WHAT CAN WE LEARN FROM THE NWP SAF AMV MONITORING?

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Abstract

To gain more benefit in numerical weather prediction (NWP) it is essential to improve our understanding of the atmospheric motion vector (AMV) errors. One of the difficulties is that the AMV errors are hard to characterize and are typically non-Gaussian and correlated. The NWP SAF AMV monitoring report is a useful resource for investigating AMV errors. Its purpose is to provide comparable AMV monitoring output from different NWP centres in order to help identify and partition error contributions from AMVs and the NWP models. The NWP SAF AMV monitoring report is freely available at http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/. The site provides more than three years of monthly observation-background (O-B) statistics plots from ECMWF and the Met Office. Recently several changes have been made to the site to allow easier plot comparison, to include new AMVs and to provide new types of statistical plots. An analysis report of the monitoring has been released and guidance notes produced for future contributors to the monitoring. Other information is available from this site including links to summaries of AMV work and links to other AMV monitoring sites. The site is intended to stimulate thought and discussion and eventually to lead to improvements in AMV derivation and improvements in the way the data is used in NWP.

INTRODUCTION

The Numerical Weather Prediction Satellite Application Facility (NWP SAF) is a EUMETSAT-funded initiative led by the Met Office, with partners ECMWF, KNMI and Meteo-France. The aim of the NWP SAF is to improve the benefits derived by European National Met. Services from NWP by developing techniques for more effective use of satellite data and to prepare for exploitation of new data and products. The AMV monitoring forms one part of the NWP SAF activities and has a primary goal of gaining a better understanding of the errors in the AMV data by comparing monitoring output from different NWP centres. An analysis of the NWP SAF AMV monitoring results was released in December 2005 and the aim is to produce update reports at 2-yearly intervals to coincide with the International Winds Workshops.

In the following sections, we provide a summary of the changes to the NWP SAF AMV site since the 7th International Winds Workshop (IWW7) in 2004, we show examples from the 2nd analysis of the AMV monitoring and conclude with some recent results comparing AMV assigned pressure to model best-fit pressure and other cloud top pressure products.

CHANGES SINCE THE 7TH INTERNATIONAL WINDS WORKSHOP (IWW7)

There have been several changes to the NWP SAF site since IWW7. The most obvious change has been to the site design to allow display of plots in pop-up windows. This approach was adopted to allow easier and more flexible comparisons of different types of plot, from different centres or for different times of the year. A second major change has been to the type of plots displayed. Before IWW7 only the speed bias density plots (Figure 1a) and map statistics plots were included. Since this time the map plots were modified to plot each satellite individually (e.g. Figure 1b) and to display the polar AMV data on polar projections. Zonal plots (statistics calculated as a function of latitude and

pressure) have been added (e.g. Figure 1c). These complement the map plots and together are useful for highlighting geographical areas of mismatch. More recently vector plots showing the mean observed vector, mean background vector and mean vector difference have been added. These can be useful for highlighting any directional component to the bias.
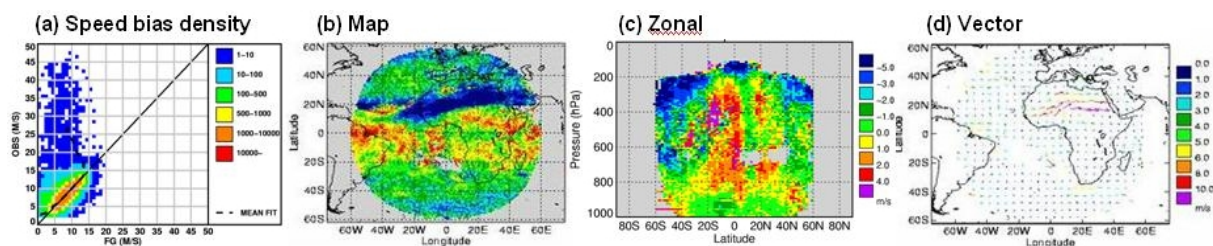
Figure 1: **Examples of the monthly O-B statistics plots displayed on the NWP SAF site, (a) density plots of observation wind speed against background wind speed, (b and c) map and zonal plots of wind speed bias, mean vector difference, normalised root mean square vector difference and number of AMVs and (d) vector plots showing the mean observed vector, mean background vector and mean vector difference.**

It was recognised that the NWP SAF AMV monitoring site has an important role to play in assessing new wind types. In the last 2 years, various new datasets have been added including the MODIS polar winds (from CIMSS and NESDIS), Meteosat-8 winds, MTSAT-1R winds, GOES 3.9 μm winds, Kalpana winds and Insat-3a winds.

A second analysis of the NWP SAF AMV monitoring was recently completed (Forsythe and Doutriaux-Boucher, 2005). Some examples from this paper are discussed in the following section. Finally all the information pages, including the action list and details of AMV usage at the Met Office and ECMWF, have been routinely updated and guidance notes produced for future contributors to the monitoring.

EXAMPLES FROM THE 2ND ANALYSIS REPORT OF THE NWP SAF AMV MONITORING

The second analysis report is more than just some examples from the NWP SAF AMV monitoring. It also includes a summary of some of the known sources of error in the AMVs, ideas for optimising the use of AMVs in NWP and a list of suggestions and recommendations for producers and users of the data. The examples themselves are based on features identified in the observation-background (O-B) monitoring, but in several cases further investigations have been carried out. Before discussing a few specific examples it is worth summarising some general observations from the plots.

General Observations

Firstly, the majority of the features observed in the O-B monitoring plots are present in the plots from both ECMWF and the Met Office (only NWP centres currently involved). The similarity might suggest that the errors in the observations dominate, although the ECMWF and Met Office models could, in some cases, share similar weaknesses. Often the O-B features persist from month to month and year to year, although some features change in intensity depending on the season. Many of the main features observed in the O-B plots, for example the slow bias in the jet regions, are observed in plots for most satellite and channel combinations. Figure 2 shows example zonal O-B speed bias plots for Meteosat-8 IR, MTSAT-1R IR, GOES-12 IR and the unedited GOES-12 IR winds. Unedited is used here to describe the winds before the speed and pressure adjustment that occurs in the autoeditor step of the NESDIS AMV processing.

There are several features common to most zonal speed bias plots: (i) a slow speed bias associated with the jets, (ii) a slow speed bias at mid levels in the extra-tropics, (iii) a fast speed bias in the tropics and (iv) in some cases a fast speed bias at high level (above ~180 hPa). The only data that does not exhibit a slow speed bias in the jets is the final GOES winds. This is due to a 10% speed increase that is applied to the extra-tropical cloud-track winds (polewards of 25N/S) that are faster than 10 m/s and have pressures above 300 hPa in the atmosphere (part of autoeditor step). Figure 2 instead shows a small fast bias in the jet regions for the final GOES IR winds, suggesting that, at least in some cases, there may be an over-correction.
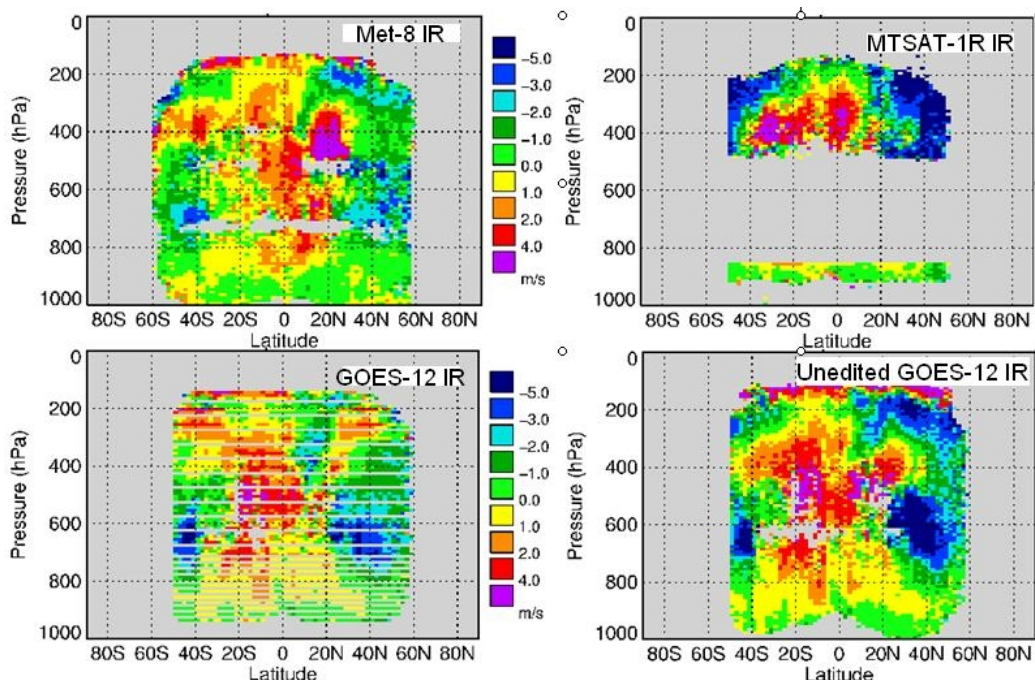
Figure 2: **O-B speed bias zonal plots for Meteosat-8 IR, MTSAT-1R IR, GOES-12 IR and unedited GOES-12 IR for February 2006 compared with the Met Office model background.**

Example 1: CIMSS MODIS mid level fast winds

The MODIS polar winds are produced at NESDIS and CIMSS. The two datasets are being brought into line in preparation for developments to the product, which will be introduced first at CIMSS before migration to NESDIS. Although the two MODIS datasets are more similar than they were when they were first produced, there are still some differences. One difference that is occasionally seen is in the speed bias density plots for mid level winds. The CIMSS data density plots sometimes show a plume of spuriously fast winds (e.g. Figure 3a). These are not observed in the equivalent NESDIS plots (e.g. Figure 3b). A plume has been observed in all channels (IR, cloudy WV and clear sky WV) from both Terra and Aqua, but is not present in all channels and satellite combinations every month.
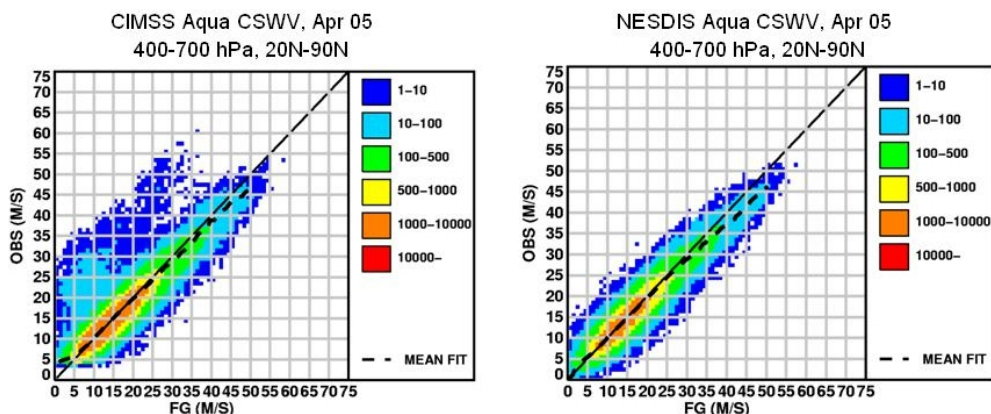

Figure 3: **Density plots of observed speed against Met Office background speed for mid level northern hemisphere AMVs from (a) CIMSS Aqua CSWV and (b) NESDIS Aqua CSWV for April 2005. Note the plume of spuriously fast winds in the CIMSS plot.**

Example 2: The Japanese Meteorological Agency (JMA) IR and cloudy WV winds

There are some notable differences between the high level IR and cloudy WV statistics for some satellites. The biggest differences are seen for the AMVs produced by JMA (GOES-9 and MTSAT-1R). The zonal plots in Figure 4 show how the slow speed bias is worse for GOES-9 IR than the GOES-9 cloudy WV winds.
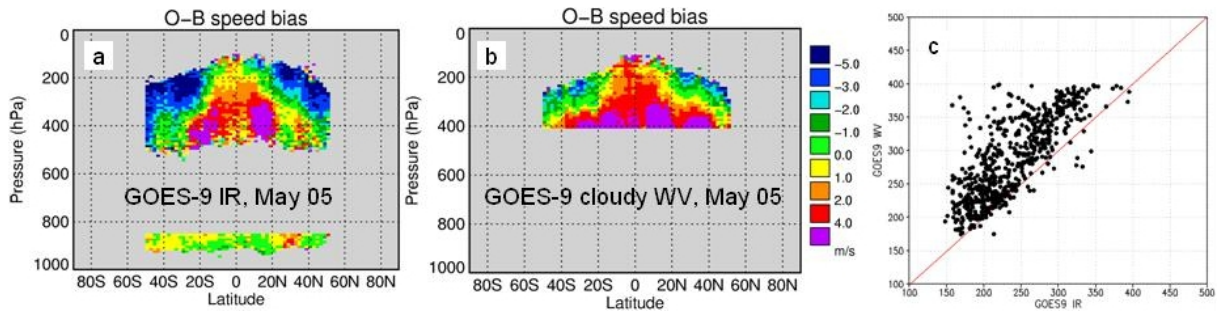
Figure 4: **(a and b) O-B speed bias plots for GOES-9 IR and WV winds for May 2005 compared with the Met Office model background, (c) scatter plot comparing the height assignment of collocated GOES-9 IR and GOES-9 cloudy WV winds.**

One possible source of the different behaviour of the two channels is the height assignment. The scatter plot in Figure 4c compares the height assignment of collocated GOES-9 IR and cloudy WV winds and shows that the cloudy WV winds are consistently located lower in the atmosphere by, on average, ~50 hPa. Because clouds are not evenly distributed, tending to be located below the high speed jet core (e.g. England & Ulbrecht, 1980), a systematic height assignment error could contribute to or counteract a slow speed bias. Conversations with JMA have indicated that there are differences in the height assignment methodology that can explain the observed differences and they are looking at improvements to the existing set-up.
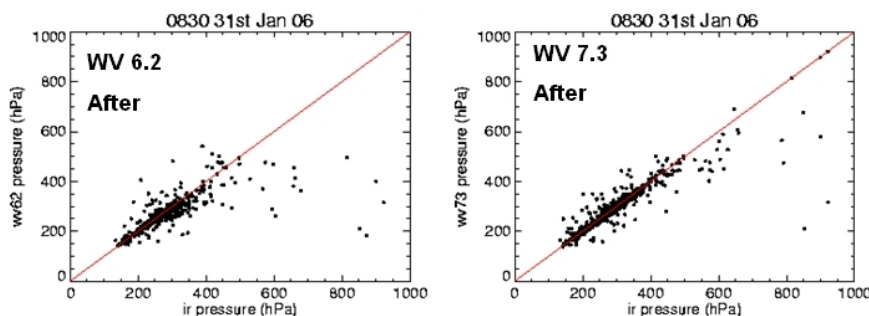
Example 3: Meteosat-8 IR and cloudy WV

Some differences were also seen between the Meteosat-8 IR and cloudy WV winds. Scatter plots of collocated IR and WV winds show good agreement at high level (above ~230 hPa for WV 6.2 and above ~ 350 hPa for WV 7.3). Below this, the heights start to diverge with the WV winds located systematically higher in the atmosphere (e.g. Figure 5).
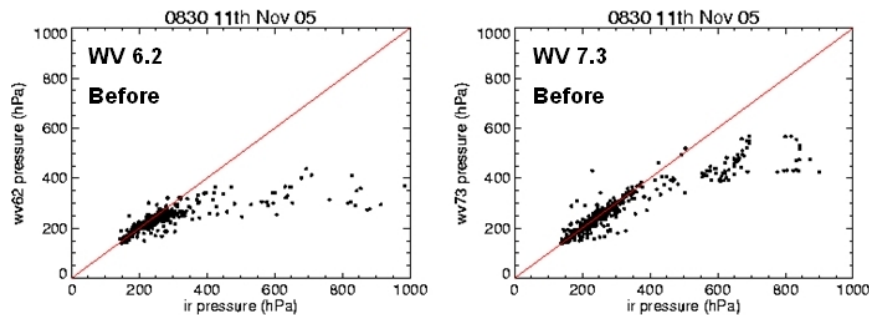
Figure 5: **Scatter plots of collocated Meteosat-8 IR and cloudy WV (6.2 and 7.3) winds for the 0830 data on the 11th November 2005. Note the divergence at mid levels with the WV winds being located higher in the atmosphere.**

Some variation might be expected between the channels in multi-level clouds as they are sensitive to different layers of the atmosphere, but good agreement of the u and v components suggests that mostly the channels are tracking the same feature. So what is causing the different AMV height assignment? Investigations at EUMETSAT revealed that atmospheric absorption above cloud top was not being allowed for in the Meteosat-8 processing stream. This was corrected with a change on 1st December 2005. A comparison of the pressures after the change shows better agreement (Figure 6).

Figure 6: **Scatter plots of collocated Meteosat-8 IR and cloudy WV (6.2 and 7.3) for the 0830 on 31st January 2006. Note the better agreement of the IR and cloudy WV pressures.**

The NWP SAF AMV monitoring plots can be used to assess the impact of AMV derivation changes. For example, comparison of the WV6.2 zonal plots for November and December 2005 (either side of 1st December 2005 EUMETSAT upgrade) show an increase in the number of mid level AMVs, a reduced slow bias around 400 hPa in the extra-tropics and an increase in the fast speed bias.

Example 4: Sahara problem

A fast speed bias can be seen over North Africa in the winter months (e.g. Figure 7). The bias is thought to be due to faster higher level winds being assigned too low. This will lead to a bigger speed bias in the winter when the sub-tropical jet, which crosses this area, is stronger. Interestingly the fast bias is only evident at night (Figure 7b). The fast bias over the Sahara is considered further in the next section comparing AMV pressure to model best-fit pressure and other cloud top pressure datasets.
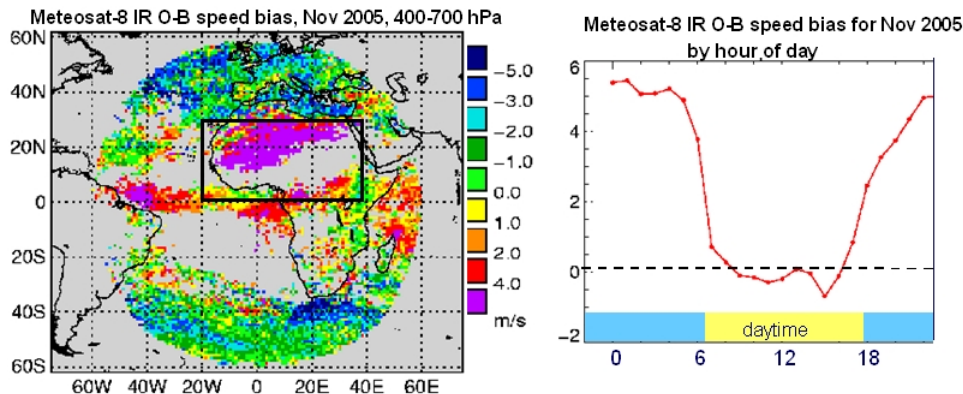

Figure 7: **(a) O-B speed bias plot for Meteosat-8 IR mid level winds compared with the Met Office model background for November, 2005, (b) speed bias as a function of hour of day for the boxed region in (a).**

COMPARISONS TO MODEL BEST-FIT PRESSURE

One way of assessing the AMV height assignment is by comparison with the model background wind column from the Met Office global model. Figure 8 shows an example of an AMV at 230 hPa. We can compare the AMV u and v values to the background wind column u and v components and derive the vector difference on each model level using the equation shown below.

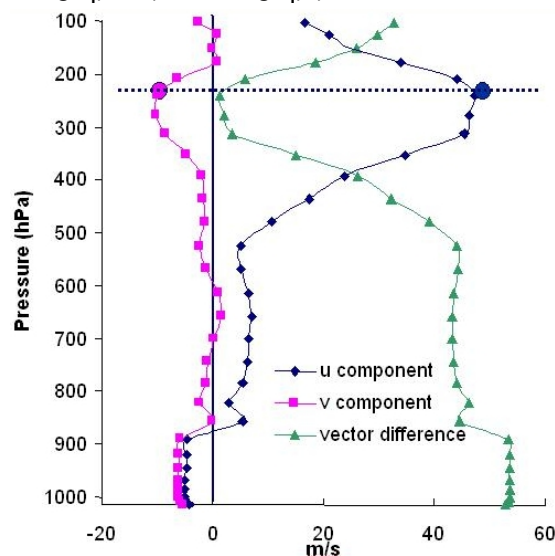Vector Difference$_i$ = $\sqrt{((ObU - BgU_i)^2 + (ObV - BgV_i)^2)}$

Figure 8: **An example of how the model best-fit pressure is derived for an AMV at 230 hPa with a u and v component indicated by the blue and pink circles. The vector difference between the observed u and v components and the background u and v components (blue diamonds and pink squares) can be calculated for each model level and gives the green triangles shown in this figure. The minimum in the vector difference profile is taken as the level of best fit.**

The model level of best fit is given by the minimum in the vector difference profile. In Figure 8, the AMV assigned pressure and model level of best-fit agree well. In using this approach it is important to be aware of some limitations. In the example in Figure 8, there is only one distinct minimum in the vector difference profile and the minimum is well-constrained to a band about 100 hPa thick. We can therefore have some confidence in the best-fit value. This is not always the case. Sometimes there is more than one minimum leading to an ambiguity in best-fit pressure and sometimes the minimum is very broad and thus badly constrained. Additionally, the background wind profile contains errors and only has a limited vertical resolution. Nevertheless the comparison of AMV pressures to model best-fit pressures is a useful technique for assessing AMV height assignment. A couple of examples are discussed in the following section that illustrate how the technique can be applied to better understand bias features observed in the NWP SAF O-B monitoring.

Case study - Sahara

We can compare the AMV and best-fit pressures for the case of the 0z run on the 8th December, which showed a marked fast speed bias at mid level over the Sahara region (see Figure 9).
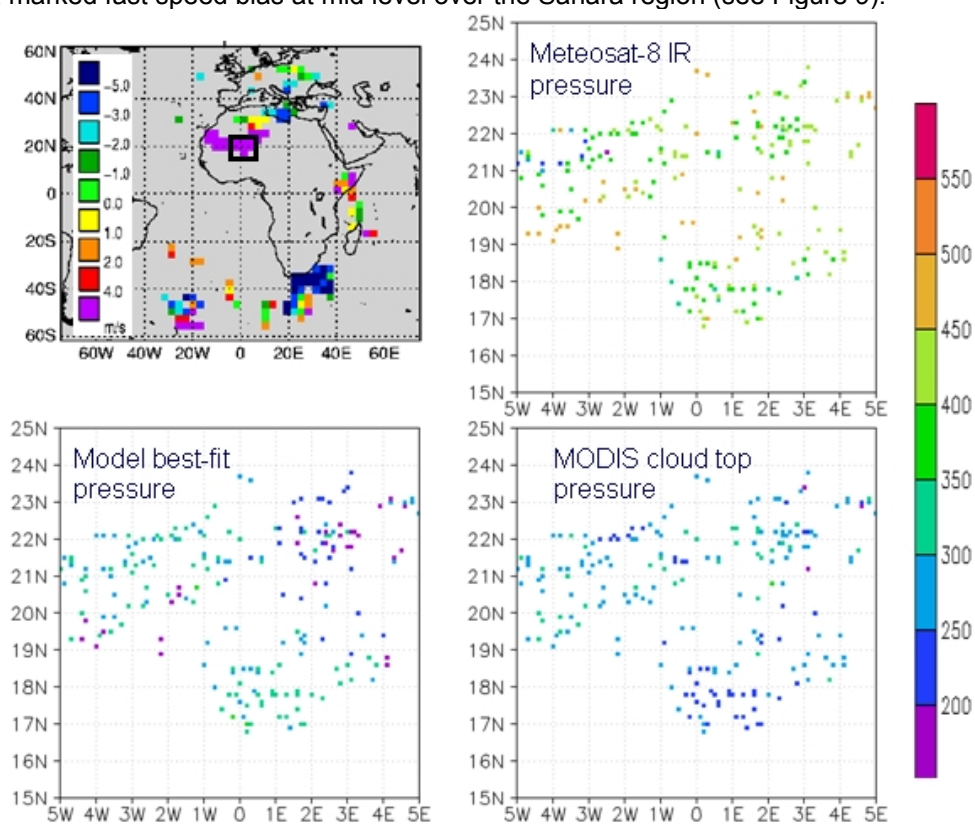
Figure 9: **A case study for 2100-0300 on the 7th-8th December showing the fast speed bias over the Sahara region. The AMVs are assigned to mid level (green colours), but both the model best-fit pressure and MODIS cloud top pressure are at higher levels (blue colours). Scale in hPa.**

The AMV pressures are mostly in the range 350-500 hPa. By comparison the model best-fit is consistently higher in the atmosphere between 150-350 hPa. The MODIS cloud top pressure product also indicates high clouds in this area, consistent with the model preferred location. Another way to look at the same information is by plotting a scatter plot of Meteosat-8 assigned pressure and model best-fit pressure compared with the MODIS cloud top pressure (see Figure 10). The collocated MODIS cloud top pressures are not valid for exactly the same time as the Meteosat-8 winds (6 hour period), so some spread is expected. What is very apparent though is the tendency for the Meteosat-8 winds to be located lower in the atmosphere. The second part of Figure 10 confirms, as expected, that the lower height assignment is linked to the use of the EBBT (Equivalent black-body temperature) method. The winds assigned using the CO_2 slicing method have heights much more consistent with both the model best-fit pressure and the MODIS cloud top pressure.
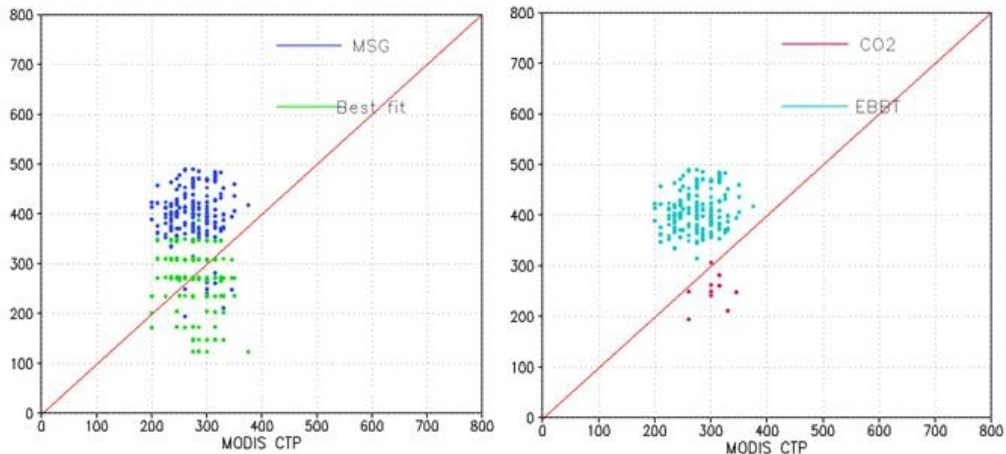
Figure 10: **Scatter plots comparing the Meteosat-8 (MSG) IR assigned pressure (blue) and model best-fit pressure (green) to the MODIS cloud top pressure. Note the good agreement of the model best-fit pressure with the MODIS cloud top pressure. With the exception of a few points, the Meteosat-8 pressure is consistently lower in the atmosphere. Also shown is the break-down of Meteosat-8 assigned pressure by height assignment method. The few cases where the CO_2 method was used agree fairly well with the MODIS cloud top pressure.**

It is not surprising that the EBBT method will put high thin cirrus cloud at mid level due to contributions from below the cloud. The more appropriate question is why the CO_2 slicing method is not used more often. Examination of a few cases indicates that the CO_2 method often fails or produces an unrealistically warm cloud top temperature. This is thought to be linked to the use of model forecast information to set the clear sky radiances. It may be particularly problematic over desert conditions where there may be more uncertainty in the representation of the surface temperature (big diurnal fluctuations). EUMETSAT are aware of the problem and are looking at ways to reduce the use of forecast information in the CO_2 height assignment.

Case study - southern edge of Meteosat-8 disc

The O-B speed bias from the 0z run on the 8th December shows a marked slow speed bias at mid level on the southern edge of the Meteosat-8 disc (see Figure 11).
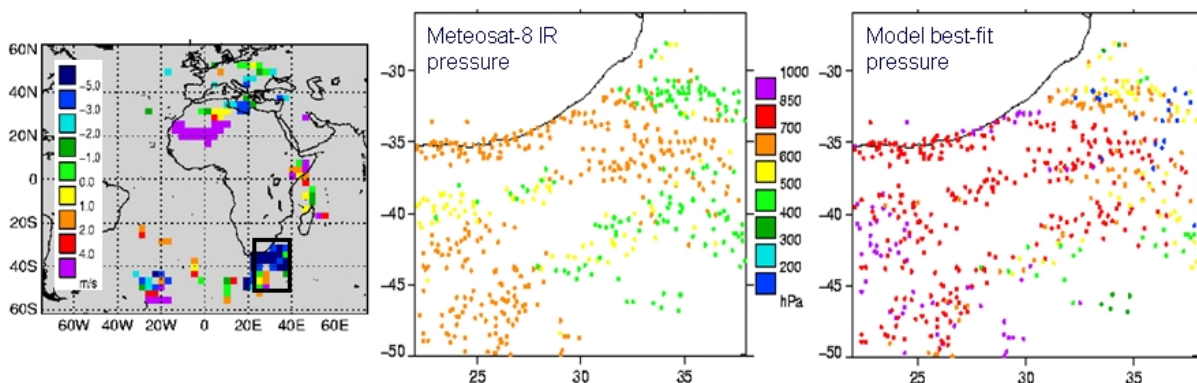
Figure 11: **A case study for 2100-0300 on the 7th-8th December showing the slow speed bias towards the southern edge of the Meteosat-8 disc. For clarity the Meteosat-8 IR pressure and model best-fit pressure plots are filtered to only show the AMVs assigned to mid level.**

The best-fit model pressure for most of the mid level AMVs is below 700 hPa. This region is commonly associated with complex multi-level cloud in the vicinity of the southern hemisphere jets and it would not be surprising if the height assignment was more problematic. One possible explanation for low level cloud being assigned to mid level could be due to radiance contributions from thin high level cloud affecting the EBBT method.

FUTURE WORK

Aside from the routine monthly updates to the AMV monitoring and updates of the information pages, the main goals for the NWP SAF AMV work are to ensure comparability of the data displayed (still some differences between ECMWF and the Met Office), include new AMV datasets as soon as is practically possible, add monitoring plots from other NWP centres (when available) and continue to analyse the results and produce update reports (at 2 yearly intervals).

In addition, it is planned to continue height assignment investigations using model best-fit pressures and other cloud top pressure products (see also Doutriaux-Boucher et al., 2006). This approach can be used to investigate some of the features identified in the NWP SAF O-B monitoring as illustrated in a couple of examples in this report. The approach could also be applied to assess different height assignment methods and height quality indicators. It could be used to compare datasets e.g. the unedited and final GOES and MODIS winds or the MTSAT-1R IR and cloudy WV winds. Finally, the mean and standard deviation statistics comparing the AMV pressures to model best-fit pressures is useful information when considering what height assignment errors may be appropriate for use in NWP and the model best-fit method could be adapted to investigate modifications to the observation operator to treat the AMVs as layer observations.

CONCLUSIONS

1. The NWP SAF AMV monitoring has already led to some improvements in AMV derivation and can be useful for designing quality control systems in NWP.
2. The monitoring can be used to evaluate new datasets or changes to existing datasets.
3. 2nd analysis conclusions include
    (i) The speed bias is often worse in regions of strong wind shear
    (ii) AMV height assignment is more prone to error in some areas e.g. multi-level cloud, over desert
    (iii) Existing quality indicators are not always a reliable guide to bad winds. A height error (or quality indicator) should help.
4. Comparisons to model best-fit and cloud top pressure products can be used to further understand features seen in the NWP SAF monitoring.
5. It is hoped that the NWP SAF AMV site and analysis reports will stimulate greater discussion within the AMV community.

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