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Correlated interchannel observation error statistics for radiances: estimation and impact in a near operational context at Environment Canada

Second Symposium on the Joint Center for Satellite Data Assimilation

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Presentation Outline

- Position of the problem
- Desroziers diagnostic:
  - Description
  - Limitations
  - Sample results:
    - Correlations
    - Variances
- Data assimilation experiments
- Conclusion, perspectives

Description of the problem

- Variational data assimilation is based on the minimization of the typical cost function:

$$J_{\mathrm{var}}(\mathbf{x}) = \frac{1}{2}\left\{ \underbrace{(\mathbf{x}-\mathbf{x_b})^{t}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b})}_{\text{Background term}} + \underbrace{(\mathbf{H}(\mathbf{x})-\mathbf{y})^{t}\mathbf{R}^{-1}(\mathbf{H}(\mathbf{x})-\mathbf{y})}_{\text{Observation term}} \right\}$$

- Covariance matrices **B** and **R** are key ingredients of the problem
- **R** matrix for radiances is the topic of this presentation

Description of the problem

- For a long time a diagonal **R** matrix was often assumed in operational data assimilation systems because:
  - Easy and inexpensive implementation
  - Easy tuning and inverse
  - Difficult to estimate the full **R.**
  - Good conditioning needed for $\mathbf{R}^{-1}$
- Correlations were accounted for indirectly using variance inflation and data thinning
- Interchannel correlations are significant for example for water vapour sensitive channels of hyperspectral IR sounders like AIRS, IASI and CrIS (eg. Garand et al., Bormann et al.)
- Weston et al. (UKmet) demonstrated some positive impact of including interchannel correlation for the IASI instrument
- In this work we don`t yet consider spatial correlations

Desroziers diagnostic: description

- The approach was introduced in Desroziers et al. 2005. It allows for a simple evaluation of the **R** matrix using assimilation experiments by-products :

$$\tilde{\mathbf{R}} = \left\langle \left(\mathbf{y} - \mathbf{H}(\mathbf{x_a})\right)\left(\mathbf{y} - \mathbf{H}(\mathbf{x_b})\right)^t \right\rangle$$

- Bormann et al. demonstrated that this method gives similar results as other methods

Desroziers diagnostic: possible limitations

- It is based on several assumptions:
  - Unbiased observations (*radiances observations are bias corrected with a necessarily imperfect approach*).
  - Uncorrelated Background and Observation errors (*this approximation is fundamental to separate the cost function in two independents parts. However, the work of Gorin et al. 2011 demonstrated that it may not be always valid for radiances*)
  - Perfectly specified Background error covariance matrix **B.** *(our **B** matrix is imperfect. It was nevertheless significantly improved with Ensemble variational approach. Work is still ongoing in this domain)*
- However, the correlation structure of the matrices looks realistic and is similar to the one diagnosed using other methods. We anticipate the need to tune Desroziers variances.

Desroziers diagnostic: results

- Desroziers diagnostic was applied to 21 days of quality controlled and bias corrected radiances assimilated in a reference cycle.
- The resulting Desroziers matrix was symmetrized:

$$\tilde{\mathbf{R}}_{sym} = \frac{1}{2}\left(\tilde{\mathbf{R}} + \tilde{\mathbf{R}}^{t}\right)$$

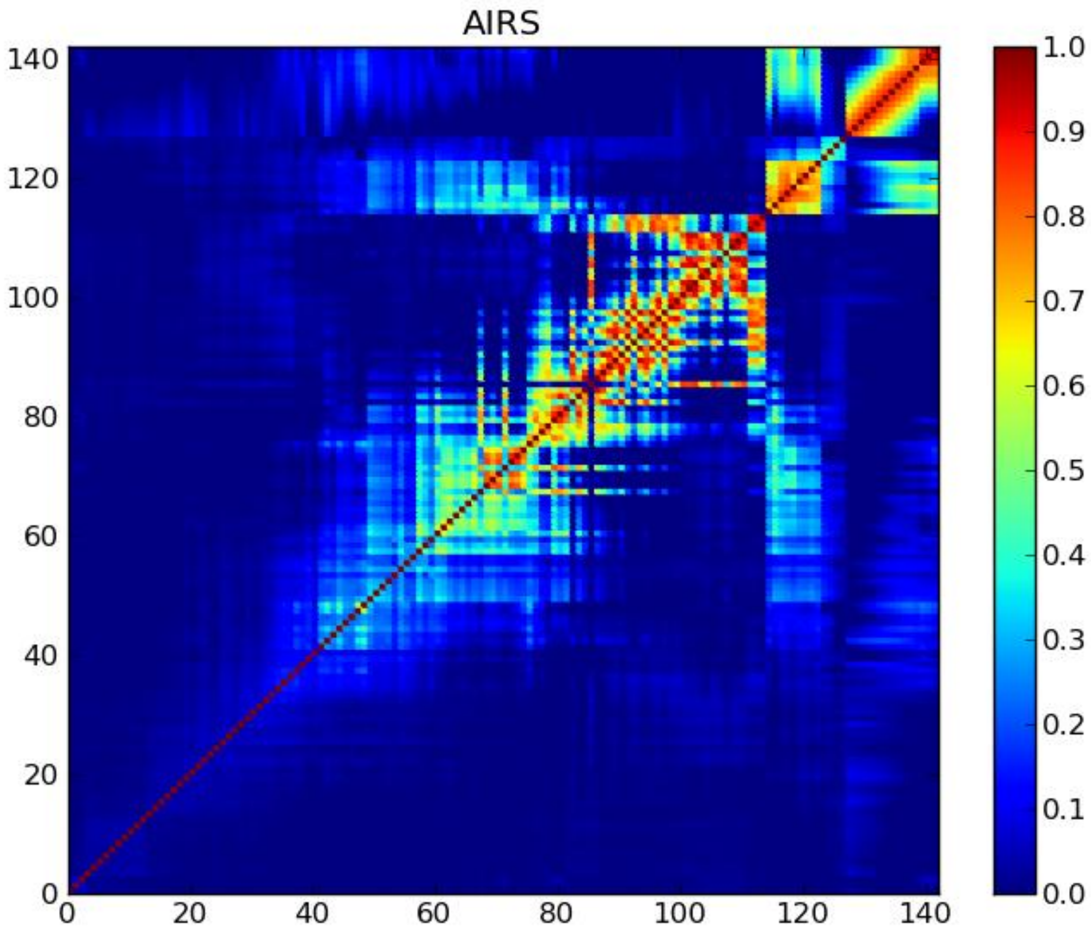
- As customary, we use the decomposition of **R** in correlation **C** and variances σ^2:

$$\tilde{\mathbf{R}}_{sym} = diag(\boldsymbol{\sigma})\mathbf{C}diag(\boldsymbol{\sigma})$$

Sample diagnosed correlations

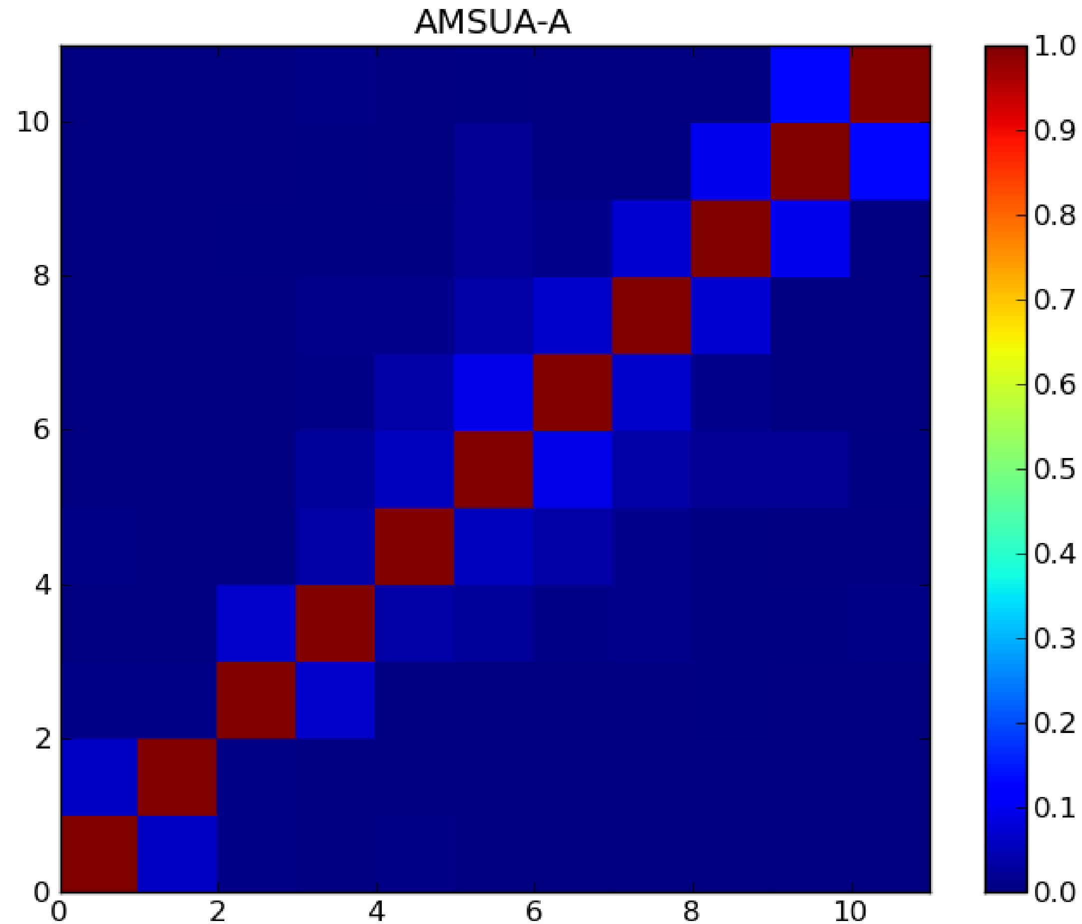
Correlation structure of the symmetrized R for the 142 AIRS channels selected for assimilation

It was checked that this matrix is positive definite

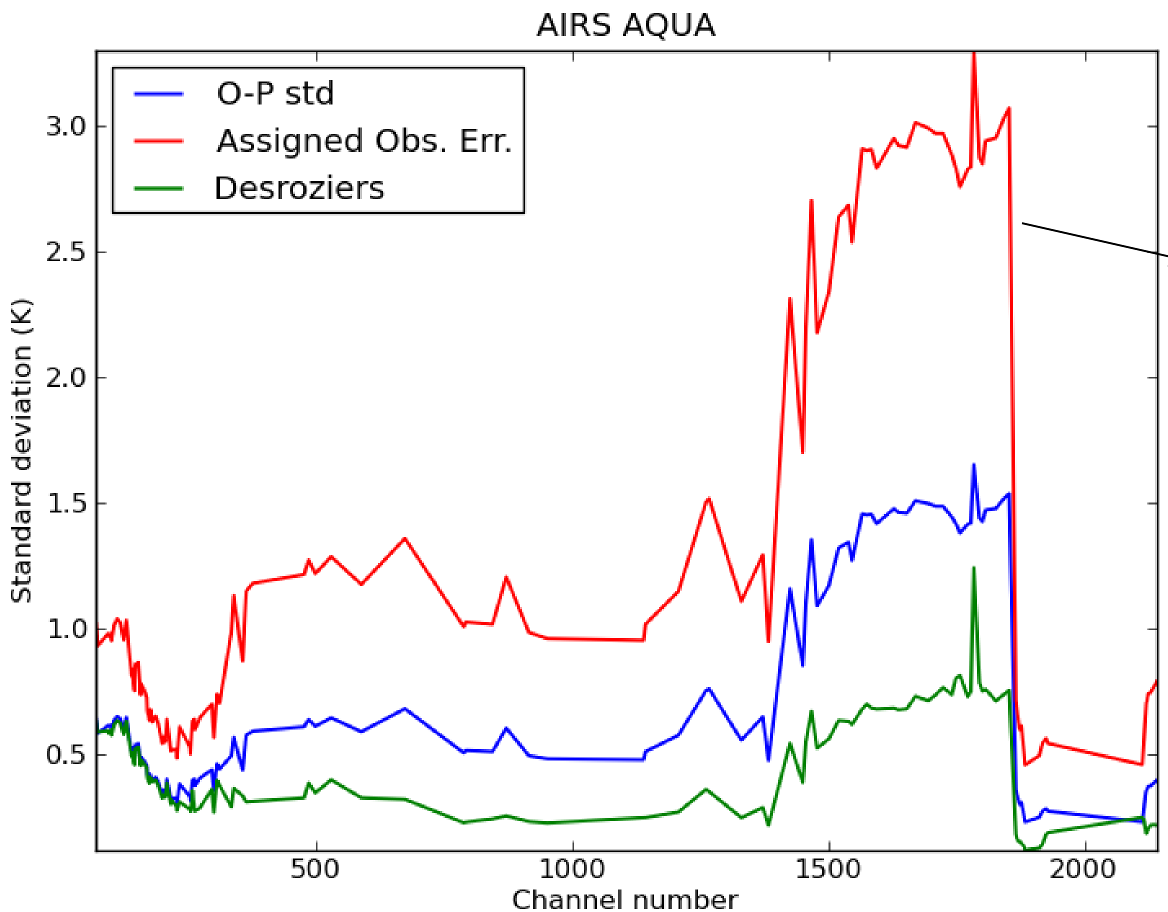


Sample diagnosed correlations

Correlation structure of the symmetrized R for the 11 AMSU-A channels selected for assimilation



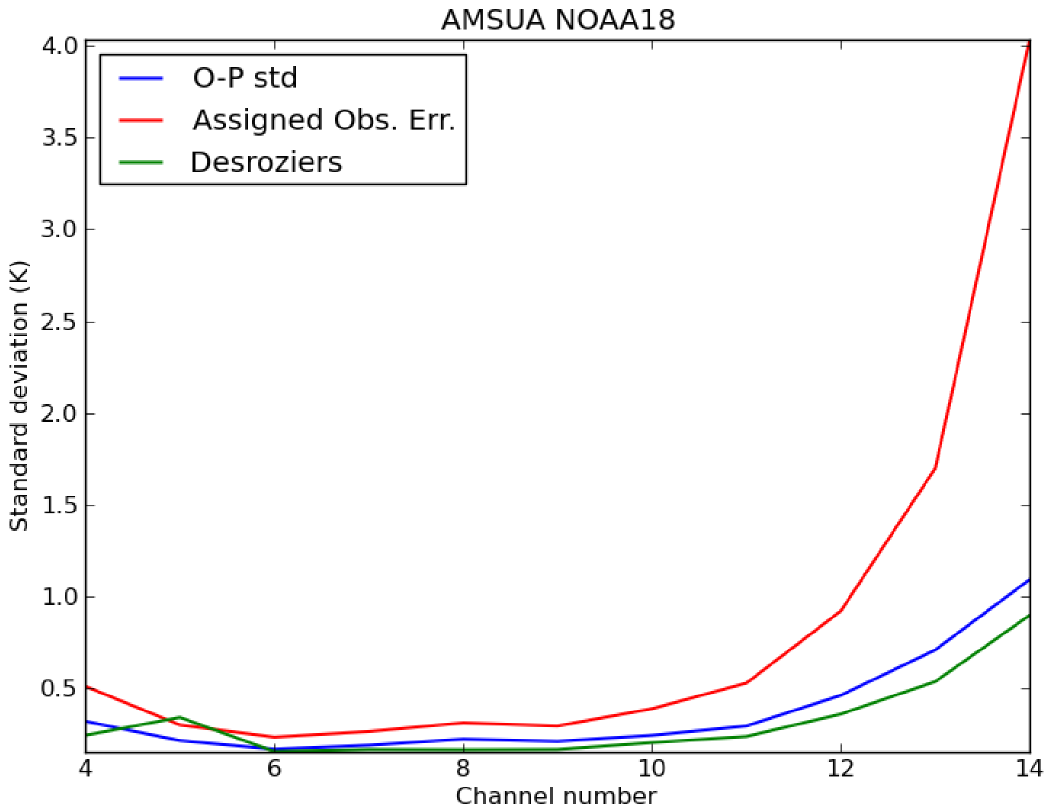
Sample diagnosed variances



Significant inflation above std(O-P)

Desroziers estimate well below std(O-P)

Sample diagnosed variances



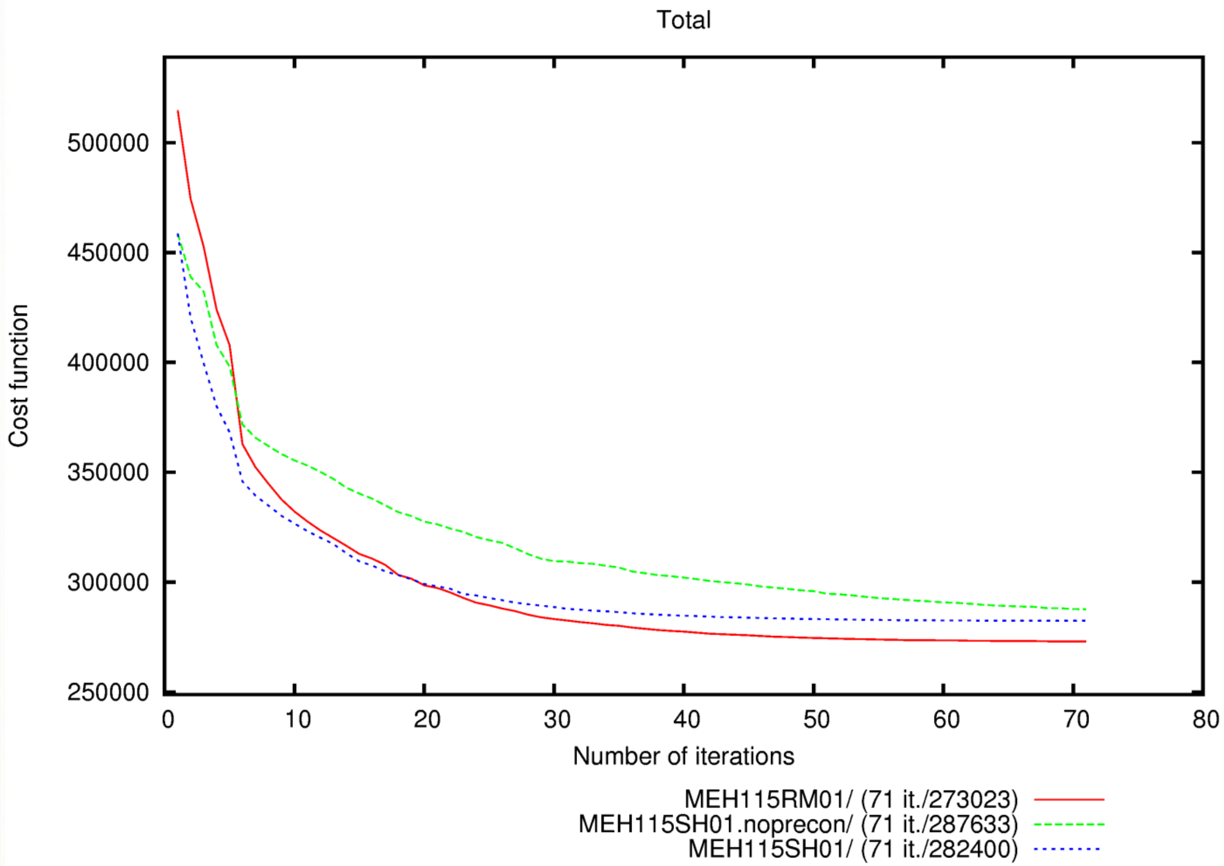
Large assigned errors for ch 13-14
To avoid temperature drift near model top

It is anticipated that, in practice, Desroziers error estimates will need some level of inflation

Assimilation experiments

- The Ensemble variational (EnVar) assimilation code (to be operational end of 2014) was modified to enable the use of non diagonal R matrices for all radiances
- The supplementary cost related to the use of non-diagonal matrices was surprisingly small (of the order of 3% in terms of CPU time)
- Variational quality control was deactivated for radiances
- A first experiment was launched using diagnosed correlations and operational variances. With a proper minimization preconditioning the convergence was good.

First analysis: Cost function minimization

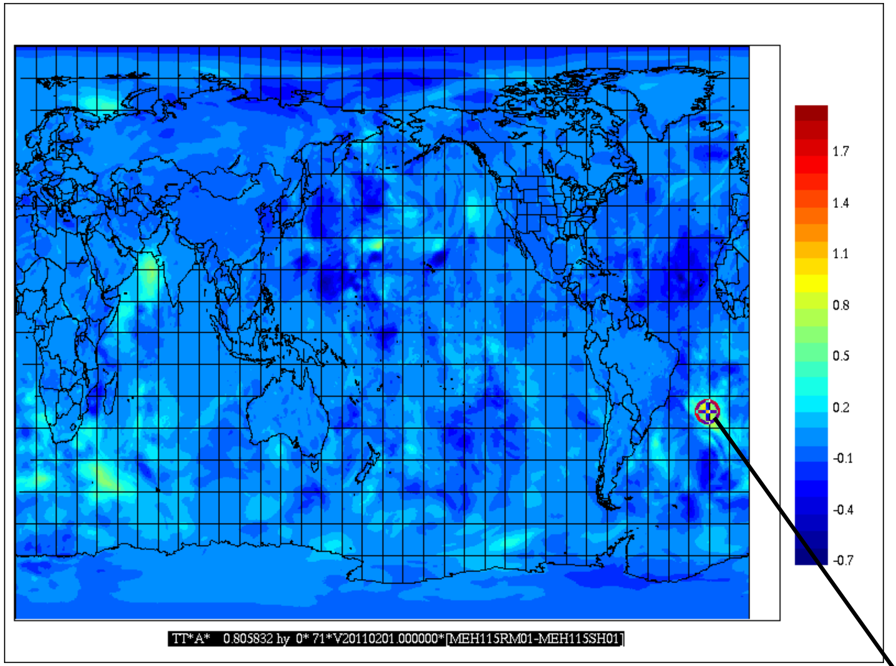


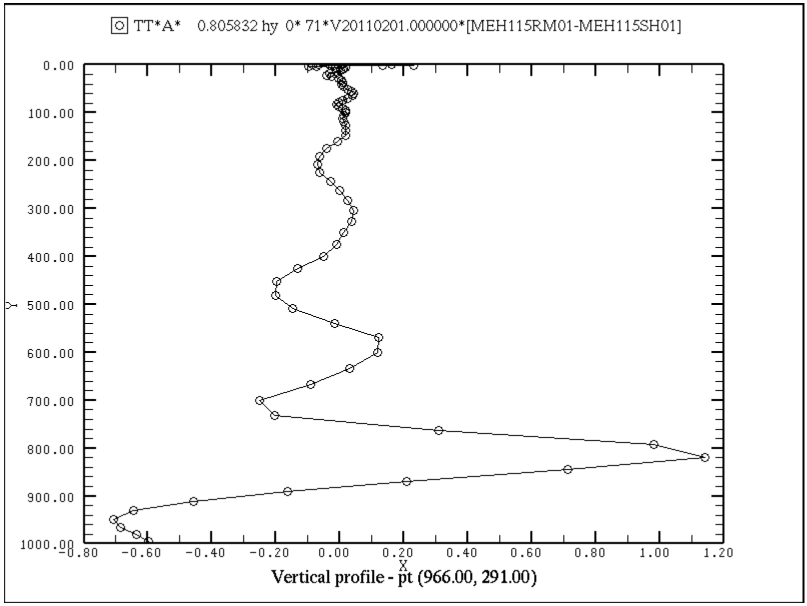
Full R matrix
and No preconditioning

With preconditioning:
- Diagonal R
- Full R matrix

Full matrix: Desroziers error correlation is used, retaining operational errors on diagonal

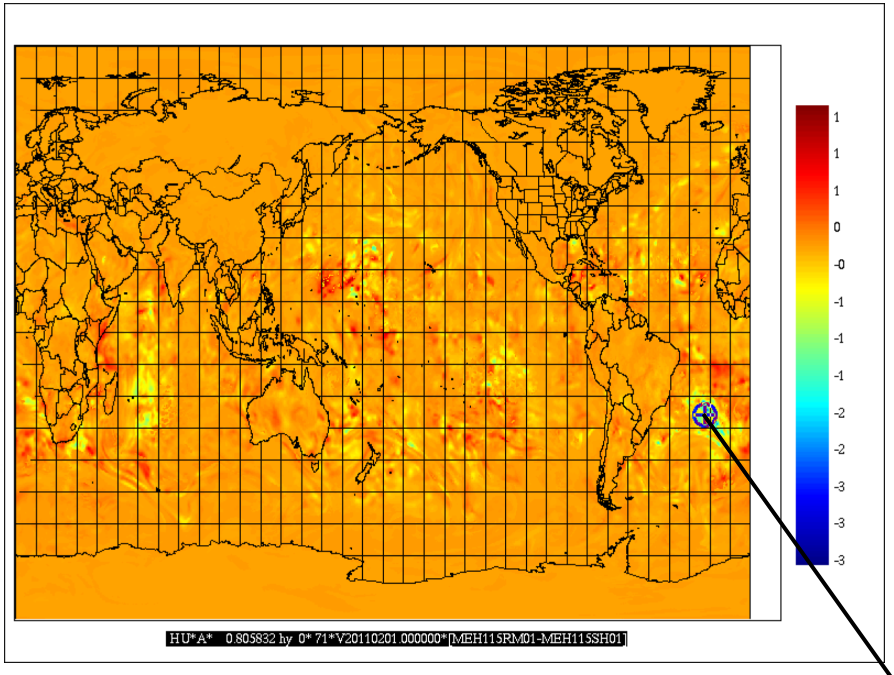
First analysis: impact on temperature field

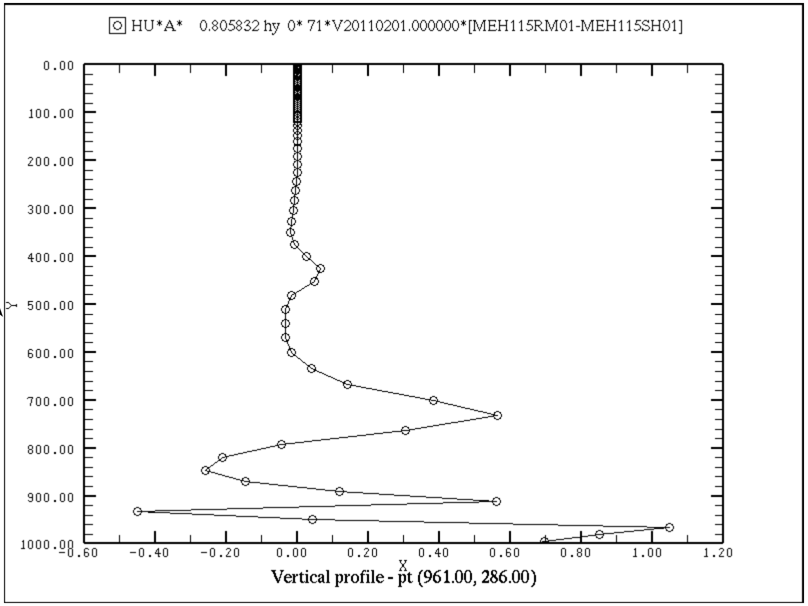




Temperature (K) analyses differences (control-experiment) around 800 hPa

First analysis: impact on humidity field





Specific humidity (g/kg) analyses differences (control-experiment) around 800 hPa

Conclusion , Perspectives

- Complete a one-month assimilation
- Due to correlations, weight of radiances in the analysis decreased, if same errors are assigned on the diagonal.
- Another experiment with tuned variances to keep radiance weight at the same level as in the future operational system is planned. Various tuning strategies are possible to achieve this goal.
- Impact of correlations on the vertical structure of analysis increments will be evaluated.
- From a technical point of view, our system is now able to account for interchannel correlations. This is an important step to optimize radiance thinning.

Reference list

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- Desroziers, G., Berre, L., Chapnik, B. and Poli, P. (2005), Diagnosis of observation, background and analysis-error statistics in observation space. *Q.J.R. Meteorol. Soc.*, **131**: 3385–3396.
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- Gorin, Vadim E., Mikhail D. Tsyrulnikov, 2011: Estimation of Multivariate Observation-Error Statistics for AMSU-A Data. *Mon. Wea. Rev.*, **139**, 3765–3780.