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Atmospheric Motion Vector observations in the ECMWF system: Second year report

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1 Executive summary

Atmospheric Motion Vector (AMV) observations are assimilated operationally in the ECMWF 4D-Var system from five geostationary (Meteosat-7, Meteosat-9, GOES-13, GOES-15, MTSAT-2) and five polar orbiting (Aqua, Terra, NOAA-15, NOAA-16, NOAA-18) satellites. In addition, AMVs from four other satellites (Meteosat-10, FY-2D, FY-2E, METOP-A) are currently passively monitored. Table 1 summarises the monitored and used AMVs. The recent changes in the operational use of the AMVs in the ECMWF system, and the main results from research work carried out during 2012 are discussed in this report.

One of the research highlights of the year was to take part in the 2nd international AMV impact intercomparison exercise which was coordinated by the international winds working group. In total 7 NWP centres reported results from AMV denial experiments performed over two 1.5 month long periods. The ECMWF results indicate that AMVs have a positive impact especially at high levels in the tropics. The results are consistent with results obtained earlier, and similar to results from other contributing NWP centres. An overview of the work is given in Section 2. The results of the intercomparison study give a good context to the results discussed in other sections of the report.

There have been some significant changes in the operationally used AMVs during the year. First, GOES-15 replaced GOES-11 on 6th December 2011 in operations. Passive monitoring of the GOES-15 AMVs revealed that the quality was mainly similar to GOES-11 AMVs, but there were some differences in the bias characteristics for IR and WV AMVs at high levels in the tropics. Data assimilation experiments have been performed to study if there is a need to blacklist the data with the degraded quality in the tropics. The results indicate that this is not necessary and the impact is more positive if the data is used. Based on the results GOES-15 AMVs were activated in late April. Details of the work are discussed in Section 3.

Another significant change is that EUMETSAT changed their AMV processing on 5th September 2012. The new AMV processing uses the cross correlation contribution (CCC) method which has been intro-

Table 1: Overview of the use of AMV data in the ECMWF system in November 2012.

	IR	Cloudy WV	Clear WV	VIS
Meteosat-7	used	used	monitored	used
Meteosat-9	used	used	monitored	monitored
Meteosat-10	monitored	monitored	monitored	monitored
GOES-13	used	used	monitored	used
GOES-15	used	used	monitored	used
MTSAT-2	used	used	monitored	used
CMA FY-2D	monitored	monitored	monitored	-
CMA FY-2E	monitored	monitored	monitored	-
MODIS AMVs from Aqua and Terra	used	used	used	-
AVHRR AMVs from NOAA-15, 16, and 18	used	-	-	-
AVHRR AMVs from METOP-A	monitored	-	-	-

duced to improve the height assignment of the AMVs (e.g Borde and Oyama, 2008). CCC test data was disseminated in parallel with the operational AMVs since end of May, and monitoring the data quality started immediately at ECMWF. Monitoring results indicate that the quality of high and mid level AMVs is clearly improved. However, for the low level IR and VIS AMVs the quality is somewhat degraded. EUMETSAT is planning to implement the so-called inversion height assignment to improve the quality of the low level winds in early 2013. The current impact studies show neutral to positive forecast impact at midlatitudes and neutral or slightly negative forecast impact in the tropics. Results of the monitoring and experimentation with the CCC AMVs are presented in Section 4.

Preparations for operational use of AVHRR (Advanced Very High Resolution Radiometer) polar AMVs from NOAA-15, -16, and -18 satellites in the ECMWF system have been done. The quality of the AVHRR AMVs from NOAA satellites is comparable to MODIS IR winds from Aqua and Terra which have been used operationally in the ECMWF system since 2003. Impact studies with AVHRR AMVs have been performed for a summer and winter period. The results indicate a neutral impact for both studied seasons. AVHRR AMVs from NOAA-15, -16, and -18 were introduced to the ECMWF system in active mode on 19th November 2012. Section 5 summarises the results.

The work on situation dependent observation errors for AMVs has continued. In the new approach the observation error is divided into two parts, one originates from the wind tracking and the other from the error in height assignment. The latter is significant especially when there is strong wind shear in the vertical. In the 1-year report the estimation of the errors was described (Salonen and Bormann, 2011). Now the focus has been on investigating the use of the new observation errors. A set of data assimilation experiments with different configurations has been performed. One main goal has been to simplify the current operational first guess check. Based on the results it seems that removing the asymmetric part from the first guess check is possible without degrading the forecast quality. However, that requires that rejection limits remain relatively tight. Investigations on using a criterion to reject observations with high error in wind due to error in the height assignment have also been done. The criterion seems to be beneficial but it should not be too tight to avoid rejecting of good quality observations. The overall impression of the results is that the use of situation dependent observation errors, the simplified first guess check and the criterion for the magnitude of the error due to error in height has positive impact on the forecast, especially below 400 hPa level. Ongoing work is testing the modifications with new model cycle, and for a winter and summer season. If the experiments show similar results the work is approaching maturity for operational implementation. The status of the work is reported in Section 6.

Finally, in Section 7 some additional ongoing activities are shortly listed.

2 2^{nd} international AMVs impact intercomparison exercise

2.1 Background

ECMWF participated to the 2^{nd} international AMV and scatterometer impact intercomparison exercise coordinated by the International Winds Working Group. In total 7 NWP centres reported results from AMV and scatterometer denial experiments performed over two 1.5 month long periods. The participating centres were ECMWF, Met Office, Météo France, DWD, NRL, JMA and KMA. Here, the emphasis is on ECMWF results related to AMVs. More details on the intercomparison study can be found from Payan and Cotton (2012).

The two periods cover the 2010 North Atlantic hurricane season (Period 1), and the 2010/11 Northern hemisphere winter season (Period 2).

- Period 1: 15 August 2010 30 September 2010.
- Period 2: 1 December 2010 - 15 January 2011.

For both periods AMV denial experiments have been performed and the results are compared to a reference suite which closely matches the operational forecast system. For period 2 also a polar winds denial experiment has been done excluding only MODIS AMVs from Aqua and Terra satellites but including AMVs from geostationary satellites. The ECMWF Integrated Forecasting System cycle 37r2 at a T799 resolution, 91 vertical levels, and 12-hour 4D-Var has been applied in the experiments. All operationally assimilated conventional and satellite observations are used.

2.2 AMV impact

2.2.1 Mean wind analysis

The AMVs have a strong impact on the tropical mean wind analysis throughthe troposphere. The upper panel of Fig. 1 shows the vector difference of the mean wind analysis at level 200 hPa for the period 1 for the ECMWF system. The most significant impact is seen in the tropics where the difference reaches values as high as 2.5 m/s. In the midlatitudes the magnitude of the changes is typically less than 0.5 m/s. The use of AMVs has a tendency to weaken the mean wind. The lower panel of Fig. 1 shows the vector difference for the Japanese Meteorological Agency (JMA) system. In contrast to the ECMWF results, the use of AMVs has a tendency to strengthen the mean wind at 200 hPa level.

The different impact on the mean tropical wind analysis has been investigated in more detail by comparing mean wind analyses from JMA and ECMWF directly. Figure 2 shows that the differences in the tropical regions between the two centres are overall significantly smaller in the experiments where AMVs are used (upper panel) than in the denial experiments (lower panel). The use of AMVs tends to bring the two systems in better agreement. The differences in the AMV denials are likely due to differences in the climatology of the forecast models of the centres. Nearly all participated NWP centres found a fairly significant impact from AMVs on the tropical mean wind analysis in the upper troposphere.

2.2.2 Forecast verification

Observation minus model background (OmB) statistics against radiosonde wind observations show an improvement in the standard deviation as well as in bias in the tropics when AMVs are used in the ECMWF analysis (Fig. 3). The main impact is between 500 and 100 hPa. This indicates that the changes seen in the mean wind analysis are supported by observations, and there is a positive impact on the short-term forecast around the radiosonde locations.

Figure 4 shows the normalised RMS error difference for 200 hPa ECMWF wind forecasts verified against radiosounding observations for combined periods 1 and 2. The results show statistically significant positive impact up to 2 day forecast range in the Northern hemisphere extratropics and in the tropics. For longer forecast ranges and in the Southern hemisphere extratropics the impact is mainly neutral.

Verification of the vector wind forecasts against each experiment's own analysis shows statistically significant positive impact at high levels in the tropics for all forecast lengths and in the extratropics up to 2-3 day forecast range (Fig. 5). This is also the case for both periods 1 and 2 separately.

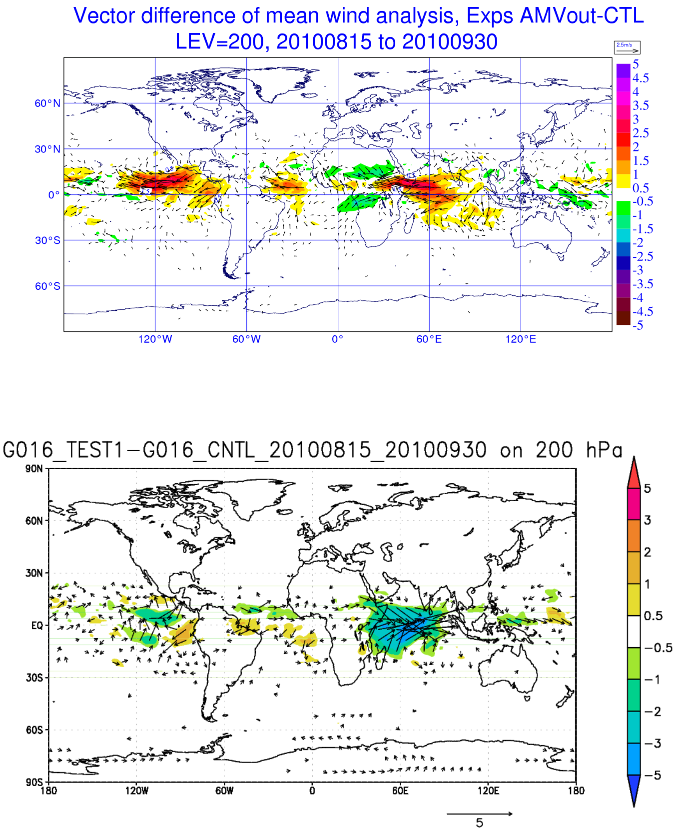


Figure 1: Difference in the mean wind analysis at 200 hPa between the AMV denial experiment and the Control for the ECMWF system (upper panel) and for the JMA system (lower panel). Shading indicates the difference in mean wind speed [m/s]. The considered period is 15 August - 30 September 2010.

For the low levels in the tropics, the apparent forecast impact depends on the choice of the verification up to the day 3 forecast range. The AMVs appear to have a strong positive forecast impact when verified against the operational analysis. However, each experiment verified against its own analysis suggests a significant negative impact, and verification against observations indicates a neutral forecast impact (not shown). The results for the verification against analyses most likely reflect differences in the variability characteristics between the AMVs and the forecast model. The verification against the operational analysis, which includes AMVs, favours the experiments with AMVs in this respect. However, the experiment with AMVs gets penalised due to this in the AMV denial. The verification against observations does not suffer from these problems and is hence considered more reliable. However, this verification measure suffers instead from poor geographical sampling. At low levels in the tropics, the forecast impact of AMVs therefore remains unclear.

Also at the other NWP centres the largest impact is seen on the short-range wind forecasts in the tropics at high level, consistent with the analysis differences. Generally, the variance of the forecast fit to radiosonde winds is improved when AMVs are added to the assimilation system, with DWD and KMA the centres showing the biggest differences in model background departures (Payan and Cotton, 2012).

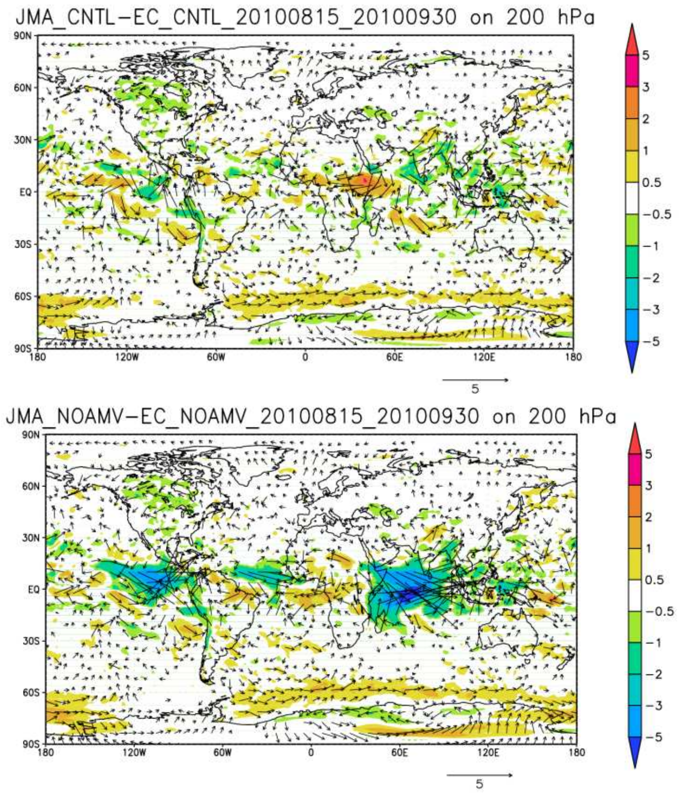


Figure 2: Vector and wind speed analysis differences between the analyses from JMA and ECMWF for period 1 at 200 hPa. Control result with AMV assimilation (upper panel) and AMV denial result (lower panel).

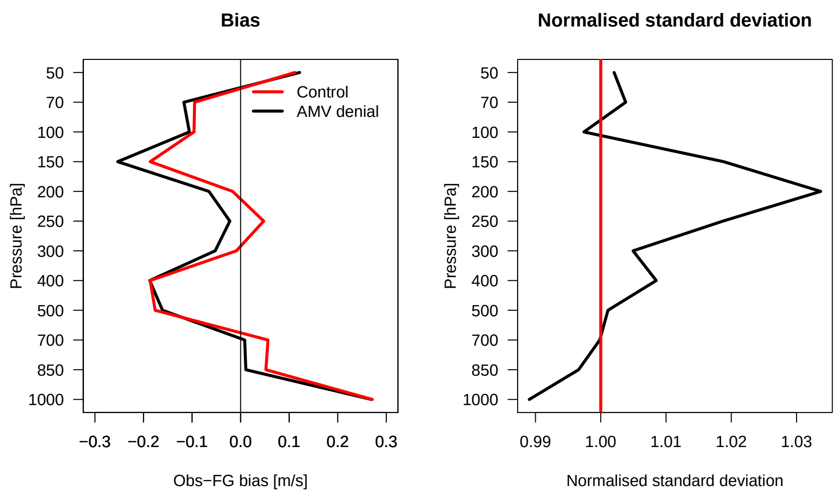


Figure 3: OmB bias (left panel) and standard deviation (right panel) for radiosonde wind observation u-component in the tropics. The AMV denial experiment is shown in black, whereas the Control is shown in red. The standard deviations have been normalised to 1 for the Control experiment. The considered period is 15 August - 30 September 2010.

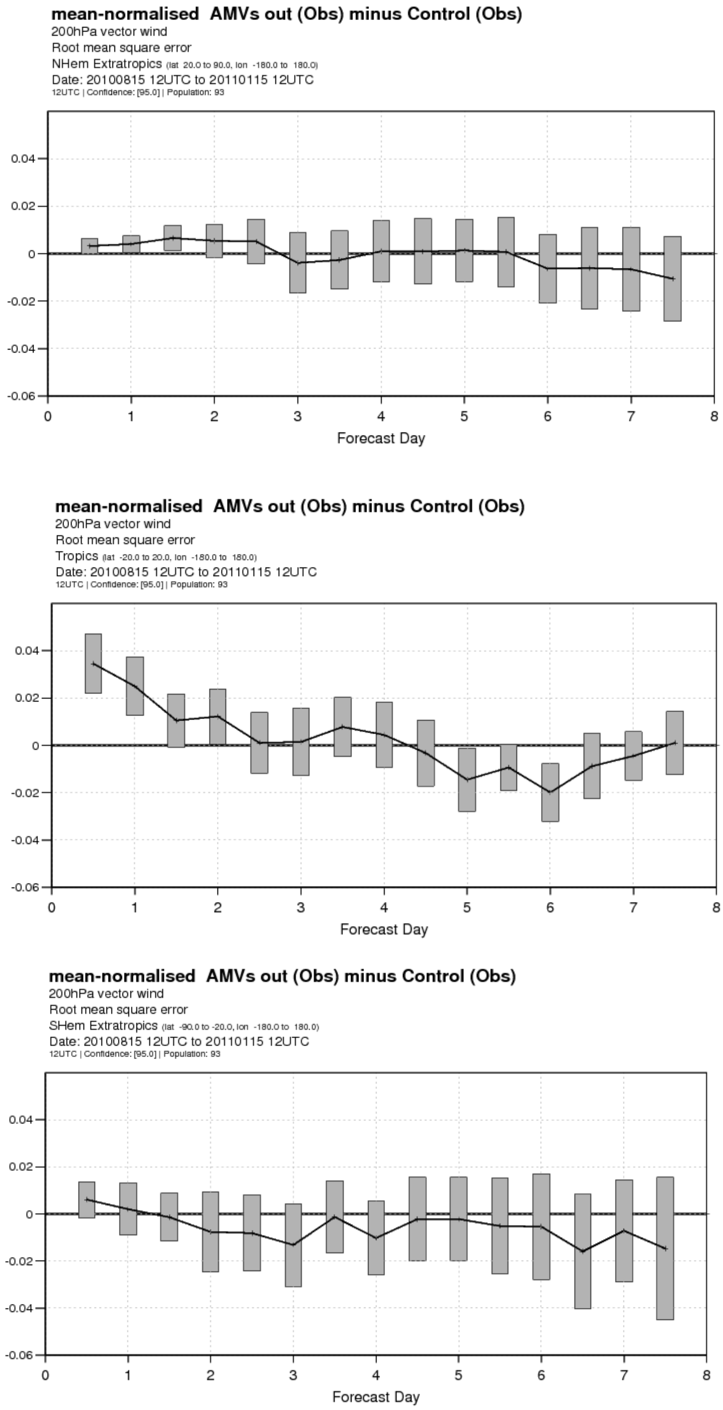


Figure 4: Normalised difference of the RMS wind error as a function of forecast range at 200 hPa level in the Northern hemisphere extratropics (upper panel), in the tropics (middle panel), and in the Southern hemisphere extratropics. Positive difference indicate benefit from assimilating AMVs. Verification is done against radiosounding observations. The considered period is 15 August - 30 September 2010, and 1 December 2010 - 15 January 2011 (93 cases).

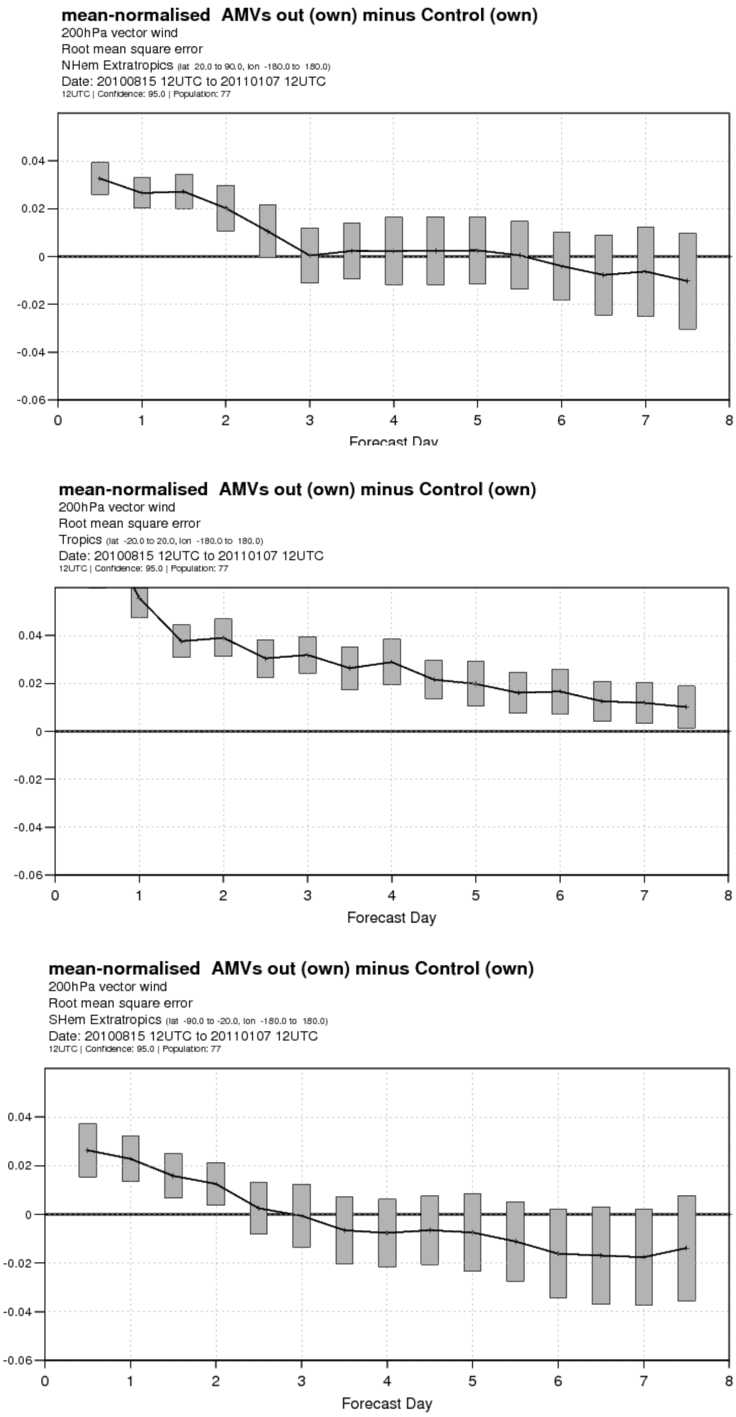


Figure 5: Sames as Fig. 4 but the verification is done against each experiment's own analysis. The considered period is 15 August - 30 September 2010, and 1 December 2010 - 7 January 2011 (77 cases).

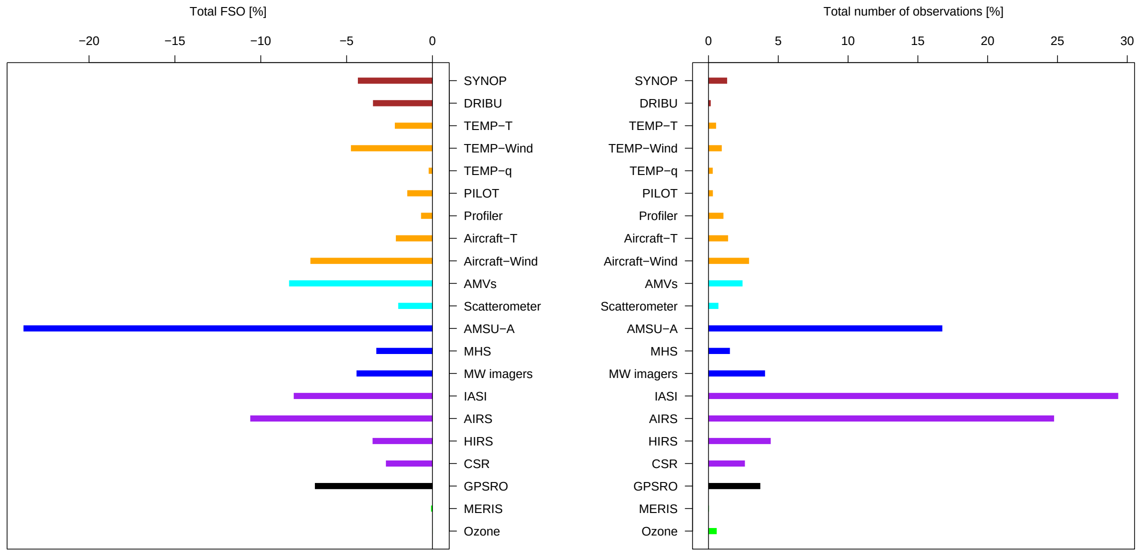


Figure 6: Left panel: contribution [%] to the total FSO from the various observing systems indicated, for period 1 (15 August - 29 September 2010). Negative values indicate a positive influence in terms of forecast error reduction from the observations. Right panel: percentage of the number of observed values per observing system over the same period.

2.2.3 Forecast sensitivity to observations

Adjoint-based diagnostics to estimate the forecast sensitivity to individual observations (e.g Cardinali, 2009) have been calculated for both periods. These give an estimate of how each observation contributed to reducing the 24-hour forecast error, measured using a dry total energy norm that includes the whole vertical range of the atmosphere.

Figure 6 shows an overview of the contributions from all observing systems used in the above experiments in terms of the total FSO. The temperature sounding radiances from AMSU-A stand out as the most beneficial observing system, followed by high-spectral resolution infrared sounders such as AIRS and IASI. The combination of all AMVs gives a similar total FSO as IASI for the period in question, and the measure is also comparable to that of wind observations from aircrafts. The influence of the AMVs is slightly larger than what is typical for other periods (typically around 7%), whereas AIRS and IASI usually contribute in a similar way, typically around 10%, whereas for the period in question the IASI contribution is a little lower. Period 2 is more typical in this respect (not shown).

All assimilated wind types contribute towards a forecast error reduction as estimated by FSO, and the size of the contribution largely reflects the number of winds assimilated for each combination. Per observation, the MTSAT and GOES-11 cloudy WV AMVs show the strongest contribution in the ECMWF system, whereas Meteosat-9 VIS winds show the smallest (not shown).

Compared to other centres, ECMWF and the Met Office are consistent in showing a FSO contribution of around 7-8% towards reducing 24-hour forecast error, similar to that of aircraft winds. The Meteo France FSO statistics for period 2 show a slightly higher AMV contribution of around 11%. The FSO results for NRL are markedly different from the other NWP centres as the geostationary AMVs provide the largest error reduction contribution at around 23%. However, NRL shows much lower impacts for AMSU-A, IASI and AIRS (Payan and Cotton, 2012).

2.3 MODIS AMVs impact

The impact of the MODIS winds has been investigated through a data denial experiment for period 2. Overall, the analysis and forecast impact of the MODIS winds is mainly confined to the polar regions over this period, whereas elsewhere, the impact on mean analyses, fit to other observations, and the forecast impact are neutral. The changes on the mean wind analysis are generally below 0.5 m/s, and therefore much smaller than what has been found when MODIS winds were first introduced in the ECMWF system (Bormann and Thépaut, 2004). This may be a reflection of improved model biases, or a result of more satellite sounding data being assimilated in some of these areas.

Observation fit statistics against radiosondes suggest that some of the systematic changes to the wind analysis are not necessarily supported by other observations, as the bias of the model background as well as the analysis is degraded slightly around 400 hPa for these observations, both over the Southern as well as the Northern polar region, e.g Fig. 7. However, the differences in bias are very small, and in terms of standard deviations, departures against radiosondes in these regions are not significantly altered, suggesting a more neutral impact on the short-term forecast around the radiosondes locations.

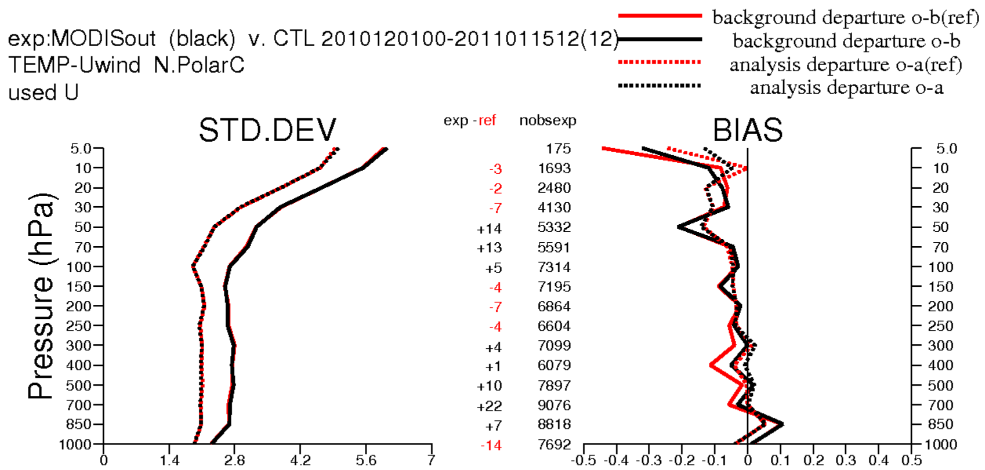


Figure 7: OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for radiosonde wind observation u-component over the north polar region (north of 65°N). The MODIS denial experiment is shown in black, whereas the Control is shown in red.

The forecast impact of the MODIS winds over the polar regions is significantly positive when the Control and the MODIS denial experiment are both verified against their own analyses, Fig. 8. However, the forecast impact is mainly confined to an area north of 60°N and south of 60°S, up to a forecast range of 4 days. An examination of time-series of forecast scores reveals that the observed forecast impact is primarily the net-result of relatively small improvements or degradations for individual cases, and no particular event stands out with very strong improvements or degradations (not shown).

2.4 Conclusions

The impact of satellite-derived AMVs has been investigated within the global NWP assimilation systems for 7 different centres. Two trial seasons of 1.5 months duration were used: the 2010 North Atlantic hurricane season and the 2010/11 Northern hemisphere winter season. In general the ECMWF results are consistent with earlier ones and similar to those of most other contributing NWP centres. In the

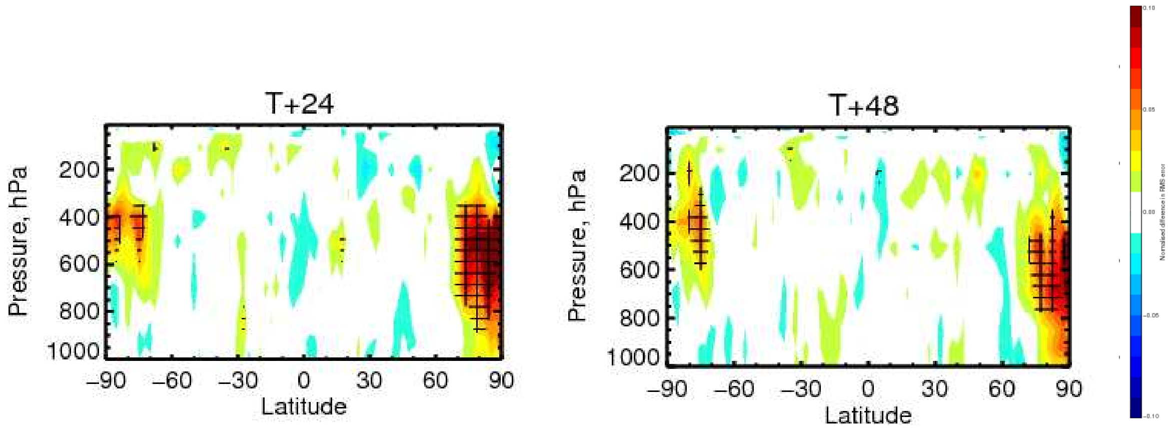


Figure 8: Zonal plot of the normalised difference (the MODIS denial experiment - the Control) in RMS error for 24-hour (left) and 48-hour (right) wind forecasts. Each experiment is verified against its own analysis. Positive values suggest an improvement from using the MODIS winds. The period is 1 December 2010 13 January 2011.

tropics and the polar regions the use of AMVs has a positive impact on wind forecasts up to 2-3 day forecast range, especially at high levels, whereas for longer forecast ranges and in the midlatitudes the impact is mainly neutral.

3 Experimentation with GOES-15 AMVs

3.1 Motivation

On 6th December 2011 GOES-15 replaced GOES-11 as the GOES-West operational spacecraft. The ECMWF system was prepared for the change, and operational monitoring of the GOES-15 AMVs begun immediately when GOES-15 data was available.

Passive monitoring of the data reveals that the quality of GOES-15 AMVs is mostly similar to the quality of GOES-11 AMVs. However, in the tropics GOES-15 IR and WV cloudy winds at levels 0 - 400 hPa have a negative bias which is not present in the GOES-11 data. Figure 9 shows the timeseries of the observation minus background (OmB) mean difference for GOES-15 IR AMVs in the tropics at 0 - 400 hPa levels for 6th December 2011 - 5th February 2012. The magnitude of the bias is typically around -1.5 ms^{-1}. Based on the monitoring results it was decided to perform data assimilation experiments before introducing GOES-15 AMVs in active mode to the system.

3.2 Data assimilation experiments

Three experiments (6th December 2011 - 5th February 2012) have been performed in order to study the impact of GOES-15 AMVs on model analyses and forecasts. The ECMWF Integrated Forecasting System cycle 37r3 at a T511 resolution, 91 vertical levels, and 12-hour 4D-Var has been applied in the experiments. All operationally assimilated conventional and satellite observations are used, only the amount of GOES-15 AMVs is varied. The following experiments have been performed:

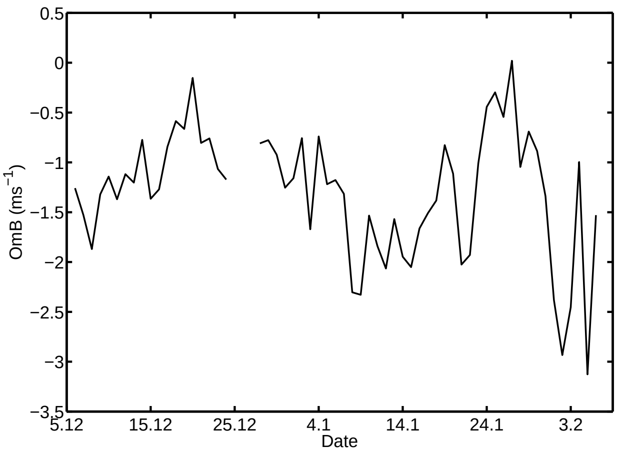


Figure 9: OmB timeseries for GOES-15 IR winds at levels 0 - 400 hPa in the tropics. Criteria QI > 80 has been applied to the data.

- **Control**: No AMVs from GOES-15 used.
- **GOES-15_all**: All GOES-15 AMVs used with similar blacklisting that was operationally used for GOES-11 AMVs.
- **GOES-15_TR_blacklisted**: GOES-15 AMVs used with similar blacklisting that was operationally used for GOES-11 AMVs, additionally GOES-15 AMVs are blacklisted in the tropics.

The blacklist applied for GOES-11 AMVs in the ECMWF system excludes the following observations:

- All VIS winds at 700 hPa and above.
- All WV winds below 400 hPa.
- All AMVs over land below 500 hPa, and additionally all AMVs over land west of 20W and north of 35N.
- Zenith angle $> 60°$.

3.3 Results

3.3.1 Observation fit statistics

In general the OmB and OmA (observation minus analysis) statistics against radiosonde, pilot and airep wind observations are rather similar for all three experiments. Some differences can be seen in the Southern hemisphere extratropics where the GOES-15_TR_blacklisted experiment shows small increase in the OmB standard deviation against these observation types. The increase in the standard deviation is seen mainly between 350 and 200 hPa levels. Figure 10 shows the observation fit statistics against radiosonde wind observation u-component in the Southern hemisphere extratropics as an example of the results. The left panel is for the control (black line) and the GOES-15_all experiment (red line), and the right panel for the control (black line) and the GOES-15_TR_blacklisted experiment (red line).

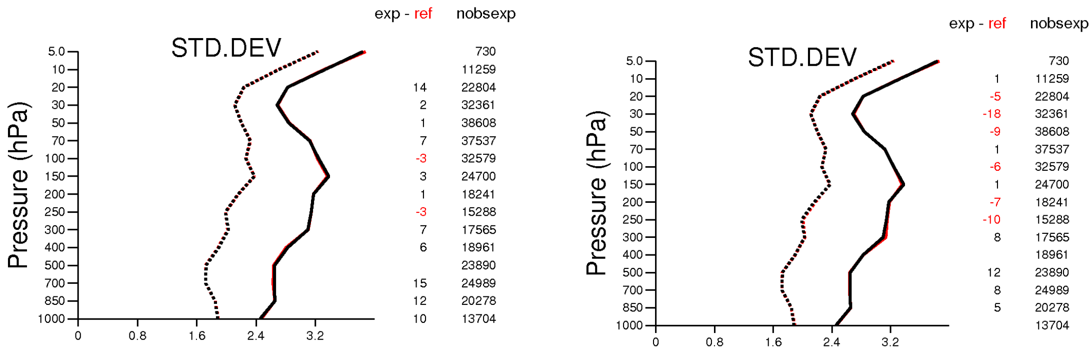


Figure 10: OmB (solid line) and OmA (dashed line) standard deviation for radiosonde wind observation u-component in the Southern hemisphere extratropics. Control run is indicated with black, and the GOES-15_all experiment (left panel) and GOES-15_TR_blacklisted experiment (right panel) with red.

3.3.2 Impact

Figure 11 shows the vector difference of the mean wind analysis at level 200 hPa between the GOES-15_all and the control experiment. The most significant changes are seen in the GOES-15 coverage area in the tropics where the difference reaches values as high as -2 ms^{-1}. At 200 hPa level the use of GOES-15 AMVs tends to weaken the mean wind field. Also at 700 hPa level significant changes are seen in the GOES-15 coverage area, at the equator the mean wind field is weakened and 5-20°N/S strengthened. The largest differences in the mean wind field are $\pm$ 2.5 ms^{-1}. At other levels both weakening and strengthening is seen but the magnitude of the changes is smaller, $\pm$1 ms^{-1} or less. In the midlatitudes the magnitude of the changes is typically less than 0.5 ms^{-1}. Also for GOES-15_TR_blacklisted experiment some weakening of the mean wind field is seen at 200 hPa level (not shown), on other levels the changes are mainly less than 0.5 ms^{-1}.

Figure 12 shows the normalised difference of the RMS wind error as a function of forecast range for the Northern hemisphere extratropics (left panel), tropics (middle panel), and the Southern hemisphere extratropics (right panel) at different pressure levels. The difference is calculated as experiment minus control, i.e. negative difference indicates positive impact. Verification has been done against the own analysis. The black line indicates the GOES-15_all experiment, and the red line the GOES-15_TR_blacklisted experiment. The general impression from the statistics is that the use of GOES-15 AMVs has mainly a positive impact. On average, scores for the GOES-15_all experiment are slightly better. However, a clear exception is seen in the 700 hPa level in the tropics where the GOES-15_all experiment shows a negative impact up to the day 5 forecast. Verification against the operational analysis (not shown) indicates also a negative impact but only up to 2-day forecast range, after that the impact is neutral, and after day 6 positive.

As discussed in Section 2, the forecast impact depends on the choice of the verification. Verification against analyses reflects differences in the variability characteristics between the AMVs and the forecast model, and the experiment with AMVs may get penalised due to this compared to the AMV denial. During the experiment period, no AMVs from the GOES-11/15 area were used in the operational analysis. To mimic the operational AMV usage when GOES-11 AMVs were still available, the verification can be done against the GOES-15_all analysis. Figure 13 shows the same as Fig. 12 but verified against the GOES-15_all analysis. Overall, the impact is mainly neutral for forecast range of 2 days and longer, and there is no negative impact at 700 hPa level.

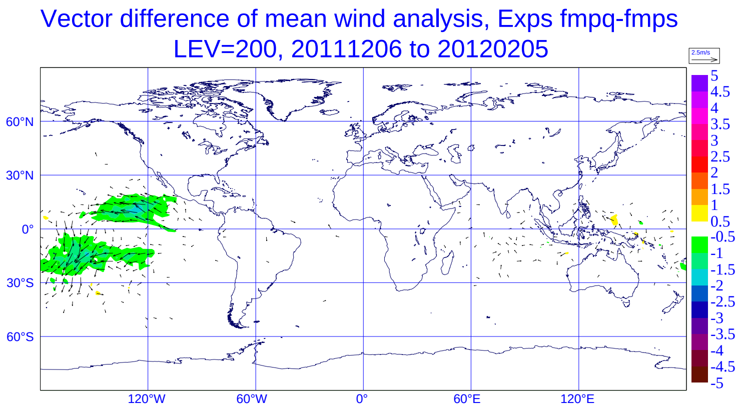


Figure 11: Difference in the mean wind analysis at 200 hPa between the GOES-15_all experiment and the Control. Shading indicates the difference in mean wind speed [m/s]. The considered period is 6 December 2011 - 5 February 2012.

Figure 14 shows the normalised difference of the RMS wind error as a function of forecast range for the 700 hPa level in the tropics when verification has been done against observations. The difference is calculated between the GOES-15_all and the control experiment. The impact is mainly neutral or slightly positive.

3.4 Conclusion and actions taken

GOES-15 replaced GOES-11 on 6th December 2011. Passive monitoring of the data revealed that GOES-15 IR and cloudy WV AMVs have a negative bias in the tropics at 0 - 400 hPa levels which was not present in the GOES-11 AMVs. Otherwise the quality of the two data sources was found to be very similar.

Three 2-month experiments have been performed. The results indicate:

- Blacklisting of GOES-15 AMVs in the tropics slightly degrades the observation fit statistics against radiosonde, pilot and airep wind observations in the Southern hemisphere between 350 and 200 hPa levels.
- Use of GOES-15 AMVs has mainly a positive impact on the forecasts. The experiment using all GOES-15 AMVs performs on average slightly better than experiment were GOES-15 AMVs were blacklisted in the tropics.
- For the experiment using all GOES-15 AMVs, verification against the own analysis and against the operational analysis indicates negative impact at 700 hPa level in the tropics. This may be more a consequence of the chosen verification than a real degradation in the forecast quality. Verification against observations and against the GOES-15_all experiment analysis shows neutral, or slightly positive impact.

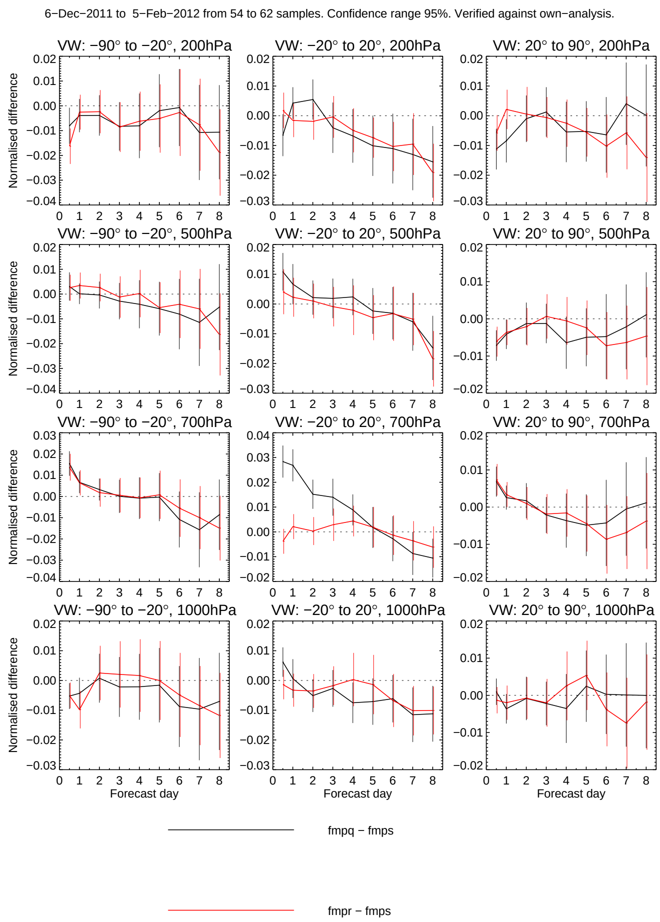


Figure 12: Normalised difference of the RMS wind error as a function of forecast range for the Northern hemisphere (left panel), tropics (middle panel), and the Southern hemisphere (right panel) at different pressure levels. Black line indicates the GOES-15_all experiment, and red line the GOES-15_TR_blacklisted experiment. Verification is done against the own analysis, and the difference is calculated as experiment minus control.

Based on the results it was decided to activate GOES-15 AMVs on 25.4.2012, applying similar blacklisting than for GOES-11 AMVs.

4 Experimentation with Meteosat-9 CCC AMVs

4.1 Introduction

EUMETSAT updated the AMV processing algorithm on 5th September 2012. The updated algorithm uses the Cross-Correlation Contribution (CCC) method to assess which pixels contribute most to the vector tracking (Borde and Oyama, 2008). This information is used to derive the final height of the AMVs. Parallel dissemination of AMVs processed using the CCC method started on 29th May 2012 to enable monitoring of the data quality, and studying the impact of the CCC AMVs on model analyses and forecasts. Processing of the test data started immediately at ECMWF.

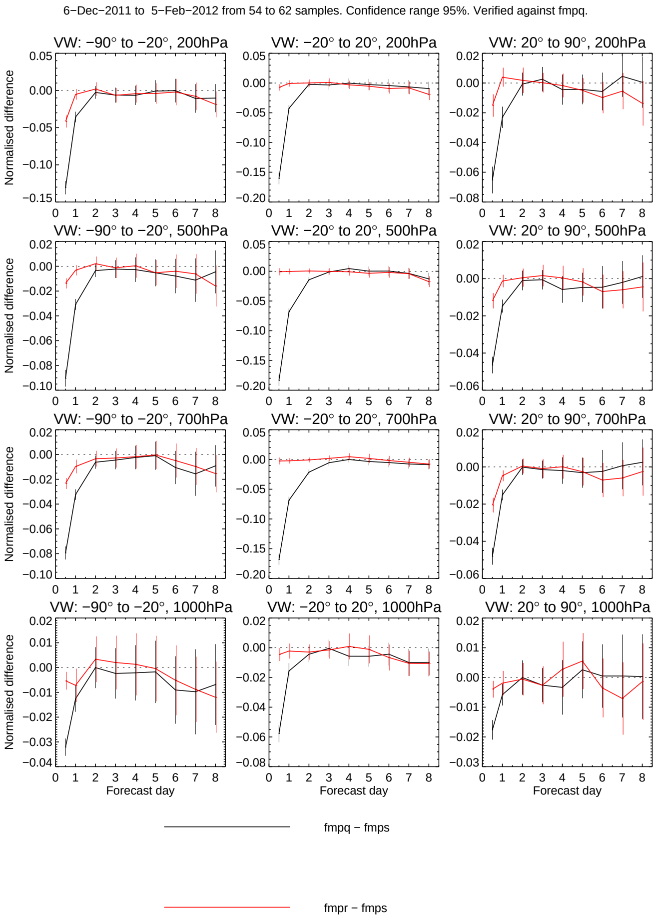


Figure 13: Same as Fig. 12 but verification is done against the GOES-15_all analysis.

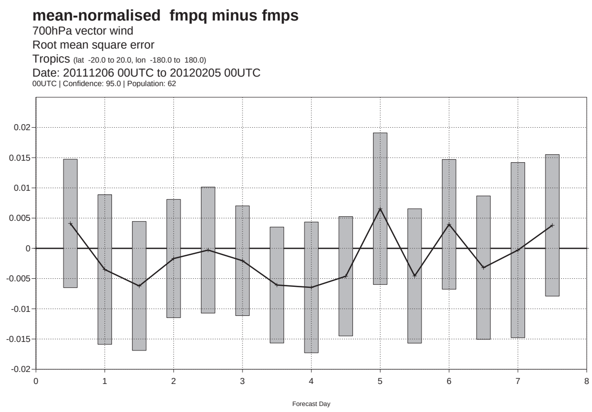


Figure 14: Normalised difference of the RMS wind error as a function of forecast range for the tropics 700 hPa level. Verification is done against observations, and the difference is calculated as GOES-15_all experiment minus control.

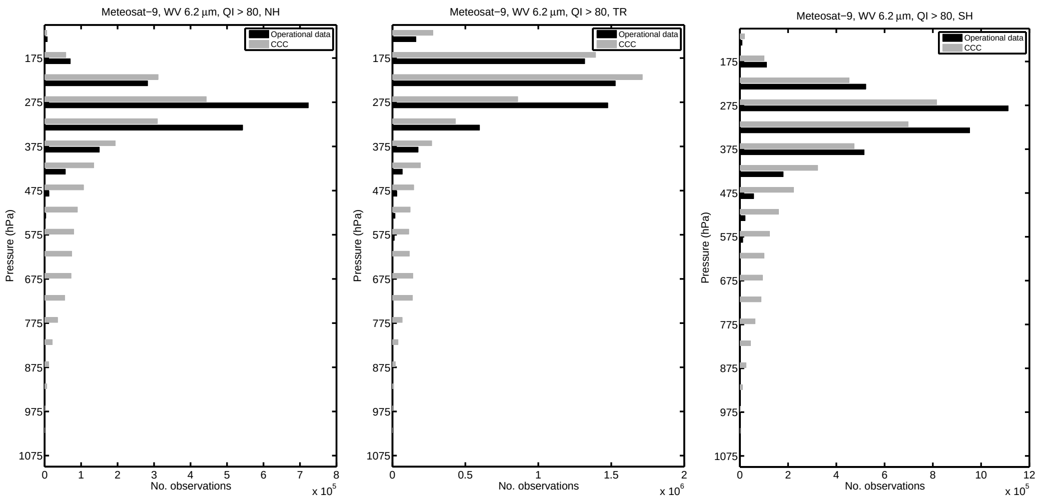


Figure 15: Histograms of the number of observations for WV 6.2 μm AMVs with QI $>$ 80. Left panel shows Northern hemisphere midlatitudes, middle panel tropics, and right panel Southern hemisphere midlatitudes, respectively. Black bars indicate the operational data set, and grey bars the CCC test data set.

Here the new CCC AMVs and the old operationally disseminated AMVs are compared to the model background field, and results from an impact study covering 10.5 weeks are discussed. The ECMWF Integrated Forecasting System cycle 38r1 at a T511 resolution, 91 vertical levels, and 12-hour 4D-Var has been applied in the experiments. The studied data set covers 21st June - 3rd September 2012. There was a gap in the processing of the CCC data at ECMWF 15th - 20th June 2012. Thus, data prior to 21st June is not considered here. The following experiments have been performed in the first place:

- **Control**: Similar to operational ECMWF setup, i.e. using the “old” Meteosat-9 AMVs.
- **CCC**: AMVs utilising the CCC method from Meteosat-9 used.

4.2 Comparison to the model background field

4.2.1 Cloudy WV, 6.2 and 7.3 μm

Figures 15 and 16 show histograms of the number of observations as a function of pressure level for WV 6.2 μm and 7.3 μm AMVs, respectively. Black bars indicate the operational data set, and grey bars the CCC test data set. The distribution of observations at different heights has altered. The number of available AMVs has significantly increased at mid-levels (400 - 700 hPa) in the CCC data set, while at high levels (above 400 hPa) the number of available AMVs is somewhat decreased especially in the midlatitudes. A small number of low level (below 700 hPa) AMVs are present only in the CCC data set. It is unlikely to track real winds at low levels at WV channels. EUMETSAT is considering alternatives to deal with this feature. Low level WV AMVs are blacklisted in NWP models, thus, this data has no impact on the model analyses or forecasts.

Figure 17 shows the zonal plots of the number of observations (upper panel), speed bias (middle panel) and RMSVD (lower panel) for WV 7.3 μm AMVs with QI $>$ 80. The magnitude of the negative bias seen at high levels in the Southern hemisphere midlatitudes has clearly decreased for the CCC AMVs

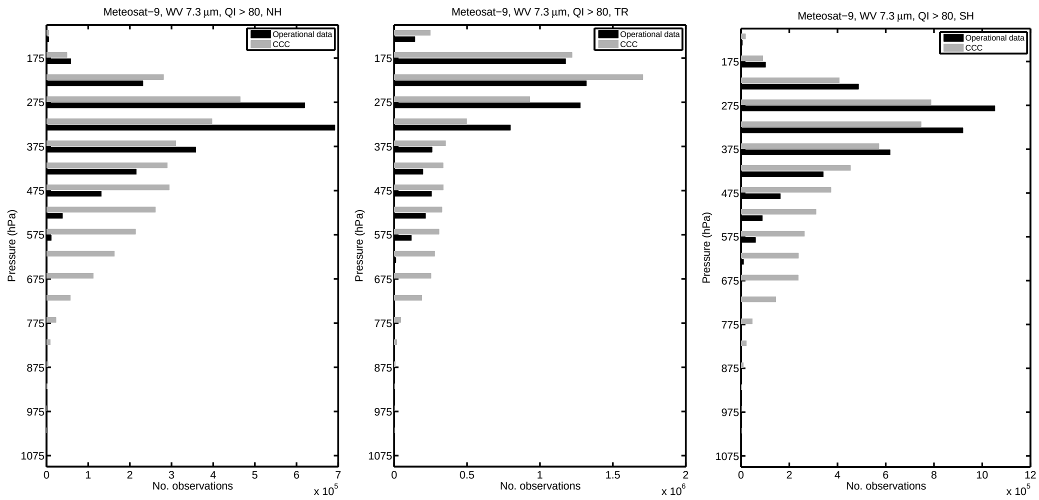


Figure 16: Same as Fig. 15 but for WV 7.3 μm AMVs with QI $>$ 80.

compared to the operational AMVs. Decrease in the RSMVD is also evident in the same area. This is a significant improvement in the AMV quality as the majority of the WV AMVs originate from the high levels.

The positive bias seen below 300 hPa over the tropics and the Southern hemisphere, and below 350 hPa over the Northern hemisphere has increased for the CCC AMVs, also the RMSVD in the same areas has increased. Comparison to the distribution of observations (upper panel of Fig. 17) reveals that at these areas there are more AMVs in the CCC data set than in the operational. This is the case also for 6.2 μm WV channel AMVs (not shown).

Currently most of the WV AMVs are blacklisted below 400 hPa height, only WV 7.3 μm channel AMVs are used operationally at mid-levels, above 600 hPa, and at midlatitudes only. Figure 18 shows the timeseries for bias (upper panel), RMSVD (middle panel), and number of observations (lower panel) for the operational data (black) and for the CCC test data (red) at the Northern hemisphere midlatitudes for active WV 7.3 μm AMVs. The statistics are on the same level for both data sets, i.e. the quality of the used data at mid-levels is similar in the operational and in the CCC data sets, but the number of used winds has almost doubled.

4.2.2 IR

The upper panel of Fig. 19 shows the zonal plots of the number of observations for QI $>$ 80. At high levels (above 400 hPa) at the Northern and Southern hemisphere midlatitudes there are slightly less CCC AMVs available than operational AMVs. In the tropics the opposite is true. At mid levels (400 - 700 hPa) the number of CCC AMVs is significantly larger than the number of operational AMVs. At low levels (below 700 hPa) the AMVs in the operational data set tend to be assigned to lower heights than in the CCC data set.

The middle and lower panel of Fig. 19 show the zonal plots of the OmB speed bias and RMSVD, respectively. Most significant changes are again seen at high levels at the Southern hemisphere midlatitudes where the negative speed bias is clearly reduced for the CCC AMVs compared to the operational AMVs. The reduction in the magnitude of the bias, and also in RMSVD, is consistent in time (not shown). The

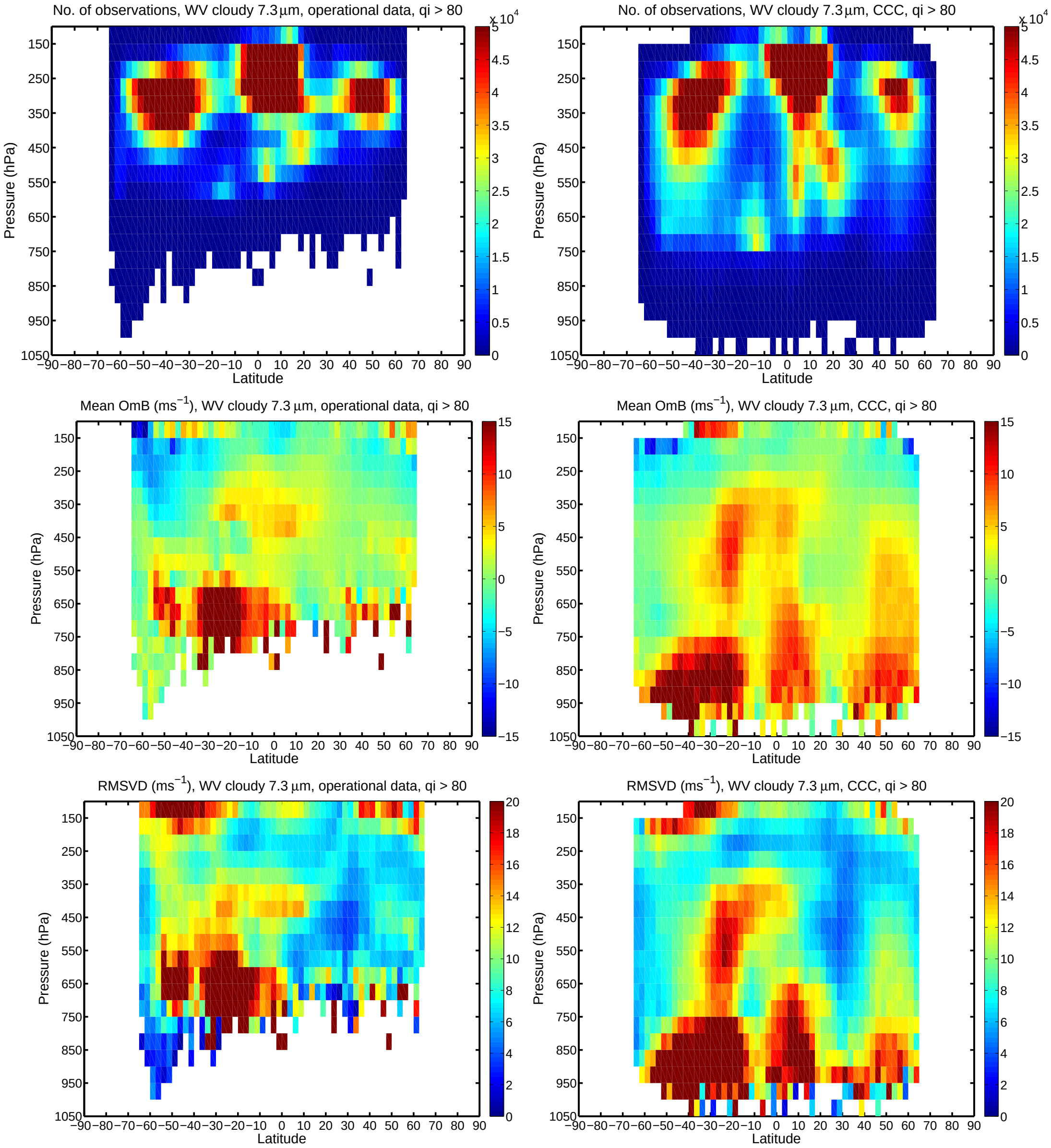


Figure 17: Zonal plot of number of observations (upper panel), speed bias (middle panel) and RMSVD (lower panel) for WV 7.3 µm AMVs with QI > 80. Left panel shows the operational data set, and right panel the CCC test data set, respectively.

middle panel of Fig. 19 indicates a slight increase in the speed bias at 300 - 500 hPa levels for the CCC AMVs in the tropics. However, the increase in the bias is seen in an area where the number of available AMVs is relatively low.

Figure 20 shows maps of the low level speed bias. Over the North African continent the positive bias is somewhat decreased for the CCC AMVs compared to the operational AMVs. However, over sea between 0 and 30S° a positive speed bias is increased, while the operational data show zero or slightly negative bias. Also north of 30N° and south of 30S° some areas of negative bias are seen in the CCC data while the operational data show slightly positive bias in the same regions. These changes are related to the general shift in the height assignment for low level AMVs noted earlier (upper panel of Fig. 19),

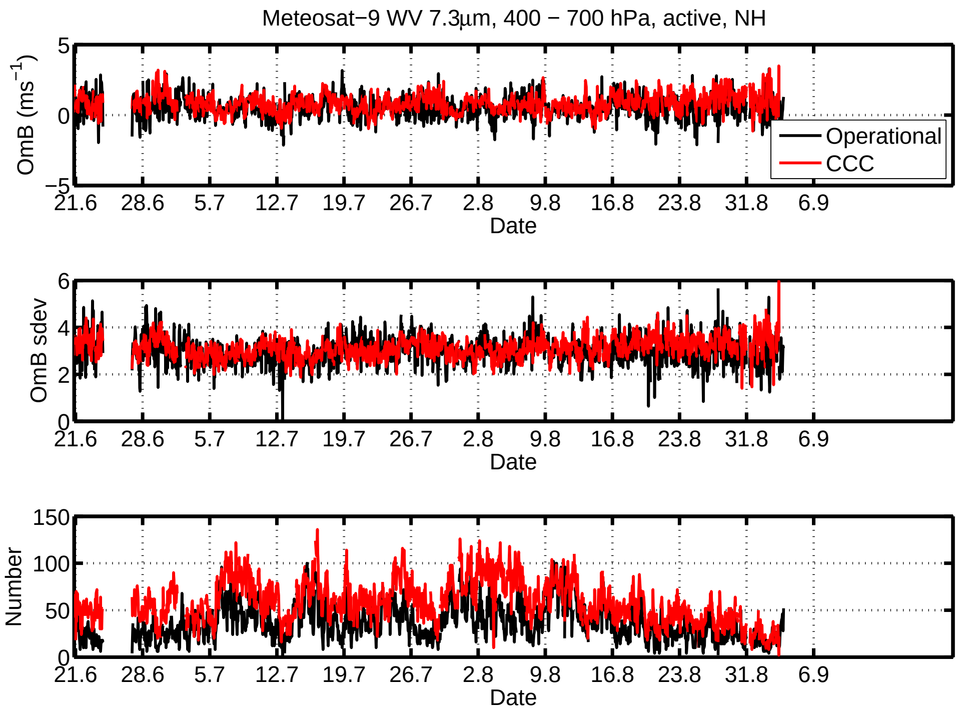


Figure 18: Timeseries for OmB speed bias (upper panel), RMSVD (middle panel), and number of observations (lower panel) for the operational data (black) and for the CCC test data (red) at the Northern hemisphere midlatitudes for active WV 7.3 µm AMVs.

and appear to be strongest in the inversion regions.

4.2.3 VIS

Low level AMVs (700 - 1100 hPa)

Figure 21 shows the zonal plots of the number of observations for VIS AMVs. In the operational data set observations tend to be assigned to lower heights than in the CCC data set. A similar feature was seen for the low level IR AMVs (Fig. 19).

Statistics show similar changes for the VIS AMVs than for the low level IR AMVs. Over the North African continent the positive bias is decreased for the CCC AMVs compared to the operational AMVs. However, over sea between 0 and 30S° a positive speed bias is increased, indicating that the observed wind is stronger than the model wind. North of 30N° and south of 30S° some increase in negative bias is seen (not shown).

Figure 22 shows the zonal plot of the mean difference (bias) between the originally assigned height and the best-fit pressure. The left panel is for the operational data set, and the right panel the CCC test data set. A negative bias indicates that the assigned observation height is higher in the atmosphere than the model best-fit pressure. There is an increase in the negative bias for the CCC data set above the 850 hPa level. This suggests that the shift to higher levels is not supported by the best-fit pressure statistics, and instead better agreement with the short-term forecast would be achieved at lower heights.

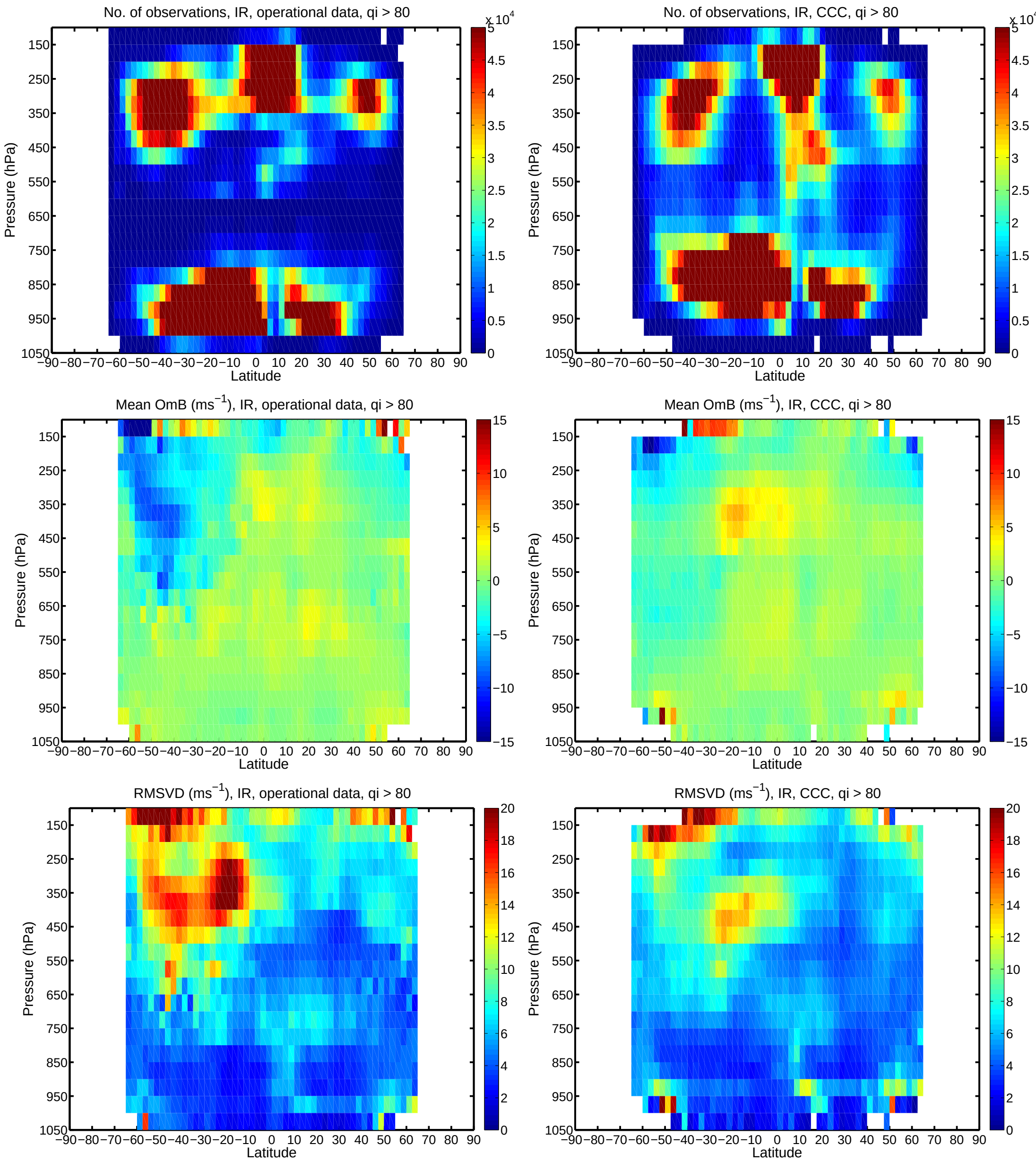


Figure 19: Zonal plot of the number of observations (upper panel), OmB speed bias (middle panel) and RMSVD (lower panel) for IR AMVs with QI $>$ 80. Left panel shows the operational data set, and right panel the CCC test data set, respectively.

4.2.4 Summary

Summary of the monitoring statistics is as follows. The quality of AMVs is generally improved at high levels, and at midlatitude mid-levels in the CCC data set compared to the old operational AMVs. At mid-levels the number of available AMVs has significantly increased, whereas at high levels the number of AMVs has somewhat decreased. At low levels there is a general shift in the height assignment for IR and VIS AMVs, the CCC AMVs are assigned to higher altitudes than the old operational AMVs. The OmB statistics indicate that at low levels the old operational AMVs agree better with the model background

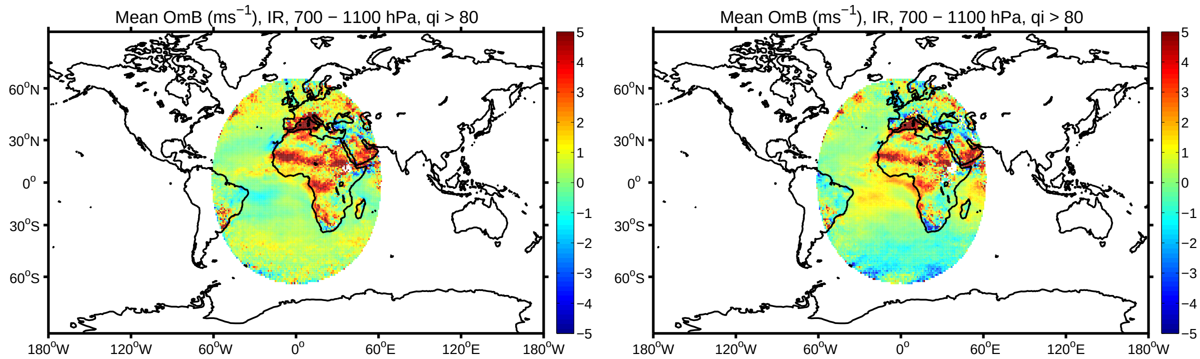


Figure 20: Map of the OmB speed bias for IR AMVs with QI > 80. Upper panel shows the operational data set, and lower panel the CCC test data set, respectively.

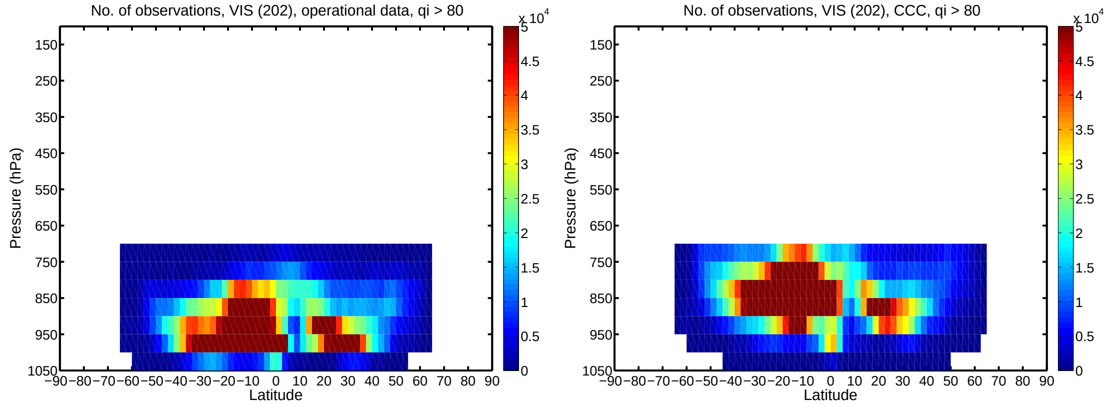


Figure 21: Zonal plot of the number of observations for VIS AMVs with QI > 80. Left panel shows the operational data set, and right panel the CCC test data set, respectively.

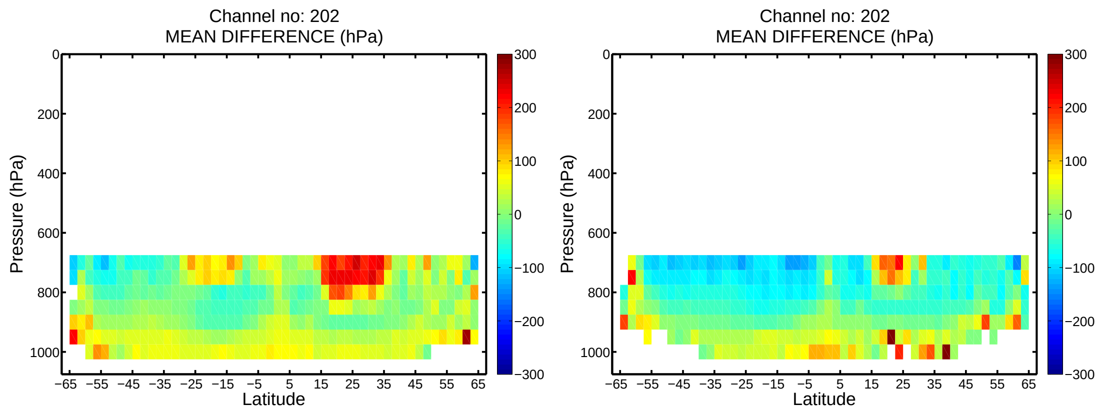


Figure 22: Zonal plot of the mean difference between the originally assingned height and the best-fit pressure. Left panel is for the operational data set, and right panel the CCC test data set, respectively.

than the CCC AMVs.

4.3 Impact assessment

4.3.1 Mean wind analysis and observation fit statistics

Comparison of the mean wind analysis between the CCC and the Control experiment reveals that above 500 hPa level the magnitude of the differences is mainly less than 0.5 ms^{-1}. However, at lower levels more significant changes are seen. Figure 23 shows the vector difference of the mean wind analysis at level 850 hPa between the CCC and the control experiment. The most significant changes are seen in the Meteosat-9 coverage area in the tropics over sea where the difference reaches values as high as 1.5 ms^{-1}. At 850 hPa level the use of the CCC AMVs tends to strengthen the mean wind field. At the 700 hPa level both weakening and strengthening of the mean wind field is seen but the magnitude of the changes is smaller than at the 850 hPa level. The changes in the mean wind analysis are at the same regions as the increase in positive bias for IR and VIS AMVs in the CCC data.

In terms of the observation fit statistics for radiosonde wind observations the statistics are rather similar for both experiments. Figure 24 shows the OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for radiosonde wind u-component over the Meteosat-9 coverage area. Experiment with operational data is shown with black, and experiment with CCC data with red, respectively. The differences in the statistics are minor.

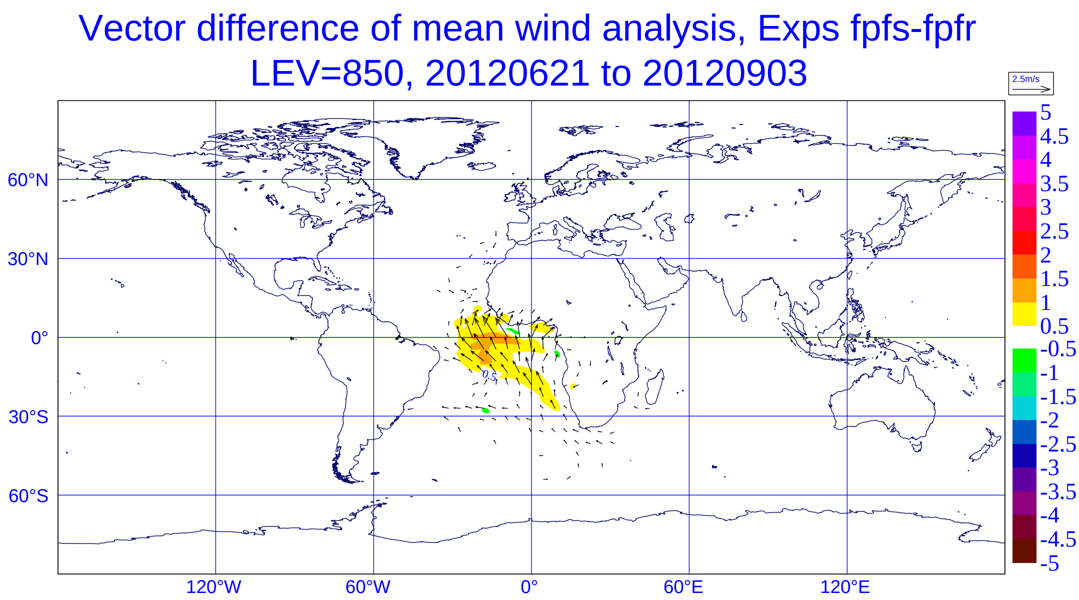


Figure 23: Difference in the mean wind analysis at 850 hPa between the CCC experiment and the Control. Shading indicates the difference in mean wind speed [m/s]. The considered period is 21 June - 3 September 2012.

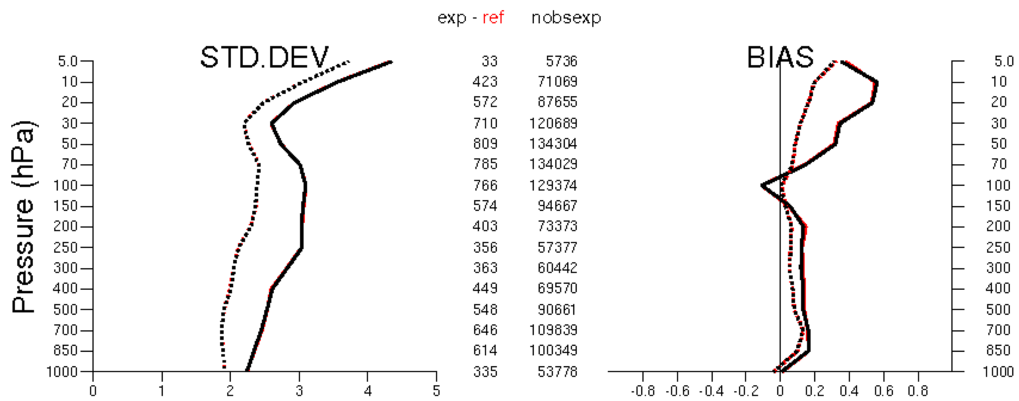


Figure 24: OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for radiosonde wind observation u-component over the Meteosat-9 coverage area. Control run is indicated with black, and the CCC experiment with red.

4.3.2 Forecast verification

The forecasts have been verified against observations, and against each experiment's own analysis. Figures 25 and 26 show the normalised difference of the RMS wind error as a function of forecast range for the Northern hemisphere extratropics (upper panel), tropics (middle panel), and Southern hemisphere extratropics (lower panel) at 200 hPa and 850 hPa levels, respectively, verified against observations. The difference is calculated as CCC minus Control, so negative values indicate a reduction in forecast error from using the CCC AMVs. The grey error bars indicate the 95% confidence range. Verification shows mainly neutral impact at Northern and Southern hemisphere extratropics at both levels, and in the tropics at 200 hPa level. At 850 hPa level there is indication of slightly negative impact in the tropics.

Figure 27 shows the map of the normalised rms difference between the CCC experiment and the Control for the 48-hour wind forecast at the 850 hPa level verified against the own analyses. Blue shades indicate positive impact and green and red shades negative impact from using the CCC AMVs. Verification against own analyses shows a degradation in the forecast quality at low levels over the region where the OmB bias of the CCC IR and VIS AMVs is increased compared to the operational AMVs. Elsewhere and at high levels the impact is mainly neutral.

4.3.3 Complementary experiments

Based on the results discussed in the previous subsection it can be concluded that at high levels the impact of using the CCC AMVs is similar to the operational AMVs. However, at low levels in the tropics and Southern hemisphere midlatitudes the forecast quality is somewhat degraded. The open question is whether some benefit is still gained from using the low level IR and VIS AMVs. To answer the question it was decided to perform the following additional experiments

- Similar to **CCC** experiment but low level IR and VIS CCC AMVs blacklisted.
- Similar to **CCC** experiment but low level IR and VIS CCC AMVs blacklisted in the tropics.

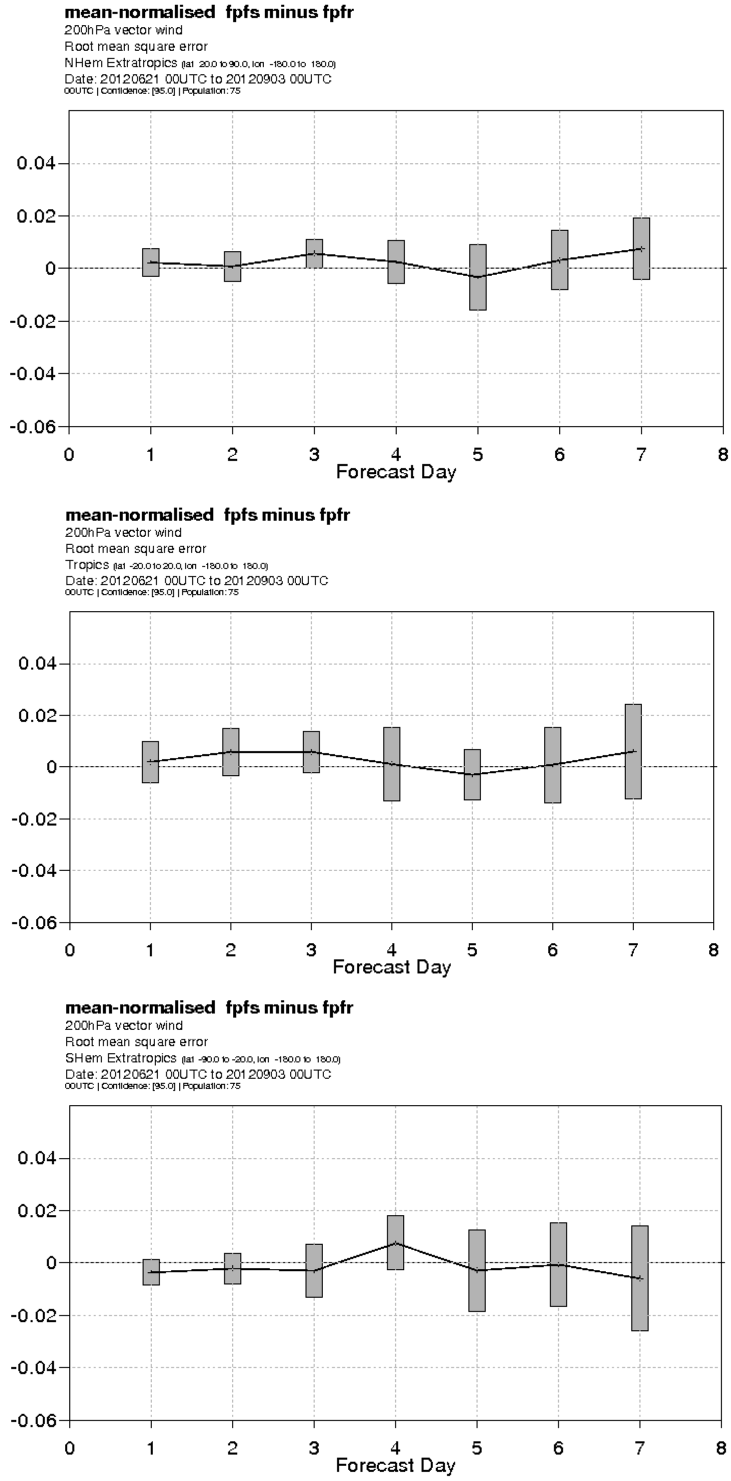


Figure 25: Normalised difference of the RMS wind error as a function of forecast range for the Northern hemisphere extratropics (upper panel), tropics (middle panel), and Southern hemisphere extratropics (lower panel) at 200 hPa level. Verification is done against observations, and the difference is calculated as CCC minus Control. Thus, negative values indicate a reduction in forecast error from using the CCC AMVs.

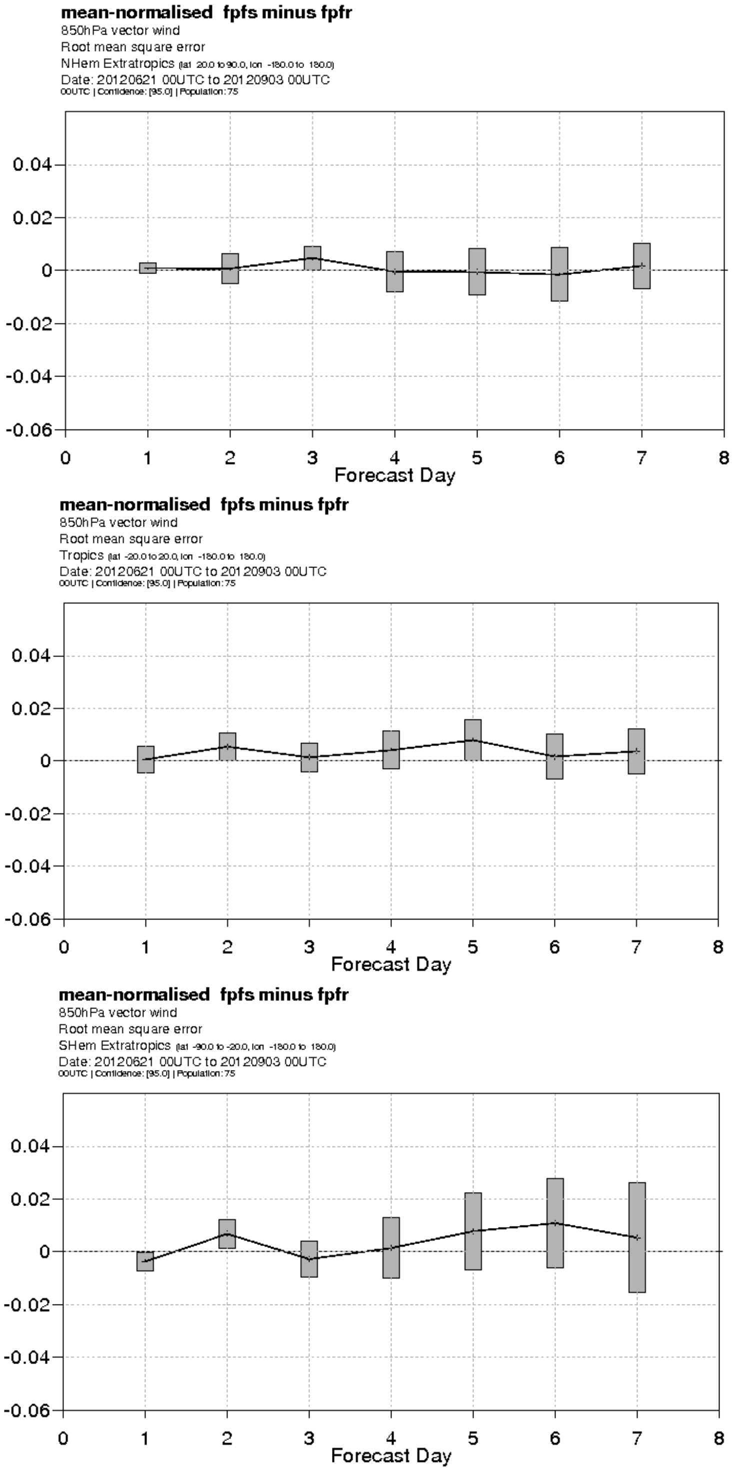


Figure 26: Same as Fig. 25 but at 850 hPa level.

Scatterometer winds allow an independent cross-validation of the changes to the mean wind analysis at low levels. The upper panel of Fig. 28 shows a map of the mean first guess departure for used scatterometer winds in the CCC experiment. The lower panel of Fig. 28 shows the first guess departure

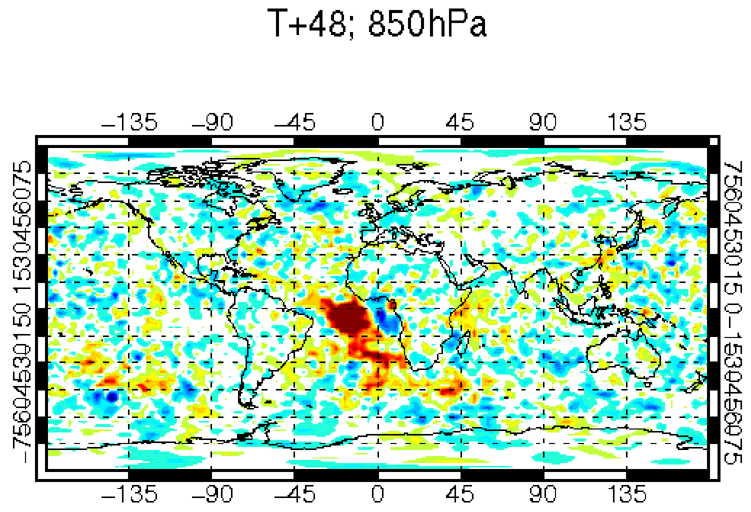


Figure 27: Map of the normalised rms difference between the CCC experiment and the Control for 48-hour wind forecast at 850 hPa level. Blue shades indicate positive impact and green and red shades negative impact from using the CCC AMVs.

difference between the experiment where low level IR and VIS CCC AMVs are blacklisted and the CCC experiment. At the South Atlantic Ocean over the area where the significant changes in the mean wind analysis are seen the first guess departures are larger in the experiment where CCC AMVs are used. This is the case also over the Gulf of Guinea. This indicates that the scatterometer winds agree better with the model background if the low level AMVs are blacklisted in these areas. However, north from the equator there is also an area where the magnitude of the first guess departures is increased in the blacklisting experiment.

Verification against observations indicates that blacklisting of low level IR and VIS CCC winds has neutral or slightly positive impact on wind forecasts at Northern hemisphere midlatitudes. This is the case for both blacklisting experiments. At Southern hemisphere midlatitudes both positive and negative impacts are seen. However, typically impacts are not statistically significant. Figure 29 shows the normalised difference in RMS error for 850 hPa wind forecasts as a function of forecast range in the tropics for the experiment where low level IR and VIS CCC AMVs are blacklisted (upper panel), and are blacklisted only in the tropics (lower panel). Blacklisting all low level IR and VIS winds indicate mainly neutral impact, and blacklisting low level winds only in the tropics neutral or slightly positive impact. Unfortunately, there are very few radiosounding or pilot wind observations available from the area over sea where the CCC winds lead to largest differences and it is difficult to draw definite conclusions.

Based on the results it seems that blacklisting the low level IR and VIS AMVs slightly improves the forecast quality. It is not evident that either of the blacklisting experiments would perform better than the other. The degradation in the forecast quality is mainly seen in the tropics but the deficiencies in the low level wind height assignment are the same also at midlatitudes. It has been decided to blacklist all low level IR and VIS CCC AMVs for the time being in the ECMWF system. There are ongoing activities at EUMETSAT to improve the low level wind height assignment, and the blacklisting decisions will be re-evaluated once the changes have been implemented. In particular EUMETSAT investigates the so-called inversion height assignment which places low level AMVs at the inversion if an inversion is found in the short term forecast. This has been shown to lead to a better height assignment in the past.

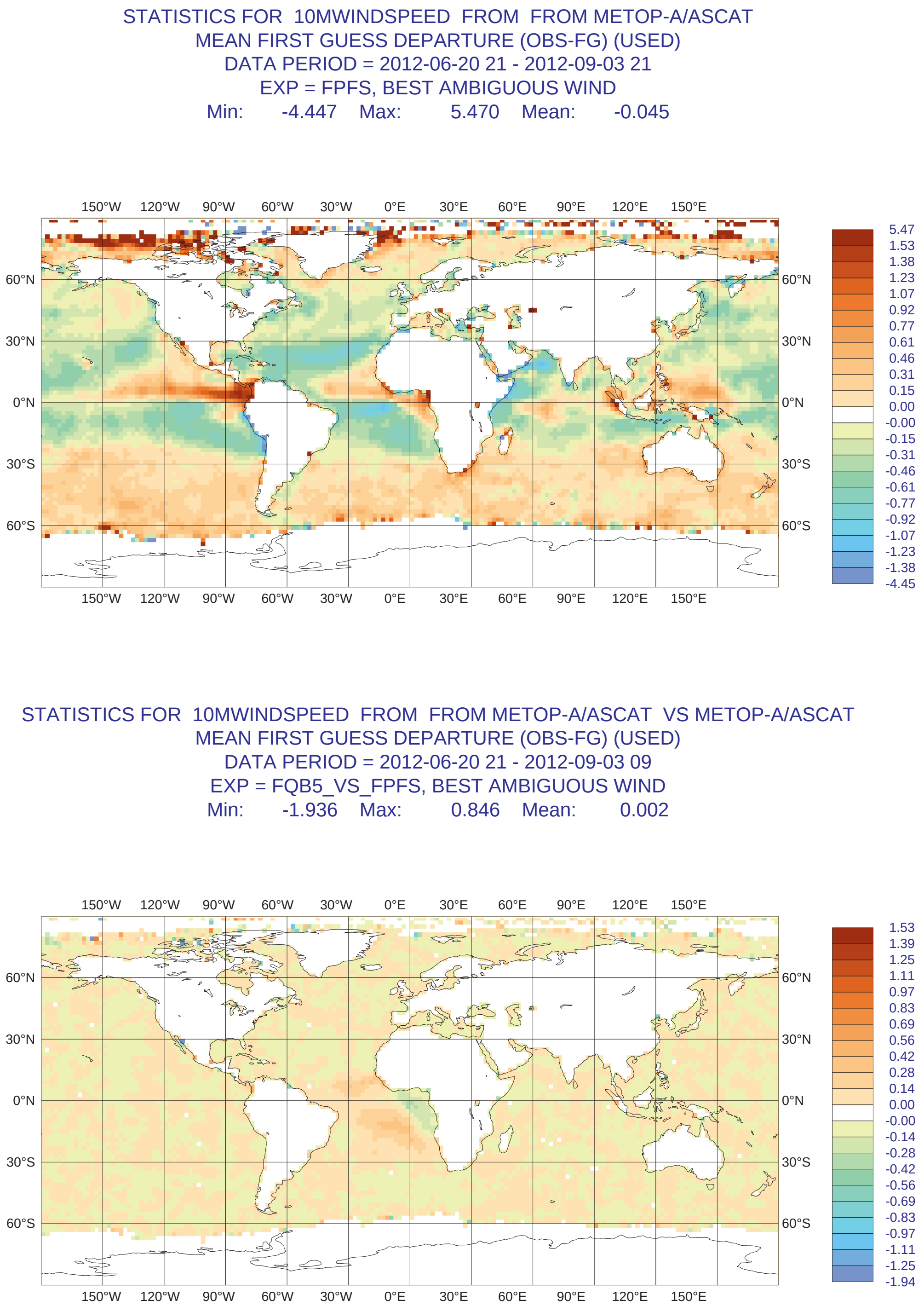


Figure 28: A map of the mean first guess departure for used scatterometer winds in the CCC experiment (upper panel), and the first guess departure difference between the experiment where low level IR and VIS CCC AMVs are blacklisted and the CCC experiment (lower panel).

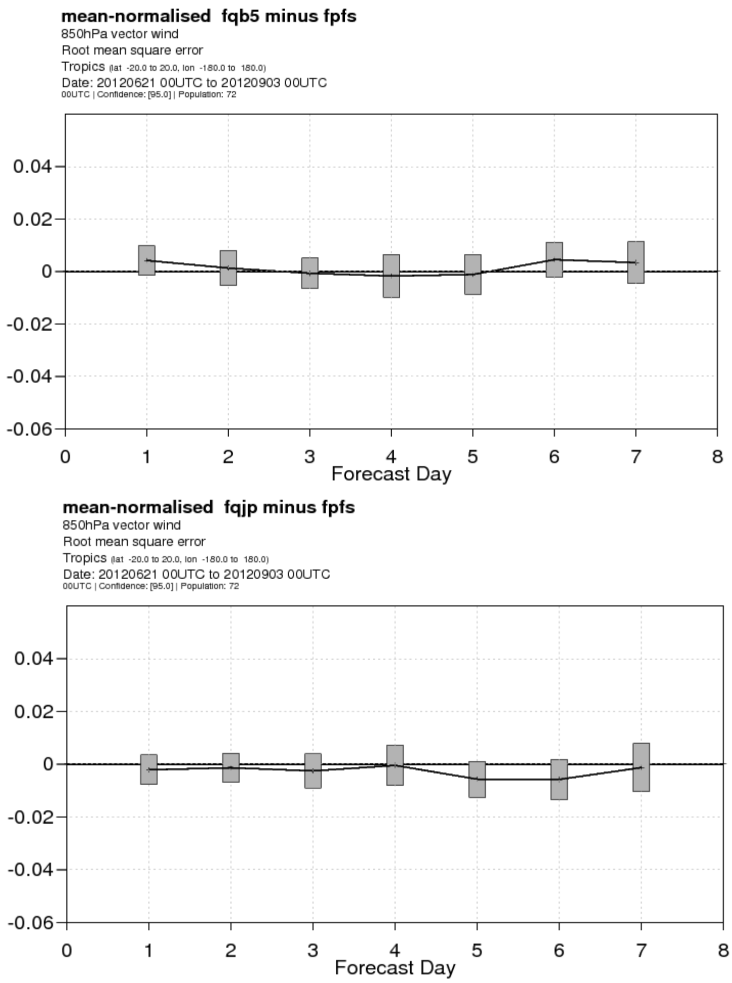


Figure 29: The normalised difference in RMS error for 850 hPa wind forecasts as a function of forecast range in the tropics for the experiment where low level IR and VIS CCC AMVs are blacklisted (upper panel), and are blacklisted only in the tropics (lower panel).

4.4 Conclusions

The general impression from the comparison is that at high levels the quality of the CCC AMVs is significantly improved compared to the operational AMVs, especially at the Southern hemisphere midlatitudes. At mid-levels there are notably more AMVs available in the CCC data set than in the operational data set. At mid-levels the quality of CCC AMVs is similar or slightly improved compared to the operational AMVs. At low levels a degradation is seen in the quality of IR and VIS AMVs when compared to the model background.

Results from the impact studies indicate that at high levels the impact of using the CCC AMVs is similar to the impact of using the operational AMVs. Below 700 hPa level notable differences in the mean wind analysis are seen over the Meteosat-9 coverage area over sea, primarily in the tropical region. The changes in the mean wind analysis are at the same regions where the increase in positive OmB bias is seen for IR and VIS AMVs in the CCC data set. These are areas where AMVs are known to have significant impact on the mean wind analysis. Verification against own analyses indicates negative impact over this area, and also verification against observations suggests slightly degraded forecast quality in the tropics. Unfortunately, the coverage of radiosounding/pilot observations is poor over sea and reliable verification against observations can not be done over that area. Scatterometer winds do not support the changes in the low level mean wind analysis. Given the current results, EUMETSAT is doing some further analysis of the height assignment in these areas. The blacklisting decisions will be re-evaluated once the changes are implemented.

5 Experimentation with AVHRR polar AMVs

5.1 Motivation and background

Polar AMVs are derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on-board the Terra and Aqua satellites and from Advanced Very High Resolution Radiometer (AVHRR) on-board the NOAA-15, -16, -18, and Metop-A satellites. AVHRR AMVs from Metop-B are expected to be available early 2013, as well as the Visible Infrared Imaging Radiometer Suite (VIIRS) AMVs from the Suomi NPP satellite. The lifetime of MODIS AMVs is approaching its end. Thus, the use of AVHRR AMVs in operations is desirable. AVHRR AMVs are also interesting for reanalysis purposes. This study investigates the impact of using AVHRR AMVs in the ECMWF system.

The MODIS IR and WV (both cloudy and clear sky) AMVs have been used in the ECMWF system operationally since January 2003. There is no WV channel on the AVHRR instrument, and only IR AMVs with infrared window (IRW) height assignment are available. WV AMVs provide two thirds of the number of MODIS winds. Thus, the lack of a WV channel on AVHRR means fewer winds with poorer quality because the advanced height assignment methods are not applicable. The AVHRR AMVs have been passively monitored in the ECMWF system since June 2008.

AVHRR AMVs are available from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) and from The National Environmental Satellite, Data, and Information Service (NESDIS). Figure 30 shows a timeseries of the observation minus background (OmB) bias, RMSVD (root mean square vector difference), and number of observations for NOAA-16 AVHRR AMVs from CIMSS (green) and NESDIS (blue) at the Northern hemisphere between 100 and 400 hPa. The considered time period is 1st June - 31st July 2011. There are notably more observations in the CIMSS data set than in the NESDIS data set, and the OmB statistics are noisier for the NESDIS AMVs. The monitoring indicate similar features for other levels and for the Southern hemisphere as well as for NOAA-15 and NOAA-18. Until now the AVHRR AMVs processed at CIMSS have been operationally monitored in the ECMWF system, and in this study it is the CIMSS AVHRR winds that are used.

Figure 31 shows the timeseries of the OmB bias, RMSVD, and number of observations for MODIS IR AMVs from Terra (blue), AVHRR AMVs from NOAA-16 (green), and from Metop-A (red) for the Northern hemisphere between 100 and 400 hPa as an example of the monitoring statistics. Passive monitoring indicates that the quality of AVHRR AMVs from NOAA-15, -16, -18 is comparable to MODIS AMVs from the IR channel in terms of observation minus background (OmB) bias and RMSVD. The Metop-A AVHRR AMVs show larger values for bias and RMSVD and are thus not included in this study. The considered NOAA AMVs are processed at CIMSS and the Metop-A AMVs at EUMETSAT. The processing methods are different and can explain the differences in the monitoring statistics.

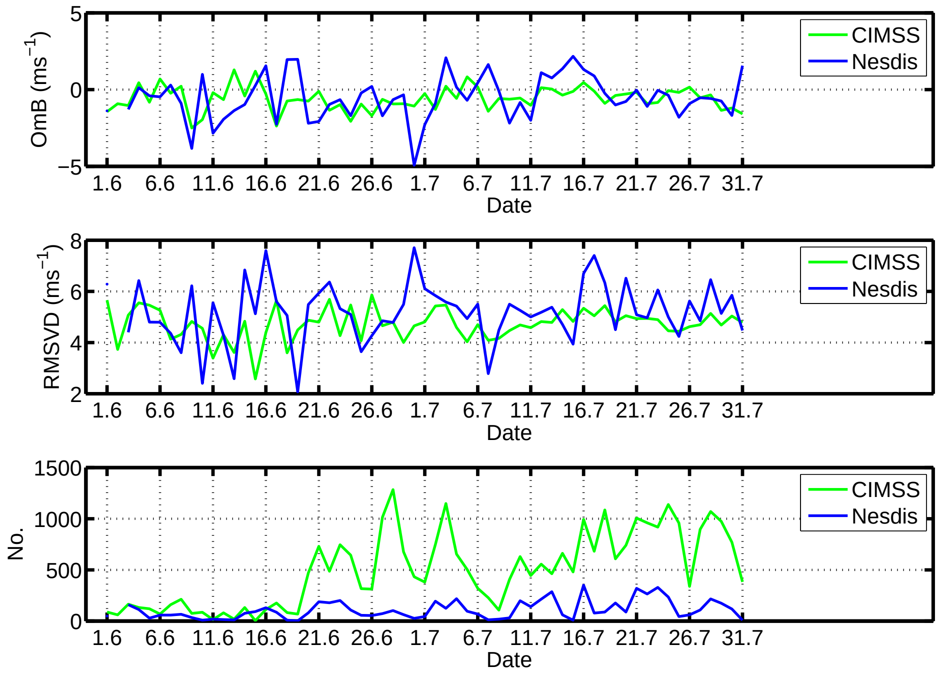


Figure 30: Timeseries of the OmB bias (upper panel), RMSVD (middle panel), and number of observations (lower panel) for NOAA-16 AVHRR AMVs from CIMSS (green), and NESDIS (blue) for Northern hemisphere between 100 and 400 hPa. The considered time period is 1st June - 31st July 2011.

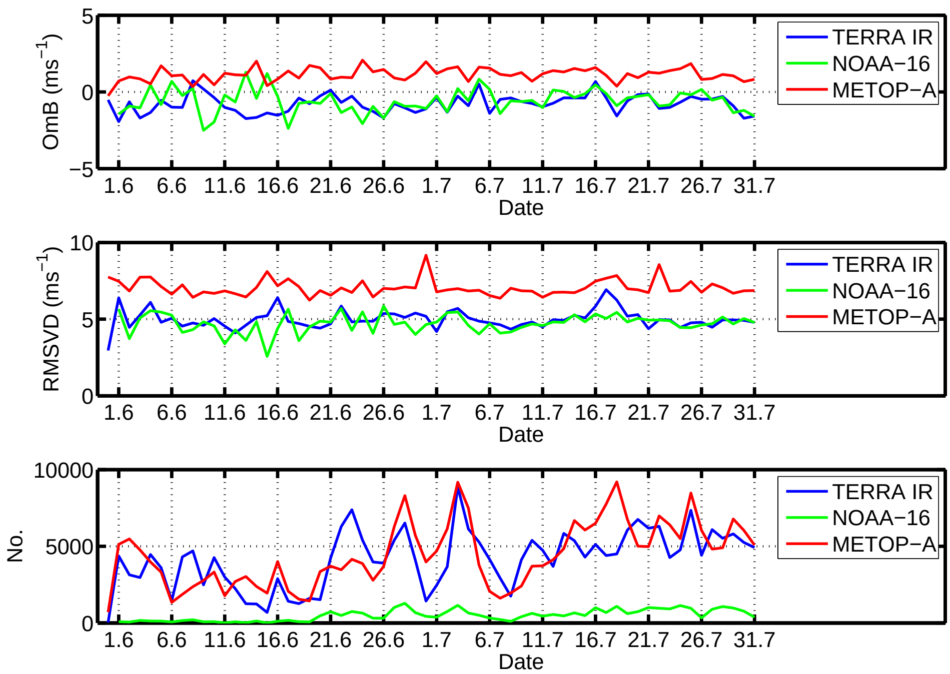


Figure 31: Timeseries of the OmB bias (upper panel), RMSVD (middle panel), and number of observations (lower panel) for MODIS IR AMVs from Terra (blue), AVHRR AMVs from NOAA-16 (green), and from Metop-A (red) for Northern hemisphere between 100 and 400 hPa. The considered time period is 1st June - 31st July 2011.

5.2 Data assimilation experiments

Experiments for a summer and a winter season have been performed in order to study the impact of AVHRR AMVs on model analyses and forecasts. The ECMWF Integrated Forecasting System cycle 38r1 at a T511 resolution, 91 vertical levels, and 12-hour 4D-Var has been applied in the experiments. All operationally assimilated conventional and satellite observations are used. The following experiments have been performed:

- **Control, summer**: 1st June - 31st July 2011, no AVHRR AMVs used.
- **AVHRR, summer**: AVHRR AMVs from NOAA satellites used with similar blacklisting that is operationally used for MODIS IR AMVs.
- **Control, winter**: 1st December 2011 - 31st January 2012, no AVHRR AMVs used.
- **AVHRR, winter**: AVHRR AMVs from NOAA satellites used with similar blacklisting that is operationally used for MODIS IR AMVs.

The blacklist applied for MODIS IR AMVs in the ECMWF system excludes the following observations:

- All winds equatorwards of 60 latitude
- All winds over land below 400 hPa.
- All winds over sea or sea-ice below 700 hPa.
- All winds below 1000 hPa or above 100 hPa.

AVHRR winds are thinned together with the MODIS AMVs.

5.3 Impact assessment

5.3.1 Observation fit statistics

The observation fit statistics against radiosounding and pilot wind observations are very similar between the Control and AVHRR experiments for both periods at Northern and Southern hemisphere midlatitudes and in particular the polar regions, indicating overall consistency between the AVHRR AMVs and these other observations. Figure 32 shows the OmB and OmA standard deviation (left panel) and bias (right panel) for radiosonde wind observation u-component over the Southern hemisphere polar cap. The control run is indicated with red, and the AVHRR experiment with black. The considered period is 1st June - 31st July 2011. The observation fit statistics against MODIS AMVs are also very similar between the Control and the AVHRR experiments (not shown).

Figure 33 shows the OmB and OmA standard deviation (left panel) and bias (right panel) for AMV wind observation u-component over the Arctic. The control run is indicated with red, and the AVHRR experiment with black. The considered period is 1st December 2011 - 31st January 2012. In terms of standard deviation the agreement of used AMVs with the model background and analysis is rather similar for both experiments. In terms of bias there are more differences but mainly at heights where the number of observations is relatively low. Statistics indicate general consistency between the MODIS and AVHRR polar AMVs. Results are similar over the Antarctic, and for the summer period as well.

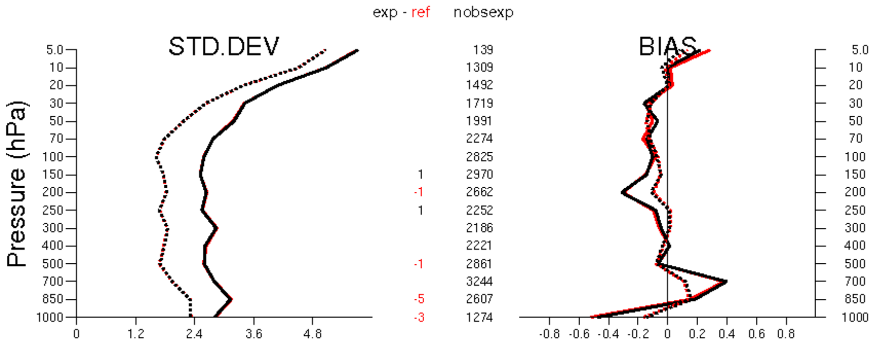


Figure 32: OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for radiosonde wind observation u-component over the Southern hemisphere polar cap. The control run is indicated with red, and the AVHRR experiment with black. The considered period is 1st June - 31st July 2011.

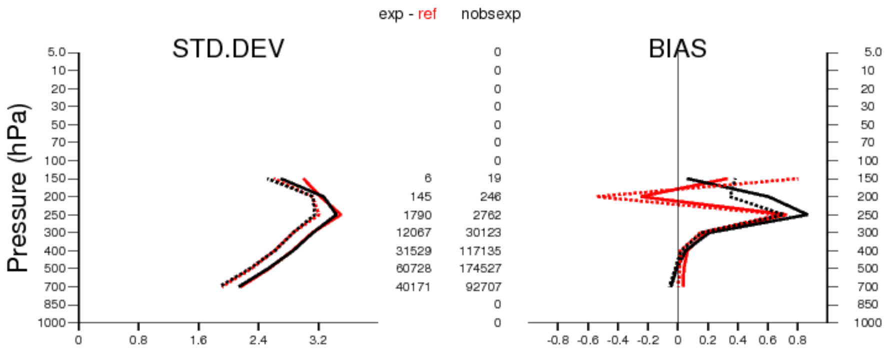


Figure 33: OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for AMV wind observation u-component over the Arctic. Control run is indicated with red, and the AVHRR experiment with black. The considered period is 1st December 2011 - 31st January 2012.

5.3.2 Mean wind analysis

Differences in the mean wind analysis are small between the AVHRR and the Control experiments. For both experiment periods the magnitude of the differences is mainly less than ± 0.5 ms^{-1}, and below 700 hPa height hardly any difference is seen. The mean polar wind analysis is not changed significantly unlike when the MODIS AMVs were introduced to the ECMWF system in the first place (Bormann and Thépaut, 2004). However, the impact is consistent with current MODIS impact discussed in Section 2. AVHRR AMVs support the information provided already by MODIS AMVs, and increase the number of used polar winds by ca. 60%.

5.3.3 Forecast verification

Forecast verification has been done against each experiment's own analysis, and against observations. Figure 34 shows the zonal plots for the normalised difference in the RMS wind error between the AVHRR and Control summer experiments for two to five day forecasts. Blue areas indicate that the AVHRR experiment has lower RMS errors than the control and green and yellow areas the opposite. Verification has been done against the own analysis. Generally the use of AVHRR AMVs has a neutral impact on the forecasts with indications of slight positive impact confined to the northern polar area. Conclusions based on verification against own analyses are similar for the winter experiments.

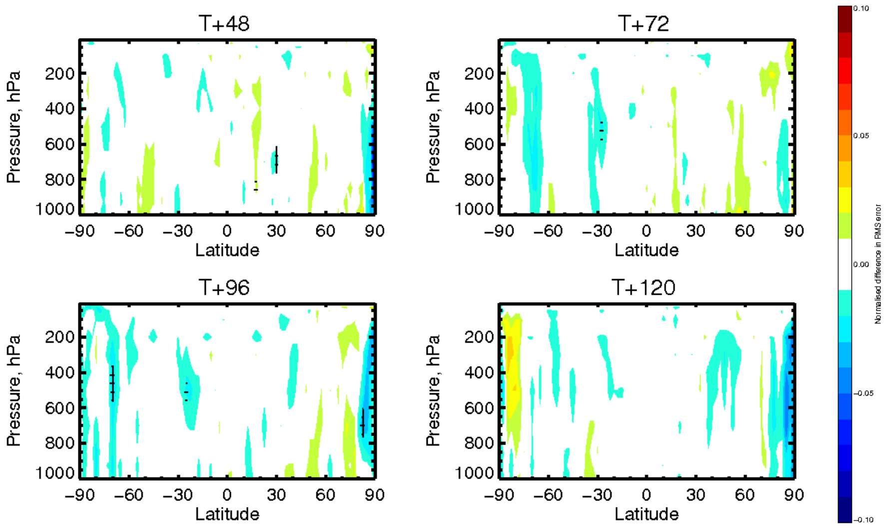


Figure 34: Zonal plots of the normalised difference of the RMS wind error between the AVHRR and Control summer experiments for two (upper left panel), three (upper right panel), four (lower left panel), and five (lower right panel) day forecasts. Verification has been done against the own analysis. Blue areas indicate that the AVHRR experiment has lower RMS errors than the control and green and yellow areas the opposite.

Verification against observations shows also mainly neutral impact at all levels from using the AVHRR AMVs for both experiment periods. Figure 35 shows the normalised difference of the RMS wind error as a function of forecast range for the Northern hemisphere extratropics (upper panel), tropics (middle panel), and Southern hemisphere extratropics (lower panel) at 200 hPa level combining the summer and winter periods (122 cases). The difference is calculated AVHRR minus Control experiment. Thus, negative values indicate reduction in forecast error from using the AVHRR AMVs, and positive values increase, respectively. In the Southern hemisphere extratropics some negative impact is seen for day 6, and in the tropics for day 3, otherwise the impact is neutral within the 95% confidence intervals.

5.4 Conclusion and actions taken

Passive monitoring indicates that the quality of AVHRR AMVs from NOAA-15, -16, -18 is comparable to MODIS IR AMVs in terms of OmB mean difference and RMSVD. In this study the impact of using the AVHRR AMVs in the ECMWF system has been investigated over two periods, 1st June - 31st July 2011 and 1st December 2011 - 31st January 2012. Observation fit statistics are very similar between the Control and AVHRR experiments for both periods. Forecast verification indicates mainly neutral impact. Operational assimilation of AVHRR AMVs has been activated on 19th November 2012. Additional experiments will be conducted to assess the impact of AVHRR AMVs when MODIS AMVs are absent. This is to further characterise to what extent the AVHRR winds can compensate for the loss of MODIS winds expected in the near future.

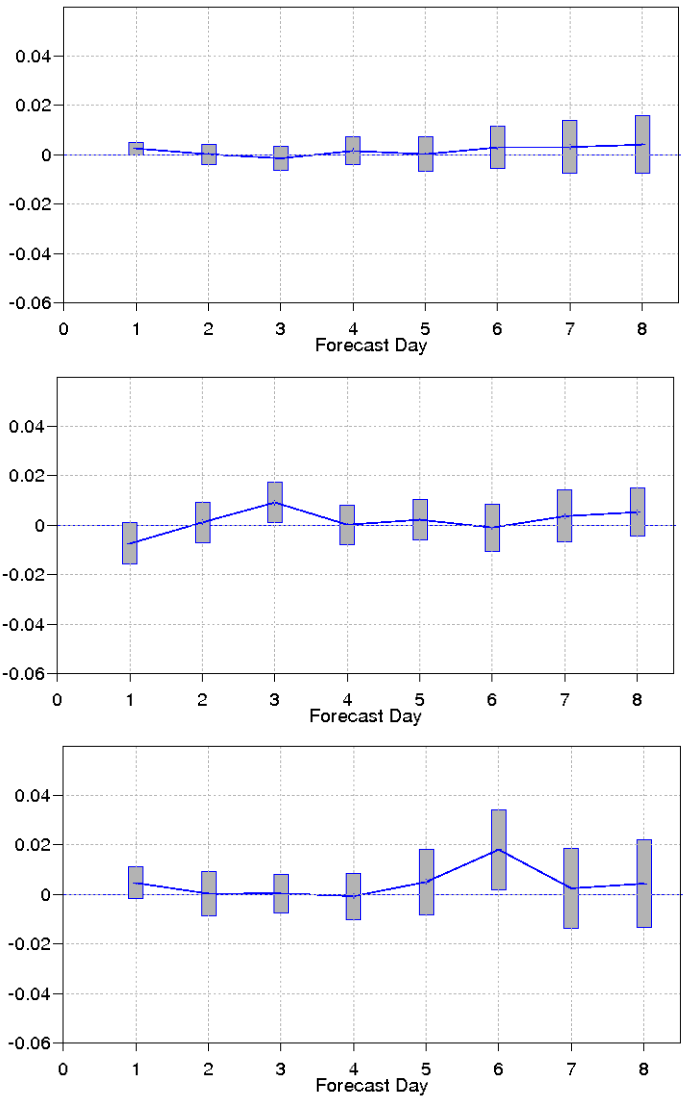


Figure 35: Normalised difference of the RMS wind error as a function of forecast range for the Northern hemisphere extratropics (upper panel), tropics (middle panel), and Southern hemisphere extratropics (lower panel) at 200 hPa level. Verification is done against observations, and the difference is calculated as AVHRR minus Control. Thus, negative values indicate a reduction in forecast error from using the AVHRR AMVs. The considered period is 1st June - 31st July 2011 and 1st December 2011 - 31st January 2012 (122 cases).

6 Status of investigations on situation dependent observation errors

6.1 Background

The Met Office has introduced an approach to estimate situation dependent observation errors for AMVs (Forsythe and Saunders, 2008). The observation error is divided into two parts, one originating from the AMV tracking and one originating from the error in the height assignment. As a result, the assumed observation errors for AMVs are larger in areas with strong wind shear, where height assignment errors are more relevant. The new method has been investigated in the ECMWF system. Estimation of the height errors and the tracking errors have been reported in the 1-year report together with the first results on assessment of the errors (Salonen and Bormann, 2011).

During the past year the emphasis of the work related to the use of the situation dependent AMV observation errors has been on answering the following questions:

- Can the model first guess check for AMVs be simplified?
- Can the observation error due to the error in height be used to exclude suspicious observations?
- What is the impact of using the new observation errors on model analyses and forecasts?

In order to find the answers a set of model experiments for July - August 2010 have been performed with the ECMWF Integrated Forecasting System cycle 37r2 at T511 (~40 km) resolution, 91 vertical levels and 12 hour 4D-Var. All operationally assimilated conventional and satellite observations have been used. The control run is similar to the current operationally used setup, i.e. the AMV observation errors vary only with height. In the experiments the new observation errors are used, and several revisions of the quality control are considered, as discussed below.

6.2 Revised quality control

The model first guess check compares observations y with the model background information Hx_b

$$\frac{1}{2}\left(\left[\frac{(Hx_b-y)^2}{\sigma_b^2+\sigma_o^2}\right]_u+\left[\frac{(Hx_b-y)^2}{\sigma_b^2+\sigma_o^2}\right]_v\right)\leq L. \qquad (1)$$

Observations which deviate from the background more than a pre-defined limit L are rejected. In eq. 1 σ_b^2 and σ_o^2 are the background and observation error variances, respectively.

Traditionally the first guess check has been very strict for AMV observations in the ECMWF system. Tight rejection limits are applied, typically L is by factor $\sqrt{10}$ smaller for AMV observations compared to limits used for conventional wind observations. In addition, the first guess check is asymmetric, i.e. an additional penalty is applied to AMV observations that under-report wind speed when compared with the first guess field. There are also some geographical dependencies in the rejection limits, the first guess check is slightly relaxed for the low level winds, and in the tropics.

The new situation dependent observation errors allow to down-weight observations in areas where wind shear is strong and the error in the height assignment can have a drastic impact. Thus, it is important to revise the first guess check and carefully consider how it could be simplified and possibly relaxed.

Experiments have been conducted to investigate removing the asymmetric part of the first guess check, and other adhoc geographical adjustments to the rejection limits. In addition variations of the rejection limit L have been tested to allow more AMV observations to pass the first guess check than in the current operational system.

Results from the model experiments indicate that it is possible to remove the asymmetric part of the first guess check, and the geographical dependencies in the rejection limits without degrading the quality of the model analyses and forecasts. This allows a significant simplification of the first guess check. However, tight rejection limits need to be retained. Relaxing the rejection limits results in degraded forecast quality at high levels, and over high latitudes (north from 80°N and south from 80°S) for short forecast ranges at all levels.

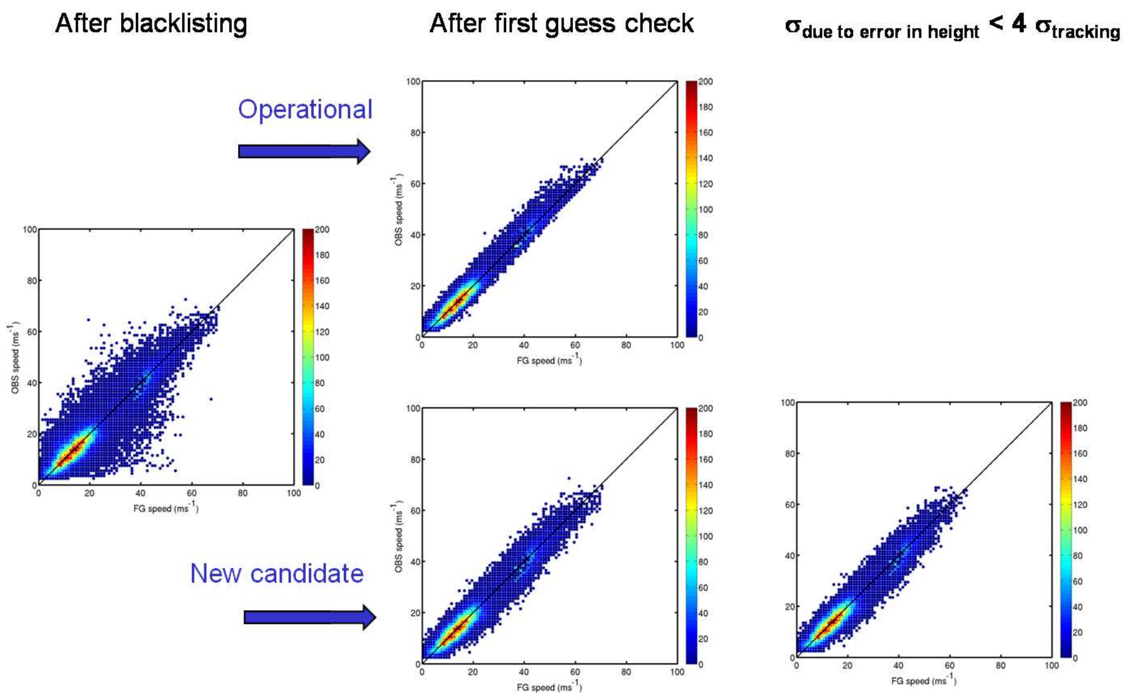


Figure 36: Demonstration of the operation of the model first guess check. The left panel shows Meteosat-9 WV AMVs at 100 - 400 hPa heights after blacklisting. The upper right panel displays the AMVs after applying the first guess check used in the operational system, and the lower middle panel the after the modified first guess which is under investigations. The lower right panel shows AMVs after applying the criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error.

Furthermore, a new quality control criterion has been investigated. Criterion 2 limits the magnitude of the observation error due to error in height, $\sigma_{o,h}$ to be smaller than n times the tracking error $\sigma_{o,t}$.

$$\sigma_{o,h} \leq n\sigma_{o,t} \tag{2}$$

Experimenting with criterion 2 using varying values for n indicates that it is an effective tool to detect and reject suspicious observations. However, a too tight criterion results in rejecting too many good quality observations, and this leads to negative forecast impact in some areas in the tropics at high levels. In the current configuration which is under further testing n is set to 4. This allows AMVs with an observation error of up to 8 - 13 ms^{-1}, depending on height of the AMV.

Figure 36 illustrates how the first guess check and the criterion 2 operate. In the left, a scatter plot of observed wind speed versus first guess wind speed is shown for Meteosat-9 WV AMVs at 100 - 400 hPa heights. The upper panel shows the scatter plot for AMVs which have been accepted by the first guess check used in the current operational system. Outliers have been removed very effectively, and also the impact of the asymmetric check is clearly seen. The lower panel illustrates the new simplified first guess check that is under investigation. In the new first guess check the asymmetric part has been removed, and the same rejection limits are used independent of the geographical location of the AMV observation. The modified first guess check rejects outliers as well. The spread in the scatter plot is notably wider compared to the operational first guess check. The effect of using the criterion 2 is illustrated in the lower right panel of Fig. 36. Excluding AMVs with large errors due to errors in height assignment is motivated by the fact that the height assignment errors are likely to be more correlated spatially, and such correlations are currently neglected.

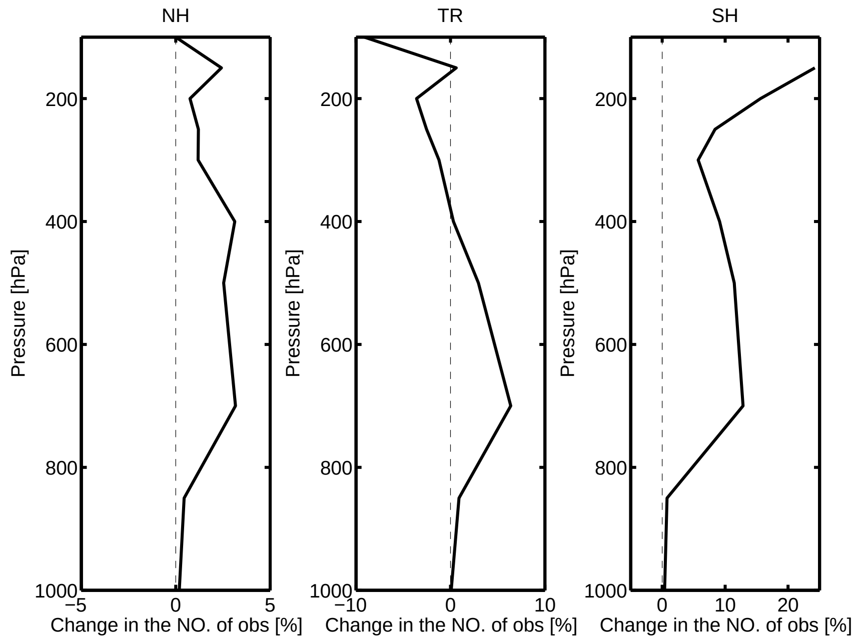


Figure 37: The relative change (percentage) in the number of used AMV observations compared to the control experiment for the northern hemisphere extratropics (left panel), tropics (middle panel), and southern hemisphere extratropics (right panel).

6.3 Impact assessment

Based on the above investigations, the following configuration has been chosen for further evaluation: the situation dependent observation errors, the above described modified first guess check, and the criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error. The control run is similar to the current operational setup.

Figure 37 shows the relative change (percentage) in the number of used AMV observations compared to the control experiment for the northern hemisphere extratropics (left panel), tropics (middle panel), and southern hemisphere extratropics (right panel), respectively. At the northern and southern hemisphere extratropics the number of used AMVs is the same or increased compared to the control experiment at all levels. The increase is more pronounced at the southern hemisphere. Also in the tropics the number of used AMVs has slightly increased below 500 hPa but at high levels the number of used AMVs is somewhat decreased. This is due to the criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error. Figure 38 shows the OmB and OmA observation fit statistics for AMVs in the tropics. Red lines indicate the experiment where the criterion is used and black the experiment without the criterion. The statistics show that the set of AMVs used in the experiment with the criterion have a better fit to the model background and analysis both in terms of bias and standard deviation, indicating that the additional criterion indeed removes AMVs that agree more poorly with the model background or the analysis.

Figure 39 shows the vector difference between the experiment and the control for the mean wind analysis at level 200 hPa. In the midlatitudes the magnitude of the changes is 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 removed without slowing down the extratropical jets. The most significant impact is seen in the tropics where the maximum values for the difference are 1.5 ms^{-1}. The vector difference is mainly positive, i.e. the mean wind is stronger

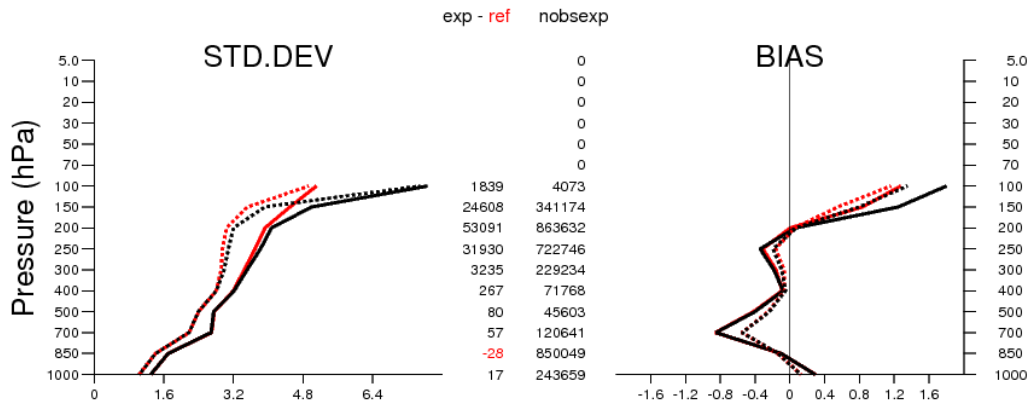


Figure 38: The OmB and OmA observation fit statistics for used AMVs in the tropics. Red line indicates the experiment where the criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error is used, and black line exactly similar experiment setup but without the criterion.

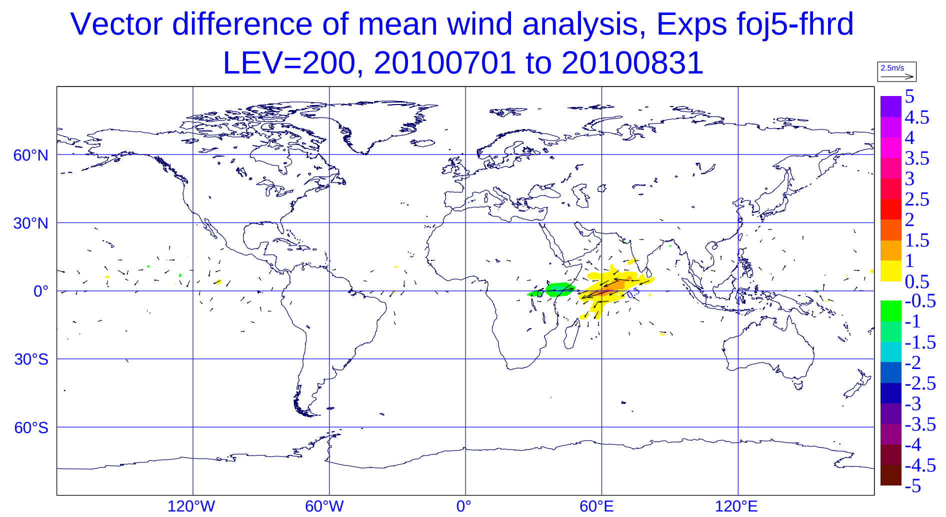


Figure 39: Difference in the mean wind analysis at 200 hPa between the experiment using situation dependent observation errors and the control. Shading indicates the difference in mean wind speed (ms^{-1}). The considered period is 1 July - 31 August 2010.

in the experiment than in the control. At 300 hPa level the modifications tested in the experiment tend to weaken the mean wind field in the tropics, the highest differences being 1 ms^{-1} (not shown). At lower levels the differences in the mean wind analysis are typically less than $\pm$0.5 ms^{-1} also in the tropics.

Verifying against the own analysis indicates mainly postivive forecast impact from using the situation

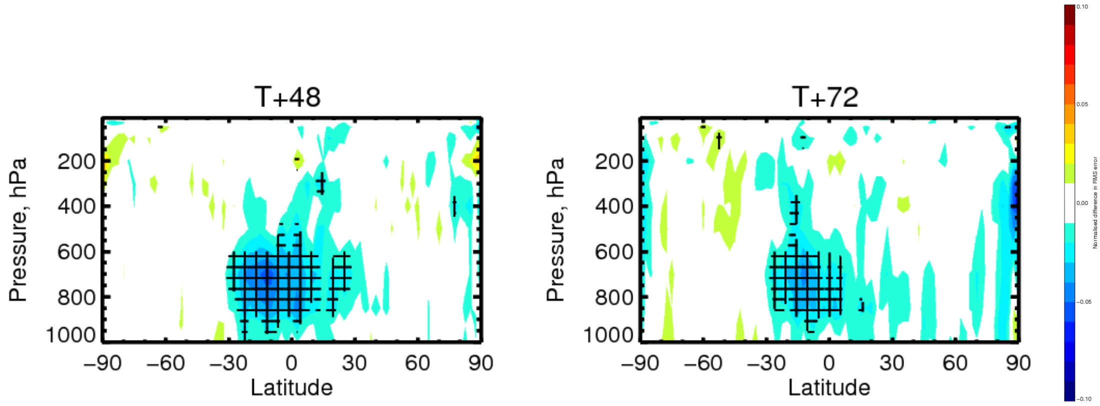


Figure 40: Zonal plot of the normalised difference (experiment - control) in RMS error for 48-hour (left) and 72-hour (right) wind forecasts. Verification is done against the own analysis.

dependent observation errors, and the criterion to limit the magnitude of the observation error due to error in height. Figure 40 shows a zonal plot of the normalised difference in RMS error for 48-hour and 72-hour wind forecasts as an example of the results. The difference is calculated as experiment minus control, i.e. blue shades indicate positive impact and green and red shades negative impact. Verification against observations shows mainly neutral results. Figure 41 shows the normalised difference (experiment minus control) in RMS error for 200 hPa (upper panel) and 850 hPa (lower panel) wind forecasts as a function of forecast range in the tropics. There is systematic indication of positive forecast impact at 200 hPa level, however the impact is not statistically significant within 95% confidence intervals. At 850 hPa level the impact in wind forecasts is neutral but for the geopotential statistically significant positive forecast impact is seen up to day 4 (not shown).

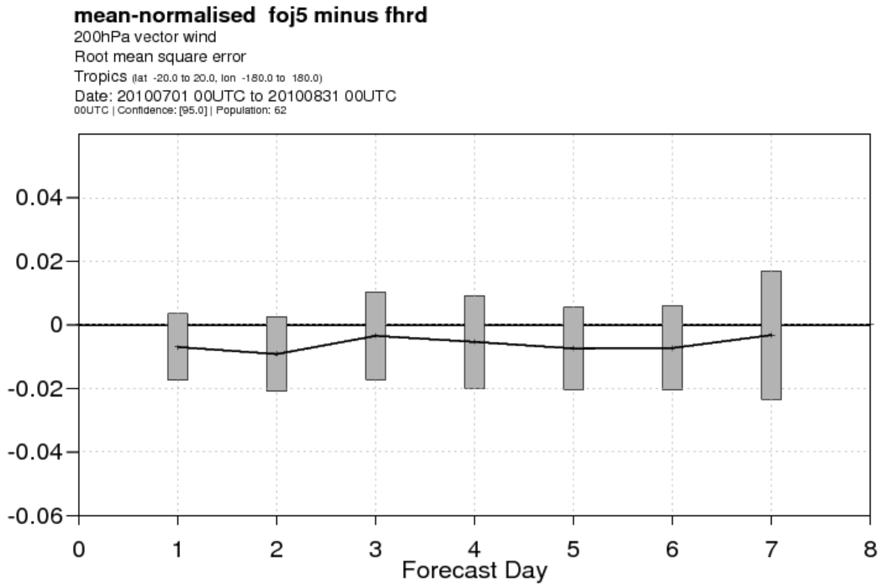
6.3.1 Ongoing work

The results discussed above are considered positive and mature. Currently similar experiment setup using the situation dependent observation errors for AMVs, the modified first guess check, and the criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error is tested with a newer cycle 38r1 for a summer and winter periods to confirm the conclusions. Observing system experiments similar to Section 2 are also planned to be conducted with the new observation errors. If the results from the new experiments are robust, the operational implementation is planned.

7 Other ongoing activities

The next significant change in the operational use of AMVs will be the replacement of Meteosat-9 with Meteosat-10 in December-January 2012/2013. The ECMWF system is prepared for the change, and the Meteosat-10 data has been processed and passively monitored at ECMWF since 30th October 2012.

An upcoming change related to GOES AMVs is the planned dissemination of hourly AMVs, now they are disseminating 3-hourly AMVs. Experimentation with the hourly GOES winds is ongoing.



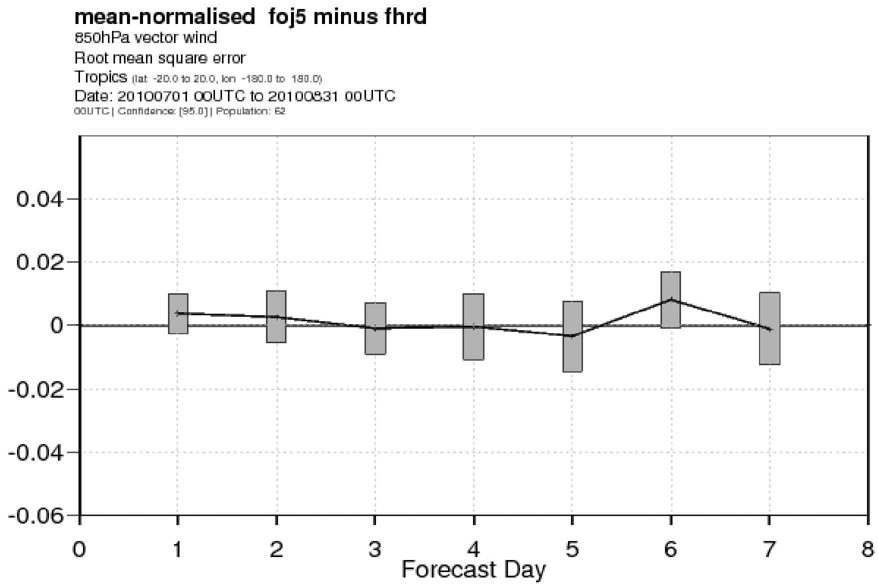


Figure 41: Normalised difference of the RMS wind error as a function of forecast range in the tropics at 200 hPa level (upper panel) and 850 hPa level (lower level). Verification is done against observations, and the difference is calculated as experiment minus Control. The considered period is 1st July - 31st August 2010 (62 cases).

Hernandez-Carrascal and Bormann (2012) have studied the characteristics and origin of the AMV errors using a simulation framework. Alternative interpretations of AMVs as vertical as well as spatial averages, and the reassigning of AMVs have been considered. Testing similar approaches in the ECMWF system with real AMVs has started.

Acknowledgements

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References

Borde, R., Oyama, R., 2008. A direct link between feature tracking and height assignment of operational atmospheric motion vectors. Proceedings of the 9th International Wind Workshop, Annapolis, Maryland, USA, 14-18 April 2008.

Bormann, N., Thépaut, J.-N., 2004. Impact of MODIS polar winds in ECMWF's 4DVAR data assimilation system. Monthly Weather Review 132, 929–940.

Cardinali, C., 2009. Forecast sensitivity to observations (FSO) as a diagnostic tool. ECMWF Technical Memorandum No.599.

Forsythe, M., Saunders, R., 2008. AMV errors: a new approach in NWP. Proceedings of the 9th International Wind Workshop, Annapolis, Maryland, USA, 14-18 April 2008 EUMETSAT P.51.

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

Payan, C., Cotton, J., 2012. Collaborative satellite winds impact study. Research report, available online at http://cimss.ssec.wisc.edu/iwwg/Docs/windsdenial-synthesisV1-1.pdf.

Salonen, K., Bormann, N., 2011. Atmospheric Motion Vector observations in the ECMWF system: 1-year report. EUMETSAT/ECMWF Felloship Programme Research Report No.23.