USING MODEL SIMULATIONS TO IMPROVE THE CHARACTERISATION OF CURRENT ATMOSPHERIC MOTION VECTORS

Angeles Hernandez-Carrascal ¹, Niels Bormann ¹, Regis Borde ², Hans-Joachim Lutz ², Steve Wanzong ³

1. ECMWF, Shinfield Park, Reading RG9 9AX, United Kingdom
2. EUMETSAT, EUMETSAT Allee 1, 64295 Darmstadt, Germany
3. University of Wisconsin Madison / SSEC / CIMSS, Madison, Wisconsin, USA

Abstract

The main objective of this study is to improve the characterization of Atmospheric Motion Vectors (AMVs) and their errors to improve the use of AMVs in Numerical Weather Prediction (NWP). It is known that AMVs tend to exhibit considerable systematic and random errors and geographically varying quality, as shown in comparisons against radiosonde or NWP data. However, there is a rather limited knowledge of the characteristics and origin of these errors: they can arise in the AMV derivation process, but they can also arise from the interpretation of AMVs as single-level point observations of wind. An important difficulty in the study of AMV errors is the scarcity of collocated observations of clouds and wind.

To overcome that difficulty, this study approaches the analysis of AMV errors using a simulation framework in which AMVs are derived from sequences of images simulated from atmospheric forecast model data. In this framework the model provides a “ground truth”, including wind and cloud distributions, which allows a detailed study of AMV errors. Provided model simulations are realistic, the analysis of AMV errors in this setting can shed light on the nature of AMVs derived from observed imagery and their errors. The model used for the simulation is the Weather Research and Forecasting (WRF) regional model, and the nominal horizontal resolution of the simulation is 3km.

This presentation shows the main results of the ongoing study. First, cloud structures from observed and simulated images are compared. Then AMVs, interpreted as single-level point estimates of wind, are evaluated by comparison to the model truth. Then we present results regarding horizontal, vertical and temporal error correlations. Finally, we evaluate AMVs interpreted as vertical and horizontal averages of wind.

INTRODUCTION

Atmospheric Motion Vectors (AMVs) derived from images from geostationary or polar satellites have long been an established ingredient to global and regional assimilation systems for Numerical Weather Prediction (NWP). Currently, AMVs largely provide the only source of upper level wind observations over the oceanic areas. In their assimilation systems, currently NWP centres interpret AMVs as single-level point observations of the ambient wind. The AMVs are assimilated subject to strict quality control, necessary as AMVs tend to exhibit considerable systematic errors and geographically varying quality, as shown in comparisons against radiosonde or model data (e.g., Bormann et al., 2002; Cotton and Forsythe, 2010).

In recent years, further progress on the improved use of AMVs in assimilation systems has been hampered, for instance, due to a limited knowledge of the detailed error characteristics (systematic and random) and the origin of these errors. Errors can arise in the winds derivation, e.g. from the recognised difficulties of assigning an appropriate height. But they can also arise from the interpretation of AMVs as single-level point observations of wind. A considerable obstacle to the study of these aspects with real data is the lack of collocated observations of wind and clouds.
An interesting alternative is to approach the study of AMV errors from a simulation framework. An NWP high-resolution forecast model of the atmosphere is used to carry out a simulation, using suitable initial and lateral boundary conditions. The output of this simulation can be used to generate simulated images with a desired horizontal resolution and geometry, e.g. those of the MSG satellite at 0 longitude and the SEVIRI (Spinning Enhanced Visible and Infrared Imager) instrument. Then AMVs can be produced from the simulated imagery. The model simulation output represents a ground truth that includes wind and cloud variables, which allows a detailed study of AMVs errors.

The potential of the simulation approach was demonstrated by a collaborative study by ECMWF, CIMSS, and EUMETSAT (von Bremen, 2008). A simulation based on the ECMWF global model was run, with a nominal horizontal resolution of 10-km. The study focussed on the performance of quality control procedures, and the characteristics of the AMVs in some situations with known problems for real AMVs. While the initial study provided a proof-of-concept of the approach, some caveats were recognized: the short study period (6 hours) and the low horizontal resolution of the model, significantly coarser than that of MSG images (3 km at nadir).

This presentation describes the main results of the first part of a new AMV simulation study, started in 2011 as a collaboration between ECMWF and EUMETSAT, with contribution of CIMSS. The model used for the simulation is the Weather Research and Forecasting (WRF) regional model, with a nominal horizontal resolution of 3km. The simulated images replicate the geometry and resolution of Meteosat-8 SEVIRI images. The study is now close to completion, and the results are described in detail in Hernandez-Carrascal et al. (2012) and Hernandez-Carrascal and Bormann (2012).

DATA

The study period spans 24 hours, starting 16 August 2006, and the study area is the prime disk covered by MSG at 0 longitude within the latitudes 58S / 58N, restriction due to the model simulation.

The WRF is a compressible non-hydrostatic regional NWP model, described in Skamarock et al. (2005). The WRF includes various microphysical quantities as prognostic variables, parameterized using the Thompson et al. (2008) mixed-phase cloud microphysics scheme. A model characteristic particularly important for this study is that clouds are not parameterized, but explicitly resolved.

An existing simulation with the WRF model was used in this study. The output of this simulation was kindly provided to ECMWF by Steve Wanzong of CIMSS. The model simulation is described in Otkin et al. (2009). The dataset was produced with version 2.2 of the WRF, run over a domain covering the prime Meteosat disk (within 58.8º latitude), with a resolution that varies from 3 km at the equator to 1.7 km at the N and S boundaries, and 52 levels in the vertical (model top at 28 hPa). The WRF was initialised on 15 August 2006 18Z, from 1 degree analyses from the Global Data Assimilation System (GDAS). The study period is covered through a 6-30 h forecast, i.e. a six hours spin-up period was allowed for the simulation to develop fine scale structures from coarser initial conditions. The fields from the simulation output were available on timesteps of 15 min throughout the study period.

SEVIRI images from the WRF simulation output were produced every 15 min over the study period using version 9 of the RTTOV radiative transfer package (Saunders et al., 2008). All 8 infrared and near-infrared channels of SEVIRI were simulated over study area. AMVs were derived by EUMETSAT from the WRF simulated imagery (SEVIRI channels IR10.8 and WV6.2), using a prototype derivation system developed in preparation for Meteosat Third Generation imagery (Borde et al., 2011). AMVs were produced half-hourly, from triplets of images. Only cloudy AMVs were produced for this study.

CLOUD STRUCTURES

Findings from simulated imagery can only be extended to observed imagery if the cloud structures produced from model simulations are realistic. From the perspective of this study, the quality of the forecast in the traditional sense is relatively unimportant. What is important is that the general appearance and variablity of cloud structures in the simulated imagery agree well with the observed imagery.
Visual comparison of simulated and observed images provides a useful first impression about cloud structures and some characteristics of the two sets of images. The main points of this comparison are:

- At the end of the study (see Figure 1), the simulated images appear generally realistic, although some systems are represented differently or misplaced in the simulation compared to the observations. The level of detail in the WRF images appears to agree qualitatively well with the observations, although the marine stratocumulus areas seem somewhat too noisy.

- At the beginning of the study (not shown), the extent of ice clouds appears overestimated and some clouds lack spatial variability. These effects are noticeable for the first 9 hours of the period. A likely reason is that the simulation is still developing fine scale structures during the first part of the period, i.e. the 6-hour spin-up allowed appears not to be sufficient.

- The distributions of brightness temperatures for the IR and WV channels compare well between observed and simulated images, especially after first 9 hours of the study period.

Regarding temporal variability, Figure 2 shows the standard deviation of the time series of brightness temperatures for each pixel in the study area with a satellite zenith angle smaller than 70 degrees, for observed and WRF simulated IR10.8 images. Only alternate timesteps have been selected for the time series. The figure shows a comparable level of temporal variability in all areas, and in particular over the ITCZ, although there are differences regarding e.g. the locations of the maxima of standard deviation, where deep convection and clear or low cloud skies alternate.

AMVS INTERPRETED AS SINGLE-LEVEL POINT ESTIMATES OF WIND

Statistical evaluation of AMVs vs. model truth

In this section, we present a statistical evaluation of the AMVs derived from the WRF simulated images, comparing them with the truth provided by the model simulation, and following the traditional interpretation of AMVs as single-level point estimates of wind. Only AMVs with QI > 80% were used. For reasons of space, only the main aspects are summarized here. A more detailed evaluation is given in Hernandez-Carrascal et al. (2012).

Table 1 shows the standard statistics for high-level AMVs derived from the WRF WV6.2 imagery and from EUMETSAT operations at the time (16 August 2006). The latter are compared against short-term operational forecasts from ECMWF global assimilation system, to provide a reference for the statistics derived from the simulated AMVs. Ideally, the AMVs from observed images should have been generated by the same derivation system that was used for the WRF imagery, but unfortunately such AMVs were available only for four timesteps, which was considered a too small sample to allow meaningful comparisons.
The WRF AMVs show a slow bias for the three latitude bands, particularly strong for SH. Both the average AMV speed and the number of AMVs are clearly smaller in the NH than in the SH, as could be expected considering that the Southern hemisphere is the winter hemisphere at the time of the study. The WRF dataset includes more AMVs than the operational one, as expected from the different temporal sampling (hourly for the dataset from operations). In addition, the WRF AMVs show, for the three latitude bands, larger biases, and larger RMSVD and NRMSVD than AMVs from operations.

Table 1 shows similar statistics for low-level AMVs derived from WRF simulated WV6.2 images (left column of each pair) and from operations at the time (right column). The finding that the WRF-simulated AMVs compare more poorly to the truth than the operational AMVs compare to short-term forecasts is to some extent unexpected, and may point to limitations of the simulation approach. The comparisons between operational AMVs and short-term forecasts include a component of forecast error, and hence would be expected to compare more poorly. One possible explanation is that this is due to a poorer performance of the EUMETSAT prototype system compared to operations at the time. However, by investigating the four time-slots for which AMVs derived from real imagery were available from the prototype system, we found that this is not the case. While the two systems produce AMVs with slightly different characteristics, the differences are much smaller than those seen here between the WRF and OPS comparisons. The poorer statistics for the
WRF-simulated AMVs are hence likely due to limitations in the simulation approach, for instance due to a poorer performance of the height assignment or the tracking step. This aspect has to be kept in mind when interpreting the results from this assimilation study.

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<th>Meteosat-8 IR10.8 AMVs - Low level, QI &gt; 80%</th>
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Table 2: Summary statistics for low-level AMVs derived from WRF simulated IR10.8 images (left column of each pair) and from operations at the time (right column).

Despite these caveats, our analysis suggests that the WRF AMVs are qualitatively broadly in line with characteristics commonly found in comparisons of real AMVs with short-term forecasts. In particular, slow biases prevail in the extra-tropics at high levels, and fast speed biases are present at low levels in the tropics – features commonly observed in real AMVs.

**Error correlations from simulated AMVs**

Knowledge about error correlations is relevant to the assimilation of AMVs, as the presence of error correlations affects important data assimilation parameters such as the setting of observation errors or data selection/thinning scales. Experimentation with error correlations would be helped by a better specification of the correlation scales, especially for vertical and temporal error correlations.

Error correlations between AMVs are unavoidable, as errors in the height assignment, the forecast data used in the winds derivation, the interpretation of the AMVs, the quality control or the spatial representativeness may all be correlated spatially, vertically, or temporally. Estimating horizontal error correlation is possible using radiosonde observations. Bormann et al. (2003) investigated spatial error correlations in real AMVs, and found significant correlations on scales of several hundreds of kilometres, with broader correlations over the tropics than over the extra-tropics. However, the sparsity of the radiosonde network and the interval between observations prevent the estimation of temporal and vertical AMV error correlations by comparison of AMVs with radiosonde winds.

Estimating AMV error correlations is quite straightforward in a simulation framework, as the model provides the true wind on a high resolution grid. In our study, we estimated horizontal, vertical and temporal error correlations for the AMVs derived from the WRF imagery. Our analysis is presented in some detail in Hernandez-Carrascal et al. (2012); the main conclusions are:

- There are significant horizontal, temporal and vertical error correlations when the AMVs are interpreted as single-level values.
- There seems to be a good qualitative agreement between horizontal error correlation scales in AMVs derived from the WRF simulated images and AMVs from observed images, with non-negligible error correlations for distances of around 300 km in the extra-tropics and even broader correlations in the tropics.
- For temporal and vertical error correlations, our analysis provide the first estimates of correlation scales, to the best of our knowledge, and we find non-negligible error correlations in the range of 6-12 h and 100 hPa, respectively.

Note, however, that the error estimates obtained in this study are larger than those found in studies with real data, so the direct applicability of the results to real data is not clear. Further investigations are possible with the simulated dataset, for instance, to investigate the origins of the correlated errors by using alternative AMV height interpretations.
AMVS INTERPRETED AS HORIZONTAL AND VERTICAL AVERAGES OF WIND

It has often been suggested, within the AMV community, that the traditional interpretation of AMVs as single-level point estimates of wind might be one of the causes of AMV errors, and that, considering the process of AMV derivation, it would be more appropriate to interpret AMVs as vertical, horizontal and time-averaged estimates of wind.

It is possible to assess the interpretation of AMVs as vertical averages by comparing AMVs against vertical averages of wind from collocated radiosonde observations, as Velden and Bedka (2009) have done. However, the radiosonde network is very sparse, and radiosonde observations are of limited help to calculate vertical averages of wind, and of no help to produce horizontal averages of wind. One of the advantages of simulation frameworks is that they allow to test different interpretations of what AMVs represent. As ground-truth winds from the model simulation are available on a high-resolution grid, it is quite straightforward to obtain vertical or horizontal averages.

In our study we explored both the impact of vertical and horizontal averaging. Regarding vertical averaging, we considered two types of layers, i.e. two types of pressure interval for the average: centred on the originally assigned pressure, or just below it in the vertical. All vertical averages were calculated using a boxcar filter. Regarding horizontal averaging, several neighbourhood radii (0, 30 and 40 km) were explored. Overall, the influence of the horizontal averaging was relatively small, and here we therefore focus on the results from the vertical averaging.

Figure 3 shows results of evaluating AMVs as horizontal and vertical averages for high-level AMVs from the WRF WV6.2 simulated imagery. The upper (resp. middle) row shows how RMSVD and bias vary when the depth of the pressure interval used for the vertical averaging increases, when the averaging interval is placed centred on (resp. below) the originally assigned pressure. The left column shows results for TR, and the right column for SH. The neighbourhood radius used in the four panels is 30 km. For reference, the lower row shows the results of evaluating the same sets of AMVs after simply reassigning each AMV to a lower level in the vertical; no average was performed in this case, either vertical or horizontal.

The two upper panels of Figure 3 show a consistent picture: a clear improvement, regarding both RMSVD and bias, as the layer depth increases, from 0 to 300 hPa. The middle panels also show a consistent picture: for the two latitude bands, there is an optimal depth around 120-140 hPa, regarding both RMSVD and bias. The figure shows that there is a clear improvement by locating the layer below the original height, especially noticeable for TR. Similar results were obtained for NH (not shown). The purpose of the evaluation depicted in the lower panel was to assess to which extent the improvement brought by locating the averaging layer below the original height was actually consequence of effectively reassigning each AMV to a higher pressure. The similarity between the middle and lower rows is striking, especially around the optimal pressure, and shows that most of the improvement brought by the vertical averaging actually comes from reassigning AMVs to a higher pressure.

The results of our study are to a large extent consistent with the findings of previous studies involving the interpretation of AMVs as vertical averages of wind (Velden and Bedka, 2009; Forsythe et al., 2010), although there are differences regarding the depth of the optimal layer. It seems that the height assignment used in this study has an overall tendency to place AMVs too high in the vertical. This bias appears to be present in the tropics as well as the extra-tropics and at all levels. The bias is also larger than indications of height assignment biases obtained with real AMVs in the past. These are typically of the order of a few tens of hPa (e.g. Salonen and Borman, 2011; Bormann et al., 2002).

A number of factors may contribute to this large height bias. It could be partly a result of small differences in the bias characteristics of the observed and simulated BTs and hence specific to the current simulation. It might also be related to the cloud analysis product used to assign the height of individual pixels. Finally, the benefit of assigning the AMVs to lower heights may indicate that the cloud top is not the most representative height for cloud motion, and instead a lower height or layer would be more appropriate.
CONCLUSIONS

This presentation has highlighted the main results of the ongoing AMV simulation study. The key findings are:

- Cloud structures from simulated WRF images are overall realistic, although the simulation seems to be still in a spin-up phase during the first part of the period, showing some unrealistic features.

- The evaluation of AMVs as single-level point observations of wind show characteristics that are broadly similar to comparisons between real AMVs and short-term forecasts. However, errors in the simulated AMVs appear larger than those in the real AMVs, so some care has to be taken when interpreting the results from this study for real data.

- Estimating AMV error correlations (EC) is quite straightforward in a simulation framework. Regarding horizontal EC, there is a good qualitative agreement between horizontal EC scales in WRF simulated AMVs and real AMVs. It is also possible to estimate vertical and temporal EC.

- Interpreting AMVs as horizontal and vertical averages of wind consistently leads to better agreement between the AMVs and model equivalents, but the improvement is quite small.
Reassigning AMVs to lower heights in the vertical brings a considerable improvement regarding both RMSVD and bias. Overall, the optimal pressure increment is around 60 to 80 hPa for high-level AMVs derived from the WRF WV6.2 simulated imagery, and around 90 hPa for the IR10.8 imagery (not shown here). An interesting point to notice is that the optimal pressure increment is roughly the same for both RMSVD and bias.

The simulation framework allows a detailed study of many other aspects of AMVs. At the time of the workshop, the focus of the study was the role of clouds and several interpretations of AMVs involving cloud variables. The results will be described in Hernandez-Carrascal and Bormann (2012).

REFERENCES


