ATMOSPHERIC MOTION VECTORS AT THE MET OFFICE: STATUS, RESULTS AND FUTURE PLANS

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Abstract

Atmospheric motion vectors (AMVs) have been assimilated operationally in the Met Office global model since the 1980s and are useful for providing dynamical information for forecast models. Despite their use over two decades, significant advances are still being made to the coverage and quality of the data. In the two years since the 7th International Winds Workshop we have made four operational AMV changes to our global model including use of the new MODIS polar wind dataset and transition from the Meteosat-7 to the new generation Meteosat-8 AMVs. Results of recent data denial experiments show that the AMVs are providing benefit despite the ever-improving global observing system. It may be possible to improve the impact further by better representing the errors in the data. Plans to improve the AMV observation errors at the Met Office are outlined, but full benefit of the approach will require more quality information from the data producers.

OPERATIONAL CHANGES SINCE IWW7

At the 7th International Winds Workshop (IWW7) in June 2004 we were assimilating SATOB-coded AMVs from GOES-9, 10 and 12 and BUFR-coded AMVs from Meteosat-5 and 7. In the two years up to April 2006 we have made 4 operational AMV changes to the global model: (1) the assimilation of the MODIS polar winds, (2) the replacement of GOES-10 and 12 SATOB-coded IR winds by GOES-10 and 12 BUFR-coded IR and cloudy WV winds, (3) the replacement of GOES-9 by MTSAT-1R AMVs and (4) the replacement of Meteosat-7 by Meteosat-8 AMVs.

The impact of the MODIS polar winds is discussed in more detail in Forsythe and Berger (2004) and Forsythe (2006) so only a short summary is included here. Overall the results using the NESDIS MODIS polar winds were modest, but positive, for the two seasons (Jan-Feb 2004 and Jul-Aug 2004) with most impact in the polar regions, particularly so in the northern hemisphere. Overall the strongest improvements were to the temperature, height and wind fields at mid levels (850 hPa – 250 hPa) at longer forecast range (T+72 onwards). Figure 1 illustrates a forecast case for the 14th August 2004 where the inclusion of the MODIS polar winds significantly improved the forecast of 500 hPa geopotential height over N. America at all forecast ranges. The figure also illustrates how the MODIS data, which is only available north of about 65N, can still improve forecasts in the mid-latitudes. The results of the MODIS trials are encouraging considering the time delay between observation time and receipt time for the MODIS winds means we are only able to use significant amounts of data in our global update runs that produce the background for the next forecast cycle. Very little data arrives in time for the main forecast runs (begin ~4 hr and 40 minutes after the start of the time window). We look forward to ongoing developments to improve the timeliness of the winds through use of direct broadcast stations and production of combined Aqua-Terra winds (Key et al., 2006). The polar AMVs are a useful addition to the observing system and we strongly support efforts to ensure continuity including the development of AVHRR winds.

The change from use of SATOB-coded GOES IR to BUFR-coded GOES IR and cloudy WV is part of the broader transition to BUFR-coded AMVs. The initial usage of the GOES BUFR data is fairly conservative and the assimilation experiment results were neutral.

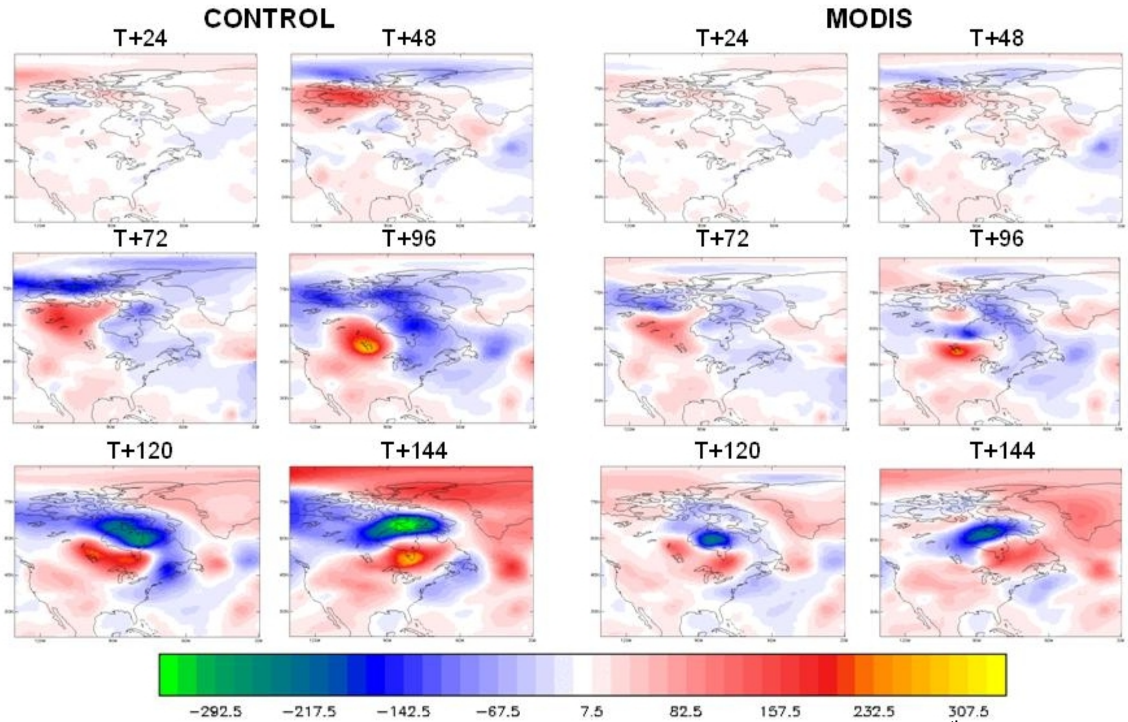

Figure 1: **Forecast error evolution for the 500 hPa geopotential height forecasts generated on 14th August 2004 for the control and MODIS trials. Forecast error is calculated as the forecast field minus the trial analysis valid at that time. Note the smaller errors for all forecast ranges in the MODIS experiment compared to the control. The figure also illustrates how the information added to the polar regions spreads equatorwards improving the medium range forecasts at lower latitudes.**

The change from GOES-9 to MTSAT-1R took place after a period of monitoring against the Met Office model background. There was a small degradation in the quality of the data, but it was considered to be of sufficient quality for operational use. The MTSAT-1R SATOB-coded winds have since been trialled (Dec 05 – Jan 06) as part of the transition work to the BUFR-coded winds. The results indicate a small positive impact, particularly in the northern hemisphere. Initial trials with the BUFR-coded data are, however, giving small negative impact.

The final operational change was made in March 2006 when the Met Office started to assimilate the Meteosat-8 winds in the global model. Meteosat-8 is the first of a series of Meteosat Second Generation satellites (MSG) that incorporate several improvements over the First Generation including extra channels, better pixel resolution and more frequent scanning. In addition, EUMETSAT are using a completely new processing stream. The Meteosat-8 AMVs have improved significantly since IWW7 and now generally outperform the Meteosat-7 AMVs. Figure 2 shows the root mean square vector difference for Meteosat-7 and Meteosat-8 IR winds compared with the Met Office background. A QI (with first guess check) threshold of 80 was applied to both datasets.

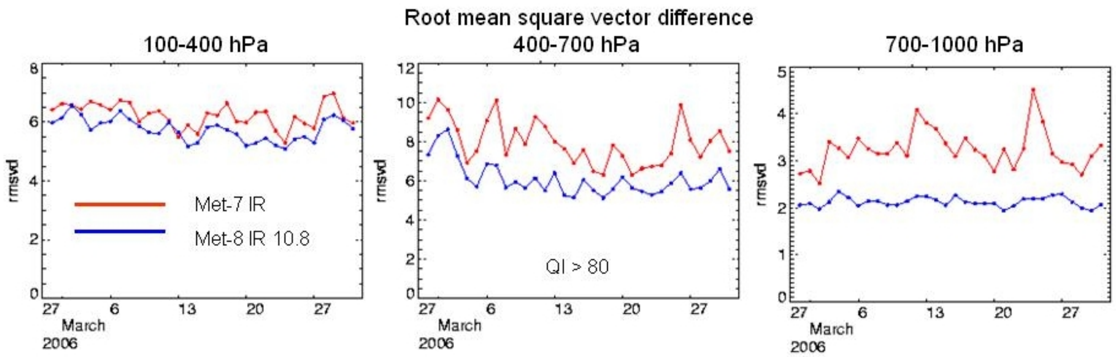

Figure 2: **Time series for March 2006 of root mean square vector difference of the Meteosat-7 and 8 IR winds compared with the Met Office model background (QI threshold of 80 applied). Note the consistently lower rmsvd of the Meteosat-8 IR winds compared with the Meteosat-7 IR winds at all levels. The difference is biggest at low level (700-1000 hPa).**

Two one-month experiments were run for Jul-Aug 2005 and Dec 2005 – Jan 2006 comparing the use of Meteosat-7 and Meteosat-8 AMVs, which gave neutral and moderately positive results respectively. Figure 3 is an example from the winter trial. It shows the impact on a reduced list of forecast parameters that are used to calculate the Met Office global NWP index (an index of the overall quality of global NWP products). The replacement of the Meteosat-7 AMVs by the Meteosat-8 AMVs gives a fairly consistent benefit (bars below the line), with the main improvement coming from the southern hemisphere pressure at mean sea level and tropical wind fields.

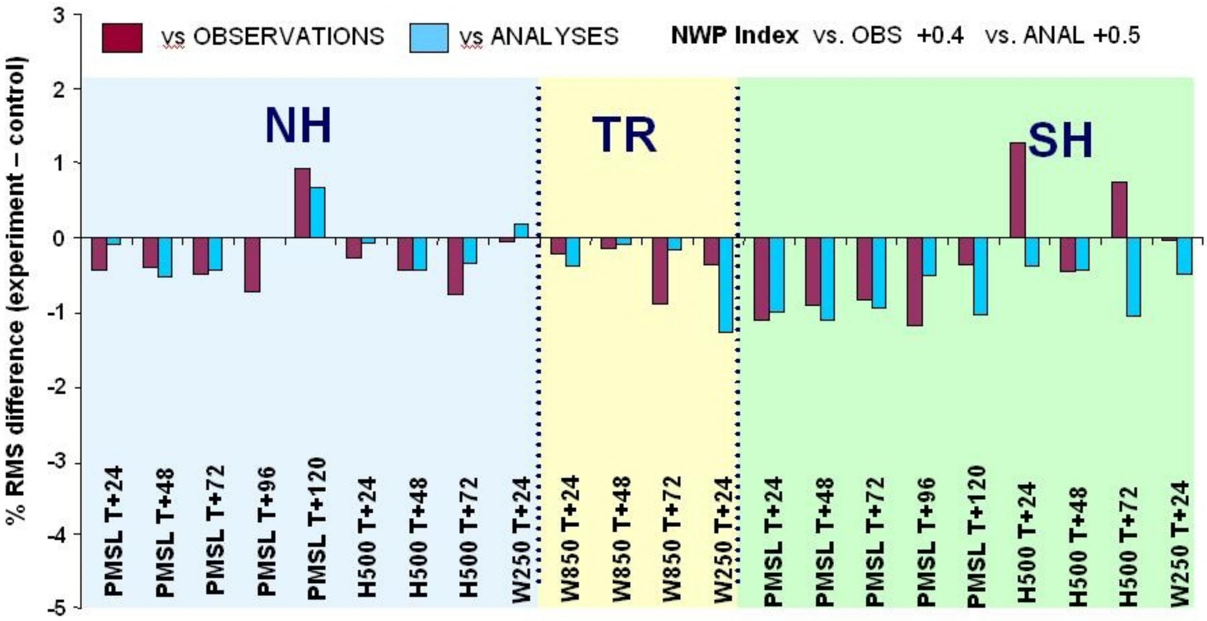

Figure 3: **Changes in % root mean square difference between the Meteosat-8 trial and control trial (uses Meteosat-7) for certain forecast parameters (pressure at mean sea level (PMSL), 500 hPa geopotential height (H500), 850 hPa and 250 hPa wind fields (W850 and W250)). Forecasts are verified against selected observations and trial analyses. Bars below the line indicate a positive result for the Meteosat-8 trial. Most forecast parameters show an improvement when the Meteosat-8 AMVs were assimilated instead of the Meteosat-7 AMVs.**

INCREASED USE OF AMVS IN 4DVAR

Only a small percentage of AMVs are currently assimilated in the Met Office global model (<5% of received data). One constraint applied to the geostationary AMVs is to consider only the batch of data from each satellite that arrives closest to analysis time; for example the Meteosat-5 AMVs valid at 1200 UTC would be used in our 12z run. All other batches in the 6 hour time window (0900, 1030, 1330, and 1500) are automatically blacklisted. However, since 2004, the Met Office global model has been using 4D-Var and this might benefit from using observations throughout the time window. An important consideration is the possible impact of temporally correlated error in the AMV data. The planned approach is to remove the time window restrictions, but introduce thinning in time using a 2 hour box size.

A one-month trial was run for Jul-Aug 2005. Some improvement was seen in the northern hemisphere and tropics, but this was outweighed by a significant negative impact in the southern hemisphere (e.g. Figure 4).

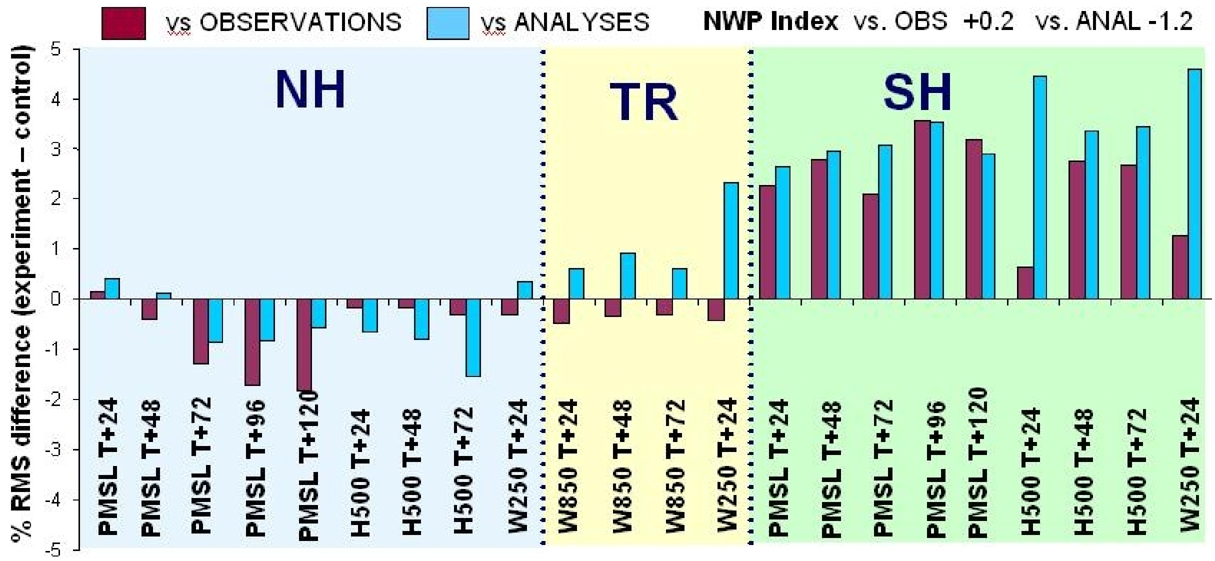

Figure 4: **Changes in % root mean square difference between the increased data usage trial and control trial for certain forecast parameters (pressure at mean sea level (PMSL), 500 hPa geopotential height (H500), 850 hPa and 250 hPa wind fields (W850 and W250)). Forecasts are verified against selected observations and trial analyses. Bars below the line indicate a positive result for the increased data usage trial. Some improvement is seen in the northern hemisphere and tropics, but significant negative impact is seen in the southern hemisphere.**

We can investigate the negative impact in the southern hemisphere further to identify possible reasons for the poorer forecasts. Figure 5 shows an example forecast-analysis error time series plot for the T+24 hr southern hemisphere 500 hPa geopotential height. The trial performs consistently worse throughout the period, but one noticeably bad case is the T+24 hr forecast valid on 19th August 2005. A forecast-analysis map plot for this time is shown in Figure 6 for the control and trial. Notice the bigger forecast-analysis error in the trial compared with the control in the southern Indian Ocean. Looking back at the mid level wind analysis increments for 18th August, shown in Figure 7, it is clear there are larger increments in the increased data usage trial compared with the control. The analysis increments are consistent with the O-B vector differences for the mid level Meteosat-8 IR AMVs. Inspection of the wind field indicates the O-B vector difference is consistent with a slow speed bias, something that is frequently observed for the mid level Meteosat AMVs on the southern edge of the disc. Investigations (e.g. Forsythe et al., 2006) suggest that some AMVs assigned to mid level in this area agree better with model winds at lower levels. In summary, it looks like AMVs with suspect height assignment may be partly responsible for some cases of forecast error. It should be noted that both control and trial use the Meteosat-8 data, but the impact may be worse in the trial because more data is assimilated and the errors may be temporally correlated. Following the negative impact, this work has been put on hold while we investigate improvements to our AMV quality control.

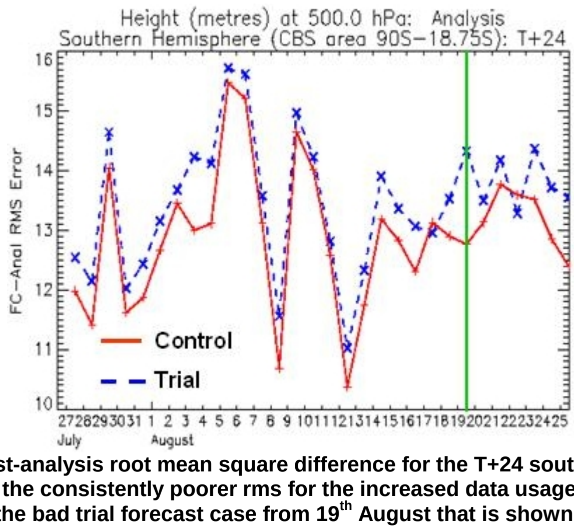

Figure 5: **Time series of forecast-analysis root mean square difference for the T+24 southern hemisphere 500 hPa geopotential height field. Note the consistently poorer rms for the increased data usage trial compared with the control. The green line marks the bad trial forecast case from 19th August that is shown in subsequent figures.**

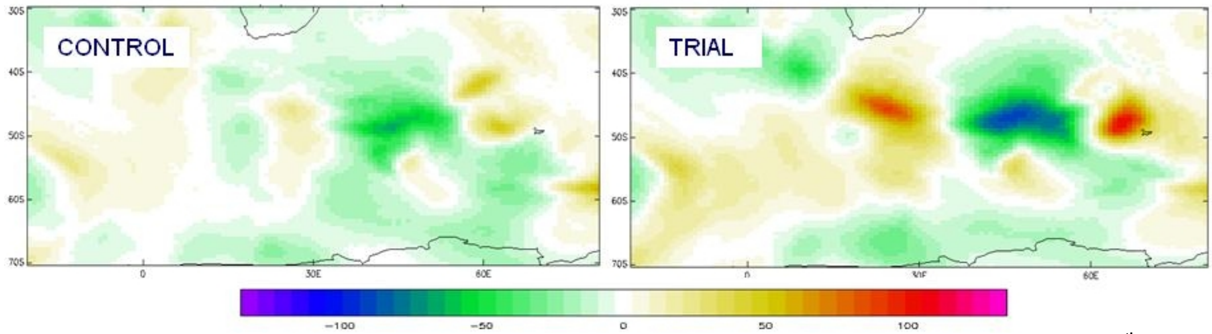

Figure 6: **Map plot showing forecast-analysis difference for the T+24 hr 500 hPa geopotential height valid on 19th August 2005 for the control and trial (units in m). The land area shown at the top is the southern tip of Africa. Note the bigger errors seen in the southern Indian Ocean in the trial compared with the control.**

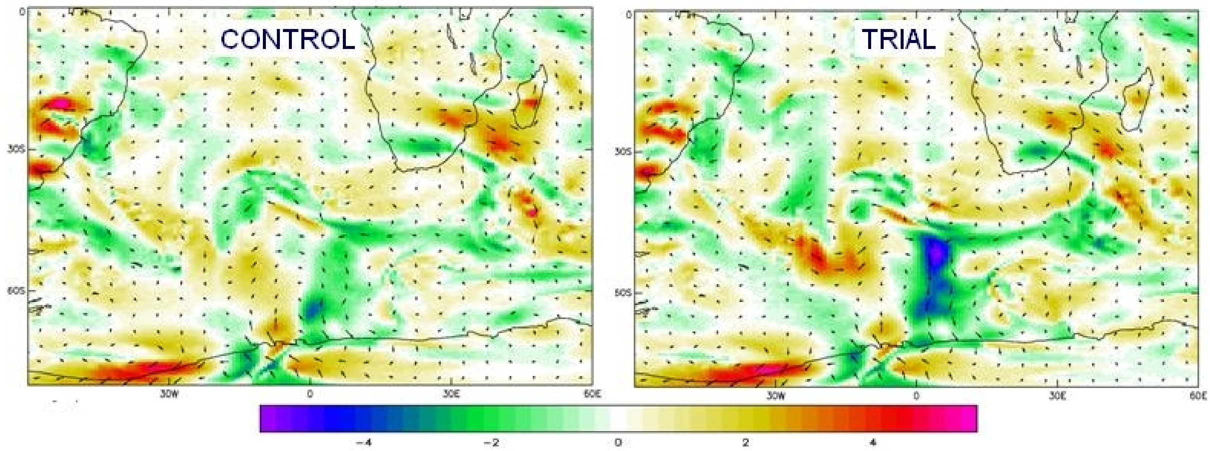

Figure 7: **Map plot showing the 500 hPa wind increments for the 18th August 2005 analysis. Note the bigger increments to the south-west of Africa in the trial compared with the control (units in m/s). These increments are upstream of the forecast error seen in Figure 6 and are consistent with O-B vector differences for the mid level Meteosat-8 IR winds.**

DATA DENIAL EXPERIMENTS

Two sets of AMV impact experiments have been run for a month during December 2005 to January 2006 using a 4D-Var N216 50 level model. The first is a conventional AMV data denial experiment and the second is an AMV addition onto a no-satellite baseline. Only very preliminary verification has been carried out.

The no-AMV experiment shows a small, but fairly consistent, degradation in forecast performance compared to the control (e.g. Figure 8). In the absence of other satellite data, the AMVs show a much bigger benefit, giving almost half the skill difference between the no-satellite baseline and the full observing system. The difference in the results is due to a large degree of redundancy in the observing system. Much of the benefit of the AMV data can also be derived from other observation types. This should not be regarded as a negative result, as it implies the observing system is robust and consistent. The approach may have implications for future trialling as impacts may be clearer to see if tested in the no-satellite + AMV framework. Further testing with the operational observation usage would, however, be required prior to any operational change to ensure there was no interaction with other satellite data.

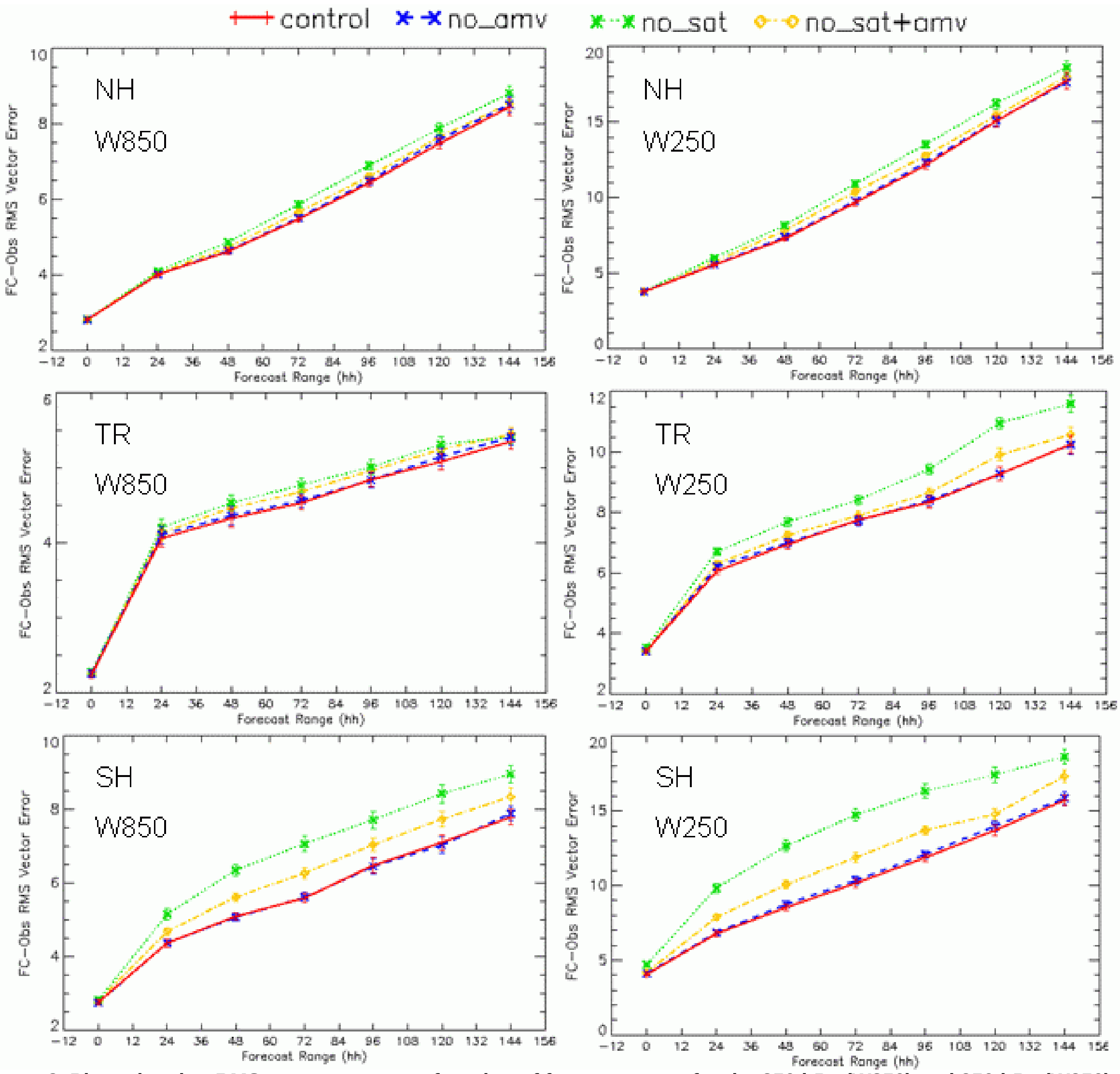

Figure 8: **Plots showing RMS vector error as a function of forecast range for the 850 hPa (W850) and 250 hPa (W250) wind fields for the northern hemisphere (NH), tropics (TR) and southern hemisphere (SH) for the four trials verified against sondes. The trials were run for one month from 12th December 2005 to 11th January 2006. The 68% error bars are calculated using $S/(n-1)^{1/2}$.**

It is hoped that a full analysis of the AMV denial experiment and the AMV on no-satellite baseline experiment should provide a better understanding of how the AMVs benefit NWP and possibly more critically may highlight areas where we may need to improve the way the AMVs are assimilated.

NEW OBSERVATION ERRORS

Like many NWP centres, the Met Office AMV observation errors vary only with pressure (see Table 1). They are based on O-B statistics from 2000, but are then doubled to alleviate problems with correlated error (Butterworth et al., 2002).

Level (hPa)	1000	850	700	500	400	300	250	200	150	100	70
Error (m/s)	3.6	2.8	4.0	4.8	6.2	6.2	5.6	5.8	6.6	11.8	11.8

Table 1: **AMV observation errors used in the Met Office models.**

But is this the best we can do? We know the errors vary widely dependent on many factors; examples include the complexity of the cloud in the target window, the height assignment method applied and errors in the forecast data (used in the height assignment and in some cases also as a first guess in the tracking). One option is to generate individual observation errors for each wind using information on the quality of the AMV vector and height assignment. Assuming the AMV vector and height errors are independent (reasonable assumption), the total AMV error can be calculated as the sum of the vector error with the error in the vector due to the height error. The error in vector due to the error in height can be calculated using the model background wind profile and an estimate of the height error. With this approach, the same height error will yield a bigger error in vector due to the error in height in regions of high vertical wind shear. It therefore allows us to down weight winds where a height assignment error would be more problematic, but allows us to give greater weight to winds where the height assignment is less critical.

The inputs required for the planned method of calculating the individual observation errors are estimates of the error in the height assignment and in the u and v wind components. Estimates are not yet available routinely with each AMV. Until they are available, we could benefit from applying the approach using fixed values for the u, v and height errors or by modifying them based on available data (e.g. pressure level, height assignment method etc.). The best longer-term solution is, however, to set the error estimates individually to reflect the confidence in the vector and height derivation. If we can reflect the AMV observation errors more accurately, we should ultimately improve the forecasts by reducing the influence of bad data and allowing good data to correct the background. With this in mind, we strongly encourage ongoing work to better characterise the AMV errors and to develop separate vector and height error estimates (or quality indicators) with each wind.

FUTURE WORK

Aside from the monitoring, future AMV work at the Met Office divides broadly into two main areas. The first involves making use of new AMV datasets. Anticipated work in this area includes adapting to planned satellite changeovers (GOES-10 to GOES-11, Meteosat-8 to Meteosat-9 and Meteosat-5 to Meteosat-7), transitioning to BUFR datasets (MTSAT-1R, Indian winds), testing new products (GOES 3.9µm winds, FY-2C winds, AVHRR winds) and checking changes to existing products (MODIS direct broadcast and other planned changes). This work inevitably takes much of the time so the second area of work, aimed at improving the way we use the AMV data in NWP, is often neglected. There are, however, many things we want to try in this area. The main objective for the coming year is to work on the individual observation error method discussed in the previous section. As part of this work, we will look at relaxing the blacklisting constraints and moving to more forecast independent data (forecast-independent QI and pre-autoeditor GOES and MODIS winds). Other slightly longer-term plans are to investigate modifications to the observation operator to treat the wind as a layer observation, revisiting the background check, development of variational quality control and revisiting use of more data in 4D-Var.

REFERENCES

Butterworth, P., S. English, F. Hilton and K. Whyte (2002). Improvements in forecasts at the Met Office through reduced weights for satellite winds. Proceedings of the 6th International Winds Workshop, Madison, 163-170.

Forsythe, M. (2006). Assimilating MODIS polar winds in the Met Office system. Met Office Forecast Research Technical Report, 483 (in review).

Forsythe, M., M. Doutriaux-Boucher and A. Garcia-Mendez (2006). What can we learn from the NWP SAF AMV monitoring? This volume.

Forsythe, M and H. Berger (2004). MODIS winds: latest results at the Met Office. Proceedings of the 7th International Winds Workshop, Helsinki, 273-280.

Key, J., W. Straka III, D. Santek, C. Velden and R. Dworak (2006). Satellite-derived winds at direct broadcast sites in the polar regions and AVHRR polar wind historical reprocessing efforts. This volume.