AMVs at the Met Office: activities to improve their impact in NWP

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Abstract

Atmospheric motion vectors (AMVs) are an important source of wind information in the troposphere, helping to better constrain numerical weather prediction (NWP) analyses. However, their assimilation in NWP models poses several challenges, largely as a result of their complicated error characteristics and also the growing demand for higher quality observations as models continue to improve.

This paper will provide an overview of some of the research activities aimed at improving the impact of AMVs at the Met Office.

The AMV height error estimates used in the Met Office individual observation error scheme have been fully revised to reflect the changes observed in the data over the last couple of years (e.g. new satellites, derivation upgrades). A key tool in this process is the use of model best-fit pressure statistics which are calculated routinely at the Met Office. The AMV quality control has also been improved by updating the spatial blacklisting criteria used to remove winds in areas where they are known to be less reliable. Assimilation experiments using the updated height error estimates together with the new quality control generally showed a small positive impact.

Ongoing efforts to improve the AMV assimilation focus on testing a temporal thinning scheme with the introduction of hourly winds from GOES and MTSAT. Initial results show positive impact when verified against observations but mixed results are found when verifying against analyses.

TEMPORAL THINNING

Observation thinning is the primary method by which NWP centres reduce data density in order to mitigate against problems with spatial and temporal error correlations. An alternative approach used at NRL is the superob procedure (e.g. see Pauley, 2003). Details of the thinning box dimensions (horizontal, vertical and temporal) applied at the different NWP centres can be found on the NWP SAF AMV pages:


The Met Office thinning criteria are detailed in Table 1 below and the ECMWF criteria are also shown for comparison. One of the current limitations of the use of AMV data at the Met Office is that strict temporal restrictions are applied so that only one wind observation is allowed per thinning box, in each 6 hour cycle. For the geostationary data sets this is done by only considering the data with observation time nearest analysis time as demonstrated in Figure 1. The time restrictions are a legacy from the days of 3D VAR and as a result a vast amount of data is not even considered for assimilation.

<table>
<thead>
<tr>
<th>Centre</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Temporal</th>
<th>Selection Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met Office</td>
<td>GEO: 2°x2°</td>
<td>GEO: 100 hPa</td>
<td>Only one wind selected per box in the 6 hour time window</td>
<td>GEO: lowest error LEO: closest to centre of box</td>
</tr>
<tr>
<td></td>
<td>LEO: 200 km x 200 km</td>
<td>LEO: 100 hPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECMWF</td>
<td>200 x 200 km</td>
<td>50-175 hPa boxes*</td>
<td>Assimilated in 30 min time-slots</td>
<td>Highest Qi. Qi2 is used for all GEO except Met-7 and MTSAT-2</td>
</tr>
</tbody>
</table>

* varies according to nearest standard pressure level

Table 1: Spatial and temporal thinning criteria for the Met Office and ECMWF
Previous attempts at removing the temporal restrictions and replacing them with temporal thinning have led to negative forecast impact, mainly in the southern hemisphere. However, since the last trials were performed several years ago there have been changes to the model, the AMV quality control, the observation errors and the AMV data itself that may see improved impact from the use of more frequent AMV data. One significant development has been the introduction of hourly data from MTSAT (March 2011) and both GOES satellites (currently in test mode but due to become operational ~ mid 2012) in addition to the hourly data already available for MSG.

A new assimilation experiment has been performed over 31 days from 14 December 2011 to 14 January 2012. The control experiment utilised the same data and QC as operations, but making use of the new hourly GOES test data in order to provide a comparable reference. The time restrictions were kept in place meaning the control experiment represented the future baseline when the GOES hourly data becomes operational. A trial experiment was also performed in which the temporal restrictions were removed and 2-hourly time thinning introduced instead, with the middle time window centred around analysis time as shown in Figure 1. The choice of time window is a compromise between using more data and avoiding the effects of correlated error: a 2 hour window resulted in approximately 3 times the number of winds assimilated. Figure 2 shows some statistics comparing VAR output from the two experiments. As expected the total observation penalty (for all observations) has increased slightly in the thinning trial as a result of the increase in the number of AMVs assimilated. It is also clear that the wind analysis is fitting closer to the AMV observations in the trial experiment than in the control (RMS reduced by about 7%).

Forecast impact at the Met Office is measured by use of a global NWP Index. This is a weighted basket of verification skill scores for a number of atmospheric parameters, at different forecast ranges. Although scores are calculated for a wide range of parameters, referred to as the extended index, only a subset of 22 actually contribute to the final NWP index. Greatest weight is given to scores in the northern hemisphere and those at shorter forecast range e.g. T+24. The extended NWP index results comparing the two experiments are shown in Figure 3. When we verify against observations we generally find a positive impact, with 18 scores significantly improved (RMS reduced by over 2%) in the extra tropics. The northern hemisphere impact in particular is almost uniformly positive. Only the

Figure 1: Schematic representation of AMV data availability within a typical 6 hour assimilation window from T-3 to T+3. The data circled are the geostationary time slots allowed in the current Met Office thinning scheme. Points representing polar data are indicative only as data from LEO platforms arrive throughout the assimilation window. The GOES data represents the hourly stream rather than the current 3-hourly operational data.
relative humidity scores in the tropics and southern hemisphere show any (small) sign of negative impact but overall the NWP Index is improved by +0.5 points which is significant considering the overall AMV contribution to the index is usually around 1.0. Verification against analysis however tells a very different story with degradation in the NWP Index of -1.7 points. Figure 3 shows that the problems are occurring mainly in the tropics and southern hemisphere, and mainly at short range (red bars are T+24). Wind and temperature scores are badly impacted by the use of more frequent AMVs and wind scores at 250 hPa in particular are much worse. The question is: why are we seeing such a negative impact versus analyses when the impact against observations is very positive? In the trial experiment we are assimilating far more AMV data and therefore it is likely that we are adding more small scale structure to the analysis. It could be that the poorer scores are due to the changes we have made to the character of the verifying analyses rather than an actual degradation of forecast quality.

For comparison with the above results we can also verify against an independent analysis from ECMWF as shown in Figure 4. This time the NWP Index score is very positive at +1.6 (a swing of over 3 points) with the northern hemisphere scores in good agreement with those found against observations. There are some degradations; height scores at 50/100 hPa in the tropics (higher than where AMVs are being used) and at T+144 in the southern hemisphere, but overall the impact is positive and more consistent with that found versus observations. Given the promising verification versus observations and ECMWF analyses, a second season trial (in northern hemisphere summer) is planned using 2-hourly thinning at which point the change could be considered for operational implementation.

Another consideration for using more data across the assimilation window is the temporal variability in the quality of some of the wind data sets. For example, as shown by Figure 5 for MTSAT, differences can be observed between the winds received at the main synoptic times, 0, 6, 12, 18 UTC (derived using 15 min interval imagery) and the intermediate time-slots (30/60 minute interval imagery). It may be necessary in future to consider allowing the observation errors to vary according to the image interval used in the AMV derivation.

Figure 3: Difference in forecast RMS (trial minus control) for a number of atmospheric parameters verifying against observations (left) and analyses (right). Differences have been separated by latitude band and forecast range; T+24 (red), T+48 (orange), T+72 (green), T+96 (blue), T+120 (purple) and T+144 (magenta). Negative values indicate a positive impact in the trial. A subset of 22 contribute to the Met Office global NWP Index.
Figure 4: As figure 3 but this time verifying against operational ECMWF analyses.

Figure 5: Hovmoeller pressure plots as a function of time of day for MTSAT-2 IR winds: O-B speed bias (left) and mean vector difference (right). Data shown is for February 2012 with QI2 > 80. The winds derived at 0, 6, 12, 18Z show better departure statistics versus the Met Office global model background.

UPDATED SPATIAL BLACKLISTING

Blacklisting is used to remove subsets of data from assimilation which show consistently poorer departure statistics. Various spatial criteria can be used for blacklisting such as pressure level, surface type, latitude and longitude etc. An alternative approach would be to allow the data through and inflate the observation errors to compensate; however blacklisting is preferred when confidence in data quality is lowest.

The spatial blacklisting applied at the Met Office has been updated to reflect changes in AMV data quality over the last few years. This was done using a mixture of O-B statistics, NWP SAF analysis reports, best-fit pressure statistics and knowledge about the limitations of the AMV derivation. For example, in the Fourth NWP SAF analysis report (Cotton and Forsythe, 2010) it was observed that the biases for MTSAT-1R had improved following derivation updates made by JMA during 2009. Most notably the fast speed bias at mid level had been significantly reduced due to changes made to the height assignment scheme (e.g. see Figure 6). Under the old blacklisting scheme, additional MTSAT rejections were in place for all mid level IR winds (300-700 hPa) and for all high level IR and WV winds in the extra-tropics. The new scheme has relaxed some of these constraints so that only a seasonal
(winter) rejection of high level IR winds in the northern hemisphere remains in place to counter the jet region slow bias.

Other examples of modifications made to the blacklisting include:
- Revise upper and lower pressure thresholds for all winds
- Introduction of topographic checks to remove winds over mountainous regions (Table 2)
- Implement CO2 slicing and WV intercept thresholds at mid level (see Feature 2.9 NWP SAF analysis reports). Winds assigned CO2 heights are rejected below 450 hPa for MSG and 500 hPa for GOES. All geostationary winds assigned below 400 hPa using the WV intercept method are rejected.
- Satellite zenith angle threshold of 68° for all geostationary winds

A full specification of the blacklisting used can be found on the Met Office NWP SAF page: http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/amvusage/ukmodel.html

<table>
<thead>
<tr>
<th>Minimum surface height (m)</th>
<th>Pressure top (hPa)</th>
</tr>
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<tbody>
<tr>
<td>1000</td>
<td>700</td>
</tr>
<tr>
<td>2000</td>
<td>500</td>
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<tr>
<td>3000</td>
<td>400</td>
</tr>
<tr>
<td>5000</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 2: Met Office criteria used to reject AMVs dependant on topography, e.g. if the terrain is at 1500m elevation than all winds below 700 hPa are rejected.

The blacklisting changes were trialled in combination with the updated observation errors and the results are discussed in the next section. The two updates were trialled together as the height errors would need adjusting in those areas where we are removing some of the spatial restrictions on the data we assimilate.

**OBSERVATION ERRORS**

It is well-known that AMVs have complicated error statistics resulting from both the tracking and height assignment steps. In July 2008, the Met Office introduced an individual observation error scheme where the error is set for each observation by combining an estimate of the error in u/v with the error in u/v due to an error in height. The latter is calculated using the model background wind profile and an estimate of the error in height (see Forsythe and Saunders, 2008, for more details). In the future it is expected that the physical height error estimates will be provided by wind producers using information from the cloud-top height products used in the derivation. For the time being the height errors are largely based on root mean square (RMS) differences of assigned pressure minus model best-fit pressure estimates. The errors are set using a look-up table dependent on (some of): satellite, channel, height assignment method, surface type, latitude band and pressure level. These were updated using 6 months of AMV data from January 2010 to June 2010. For example, Figure 7 shows the frequency of observed minus model best-fit pressure differences as a function of height for Meteosat-9 IR10.8 winds over land, assigned using the EBBT method. The RMS values are particularly large between 600 hPa and 800 hPa as a result of a positive pressure difference, i.e. the
winds have been assigned lower in the atmosphere than where the model suggests they should be. As a result the new error profile shown in Figure 8 has been inflated to account for this peak in RMS. In general the new errors largely follow the values estimated using best-fit pressure statistics but with some manual intervention, e.g. smoothing, removal of statistical artefacts and consultation of zonal O-B plots.

The new height error estimates and updated spatial blacklisting (see previous section) were trialled as a package over 2 seasons of one month duration. The overall impact was fairly small but the main NWP Index scores were on the positive side of neutral for both seasons, against both observations and analyses (Table 3). As a result it was decided to implement the package operationally with parallel suite 27 on 20 July 2011.

<table>
<thead>
<tr>
<th>Trial Period</th>
<th>NWP Index v Observations</th>
<th>NWP Index v Analysis</th>
</tr>
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<tbody>
<tr>
<td>15 Dec 2009 - 15 Jan 2010</td>
<td>+0.1</td>
<td>+0.3</td>
</tr>
<tr>
<td>1 June 2010 – 30 June 2010</td>
<td>+0.1</td>
<td>+0.2</td>
</tr>
</tbody>
</table>

*Table 3: NWP Index scores for the revised height errors and updates spatial blacklisting package.*

*Figure 7: Histograms of observed pressure minus model best-fit pressure for different pressure intervals (100 hPa bins) for Meteosat-9 IR 10.8 AMVs assigned using the EBBT height assignment method over land. The red curves show a fitted (scaled) Gaussian distribution.*
CONCLUSIONS

This paper has given an overview of some of the research activities aimed at improving the impact of AMVs at the Met Office. However, there are still a number of areas to address in order to improve AMV impact on NWP forecasts.

The AMV height error estimates used in the Met Office individual observation error scheme have been fully revised to reflect the changes observed in the data over the last couple of years (e.g. new satellites, derivation upgrades). The AMV quality control has also been improved by updating the spatial blacklisting criteria used to remove winds in areas where they are known to be less reliable. Key changes include the introduction of topographic checks to remove winds over mountainous areas and the relaxation of some of the spatial MTSAT restrictions. Assimilation experiments using the updated height errors together with the new quality control generally showed a small positive impact. These were implemented operationally in July 2011.

Ongoing efforts to improve the AMV assimilation focus on testing a temporal thinning scheme with the introduction of hourly winds from GOES and MTSAT. An initial assimilation experiment using 2-hourly thinning in place of the current time restrictions has been performed. This showed significant positive impact when verified against observations but mixed results were found against analyses: very negative versus own analysis but very positive versus an independent ECMWF analysis. It is hypothesised that the poorer scores versus own analysis are actually due to the changes we have made to the character of the analysis (adding more structure) rather than a degradation of forecast quality. A second season trial is planned before consideration for operational use.

REFERENCES


Figure 8: Profiles of height error estimates for Meteosat-9 IR10.8 winds assigned EBBT heights over land. The red line shows the old operational errors, black shows the RMS of the observed minus best-fit pressure statistics and green shows the new operational values.