CHALLENGES AND PLANS FOR THE ASSIMILATION OF ATMOSPHERIC MOTION VECTORS AT ECMWF

Niels Bormann, Claire Delsol, and Jean-Noël Thépaut

European Centre for Medium-range Weather Forecasts (ECMWF),
Shinfield Park, Reading, RG2 9AX, United Kingdom; email: n.bormann@ecmwf.int

Abstract

This paper summarises challenges and plans concerning the assimilation of Atmospheric Motion Vectors (AMVs) at ECMWF. We review the expected evolution in the AMV coverage, outline plans for a thorough review of the approach to assimilating AMVs, and introduce a project to use sequences of simulated satellite images to better characterise AMVs.

While the AMV coverage from geostationary satellites is fairly secure over the coming years, Numerical Weather Prediction (NWP) centres face the threat of losing the polar AMVs once MODIS has come to the end of its life. Developments of alternatives (such as a Molniya imager or infrared winds from AVHRR) are highly welcomed.

A review of the assimilation of AMVs will start with a revision of quality control procedures to bring these better in line with current data characteristics. Flow-dependent quality control and observation errors should be investigated, for instance, to better account for height assignment error in the assimilation. Long-term, we aim to explicitly take correlated observation errors in the AMVs into account to improve the extraction of small-scale information in the AMV assimilation.

To better characterise AMVs and their errors we propose a project to use sequences of satellite images simulated from high-resolution NWP fields in cloudy and clear-sky areas. The framework allows the unique possibility of comparing the derived AMVs with the true atmospheric fields that produced the image sequence.

INTRODUCTION

Atmospheric Motion Vectors (AMVs) from geostationary and polar imagers have an established positive impact on numerical weather forecasts (e.g., Thépaut et al. 2006). However, several caveats for the use of AMVs have been identified over the years, such as the complexity of their errors and the general interpretation of what AMVs represent. Consequently, there is a continuous need to improve the AMV product, but also to enhance the methods and approaches used to assimilate these data in order to maximise the information that is extracted in the analysis. This is especially true in the context of the ever improving observing network. In the following, we will review the relevant areas which are of particular concern for the assimilation of AMVs at ECMWF.

EVOLUTION OF COVERAGE

Good geographical and temporal coverage is one of the strengths of the AMV data from the current suite of satellites, especially since the generation of polar AMVs from MODIS (Key et al. 2003). Some of the largest forecast impacts from AMVs have been achieved when AMVs with good coverage are included in areas otherwise poorly observed (e.g., Indian Ocean coverage provided by Met-5, Lalaurette et al. 1998; MODIS winds over the polar regions, Bormann and Thépaut 2004). It is considered important for Numerical Weather Forecasting that the current geographical AMV coverage is maintained.

For AMVs from geostationary satellites, continued coverage appears secure over the next few years. The current coverage as considered by ECMWF is illustrated in Figure 1. ECMWF is currently not using AMVs from the Japanese MTSAT-1R, leading to a gap in coverage of used AMVs over the Pacific region. First trials with a tightly quality-controlled sample of MTSAT-1R AMVs show encouraging results, and operational use of these winds in the ECMWF system is expected in due course, pending successful completion of further testing (Delsol et al. 2006). This will close the current gap in the AMV usage over the Pacific region, albeit still with at a much poorer coverage compared to other areas of the globe. Winds from the Chinese FY-2C promise a further improvement in coverage over the West Pacific/East-Asia/Indian Ocean region, and ECMWF will continue to monitor these and provide feedback on the quality, especially on the provision of quality indicator information (Delsol et al. 2006). A number of changes of operational satellites are expected over the next two years, such as Meteosat-9 taking over from Meteosat-8, Meteosat-7 taking over the Indian Ocean coverage from Meteosat-5, and GOES-11 replacing GOES-10. As usual, winds from the new operational satellites will be monitored and subsequently assimilated provided the quality proves acceptable. Also during the next two years, AMVs could be available from INSAT-3D and the Korean COMS.

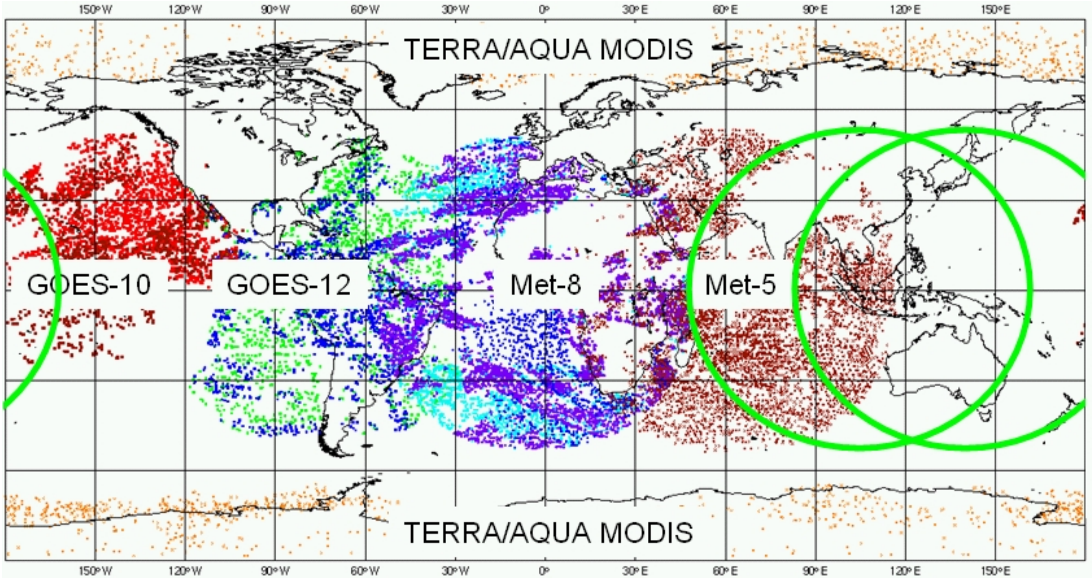

Figure 1: **Sample of coverage of AMVs considered at ECMWF, taken for the 6-hour period around 5 April 2006, 6 UTC. Dots indicate winds used in the operational analysis; green circles indicate FY-2C and MTSAT-1R viewing areas.**

For AMVs over polar regions, maintaining coverage beyond the life-time of the MODIS instruments is currently not secured, and a significant reduction in forecast quality has to be expected if no alternative source of polar wind information can be found. The imagers currently planned until 2015-2020 for Metop or NPOESS (AVHRR, VIIRS) do not include a water vapour channel which provides 60-70 % of the winds in case of MODIS. A suitable imager in Molnya orbit as proposed by Riishøjgaard et al. (2006) would be capable of preventing the significant loss in coverage. Alternatively, current experimentation at ECMWF and elsewhere indicates that while MODIS water vapour (WV) winds provide the bulk of the forecast impact, infrared (IR) MODIS AMVs alone can also achieve significant positive impact (Thépaut et al. 2006, Riishøjgaard 2006). These studies support the real-time derivation of IR AMVs from AVHRR or VIIRS, to address the gap otherwise expected after the life-time of MODIS.

QUALITY CONTROL

Quality control of observations is an important part of any assimilation system in order to protect the assimilation from spurious observations. Quality control has long been recognised as a particularly crucial area of attention in order to achieve positive forecast impact from the assimilation of AMVs.

The current approach to quality control for AMVs at ECMWF is as follows (see also Fig. 2):

Selection by QI thresholds: The quality indicator information provided with the AMVs is used to select a good-quality sample of winds by applying a quality indicator threshold (e.g., Rohn et al. 2001). The thresholds have been defined using results from the routine monitoring of the AMV data, and they depend on satellite, channel, geographical region, and level. In regions of known deficiencies in the AMV quality, AMV data are not used altogether, for instance at lower levels over land.

Check against the First Guess (FG): AMVs are compared with the FG wind interpolated to the assigned AMV pressure, and those AMVs which differ too much from the FG are rejected (e.g., Järvinen and Unden 1997). The check is currently very tight, and it is asymmetric with even tighter limits for AMVs which are slower than the FG. The latter is a feature to address the slow speed bias otherwise common for high level mid-latitude AMVs. The limits that are used are the same for all AMVs, regardless of the satellite, channel, etc.

Variational quality control: Variational quality control is also applied to AMVs, and this down-weighs data whose departures are more likely to belong to a white-noise distribution than a Gaussian (Andersson and Järvinen 1999). It has little influence in the case of AMVs due to the tight FG check limits.

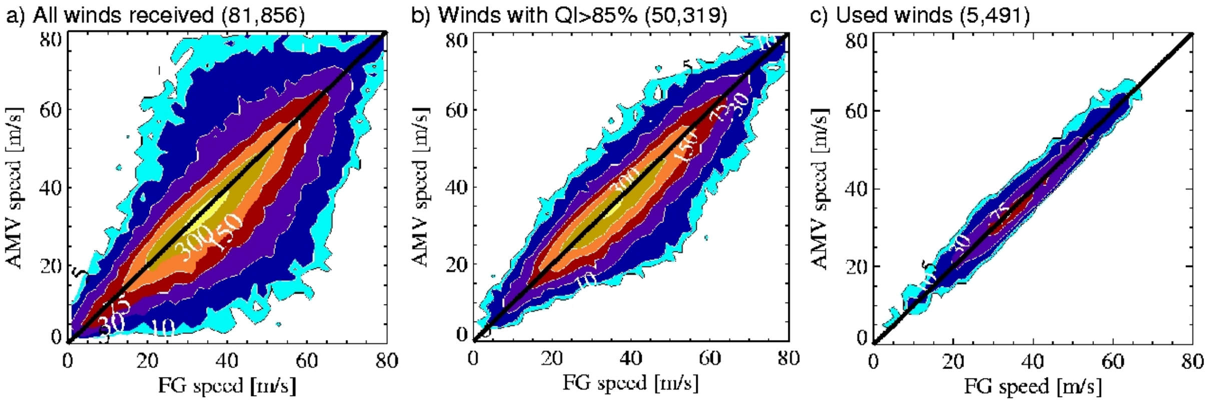
a) All winds received (81,856)
b) Winds with QI>85% (50,319)
c) Used winds (5,491)

Figure 2: **Illustration of quality control applied to Met-8 Southern Hemisphere IR AMVs above 400 hPa. a) Histogram of FG speed versus AMV speed for all winds received. b) As a), but for the sample of winds with a forecast-independent QI>85%. c) As b), but for the sample of used winds, ie., after additionally applying the FG check and thinning. The numbers of winds in each plot are indicated in brackets in the heading.**

The current approach has a number of disadvantages. For instance, height assignment errors are not directly addressed as the QI does not directly reflect the quality of the height assignment. Also, quality differences arising from the tracer quality or the general situation of the scene that was used in the AMV derivation are also not taken into account. Improvements in these areas require winds producers to provide further information on individual AMV quality. Another shortcoming of the current quality control procedures is the tightness of the FG check, which means that the sample of used winds is very heavily constrained by the FG which we whish to correct. The asymmetric limits have been tuned over a decade ago, and they therefore do not reflect current satellite and channel-specific data characteristics. This has been highlighted, for instance, in recent experiments with Met-8 winds, for which the slow speed bias at high levels over the extra-tropics is considerably reduced, and the asymmetric FG check now at times leads to a small positive bias (e.g., Delsol et al. 2006).

As a result, our revision of quality control procedures will start with a revision of the FG check, in order to better reflect current characteristics, with the aim to have a less tight and possibly less asymmetric check. In this context a framework that can easily be adapted to new satellites would be desirable, as would be a robust way to address speed biases commonly found in AMVs separately from the FG check. A completely symmetric FG check is likely to require renewed efforts to develop alternative ways to address speed biases. Bias correction methods based on height reassignment have previously been explored by Bormann et al. (2002) who demonstrated improvements in the biases of the AMVs vs the FG, but at the expense of slightly degraded forecasts.

Further quality control information provided by the producers will be incorporated in the quality control procedures if and when they become available. Also, more flow-dependent quality control could be explored, such as flow-dependent QI thresholds (addressing for instance limitations in the QI in regions of strongly curved flow), or employing information on wind shear to avoid using winds in high-shear regions for which uncertainty in the height assignment could be very problematic.

OBSERVATION ERRORS

Assigning observation errors is another important aspect of the assimilation of any observation, as observation errors together with background errors determine the relative weight that observations receive in the assimilation system. For AMVs, assigning appropriate observation errors is made more difficult by the presence of spatial error correlations for distances up to about 800 km (Bormann et al. 2003).

Observation errors for AMVs in the ECMWF system are assumed to be uncorrelated, and thinning to 200 km resolution is used to reduce the influence from spatial error correlations. Observation errors assigned to each wind depend on the pressure level only, and the same values are used for all geostationary AMVs, whereas polar AMVs have somewhat smaller observation errors assigned to them (von Bremen et al. 2004). The values used for observation errors are somewhat inflated, ie they are larger than what studies of the AMV observation errors suggest, and they are at times larger than the standard deviation of FG departures for AMVs. Error inflation is another pragmatic way to reduce the effect of neglecting error correlations in the AMV data.

Improvements in the representation of AMV errors in the assimilation are possible in a number of areas. Observation errors could be made more dependent on satellite, channel or QI to better reflect differences in the quality of the winds. Also, the influence of height assignment error could be taken into account by using an estimate of the wind shear to translate height assignment error to a wind error, with larger error in regions of larger shear. Statistics of FG departures vs shear, for instance, show characteristics consistent with the expected influence from a height assignment error of approximately 40 hPa (Fig. 3). Such approaches could be used to better model the situation-dependence of the effect of height assignment error in AMVs.

It is worth recalling that a revision of errors assigned to AMVs needs to reflect our relatively limited ability to calculate estimates of the actual AMV observation error. Statistics from AMV/radiosonde collocations provide only results of the combined AMV *and* radiosonde error, and to separate the two requires methods such as used in Bormann et al. (2003). These methods rely on rather large data samples and are largely impractical to study flow- or QI-dependent observation errors. In addition, if error correlations are neglected in the assimilation, as is currently done for AMVs, no clear method exists to determine the “optimal” observation errors together with an “optimal” choice of thinning scales. We therefore favour cautious approaches to the modelling of AMV errors. This is in contrast to the recently suggested concept of the so-called Expected Error (EE, Le Marshall et al. 2004) which uses multiple linear regressions against the components of the QI and predictors derived from FG information to estimate expected radiosonde-AMV departures.

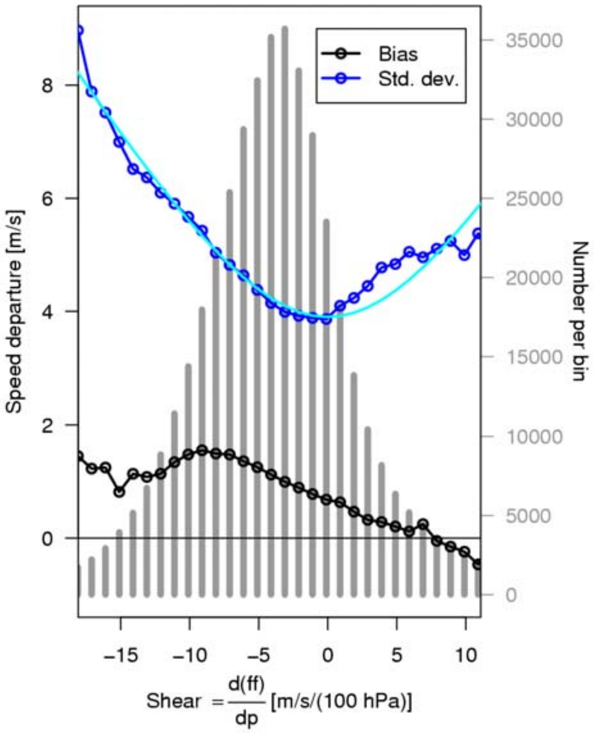

Figure 3: **Statistics of speed departures against the FG for high level Met-8 AMVs from the 6.2µm WV channel versus an estimate of the local shear in wind speed. Data coverage is 1-10 January 2006, and only winds which are not blacklisted are shown. The shear estimate has been calculated by simply subtracting FG wind speeds ±50 hPa around the assigned pressure level. The bias is shown in black, and standard deviation is shown in blue. Grey bars indicate the distribution of winds (right y-axis). Displayed in cyan is the behaviour of the standard deviation that would be expected if it was made up of uncorrelated and constant contributions from an AMV vector error and the FG error, in addition to a shear-dependent contribution from the height assignment error, with an assumed uncertainty of 40 hPa in the assigned pressure.**

Another area requiring attention is error correlations in the AMV data (Bormann et al. 2003). Currently, thinning is used to reduce the effect of spatial error correlations. No thinning in time is performed, even though it is likely that AMVs possess temporally correlated errors, especially in the case of hourly AMVs. A short-term solution to this would be to trial the impact of temporal thinning. Long-term we intend to take spatial and temporal error correlations explicitly into account in the assimilation. Note that spatial error correlations in the AMVs mean that the larger-scale structures represented in the AMV field have larger errors, but smaller-scale structures have smaller errors than would be implied if the errors were uncorrelated. Explicitly taking the error correlations into account in the assimilation is therefore expected to improve our ability to extract information on smaller-scales captured by the AMV field.

AMVS FROM SIMULATED SATELLITE IMAGES

The underlying challenge for quality control, specification of errors, and assimilation of AMVs is the fact that many aspects contribute to AMV errors, as a result of the processing steps necessary in the AMV derivation. These include navigation and calibration errors, errors arising from the tracking and the height assignment for the tracked cloud, and errors introduced through the use of forecast data and radiative transfer models. Also, the current practice in the assimilation is to assume that the clouds are passive tracers, and that the cloud motions represent the wind at a single level at the assigned height. All these aspects, and the last ones in particular, introduce errors that are often difficult to characterise, given the lack of detailed knowledge of the “true” state of the atmosphere. Detailed observational campaigns would be required for a better characterisation of some of these aspects, but the required campaigns would be very expensive and likely to be limited to only a few cases (e.g., Hasler et al. 1979).

Here we introduce the framework of using sequences of images simulated from NWP data in clear-sky as well as cloudy-sky regions to better study the characteristics of AMVs. Satellite images have recently been simulated from a T2047 (~10 km) forecast run of the ECMWF global model (e.g., Fig. 4), providing high-resolution images for the Meteosat and GOES satellites every 15 min. The radiative transfer model used in these calculations is RTTOV-Cloud, and images simulated with RTTOV-Cloud from operational ECMWF fields have been shown to display a large degree of realism (e.g., Chevallier and Kelly 2002). Images can be simulated for IR as well as WV channels. We are working together with CIMSS and EUMETSAT to now derive AMVs and other products from the simulated images.

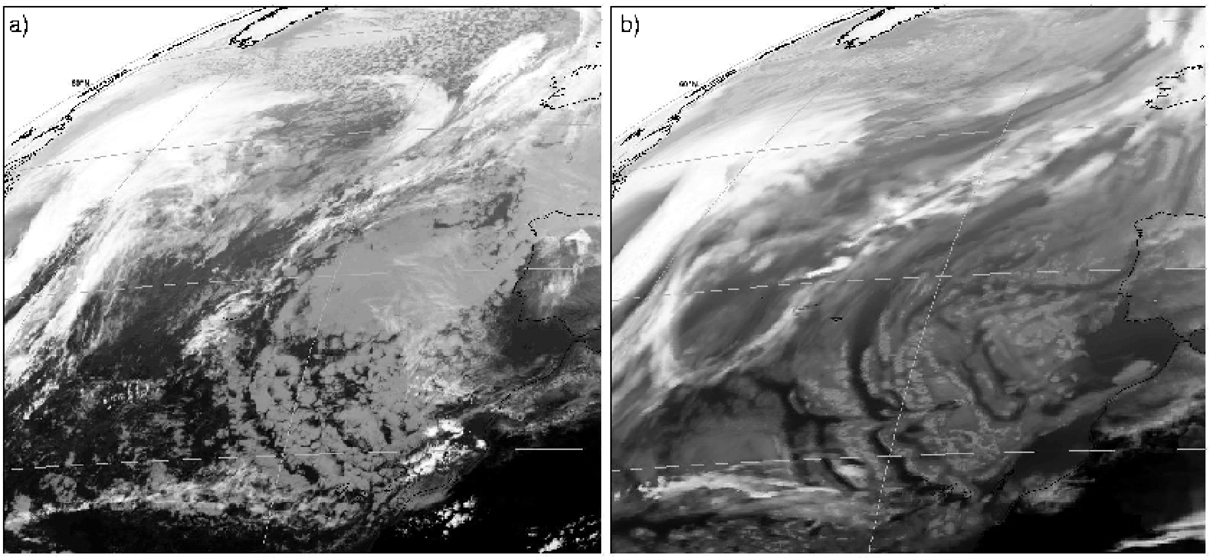

Figure 4: **Observed (a) and simulated (b) Met-8 10.8 micron IR image for 1545 UTC on 2 January 2006. The simulated image is from a 27 h 45 min forecast.**

The advantage of the approach is that the atmospheric state which generated the image sequence is entirely known, including the position of the clouds, and the underlying wind field. A comparison of the derived products with the NWP fields used to generate the image sequence will therefore allow a detailed characterisation of the AMV errors leading to further insights as to how AMVs provide information on the atmospheric wind field. A range of aspects can be studied, for instance: How well are current height assignment schemes performing? Which height should the AMV be assigned to (cloud top/base/etc)? Do AMVs represent single-level wind observations or layer quantities, and if the latter, can we provide better estimates how these layer quantities should be calculated? In other words, can we provide a better observation operator for cloudy sky AMVs as opposed to the currently employed interpolation to the assigned height? The framework could also be used to obtain a better inventory of the various different contributions to AMV error, including a better characterisation of which aspects contribute most to spatially correlated errors in the AMVs.

While the proposed framework is likely to significantly enhance our understanding of AMVs, it should also be noted that not all findings will be applicable one-to-one to real observations. The scales represented in the simulated images are still somewhat coarser than in real imagery, and the cloud physics in the NWP model and the radiative transfer calculations are currently considerably parameterised. This will need to be taken into account when interpreting the results of the study.

CONCLUSIONS

In this contribution we summarised challenges and plans concerning the assimilation of AMVs at ECMWF over the next few years. We reviewed the expected evolution in the AMV coverage, outlined plans for a thorough review of the approach to assimilating AMVs, and proposed a project to use sequences of simulated satellite images to better characterise AMVs. We note that maintaining AMV coverage over the polar regions is considered very important, and we strongly support developments to derive AMVs from an IR channel of AVHRR or VIIRS or the provision of a dedicated Molniya imager. Coverage of AMVs from geostationary satellites is expected to be stable over the next few years; the Pacific region remains the area with the poorest coverage.

The revision of a number of assimilation choices is expected to lead to an improved assimilation of AMVs. Areas that require attention are the revision of quality control checks, especially the check against the FG which is currently very tight and asymmetric. The asymmetric aspect has been tuned to the AMV bias characteristics of about a decade ago, and experimentation with Met-8 AMVs has highlighted that a retuning of these limits is necessary. Another area of improvements is a more detailed modelling of the AMV observation error, including efforts to take into account the uncertainty arising from height assignment error. Long-term, correlated observation errors in the AMVs will be taken into account to improve the extraction of small-scale information in the AMV assimilation.

To improve our understanding of AMV characteristics and errors, ECMWF in cooperation with EUMETSAT and CIMSS have launched a project to derive AMVs from satellite imagery simulated from high-resolution NWP model fields. The synthetic imagery includes simulations for clear as well as cloudy regions. Comparison of the derived AMVs with the generating NWP fields is expected to give further insights about the error characteristics of AMVs, the performance of height assignment, and allow a better formulation of the observation operator, for instance through a situation dependent layer averaging.

REFERENCES

Andersson, E. and H. Järvinen, 1999: Variational quality control. Quart. J. Roy. Met. Soc., **125**, pp 697-722.

Bormann, N., G. Kelly, and J.-N. Thépaut, 2002: Characterising and correcting speed biases in Atmospheric Motion Vectors within the ECMWF system. Proc. Sixth International Winds Workshop, Madison, Wisconsin, USA, available from: EUMETSAT, Darmstadt, Germany, pp 113-120.

Bormann, N., S. Saarinen, G. Kelly, and J.-N. Thépaut, 2003: The spatial structure of observation errors in Atmospheric Motion Vectors from geostationary satellite data. Mon. Wea. Rev., **131**, 706-718.

Bormann, N. and J.-N. Thépaut, 2004: Impact of MODIS polar winds in ECMWF's 4DVAR data assimilation system. Mon.Wea.Rev., **132**, pp 929-940.

Chevallier, F., and G. Kelly, 2002: Model clouds as seen from space: Comparison with geostationary imagery in the 11-µm window channel. Mon. Wea. Rev., **130**, 712-722.

Delsol, C., N. Bormann, and J.-N. Thépaut: Status of Atmospheric Motion Vectors at ECMWF. Proc. Eighth International Winds Workshop, Beijing, China, available from: EUMETSAT, Darmstadt, Germany.

Hasler, A.F., W.C. Skillman, and W.E. Shenk, 1979: In situ aircraft verification of the quality of satellite cloud winds over oceanic regions. J. Appl. Met., **18**, pp 1481-1489.

Järvinen, H. and P. Undén, 1997: Observation screening and background quality control in the ECMWF 3DVAR data assimilation system. Tech. Memo. 236, ECMWF, Reading, UK, 33 pp.

Key, J.R., D. Santek, C.S. Velden, N. Bormann, J.-N. Thépaut L.P. Riishøjgaard Y.Zhu, and W.P. Menzel, 2003: Cloud-drift and water vapour winds in the polar regions from MODIS. IEEE Trans. Geosci. Remote Sens., **41**, pp 482-492.

Lalaurette, F., A. Garcia-Mendez, and M. Rohn, 1998: Monitoring SATOB products at ECMWF: Availability, quality control, and impact. Proc. Fourth International Winds Workshop, Saanenmöser, Switzerland, available from: EUMETSAT, Darmstadt, Germany, pp 239-346.

Le Marshall, J, R. Seecamp, A. Rea, M. Dunn, J. Jung, J. Daniels, and C. Velden, 2004: Error characterization and application of Atmospheric Motion Vectors over Australia and high latitudes. Proc. Seventh International Winds Workshop, Helsinki, Finland, available from: EUMETSAT, Darmstadt, Germany, 127-136.

Riishøjgaard, L.P., M. Sienkiewicz, and Guang Ping Lou, 2006: The impact on forecast skill of water vapour and window channel winds from MODIS. Proc. Eighth International Winds Workshop, Beijing, China, available from: EUMETSAT, Darmstadt, Germany.

Riishøjgaard, L.P., B. Atlas, D. Chesters, K. Holmlund, J. Key, S. Kidder, A. Krueger, P. Menzel, J.-N. Thépaut, C. Velden, and T. Vonder Haar, 2006: The Molniya orbit imager. Proc. Eighth International Winds Workshop, Beijing, China, available from: EUMETSAT, Darmstadt, Germany.

Rohn, M., G. Kelly, and R. Saunders, 2001: Impact of a new cloud motion wind product from Meteosat on NWP analyses. Mon. Wea. Rev., **129**, pp 2392- 2403.

Thépaut, J.-N., N. Bormann, C. Delsol and G. Kelly, 2006: Impact of Atmospheric Motion Vectors on global numerical weather prediction. Proc. Eighth International Winds Workshop, Beijing, China, available from: EUMETSAT, Darmstadt, Germany.

Von Bremen, L., J.-N. Thépaut, G. Kelly, 2004: Assimilation of polar winds and recent satellite winds impact studies at ECMWF. Proc. Seventh International Winds Workshop, Helsinki, Finland, available from: EUMETSAT, Darmstadt, Germany, 255-263.