Accounting for correlated observation error in the assimilation of high resolution sounders

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1) Introduction

Currently data from high resolution sounders, such as AIRS (Atmospheric Infrared Sounder on the NASA satellite Aqua) and IASI (Infrared Atmospheric Sounding Interferometer on the EUMETSAT satellite Metop-A), are used with diagonal observation error covariance matrices (R) within the Met Office 4D-Var assimilation scheme, assuming no correlation between channels. This is inadequate due to the presence of errors of representativeness, forward model error and errors associated with the pre-processing of the data. Previous work both at the Met Office (Stewart et al, 2009) and ECMWF (Bormann et al, 2010) has demonstrated that correlations exist in IASI data particularly for channels sensitive to water vapour. It is likely that a better description of the error correlations in 4D-Var will allow for improved use of the water vapour channels. This poster shows the results of performing a diagnostic technique described by Desroziers (2005) on the AIRS and IASI data to estimate the true structure of the R matrices. Initial tests using the full matrices resulted in the 4D-Var minimisation becoming unstable leading to non-convergence and increased computational cost. To counter this, the raw matrices have been reconditioned. Initial results from trialling these matrices in the Met Office assimilation scheme are also shown.

2) Desroziers Diagnostic

To estimate the structure of the full R matrix I have used the diagnostic procedure introduced by Desroziers et al. (2005). This uses observation minus background (O-B) and observation minus analysis (O-A) statistics to produce observation error variances and covariances. The formula is:

$$ R = \left( \begin{array}{cc} y - H(x) & y - H(x) \end{array} \right) \left( \begin{array}{cc} y - H(x) & y - H(x) \end{array} \right)^T $$

A key assumption which is used in the derivation of the above formula is that the R and B matrices used in the assimilation to produce the O-A and O-B statistics are exactly correct. However in this project we know that the R matrices are not correct initially. Therefore the results should not be entirely trusted. However it has been shown, in very simple examples, that iterating the Desroziers diagnostic after starting with incorrect errors can lead to convergence to the true errors which is encouraging.

3) IASI channels used

After symmetrising the diagnostic matrices and making sure they were positive definite the full matrices were used in a 4D-Var assimilation. The results are as follows:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Processed channels</th>
<th>Assimilated channels</th>
<th>Full matrix condition number</th>
<th>Sub matrix condition number</th>
</tr>
</thead>
<tbody>
<tr>
<td>IASI</td>
<td>314</td>
<td>138</td>
<td>266683</td>
<td>1956.6</td>
</tr>
<tr>
<td>AIRS</td>
<td>324</td>
<td>142</td>
<td>12373.9</td>
<td>12287.5</td>
</tr>
</tbody>
</table>

A suggested reason for the increased number of iterations was that the matrices had high condition numbers. The condition number of a matrix is defined as the ratio of the largest eigenvalue to the smallest eigenvalue. It is a measure of how easily the matrix is, so the smaller the condition number the easier it is to invert. Figure 4 shows the condition numbers of the raw diagnostic matrices.

4) 4D-Var Results

The Desroziers diagnostic was run on output from the Met Office's 4D-Var assimilation scheme (VAR). The results from this are shown in figure 2. There are weak error correlations between temperature sounding channels, slightly stronger error correlations between window channels and very strong error correlations between water vapour sensitive channels.

The diagnosed standard deviations are much smaller than the currently used operational ones. The water vapour sensitive channels have the largest standard deviations. This is due to larger representativeness errors for these channels.

Inflated operational standard deviations

5) Timings

Operationally at the Met Office a conjugate gradient based minimisation is now used where a fixed number of 60 iterations are performed. Putting the full matrices into this scheme leads to mixed results. The minimisation fails when using the raw matrices, but using the reconditioned matrices results in a successful convergence of the minimisation. Figure 6 compares the standard deviations from the raw matrices and the reconditioned ones.

6) Conditioning

The Desroziers diagnostic is not perfect but gives a good general idea of what the correlation structure is. Therefore the raw diagnostic matrices need to be edited to make sure they are symmetric and positive definite when being tested in the assimilation.

7) Initial Trial Results

A month long trial using just the full R matrix for IASI is currently running. A full R matrix is used as part of the quality control procedure in the OPS and results in less observation rejections due to non-convergence or bad retrieved brightness temperatures. A different full R matrix is also used in the 4D-Var assimilation scheme and results in more weight being given to the IASI observations.

Figure 7 shows results from the first 17 days of this trial and that these changes result in a positive impact and an overall reduction in RMS error in the Met Office forecast system.

8) Conclusions

Initial results from trialling the use of these reconditioned full R matrices show positive impact. Future work will include further testing and trialling and hopefully operational implementation.

References

