ECMWF Feature article

from Newsletter Number 136 – Summer 2013

METEOROLOGY

Winds of change in the use of Atmospheric Motion Vectors in the ECMWF system

www.ecmwf.int/en/about/news-centre/media-resources

doi:10.21957/dgp5p0z3

This article appeared in the Meteorology section of ECMWF Newsletter No. 136 – Summer 2013, pp. 23–27.

Winds of change in the use of Atmospheric Motion Vectors in the ECMWF system

Kirsti Salonen, Niels Bormann

The use of Atmospheric Motion Vectors (AMVs) in the ECMWF system is undergoing an extensive revision. The aim is to ensure effective and realistic use of AMVs in data assimilation in order to improve their impact on model analyses and forecasts. The main amendment will be the introduction of situation-dependent observation errors. This is done to ensure that the errors assigned in the data assimilation better account for height assignment errors of the observations. The use of situation-dependent observation errors also enables notable simplifications to the AMV quality control. The modifications give significant positive impact on model analyses and forecasts especially at low levels, and they are planned to be implemented to the ECMWF Integrated Forecasting System (IFS) cycle 39r1 later this year.

Information about AMVs currently used in the ECMWF analysis is given in Box A.

Situation-dependant observation errors

Errors in the AMVs originate mainly from two sources: errors in the height assignment and errors in the wind vector tracking. The impact of errors in height assignment is highly situation dependent. It can be very significant in regions where wind shear is strong but on the other hand it is less relevant in areas where there is not much variation in wind speed with height. *Forsythe & Saunders* (2008) have introduced an approach to estimate situation-dependent observation errors for AMVs and this method has been investigated in the ECMWF system.

AMVs used in the ECMWF analysis

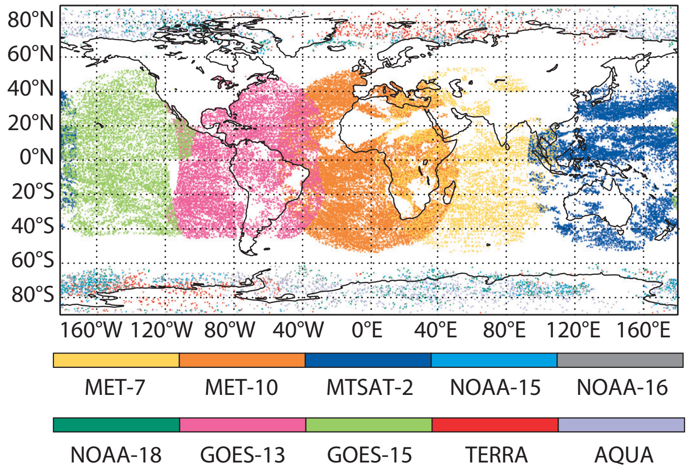
A

AMVs are wind observations derived by tracking clouds in the infrared (IR), water vapour (WV), or visible (VIS) channel, or clear-sky features in the WV channel. It is assumed that the tracked features act as passive tracers of the atmospheric flow. AMVs are interpreted as single-level wind observations assigned to a representative pressure level provided by the AMV producers.

AMVs are obtained both from geostationary and polar-orbiting satellites, and they constitute an important source of tropospheric wind information for global and regional data assimilation systems. Currently AMVs from the following satellites are actively used in the ECMWF analysis.

- Five geostationary satellites: Meteosat-7, Meteosat-10, GOES-13, GOES-15 and MTSAT-2.
- Five polar-orbiting satellites: Aqua, Terra and NOAA-15,-16,-18.

In addition AMVs from five other satellites (FY-2D, FY-2E, MetOp-A, MetOp-B, NOAA-19) are operationally monitored. New AMV data sets are routinely being investigated, the latest being AMVs from MetOp-B, and the hourly wind product from the GOES satellites.



The figure illustrates the 12-hour sample coverage for active AMVs.

doi:10.21957/dgp5p0z3

Height assignment errors

The error in the height assignment is thought to be the dominant source of error for AMVs. These errors can originate from several sources. Each height assignment method has built-in assumptions which will affect the accuracy of the assigned height depending on the atmospheric conditions. Identification of the representative pixels in the target box to be used in the height assignment is important. In addition, errors in the NWP temperature and humidity profiles applied in the height assignment methods contribute to the height error. Also problems may arise because the AMV observation and the model counterpart do not represent the same phenomena. For example, high-level AMVs are assigned to an estimate of the cloud top, yet it is unclear whether this is the appropriate height or whether the cloud motions are more representative of the wind at a level within the cloud.

In order to estimate the wind error due to error in height assignment an estimate of the height error is required. One option would be to use estimates of height errors provided by the AMV producers but these are not yet operationally available. Thus, currently the height errors are estimated based on model best-fit pressure statistics for the ECMWF system. The best-fit pressure is defined as the height where the vector difference between the observed and the model background wind is the smallest. Typical values for the height errors are of the order of 70 to 110 hPa. Comparison of best-fit pressure statistics for the ECMWF and Met Office systems has shown that the statistics are very similar for both systems (*Salonen et al*., 2012). This result increases confidence that the concept of best-fit pressure is useful in estimating the magnitude of the height errors.

In the ECMWF system, the height errors are defined for all satellites, channels and height assignment methods and are regularly updated when changes in the AMV processing take place. The height error is converted to a wind error following the *Forsythe & Saunders* (2008) approach. In the ECMWF implementation it is assumed that there are no clouds or water vapour features suitable for AMV tracking above the height of the model tropopause.

Tracking errors

Tracking errors originate also from several sources. In some cases the cross-correlation fails to locate the correct tracer in the search area. For example, the shape and orientation of the dominant feature affects the tracking accuracy. Also, if there are several features moving with different speed and directions in the target window, the result may be a compromise between the different motions (e.g. in case of multi-layer clouds). For AMVs from polar satellites the parallax error can also be significant.

For the ECMWF system tracking errors are estimated from observation minus model background statistics by selecting cases where the wind error due to error in the height assignment is small. Also the tracking errors have been studied separately for all satellites, channels and height assignment methods. As the differences are relatively small, we currently distinguish only between geostationary and polar orbiting satellites. The defined tracking errors vary from 2 ms^{-1} to 3.2 ms^{-1} depending on height and satellite.

Final observation error

The final observation error for each AMV combines the tracking error and the error due to error in height assignment, resulting in a highly situation-dependent observation error. Figure 1 displays the observation minus model background field (upper panel) and the corresponding assumed observation errors (lower panel) for the zonal component of cloudy water vapour AMVs for levels 100–400 hPa at 12 UTC on 1 June 2012. Comparison of the panels indicate that at locations where there are significant differences between the observed and the model wind speed, the situation-dependent observation errors reach higher values. Thus, the behaviour of the observation errors is consistent with expectations. On average the situation-dependent observation errors are of the same magnitude or slightly larger than the current observation errors in the operational system.

The new observation errors imply that AMVs will receive less weight in the analysis in areas of strong wind shear, whereas they will receive more weight in areas where there is less variation of wind with height.

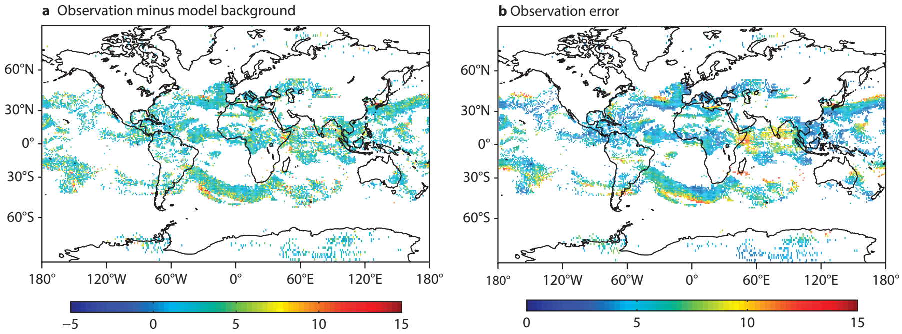


Figure 1 (a) Mean observation minus model background difference and (b) mean observation error for the zonal component of cloudy water vapour AMVs for levels 100–400 hPa at 12 UTC on 1 June 2012.

Revised quality control

Before an observation is accepted to be used in the model analysis it goes through several quality control steps. One of these is the model first-guess check where observations are compared with their model counterparts. If an observation deviates from the model first-guess field more than a pre-defined limit it is rejected.

Original checks

Traditionally the first-guess check has been very strict for AMVs in the ECMWF system. The rejection limits applied for AMVs are over three times tighter compared to the limits used for conventional wind observations, and the limits have also some geographical dependencies. In addition, in the current operational system the first-guess check is asymmetric: it is tighter for AMVs that under-report wind speed when compared to the model first-guess field. This feature has been implemented primarily to avoid that AMVs slow down the extra-tropical jets.

Figure 2 illustrates how the first-guess check operates. A scatter plot of observed wind speed versus first-guess wind speed is shown in the top left panel for Meteosat-10 cloudy water vapour AMVs at 100–400 hPa levels. The upper-right panel shows the scatter plot of AMVs which have been accepted by the first-guess check used in the current operational system. Outliers have been removed effectively and also the impact of the asymmetric check is clearly seen.

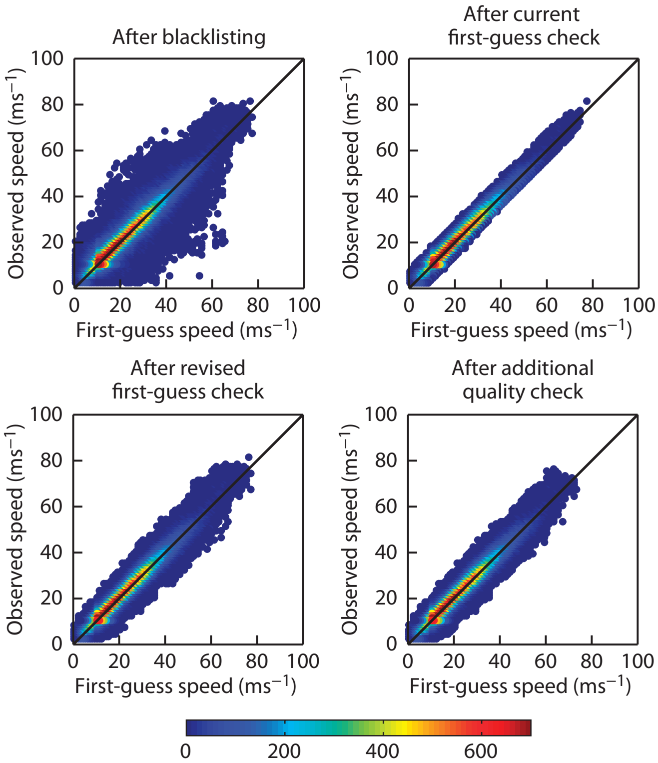


Figure 2 Demonstration of the operation of the model first-guess check. The upper-left panel shows Meteosat-10 cloudy water vapour AMVs at 100–400 hPa heights after blacklisting. The upper-right panel displays the AMVs after applying the current operational first-guess check, and the lower-left panel after the revised first-guess check. The lower-right panel shows AMVs after applying the additional quality criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error.

 doi:10.21957/dgp5p0z3

Revised checks

Introduction of the situation-dependent observation errors gives the opportunity to re-evaluate the first-guess check for AMVs. The situation-dependent observation errors allow a reduction in the weight given to observations in areas where wind shear is strong and the error in the height assignment can have a drastic impact, such as the regions with extra-tropical jets.

Several experiments have been conducted to investigate removing the asymmetric part of the AMV first-guess check, and the other ad hoc geographical adjustments to the rejection limits. In addition, variations of the rejection limits have been tested to allow more AMV observations to pass the first-guess check than in the current operational system. Results of the experiments reveal that with the situation-dependent observation errors it is possible to (a) use a symmetric first-guess check for AMVs similar to that used for conventional wind observations and (b) remove the geographical dependencies in the rejection limits for AMVs. However, rather tight rejection limits need to be retained, as relaxing the rejection limits results in degraded forecast quality.

The lower-left panel of Figure 2 illustrates how the revised first-guess check operates. Also the revised first-guess check effectively removes outliers but the spread in the scatter plot is symmetric and notably wider compared to the operational first-guess check.

New quality control criterion

Furthermore, a new quality control criterion has been investigated. The criterion limits the magnitude of the observation error due to error in height assignment to be smaller than *n* times the tracking error. The new quality control criterion is motivated by the fact that the height assignment errors are likely to be more correlated spatially, and such correlations are currently neglected in assimilations.

Experimentation with the criterion with varying values for *n* indicates that it is an effective tool to detect and reject suspect observations. However, a too tight criterion results in rejecting too many good quality observations and leads to negative forecast impact. In the configuration to be implemented operationally *n* is set to 4. The value has been chosen after trial and error based on a set of model experiments. This allows AMVs with an observation error up to 8–13 ms^{-1} to enter the analysis, depending on the height of the AMV.

The effect of using the new quality control criterion is illustrated in the lower-right panel of Figure 2. The criterion rejects on average 1% of the AMVs on top of the revised first-guess check.

Impact on model analysis and forecasts

The impact of using the situation-dependent AMV observation errors and the revised quality control described above has been investigated for two 3-month periods. The winter period covers 1 January to 31 March 2012, and the summer period 1 June to 31 August 2012. IFS cycle 38r2 at a T511 resolution, 137 levels, and 12-hour 4D-Var has been used in the experiments. All operationally assimilated conventional and satellite observations are used. In the control experiments AMVs are treated as in the current operational system, and in the test experiments the revised system is used.

Figure 3 shows the relative change in the number of used AMVs compared to the control experiment for the northern hemisphere extra-tropics (left panel), tropics (middle panel), and southern hemisphere extra-tropics (right panel). Also shown is the number of AMVs used in the control experiments. Both the winter and summer periods behave similarly and in Figure 3 the periods are combined. The results show that:

- Below 850 hPa the number of AMVs used in the control and test experiments is almost the same.
- In the extra-tropics at higher levels the number of used AMVs is increased in the revised system by 5 to 15% depending on height and hemisphere.
- In the tropics some increase in the number of used AMVs is seen between 850 hPa and 500 hPa but at higher levels the number of used AMVs is almost the same for the control and test experiments.

Overall in the revised system the number used AMVs increased by about 4% compared to the current operational system.

Differences in the mean wind analysis between the control and test experiments are mainly seen in the tropics and the magnitude is typically less than 0.5 ms^{-1}. This is a positive result, as it supports that the asymmetric part of the first-guess check can be safely removed without slowing down the extra-tropical jets.

The revised assimilation of AMVs leads to a significant positive forecast impact below 500 hPa especially in the tropics but also at higher latitudes. Figure 4 shows zonal plots of the normalised difference in the root-mean-square error for 48- and 72-hour wind forecasts for the summer period. The difference is calculated as test experiment minus the control experiment (i.e. blue shades indicate positive impact and green and red shades negative impact). The verification has been applied against each experiment's own analysis. The results are similar for the winter period. Verification against observations also shows positive impact especially over the northern hemisphere extra-tropics.

Overall the use of the situation-dependent observation errors and the revised first-guess check clearly improves the use of AMVs in the ECMWF system with a positive impact on the model forecasts.

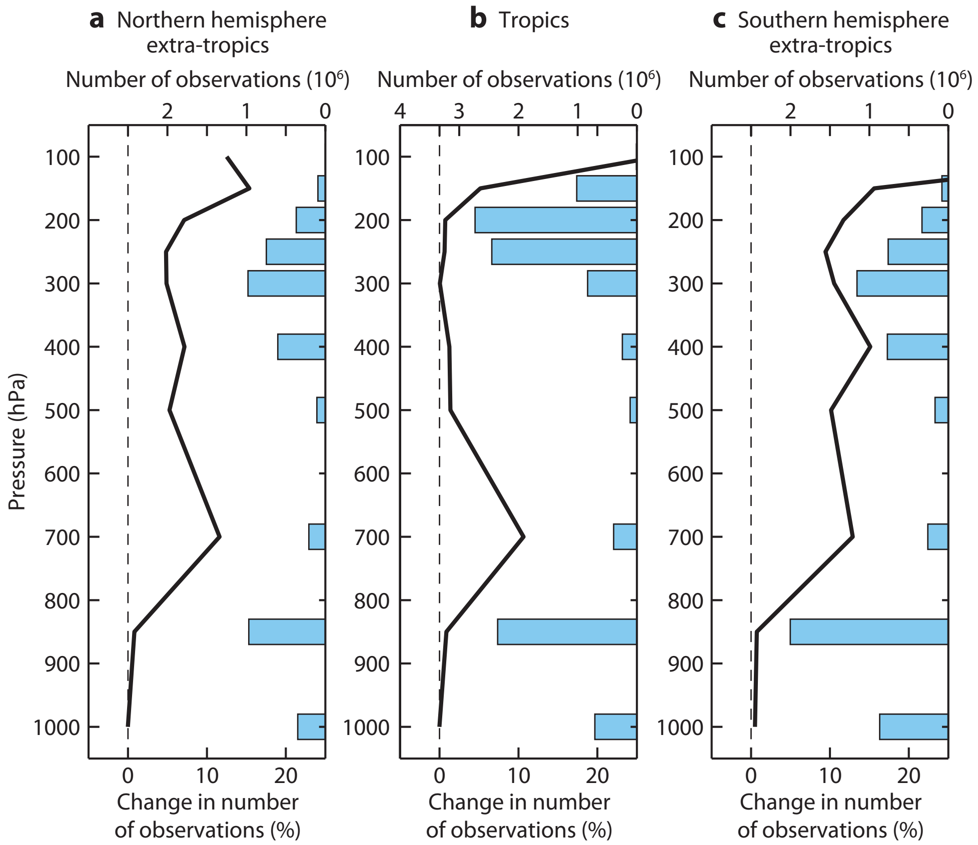


Figure 3 The relative change (percentage: black solid line) in the number of used AMVs compared to the control experiment for (a) northern hemisphere extra-tropics, (b) tropics and (c) southern hemisphere extra-tropics. The pale blue bars indicate the number of AMVs used in the control experiments. The periods are 1 January to 31 March 2012 and 1 June to 31 August 2012.

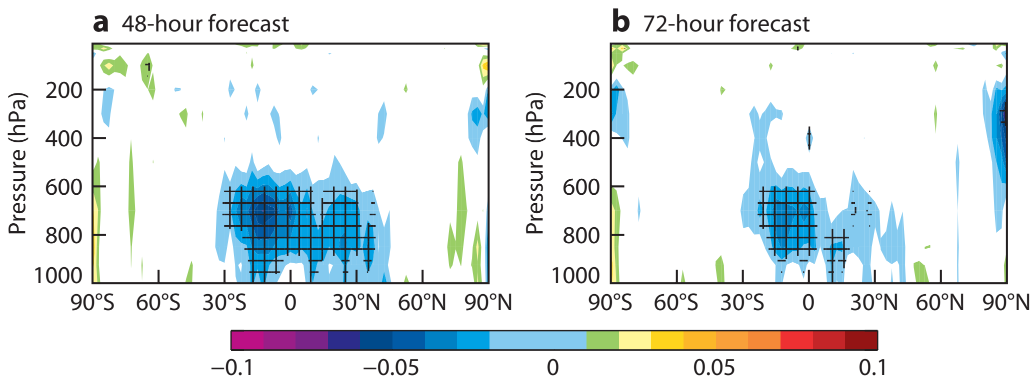


Figure 4 Zonal plot of the normalised difference (test experiment minus control) of the root-mean-square errorfor (a) 48-hour and (b) 72-hour wind forecasts. Verification is done against each experiment's own analysis. The period is 1 June to 31 August 2012.

doi:10.21957/dgp5p0z3

Concluding remarks and future plans

Situation-dependent observation errors together with a revised quality control for AMVs will be introduced in IFS cycle 39r1. Experimentation with the revised system shows that it is possible to get significant positive impact on forecasts from an existing observation type by refining the way it is exploited. Also the number of used AMVs will slightly increase compared to the current operational usage. The most important change is that the uncertainties in the AMV height assignment are taken into account in the observation errors, leading to more realistic use of the observations.

Work on further improving the use of AMVs continues. One area is the height allocation and interpretation of AMVs. For instance, as a part of our study regarding height assignment errors, we found indications of height assignment biases that varied, for instance, with level and between satellites. These could be investigated further and possibly corrected.

The traditional interpretation of AMVs is a single-level point estimate of wind at the pressure level assigned to the AMV during the derivation. A recent study by *Hernandez-Carrascal & Bormann* (2012) has investigated alternative ways of interpreting AMVs using a simulated framework. Simulated AMVs were considered, for example, as an average wind over the cloud layer. Also, other studies have suggested some benefit from interpreting AMVs as layer averages. Work is ongoing to further investigate these aspects in the data assimilation context.

Further reading

Forsythe, M. & **R. Saunders,** 2008: AMV errors: a new approach in NWP. In *Proc. 9th International Wind Workshop*, Annapolis, Maryland, USA, 14–18 April 2008. *EUMETSAT P.51*.

Hernandez-Carrascal, A. & **N. Bormann,** 2012: Atmospheric Motion Vectors from model simulations. Part II: Interpretation as spatial and vertical averages of wind and role of clouds. *ECMWF Tech. Memo. No. 678.*

Salonen, K., J. Cotton, N. Bormann & **M. Forsythe,** 2012: Characterising height assignment error by comparing best-fit pressure statistics from the Met Office and ECMWF system. In *Proc. 11th International Wind Workshop*, Auckland, New Zealand, 20–24 February 2012.

doi:10.21957/dgp5p0z3