OPERATIONAL USE OF
ATMOSPHERIC MOTION VECTORS AT ECMWF

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Abstract

A review of the status of Atmospheric Motion Vectors (AMVs), monitored and assimilated operationally at the European Centre for Medium Range Weather Forecasts (ECMWF), is presented. The period since the last workshop saw a number of satellite replacements. Currently, data from five different geostationary satellites are used in operations (from METEOSAT-9 and -7, GOES-11 and -12, and MTSAT-1R), together with polar AMVs from MODIS on Terra and Aqua.

A number of additional AMV datasets are being monitored with a view of eventual operational assimilation, and we report on the results of the monitoring efforts so far. Winds have been derived by CIMSS from the infrared channel of the AVHRR instrument on the NOAA satellites. While the data are relatively sparse, assimilation trials in a system that uses a limited amount of satellite observations document a small positive forecast impact from the AVHRR winds. This also makes the data attractive for reanalyses. In addition, direct-broadcast MODIS winds are now available to improve the timeliness of this important dataset. A greater coverage is obtained for the early-cutoff NWP runs. AMVs from CMA's FY-2C now include quality indicator information, prompting a re-assessment of the quality of these winds. Lastly, winds from the stereo-viewing MISR instrument on Terra have been compared to the ECMWF first guess, showing broadly similar first guess statistics to other AMVs from geostationary or polar satellites, despite a supposedly much better height assignment.

INTRODUCTION

Atmospheric Motion Vectors (AMVs) derived from image sequences from geostationary or polar orbiting satellites continue to be a sizeable ingredient to ECMWF's operational data assimilation system. Currently, data from 5 geostationary and 2 polar satellites are assimilated operationally (Fig. 1).

The period since the last Winds Workshop saw a number of satellite changes: GOES-11 AMVs replaced GOES-10 winds in the operational system from 17 August 2006 onwards. MTSAT-1R AMVs were introduced actively in the operational assimilation on 12 December 2006, after an extensive monitoring and experimentation period (Delsol et al. 2006). Furthermore, METEOSAT (MET)-7 took over the Indian Ocean coverage from MET-5 in February 2007, whereas MET-9 winds were used operationally instead of MET-8 ones from 27 March 2007 onwards.

Monitoring of AMVs and evaluation of new products and product upgrades is an ongoing task at ECMWF. Of particular interest are new products that improve the coverage and have the potential to improve forecasts in the operational system. Here, we report on a first evaluation of new polar AMVs from the AVHRR instrument, coverage improvements gained through the direct broadcast MODIS winds, improvements in the quality of the Chinese FY-2C winds, and a first evaluation of winds from the MISR instrument.
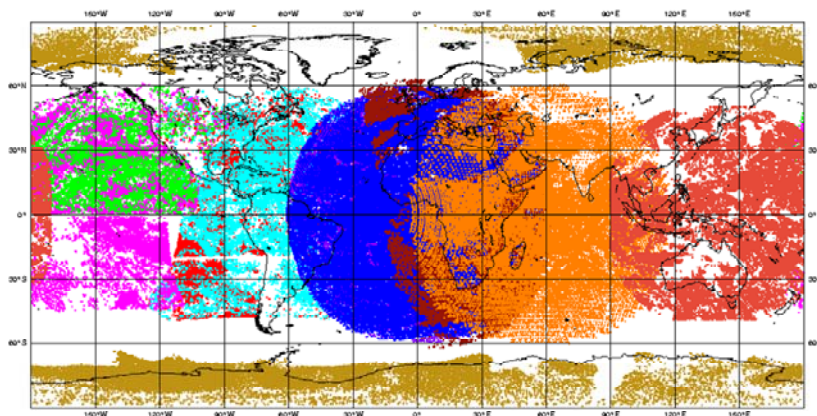
Figure 1 **: Example of AMV coverage at ECMWF (9th April 2008 06UTC cycle): 374104 observations. Pink and green are GOES11, red and light blue GOES12, dark blue and brown-red Met-9, orange Met-7 and dark orange MTSAT-1R. Gold are AMVs from polar orbiters Terra and Aqua.**

AVHRR AMVs

Polar AMVs have recently been derived by CIMSS from AVHRR imagery from the NOAA satellites (Dworak et al. 2006). Compared to MODIS winds, AMVs derived from AVHRR data have the drawback that no WV channel is available on AVHRR. Therefore, no WV winds are available (these account for about 2/3 of the data in the case of MODIS winds), and the height assignment for the remaining IR winds is poorer as no semi-transparency correction can be performed. Nevertheless, given the significant positive impact of MODIS winds observed in the past (e.g., Bormann and Thépaut 2004), and the limited lifetime of the MODIS instrument, there is considerable interest in the Numerical Weather Prediction (NWP) community to explore the use of AVHRR AMVs. Also, with the data covering over 25 years, AVHRR winds provide an attractive dataset for reanalysis purposes.
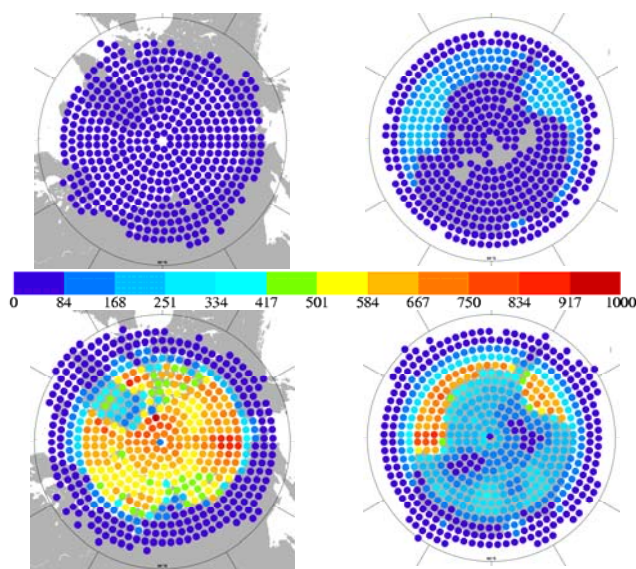

Figure 2: **Number of used AMVs (all levels) per indicated equal-area bin. Top row: AVHRR from all NOAA-satellites; bottom row: MODIS winds (IR and WV, Terra and Aqua). Left: Arctic; right: Antarctica.**

The forecast impact of AVHRR winds has been studied by adding AVHRR winds to a baseline system that makes limited use of other satellite observations (Kelly and Thépaut 2007). Here, our control baseline is a system that uses conventional observations and data from one AMSU-A on-board NOAA-18 only. In the AVHRR experiment, AVHRR winds were added to this baseline system. We also performed a MODIS experiment, in which we added instead the MODIS winds to the baseline

system. For all experiments we used ECMWF's incremental 12-hour 4DVAR, with a model resolution of T511 (~40km), an incremental analysis resolution of T159 (~125 km), and 60 levels in the vertical. The study period was 1 January - 14 February 2007 (45 forecasts). The AVHRR winds evaluated here have been derived in near real time at CIMSS from consecutive polar overpasses of the NOAA-satellites (NOAA-15, -16, -17, -18), with each satellite treated separately in the processing. For the MODIS winds, data from the operational global NESDIS processing were used. Quality control for both datasets is as described in Bormann and Thépaut (2004), with IR winds below 400 hPa over land and below 700 hPa over sea/ice excluded from the analysis, and similarly, WV winds below 400 hPa over land and below 700 hPa over sea/ice also excluded in case of the MODIS winds.

Compared to the experiment with the MODIS winds, the most striking feature is that far fewer AMVs are used in the AVHRR experiment (Fig. 2). This is partly due to the lack of WV winds, but the IR winds alone also do not match the number of winds typically obtained through MODIS IR winds. As expected, monitoring statistics for the AVHRR AMVs are also somewhat poorer than for MODIS, with larger standard deviations and biases (Fig. 3). This largely reflects the lack of the WV channel available in the processing.
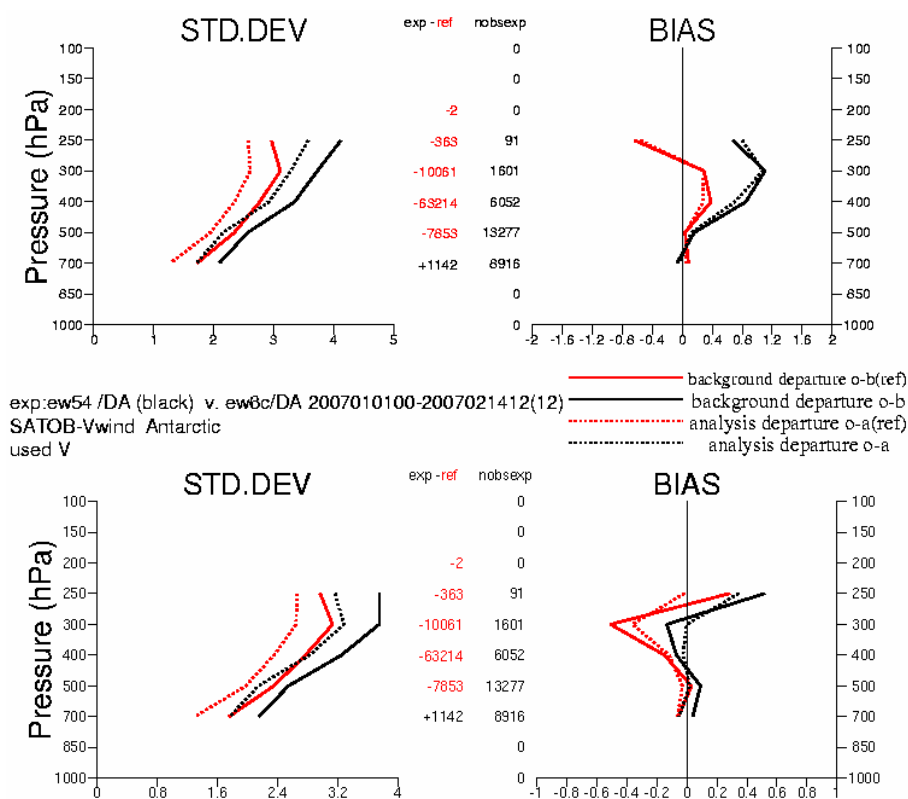
Figure 3: **Statistics for used AMVs over the Antactic region. Black shows statistics for the AVHRR winds, whereas statistics for MODIS winds are shown in red. Solid lines indicate statistics for first-guess departures; dotted lines for analysis departures. Standard deviation [m/s] is on the left and bias [m/s] on the right, with the u-component shown in the top row and the v-component shown in the bottom row. The numbers between the two column give the difference in the number of used winds (AVHRR-MODIS).**

The impact on mean forecast scores is small but positive and can be best seen on maps of the root mean square forecast error difference for the 500 hPa geopotential between the AVHRR experiment and the control (Fig. 4). Very little impact is found in the Northern Hemisphere for this period. For comparison, a similar plot is shown for the MODIS experiment. The impact from the MODIS AMVs is similar to that of the AVHRR AMVs over the Southern Ocean, but extends further to the south over the polar ice.
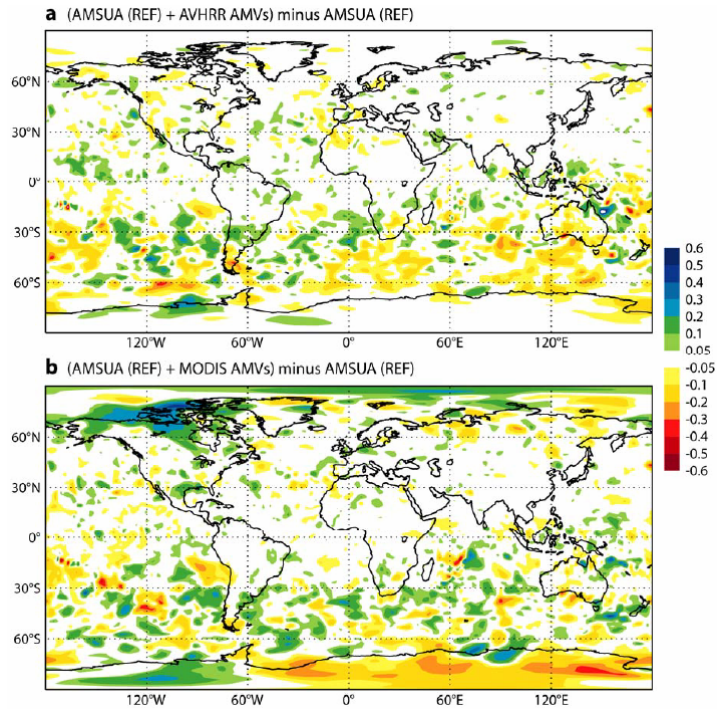
a (AMSUA (REF) + AVHRR AMVs) minus AMSUA (REF)

b (AMSUA (REF) + MODIS AMVs) minus AMSUA (REF)

Figure 4: Normalised differences in the root mean square error of the 500 hPa geopotential forecast for the AVHRR experiment minus the Control (a), and the MODIS experiment minus the Control (b).

DIRECT BROADCAST MODIS AMVS

Direct Broadcast MODIS AMVs have been available since mid-2006 (Key et al. 2006). The data makes use of direct broadcast stations for the winds generation, and therefore improves the otherwise poor timeliness of the global NESDIS dataset. For the NESDIS dataset, a latency of 6-7 hours is typical.
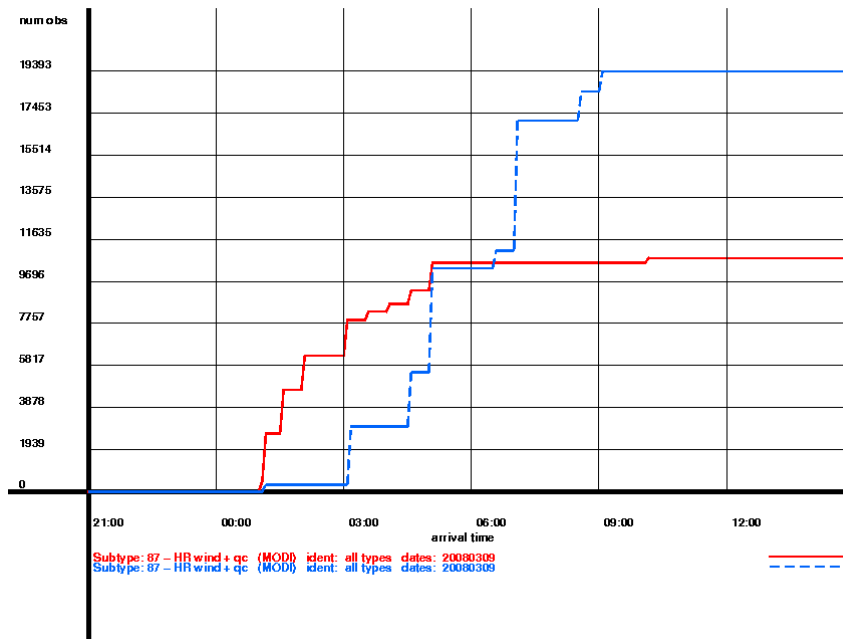
Figure 2: Numbers of MODIS winds valid for the 21-3Z period available at the indicated arrival time. Numbers for direct broadcast winds are in red and the global NESDIS dataset is in blue. Data taken for 9 March 2008.

Data timeliness is particularly crucial for NWP centres with short cut-off assimilation cycles. For instance, ECMWF runs a so-called "early delivery" stream from which the 10 day operational forecasts are run, interleaved with a delayed cut-off stream which allows for the assimilation of late data. The two streams use a 6 h and 12 h time window, respectively. The extraction time for the early delivery is an hour after the end of the time window, for instance at 4 Z for the 21 - 3 Z window for the 0 Z early delivery run. In contrast, the 0 Z delayed cut off run benefits from a 12 h window (21 - 9 Z) and a less restrictive data extraction time at 14 Z. The latency of the NESDIS MODIS winds means that typically only a small portion of the MODIS winds makes it into the early delivery analysis which is used for the operational forecast.

Figure 5 highlights the considerable improvement in terms of arrival times offered by the direct broadcast MODIS winds. Only 1/6 of the NESDIS MODIS winds arrive in time for the cut-off time at 4 Z for the early delivery analysis. The red line shows the earlier arrival of a larger amount of direct broadcast MODIS winds - roughly 3 times more by the cut-off time for that day, with about 3/4 of the direct broadcast data arriving in time for the early delivery extraction. This directly translates into improved coverage for the MODIS winds for the early delivery analysis (e.g., Fig. 6). Note that the final coverage for the direct-broadcast and the NESDIS AMVs tend to differ, explaining the difference in the total number of winds in Fig. 5.
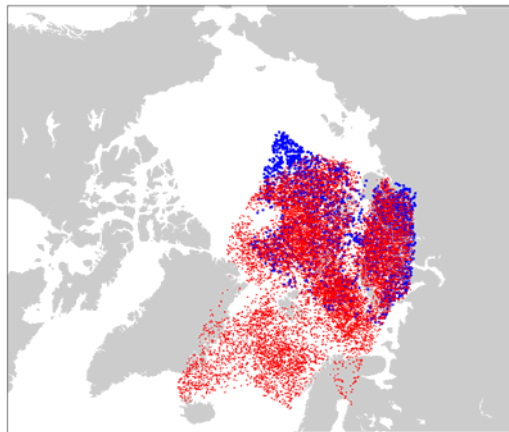
Figure 6: **Coverage of NESDIS MODIS winds (blue) and direct broadcast MODIS (red) winds for a 6-hour cycle around 1 Dec 2007 12 Z with ECMWF's early cut-off time.**

Further work is required to establish that the direct broadcast MODIS winds are of comparable quality to the NESDIS MODIS winds. Also, assimilation trials are needed to asses to what extent the improved coverage leads to better forecasts.

FY-2C AMVS

On 19 October 2004, China Meteorological Administration (CMA) launched the FY-2C satellite, CMA's first operational geostationary meteorological satellite. It is positioned at 105⁰ E adding coverage to Asia and the West Pacific, with some overlap with EUMETSAT's MET-7 (IODC) and Japan Meteorological Administration (JMA)'s MTSAT-1R.

FY-2C data first became available at the end of 2005, and monitoring studies were conducted at ECMWF shortly afterwards (Delsol et al. 2006). The data at the time did not contain quality indicator (QI) information (Holmlund 1998). This limited our ability to evaluate the data in the ECMWF system as no selection criteria was available. FY-2C data has since included a quality indicator which has allowed us to re-visit this improved dataset.

An experiment was set up to look at the quality of the FY-2C AMVs for the month of December 2007 using ECMWF's IFS cycle 32r3 (T159 L91). In this experiment, FY-2C winds were monitored

passively. Only two "channels" are available: IR and WV, the latter containing a mixture of clear and cloudy water vapour AMVs. In the future, it is hoped that information is included in the data to indicate whether the AMVs were derived from cloudy or clear-sky scenes, as this leads to different characteristics in the AMVs, therefore requiring different quality control.

As a first impression, it is clear that the quality of the data has improved since the first sample (without the QI) was made available. Strong biases are nonetheless still present in the data. The most prominent biases can be found in the mid-to-high level Northern Hemisphere (NH) extra-tropics where observations are considerably slower than the first guess (FG; see Fig. 7). This strong negative bias is present despite a selection using forecast dependent QI > 80.
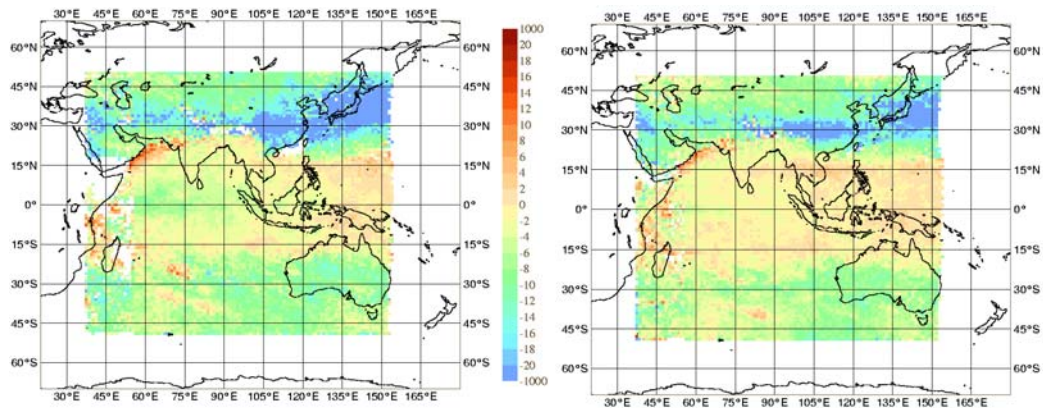
Figure 7: **Mean windspeed bias (observation minus first guess) (m/s) for FY-2C high level IR (a) and WV (b) AMVs selected with forecast dependent QI > 80 for the period of December 2007.**

Zonal mean wind speed bias plots (Figure 8) show more clearly the vertical extent of strong negative biases in the extra-tropics. For comparison, Figure 9 shows the zonal mean wind-speed bias plots for IR winds for the neighbouring satellite MET-7 for the same period. While the QI threshold of 80 does a considerably better job of removing the biased data for MET-7, the patterns of negative biases at high levels in the extra-tropics and fast biases in the tropics are also present. Statistics for FY-2C AMVs against QI (not included here) show that using a higher QI threshold or using the forecast independent QI would not remove the poor quality data. Very few AMVs would pass the pre-assimilation quality control at ECMWF, and assimilation trials are therefore not considered a priority at this stage.
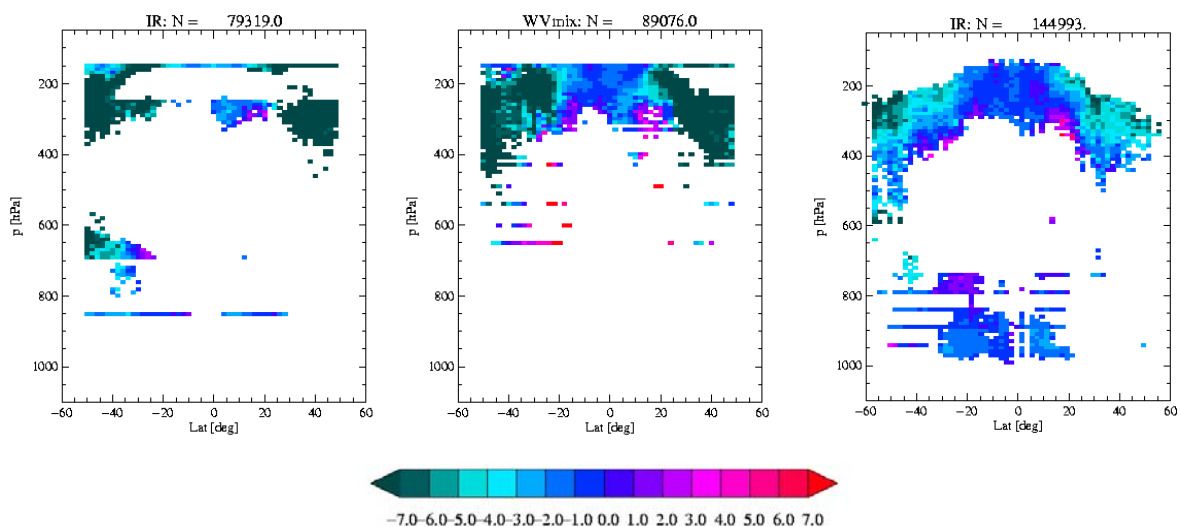

Figure 8: **Left: Zonal mean windspeed bias (observation minus first guess) (m/s) for FY-2C IR AMVs for the period 1-10 December 2007 (forecast dependent QI > 80). Middle: As on the left, but for the FY-2C WV AMVs. Right: As on the left, but for MET-7 IR winds.**

MISR AMVS

Cloud track winds have been derived from data from the MISR instrument for some time now (e.g., Davies 2006). The winds are derived from sequences of multi-angle VIS and near-IR imagery, using stereographic methods for the height assignment. The latter allows a very accurate height assignment (error of ~300 m). MISR winds provide global coverage, albeit with relatively few winds per orbit.

Here, we present a preliminary evaluation of MISR winds from the Terra satellite against the operational ECMWF FG over the 6 day period 24-29 October 2006 (model resolution of the ECMWF system at the time was already T799, ie ~25 km). We consider only the winds labelled by the winds producers as "good" or "very good". The sample is rather small (30,500 winds over 6 days), making the dataset somewhat less attractive for data assimilation. As MISR winds are reported on height levels, the necessary conversions were based on FG profiles using the moist hydrostatic equation. We also derive monitoring statistics for "conventional" AMVs from the METEOSAT satellites, GOES, and MODIS winds over the same period, in order to gauge the performance of the MISR winds. Note, that no attempt has been made in the statistics shown here to address the different sampling of the MISR and the "conventional" AMVs. Note also that the study period of 6 days is rather limited, allowing only some tentative conclusions.
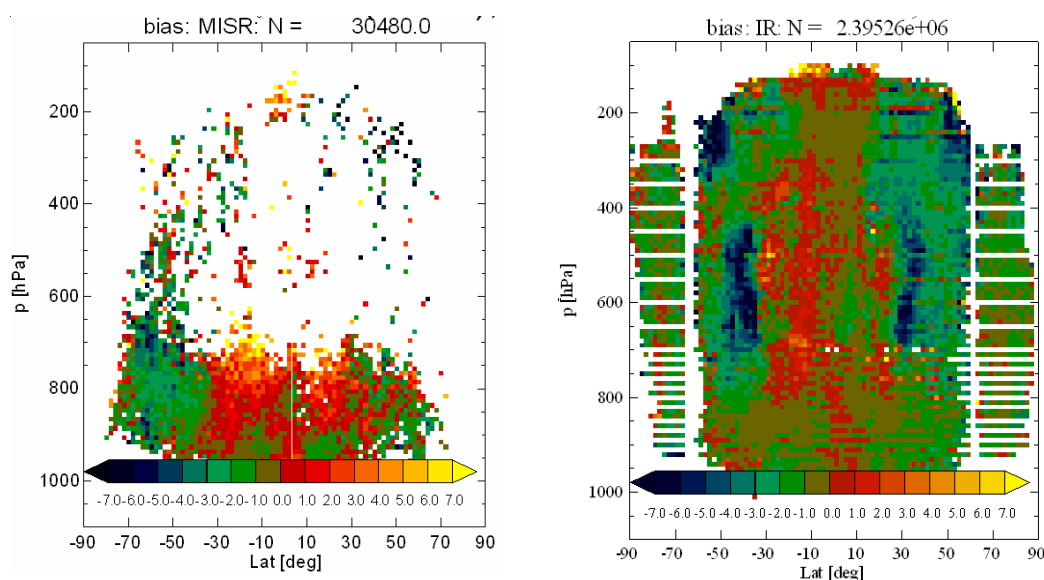
Figure 10: **Zonal mean speed biases (AMVs-FG) for MISR winds (left) and "conventional" AMVs from GOES 11/12, MET-5/8, and MODIS (all QI>60) for the 6-day study period.**

Overall, MISR winds compare similarly well or slightly more poorly to the ECMWF FG as "conventional" AMVs. Most MISR winds are confined to lower levels, and here zonal means of the speed bias for MISR winds against the FG show biases mostly in the range of ±2 m/s (e.g., Fig. 10). Fast biases prevail in the tropics and slow biases over the extra-tropics. These general patterns of the biases show some similarities with those from the "conventional" AMVs. As height assignment is considered more accurate for the MISR winds, this finding either points to biases in the FG, or it might suggest that aspects other than height assignment (e.g., passive tracer assumption) contribute significantly to speed biases in cloud track winds in general. Root mean square difference between MISR winds and the FG also show similar values as conventional AMVs, again with a small advantage for the conventional AMVs (not shown).

Given the quality displayed in this limited sample, MISR winds could be considered for assimilation to assess their impact within a forecasting system. A larger dataset covering a longer period is required for further data characterisation and assimilation studies.

SUMMARY AND CONCLUSIONS

AMVs continue to contribute to the extensive space-based observing system used operationally at ECMWF. At the time of writing, AMVs from 5 geostationary and 2 polar orbiting satellites are used routinely. In this paper, several datasets have been monitored and evaluated with considerations for future assimilation. The main findings are:

- Polar winds derived from the AVHRR instrument on-board the NOAA satellites show promising forecast impact, at least within an assimilation system that makes limited use of other satellite data. The impact is observed even though the AVHRR winds are much less numerous and show somewhat poorer monitoring statistics compared to MODIS winds. AVHRR winds will be operationally monitored passively from summer 2008 onwards.
- Direct broadcast winds from MODIS significantly improve the timeliness of the MODIS winds compared to the global NESDIS dataset. This leads to a better coverage of MODIS AMVs available for the early delivery cycle of the ECMWF assimilation system. Direct broadcast winds will be operationally monitored passively from summer 2008 onwards.
- AMVs from the Chinese geostationary FY-2C satellite now include QI-information, allowing a somewhat improved quality control of the data. Monitoring statistics show some improvements compared to earlier datasets (e.g., Delsol et al. 2006), but the presence of strong speed biases remains problematic. FY-2C winds will be operationally monitored passively in the second half of 2008.
- Comparison statistics of MISR winds against the ECMWF FG over a limited period of 6 days show similar to slightly poorer characteristics compared to conventional AMVs currently used in the ECMWF system. Speed bias pattern show some similarities, despite more accurate height assignment for the MISR winds. Very few MISR winds are available.

Future work will consider the direct broadcast MODIS winds and the AVHRR AMVs within the operational assimilation framework. These will add to the robustness of the polar winds dataset used at ECMWF. Further work is encouraged regarding the derivation of FY-2C winds, as it provides good coverage in an area otherwise still relatively poorly covered by wind observations. Once available, FY-2D winds will also be evaluated. MISR winds now show acceptable data quality, and data assimilation experiments could be considered. A larger dataset covering a longer period is required for this.

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