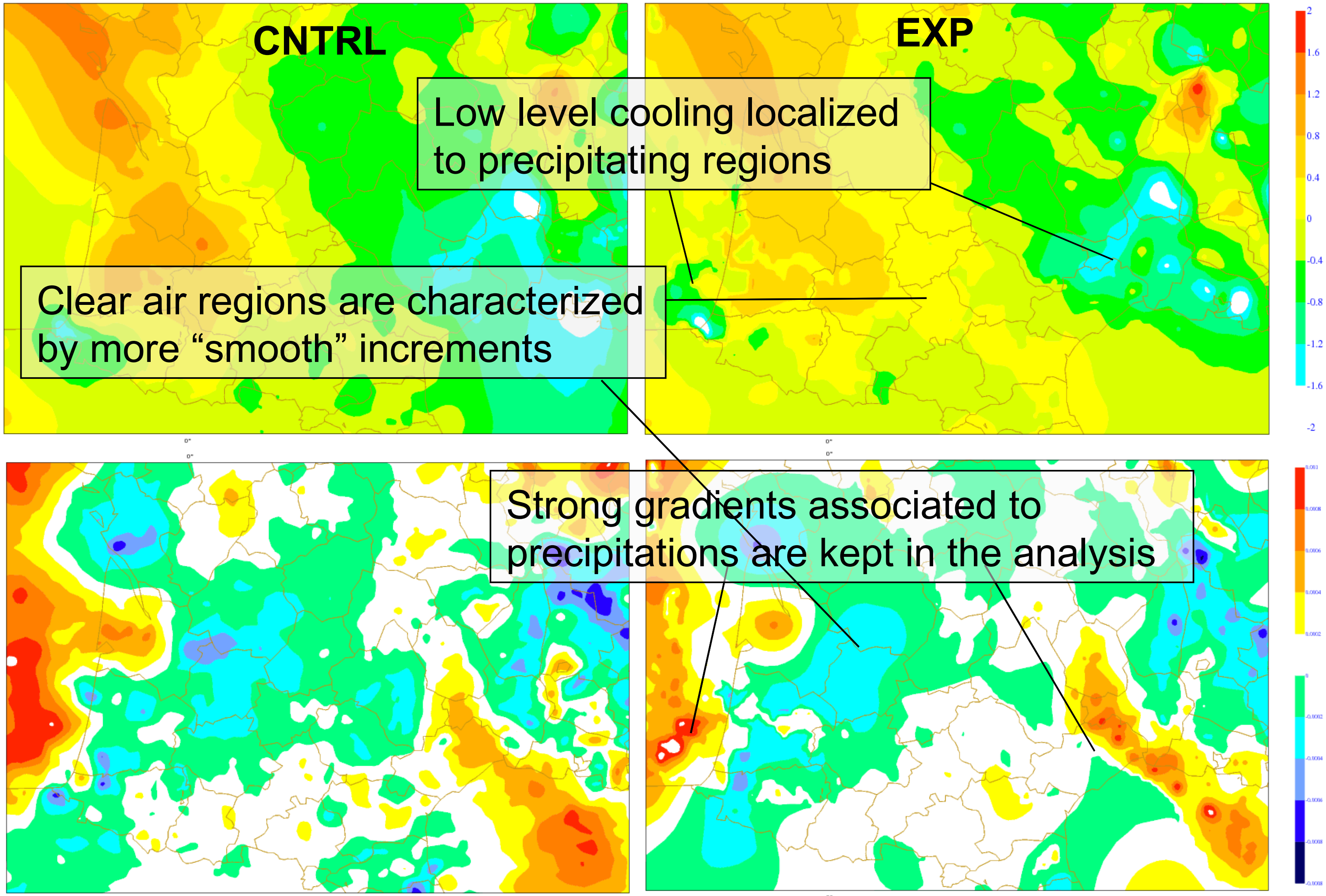
EXP: CNTRL using simultaneously (B_p, B_{np})

Mask deduced from observed reflectivities (zoom)



Inc(T)$_{950hPa}$

Inc(q)$_{800hPa}$

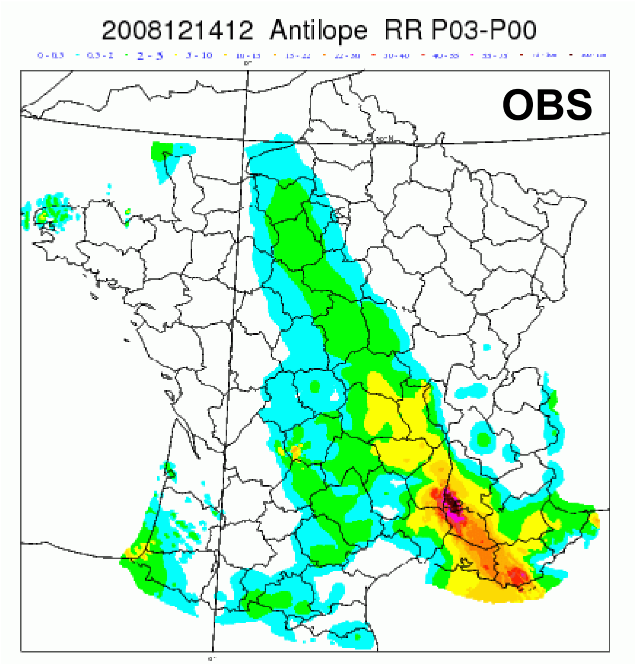


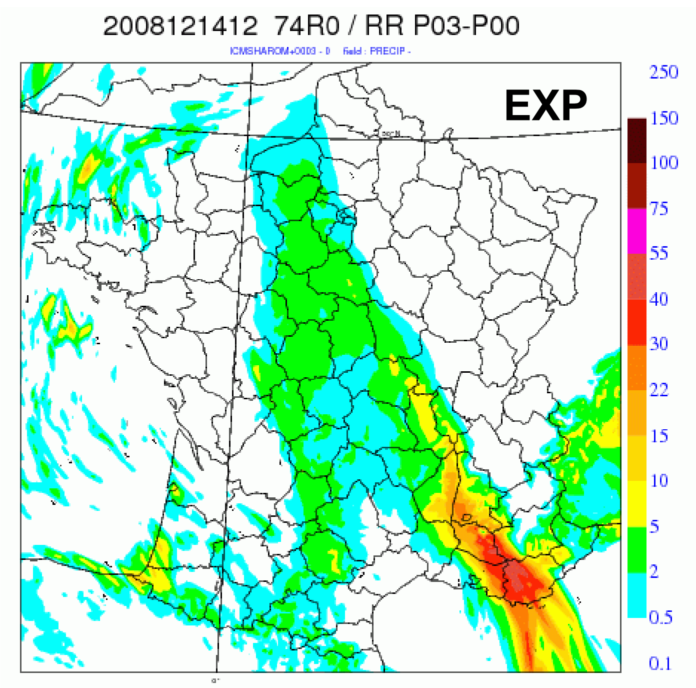
Real case experiment

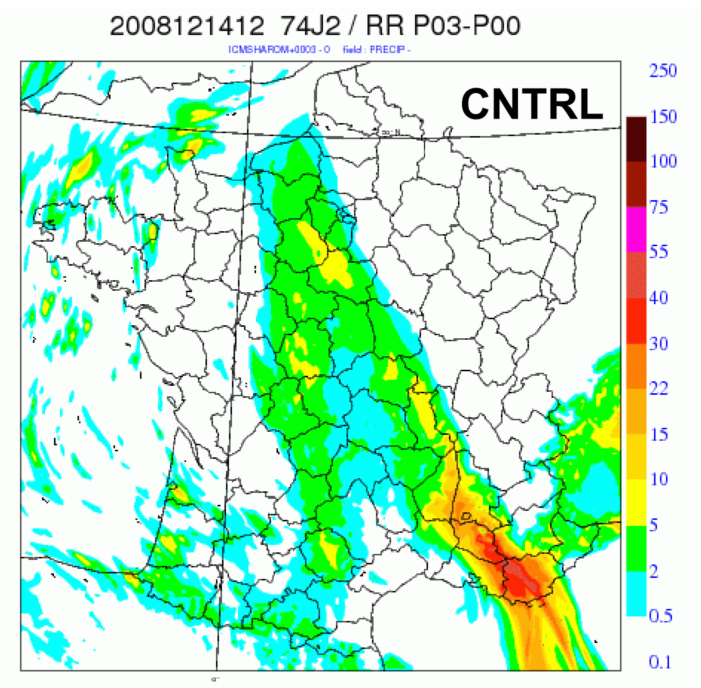
• For that first experiment, the use of the heterogeneous B matrix aims mostly at reducing precipitations realistically during the first hours of forecast

• Obviously more cases are needed and this approach will be evaluated on long periods of cycled assimilations

⇒ **Other possible applications:** specific data assimilation in fog conditions...





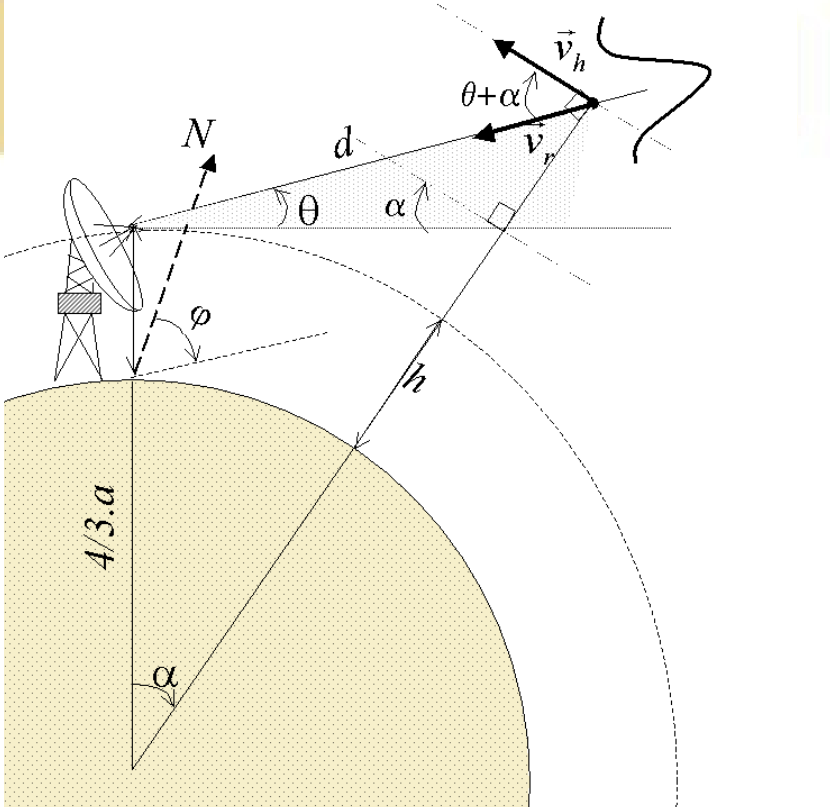


3h cumulated rainfall

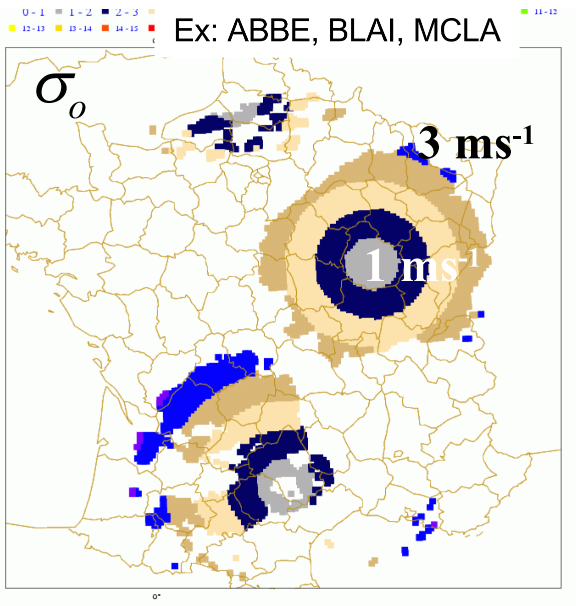
Thank you for your attention!

METEO FRANCE
Toujours un temps d'avance

Doppler wind observation operator



- **Follows closely HIRLAM's** (Linskog et al, 2004)**:** Vr computed using the earth's effective radius model
- fall speed and side lobes contributions neglected
- Broadening of the radar beam simulated by a Gaussian function
- TL/AD



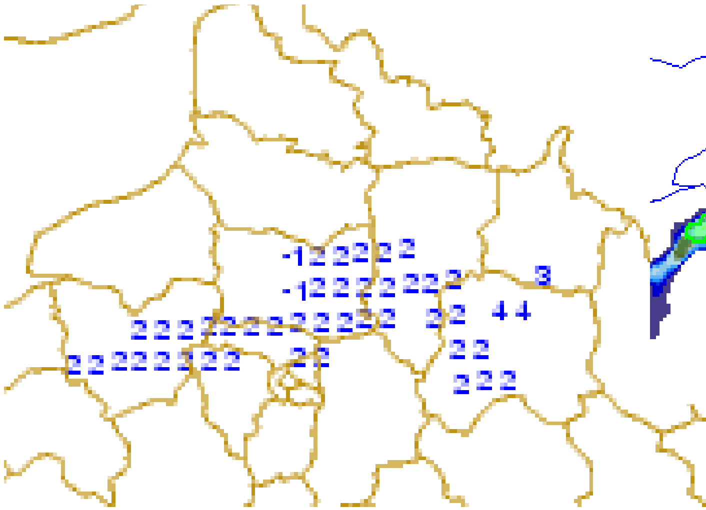
Screening

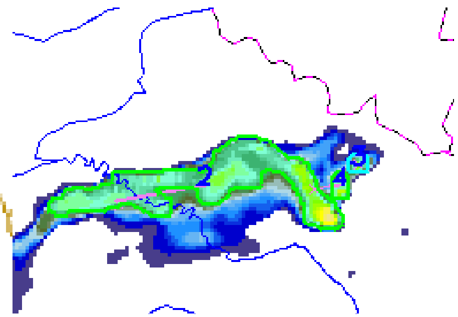
- σ_o proportional to the distance from the radar to take into account the beam broadening
- innovations (obs-guess) between +/- 20 ms^{-1} are kept
- thinning within15x15 km^2 boxes using a sorting criteria based on the distance and on the number of observations per profiles

Impact sur l’analyse

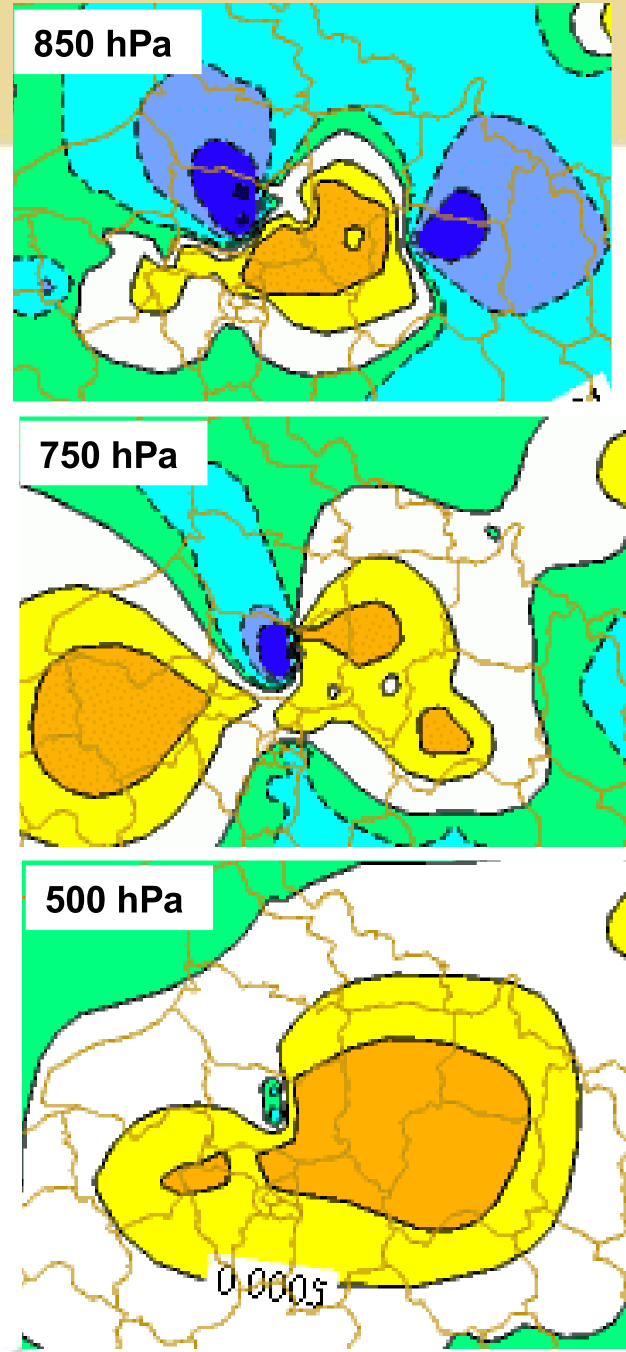
Incréments (humidité spécifique)

Localisations Pseudo-obs





Cellules observées



Problème de propagation irréaliste des incréments

⇒ l’extension horizontale des incréments d’analyse dépend des fonctions de structures de la matrice B et de la densité des observations assimilées

L'incrément s'écrit alors: $\delta x = \mathbf{B}^{1/2}\chi = \begin{pmatrix} \sqrt{\alpha}\mathbf{B}_1^{1/2} & \sqrt{\beta}\mathbf{B}_2^{1/2} \end{pmatrix} \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix}$

$\Rightarrow$ **On double la variable de contrôle**

Termes de la fonctions coût:

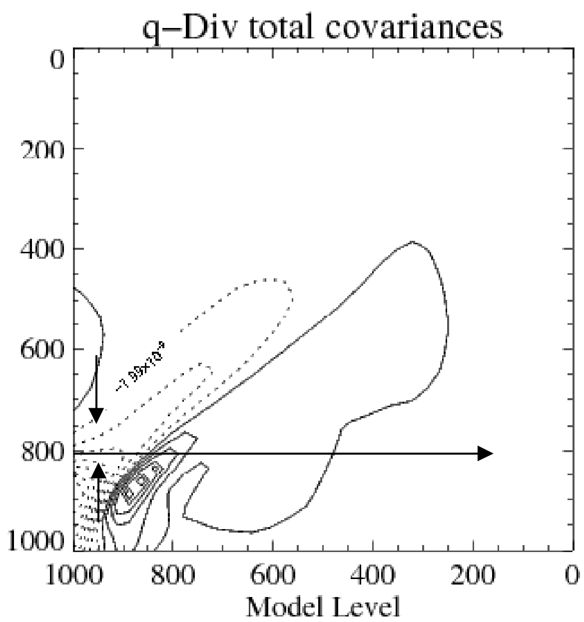
$$J_{b_\chi} = \frac{1}{2}\left(\chi_1^T \chi_1 + \chi_2^T \chi_2\right)$$

$$J_{o\chi} = \left(\mathbf{HB}^{1/2}\chi - d\right)^T \mathbf{R}^{-1}\left(\mathbf{HB}^{1/2}\chi - d\right)$$

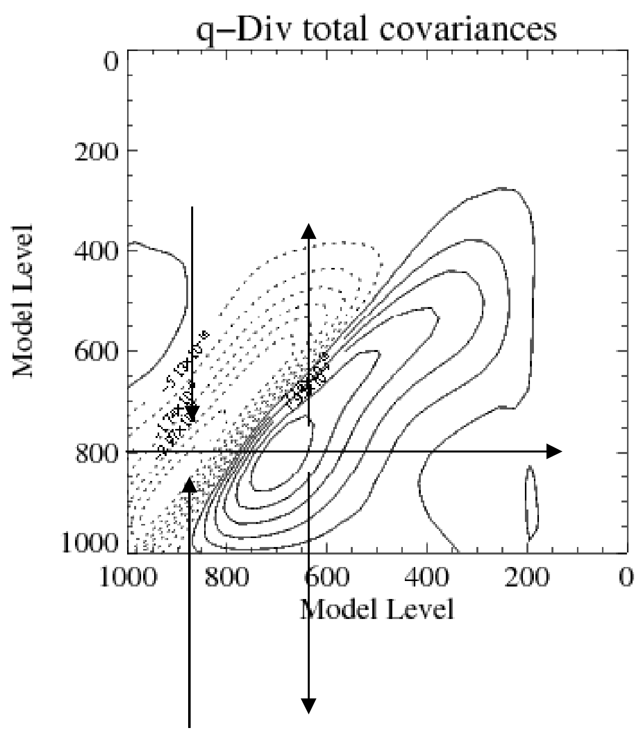
Gradients:

$$\nabla_\chi J_b = \begin{pmatrix} \chi_1 \\ \chi_2 \end{pmatrix}$$

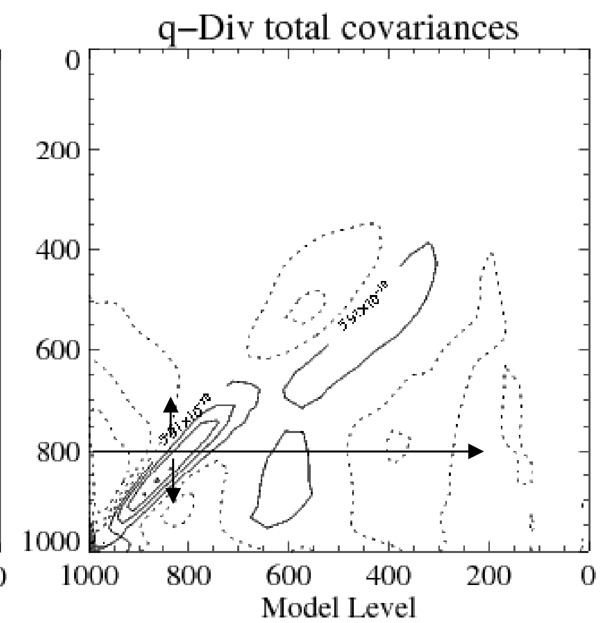
$$\nabla_\chi J_o = \begin{pmatrix} \alpha^{T/2}\mathbf{B}_1^{T/2} \\ \beta^{T/2}\mathbf{B}_2^{T/2} \end{pmatrix} \mathbf{H}^T \mathbf{R}^{-1}\left(\mathbf{H}\left(\alpha^{1/2}\mathbf{B}_1^{1/2}\chi_1 + \beta^{1/2}\mathbf{B}_2^{1/2}\chi_2\right) - d\right)$$



$B_{\text{arome oper}}$

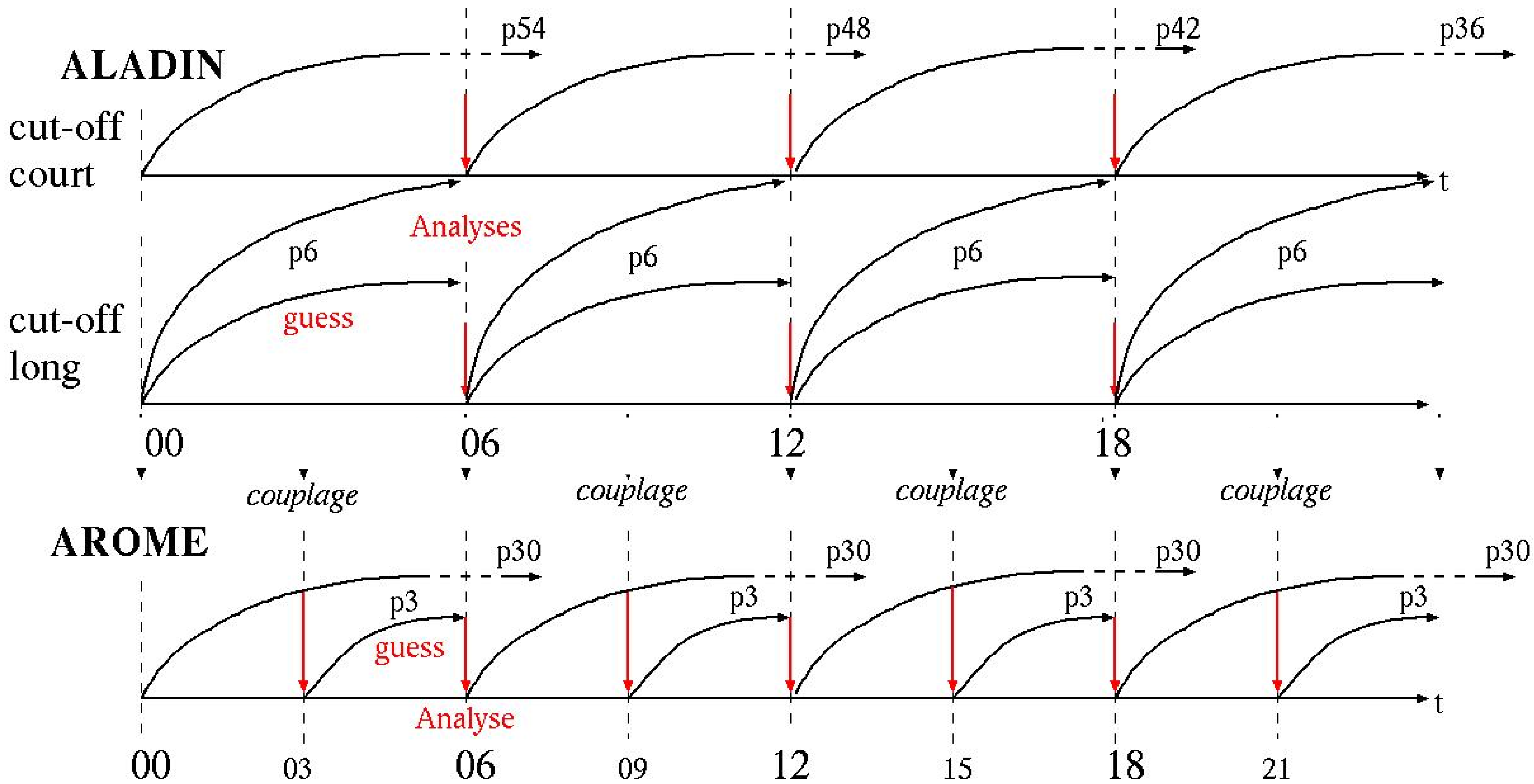


B_{precip}



$B_{\text{air clair}}$

Cycling strategies



Assimilation of objects based on structure matching

• This approach aims at shifting a misplaced simulated structure of heavy precipitations towards the observed structure that is the closest in the structure space, using pseudo-observations deduced from the background.

• These structures, or “object”, are deduced from radar reflectivity (or satellite) image processing over a certain time period previous to the analysis time.

$$\begin{cases} y\left(\tilde{C}_o\right) = H_{RH}\left(x_b\left(\tilde{C}_m\right)\right) + \varepsilon_A & \text{If matching} \\ y\left(\tilde{C}_o\right) = f(RH, Ctop) & \text{If lonesome} \end{cases}$$

$$\begin{cases} y\left(\tilde{C}_m\right) = H_{RH}\left(x_b\left(\tilde{C}_m\right) - \varepsilon_D\right) & \text{If moving} \\ y\left(\tilde{C}_m\right) = H_{RH}\left(x_b\left(\tilde{C}^*_m - \tilde{C}_m\right)\right) & \text{If stationnary} \end{cases}$$

With H_{RH}=<RH>$_c$