Understanding AMV Errors through the NWP SAF monitoring and Analysis reports

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Abstract

The AMV monitoring report [http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/](http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/) is delivered under the auspices of the NWP SAF (Satellite Application Facility on Numerical Weather Prediction), a EUMETSAT-funded project that exists to coordinate research and development efforts among the SAF partners to improve the interface between satellite data and NWP for the benefit of EUMETSAT member states. The NWP SAF AMV monitoring website hosts information on how AMVs are used at various NWP centres, bespoke investigations and links to near real-time AMV monitoring. But perhaps most importantly of all it hosts an archive of O-B monthly monitoring plots that display differences between AMVs (O) and NWP model background winds (B) valid at the same location and time. The accompanying series of ‘analysis reports’ are in-depth studies of these statistics with the aim to improve our understanding of the AMV errors and analyse any changes in the data. The analysis reports are currently produced every 2 years to coincide with workshops organised by the International Winds Working Group (IWWG).

In this paper we highlight recent developments to the NWP SAF AMV monitoring website and present some examples from the 5th analysis report released in February 2012 (Cotton, 2012).

RECENT DEVELOPMENTS

Changes to the website since the 10th International Winds Workshop include:

1. The information on how AMVs are used in different NWP systems was updated [http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/amvinfo.html](http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/amvinfo.html)
2. February 2012: web pages were reviewed and relevant information relocated under a new NWP tab
3. March 2011: a new investigation was added [http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/investigations.html](http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/investigations.html) . This compared model best-fit pressure statistics produced by the Met Office and ECMWF and relates to an ongoing item on the NWP SAF AMV action list regarding further investigation of height assignment differences. The investigation was produced in collaboration with Kirsti Salonen, ECMWF.
4. November 2010: Metop-A AVHRR polar winds produced by CIMSS and EUMETSAT were added to the monthly monitoring
5. November 2010: new look vector plots were added. To make the plots clearer, black vectors are drawn over a coloured background rather than coloured vectors drawn over a white background.
6. June 2010: plots converted from jpeg to a higher resolution gif format. The archived plots were also updated.

METHODOLOGY

The monitoring statistics in the following examples are calculated by comparing AMV wind observations with model background estimates from a recent short range forecast, valid at the observation times. Both the AMVs and the model forecast contribute to the differences seen in the plots; neither can be assumed to be true. But by comparing plots of the same observations against different NWP backgrounds, it may be possible to separate error contributions from the observations and models. Wherever possible the NWP SAF AMV monitoring provides easily comparable plots from the Met Office and ECMWF global forecast models.
All plots in this report, unless stated otherwise, are produced using observations with quality indicator (QI) values greater than 80 for the geostationary winds and greater than 60 for the polar winds. The QI used is the EUMETSAT-designed QI without model first guess check. Throughout this document the tropics latitude band refers to the area between 20°S and 20°N, the northern hemisphere is north of 20°N and the southern hemisphere south of 20°S.

To diagnose possible errors in height assignment it is often useful to compare the AMV assigned pressure to the model best-fit pressure. The model best-fit pressure is calculated by: (1) finding the model level below 100 hPa with the smallest vector difference between the AMV and model background wind and (2) vertically interpolating to find the minimum using a parabolic fit to this model level and the two neighbouring levels. Filters are then applied to the data to remove cases where the best-fit pressure is not well constrained (e.g. secondary minima) but note that there are likely to be error contributions from the model background wind field.

EXAMPLES FROM THE 5TH NWP SAF AMV ANALYSIS REPORT
In this section we present examples of some of the features identified in the 5th analysis report.

Example 1. Low level Somali Jet
For several years Meteosat-9 visible AMVs have shown a marked slow bias during July and August around the Gulf of Aden, near the north east tip of Somalia. The feature is present in Meteosat-9 visible 0.8µm and high resolution visible AMVs versus both the Met Office and ECMWF models, but is not as noticeable in data derived from the IR channel. As this feature lies in the overlap region between the Meteosat-9 and Meteosat-7 disks we can compare their statistics (Figure 1). In this case there are markedly different departure statistics near the Gulf of Aden; Meteosat-7 visible winds are faster than the model, rather than slower like Meteosat-9. This is in agreement with previous work that has shown Meteosat-7 to exhibit spuriously fast winds at low level in this area as described in Feature 2.7 in the fourth analysis report (Cotton and Forsythe, 2010).

Mean Met Office analysis wind vectors for August 2011 show that the slow bias for Meteosat-9 is associated with the strengthening of the Arabian branch of the South Asia summer monsoon winds (Figure 2). This feature is commonly known as the Somali Low Level Jet and normally peaks in July and August which coincides with the appearance of the slow bias in the visible AMVs.

In an attempt to isolate the possible source of the observed errors the first thing to consider is how well the models are performing in these situations. It has been shown that for previous monsoon seasons the strength of the Somali jet in the ECMWF analysis is quite different compared to the Met Office analysis and forecasts (Milton et al., 2011). Met Office analyses at 925 hPa were found to be systematically stronger by 2.5 m/s within the jet (10% of the observed wind speed) with a similar outcome for short range T+24 forecasts. This is in agreement with the fact that although the apparent AMV slow bias is similar for both models, it is slightly worse versus the Met Office background. One suggested reason for the differences between the models is that the ECMWF analysis is fitting closer to the observations and if true for the AMVs this would act to reduce the speed of the jet winds. Although there are clearly some systematic differences in the models, the magnitude of the AMV speed bias (20 m/s) suggests that the AMV errors are dominating. This theory is reinforced by comparing the AMV departure statistics to those from the ASCAT instrument on MetOp-A (Figure 2). In the Somali jet region there is generally good agreement between the scatterometer ocean-surface 10 m winds and the collocated Met Office model estimates.
Figure 1: Map plots of mean O-B speed bias for Meteosat-9 visible AMVs versus the Met Office (left) and ECMWF (centre) model backgrounds for August 2011. Also shown is the mean O-B speed bias for Meteosat-7 visible AMVs versus the Met Office model background (right).

Figure 2: Map plots of mean O-B speed bias for 25-km ASCAT winds versus the Met Office model background for August 2011 (left). Also shown are the mean Met Office model analysis wind vectors at 925 hPa for August 2011 (right).

To investigate why the AMVs are being derived with much slower speeds than the models we can look at an individual case study. Although a small slow bias is present for most of August, there is a clear spike for the 12z run on 10 August which could be the root cause of the marked signal seen in the map averages. Looking closer within the 12z model run shows that there are many Meteosat-9 high resolution visible AMVs with negative speed biases exceeding 20 m/s and that this occurred most frequently for data extracted at 1230z. Comparisons with Met Office model best-fit pressure estimates indicate that these slow winds may have been assigned too low in the atmosphere by in excess of 200 hPa. This would suggest that slower, mid level winds have been incorrectly assigned down to low level within the Somali Jet. To verify whether this is the case we can investigate a McIDAS visualisation of the high resolution visible data at 1230z (Figure 3). Interpretation of the imagery and data allows a number of features to be identified:

A) In the area southeast of the island of Socotra there are moderately strong AMVs assigned at ~840 hPa that are tracking narrow lines of clouds. These tracers are aligned parallel to the African coast and are easily distinguished as part of the low level south westerly monsoon flow which is gently curving clockwise. These closely-spaced cloud bands indicate relatively strong low-level winds and the AMVs show good agreement with the model wind speed.

B) Faint cirrus plumes within the upper level Easterly Jet.

C) Cloud formation along the southern, windward slopes of Socotra Island indicating the low level wind direction (see also Figure 4). As the clouds are suppressed from flowing over the terrain in the southerly flow this indicates a low level inversion. An inversion is known to persist over the western Arabian Sea during the Southwest Monsoon (Hubert et al., 1983). The rather stationary wave like cloud just to the south of the island could be a gravity wave on the inversion interface and the AMVs tracking this show very poor agreement in both speed and direction. It is possible that island effects together with the presence of an inversion are dominating the errors here.

D) Brighter, shallow convective clouds indicating a weakening of the low level inversion here or clouds that have broken through. The AMVs are slow at ~5 m/s, tracking from the west or
northwest and assigned much lower at around 920-960 hPa. In this case the collocated model winds are clearly part of the Somali Jet with speeds in excess of 25 m/s (50 knots) from the south or southwest. It seems likely the AMVs have been assigned too low as model best-fit pressure statistics of around 700 hPa are well constrained. Note also that the two vectors assigned higher at ~750 hPa near 10:56°N 54:22°E show better fit with the model.

Overall the slow bias appears to be the result of some instances of height assignment error (e.g. case D), as well as the influence of islands (case C) with high mountainous terrain (up to 1500m) located within a very strong low level jet.

Visualisation of Meteosat-7 visible data for this case (not shown) reveals that no AMVs have been extracted at very low level i.e. below 900 hPa. In particular, there are no Meteosat-7 AMVs tracking the problematic clouds south of the island of Socotra. This suggests that one reason why the slow bias is present in the MSG visible and high resolution visible data, and not in the Meteosat-7 visible data, is the enhanced spatial resolution of the imagery (3km/1km versus 5km respectively).

Figure 3: McIDAS visualisation of 1km Meteosat-9 high resolution visible imagery at 1227z over the tip of Somalia. Collocated Meteosat-9 high resolution visible AMVs (coloured by speed) and Met Office model winds (black) have been plotted along with the AMV assigned pressure. A long barb represents 5 m/s and a pennant 25 m/s. AMVs extracted at 1230z only.

Figure 4: Close-up of the narrow tracer south of Socotra Island. The low-level wind direction can be seen from the cloud formations on the windward slopes of the island.
Example 2. Model improvements at mid level

Geostationary AMVs derived at mid level (400-700 hPa) have generally tended to show quite poor O-B statistics overall, but countered by the fact there are fewer winds extracted here compared to at low or high level. Two dominant features that have been described in previous analysis reports are AMVs that are much faster than the model in the tropics (Feature 2.8) and AMVs much slower than the model in the extra-tropics (Feature 2.9). The errors are thought to be largely the result of height assignment errors (Table 1).

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<thead>
<tr>
<th>Feature</th>
<th>Resulting from</th>
<th>Likely cause</th>
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<tbody>
<tr>
<td>Tropical fast bias</td>
<td>AMVs assigned too low in comparison to model best-fit pressure and other cloud top pressure products.</td>
<td>– Limitation of EBBT method for semi-transparent clouds (contributions from below cloud)</td>
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<td></td>
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<td>– Multispectral techniques not used often enough (or fails) for genuine high level clouds</td>
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<tr>
<td>Mid latitude slow bias</td>
<td>AMVs assigned too high in atmosphere compared to model best-fit pressure</td>
<td>– CO2 and WV channels less sensitive at mid levels.</td>
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<td>– High wind shear below upper level Jet winds</td>
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<td>– Multilayer cloud scenarios</td>
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Table 1: Geostationary AMV problems at mid level and their possible causes.

From analysing zonal and map plots of GOES-11 IR winds, there is an apparent improvement in mid level biases during 2011 versus the Met Office (and to a smaller extent ECMWF) models. For example comparing plots from the same months for the first quarters of 2010 and 2011 as in Figure 5 seems to show a significant reduction in speed bias and vector differences in both the tropics and extra-tropics. For GOES East (GOES-12 until mid April 2010, then GOES-13) any improvement in statistics is much more subtle. To verify whether this apparent change in the mid level GOES-11 statistics is real or part of some inter-annual variability we can make use of long term time-series. These can be constructed from CGMS (Coordination Group for Meteorological Satellites) approved monthly statistics calculated routinely at the Met Office (model) and NOAA (radiosonde).

Figure 6 shows how the RMS vector difference and mean speed bias have evolved for mid level GOES-11 IR AMVs since the beginning of 2009. The departures versus the Met Office model show an improved fit for all latitude bands, particularly from April/May 2010 onwards. As expected there are clearly some seasonal variations, with the greatest differences in the winter hemisphere, but at the very least there is a noticeable downwards trend (improvement) in the RMS statistics. For O-B speed bias the improvement is not quite as clear-cut, though still discernable. Generally the negative speed bias in the extra-tropics is worse in the winter hemisphere (clearest in the northern hemisphere) and even taking account for the seasonal variation there is an upwards/improving trend in speed bias. In the tropics, although the mean level of fast bias remains constant about +1 m/s throughout, the variation around this tends to dampen down from around April/May 2010 onwards.

The key question is have the GOES-11 mid level winds improved due to changes in the observations (e.g. algorithm upgrades) or due to changes in the model winds? Figure 6 also shows equivalent GOES-11 CGMS statistics produced by NOAA but this time verifying against collocated radiosonde observations. The time series show no clear indication of any significant changes in the AMVs during this time. RMS levels in the northern hemisphere have remained relatively constant since January 2009, varying seasonally between 6-7 m/s. It should be noted that there are very few radiosonde matchups in the tropics and southern hemisphere hence the statistics are noisier in comparison.

The above results would suggest that the improved fit of GOES-11 with the Met Office models is due to changes in the forecast winds in the Pacific region (see also the update on Feature 4.1 in the 5th analysis). The Unified Model (UM) underwent several major upgrades during late 2009 and early 2010 that could have played a role in reducing the biases seen versus the Met Office model. In November 2009 the vertical resolution of the model was upgraded from 50 to 70 levels with a number of
performance benefits, particularly in the tropics. A second large package of changes was implemented in March 2010 with the key upgrade being an increase in horizontal resolution to 25 km (N512) which, amongst other things, led to an improvement in extra-tropical wind biases. Further changes in July 2010 included an updated cloud scheme which resulted in more accurate tropical temperature profiles and therefore better tropical winds.

Why have the GOES-11 winds improved and not those from GOES-E? One factor may be that, compared to the other geostationary satellites, the mid level biases for GOES-11 were worse to start with. Reasons put forward for this include the lack of a CO₂ channel (only introduced with GOES-12) for assigning high level clouds and also the slightly unusual wind characteristics found in the Pacific which make height assignment more difficult. For example, in the tropics of the GOES-11 region a wind speed minima is often found at mid level and therefore any error in assigning heights to low or high level clouds will likely lead to a fast bias.

![Figure 5: Zonal plots of O-B speed bias for unedited GOES-11 IR AMVs for January 2010 (left) and January 2011 (right). Data compared with the Met Office model background.](image)

![Figure 6: Time series of monthly CGMS statistics for GOES-11 mid level IR AMVs: root mean square vector difference (top) and O-B speed bias (bottom) for January 2009 to September 2011. Statistics calculated against the Met Office global model background (left) and versus radiosonde matchups (right) for AMVs with QI1 > 80% (with first guess). Radiosonde statistics courtesy of Hongming Qi, NOAA.](image)

**Example 3. High level MTSAT fast bias**

High level statistics are dominated by a slow speed bias in the jet regions (worse in the winter hemisphere) and there tends to be a positive speed bias in the tropics, but this is less pronounced than at mid level. MTSAT AMVs derived from WV imagery show a more general widespread fast bias at high level, even in the extra-tropics, though still punctuated by areas of slow bias during intense jet periods. More structured and well-defined areas of fast bias can be observed in the North West Pacific during July-September as shown in Figure 7 for August 2011.

Hovmoeller plots (not shown) of the temporal variation in O-B for MTSAT-1R WV winds between longitudes 120E-140E show a strong bias signal and high vector RMS for data valid on 5-6 August 2011 at around 20-35N. A MoIDAS visualisation at this time shows a large swathe of AMVs curving across South Korea, Japan and the Philippine Sea which are considerably faster than the collocated...
model estimates (Figure 8). In the worst cases the O-B speed bias is in excess of 20 m/s for some winds. The imagery shows that the problem AMVs are tracking the high level outflow from Typhoon Muifa centred to the south west of Japan. Visually the AMVs appear broadly consistent, with a smooth clockwise flow following the upper level cirrus outflow with evidence of transverse banding in the imagery. This general consistency is also reflected in the high QI (without first guess) values assigned to the winds.

Figure 9 shows a comparison between observed and model best-fit pressure for IR and WV winds located within the vicinity of the typhoon (box 10-40N, 120-140E). On average the WV winds have been assigned nearly 40 hPa lower than the model preferred location (left plot). The IR winds show a much closer fit to the model with a mean (observed - model) pressure difference of just +3 hPa (right plot) and consequently show better O-B statistics compared to the WV winds.

The middle plot in Figure 9 shows what happens if we consider only WV observations with O-B speed biases exceeding 8 m/s, as is the case for the problem winds associated with the outflow from Typhoon Muifa. The result is a cluster of winds assigned WV intercept heights between 180-280 hPa whilst model best-fit heights are much higher in the atmosphere at 110-180 hPa (mean pressure difference +80 hPa).

The model best-fit pressure comparisons, combined with some large directional disagreements with collocated model vectors, indicate that the AMVs have likely been assigned too low in the atmosphere. Cloud top height information from CALIPSO is not available for this case study due to the instrument payload being switched off between 4-10 August 2011.

Figure 7: Map plots of O-B speed bias for high level MTSAT-2 WV (left) and MTSAT-1R (right) WV AMVs in August 2011. MTSAT-1R was used as backup from 3-15 August inclusive, MTSAT-2 during the remainder of the month.

Figure 8: McIDAS visualisation of 4 km resolution MTSAT-1R IR10.8 imagery at 0530z, 6 August 2011. Overlays of MTSAT-1R cloudy WV AMVs (left) and collocated Met Office model winds (right) have been plotted for high level winds with QI2 > 60. Winds extracted at 0530z only. A long barb represents 5 m/s and a pennant 25 m/s.
CONCLUSIONS

The NWP SAF AMV monitoring website hosts a collection of resources aimed at better understanding the error characteristics of this important source of tropospheric wind information. The monitoring has continued to develop over the past two years with a new addition being an investigation comparing model best-fit pressure statistics between the Met Office and ECMWF systems. The largest and most significant part of the website is an archive of monthly monitoring plots that display AMV departure statistics against both the Met Office and ECMWF global NWP models. In this paper we have highlighted some examples from the 5th NWP SAF analysis report which is part of an ongoing effort to diagnose where significant biases are occurring in the AMV data and what the likely causes are.

Several features previously identified in the monitoring appear to have improved since the 4th analysis report. Perhaps the largest improvement has been for the GOES-West winds at mid level when compared against the Met Office model. A significant reduction in speed bias and vector difference can be observed in both the tropics (Feature 2.9) and extra-tropics (Feature 2.8) which is likely a result of improvements made to the model winds in this region of the Pacific.

At low level the largest departures from the model are the result of significant height assignment errors which can lead to spuriously fast AMVs assigned too low. Other more localised biases appear to be caused by orographic influences, sometimes in combination with seasonal enhancements in the strength of the low level flow e.g. Somali low level jet.

Departures at high level are dominated by the slow bias associated with the sub-tropical/polar jets. In the 5th analysis, a marked fast bias associated with the passage of a Typhoon was observed for MTSAT WV winds.

The NWP SAF welcomes any feedback from users on the AMV monitoring resources as well as suggestions for future developments.

REFERENCES


