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Assimilation experiments using non-diagonal radiance observation error covariances at Environment Canada

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Introduction

Model background and observation error statistics are key inputs of modern data assimilation systems used in Numerical Weather Prediction. For a long time, it was often assumed in operational context that the observation covariance error matrix is diagonal. The neglected error correlations were, in principle, accounted for indirectly via for example data thinning or error inflation. In the case of radiances from vertical sounders, the advent of hyperspectral infrared sounders such as AIRS (Atmospheric Infrared Sounder), IASI (Infrared Atmospheric Sounding Interferometer) and the recently launched CrIS (Cross-track Infrared Sounder) with their thousands of channels represented an important challenge for the data assimilation community. Recently, inter-channel observation error covariance matrices were estimated for these instruments by various authors (e.g. Garand et al. 2006, Bormann et al. 2010) using different methods which gave consistent results. The purpose of this study is first to estimate radiances observations error statistics including inter-channel correlations for all currently assimilated instruments (microwave and infrared) and then to evaluate the impact of their use in a near operational context in Environment Canada's upcoming Ensemble-variational (EnVar) global assimilation system.

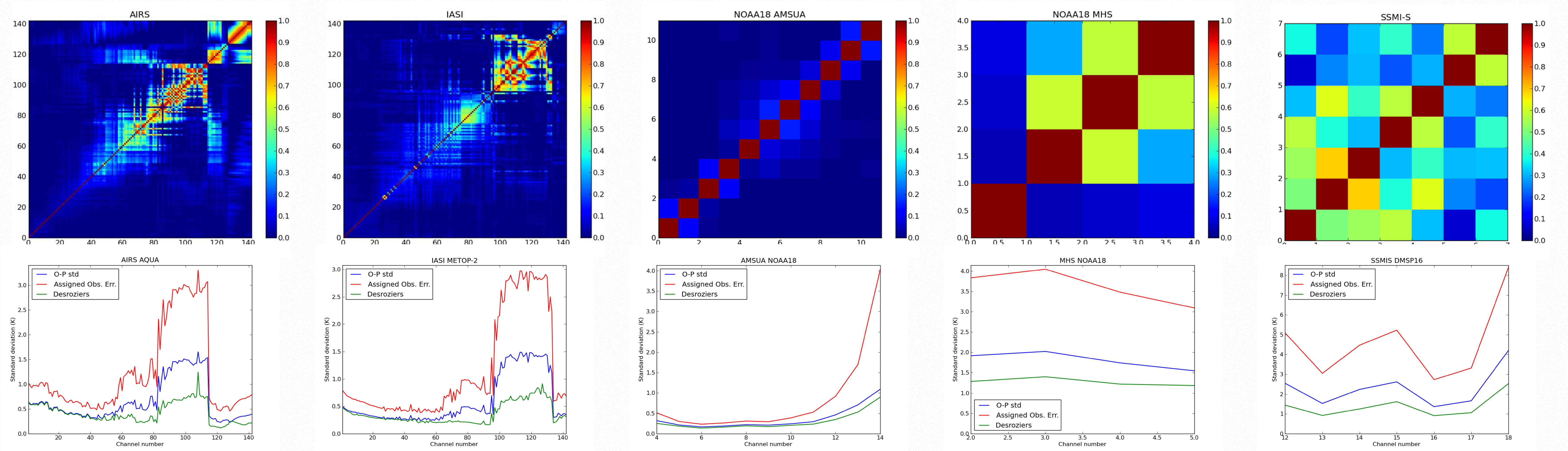
Covariance estimation

In this study, the observation error covariance matrix is based on Desroziers diagnostic (Desroziers 2005) obtained a posteriori from (O-F) and (O-A) statistics in a cycle:

$$\tilde{\mathbf{R}} = \left\langle (\mathbf{y} - \mathbf{H}(\mathbf{x}_a))(\mathbf{y} - \mathbf{H}(\mathbf{x}_b))^t \right\rangle$$

where **y** is the observation vector, $\mathbf{x}_b$ is the assimilation background model state, $\mathbf{x}_a$ is the analyzed model field, **H** is the observation operator (here RTTOV-10 fast radiative transfer model), and **<…>** stands for averaging. Simplifying assumptions include: unbiased observations, no correlation between background and observation error and a realistic background error covariance matrix **B**. This approach was chosen because it is simple to implement. Also the work of Bormann et al. 2010 demonstrated that it gives qualitatively similar results to more complicated methods. We estimated the covariances using 21 days of quality controlled and bias corrected brightness temperatures from a reference cycle. The diagnosed matrices were symmetrized and spitted in variance and correlation matrices:

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



The diagonal elements of the diagnosed Desroziers variances are by construction lower than the O-F values. Since in practice it is found that inflated errors are required, it decided to start with operational diagonal values and to use the Desroziers correlation to define off-diagonal terms.

Assimilation system description

- It is a prototype of the experimental assimilation system to be implemented in fall 2014:
  - 4D-EnVar system (4D assimilation system without tangent linear and forecast model adjoint)
  - The **B** matrix used results from the blending of an homogeneous isotropic matrix obtained using the NMC method with the covariance matrix of the Ensemble Kalmann Filter assimilation system (192 members on a 600x300 vertical grid with 72 staggered vertical levels and a model top at 2 hPa)
- 600x300 Gaussian analysis horizontal grid.
- The assimilation system and the Global Environmental Multiscale (GEM) version 4 forecast model share the same vertical coordinate: 80 levels with a top at 0.1 hPa
- 15 km Yin-Yang forecast model horizontal grid
- To save time, all the experiments presented here were performed offline without two-way coupling between the EnVar and the EnKF system

Assimilated Observations

- Surface (SYNOP/SHIP/BUOYS/DRIFTER)
- Radiosondes
- Aircrafts

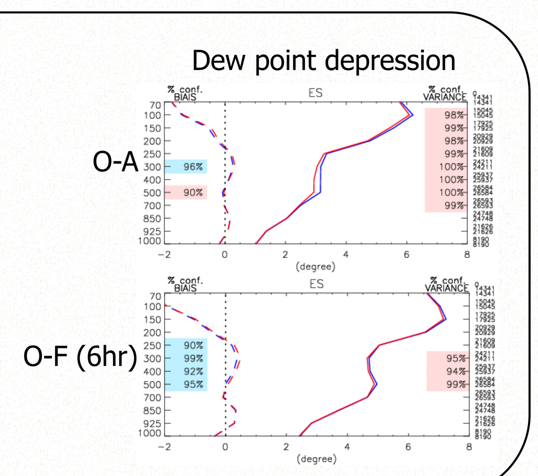
- Satellite winds (geostationary imagers +MODIS)
- GPS radio occultations (COSMIC,GRACE)
- Scatterometers: Quickscat

- Microwave radiances:
  - AMSU-A from NOAA (15,16, 18 and 19), AQUA and METOP-2 (11 channels)
  - AMSU-B and MHS from NOAA (16, 18 and 19) and METOP-2 platforms (4 chan.)
  - SSMI-S from DMSP-16 (7 chan.)

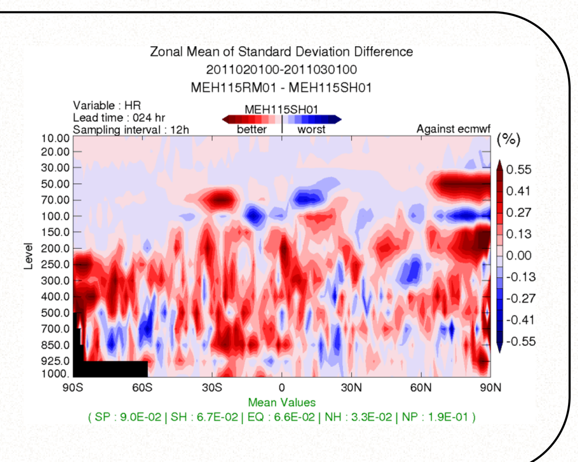
- Infrared radiances:
  - AIRS from AQUA (142 channels)
  - IASI from METOP (142 channels)
  - Geostationary imagers (1 H_2O channel): GOES-11,METEOSAT-7 and MSG-2

Verification scores

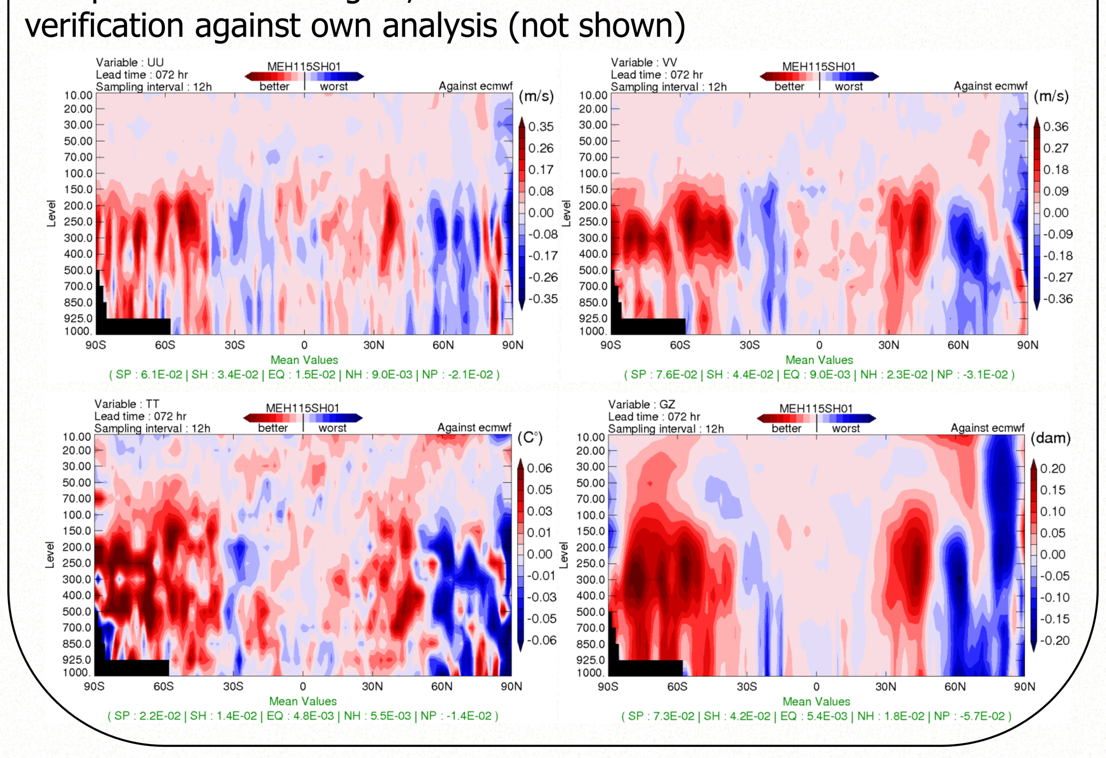
Use of the non-diagonal R matrix leads to a better fit to dew point depression observations from radiosondes as it could be anticipated from the decrease of the weight of water vapor sensitive channels (from AIRS, IASI, AMSU-B and SSMI-S) which exhibit significant inter-channel observation error correlations.



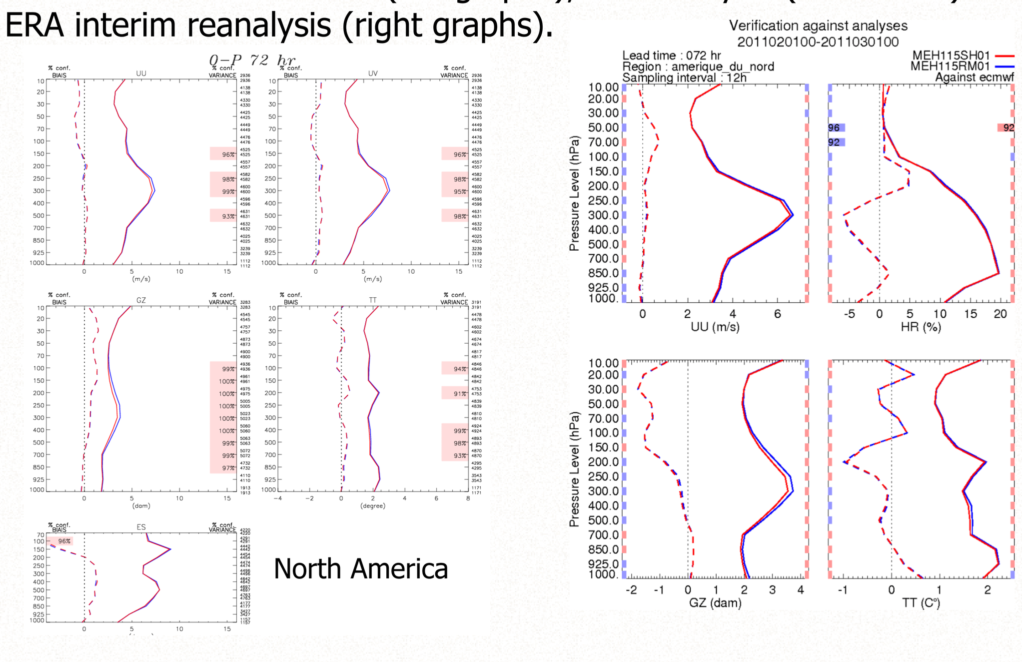
Relative humidity 24 hours forecasts verifications against ERA interim reanalysis demonstrate an improvement with the non diagonal R matrix. Similar results (not shown) are obtained with verification against own analysis.



Verifications of 72 hours forecasts of winds, geopotential height and temperature against ERA interim reanalysis demonstrated that the impact of using a non diagonal R matrix in our experiment is positive except in the arctic. Again, similar results were obtained with verification against own analysis (not shown)



In north America, significantly positive impact of using a non diagonal R matrix on 72 hours forecasts was demonstrated both against radiosondes observations (left graphs), own analysis (not shown) and ERA interim reanalysis (right graphs).



Conclusion and final remarks

The assimilation code that will be used in Environment Canada future operational 4D-EnVar was modified to be able to use non diagonal observation error covariance matrices to account for radiances inter-channel error correlations. The computing cost relative increase associated to this enhancement is of the order of only 3%. Correlations matrices were estimated for all assimilated radiances from statistics of a reference assimilation cycle using the Desroziers diagnostic. As diagnosed variances are small compared to those to be used operationally with a diagonal matrix, it was decided to perform a first assimilation experiment with a non diagonal observation error using the diagnosed correlations and operational variances. To obtain a good cost function minimization convergence it was necessary to re-compute an estimate of the Hessian matrix used by the M1QN3 quasi-Newton minimization algorithm for preconditioning. With a proper preconditioning no convergence problem was observed during the cost function minimization. The comparison between the control and the experiment using a non diagonal R matrix for radiances made during one month of assimilation was mostly favorable to the experiment both against radiosonde observations and analysis. Some difficulties were nevertheless observed in the Arctic and will be investigated. Additional tuning of the variances is planned, keeping Desroziers's correlations, and modifying the level of error inflation.