Atmospheric Motion Vectors: Past, Present and Future

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ABSTRACT

Atmospheric motion vectors (AMVs) are derived by tracking clouds or areas of water vapour through consecutive satellite images. They are an important source of tropospheric wind information for numerical weather prediction (NWP), particularly over the oceans and at high latitude where conventional wind data (sondes and aircraft) are scarce. Fujita pioneered the development of AMVs during the 1960s and 70s and they have been assimilated operationally since the 1980s. Results of recent data denial experiments show that the AMVs are providing benefit despite the ever-improving global observing system. But it may be possible to improve the impact. One of the difficulties is that the AMV errors are hard to characterise. Improving our understanding of the errors may highlight where the wind derivation and height assignment can be improved and may provide useful guidance for AMV assimilation in NWP including blacklisting, observation errors and the observation operator. By working together within the AMV community to improve the AMV data (including access to more information on the data quality) and to improve the assimilation strategy, we should be able to gain more impact from this data type in NWP.

1. Introduction

In the 20-30 year history of atmospheric motion vector (AMV) assimilation in NWP they have been known by many names including satellite winds, cloud motion winds and feature track winds. They are produced by tracking cloud or areas of water vapour in consecutive satellite images. Traditionally geostationary imagery was used due to the frequent viewing of the same area of the Earth's atmosphere. The AMVs can be produced by tracking in several channels including the infrared window at 11 µm (IR), the WV absorption (WV), the visible (VIS) and the infrared 3.9 µm. The main derivation steps are:

1. Correct and rectify the raw data
2. Locate a suitable tracer within the image
3. Perform a cross-correlation to locate the same feature in an earlier or later image
4. Calculate the vector from the displacement in tracer location
5. Assign a height to the vector
6. Perform quality control

The final AMV is an average of two or three component vectors calculated from a sequence of three or four images. An example of the tracking step is shown in Figure 1. For further details of the AMV derivation see Schmetz et al. (1993) and Nieman et al. (1997).

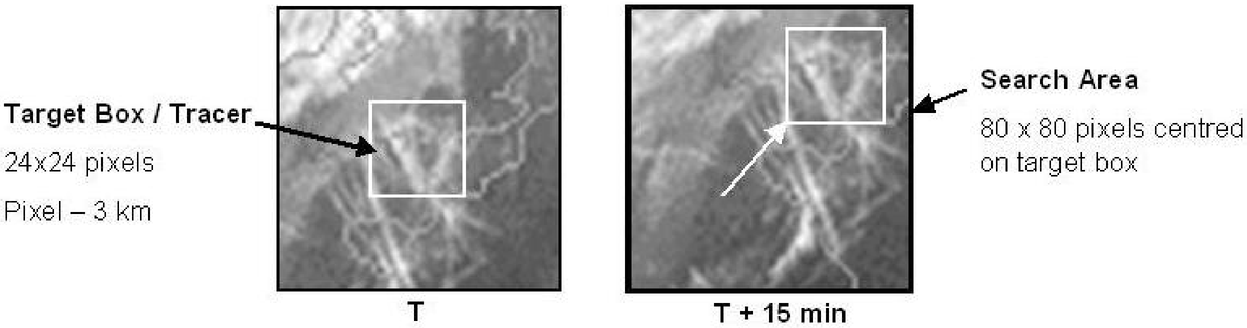


Figure 1: An illustration of the AMV tracking step for Meteosat-9 IR AMVs. The location of the target in the later image is determined by best match of the individual pixel counts of the target with all possible locations of the target in the search area using cross-correlation in the Fourier domain. The wind vector is taken as the displacement between the locations of the target boxes in the two images.

Many centres produce the AMV data including EUMETSAT in Europe, NOAA/NESDIS and CIMSS in the USA, JMA in Japan, IMD in India, CMA in China, CPTEC in Brazil and BoM in Australia. There is some variation in the details of the AMV derivation from centre to centre, which can complicate the assimilation.

There are various sources of error in the AMV data that can be introduced in the tracking and height assignment. Sometimes all AMVs in a particular area will be affected by the same errors and similar errors can persist to the next derivation cycle. This tendency means that the AMV data have temporally and spatially correlated errors. Another consideration for NWP is how well the final AMV represents the wind field at a specific location, height and time. As Schmetz & Nuret (1989) stated, the AMVs could only give an unbiased estimate of the winds if clouds were conservative tracers randomly distributed within and floating with the airflow. This is clearly not the case; clouds are not randomly arranged, but associated with specific conditions (ascending air masses) and some clouds do not move with the wind. This will remain a limitation even if we can improve the AMV data quality and representation of the errors.

In the following sections I shall cover why NWP centres are interested in AMVs, how they have evolved, some of the main areas of current research and what developments we can expect to see in the future.

2. Why do we care about AMVs for NWP?

Although they do not provide wind profile information, the AMVs are the only tropospheric wind data type to have good areal coverage, particularly over the southern oceans and at high latitudes. Why is this important? Although the mass field, which is well observed, can be used to derive the wind field in the extra-tropics, it is less good in the tropics and for smaller scale features where geostrophic coupling is weaker. For best results, models require information on both the mass field and the wind field.

Two sets of AMV impact experiments have been run for a month during December 2005 to January 2006 using the Met Office 4D-Var model at N216 50 level resolution. The first is a conventional AMV data denial experiment and the second is an AMV addition onto a no-satellite baseline. The no-AMV experiment shows a small, but fairly consistent, degradation in forecast performance compared to the control (e.g. Figure 2). 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.

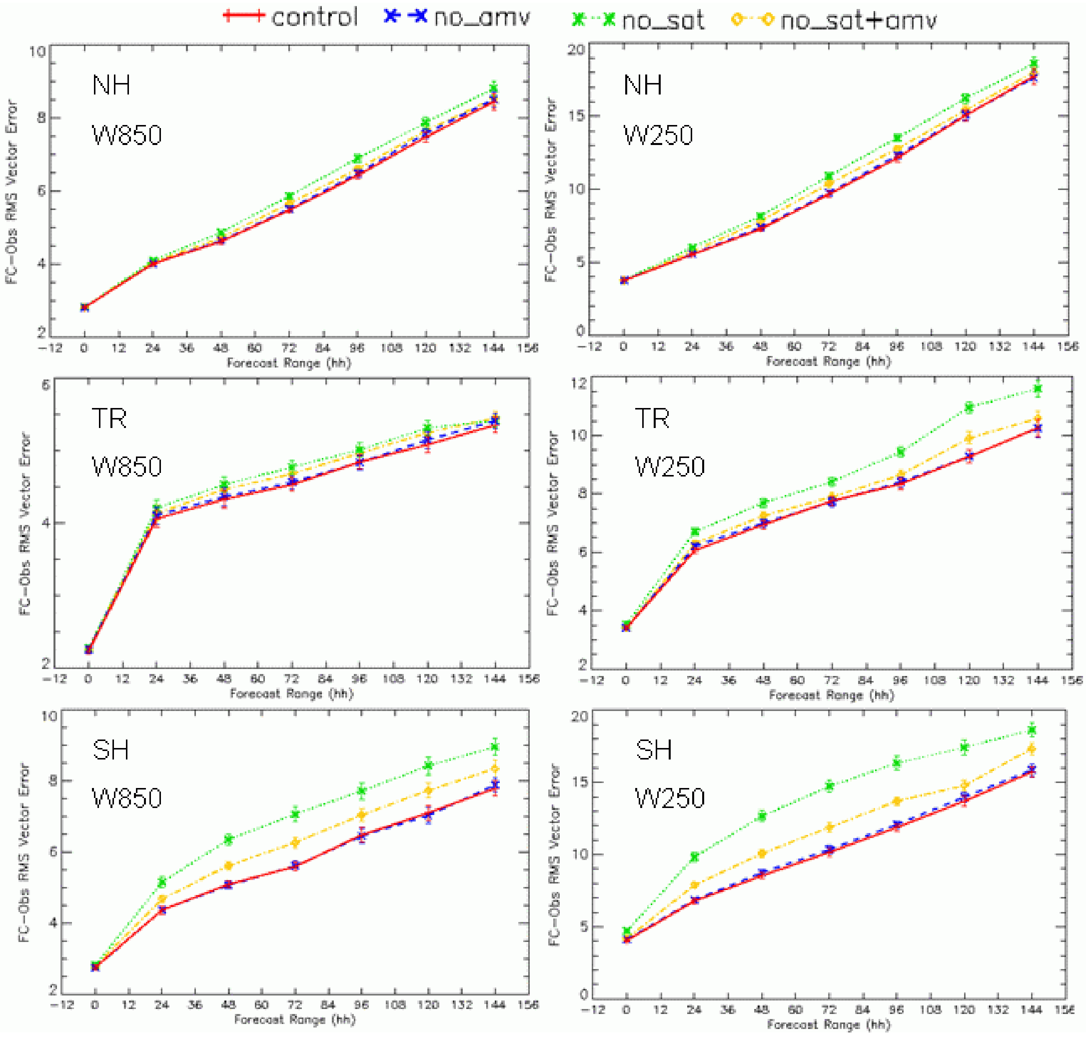


Figure 2: Plots showing RMS vector error as a function of forecast range for the 850 hPa (W850) and 250 hPa (W250) wind fields for the northern hemisphere (NH), tropics (TR) and southern hemisphere (SH) for the four trials verified against sondes. The trials were run for one month from 12th December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

Several studies have shown the benefit of AMV data on tropical cyclone track forecasts (e.g. Soden et al. 2000). Results of a recent study at CIMSS using the GFS model at low resolution during the 2005 tropical cyclone season showed a negative impact on tropical cyclone track accuracy at all forecast ranges when GOES AMVs were removed from the system (Howard Berger, pers. comm.).

3. The Past

Tetsuya Fujita pioneered the work on remote sensing of atmospheric motion in the 1960s and 70s. His work utilised data from the first polar and geostationary meteorological satellite missions: TIROS-1 launched in 1960 and ATS-1 launched in 1966. The early work was targeted at improving understanding of atmospheric circulation at all scales and validation of AMVs against winds derived from ground cameras; for more information see Menzel (2000). Routine production of the AMVs began in the mid to late 1970s. In 1979, the First GARP Global Experiment (FGGE) was run where AMVs from five geostationary satellites were produced twice daily for a year. An assimilation experiment at ECMWF during this time showed positive benefit of the AMV data although some errors in both the AMV data and the model were noted (Kållberg et al. 1982).

Since this time the quality and quantity of AMV data have markedly increased as evidenced from long-term time-series statistics (see example in Velden et al. 2005) and reprocessed AMVs (e.g. Gustafsson et al. 2002). This can partly be explained by improvements to the satellite imager instruments; for example the greater channel range (12 on the Meteosat Second Generation SEVIRI imager), the shorter time interval between image scans (15 minutes) and the improved pixel resolution (pixel size at sub-satellite point as low as 1 km, but more typically 3-4 km). Some of the extra channels can be used for tracking; for example the visible and near-infrared channel at 3.8µm provide additional low level vectors during the day and night respectively and the water vapour absorption region around 7µm can be used to track high level clouds and gradients in water vapour in clear sky areas. By tracking in more channels, the coverage of AMV data is improved, but probably of more importance is the improvement to height assignment made possible through the use of multi-channel height assignment methods using the water vapour and carbon dioxide channels. The other main development area has been in the derivation. This is now fully automatic at most centres, which has enabled the production of AMVs at higher spatial and temporal resolution. The methodology has been improved and quality indicators have been developed (e.g. Holmlund 1998; Hayden & Purser 1995). The quality indicators (QIs) are sent in the BUFR with each AMV and can be used for thresholding and thinning selection in NWP. Although they are useful, a major limitation of the existing QIs is a lack of sensitivity to height assignment error, which is thought to be the main source of error in the AMV data.

One major development in recent years has been the routine provision of AMVs over the polar regions by tracking clouds and clear sky water vapour features in MODIS and AVHRR imagery. AMVs are generated in the same way as for geostationary data by tracking motion between successive images; this is possible in the polar regions where the polar orbiter overpasses overlap. They thus provide a very complementary data source to the traditional geostationary winds and together provide almost complete global coverage.

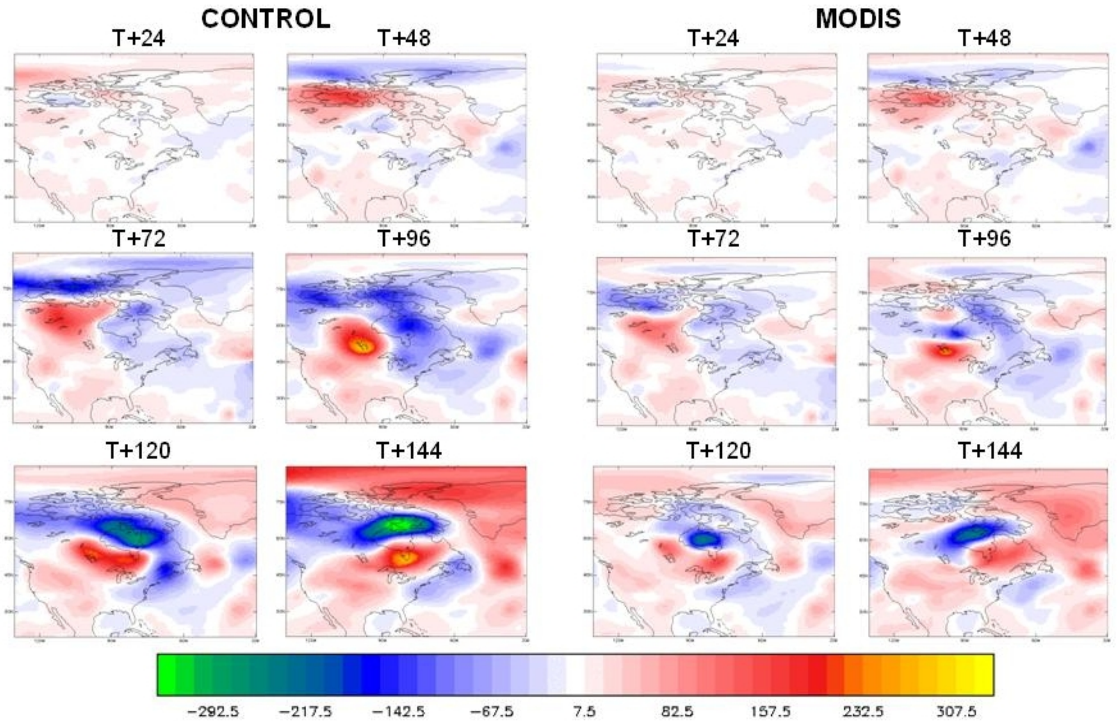


Figure 3: Forecast error evolution for the 500 hPa geopotential height forecasts generated on 14 August 2004 for the control and MODIS trials. Forecast error is calculated as the forecast field minus the trial analysis valid at that time.

Assimilation trial results using the NESDIS MODIS polar winds were modest, but positive, at most NWP centres with most impact in the polar regions (e.g. Bormann & Thépaut 2004; Forsythe 2006). At the Met Office the strongest improvements were to the northern hemisphere temperature, height and wind fields at mid levels (850 hPa – 250 hPa) at longer forecast range (T+72 onwards). Figure 3 illustrates a forecast case for 14 August 2004 where the inclusion of the MODIS polar winds significantly improved the forecast of 500 hPa geopotential height over North America at all forecast ranges. The figure also illustrates how the MODIS data, which are only available polewards of 65N/S, can 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 (averages 280 minutes) 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 few MODIS winds arrive in time for the main forecast runs. Improvements in the AMV data coverage in both cycles has been observed following the introduction of direct broadcast MODIS AMV assimilation at the Met Office in December 2006. The direct broadcast MODIS winds do not provide full polar coverage, but arrive on average 100 minutes sooner than the conventional MODIS winds (see Key et al. 2006 for more information).

4. The Present

In terms of current work perhaps the first question to ask ourselves is do we believe we can improve the impact of AMV data in NWP. I think we can, although it is going to be hard with the ever improving observing network. One of the main difficulties for AMV data are their complicated errors. The main source of error is thought to be the height assignment. This is likely to be more of a problem in regions of high wind shear, where an error in the height could introduce a large vector error. As an example if a wind is assigned 80 hPa too low or too high in a region of strong shear the resultant vector error could be more than 10 m/s.

To improve the impact in NWP I believe the best approach is to attack on several fronts through improving the AMV data quality and improving the way the data are assimilated. To achieve this it is essential to understand more about the AMV data and the sources of error.

There are several reasons why the height assignment can be problematic. Firstly it can be difficult to identify which pixels from the target area to use in the height assignment. The target can contain over 100 pixels and these may reflect cloud at different levels in the atmosphere, only some of which may have contributed to the tracking step. Secondly, assumptions are made about which level in the cloud controls the motion.

Generally the AMVs are assigned the height of the cloud top, except in some cases for low level winds which are assigned to the level of cloud base. One idea is to represent the AMVs instead as layer winds. Finally the height assignment methods themselves have limitations.

AMV height assignment relies on the use of radiative transfer models, forecast profiles of temperature and moisture and observed radiances in one or more channels. There are some general error sources affecting all height assignment methods including the limitations of radiative transfer models to accurately represent the real world, the accuracy and resolution of short-period forecasts and the calibration of the satellite channels.

There are two main approaches to cloud top height assignment. The equivalent black-body temperature (EBBT) approach compares the measured brightness temperature to forecast temperature profiles from an NWP model to find the level of best agreement. The main draw-back is for semi-transparent or sub-pixel cloud where the observed radiance will contain contributions from below the cloud and in these situations the wind will be assigned to too low a level. The second approach utilizes radiances in more than one channel, either using the CO_2 and IR channels (CO_2 slicing e.g. Menzel et al. 1983) or the WV and IR channels (WV intercept techniques e.g. Szejwach 1982). Although the two methods are often described differently, they are essentially the same approach that utilises the differences in radiances in two channels in cloud and clear sky areas. The main advantage of the multi-spectral approach is for higher level semi-transparent and sub-pixel cloud, where the EBBT method will tend to put the AMVs too low. The main disadvantage is that they lose sensitivity lower in the troposphere.

Most AMV producers apply a cloud base technique to low level AMVs following work by Hasler (1979) who compared aircraft wind data to AMVs produced from tracking cumuli type marine cloud and found the AMVs were best correlated with the wind at cloud base. A final correction is applied to low level winds in some derivation schemes in inversion regions to alleviate the problem where AMVs are assigned too high due to an under-representation of the depth of the inversion in the model temperature profile. The inversion correction will relocate the AMV to the minimum temperature of the inversion. Although ideally this correction should not be necessary (higher resolution and more realistic temperature profiles in the future may make it redundant) it nonetheless is thought to be useful in the current system.

Errors in the AMV derivation can be better understood by assessing some of the potential sources including navigation, calibration, tracking, radiance biases, forecast data, radiative transfer models, height assignment, the assumption that clouds are passive tracers and the validity of assigning the motion to a specific height. Alongside this more theoretical approach, it is useful to investigate the AMV data quality by comparisons to NWP model short-period forecasts, to other wind observations and to other sources of cloud top pressure.

The Satellite Application Facility for Numerical Weather Prediction (NWP SAF) AMV monitoring has a primary goal of gaining a better understanding of the errors in the AMV data by comparing monthly O-B monitoring output from different NWP centres. The NWP SAF AMV monitoring is freely available at http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/ and analysis reports are produced every 2 years. The AMV height assignment can be investigated by comparison with model best-fit pressures (e.g. Forsythe et al. 2006) or sonde/wind profiler best-fit pressures (e.g. Daniels et al. 2006) and by comparison with other cloud top pressure methods. A visual inspection of AMVs overlain on the satellite imagery can be beneficial for matching some problems with specific cloud features in the imagery. Using this combined approach it has been possible to identify some general trends in the height assignment quality and to note some specific cases where the height assignment methods may not be performing optimally.

Care is required in interpreting the results of these investigations. Errors exist in the NWP model backgrounds, in the AMV data and in other wind observations; none can be assumed to be the truth. However, we can have more confidence if several approaches yield similar results, particularly if the problem can be understood from knowledge of the limitations in the AMV derivation. One example is provided below where investigation helped to lead to improvements in the AMV derivation and ultimately the data quality.

The NWP SAF AMV monitoring plots can be useful as a starting point for identifying trends. A fast speed bias (more than 8 m/s) can be seen over North Africa in the winter months (e.g. Figure 4). The bias is thought to be due to faster higher level winds being assigned too low as suggested by the low height bias between 300 and 500 hPa in Figure 5. This will lead to a bigger speed bias in the winter when the sub-tropical jet, which crosses this area, is stronger.

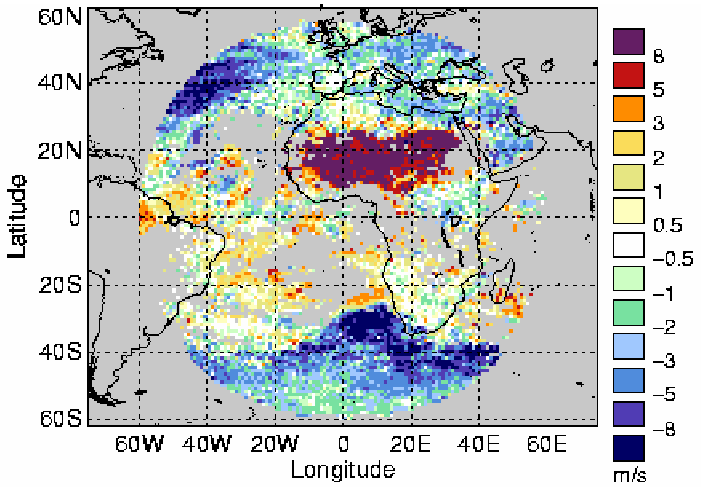
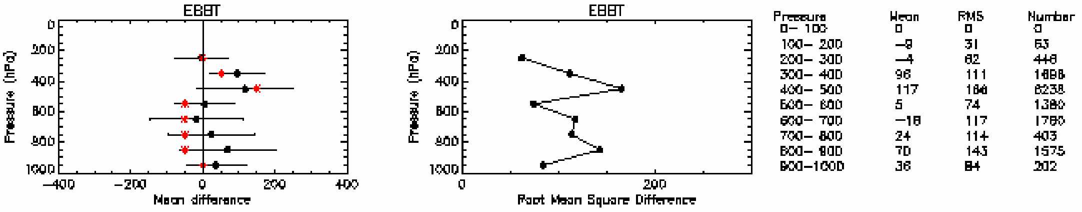


Figure 4: O-B speed bias plot for Meteosat-8 IR mid level winds compared with the Met Office model background for November 2005.



Pressure	Mean	RMS	Number
0– 100	0	0	0
100– 200	−8	31	63
200– 300	−4	82	448
300– 400	96	111	1886
400– 500	117	166	6238
500– 600	5	74	1380
600– 700	−18	117	1780
700– 800	24	114	403
800– 900	70	143	1575
900–1000	36	84	202

Figure 5: Mean difference and root mean square difference between the observed pressure and best-fit pressure for Meteosat-8 IR EBBT winds for November-December 2006. In the mean difference plots, the black dots represent the mean and the bars either side represent the standard deviation. The red dots indicate the mode of the distribution.

We can also compare with the MODIS cloud top pressure product for a specific case (see Figure 6).

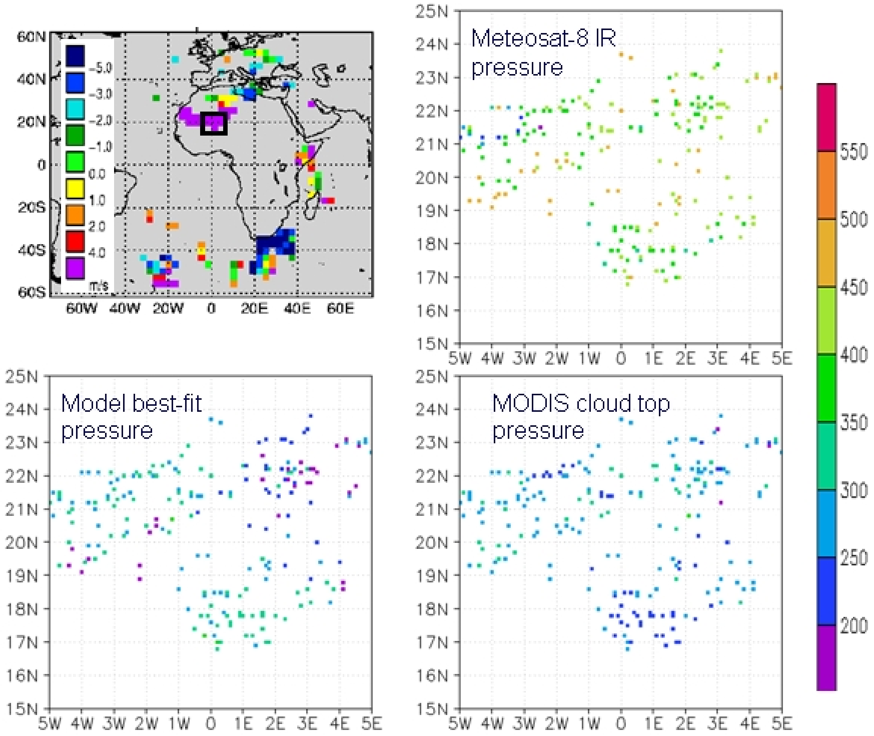


Figure 6: A case study for 2100-0300 on 7-8 December showing the fast speed bias over the Sahara region. The AMVs are assigned to mid level (green colours), but both the model best-fit pressure and MODIS cloud top pressure are at higher levels (blue colours). Scale in hPa.

The AMV pressures are mostly in the range 350-500 hPa. By comparison the model best-fit and MODIS cloud top pressure are consistently higher in the atmosphere between 150-350 hPa. We can take it one step further and separate out by height assignment method (see Figure 7). Figure 7 shows that the AMVs are assigned lower when the EBBT (equivalent black-body temperature) method is used.

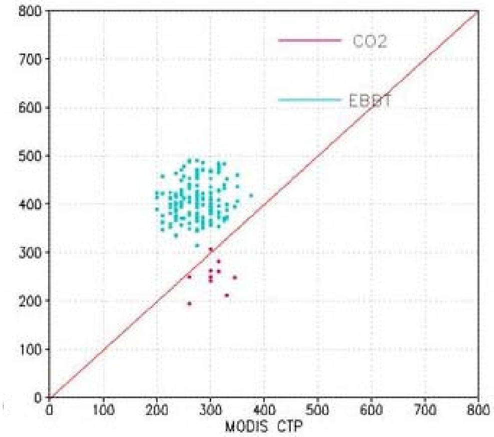


Figure 7: Scatter plot comparing the Meteosat-8 IR assigned pressure to the MODIS cloud top pressure, subdivided by the AMV height assignment used.

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. Further investigations at EUMETSAT highlighted a problem with the CO_2 slicing method in cases of low level inversions where there can be more than one cloud-top pressure solution. An improvement to the strategy was identified and implemented operationally on 22 March 2007. Subsequent investigations have indicated that the new strategy has markedly reduced, but not eliminated, the fast speed bias with most improvement seen at night-time when a low level inversion is likely to be present.

This example for the Saharan region illustrates how investigations of specific cases can be useful to understand the possible cause of poor statistics; for further examples see Forsythe & Doutriaux-Boucher (2005) and Forsythe et al. (2006).

Alongside these ongoing AMV investigations, several specific activities have been recommended by the CGMS working group on winds. Three examples are included below.

1. There should be a comparison of the operational algorithms of all satellite wind producers for the height assignment of AMVs from clouds using a common data set from SEVIRI on MSG, and the same ancillary data.
2. There should be a comparison of standard methods for the height assignment of AMVs with the new measurements from instruments on the A-train (e.g. with cloud lidar).
3. An experiment should be performed to apply operational AMV retrieval algorithms to simulated images from high resolution NWP fields.

The last item is an interesting approach that has the advantage of knowing truth and could be used in a number of ways to investigate the AMV derivation process and how the AMVs may be best represented (see Bormann et al. 2006 for more information).

The current AMV assimilation approach at most NWP centres is fairly unadventurous and involves applying quality indicator thresholds, spatial and temporal blacklisting, thinning the data (typical scale of one observation per 200 km by 200 km by 100 hPa box) and removing data which deviate too far from the background. The AMVs are generally treated as point observations in space and time, although neither assumption is true. The observation errors typically vary only with pressure (those used at the Met Office are shown in table 1) and are calculated from O-B statistics, but inflated to alleviate problems with correlated error (e.g Butterworth et al. 2002).

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

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

The result of the quality control is to remove the majority of the observations. At the Met Office typically only 2% remain (see Figure 8 for examples of the extracted and used data coverage).

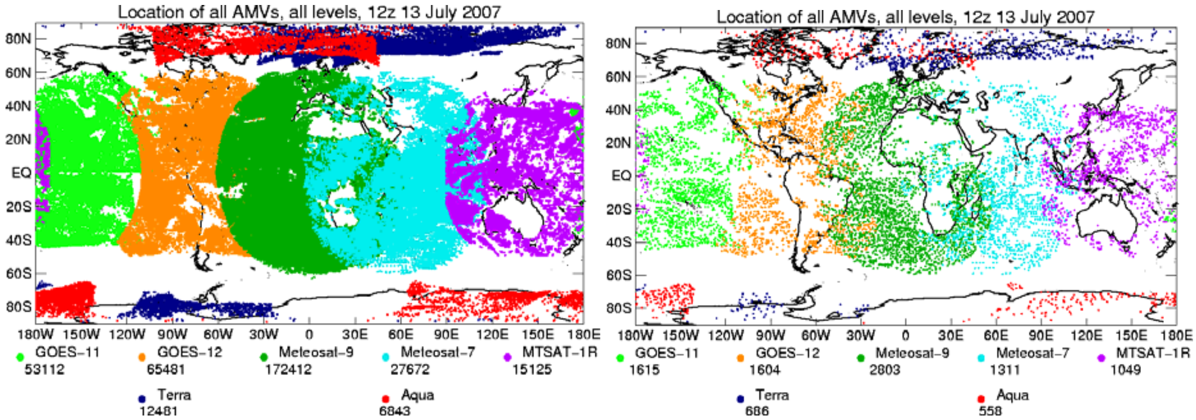


Figure 8: Data coverage plots showing extracted AMV data (left) and assimilated data (right). The number of winds assimilated is only 80602 for this 6 hour assimilation cycle, just 2% of the 460641 winds received.

Figure 9 shows how the quality control removes most of the data of more dubious quality.

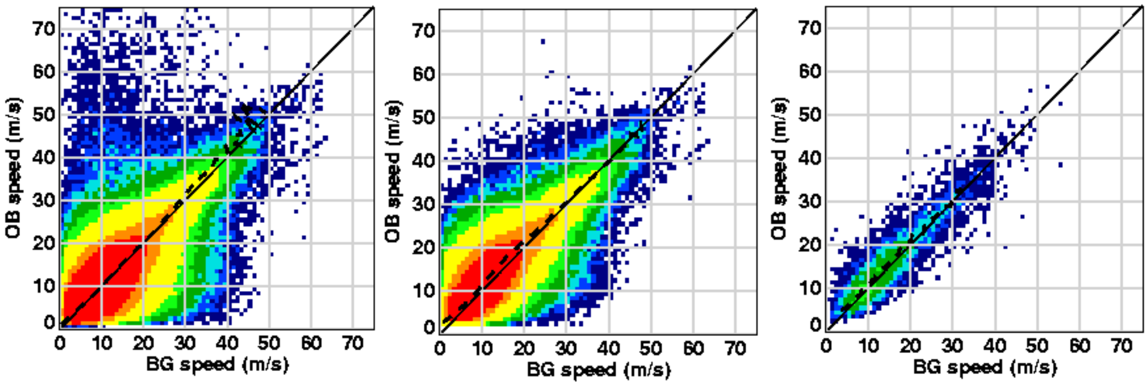


Figure 9: O-B speed bias density plots for Meteosat-9 IR high level (above 400 hPa) tropical (20S-20N) winds for July 2007 compared witht the Met Office model background. The left plot shows all the data extracted (rms of 4.9 m/s), the middle plot shows the data remaining after a model-independent QI threshold of 80 is applied (rms of 4.1 m/s), the right hand plot shows the used data (rms of 2.6 m/s) after further blacklisting, thinning and a background check are applied.

Although the current strategy does remove most of the poorer quality data it is clearly very wasteful and there is evidence from some experiments that some poorer quality data are still assimilated and can have detrimental impact on forecast quality (e.g. Forsythe & Saunders 2006). So can we improve our approach? I believe the answer is yes. Three areas that may be particularly important to consider are the observation errors, the observation operator and whether there is a better way to handle the spatially and temporally correlated errors.

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 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. If we assume the AMV vector and height errors are independent (reasonable assumption), the total AMV error can be calculated by combining the vector error with the error in vector due to the height error. The latter 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 observation error in regions of high vertical wind shear. It therefore allows us to down-weight winds where a height error would be problematic and allows us to give greater weight to winds where the height assignment is less critical.

The inputs required for this approach are estimates of the error in the height assignment and in the u and v wind components. Until these are available routinely with each AMV we can adjust the u and v component errors using the model independent quality indicator and select the height errors (based on the best-fit statistics) dependent on satellite, channel, height assignment method, pressure level and geographical location. Figure 10 shows an example of the new errors (right) compared to the currently used pressure-based errors (left). The new error approach yields more variable errors.

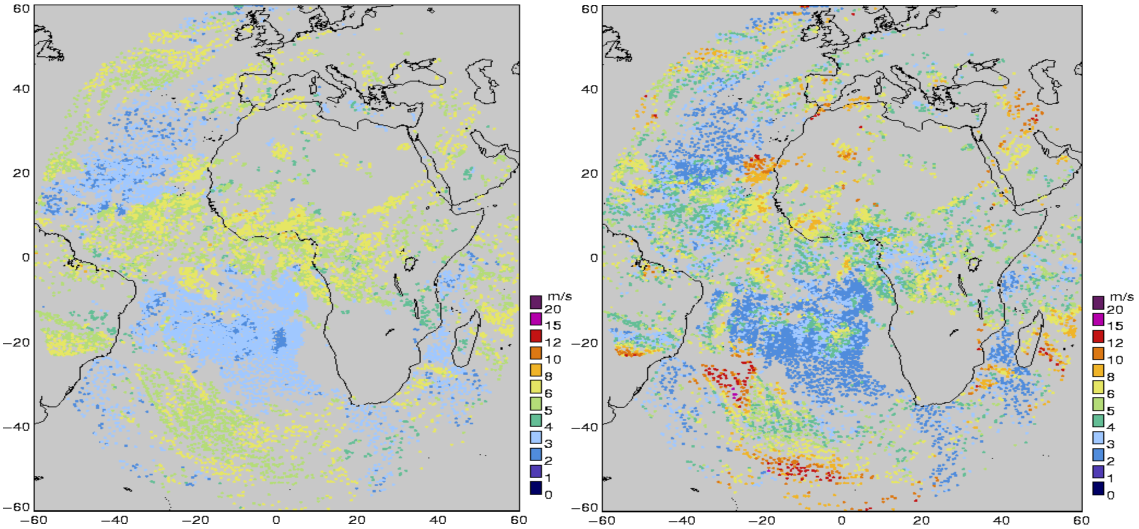


Figure 10: Plots showing the old (left) and new (right) AMV observation errors for Meteosat-9 IR winds for the 00 UTC run on 25 May 2007.

Initial impact experiment results show a small positive benefit using the new errors. Further benefit may be possible when estimates of the vector and height error are available with each wind, which reflect the confidence in the vector and height derivation.

A second consideration for optimising the assimilation is that the AMVs represent the movement of a layer of the atmosphere and are a spatial and temporal average. Some centres are looking at modifying the observation operator to represent the AMV as a layer observation, for example Rao et al. (2002) and Bormann et al. (2002). It is not immediately clear what observation operator to use. Some factors to consider are the shape, width and placement of the layer operator relative to the AMV assigned pressure. Investigations are ongoing at CIMSS and, together with the simulated data study mentioned earlier, may yield useful advice. Further information on a suitable layer thickness may be possible through use of information such as optical thickness or diversity of pixel heights in the target area.

The third area of the AMV assimilation I would like to draw your attention to relates to the temporally and spatially correlated nature of the AMV errors. A study by Bormann et al. in 2003 using a 1-year dataset of AMV-radiosonde collocation pairs showed statistically significant spatial error correlations for distances up to 800 km. This is not allowed for directly by the NWP assimilation and so precautions need to be taken. Currently most centres thin the data; however, it is not desirable to thin to the full 800 km so often a compromise is reached by thinning the data to 200 km resolution and inflating the observation errors. Clearly this is not ideal as a lot of potentially useful information is thrown away. Some centres are looking at new techniques to allow for correlated error explicitly in the assimilation, which would allow data to be used at higher resolution.

AMVs have other uses beyond global NWP. The derivation can be adjusted to use smaller target size and image intervals (3-5 minutes) to produce high resolution AMV datasets reflecting the motion of smaller scale features of the flow. An obvious application would be for assimilation in mesoscale NWP models. However, until the spatial and temporal correlations can be handled directly, it is likely the benefit may be limited due to the need to thin in space and time. Other applications of mesoscale AMV fields are for tropical cyclone studies (e.g. Velden et al. 2005) and for input to convective initiation nowcasting (e.g. Bedka and Mecikalski 2005, and Mecikalski and Bedka 2006).

AMVs can be used to derive other products, for example tropical divergence (e.g. Schmetz et al. 2005) and vorticity fields. The WV 6.2 µm channel on the Meteosat Second Generation SEVIRI imager is particularly useful for deriving divergence as it peaks in quite a narrow region of the upper troposphere (Figure 11). The main use of these derived products is likely to be for nowcasting, tropical cyclone studies and model

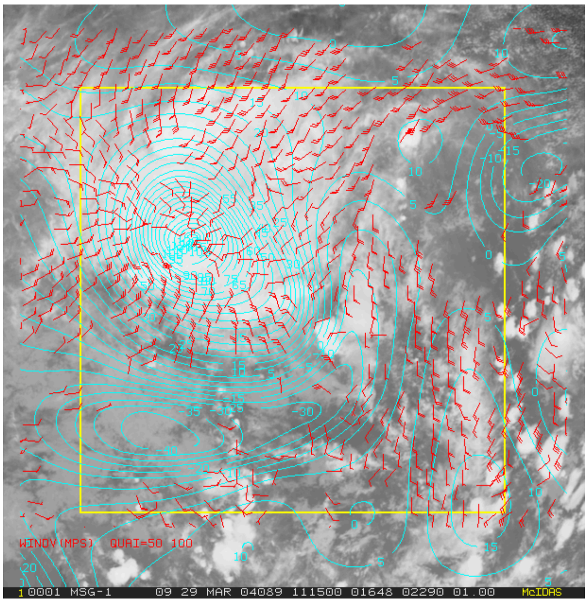


Figure 11: Isolines give the upper tropospheric divergence pattern derived from the WV 6.2 µm AMVs. Date: 29th March 2004, 11:15 UTC. From Schmetz et al. (2004).

validation, although it has been asked whether tropical divergence could be assimilated directly in NWP. The main incentive for this approach is that the tropical divergence is not always well captured in NWP and is unlikely to be corrected through AMV assimilation with the current spatial thinning due to the scale of many divergence features (300-500 km). The general consensus is that the derived fields would be hard to assimilate.

Another use of AMV data is for reanalysis studies such as ERA-40. EUMETSAT have reprocessed old geostationary satellite imagery using the latest AMV derivation software to produce higher quality and higher resolution AMV datasets for assimilation in the reanalyses (e.g. Gustafsson et al. 2002). CIMSS are producing a 20-year AVHRR polar AMV dataset to help address the fairly sizeable Arctic wind field errors observed in current NCEP/NCAR and ECMWF reanalysis products (see Dworak et al. 2006).

5. The Future

NWP models are always going to need wind data to represent the divergent component of the flow properly. This is particularly important in the tropics and for smaller scale features of the flow. The latter is only likely to become more important as model resolution improves. Therefore there is a need to maintain or improve the wind component of the global observing system. Preferably the data should provide good horizontal, temporal and vertical coverage.

The AMVs have the capability to provide good horizontal and temporal coverage, but do not provide the vertical resolution. This may be provided in the future by Doppler wind lidar (DWL), for example the ADM-Aeolus mission planned for launch in 2009. DWL has the advantage of providing wind component profiles and simulated data experiments have predicted good forecast impact (e.g. Tan & Andersson 2005; Stoffelen et al. 2006), but with only one satellite there will be limited horizontal resolution and only the cross-track component of the wind is provided. In terms of the AMVs, it is important to maintain or improve the spatial and temporal coverage. Ideally a minimum of 5 geostationary and 2 polar satellites are required to provide imagery data for AMV derivation, preferably maintaining a good channel range for tracking and height assignment. One known risk is a probable gap in availability of a WV channel for polar AMVs when MODIS is no longer available.

Looking further ahead, winds could be generated from hyperspectral sounders on geostationary platforms. The large number of channels could provide the required vertical resolution to produce vertical profiles of wind velocity (see Figure 12).

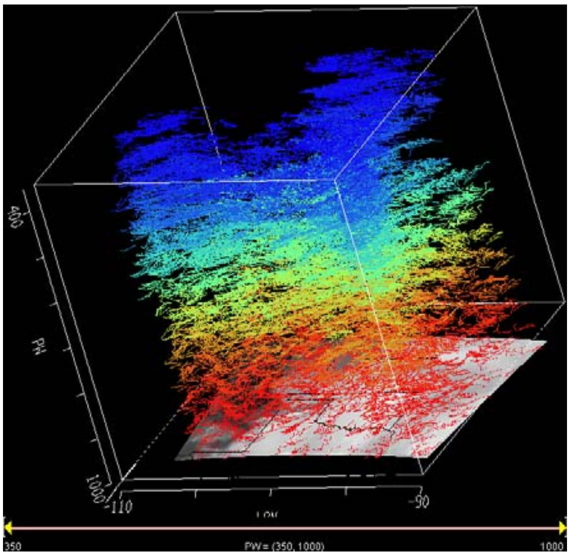


Figure 12: VisAD display [latitude-longitude-altitude (hPa) cube] of simulated GIFTS winds illustrating the data density and vertical distribution that could be achievable from hyperspectral sounders of the future. From Velden et al. (2005).

The method under development at CIMSS involves applying AMV tracking techniques to constant level moisture analyses derived in clear-sky areas from the hyperspectral sounding data (see Velden et al. 2004). Aside from the main advantage of providing wind profile information, it is likely the height assignment error of these AMVs will be less than those produced via the conventional approach.

There is a general preference within the assimilation community to work towards direct radiance assimilation. This is already possible in clear sky areas and is one reason why geostationary clear sky WV winds are not considered for operational assimilation. It is currently much harder in the cloudy regions. Work is ongoing in this area at several centres, but it is unlikely that the models will improve sufficiently over the next few years to represent the cloud well enough (particularly in the tropics) or at sufficient resolution (spatial and temporal) to make the AMVs redundant. It is therefore important to continue working to extract as much useful information as possible from this important source of wind data.

6. Conclusions

AMVs were first produced in real time in the 1970s. Since this time the data volume, coverage and quality have markedly increased. Recent impact experiments at the Met Office and elsewhere have shown that the AMV data are still providing benefit to forecast accuracy and to hurricane track forecasts. It is, however, becoming increasingly important to improve the quality of the AMV data and the NWP assimilation strategy to maintain or improve the AMV contribution to the observing system.

A major limitation of the AMV data is the complicated and spatially correlated errors. With limited resources at any one centre, it is important that data providers and assimilators continue to work together. The combination of a theoretical analysis of the limitations of the AMV derivation and further statistical comparisons of the AMV data with model backgrounds and other observations could help highlight parts of the AMV derivation that can be improved, and could be used to develop estimates of the vector and height errors. These errors can be used to improve the representation of the AMV errors in NWP. It is also important to consider what AMVs are representative of, for example if they reflect the motion of a layer and, if so, how this is best reflected via changes to the observation operator in NWP. By a combination of improvements to the AMV data quality and improvements to the assimilation scheme, it should be possible to derive more impact from AMV data in NWP.

Looking towards the future, wind observations will remain an important part of the global observing system and AMVs are expected to remain an important source of wind data for NWP for many years.

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