The vertical resolution of the IASI assimilation system – how sensitive is the analysis to the misspecification of background errors?

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The NWP community has over two years of experience with the operational assimilation of IASI data. Although most centres have shown considerable positive impact from assimilating IASI data, we are far from reaching the full potential of the instrument. Pre-launch studies[1,2] based on optimal estimation theory[3] showed that we would be able to extract high-resolution NWP profile information from IASI, but it is difficult to show in an operational context whether this information does, in fact, reach the analysis. One way in which we may be limiting the potential of IASI is by using only a small subset of the spectrum, for which one proposed solution is the assimilation of principal components of the spectrum. However, the assimilation system may be more fundamentally limited by the form of, and errors in, the assumed background error covariance matrix, **B**.

The work presented here begins to assess the sensitivity of the assimilation system to misspecification of **B**. The optimal analysis[3] is only optimal if the observation and background errors are correctly specified. We investigate the impact of weighting function shape on the sensitivity of the calculated analysis error to errors in **B** for several different misspecification scenarios. This will help to determine whether we can expect any analysis problems from the assimilation of principal components, which have highly non-localised weighting functions. Future work will assess whether the pre-launch estimates of vertical resolution are realistic for the current assimilation system, given that we do not know **B** perfectly, and will establish whether the analysis error is vulnerable to misspecification of any particular eigenmodes of **B**.

1. The sub-optimal analysis system

Optimal estimation theory (e.g. [3]) shows that the optimal analysis operator, **W**, is given by:

(1) $$\mathbf{W}_a = \mathbf{B}_a\mathbf{H}_a^T\left(\mathbf{H}_a\mathbf{B}_a\mathbf{H}_a^T + \mathbf{R}_a\right)^{-1}$$

Where **H** is the linearised forward observation operator, **B** is the background error covariance, **R** is the observation error covariance, and the subscript *a* shows that these values are *assumed*.

The analysis produced by $\mathbf{W}_a$ will only by the optimal analysis if the assumed values are equal to the true values. We assume that the observation errors and linearised forward model operator are correctly specified, and that only **B** can vary from its true value:

(2) $$\mathbf{W}_a = \mathbf{B}_a\mathbf{H}^T\left(\mathbf{H}\mathbf{B}_a\mathbf{H}^T + \mathbf{R}\right)^{-1}$$

The true analysis error covariance **A** is given by:

(3) $$\mathbf{A} = \left(\mathbf{I} - \mathbf{W}_a\mathbf{H}\right)\mathbf{B}\left(\mathbf{I} - \mathbf{W}_a\mathbf{H}\right)^T + \mathbf{W}_a\mathbf{R}\mathbf{W}_a^T$$

We rewrite (3) as the optimal analysis error and the component related to misspecification of **B**:

(4) $$\mathbf{A} = \mathbf{A}_a + \left(\mathbf{I} - \mathbf{W}_a\mathbf{H}\right)\left(\mathbf{B} - \mathbf{B}_a\right)\left(\mathbf{I} - \mathbf{W}_a\mathbf{H}\right)^T$$

We investigate the sensitivity of the right-hand term in (4) to the form of **H**, i.e. the shape of the Jacobian.

2. Jacobian shapes tested

1. Delta function
2. Idealised Jacobian shape, as used by [3], 150 or 20 equally spaced identical Jacobians
3. IASI Jacobians derived from RTIASI simulation of the US Standard atmosphere
4. Principal components of IASI Jacobians derived from RTIASI simulation of the US Standard atmosphere, normalised by the same observation error as assumed for channel assimilation

3. B-matrix experiments

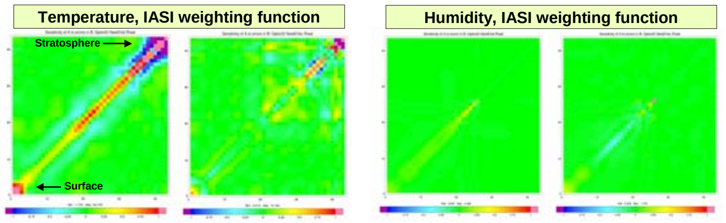
The right-hand term in equation (4) has been evaluated for various ways of misspecifying **B,** and for different forms of **H**. In each case, true **B** was taken to be the Met Office operational 1D-Var background error covariance matrix. The following misspecifications of **B** were investigated:

1. The error variances of **B** are incorrect by a given factor, but the correlations are correct
2. The error variances are correct, but the correlations are incorrect
3. The eigenvalues of **B** are incorrect but the eigenvectors are correct
4. The eigenvectors of **B** are incorrect but the eigenvalues are correct
5. The specification of **B** is completely incorrect and a new matrix is used
6. The specification of **B** is completely incorrect, but the scenario is the reverse of 5

For scenarios 2, 3, 4 and 5, $\mathbf{B}_a$ was derived from a new estimate of the error covariances calculated from new 4D-Var covarinace statistics. For scenario 6, **B** was the new error covariance matrix, and $\mathbf{B}_a$ the operational error covariance matrix – this scenario corresponds to the performance of the current operational 1D-Var preprocessor.

Results A

Temperature, IASI weighting function | Humidity, IASI weighting function

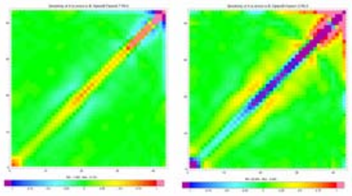


New Eval | New Evec | New Eval | New Evec

The humidity response in this series of experiments tends to be weaker because the two B matrices are fairly similar for humidity, but have very different variances for temperature.

Results B

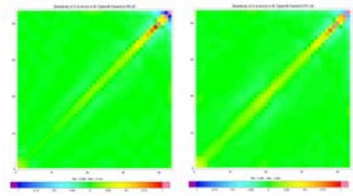
Temperature, ideal weighting function



B_a=B*0.7 | B_a=B*1.5

Results C

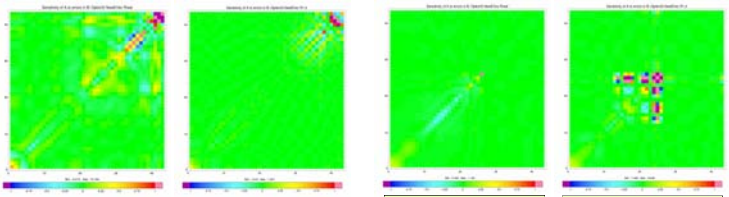
Temperature, B_a=B*0.9, ideal weighting fn



R=0.2K | R=1.0K

Results D

Temperature | Humidity, IASI weighting function



IASI channels | IASI PCs | IASI channels | IASI PCs

Conculsions

With Delta function Jacobians, the analysis error is relatively insenstive to **B**-$\mathbf{B}_a$

Idealised Jacobians and real Jacobians show similar sensitivities to errors in **B** except for humidity above mid-troposphere.

The largest additional analysis errors arise at high altitudes, and at the surface.

When altering the error variances or eigenvalues, the effect is mostly along the diagonal of the matrix. Altering the correlation structure or eigenvectors of the matrix introduces errors in the analysis which are correlated across many levels **(Results A)**

For simple scaling experiments (scenario 1) , if $\mathbf{B}_a$ is much smaller than **B**, the analysis error is greater than assumed on the diagonal, if $\mathbf{B}_a$ is much larger than **B**, the analysis error correlations between levels are greater than assumed. **(Results B)**

For idealised Jacobians, the number of channels has little effect on the size or structure of the additional error term (assuming the channels span the entire atmospheric profile). Results are quite insensitive to observation error. **(Results C)**

Properly noise-normalised principal component Jacobians appear to show less sensitivity to **B**-$\mathbf{B}_a$ than channel Jacobians in temperature, but show greater sensitivity to misspecification of the eigenvectors in humidity analysis **(Results D)**

References

[1] Collard, A.D., (1998). Notes on IASI Performance. *Met Office NWP Technical Report 256*

[2] Prunet, P. et al (1998): The information content of clear sky IASI radiances and their potential for numerical weather prediction. *Q.J.R. Meteorol. Soc.*, **124**, p211-241

[3] Rodgers, C.D. (2000): Inverse methods for atmospheric sounding – Theory and Practice. *World Scientific*

[4] Eyre, J.R. (1987): On systematic errors in satellite sounding products and their climatological mean values.*Q J R Meteorol Soc*, **113**, p279-292

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