# Status of assimilation methods at Météo-France
# speaker: C. Fischer

1. 4D-En-VAR
2. Heterogenous B & cloudy IR radiances
3. Other stuff (EnDA, B, …)

dépasser les frontières

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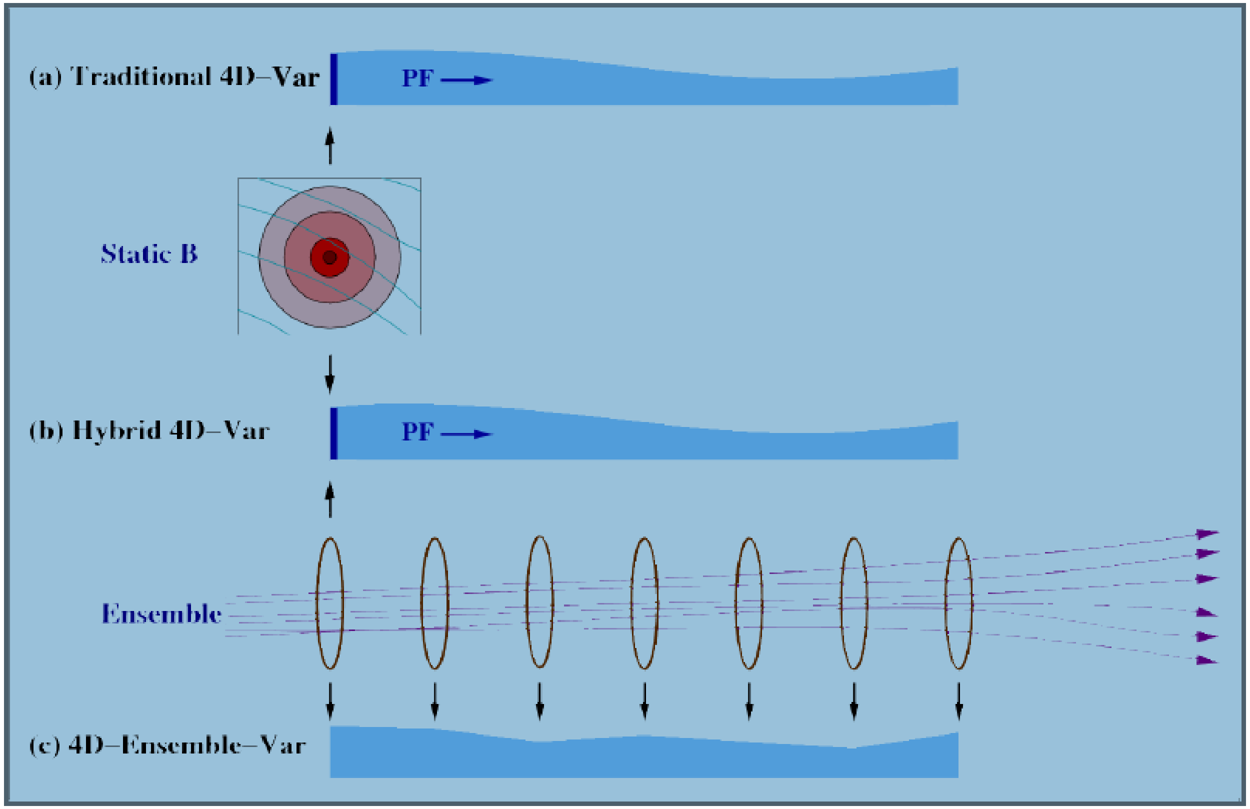
# 4D-Var / Hybrid 4D-Var / 4D-En-Var




Barker and Clayton, 2011

# Investigations into an alternative 4D DA method (G. Desroziers, J-T Camino, L. Berre)

- 4D-Var
  - ✓ Simplified description of **B** at initial time , and linear evolution of covariances.
  - ✓ Possible improv. via an ens. of pert. 4D-Var (Météo-France, ECMWF) : spat./temp. variations of error variances and correlations (wavelets).
  - ✓ Difficult development and maintenance of TL/AD.
  - ✓ Poor scalability of TL/AD.

- 4D-Var based on a 4D ensemble : 4D-En-Var
  - ✓ Similar to En-KF.
  - ✓ Keeps benefits of 4D-Var (global analysis, add. terms, outer-loop, …)
  - ✓ Localization of the raw covariances made in model space.
  - ✓ Minimization cost similar to 3D-Var.
  - ✓ Natural parallelization, and NL evolution of covariances.

# 4D-En-Var formulation

- Minimization of

$$J(\underline{\delta\mathbf{x}}) = \underline{\delta\mathbf{x}}^T \underline{\mathbf{B}}^{-1} \underline{\delta\mathbf{x}} + (\underline{\mathbf{d}} - \underline{\mathbf{H}}\ \underline{\delta\mathbf{x}})^T \underline{\mathbf{R}}^{-1} (\underline{\mathbf{d}} - \underline{\mathbf{H}}\ \underline{\delta\mathbf{x}}), \text{ with}$$

$\underline{\mathbf{d}}$ 4D vector of the innovations distributed in time,

$\underline{\mathbf{H}}$ 4D linearized observation operator,

$\underline{\mathbf{R}}$ 4D (but diagonal !) covariance matrix of obs. errors,

$\underline{\delta\mathbf{x}}$ 4D vector of the increments to be added to the 4D bg $\mathbf{x}^b$, composed of K sub-elements (K slots for the pert. in time)

$\underline{\mathbf{B}}$ 4D covariance matrix of bg errors, given by an ensemble.

(Lorenc, 2012)

# 4D-En-Var formulation

$$\underline{\mathbf{X}}^{f} = (\underline{\mathbf{x}}^{f'}_{1}, \dots, \underline{\mathbf{x}}^{f'}_{L}),$$

where L is the ensemble size and

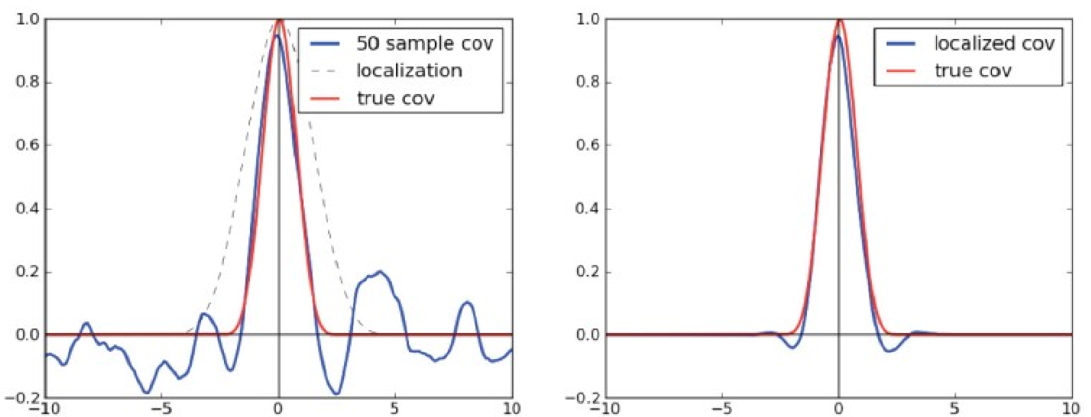
$$\underline{\mathbf{x}}^{f'}_{l} = \underline{\mathbf{x}}^{f}_{l} - \langle\underline{\mathbf{x}}^{f}\rangle / (L-1)^{1/2}, \; \mathbf{l} = 1, L,$$

are the deviations of the 4D pert. forecasts from the ens. mean traject.

$$\underline{P} = \underline{\mathbf{X}}^{f} (\underline{\mathbf{X}}^{f})^{T}$$

Localization of bg error cov. (Schurr product):

$$\underline{B} = \underline{P} \circ \underline{C}$$




Whitaker, 2011

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# Implementations of 4D-En-Var

- $\delta \mathbf{x} = \mathbf{B}^{1/2} \chi$
  $= ( \mathbf{P} \circ \mathcal{C} )^{1/2} \chi$
  $= \Sigma_{l=1,L} \mathbf{x}^{f'}_l \circ ( \mathcal{C}^{1/2} \chi_l )$

  $J^b(\chi) = \Sigma_{l=1,L} \chi_l^T \chi_l$, dim $\chi$ = $N(N_c) \times L$ (or $K \times N_c \times L$ in 4D with model error)

  Use of a Conjugate Gradient (CG) with $\mathbf{B}^{1/2}$ change of variables.

  (Buehner 2005, 2010)

- $\delta \mathbf{x} = \Sigma_{l=1,L} \mathbf{x}^{f'}_l \circ \alpha_l$ , with $\alpha_l = \mathcal{C}^{1/2} \chi_l$

  $J^b(\alpha) = \Sigma_{l=1,L} \alpha_l^T \mathcal{C}^{-1} \alpha_l$, dim $\alpha$ = $N(N_c) \times L$ (or $K \times N_c \times L$ in 4D with mod. error)

  Use of a Double Preconditioned CG (DPCG) with $\mathcal{C}$ preconditioning.

  (Lorenc, 2003; Wang et al 2007; Wang 2010)

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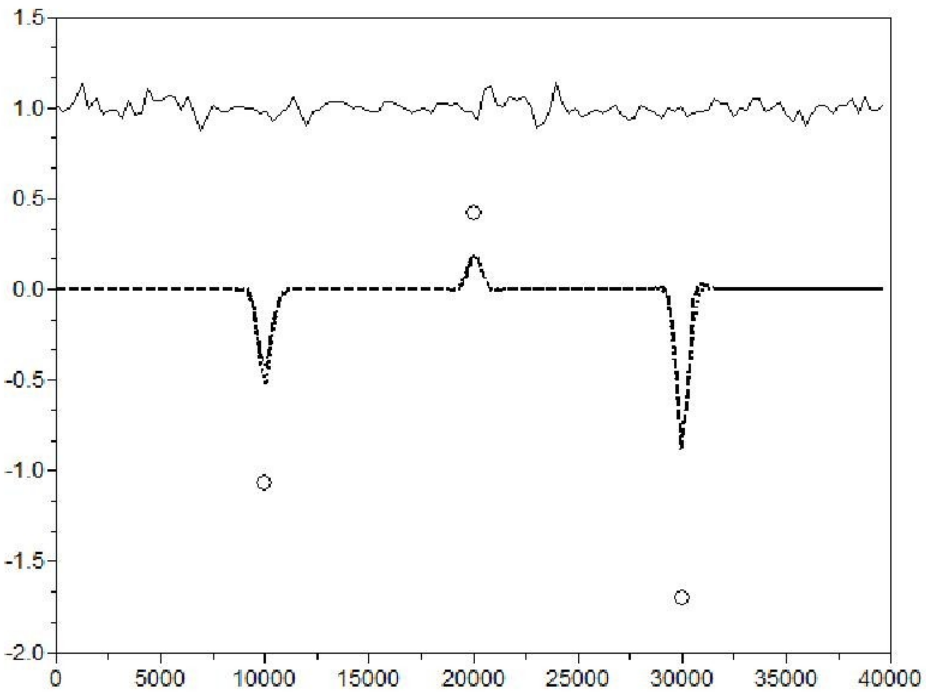
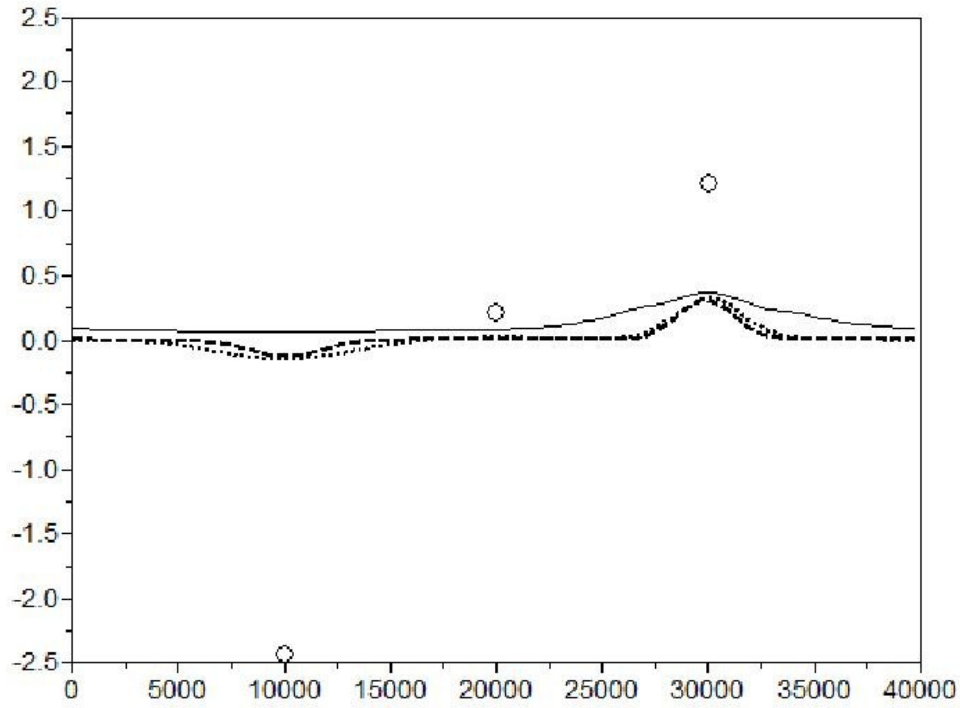
# Comparison of increments 4D-En-Var / 4D-Var (Burgers model; *paper in preparation*)




Observations at $t_0$

$\delta \mathbf{x}_0$ at $t_0$ :

- 4D-En-Var (dashed)
- 4D-Var (dotted)
- bg error square-root (solid)




Observations at $t_f$ ($t_0$+6h)

$\delta \mathbf{x}_f$ at $t_f$ :

- 4D-En-Var (dashed)
- 4D-Var (dotted)
- bg error square-root (solid)

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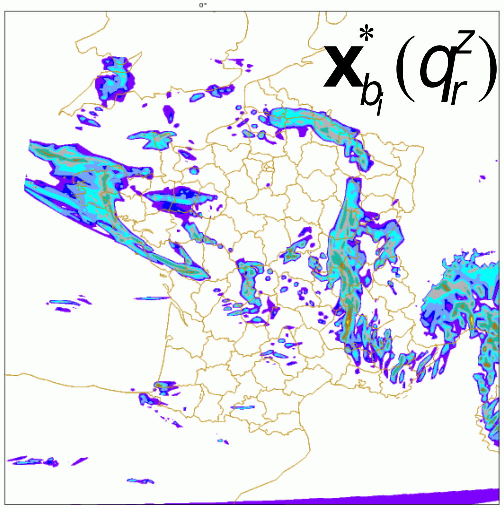
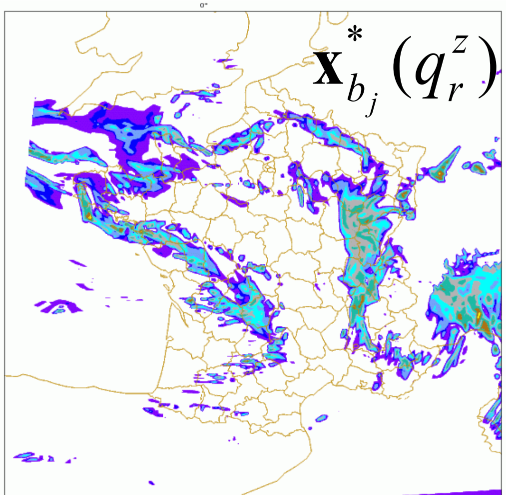
# Modeling B for specific meteorological phenomena

(Montmerle and Berre 2010)

Forecast errors are decomposed using features in the background perturbations that correspond to a particular meteorological phenomena.

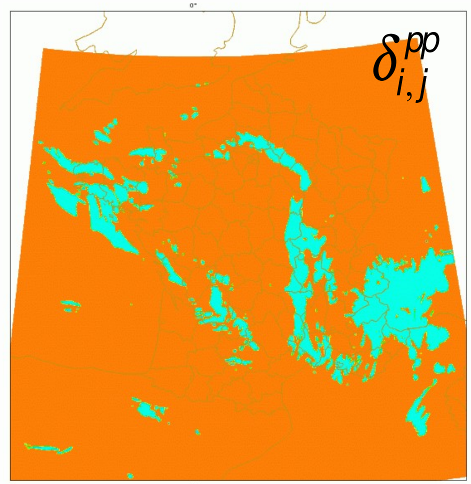


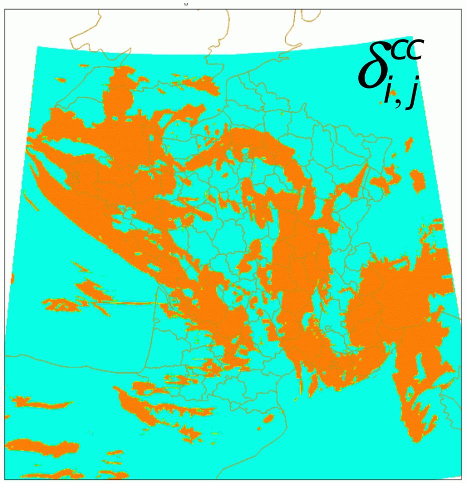




Example for precipitation

<———

Binary masks: **1 | 0**




*rain/rain* *non rainy/non rainy*

$$\varepsilon_{f_{ij}} = \mathbf{x}^*_{b_i} - \mathbf{x}^*_{b_j} \approx \left[G\delta^{pp}_{ij}\right]\varepsilon_{f_{ij}} + \left[G\delta^{cc}_{ij}\right]\varepsilon_{f_{ij}} + \left[G\delta^{cp}_{ij}\right]\varepsilon_{f_{ij}}$$

(G : Gaussian blur)

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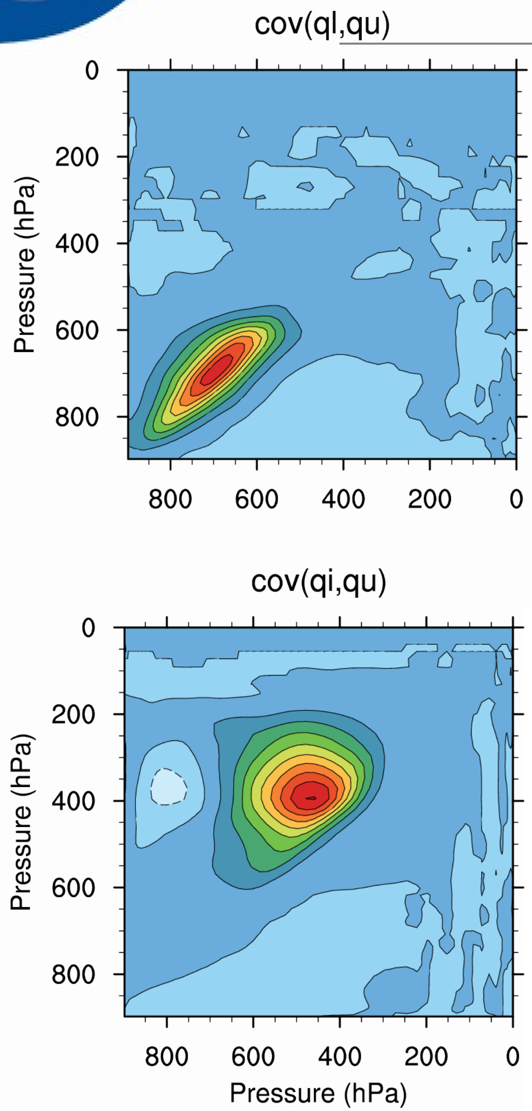
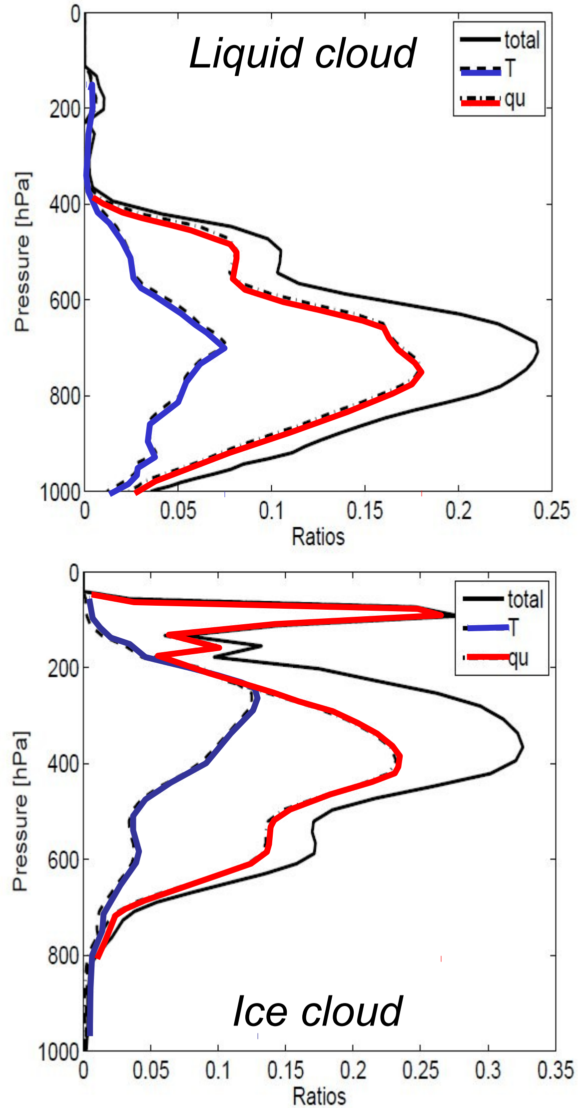
# Assimilation of cloudy radiances in a 1DVar: B




*Vertical covariances between qi, ql and the unbalanced humidity $q_u$*




*% of explained error variances for $q_l$ (top) and $q_i$ (bottom)*

**Computation of background error covariances for all hydrometeors in clouds:**

A mask-based method similar to Michel et al. (2011) is used, along with an extension of $\mathbf{K_p}$:

$$\begin{cases}\delta T = \delta T \\ \delta q = T_0 \delta T + \delta q_u \\ \delta q^{\alpha} = T_1 \delta T + T_2 \delta q_u + \delta q_u^{\alpha}\end{cases}$$

$$\alpha \in \{l, i, r, s\}$$

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# Assimilation of cloudy radiances in a 1DVar

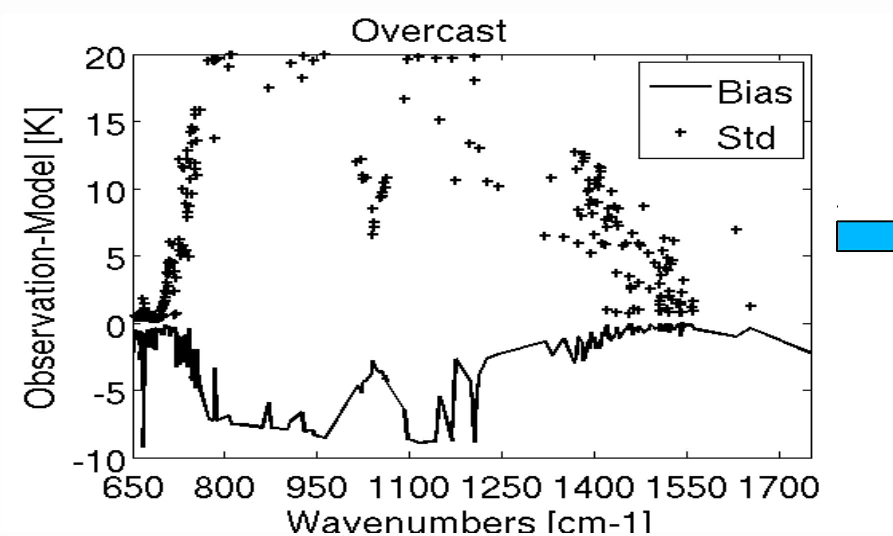
Martinet et al. (2012)

**Problematic:** Non-Gaussian innovations due to wrong location of simulated structures and model deficiencies

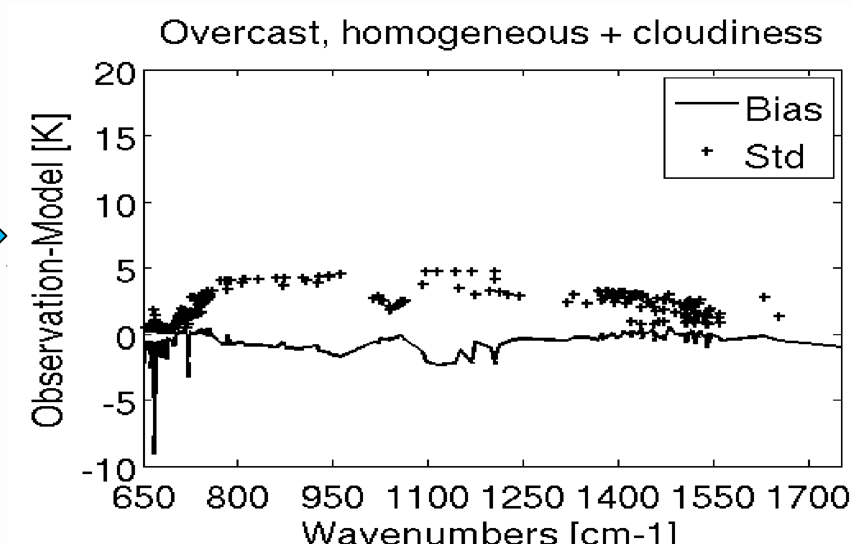
⇒ **Simulation of IASI radiances using profiles of ql and qi**. Modelling of multi-layer clouds and cloud scattering with RTTOV-CLD.

⇒ **Selection of homogeneous overcast scenes** from a database of profiles extracted from AROME forecasts by comparing simulated and observed AVHRR radiances co-located with the IASI field of view

*Raw innovations*




*Innovations after screening*

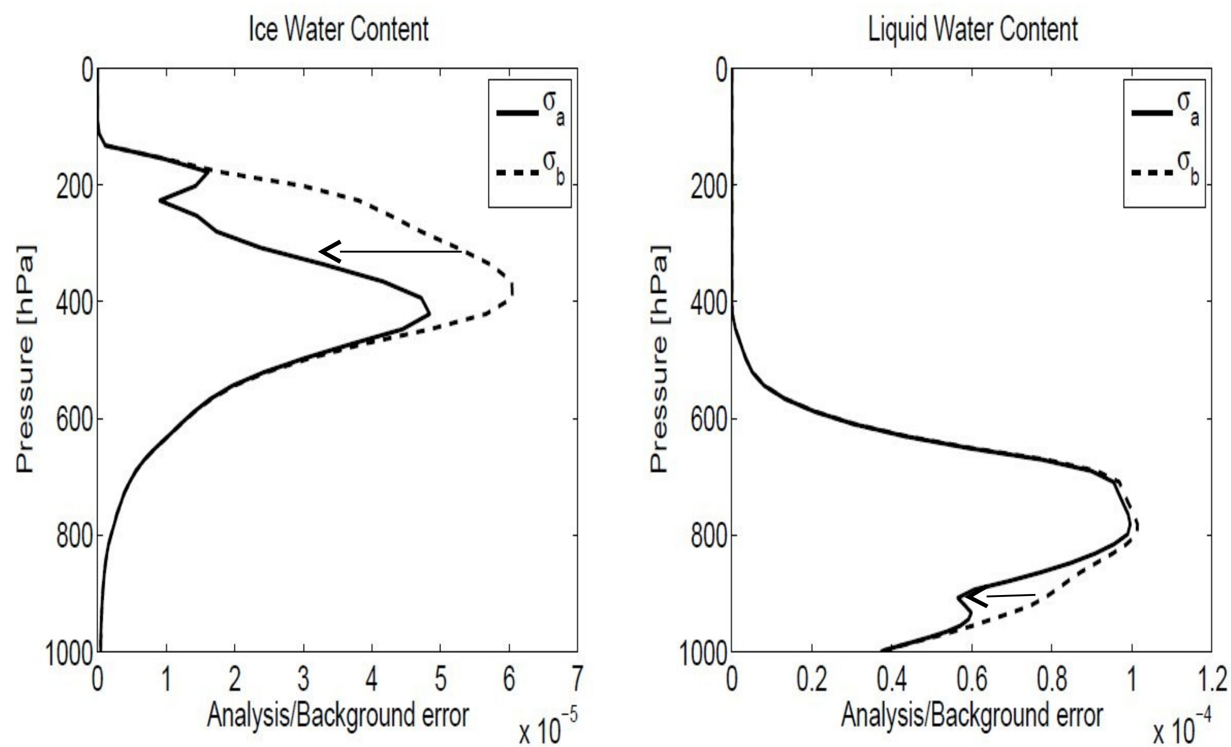


# Assimilation of cloudy radiances in a 1DVar: stats of increments

**Assimilation of IASI cloudy radiances**

$q_l$ and $q_i$ have been added to the state vector of a1DVar, along with T and q

*Reduction of background error variances for selections of high opaque cloud (left) and low liquid cloud (right)*




⇒Error stdevs are reduced for $q_l$ and $q_i$ (same as for $T$ and $q$ - not shown -), increments are coherently balanced for all variables.

Martinet et al. (2012)

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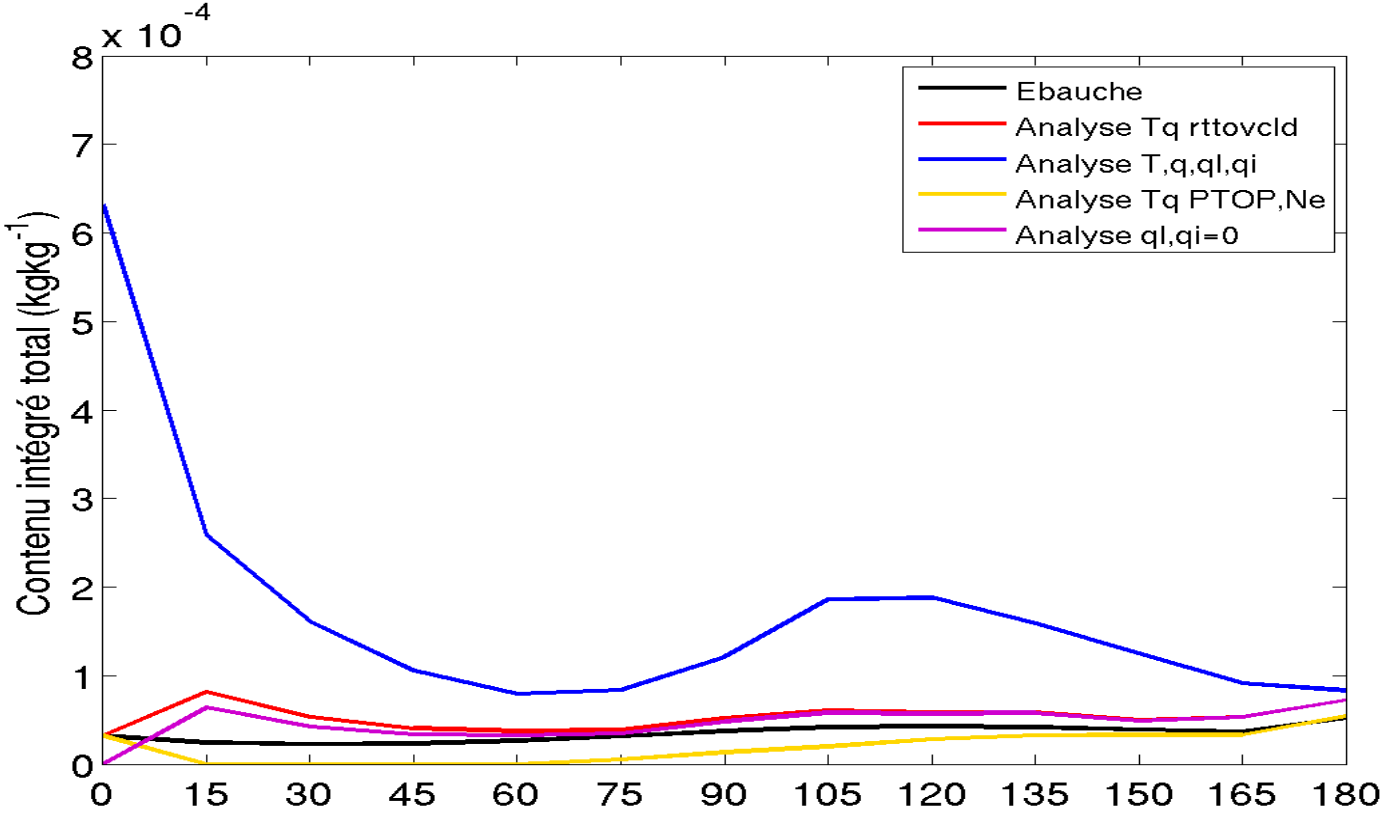
# Assimilation of cloudy radiances in a 1DVar: impact in forecast

## Evolution of analyzed profiles using AROME 1D

Example for low semi-transparent ice clouds:




*Time evolution of integrated ice cloud contents (min)*

⇒ Thanks to the multivariate relationships and despite the spin-down, integrated contents keep values greater than those forecasted by the background and by other assimilation methods up to 3h

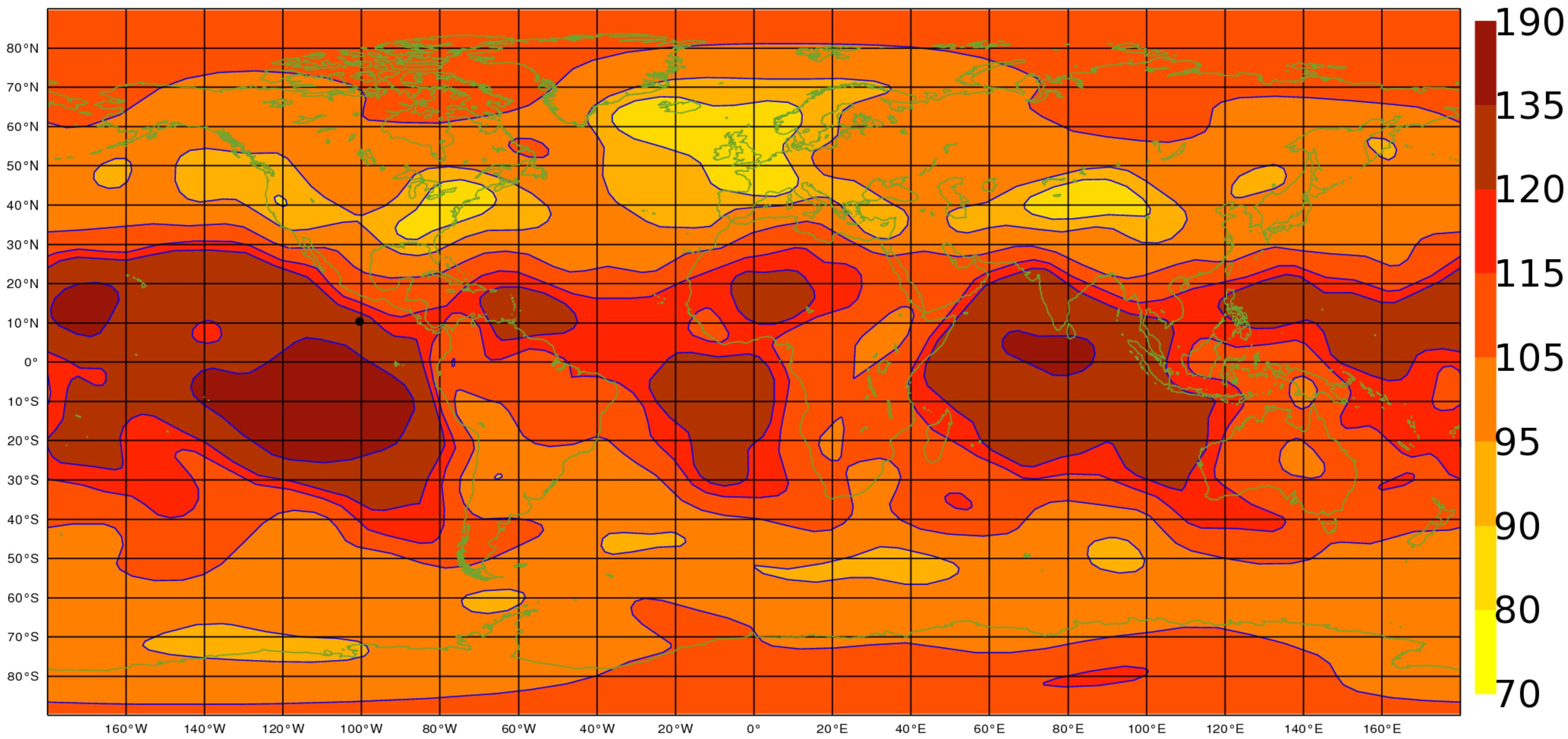
# Some concluding items

- Wavelets in Arpège 4D-VAR: presently tested in E-suite
- Heterogeneous B: rain/no-rain & radar assim (Montmerle, 2010), fog/no fog (Ménétrier & Montmerle, 2012); implementation in official codes on hold
- Other Arome B matrix aspects (Yann Michel):
  - Vertical deformation
  - Displacement error (PhD work just started)
- Implication in OOPS: actively take part in implementation of 4D-En-VAR (one solution implemented for L96 & QG models)

# Recent evolutions and plans for (Arpège) EnDA

- Model error through inflation of forecast perturbations (2012).
- Flow-dependent correlations, with wavelet spatial filtering (2013).
- Increase of ensemble size (~ 24 members, 2014).
- Towards 4D-En-Var.
- Plans to install an Arome EnDA (AEARO) in link with EPS (PEARO)

# 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, and also Fisher 2003,
Deckmyn and Berre 2005, Pannekoucke et al 2007)

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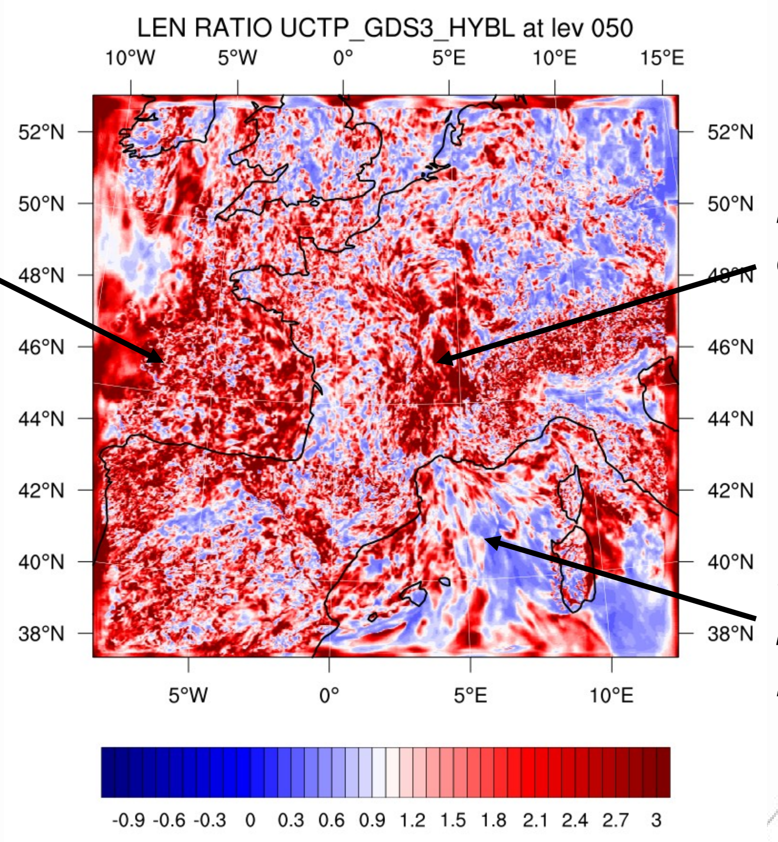
# Vertical deformation for Jb in AROME

- A vertical deformation can be added to the Jb in AROME
- It can be estimated over a small ensemble (AEARO with 6 members) despite strong sampling noise, with spatial filtering
- References: Michel (2012 a,b)

*Larger vertical lengthscale due to coupling*




*Larger vertical lengthscale in convective precipitation*

*Smaller vertical lengthscale in the inflow over the Mediterranean (Hymex case)*

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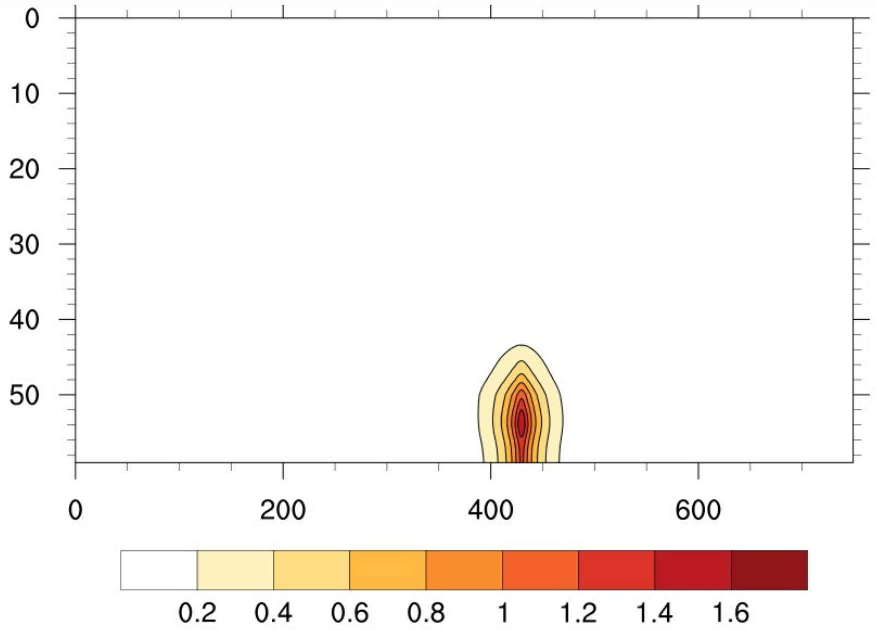
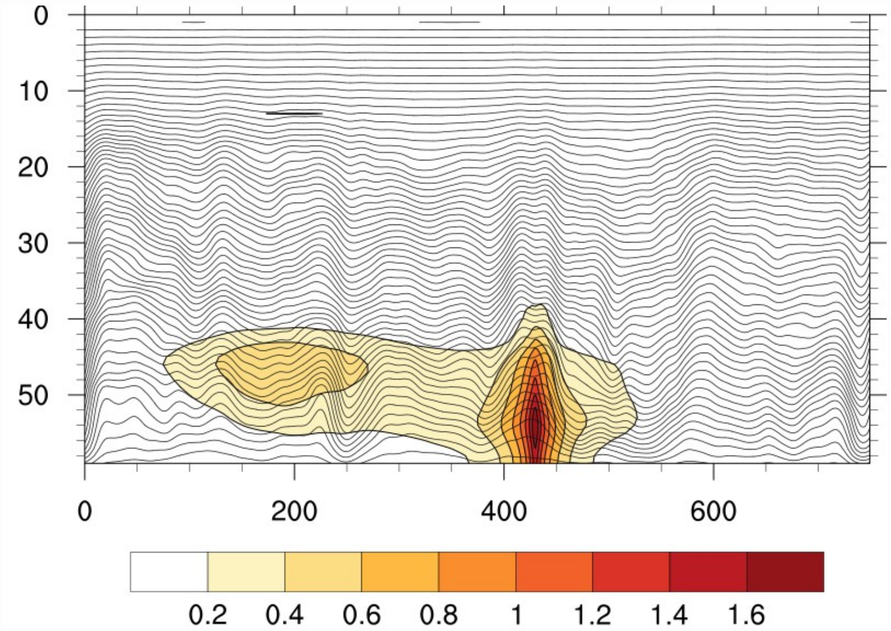
# Vertical deformation for the in AROME

- Test with single obs. shows interaction with the balance (shown: T)
- Compact support formulation (following V. Guidard & C. Fischer) helps
- Further work concerns 3D deformation => post-doc in GMAP (J. Beezley)




*Original Jb*




*With vertical deformation (contours)*

- þakka þér fyrir athygli þína