Accounting for IASI Inter-Channel Correlated Observation Errors in the GSI

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Introduction

Numerical weather prediction requires precise initial conditions to provide an accurate forecast. The true state of the atmosphere, which is unknown, can be estimated by combining observations with short range forecasts, or model background. This estimate, called the analysis, can then be used as an initial condition. Determining the analysis depends not only on the observations and background, but also on their errors.

At the National Center for Environmental Prediction (NCEP), data assimilation is executed with the Gridpoint Statistical Interpolation (GSI). IASI provides a wealth of observations and has proven to be extremely beneficial to numerical weather prediction. In the GSI, 616 IASI channels are used, 165 of which are actively assimilated. These channels include the longwave upper and lower temperature sounding channels, longwave window channels, and ozone channels. Inter-channel error correlations are not accounted for within the GSI, however they are suspected to exist. The purpose of this study is to ultimately improve the specification of observation errors in the operational GSI by improving their estimates and by properly accounting for these inter-channel error correlations.

Theory and Methods

The goal of data assimilation is to determine the analysis state $\mathbf{x}^a$ that minimizes a cost function

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}(\mathbf{y}^o - H(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}^o - H(\mathbf{x})) \qquad (1)$$

where $\mathbf{x}^b$ denotes the background state, $\mathbf{B}$ the background error covariance matrix, H the nonlinear observation operator, $\mathbf{y}^o$ the observations and $\mathbf{R}$ the observation error covariance matrix.

In current NCEP operations, $\mathbf{R}$ is assumed to be diagonal, and does not account for inter-channel correlations. To estimate the full $\mathbf{R}$, the Desroziers diagnostic is used. This method assumes that observation and background errors are uncorrelated and are perfectly specified in the analysis. For a pair of analysis and background departures (observation minus guess), denoted by A and B respectively, the error covariance is given by the expected value

$$\mathbf{R} = E[(A)^T B].$$

For channels r and c of IASI, this means that inter-channel error covariances can be estimated by computing

$$\mathbf{R}_{r,c} = \frac{1}{p}\sum_{k=1}^{p} A_{k,r}B_{k,c} - \frac{1}{p^2}\sum_{k=1}^{p} A_{k,r}\sum_{k=1}^{p} B_{k,c} \qquad (2)$$

where p denotes the size of a set of departure pairs.

Experimental Setup and Considerations

The Desroziers diagnostic in (2) is used to compute observation error covariance matrices for both IASI instruments. Here, departure pairs are made for observations that are actively assimilated and are within 60 minutes and 25 kilometers of one another. Furthermore, only observations that are over the sea and free of cloud contamination are used.

Correlation matrices computed from April 4, 2014 to May 8, 2014 are shown below. Both instruments exhibit minimal inter-channel correlations in the upper temperature channels. The window channels show stronger inter-channel correlations.

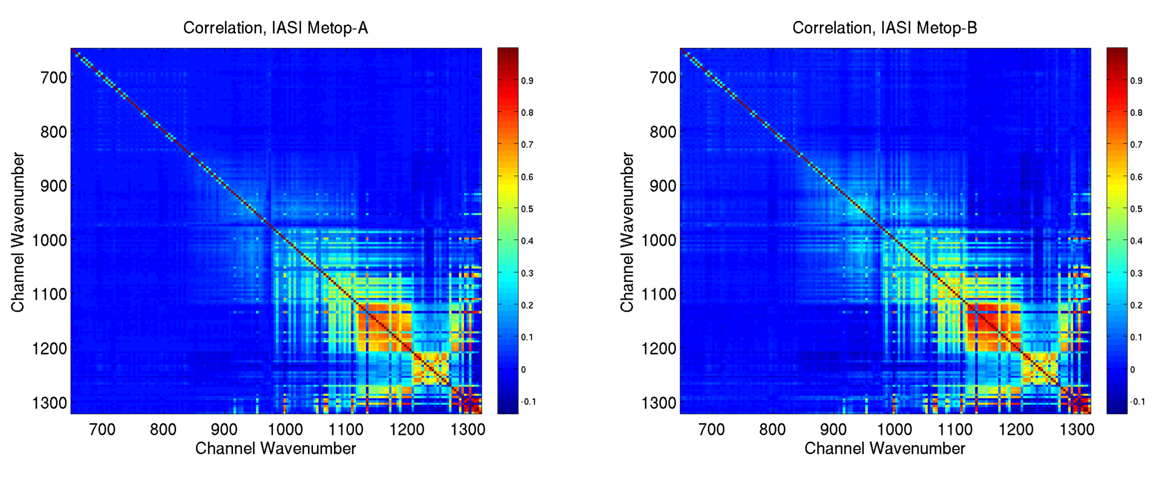

Figure 1: Observation error correlations for both IASI instruments.

The condition number of a matrix, K, is defined as the ratio of its largest eigenvalue to its smallest. Minimizing the cost function in (1) requires the computation of $\mathbf{R}^{-1}$ which can be expensive if $\mathbf{R}$ is poorly conditioned (K is large). The covariance matrices corresponding to the matrices above have condition number 587 and 567 respectively. To recondition $\mathbf{R}$ in these experiments, its diagonal is inflated by a small standard deviation σ:

$$\mathbf{R}_{r,r} = \left(\sqrt{\mathbf{R}_{r,r}} + \sigma\right)^2.$$

Here a value of $\sigma = 0.05$ is used, giving $\mathbf{R}$ a condition number of approximately 70.

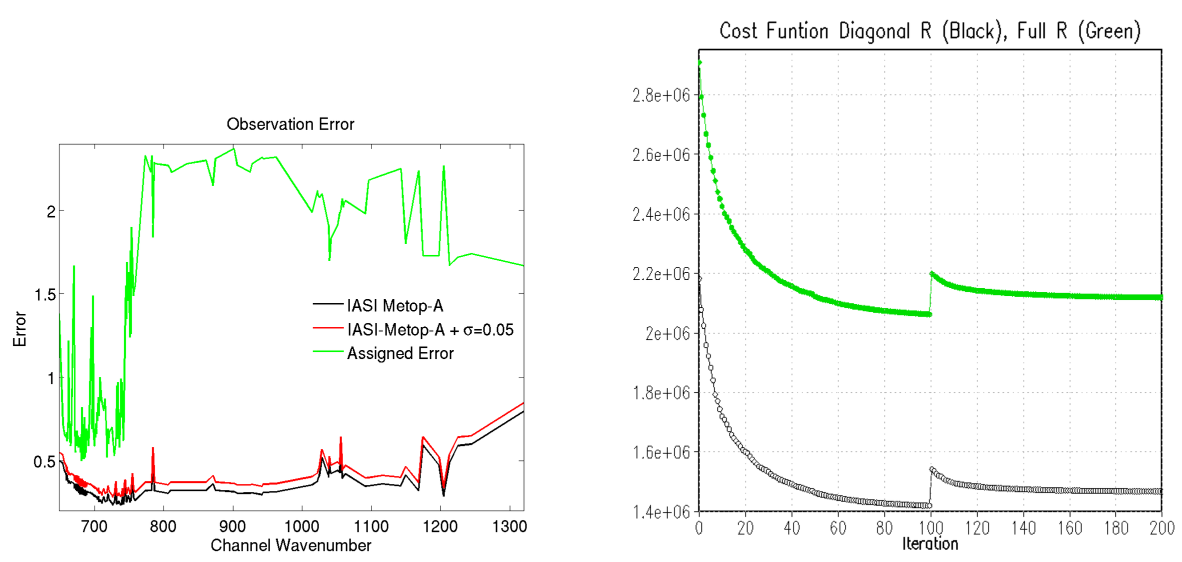

Figure 2: IASI observation errors determined from the Desroziers diagnostic and inflated values, compared to the prescribed observation errors (left) and the value of the cost function during the minimization using both the full error covariance matrix and the original prescribed errors (right).

Results

Full observation error covariances for IASI were used over the sea in a month long assimilation experiment using the Global Forecast System (GFS).

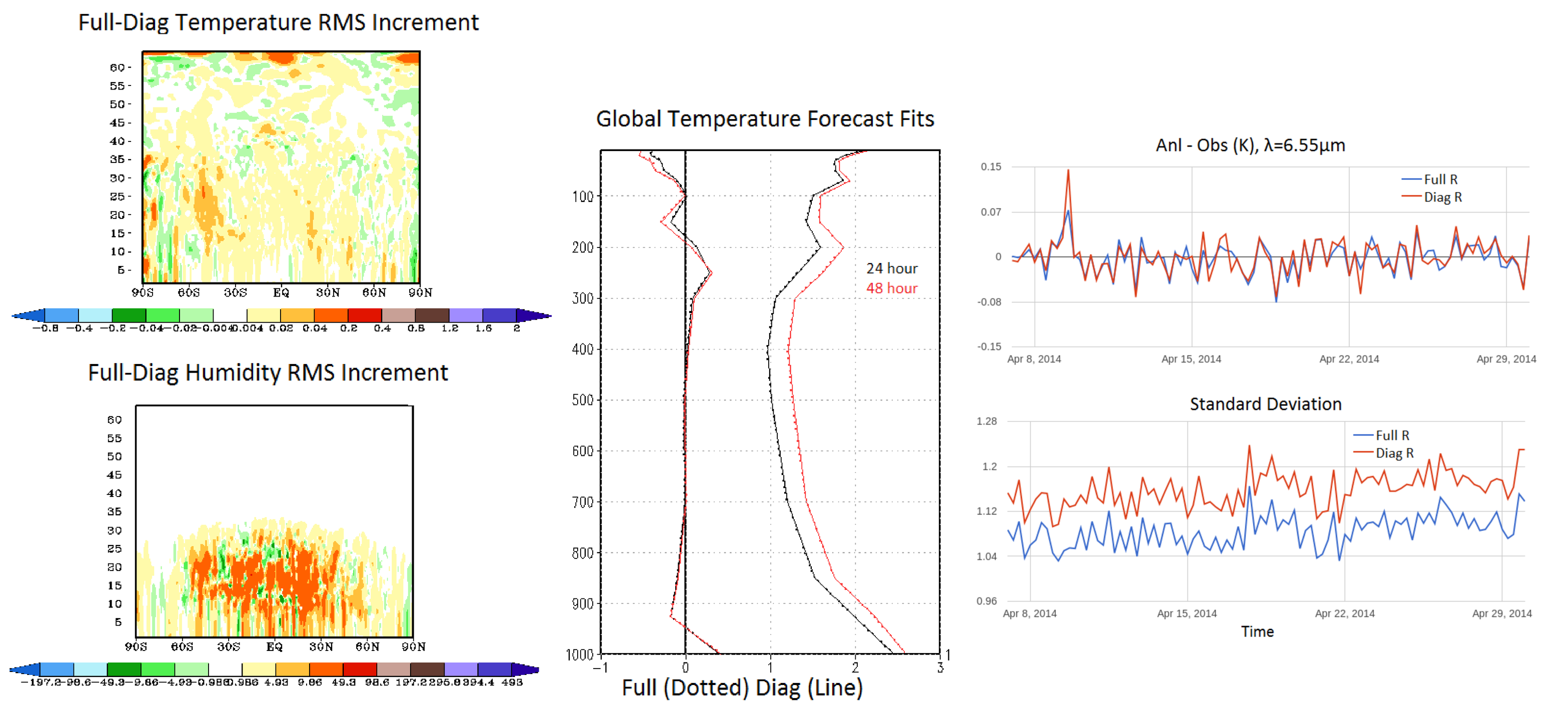

Figure 3: Analysis RMS Increments for Temperature and Humidity (left), the global fit to RAOB temperature observations (center) and an IASI-A humidity channel fit (right).

The full observation error covariances were iterated in three successive week long assimilation experiments.

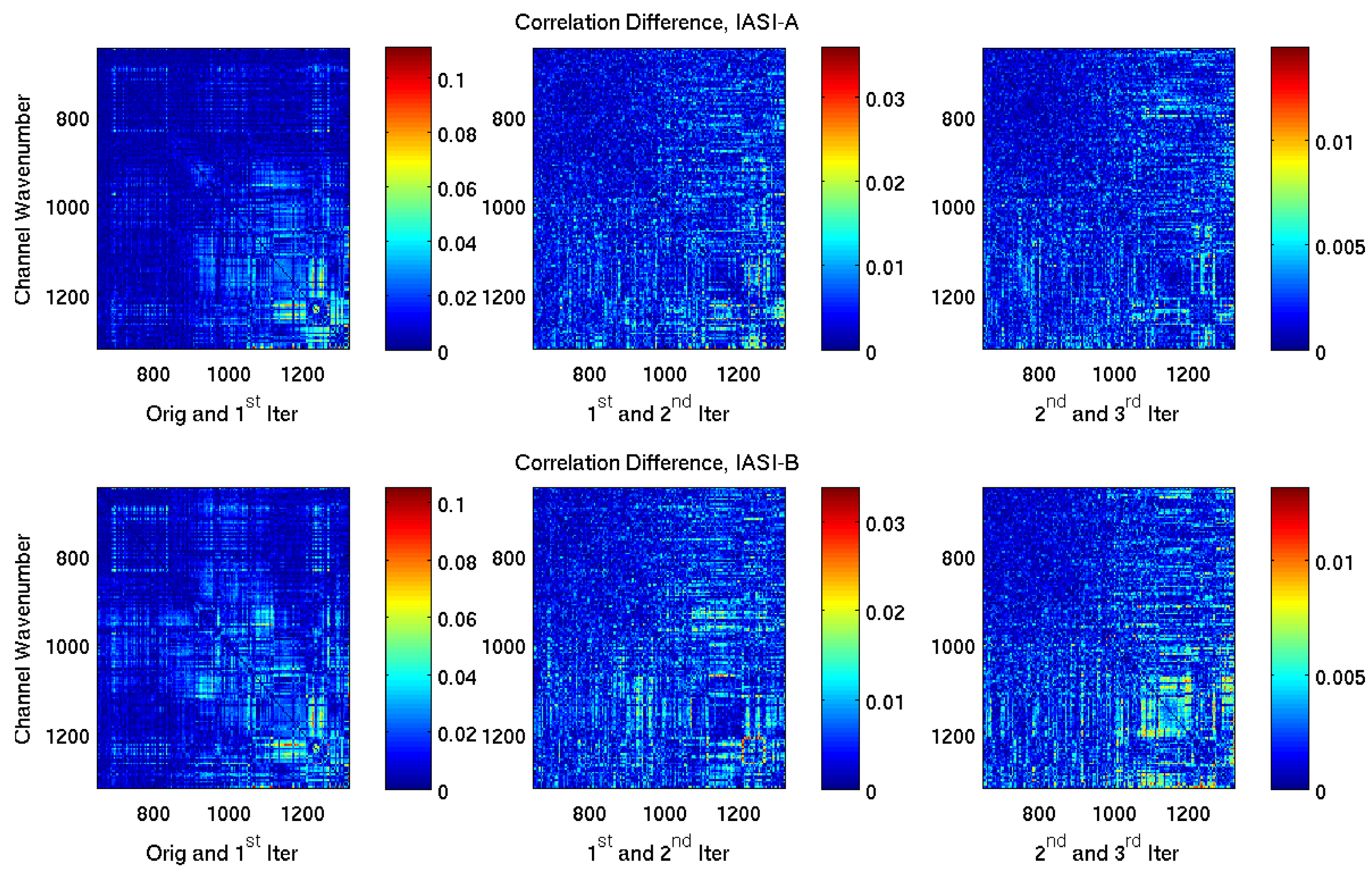

Figure 4: Differences in the observation error correlation matrices for IASI Metop-A (top) and IASI Metop-B (bottom) after iterating the full observation error covariances in three assimilation experiments.

Summary of Results

- Inter-channel observation error correlations exist for both IASI instruments, and the currently assumed errors are much larger than the diagnosed values.
- Overall, using fully correlated observation error covariances for IASI improved the fit to temperature and humidity observations. The fits to humidity channels from IASI and other satellite instruments were also improved, even though no IASI humidity channels are actively assimilated.
- Analysis increments for temperature, humidity and ozone were increased by using a full error covariance.
- The full observation error covariance computed from the Desroziers diagnostic should be iterated in an assimilation experiment to obtain the best estimate of the true covariance. The resulting diagnostic will converge after two to three iterations.

Forthcoming Research

Upcoming research will focus on:

- Different methods of reconditioning the full covariance matrix, and reconditioning more or less aggressively,
- Using full covariances over land and globally,
- Using full covariances for AIRS and CrIS, and
- Computing inter-channel error covariances for passive channels.

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Acknowledgments

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