EVALUATION OF AMVS DERIVED FROM ECMWF MODEL SIMULATIONS

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Abstract

Atmospheric Motion Vectors (AMVs) have been derived at CIMSS from synthetic satellite images, simulated from a high-resolution ECMWF model forecast, and the resulting AMVs have been compared 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. Caveats are that the cloud representation in the forecast model may still differ from reality and that the model resolution used (~10km) still lags behind the resolution of today's satellite imagery used for AMV derivation (typically 3-5 km). The study is primarily intended as a proof-of-concept study.

Comparison statistics for simulated AMVs against the model truth are broadly similar to monitoring statistics commonly observed for real AMVs. In particular, slow speed biases prevail at high levels in the extra tropics, and fast biases in the tropics. An analysis of the CIMSS quality control reveals that the auto editor acts more through data removal than through data adjustments in the simulated dataset. Also, the use of forecast data in the quality control step has a small, but noticeable effect on the final wind dataset, whereas winds before CIMSS quality control show little sensitivity to the forecast data used in the processing. A detailed study of two situations with known problems for real AMVs (low-level inversions and high-level winds) shows rather noisy wind speeds in both situations. Also, for high-level winds, speed biases are still present even in situations when height assignment is less important, and these biases appear to be linked to cloud thickness and evolution over the tracking period. Further studies are suggested to corroborate the current findings and to evaluate the applicability of the findings to real data.

INTRODUCTION

Atmospheric Motion Vectors (AMVs) derived from image sequences obtained from geostationary or polar satellite data are an established ingredient to global and regional data assimilation systems. However, the monitoring of AMVs against short-range forecast information that is used in the assimilation or against collocated radiosonde observations often shows considerable biases or larger, more random deviations in certain geographical regions. It is generally accepted that a large proportion of these biases or deviations can be attributed to the indirect measurement method of AMVs, i.e. the AMV processing and the interpretation of the AMVs as single-level wind observations. Further analysis of the origin of the problems and improvements in the interpretation of the AMVs are difficult as other correlative observations with sufficient coverage and including detailed information on winds and clouds are not usually available.

The rationale of this study has been to investigate AMVs derived from simulated image sequences covering a 6-hour period by comparing the derived AMVs to the wind field of the atmospheric model underlying the image simulations. Recent studies have shown this to be an effective approach for examining the potential properties of AMVs from future satellites/instruments (Velden et al. 2005, Wanzong et al. 2007, Genkova et al. 2007). In this framework the “true” wind field and the position and vertical extent of the cloud or humidity features are exactly known. This provides the opportunity to characterize in detail the errors that have arisen in the AMV processing and/or arise from the assumption that clouds are near-perfect passive tracers of the ambient wind at a single level and location. The study also allows us to shed light on height assignment which has long been established as one crucial area for AMV processing.

There are of course some caveats with the approach of this study. Firstly, the chosen 6-hour period is rather short, and the study is primarily intended as a demonstration study. Secondly, the underlying assumption of using simulated imagery for the characterization of AMVs is that the simulation adequately represents reality. While past studies have demonstrated a high degree of realism in cloudy satellite images simulated from ECMWF fields, they also found shortcomings, for instance in the representation of cirrus clouds (e.g., Chevallier and Kelly 2002). Also, the model resolution that is computationally possible for this study is still significantly lower than the 3-5 km resolution of today’s geostationary imagers. Therefore, it should be stressed that not all findings of the study will be directly valid for real observations and some care will be needed when interpreting the results.

The following is a summary of a more comprehensive report, available from EUMETSAT’s NWP SAF.

SIMULATED DATA

The simulations presented here are based on a high-resolution (T2047, ~10 km) forecast from the ECMWF model. The forecast data was used to simulate METEOSAT-8 infrared imagery (6.2, 7.3 and 10.8 µm) in clear and cloudy conditions. The forecast serves as the “true” atmosphere in our framework. The images were simulated with RTTOV-Cloud (e.g., Chevallier and Kelly 2002) and model fields between the 24 and 30-hour forecast range in 15-minute intervals were used for the simulation (covering 12-18 Z on 2 January 2006).

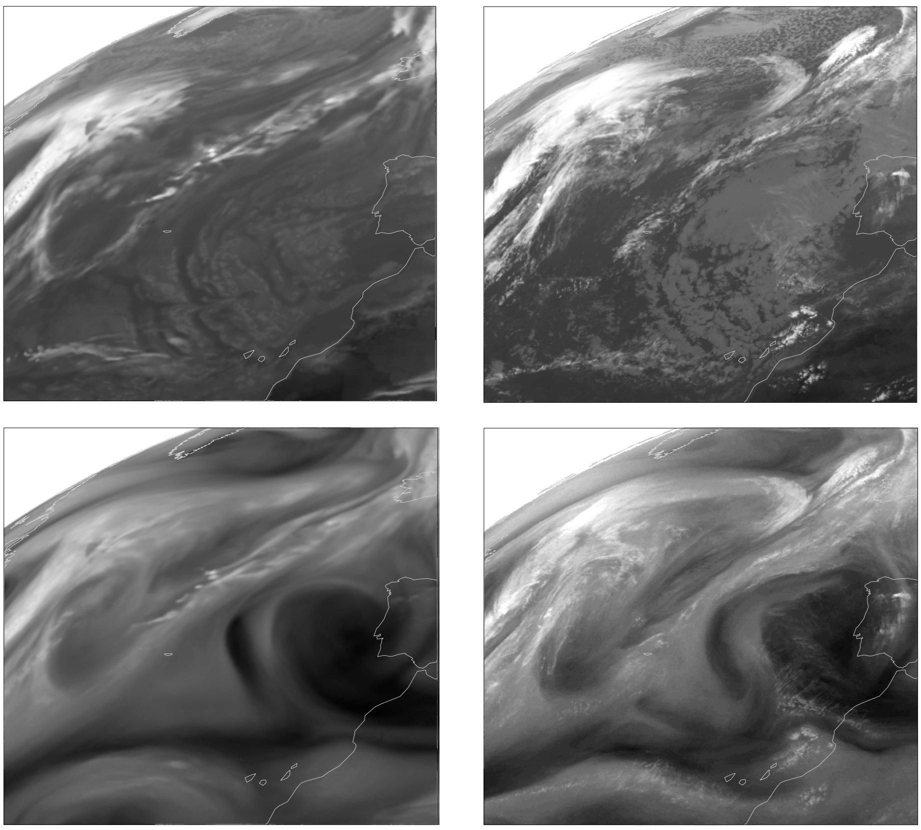

Figure 1: **Detail of a simulated (left) and observed Meteosat-8 (right) IR 10.8 µm (top) and 6.2 µm (bottom) image (2 Jan 2006, 15.45UTC).**

Figure 1 (top) shows an example of a simulated and the corresponding observed IR image. While the simulated image appears generally realistic, there is clearly additional structure in the real infrared image. In contrast to the infrared simulation the simulated WV image shows an under-representation of cirrus (Fig. 1, bottom).

The sequences of images were processed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) to derive AMVs using the standard CIMSS processing (e.g., Velden et al. 1997; Nieman et al. 1997). The CIMSS retrievals were processed with operational NOGAPS forecasts and ECMWF model data from the "truth" forecast, respectively. This allows us to investigate the relative impact of the model data on the AMV product. CIMSS made available the winds sets before quality control ("raw") as well as quality-controlled AMVs; the latter passed a number of internal quality checks and were post-processed by a recursive filter (e.g., Hayden and Purser 1995).

GENERAL RESULTS

Comparison to monitoring statistics for real AMVs

Difference statistics for simulated AMVs against the truth can be compared to monitoring statistics of real AMVs against a short-term forecast (first guess, FG). In the following, the monitoring statistics for real data are taken from the operational ECMWF system (T799 resolution, 91 levels) for the same study period.

The patterns of speed biases and normalized root mean square vector differences (NRMSVD) for simulated and observed AMVs show several similarities (e.g., compare Fig. 2, left/middle and right). For instance, negative speed biases prevail at high levels in the Extra-tropics and positive biases at mid-levels in the Tropics, especially in the dataset before quality control. The bias in the Northern Extra-tropics for IR high-level AMVs is -1.64 m/s and -0.96 m/s for simulated AMVs (after auto-editing) and real observations, respectively. NRMSVD values are 0.32 and 0.29, respectively. This confirms that a simulation study of this type can adequately represent true observation statistics. Nevertheless, some differences exist, for instance in terms of the coverage in the vertical of WV winds (not shown) or the zonal mean bias characteristics for low-level AMVs. Note, that real AMV-FG statistics include contributions from the forecast errors, whereas for the simulations we compare AMVs to the "truth". Also, the real Meteosat-8 AMVs were derived with the EUMETSAT processing rather than the CIMSS processing; however, differences in monitoring characteristics for EUMETSAT and CIMSS-derived AMVs are usually reduced when CIMSS winds before auto-editing are considered (e.g., (http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/index.html).

Influence of CIMSS quality control

For the set of AMVs before quality control, no significant differences could be found between the retrievals based on the ECMWF "truth" and the ones based on NOGAPS forecast data. For the "raw" AMVs, the forecast data is used in the height assignment step only, and it appears that errors in the forecast data are less important in this step in our simulation.

Application of the "auto-editor" and other quality-control measures improve the comparison statistics considerably, but mainly through data removal rather than correction. Figure 2 (left) shows zonal mean speed biases for IR "raw" AMVs and the bias and NRMSVD (not shown) are very large (-5.89 m/s and 0.60, respectively). In the post-processing about 9000 AMVs were excluded.

After the CIMSS quality control, AMVs derived and post-processed with ECMWF fields compare better with the "true" winds than those derived with NOGAPS fields (for instance, bias and NRMSVD for high-level cloudy WV AMVs over the Southern Hemisphere are -1.5 m/s and 0.38 for NOGAPS AMVs, and -0.6 and 0.35 for ECMWF AMVs). The ECMWF fields used represent the truth in this study, so that the processing with the ECMWF fields eliminates forecast errors otherwise present in the NWP data. The finding that winds processed with the NOGAPS forecasts compare more poorly to the truth suggests that the CIMSS quality control shows some sensitivity to forecast errors. However, NWP errors are also clearly not a dominant error source.

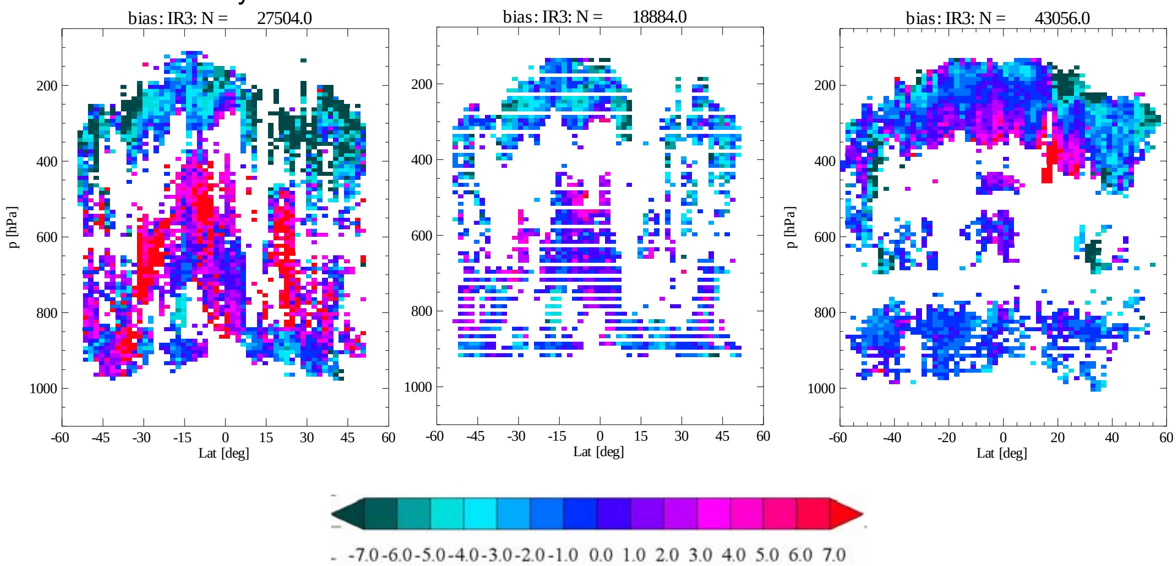

Figure 2: **Zonal mean speed bias (AMV-truth, m/s) for simulated IR AMVs (left before auto-editing, middle after auto-editing) derived with the NOGAPS background. Also shown is the equivalent zonal mean speed bias for real Meteosat-8 AMVs (Jan 2006 12-18UTC). Quality indicator>60. Numbers at the top indicate the number of winds in the sample.**

In the CIMSS processing, the auto-editor also increases the wind speed for certain high-level winds, and it allows adjustments to the assigned heights. The latter is based on deriving a “best fit” pressure relative to an analysis of the 3-dimensional AMV wind field, with NWP model data as a background constraint.

A detailed analysis of the auto-editor changes reveals that the modifications are relatively small for the simulated dataset. For IR high-level winds (H_2O intercept method used for height assignment) the increase is, on average, from 12.1 m/s to 12.35 m/s and the differences between original and reassigned pressures show standard deviations around 20 hPa with a mean close to zero. The AMV-minus-truth bias is therefore reduced from -2.16 to -1.75 m/s only, whereas the NRMSVD improves from 0.43 to 0.4. The findings are in contrast to the experience from NWP SAF AMV monitoring statistics (http://www.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/index.html) where considerable differences are found between raw and auto-edited winds. This may be due to the under-representation of high cirrus clouds in the simulated images as noted earlier.

The most significant and positive changes due to the auto-editor can be reported for mid-level IR winds (with IR window channel method used for the height assignment). The auto-editor assigns winds about 26 hPa higher, which corresponds to a model speed increase of 0.65 m/s. The positive bias is reduced from 0.70 m/s to 0.17 m/s.

ANALYSIS OF TWO SITUATIONS WITH KNOWN PROBLEMS FOR REAL AMVS

Two case studies focus on situations in which AMV retrievals generally exhibit systematic problems, namely lower level temperature inversions with clouds near the top of the planetary boundary layer and cirrus clouds. For both case studies only situations with idealistic atmospheric conditions are extracted.

Low-level temperature inversions

Low-level temperature inversions in tropical regions are areas in which GOES AMVs typically exhibit considerable positive biases, for instance over the eastern Pacific. Investigations at ECMWF and the Met.Office (Forsythe 2008) suggest that GOES low-level winds tend to be assigned too high in the atmosphere in these conditions. The origin of the problem is unlikely to be linked to the GOES imager, but rather to the AMV processing, and it is therefore studied here with the METEOSAT-8 data. CIMSS/NESDIS employs a "cloud base" reassignment method to most low-level marine tracers, based on a histogram method (LeMarshall et al. 1993). The approach lowers height assignments from the cloud top to an estimated cloud base.

To investigate AMVs in low-level temperature inversion regions, we extracted only those AMVs for which a low-level temperature inversion could be detected in the ECMWF model truth. The simulation framework allows us to compare the simulated AMVs with the true model wind at the inversion cloud as inferred from the model cloud cover field. Only IR AMVs are investigated here. The main findings for simulated AMVs are:

i) Assigned AMV heights are, on average, too low in the atmosphere (~20 hPa), i.e. below the detected model cloud base. This finding is in contrast to the experience with real AMV retrievals.
ii) The correlation between model wind speeds at the assigned height and at the cloud base height is very high (Fig. 3, left). It can be concluded that the height assignment is adequate.
iii) The correlation between observed AMV speeds and model speeds (at cloud base height or assigned height) is poor (Fig. 3, right). It can be concluded that the derived speeds are very noisy. This may be due to the lower wind speeds and the spatial resolution of the model simulation (~10 km) which is still considerably poorer than that of today's geostationary imagers (3-5 km).

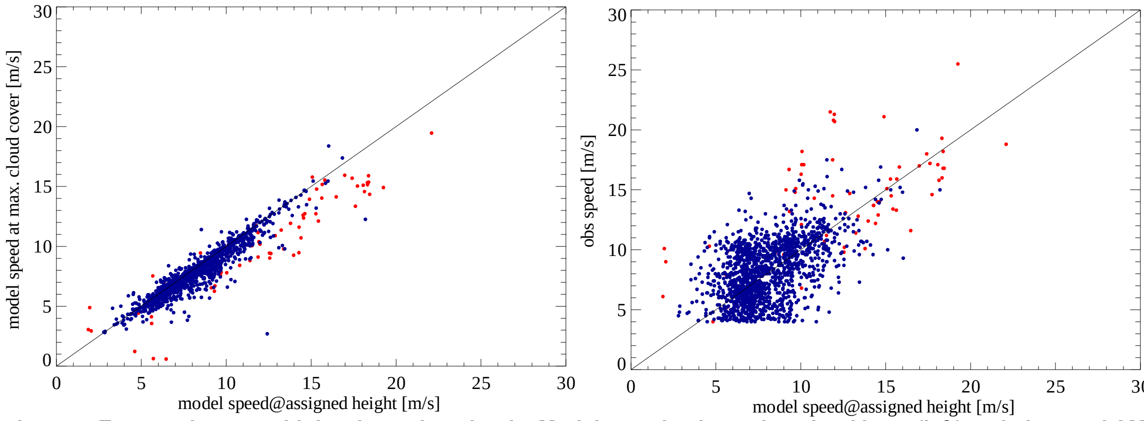

Figure 3: **Extracted cases with low inversion clouds. Model speed at inversion cloud base (left) and observed AMV speed (right), respectively versus model speed at originally assigned AMV height (after auto-editing and QI>60).**

High-level cirrus clouds

Monitoring of real extra-tropical high-level AMVs (especially in higher wind-speed regimes) typically shows negative speed biases against both other observations and model data. Such biases were also found in the simulated data, and it was therefore decided to investigate these further.

The negative speed bias is commonly attributed to height assignment problems (e.g., Bormann et al. 2002). However, during the course of the present study it was found that height assignment alone cannot explain all biases found in the simulated dataset. In the following, we will therefore characterise the negative bias only for situations in which height assignment can be ruled out as primary error source, i.e. situations with little vertical wind shear and no multi-layer clouds (with the selection based on the ECMWF model data). The limitation to situations in which height assignment should be of lesser importance does not mean that height assignment does not provide another additional source of bias in the general case.

In the following, only high-level IR and WV winds with the H_2O intercept method have been investigated, and we restrict our sample to situations with little vertical wind shear and without multi-layer clouds. Only "raw" winds are considered. The main findings are:

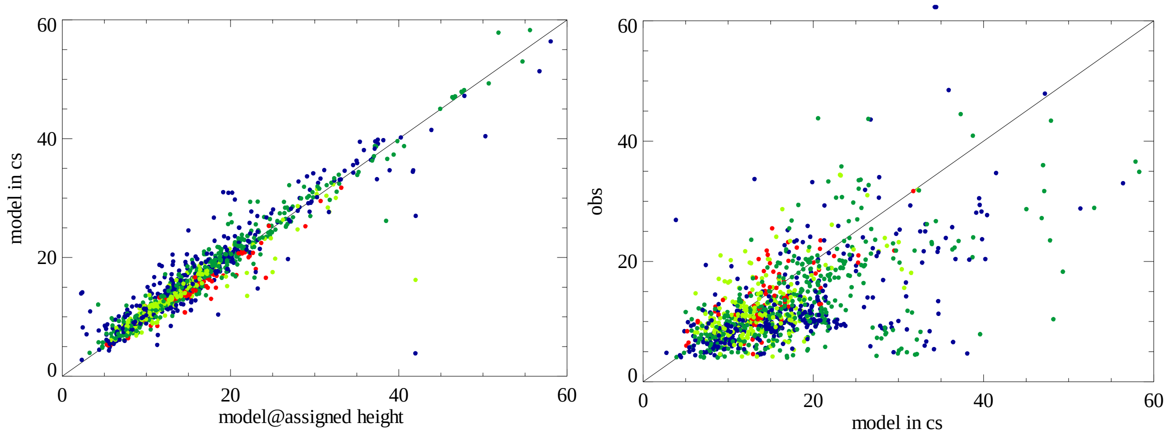

Figure 4: **Mean model wind speed [m/s] in the cirrus cloud versus model speed at the originally assigned height for IR AMVs (left). On the right the observed AMV speed [m/s] is plotted versus the mean model wind speed in the cirrus cloud. The colour coding corresponds to the thickness of the cirrus cloud in terms of numbers of model levels. Blue, dark green, bright green, red is from thin to thick cirrus. ("raw" AMVs, i.e. before autoediting, QI>60).**

i) Strong negative speed biases are still present in situations with little vertical wind shear and no multi-layer clouds.

ii) Model wind speeds at the assigned heights agree well with linear averages of model speeds in the cirrus cloud (Fig. 4, left). This confirms that height assignment is a minor error source for the selected cases, as intended by our selection. The main deviations between AMVs and the truth (Fig. 4, right) arise from uncertainties in the tracked speed

iii) The negative bias is larger for thin cirrus. IR AMVs have larger bias than cloudy WV AMVs (-3.7 and -3.0 m/s, respectively).

iv) The bias appears to be linked to changes in the evolution of the clouds: Situations with a change in the tendency of the cloud evolution during the tracking (e.g., cloud decay followed by cloud growth) show the highest bias in the AMVs. The effect of cloud evolution was studied using the model cloud data associated with the images used in the tracking.

SUMMARY

In this study we used AMVs derived from images simulated from a high-resolution ECMWF forecast to investigate characteristics of AMV data. The main findings are:

- The simulated AMVs exhibit broadly similar characteristics against the model truth as are commonly observed in monitoring statistics of real AMVs against short-range forecasts. This indicates that, overall, the simulation is adequately representing the characteristics of the real data.
- Before the CIMSS quality control, the simulated AMVs show relatively little sensitivity to the source of forecast data used in the AMV processing. However, quality control in the CIMSS processing (including the auto-editor) is weakly sensitive to the choice of forecast data. For the given dataset, the CIMSS quality control acted primarily through removal of poorer data, rather than through adjustments to the assigned height in the auto-editor.
- At least some of the negative bias observed at high levels in the extra-tropics appears to be due to the fact that clouds do not act as passive tracers and their motions do not fully represent the ambient wind. Biases are still present in situations in which height assignment is of less importance, and the largest biases are observed for thin cirrus clouds with considerable evolution between the images used in the tracking.
- Characteristics for AMVs in low-level inversion regions point to tracking problems in the simulated dataset. The characteristics for the simulated data agree less with experience from real AMVs in these situations.

The above findings for the simulated AMVs provide a number of interesting insights into AMVs and their interpretation. The interpretation of the results for real AMVs is not straightforward, not least due to the limited study period of 6-hours and the still considerable differences between the nominal model resolution of 10 km and that of today's geostationary imagers (3-5 km). Nevertheless, the study poses some important questions that deserve further attention. Especially intriguing is the finding that cloud evolution contributes to the bias seen for high level winds in the simulated dataset. While physically very plausible, this is an aspect that has received much less attention over the years, compared to, for instance the issue of height assignment for AMVs. Height assignment is doubtlessly a crucial issue for AMVs, but the assumption that clouds are passive tracers is equally fundamental in the interpretation of AMVs. Further studies are needed to determine to what extent clouds can be treated as passive tracers. One possibility would be to use the simulation framework, but to derive AMVs directly from model cloud fields on model or isentropic levels, in order to completely eliminate the height assignment aspect. A cloud-resolving model may be more suited for this purpose than the global ECMWF model. Another possibility would be to investigate with real AMVs whether situations with thin cirrus clouds and a certain cloud evolution over the tracking period can be linked to stronger biases in the AMVs. If the current findings apply to real data, a quality flag that indicates cloud thickness could prove a useful addition to the AMV product.

There is also still scope for further investigations based on the current simulated dataset. Comparisons to EUMETSAT-derived AMVs will further highlight the differences in the AMV processing and quality control used at CIMSS and at EUMETSAT. EUMETSAT-derived winds were not yet available for the present study, but should be available in due course. Furthermore, the aspect of interpreting AMVs as layer or horizontal averages rather than single-level point observations could be studied in more detail. Also, the simulation framework lends itself well to the study of spatial error correlations in AMVs (e.g., Bormann et al. 2003).

For future simulations, we recommend a higher model resolution and a longer study period.

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