ATMOSPHERIC MOTION VECTORS: A SUMMARY OF WORLDWIDE ACTIVITIES TO IMPROVE THEIR IMPACT IN NUMERICAL WEATHER PREDICTION

Mary Forsythe¹, Régis Borde², Niels Bormann³, Jaime Daniels⁴, Iliana Genkova³, Kenneth Holmlund⁵, Roger Saunders¹, Johannes Schmetz², Chris Velden³, Lüder von Bremen³, Steve Wanzong⁵

(1) Met Office, FitzRoy Road, Exeter, EX1 3PB, United Kingdom
(2) EUMETSAT (3) ECMWF (4) NOAA/NESDIS (5) CIMSS

Abstract

The International Winds Working Group (IWWG), under the Coordination Group for Meteorological Satellites (CGMS), is responsible for coordinating a number of activities aimed at improving the quality of satellite-derived atmospheric motion vectors (AMVs) and their representation in assimilation systems for numerical weather prediction (NWP). Some key areas of work include: (1) an inter-comparison of different AMV derivation methods, (2) an approach for evaluating AMVs using simulated imagery generated from high resolution NWP, (3) comparisons of AMV impact at different NWP centres and (4) studies to evaluate treatment of AMVs as layer observations. The quality of AMVs is also routinely assessed as part of the EUMETSAT Satellite Application Facility for Numerical Weather Prediction (NWP SAF) activities, with analysis reports produced every two years. The number and range of ongoing AMV projects is testament to a large collaborative effort within the AMV community to address key issues with the data. It is hoped this work will ultimately lead to improved impact from this type of observation in NWP.

INTRODUCTION

Atmospheric motion vectors (AMVs) are generated by tracking clouds or gradients in water vapour through consecutive satellite images. They have been assimilated in NWP for many years, but they are not without complications. Firstly the errors are hard to characterise. This is partly due to the derivation process where we move a long way from the raw radiance data with their more easily understood and represented errors. Secondly we make various assumptions in the derivation and assimilation. For example, we treat the winds as representative at a point in space and time, we assume the clouds move passively with the winds and we assume there is no spatially and temporally correlated error, which is very certainly not the case. Thirdly AMVs are produced at a number of centres, and although broadly similar, differences exist between the derivation approaches at each.

In order to see more benefit from AMV data in NWP it is important to address some of these issues. In support of this effort, a number of collaborative projects have been initiated in recent years involving a range of centres worldwide. These have been coordinated through the International Winds Working Group (IWWG), a formal working group of the CGMS since 1994. The IWWG provides a forum for discussing and coordinating development of satellite-derived winds, with the main focus on winds derived from tracking features in geostationary and polar satellite imagery. For more information visit the web site at http://cimss.ssec.wisc.edu/iwwg/iwwg.html.

AMV activities are also undertaken as part of the EUMETSAT Satellite Application Facility for Numerical Weather Prediction (NWP SAF). The main target of this work is to better understand the AMV errors so we can improve the derivation and assimilation and ultimately the impact in NWP. For further information about the NWP SAF AMV activities see Forsythe et al. (2009) or visit the web site at http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/index.html.
Within this paper we will summarise some of the main ongoing collaborative initiatives.

1. NWP SAF MONITORING

Four types of monitoring plot are provided each month (examples shown in Figure 1):

1. Density plots of observation wind speed against background wind speed.
2. Map plots of speed bias, mean vector difference, normalised root mean square vector difference and number.
3. Zonal plots showing the same statistics as the map plots but as a function of latitude and pressure.
4. Vector plots showing mean observed vector, mean background vector and mean vector difference.

![Figure 1: Examples of the NWP SAF AMV monthly monitoring plots](image)

The monitoring statistics are calculated by comparing wind observations with 6 hour model forecasts valid at the observation times (also known as model background). Both the AMVs and the model background 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.

A key part of the NWP SAF AMV work is to generate analysis reports every 2 years, with the main focus on maintaining a list of features seen in the plots. We take this further by carrying out follow-up investigations to better understand the cause and consider solutions. A simple example is provided below.

The speed bias density plots for the NESDIS MODIS IR winds show a streak of very slow AMVs (Figure 2). This is not seen in plots of the polar AMVs produced using the CIMSS processing or the NESDIS winds derived from the water vapour channel.

![Figure 2: Speed bias density plots for NESDIS Terra IR low level (below 700 hPa) winds for August 2007 compared with the Met Office model background in (left) the northern hemisphere (60N-90N) and (right) the southern hemisphere (60S-90S).](image)

Figure 3 shows their distribution. At low and mid level they are concentrated around the edges of the polar continents. At high level they are located over the high Antarctic land mass.
It is likely the slow winds are generated from tracking surface features. These would normally be filtered out by the processing, but due to a technical error this was not happening. NESDIS implemented a correction on 27 October 2009.

The NWP SAF AMV monitoring and analysis reports provide a useful resource for recording problems identified in the monitoring together with possible causes and solutions. In some cases this has already led to improvements in the AMV derivation. The fourth analysis report will be released ahead of the 10th International Winds Workshop in February 2010.

2. AMV INTER-COMPARISON STUDY

The AMV inter-comparison study involves AMV producers generating data using a common data set from SEVIRI and the same ancillary data (recommendation from CGMS-34). Several centres were involved including CIMSS/NESDIS, EUMETSAT, JMA, KMA, the National Institute for Space Research in Brazil and the Nowcasting SAF.

The aim of the study is to identify similarities and differences between AMV datasets in terms of speed, direction, height assignment and quality indicators and where differences are seen, to understand why. The plan is to use this approach to identify best practice for AMV derivation and to reduce the differences between centres. For results and further information see Genkova et al. (2009).
3. SIMULATED IMAGERY STUDY

The approach used in the simulated imagery study involves deriving AMVs using synthetic satellite images simulated from a high-resolution model forecast and comparing the resulting AMVs to the model wind field used in the simulation. This framework is attractive as the atmospheric truth (including the wind field and cloud distribution) is exactly known, allowing a detailed characterisation of AMVs, their processing, and their interpretation as single-level wind observations. Limitations of the approach include the realism of the cloud representation in the forecast model and the cost of running very high resolution models required to adequately simulate the resolution of current satellite imagery.

The approach was tested with a short NWP SAF-funded study using a 6 hour period, 10 km resolution ECMWF model and AMVs generated at CIMSS (see von Bremen, 2008). Figure 4 shows an example of the simulated and observed IR SEVIRI imagery.

![Figure 4: Simulated (left) and observed (right) Meteosat-8 IR 10.8µm image (2 Jan 2006, 15:45 UTC).](image)

The aim is to carry out a more extensive study using one or more higher resolution models and a longer time period. Several topics could be addressed with this approach including:

1. Association of AMV errors with cloud type and evolution
2. Assumption of cloud moving passively with the wind
3. Impact of treating AMVs as layer winds
4. Characterisation of spatial and temporal error correlations
5. Evaluation of changes to the AMV derivation
6. Preparation for future instruments (e.g. Wanzong et al., 2009)

4. COMPARING USAGE AND IMPACT OF AMV DATA IN NWP

At the 8th International Winds Workshop it was requested that the NWP SAF host pages on AMV usage at different centres. Pages are available for 6 centres: DWD, ECMWF, Environment Canada, Météo-France, the Met Office and JMA, with 2 more in the pipeline (NRL and BoM). The web page summaries are in a standard format to allow easy comparisons and provide details on:

1. Model and data assimilation details (resolution, time window etc)
2. AMV types assimilated
3. Quality control (blacklisting, quality indicator thresholds, thinning and background check)
4. Observation errors
5. History of changes

The intention is to update these pages at least annually and expand the number of contributing NWP centres.

Alongside this initiative there has been an effort to compare results of AMV data denial experiments for a common period (12 December 2007 – 12 January 2008). 6 NWP centres participated in this
exercise (DWD, ECMWF, GMAO, Météo-France, the Met Office and NCEP). It is not straight-forward to compare output due to differences in plotting systems, colour scales etc. However, it has been possible to identify some similarities and differences. An example of the mean differences in upper level wind analyses between the experiments without AMVs and control trials are shown for 3 centres in Figure 6. These plots show a tendency when assimilating the AMVs to weaken the westerly flow in the tropical Pacific (less prominent in Met Office trial) and to accelerate a weak easterly flow in the equatorial Indian Ocean (less prominent in ECMWF trial).

![Figure 6: Vector difference between the mean 200/250 hPa wind analyses for the no AMVs trial minus control trial for (top) ECMWF, (middle) Météo-France and (bottom) the Met Office.](image)

Overall the data denial trials indicate a small benefit from assimilating the AMVs. A bigger benefit has been seen in a previous denial trial (Winter 2005-2006) at the Met Office. It is possible the reduced
impact relates to advances in the models and observing systems, but may also reflect some temporal variation in AMV impact on forecast skill. We would probably benefit from running longer denial trials and evaluating other measures of impact, for example sensitivity and adjoint approaches (e.g. Cardinali, 2009). An interesting study is being undertaken at ECMWF, which combines these approaches.

5. DEVELOPING THE AMV DERIVATION

One of the main difficulties for the AMV derivation is to clearly identify the pixels in the target box that dominate in the tracking process, in order to select them for the height assignment calculation. A good pixel selection process should ensure a direct link is kept between the tracked feature and the calculation of the height. The most common method sorts the coldest pixels in the target box and uses them to calculate the AMV height. However, recent work showed that some of the coldest pixels can have very small and/or negative contributions to the cross correlation process. One recent collaborative development between JMA and EUMETSAT has focused on improving this step by selecting pixels based on their contribution to the cross correlation coefficient (see Borde & Oyama, 2008; Oyama et al., 2008 and Borde et al., 2008).

Another key consideration for improving the AMV derivation is to provide enhanced information on AMV quality. All the main producers provide a standard set of quality indicators based on work initially carried out at EUMETSAT (Holmlund, 1998) and CIMSS (Hayden and Purser, 1995). More recently BoM and CIMSS have worked together to develop an expected error (Le Marshall et al., 2004). Looking ahead to the future, the preferred approach is for the producers to generate estimates of vector and height error based on information available during the derivation e.g. making use of cloud top height error estimates generated as part of the optimal estimation approach. These can be used directly in the assimilation e.g., Forsythe & Saunders (2008). More generally it is likely that advances in satellite data processing will provide more information on cloud type and microphysical properties that may prove useful in improving NWP representation of the AMVs (e.g. as layer observations) and their errors.

6. TREATMENT OF AMVS AS LAYER OBSERVATIONS

One idea for optimising the assimilation of AMVs is to represent the AMVs as layer observations. Some initial work has been carried out e.g., Rao et al. (2002), Bormann et al. (2002) and Velden & Bedka (2009). Results suggest that we can reduce the observation-background statistics using this approach. Some factors to consider are how to design the layer observation operator including the shape, width and placement relative to the AMV assigned pressure. It is likely the optimal layer width will vary depending on the feature tracked (e.g. variability in cloud top height within the target area and optical thickness of the cloud). Initially CIMSS and the Met Office are collaborating to investigate an approach based on statistically-generated layer widths, but in the medium term it may be more beneficial to receive information on layer width with each AMV as a physically-based output from the derivation scheme.

7. FURTHER WORK

The intention is to provide updates on the ongoing activities at the biennial International Winds Workshops. Continued effort will depend on the results and discussion within the community. In addition to the ideas already discussed, other activities that may be undertaken in the next few years include:

1. Assessment and feedback on new AMV datasets from an expanding number of AMV producers
2. Re-evaluation of height assignment approach for low level winds
3. AMV height assignment validation e.g. using A-train
4. Evaluation of benefit of allowing for correlated error in the assimilation
5. Comparisons to ADM Doppler wind lidar
6. Evaluation of how best to derive and assimilate mesoscale AMV products for high resolution NWP
7. Evaluation of potential of hyperspectral sounding winds e.g. MTG-IRS
8. Evaluation of MISR winds (use stereo-based height assignment)

SUMMARY

There are a range of collaborative studies and developments ongoing within the AMV community including inter-comparisons of AMV derivation schemes, use of simulated imagery, comparisons of AMV usage and impact in NWP, AMV error analyses and work to improve the derivation and assimilation approaches. The studies have already yielded interesting results and have in some cases resulted in improvements to AMV data quality. With limited resources at any one centre it is important for the AMV community to discuss and prioritise the development options and to work together on achieving them. This work is coordinated by the International Winds Working Group and discussed at the annual CGMS meetings and biennial International Winds Workshops. The next workshop will be hosted by JMA in Tokyo in February 2010.

REFERENCES


