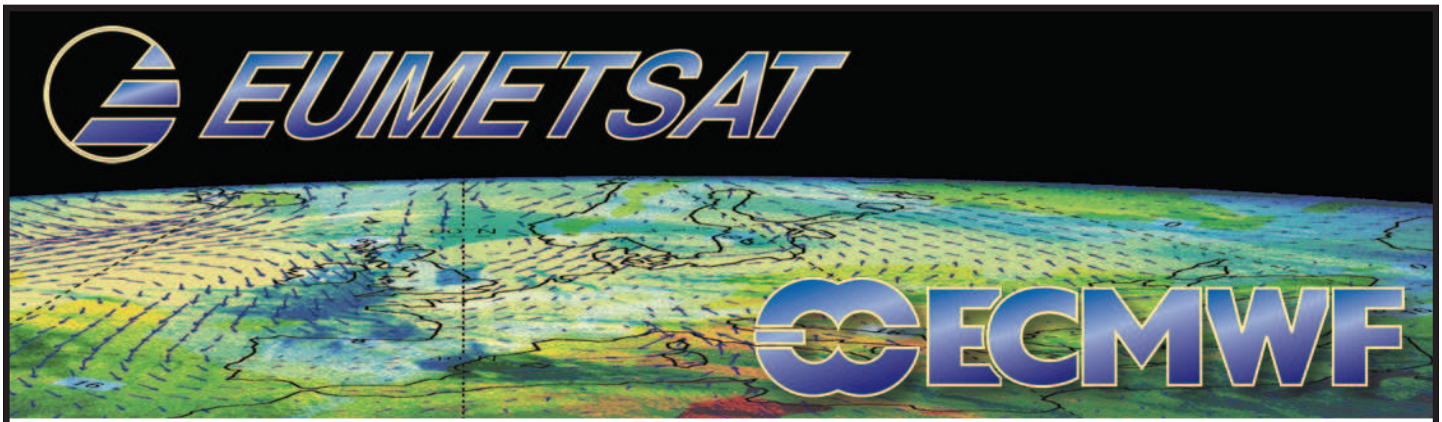

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Atmospheric Motion Vector observations in the ECMWF system: 1-year report

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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-11, GOES-13, MTSAT-2) and two polar orbiting (Aqua, Terra) satellites. In addition, AMVs from seven other satellites (FY-2D, FY-2E, NOAA-15, NOAA-16, NOAA-17, NOAA-18, METOP-A) are passively monitored. Table 1 summarises the monitored and used AMVs. The changes in the operational use of the AMVs, and the main results from research work carried out between October 2010 and September 2011 are discussed in this report.

A significant change in the operationally used AMVs has been that the Meteorologial Satellite Center of the Japan Meteorological Agency (JMA/MSC) started to disseminate hourly-derived IR, WV, and VIS AMVs from MTSAT-2. Earlier the AMVs were disseminated every 3-hours on the northern hemisphere and every 6-hours on the southern hemisphere. Also the image intervals used in the AMV derivation were changed. Results on monitoring the quality of the new 1-hourly AMVs, and on impact studies are presented here. It can be concluded that the quality of the 1-hourly MTSAT-2 AMVs is comparable to the quality of the old MTSAT-2 AMVs. Impact studies indicate improvements in the forecasts when MTSAT-2 AMVs are used in general, and when 1-hourly AMVs are used in particular.

The research work towards a general enhancement of the assimilation of AMVs in the ECMWF system is ongoing. This includes detailed studies on the observation error characteristics, and how to better take them into account in the assigned observation errors. Consequently, the NWP model quality control procedures, such as the first guess check, will be revised. The two main sources of AMV observation errors are errors in the wind vector derivation, and errors in the height assignment of the tracers. Currently, the observation errors applied in the operational ECMWF system for AMVs vary only with height. Forsythe and Saunders (2008a) have introduced an approach to estimate situation dependent AMV observation errors. The method is investigated in the ECMWF system. Situation dependent observation errors have been derived, and their impact on model analysis and forecasts is now carefully considered. The new approach allows to down-weight observations in regions with high vertical wind shear where errors in height assignment are problematic, and observations in regions where the height assignment error is less critical can get larger weight in the model analysis. Preliminary results are encouraging.

Table 1: Overview of the use of AMV data in the ECMWF system in September 2011.

	IR	Cloudy WV	Clear WV	VIS
Meteosat-7	used	used	monitored	used
Meteosat-9	used	used	monitored	used
GOES-11	used	used	monitored	used
GOES-13	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 METOP-A, NOAA-15, 16, 17, and 18	monitored	-	-	-

In order to estimate the AMV observation error due to error in height assignment, a height error estimate is required. Comparison of the assigned pressure to the model best-fit pressure is one option to estimate the magnitude of the height error. In the context of estimating the situation dependent observation errors for AMVs used in the ECMWF system, the model best-fit pressure statistics have been compared between the Met Office and ECMWF global assimilation systems. The results obtained from the best-fit pressure comparison study show that the statistics are generally very similar for both systems in terms of systematic differences and standard deviation. The results are also in good agreement with earlier findings about the characteristics of height assignment methods, and quality of the observations. Based on the results it can be concluded that the model best-fit pressure is a useful quantity for the AMV height uncertainty estimation.

More detailed discussion on the above introduced subjects is presented in the following sections. The report is organised as follows. Section 2 describes the changes in the dissemination of MTSAT-2 AMVs and presents results on the data monitoring and impact studies. Section 3 provides background information for the work towards using situation dependent observation errors for AMV observations in the ECMWF system. Section 4 reports the results from the best-fit pressure comparison study done together with Met Office. Section 5 describes the estimation of the situation dependent observation errors for AMVs in the ECMWF system, and shows preliminary results from impact studies. Finally, Section 6 discusses some ongoing activities.

2 MTSAT-2 hourly winds

2.1 Motivation

The Meteorologial Satellite Center of the Japan Meteorlogical Agency (JMA/MSC) started to disseminate hourly-derived IR, WV, and VIS AMVs from MTSAT-2 on 28th March 2011 at 03 UTC. Earlier the AMVs were disseminated every 3-hours on the northern hemisphere and every 6-hours on the southern hemisphere. At the same time the image intervals used in the AMV derivation were also changed. Table 2 summarises the old and the new data sets.

The changes in the disseminated data were significant. Thus, it was decided to blacklist all MTSAT-2 AMVs in the ECMWF system until the quality of the new data had been thoroughly verified. This was done by passive monitoring of the observations against their model counterparts, and by performing data assimilation experiments to study the impact on model analysis and forecasts. The results are reported in the following subsections.

2.2 Monitoring the data quality

The AMV data quality is routinely monitored with observation minus background (OmB) and observation minus analysis (OmA) statistics. Based on the long term monitoring, decisions on which data is used and which data is blacklisted are made. MTSAT-2 AMVs from the following areas are blacklisted:

- All VIS winds at 700 hPa and above.
- WV winds below 400 hPa.
- IR winds north of 20°N.
- All winds over land below 500 hPa and additionally all winds over land (any height) North of 20°N in any region that is east of 100°E.

Table 2: MTSAT-2 AMV products. Shaded lines show the dataset disseminated before 28th March 2011 03 UTC. These were incremented with the newly disseminated AMVs (unshaded lines).

AMV type	Time	Image Sector	Image Interval (min)
IR 10.8μm	00, 06, 12, 18	Full disk	15
	03, 09, 15, 21	Northern Hemisphere	30
	02, 04, 05, 08, 10, 11, 14, 16, 17, 20, 22, 23	Northern Hemisphere	30
	01, 07, 13, 19	Northern Hemisphere	60
	01, 02, 03, 04, 05, 07, 08, 09, 10, 11, 13, 14, 15, 16, 17, 19, 20, 21, 22, 23	Southern Hemisphere	60
WV 6.8μm	00, 06, 12, 18	Full disk	15
	03, 09, 15, 21	Northern Hemisphere	30
	02, 04, 05, 08, 10, 11, 14, 16, 17, 20, 22, 23	Northern Hemisphere	30
	01, 07, 13, 19	Northern Hemisphere	60
	01, 02, 03, 04, 05, 07, 08, 09, 10, 11, 13, 14, 15, 16, 17, 19, 20, 21, 22, 23	Southern Hemisphere	60
VIS 0.63μm	00, 06	Full disk	15
	03, 09, 21	Northern Hemisphere	30
	02, 04, 05, 08, 22, 23	Northern Hemisphere	30
	01, 07	Northern Hemisphere	60
	01, 02, 03, 04, 05, 07, 08, 21, 22, 23	Southern Hemisphere	60

Time series of the monitoring statistics are an effective way to detect if there are any changes in the data quality. Figure 1 shows the mean wind speed (upper panel), mean difference between the observation and the model background and analysis (second panel), standard deviation of the OmB and OmA (third panel), and number of observations (lower panel) for IR AMVs between 0 and 400 hPa in the tropics (20°S - 20°N). There is a clear change in the number of available observations at 28th March when the dissemination of the 1-hourly winds started, otherwise the statistics stay on the same level than for the old data. Results for the other channels are similar.

Figure 2 shows the wind speed bias (top), RMS error for the vector wind difference (middle), and the number of available winds (bottom) for used WV AMVs between 100 and 400 hPa as a function of the hour of the day. The statistics are shown separately for the southern hemisphere, tropics, and the northern hemisphere. The considered period is September 2011. There is positive bias indicating that the observed wind speed is stronger than the model background wind. The magnitude of the bias is similar to that seen in the old data. A striking feature is that at 00, 06, 12, and 18 UTC there is a peak in the number of observations in the southern hemisphere. This is a result of the MTSAT-2 scan schedule. For the southern hemisphere wind derivation is not possible in the hour preceding the synoptic hours, but 2 sets of AMVs are available for the next hour.

Based on the monitoring statistics it can be concluded that the general quality of the hourly AMVs is on the same level than the quality of the old data.

2.3 Data assimilation experiments

Four experiments (4 April 2011 - 3 June 2011) have been performed in order to study the impact of AMVs from MTSAT-2 on model analyses and forecasts. The ECMWF Integrated Forecasting System cycle 37r2 at a

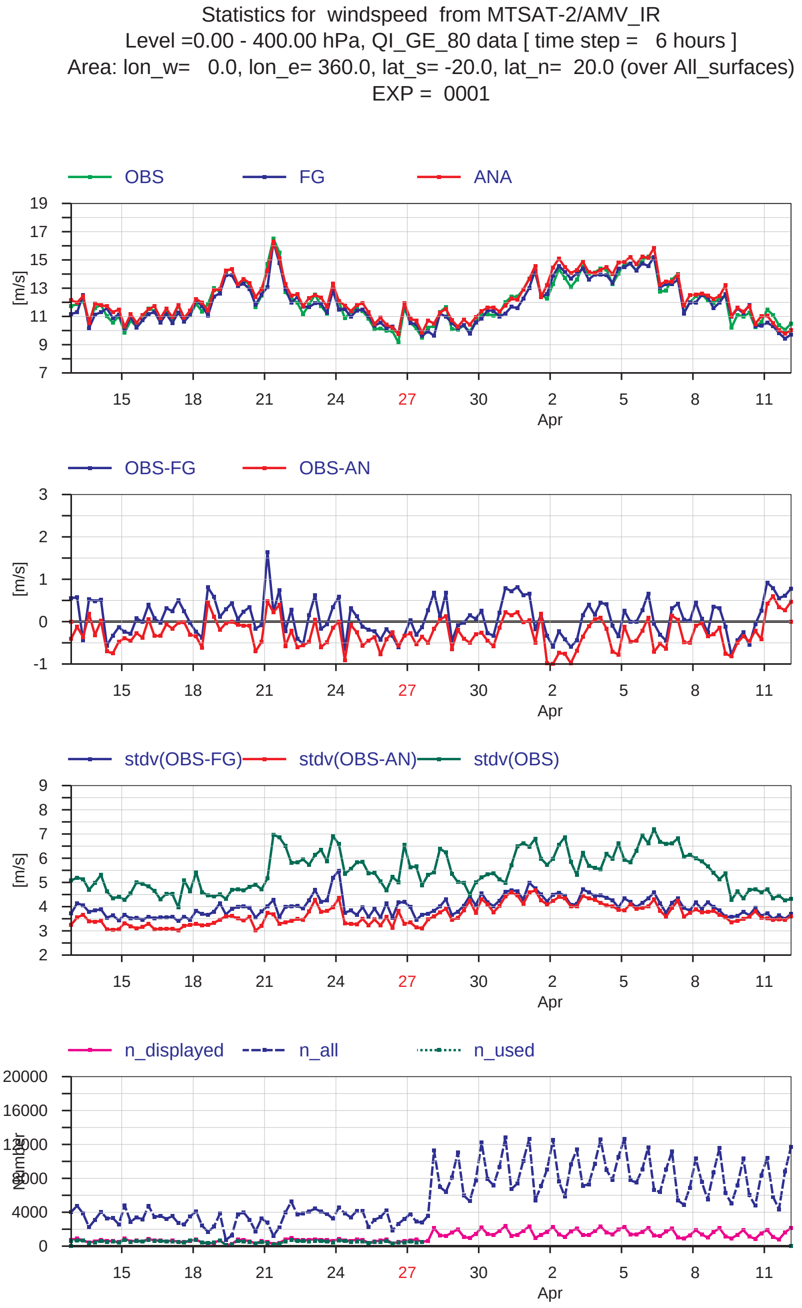

Figure 1: Upper panel: Time series of mean wind speed. Green line indicates observed, blue line first guess, and red line analysis, respectively. Second and third panel: Time series of first guess and analysis departure statistics. Blue line indicates observation minus background, red line indicates observation minus analysis, and green line in the third panel shows the standard deviation of the observations. Lower panel: time series of the number of available observations. Blue line indicates all available observations, green line the number of used observations. The considered area is 20°S - 20°N, 0 - 400 hPa. Observations are filtered applying a QI threshold of 80%.

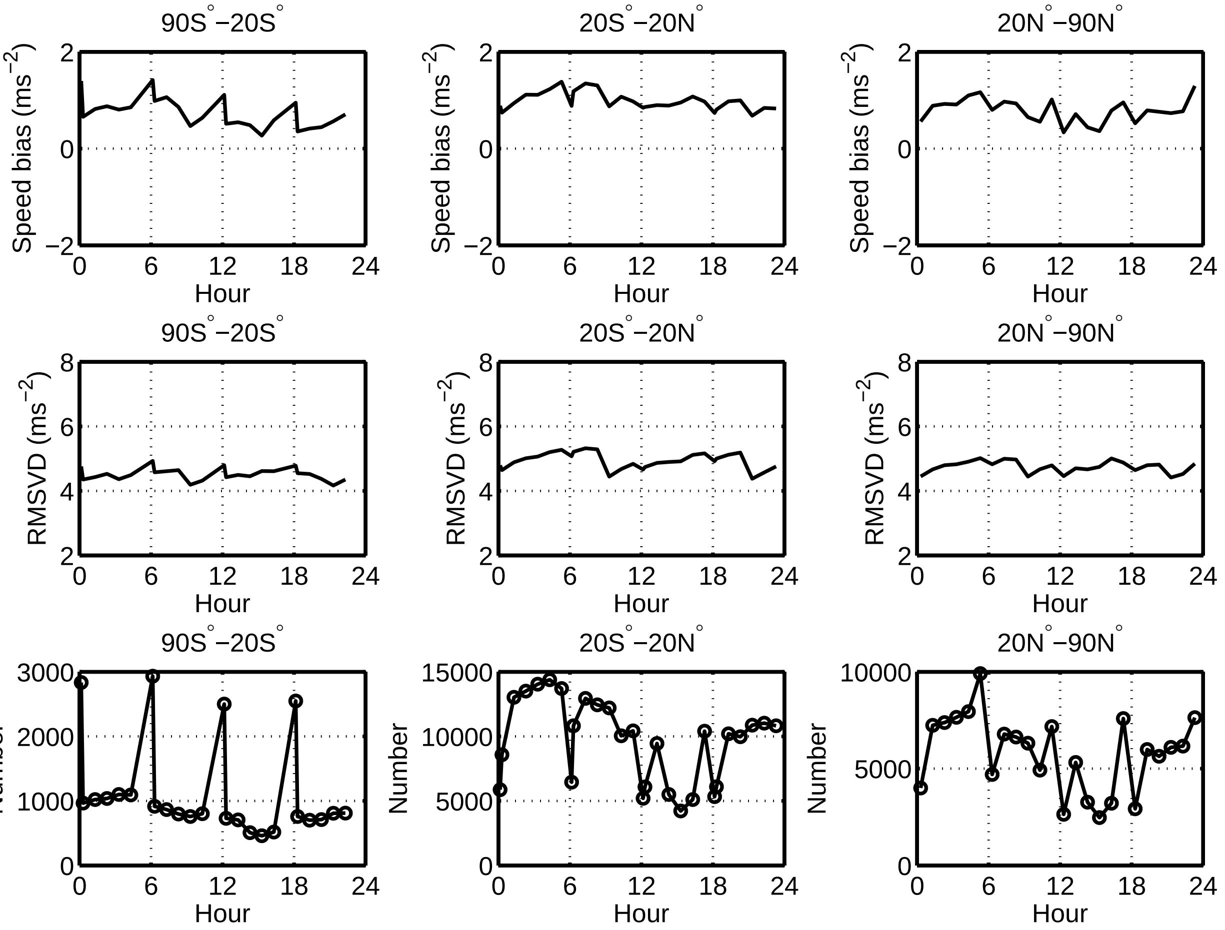

Figure 2: Wind speed bias (top), RMS error for the vector wind difference (middle), and number of available AMVs (bottom) for used WV AMVs between 100 and 400 hPa as a function of the hour of the day. Considered period is September 2011.

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 MTSAT-2 AMVs is varied. The following experiments have been performed:

- Control: No AMVs from MTSAT-2 used.
- Experiment 1: 6-hourly MTSAT-2 AMVs used (00, 06, 12, 18).
- Experiment 2: 3-hourly MTSAT-2 AMVs used (00, 03, 06, 09, 12, 15, 18, 21).
- Experiment 3: 1-hourly MTSAT-2 AMVs used.

Figure 3 shows the OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) as a function of height for *u* component of the radiosonde wind observations at the MTSAT-2 data coverage area. Black lines indicate the control experiment, and red lines experiment with 1-hourly MTSAT-2 AMVs. The standard deviation is decreased for the experiment with 1-hourly MTSAT-2 AMVs compared to the control experiment. This indicates that the observations fit better the model background when MTSAT-2

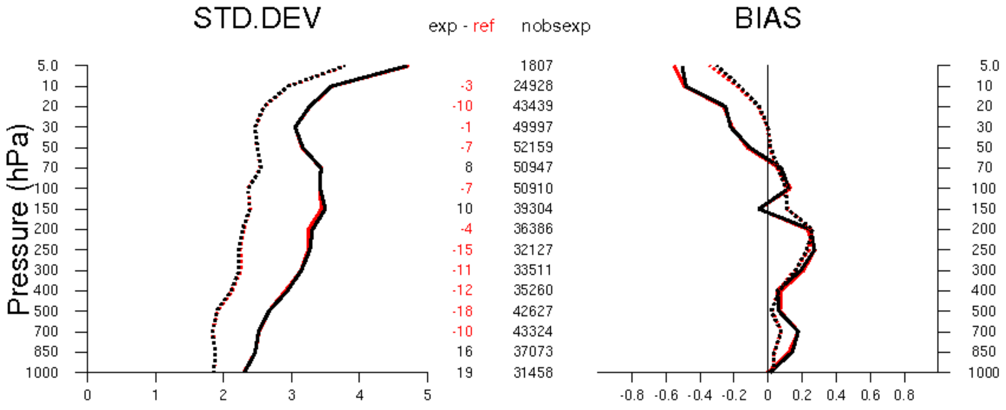

Figure 3: OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for radiosonde wind observation u-component at the MTSAT-2 data coverage area. Control run is indicated with black, and the experiment with 1-hourly MTSAT-2 AMVs is indicated with red.

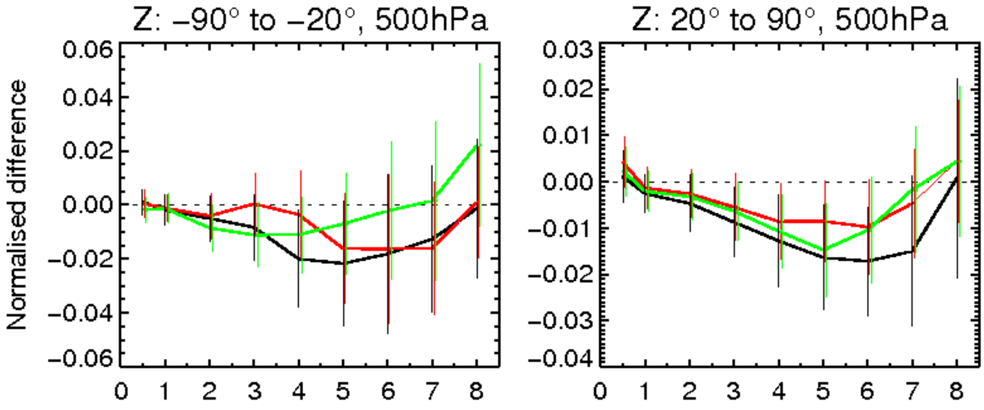

Figure 4: Normalised RMS difference (experiment - control) in 500 hPa geopotential as a function of forecast range (days). Black line indicates the experiment with 1-hourly, red line 3-hourly, and green line 6-hourly MTSAT-2 AMVs, respectively.

AMVs are used. Changes in the bias are small. Similar improvements in the observation fit statistics can be seen in all experiments, and also outside the MTSAT-2 data coverage area. However, largest improvements are found when the 1-hourly MTSAT-2 AMVs are used.

The impact of using MTSAT-2 AMVs on forecasts has been investigated by verifying the experiments against their own analysis, and against the operational ECMWF analysis. Figure 4 shows the normalised RMS difference between the experiments and the control for 500 hPa geopotential. In Fig. 4 the verification has been done against the own analysis. The error bars indicate 95% confidence intervals. In general, the normalised RMS scores indicate that the use of MTSAT-2 AMVs has a positive impact on the 500 hPa geopotential forecasts, and that the impact is statistically significant. The largest positive impact is seen for the experiment utilising 1-hourly MTSAT-2 AMVs. Similar impacts can be seen on other levels as well. Verification against the operational ECMWF analysis support these conclusions.

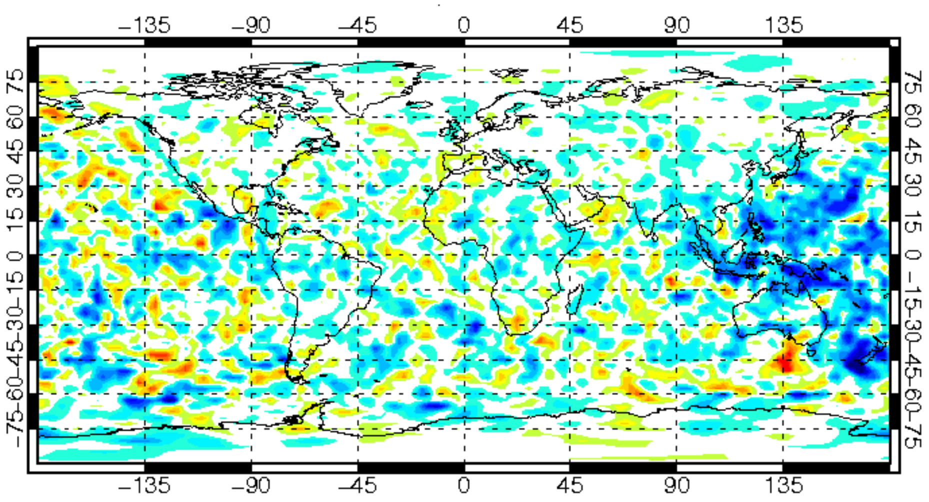

Figure 5: Normalised difference (experiment - control) in RMS error for 48-hour wind forecasts at 200 hPa level

Figure 5 shows the normalised difference in the RMS error for 48-hour wind forecasts at 200 hPa level verified against the own analysis. The difference is calculated as experiment minus control. Thus, blue shades indicate positive impact and green and red shades negative impact from using the 1-hourly MTSAT-2 AMVs in the model analysis. A positive impact is seen especially at the MTSAT-2 data coverage area. Improvements can be seen also on other levels, and forecast ranges.

2.4 Actions taken

Passive monitoring of the 1-hourly disseminated MTSAT-2 AMVs has indicated that the quality of the new MTSAT-2 AMVs is similar to the old ones. Data assimilation experiments show positive impact. Based on the monitoring statistics and the results obtained from the impact studies, use of 1-hourly MTSAT-2 AMVs has been activated on 23rd August 2011 in the operational ECMWF system.

3 Motivation and background: situation dependence in the AMV observation errors

A good forecast requires that the initial state of the atmosphere is known accurately, and that the NWP model is a realistic representation of the atmosphere. Data assimilation methods are used to produce initial conditions for NWP models. The NWP model background field, typically a short-range forecast, is updated with observations in a statistically optimal way. A correct specification of background and observation errors, and error correlations is essential as they determine to what extent the model background field is corrected to fit the observations.

One of the largest error sources for AMVs is the height assignment of the tracers (e.g. Nieman et al., 1993; Jung et al., 2010). Several height assignment methods are in operational use. Each of them have their own assumptions and error characteristics. The magnitude of the AMV observation error due to error in the height assignment is highly situation dependent. It can be very significant in regions where wind shear is strong, but is less relevant in areas where there is not much variation in wind speed with height. Another important source of error for AMVs is the tracking error, i.e. errors in the wind vector derivation. Currently, the observation errors applied in the operational ECMWF system for AMVs vary only with height. Thus, observation errors are independent of satellite, channel, and height assignment method as well as the prevailing atmospheric conditions.

There are two main approaches to take into account the situation dependence in the AMV observations errors discussed in the literature. The statistically-based expected error (EE; Le Marshall et al., 2004) estimates the total error in each AMV based on regressions between AMV and radiosonde wind observation differences, and a set of predictors, including the vertical wind shear, a temperature lapse rate, and the components of the forecast-dependent quality indicator. The Forsythe and Saunders (2008a) approach is more physically-based, and aims to identify and quantify the error sources in the AMV observations. The main focus in this work has been on the latter approach.

The Forsythe and Saunders (2008a) approach devides the AMV observation error into two parts, one originating from the AMV tracking and one originating from the error in the height assignment.

$$[\text{total u/v error}]^2 = [\text{Tracking error in u/v}]^2 + [\text{Error in u/v due to error in height assignment}]^2 \tag{1}$$

The advantage of the approach is that it allows to down-weight observations in regions with high vertical wind shear where errors in height assignment are problematic, and give greater weight for observations on regions where the height assignment error is less critical. Other errors may also contribute to the total AMV observation error, e.g. errors of representativeness, but these are not explicitly modelled here.

In this work, the height errors are estimated based on model best-fit pressure statistics. The model best-fit pressure is defined as the height where the vector difference between the observed and the model background wind is the smallest. Another option would be to use producer provided estimates for the height errors. However, these are not yet operationally available. The height error estimate, E_p, is converted to a wind error due to the error in height using equations 2 and 3 in each case (Forsythe and Saunders, 2008a)

$$E_{vp} = \frac{\sqrt{\sum W_i (v_i - v_n)^2}}{\sum W_i}, \tag{2}$$

where

$$W_i = \exp\left(-\frac{(p_i - p_n)^2}{2E_p^2}\right) * dP_i. \tag{3}$$

In equations 2 and 3 i is the model level, v_i is the wind component on model level i, v_n is the wind component at the observation location, p_i is the pressure on model level i, p_n is the pressure assigned to the AMV, and dP_i is the layer thickness. The formulation assumes a Gaussian distribution of height error, and E_p defines the width of the weighting function. In the ECMWF implementation, an upper limit for the weighting function is set to the height of the model tropopause. It is assumed that there are no clouds or water vapour features suitable for AMV tracking above that height.

The following sections document the work done so far towards using situation dependent observation errors for AMVs in the ECMWF system.

4 Best-fit pressure comparison study for Met Office and ECMWF systems

In order to get an impression of the usability of the model best-fit pressure in characterising the height assignment error, the best-fit pressure statistics have been compared from the Met Office and ECMWF global assimilation systems. The statistics have been calculated for February - March 2010. The data has been filtered

Table 3: Satellite, channel and height assignment method combinations studied for February – March 2010. Unknown height assignment means that the information is not provided in the disseminated data.

Satellite	Channel	Height assignment methods
Meteosat-7	IR	unknown
	VIS	unknown
	Cloudy WV	unknown
Meteosat-9	IR 10.8	CO2 slicing, H_2O intercept, EBBT
	HRVIS	CO2 slicing, EBBT
	VIS 0.8	CO2 slicing, EBBT
	Cloudy WV 6.2	CO2 slicing, H_2O intercept, EBBT
	Cloudy WV 7.3	CO2 slicing, H_2O intercept, EBBT
MTSAT-1R	IR	H_2O intercept, EBBT
	VIS	EBBT
	Cloudy WV	H_2O intercept
GOES-11	IR 10.7	H_2O intercept, EBBT, cloud base
	IR 3.8	EBBT, cloud base
	VIS	EBBT, cloud base
	Cloudy WV	H_2O intercept, EBBT
GOES-12	IR 10.7	CO2 slicing, H_2O intercept, EBBT, cloud base
	IR 3.8	EBBT, cloud base
	VIS	EBBT, cloud base
	Cloudy WV	CO2 slicing, H_2O intercept, EBBT
TERRA	IR	H_2O intercept, EBBT, cloud base
	Cloudy WV	H_2O intercept, EBBT
	Clear Sky WV	EBBT
AQUA	IR	H_2O intercept, EBBT, cloud base
	Cloudy WV	H_2O intercept, EBBT
	Clear Sky WV	EBBT

applying a QI threshold of 80% to all geostationary AMVs and a QI threshold of 60% to all polar AMVs. The QI used is the EUMETSAT quality indicator without first guess check. The best-fit pressure statistics have been considered separately according to satellite, channel, height assignment method, and surface type (land/sea). Table 3 summarises the data sets. The total amount of AMV observations fullfilling the QI criteria for the studied period is ca. 37 000 000.

4.1 Commonly used height assignment methods and their typical error characteristics

Most commonly used height assignment methods are the equivalent black-body temperature (EBBT), carbon dioxide (CO_2) slicing, water vapour (H_2O) intercept, and cloud base techniques (Jung et al., 2010). AMV observations utilising these height assignment methods have been used also in this study.

The EBBT technique is based on comparing measured brightness temperatures to forecast temperature profiles. The level of best agreement is chosen for the observation height. The method works best for opaque clouds. For semitransparent and small clouds the method will assign the observation too low in the atmosphere (Nieman et al., 1993).

The CO_2 slicing technique (Menzel et al., 1983) combines IR longwave-window channel data with CO_2 absorption channel data to specify a cloud height. The height is determined from the ratio of the difference between the true cloud affected radiance and the estimate of the cloud-free radiance for the two different spectral channels. The method fails when the difference between the observed and clear radiances is less than the instrument noise in any of the channels. Typical situations are e.g. low broken clouds, or thin cirrus clouds. The method has also difficulties in situations where clouds are in two or more layers. In this case the CO_2 slicing technique assigns the observation height somewhere in between the cloud layers.

The H_2O intercept technique (Szejwach, 1982) is based on the fact that radiances in the WV channel observing a single cloud layer vary nearly linearly with the radiances from IR channel as a function of cloud amount in a field of view. The radiance measurements are used together with radiative transfer calculations for both spectral channels. The intersection of the measured and calculated radiances will occur at clear sky and opaque cloud radiances. The cloud height is extracted from the cloud radiance intersection. The WV radiances originate primarily from the upper troposphere, thus the height determinations below 600 hPa height are typically rejected.

In the cloud base height assignment method a histogram of the brightness temperatures is derived in the target area (Le Marshall et al., 1994). The cloud base temperature is estimated using Hermite polynomials fitted to the histograms. The obtained cloud base temperature is then compared with forecasted temperature to determine the cloud base height. The cloud base height assignment method is used for low level clouds only.

4.2 Characteristics of the model best-fit pressure calculation

The calculation of model best-fit pressure consists of two steps. First the model level with the smallest vector difference between the observation and the model background wind is found. Second, the true minimum is calculated by using a parabolic fit to the vector difference for this model level and the two neighbouring levels. The model best-fit pressure is calculated only if the following criteria are fulfilled:

1. The vector difference between the observed and the model background wind is less than 4 ms^{-1}.
2. The vector difference is greater than the minimum difference +2 ms^{-1} outside of the $\pm$100 hPa from the best-fit pressure.

The former criterion is designed to exclude cases where there is no good agreement between the AMV wind observation and the model wind at any level. The latter criterion excludes cases where there is a secondary, or a very broad minimum. Both ECMWF and Met Office systems use a similar approach to calculate the model best-fit pressure. A minor difference in the calculation is that in the ECMWF approach the minimum closest to the assigned observation height is chosen, whereas in the Met Office approach the actual minimum is chosen.

Figure 6 shows examples of vector wind difference profiles and the model best-fit pressure calculation. The left panel of Fig. 6 illustrates a case where the model best-fit pressure is calculated. The originally assigned observation height is 260 hPa (dashed line) and the model best-fit pressure is 160 hPa (solid line) where there is a clear minimum in the vector wind difference profile. The middle panel of Fig. 6 illustrates a case where the vector difference is greater than 4 ms^{-1} at all heights. The originally assigned observation height is 850 hPa. There is a minimum in the vector difference profile at the observation height but as the minimum is 5.9 ms^{-1}, it is considered that there is no good agreement between the observed and the model background wind and the best-fit pressure is not calculated. Finally, the right panel of Fig. 6 gives an example of a case where there is a broad minimum in the vector difference profile. Thus, criteria 2 is not fulfilled and the best-fit pressure is not calculated.

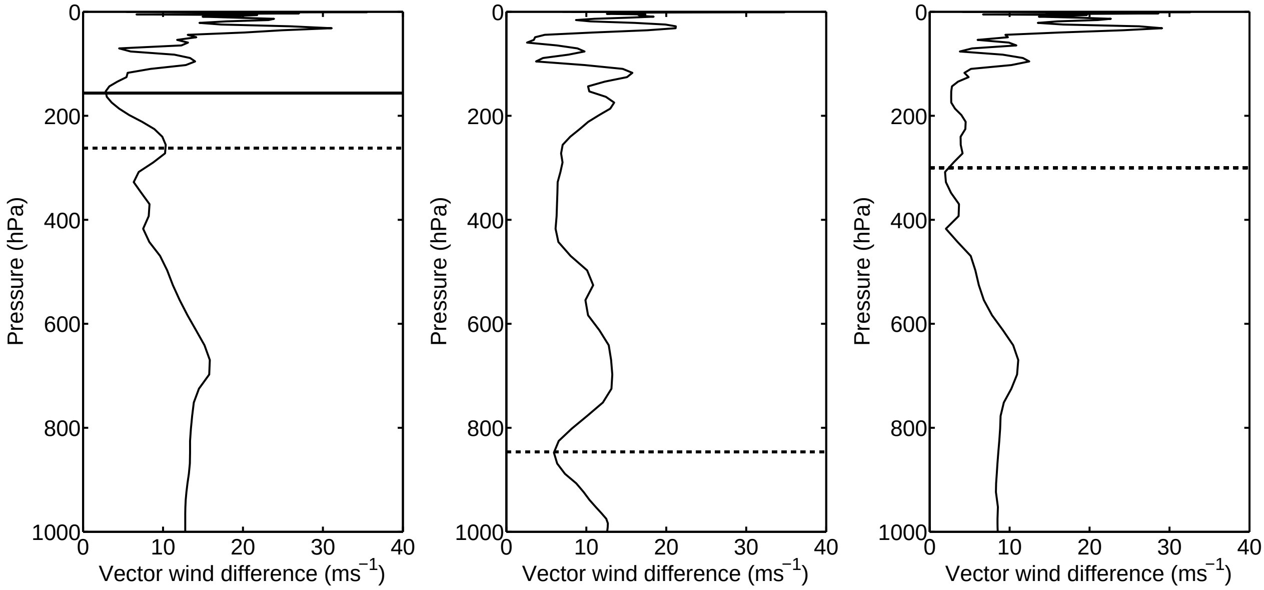

Figure 6: Examples of vector wind difference profiles as a function of pressure. Criteria for best-fit pressure calculation fulfilled (left panel), vector wind difference greater than 4 ms^{-1} (middle panel), and broad minimum (right panel). Dashed horizontal line indicates the observation height, and solid horizontal line the calculated model best-fit pressure.

An interesting question is how often the model best-fit pressure is actually calculated. The following results are based on the ECMWF experiments only but similar results have been obtained at Met Office. Figure 7 shows the percentage of the cases where the best-fit pressure is calculated (black bars), is not calculated because criteria 1 is not fulfilled (grey bars), and is not calculated bacause criteria 2 is not fulfilled (white bars). The grey line shows the number of cases in each latitude band. The best-fit pressure is calculated in 25 – 30% of the cases. In ca. 7% of the cases there is no good agreement between the observed and the model background wind, i.e. criteria 1 is not fulfilled, and in 63–68% of the cases there are multiple or a broad minima, i.e. criteria 2 is not fulfilled.

4.3 Comparison of best-fit pressure statistics

In this section, some remarks are made on the behaviour of the best-fit pressure statistics, and on similarities and differences between the ECMWF and Met Office systems. Comparisons are done in terms of mean difference (bias) and standard deviation of the assigned observation height minus model best-fit pressure. All comparison figures can be found from

`http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/investigations/bfpress/10_03/intro.html`

Geostationary AMVs

The three most commonly used height assignment methods in the studied data sets have been CO_2 slicing, H_2O intercept, and EBBT height assignment. In the following the results are discussed according to this categorization.

Figure 8 shows the zonal plots of the bias (upper panels) and standard deviation (lower panels) for Meteosat-

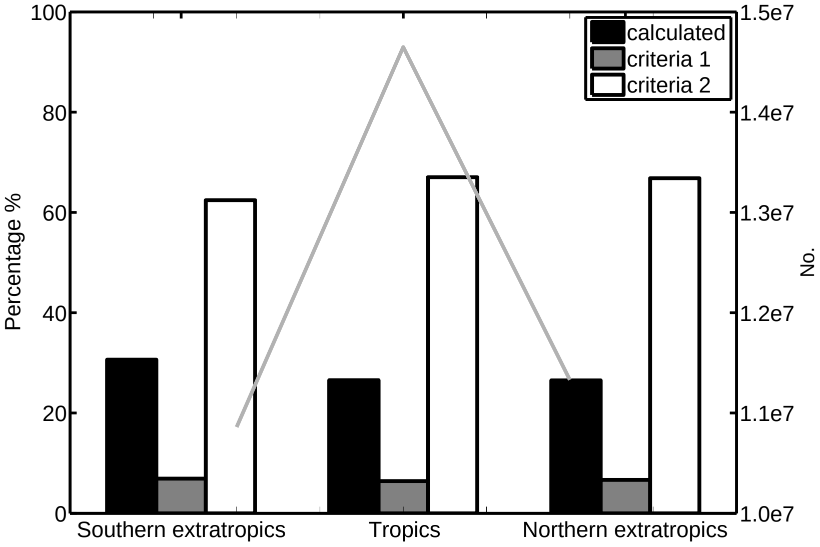

Figure 7: Percentage of the cases where the best-fit pressure is calculated (black bars), is not calculated because there is no good agreement between the observed and backgound wind (grey bars), and is not calculated bacause there is a second or a broad minima (white bars). The grey line shows the number of cases in each latitude band (right y-axis).

9 IR channel AMVs utilising the CO_2 slicing height assignment over sea for Met Office (left panel) and for ECMWF (right panel). The bias is small above 400 hPa height and between 50°S and 50°N, except in the tropics below 200 hPa height where some positive bias is found. At lower levels, and polewards significant negative bias is seen. Thus, in these areas the assigned observation height is higher in the atmosphere than the model best-fit pressure. In terms of standard deviation the pattern is similar. The standard deviation is low above 400 hPa height and between 50°S and 50°N but increases for lower levels and polewards. The ECMWF statistics show somewhat larger standard deviation at mid levels than the Met Office statistics. Similar behaviour of the statistics is seen for WV channel AMVs (not shown). However, the WV channel AMVs have larger positive bias in the tropics below 300 hPa than the AMVs derived from the IR channel.

AMVs applying the CO_2 slicing height assignment are available also from GOES-12. In general the statistics look rather similar to the Meteosat-9 statistics, i.e. there is an increase in the bias and standard deviation below 400 hPa. However, the magnitude of the bias as well as standard deviation tends to be slightly smaller than in the corresponding Meteosat-9 statistics. Also for GOES-12, the ECMWF statistics show increased variation at mid levels compared to the Met Office statistics.

The Meteosat and GOES AMVs applying the H_2O intercept height assignment technique share very similar characteristics in the statistics as the AMVs applying the CO_2 slicing height assignment. However, the overall agreement is slightly worse. The assigned observation height and the best-fit pressure agree generally well above ca. 300 hPa height and between 30°S and 30°N, but increase in the bias as well as standard deviation is seen at lower levels and polewards. The bias polewards of 30°S and 30°N is typically negative indicating that the assigned observation height is higher in the atmosphere than the model best-fit pressure. For AMVs from Meteosat-9 IR channel the statistics are worse over sea than over land in the midlatitudes. In general, the statistics are slightly better for the GOES AMVs than for the Meteosat AMVs.

The best-fit pressure statistics for AMVs from the MTSAT-1R assigned with the H_2O intercept method are somewhat different compared to statistics for the Meteosat and GOES AMVs (Fig. 9). The statistics show good agreement between the assigned and the best-fit pressure above ca. 300 hPa height also for MTSAT-1R

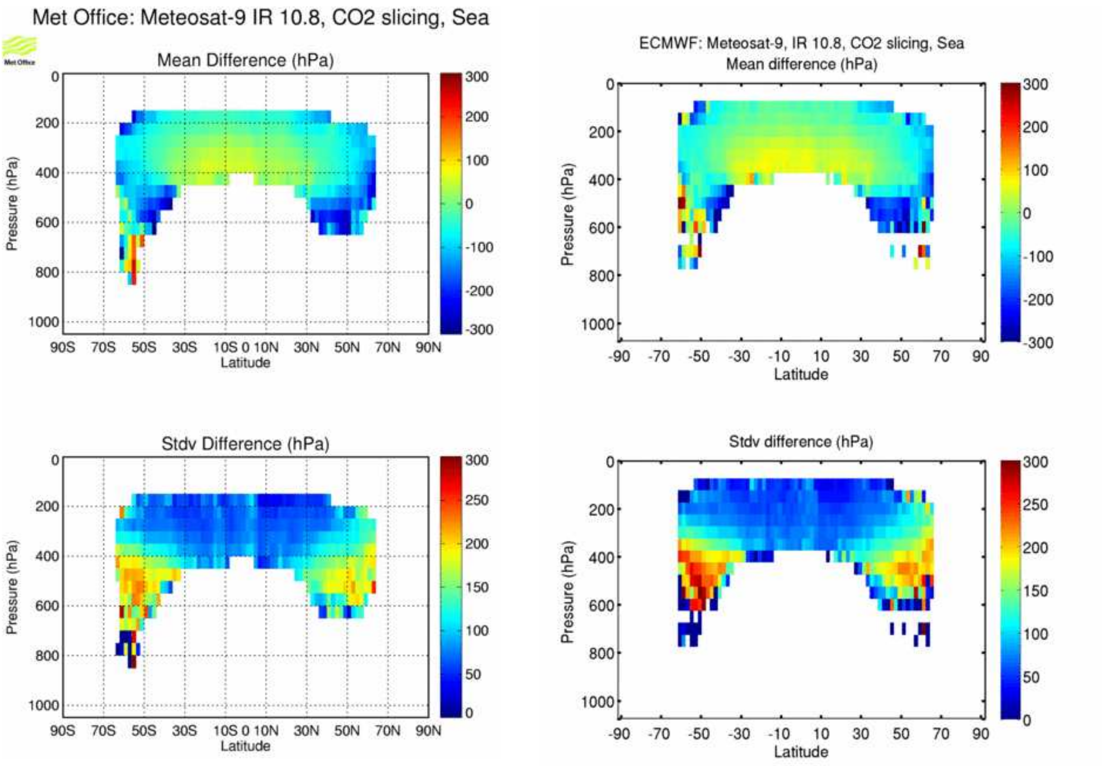

Figure 8: Zonal plots of the mean difference (upper panels) and standard deviation (lower panels) of assigned observation height minus model best-fit pressure for Meteosat-9 infrared channel AMVs over sea. The utilised height assignment method is CO_2 slicing. Statistics for Met Office system are shown on the left and for the ECMWF system on the right, respectively.

AMVs applying the H_2O intercept height assignment. Below 300 hPa there is an increase in the bias and in the standard deviation but the bias is positive, i.e. the assigned observation height is lower in the atmosphere than the model best-fit pressure. The ECMWF statistics show more significant bias at the mid levels compared to the Met Office statistics for MTSAT-1R AMVs from the IR channel.

The CO_2 slicing and the H_2O intercept height assignment methods are typically applied for AMVs originating above 600 hPa height whereas the EBBT height assignment method is used for AMVs originating from all heights. The general impression is that the agreement with the EBBT assigned observation height and the model best-fit pressure is not as good as for the AMVs applying the CO_2 slicing and the H_2O intercept methods.

Figure 10 shows the zonal statistics for Meteosat-9 IR channel AMVs utilising the EBBT height assignment over land. Below 600 hPa height there is a stong positive bias in the tropics, extending up to 30°S and 30°N. This indicates that the assigned observation height is lower in the atmosphere than the model best-fit pressure. This feature has been reported in detail in the NWP SAF analysis reports (e.g. feature 2.7 in Cotton and Forsythe, 2010). The explanation is that in many cases the height of semi-transparent clouds is assigned too low due to temperature contributions from below the cloud over the hot African land surface. Again, the bias tends to be more pronounced in the ECMWF statistics.

GOES AMVs applying the EBBT height assignment show generally rather good agreement between the assigned observation height and the model best-fit pressure. However, for low level VIS channel AMVs there is a significant negative bias between 800 and 600 hPa over sea (Fig. 11). Also this feature has been addressed in

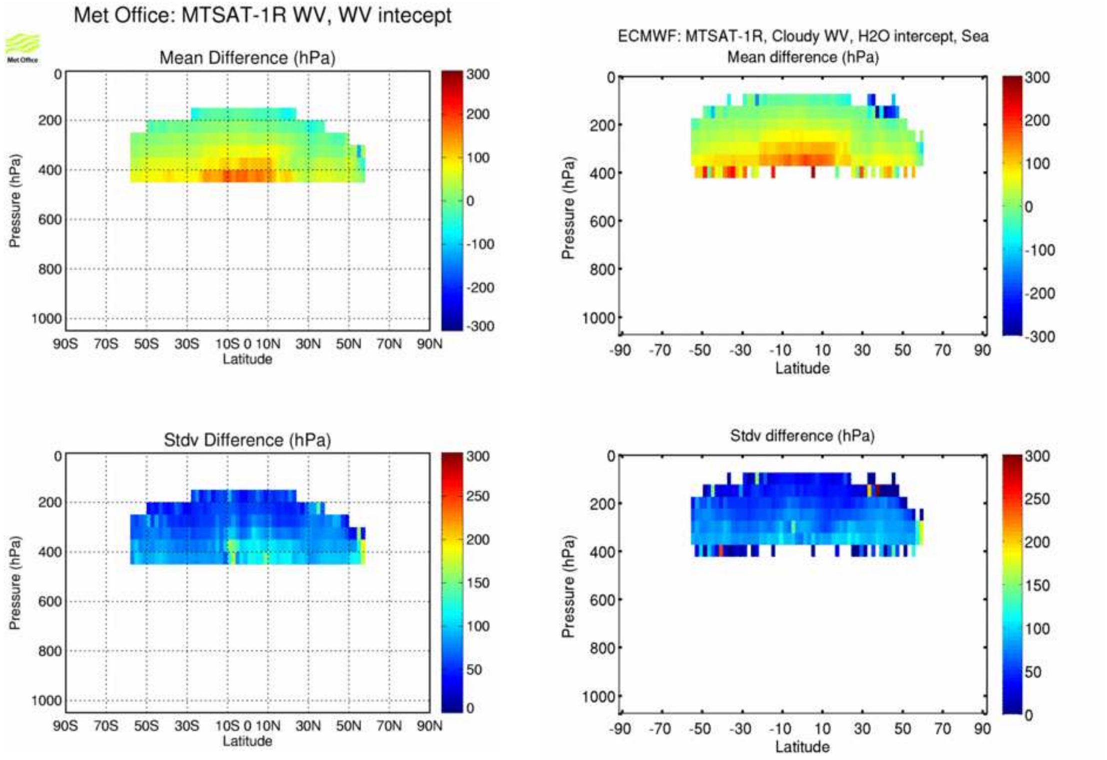

Figure 9: Zonal plots of the mean difference (upper panels) and standard deviation (lower panels) of assigned observation height minus model best-fit pressure for MTSAT-1R WV channel AMVs over sea (for Met Office not defined). The utilised height assignment method is H_2O intercept. Statistics for Met Office system are shown on the left and for the ECMWF system on the right, respectively.

the NWP SAF analysis report (Forsythe and Saunders, 2008b). There are problems in height assignment in the stratocumulus inversion regions of the Pacific and Atlantic, related to the use of forecast profiles with relatively coarse resolution in the vertical.

For MTSAT-1R AMVs applying the EBBT height assignment positive bias is seen at low levels. Compared to other producers, the low level MTSAT-1R AMVs are assigned to a quite narrow band around 950 - 850 hPa, and only relatively few observations are assigned to high levels using the EBBT method.

Polar AMVs

AMVs from Aqua and Terra are available from IR and WV (cloudy and clear sky) channels. In general, the best-fit pressure statistics are rather similar for both ECMWF and Met Office systems.

AMVs applying the H_2O intercept height assignment method originate mainly above 600 hPa height. For IR and cloudy WV AMVs the bias is small both over land and sea. The standard deviation varies mainly between 50 and 150 hPa, and it has a tendency to decrease with increasing height.

For AMVs applying the EBBT or the cloud base height assingment method, the bias and the standard deviation are rather large below 500 hPa height, especially on northern hemisphere (Fig. 12). Again, the ECMWF statistics show more pronounced bias. Above 500 hPa height the best fit pressure statistics indicate much better agreement.

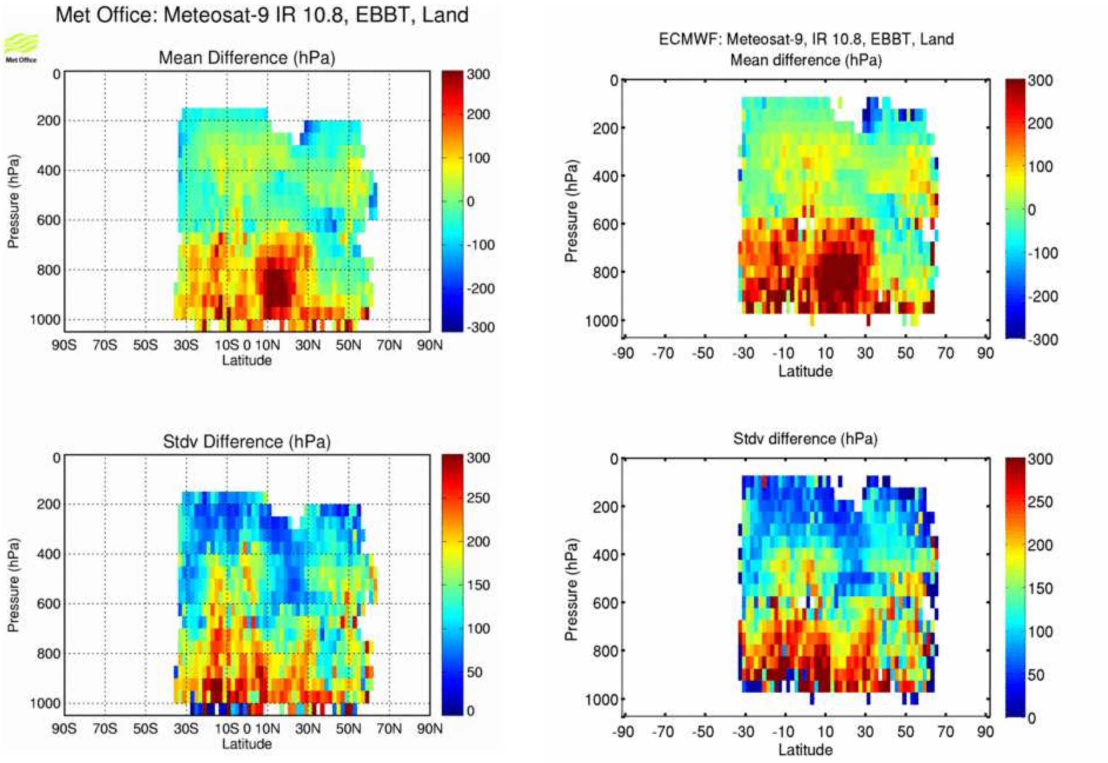

Figure 10: Zonal plots of the mean difference (upper panels) and standard deviation (lower panels) of assigned observation height minus model best-fit pressure for Meteosat-9 IR channel AMVs over land. The utilised height assignment method is EBBT. Statistics for Met Office system are shown on the left and for the ECMWF system on the right, respectively.

4.4 Discussion

A general conclusion from the comparison of the best-fit pressure statistics for ECMWF and Met Office systems is that the statistics are mostly very similar to each other. Some differences are seen e.g. at mid levels where the ECMWF statistics show occasionally more pronounced biases and standard deviations than the Met Office results. The differences in the biases can partially be explained with the different way in which the multiple minima are handled in the best-fit pressure calculation. In the ECMWF system the minimum closest to the assigned observation height is chosen, while the Met Office system chooses the actual minimum in the difference profile. Different producing centers also share many of the same characteristics. The studied data set consists of 37 000 000 AMV observations. Thus, the results and conclusions are based on enormous amount of data even though the best-fit pressure can be calculated only in 25 – 30% of the cases.

The largest systematic differences between the assigned observation height and model best-fit pressure are typically found below 400 hPa height. In most of the cases where the bias is positive, i.e. the assigned observation height is lower in the atmosphere than the model best-fit pressure, the applied height assignment method is EBBT. Earlier studies (e.g. Nieman et al., 1993) have indicated that this height assignment method often assign the observation too low in the atmosphere. The largest negative biases occur for IR channel AMVs appyling either CO_2 slicing or H_2O intercept heigtht assignment methods, and for VIS channel AMVs applying the EBBT height assignment method.

Di Michele et al. (2011) have compared assigned heights for Meteosat-9 AMVs to the cloud top height infor-

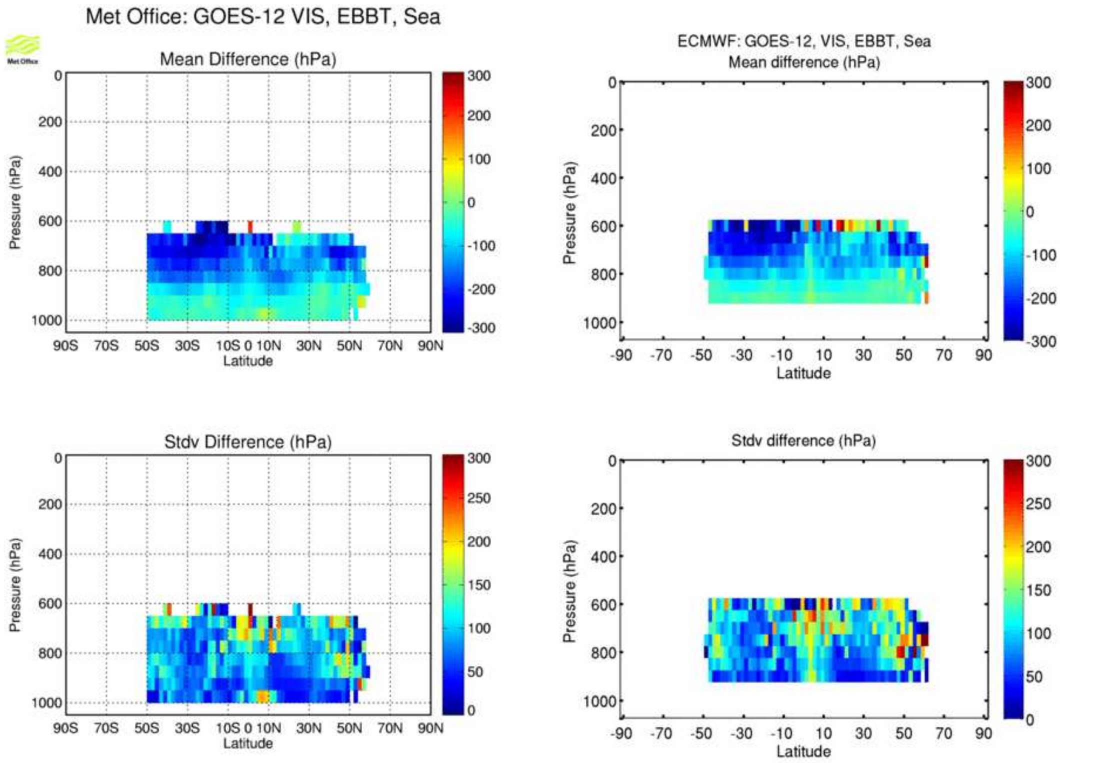

Figure 11: Zonal plots of the mean difference (upper panels) and standard deviation (lower panels) of assigned observation height minus model best-fit pressure for GOES-12 VIS channel AMVs over sea. The utilised height assignment method is EBBT. Statistics for Met Office system are shown on the left and for the ECMWF system on the right, respectively.

mation from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) for a one month period. The results from the best-fit pressure comparison are well in line with the results presented in Di Michele et al. (2011). The magnitude of the the bias and standard deviation are roughly of the same order.

In this study all geostationary AMVs with forecast independent QI over 80, and polar AMVs with QI over 60 have been considered. AMV observations, as well as all other observation types, go through various quality control procedures before they are accepted to be used in the model analysis. Spatial blacklisting is one essential phase of the quality control. Blacklist decisions are based on long term monitoring of the quality of the data. The NWP SAF monitoring reports (e.g. Cotton and Forsythe, 2010; Forsythe and Saunders, 2008a) document the known features of AMV observations.

There are some differences in the ECMWF and Met Office model AMV blacklists but for the most part they are rather similar. Details about the blacklisting decisions for both models can be found from

`http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/amvinfo.html`

Many of the problematic areas seen in the best-fit pressure statistics are actually already excluded in the operationally applied blacklistings. A good example of this is the low level IR and WV polar AMVs. Long term monitoring of these observations has indicated that the quality of the observations is not very good. Thus, at ECMWF all Aqua and Terra WV AMVs over sea are blacklisted below 550 hPa height, and over land below 400 hPa height. IR AMVs are blacklisted below 700 hPa over sea, and below 400 hPa over land. At Met Office all polar WV AMVs are blacklisted below 600 hPa height, and all IR winds are balcklisted below 600 hPa over

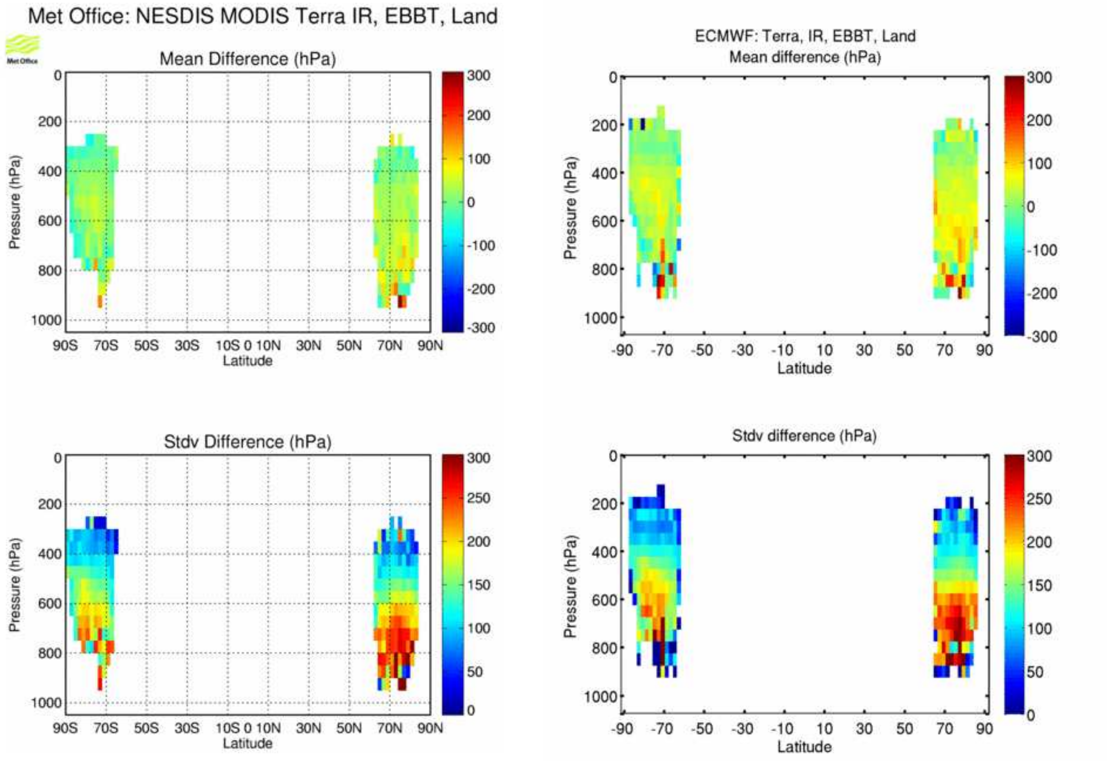

Figure 12: Zonal plots of the mean difference (upper panels) and standard deviation (lower panels) of assigned observation height minus model best-fit pressure for Terra IR channel AMVs over land. The utilised height assignment method is EBBT. Statistics for Met Office system are shown on the left and for the ECMWF system on the right, respectively.

land and sea ice. These blacklisting decisions are in good agreement also with the behaviour of the best-fit pressure statistics.

Based on the obtained results it can be concluded that the best-fit pressure statistics give reliable information about the uncertainties in the AMV observation height assignment. Standard deviations will be used in section 5. Biases could be used to reassign observation heights.

5 Situation dependent observation errors for AMVs in the ECMWF system

This section describes the estimation of situation dependent AMV observation errors for the ECMWF system, compares the new and the old observation errors, and shows some preliminary results from performed impact studies.

5.1 Estimation of the errors

The height errors and tracking errors have been estimated from the model best-fit pressure and OmB statistics for February - March 2010, and May - June 2010. Operationally used QI thresholds, and geographical selection criteria have been applied for the data.

Figure 13 shows the pressure errors as a function of height for Meteosat-9, GOES-11, and MTSAT1-R IR

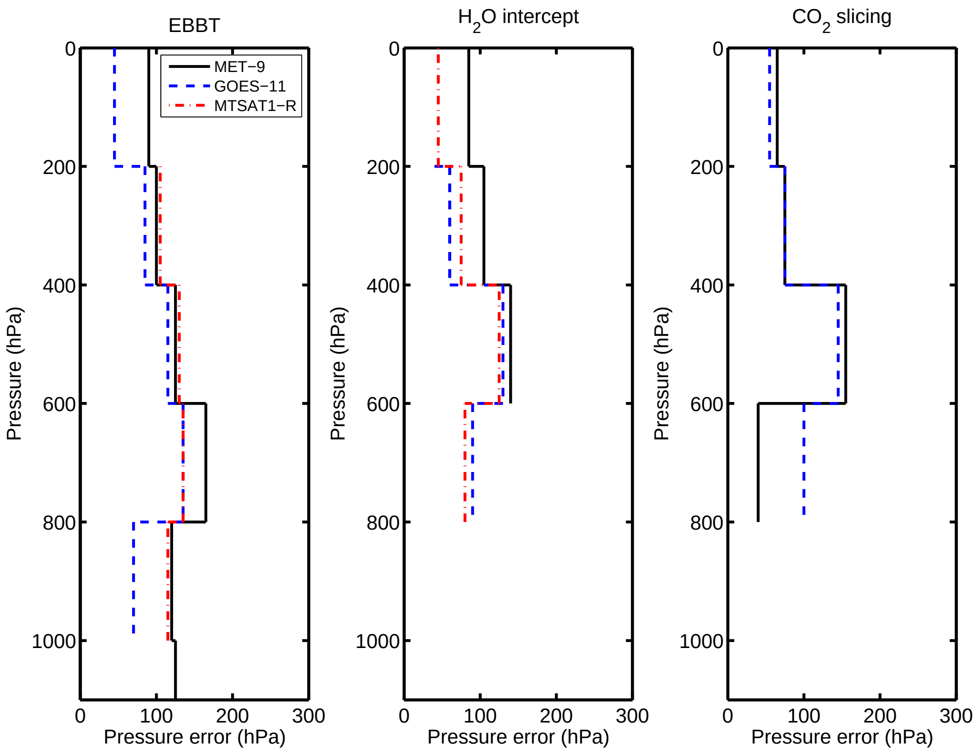

Figure 13: Pressure error estimates based on best-fit pressure statistics for Meteosat-9 (black solid line), GOES-11 (blue dashed line), and MTSAT1-R (red dash dotted line) infrared channel AMVs utilising EBBT (left panel), H_2O intercept (middle panel), and CO_2 slicing (right panel) height assignment methods, respectively.

channel AMVs utilising the EBBT (left panel), the H_2O intercept (middle panel), and the CO_2 slicing (right panel) height assignment methods, respectively, as an example of the results. The statistics have been examined separately for all satellites, channels, and height assignment methods. The height error estimates vary typically between 70 hPa and 120 hPa. The largest height error estimate of 260 hPa was found for GOES-13 cloudy water vapour AMVs at 400 – 600 hPa height, and the smallest height error estimate of 25 hPa for Meteosat-9 visible channel AMVs at 600 – 800 hPa height. A default value of 80 hPa is used, if a pre-defined height error estimate does not exist.

The tracking errors have been estimated from cases where the error due to the error in height is close to zero. Also the tracking errors have been studied separately for all satellites, channels, and height assignment methods but as the differences were relatively small, at the moment the tracking errors are defined separately only for AMVs from geostationary, and polar orbiting satellites. Figure 14 shows the tracking error estimates used for AMVs from geostationary satellites. The tracking error estimates vary between 1.0 ms^{-1} and 2.4 ms^{-1}. A default value of 2.0 ms^{-1} is used if a predefined value does not exist.

Finally, the total observation error for each AMV observation is calculated by combining the tracking error and the wind error due to error in observation height with equation 1.

5.2 Assessment of the new observation errors

In order to evaluate the realism of the new situation dependent observation errors, and to compare the situation dependent observation errors with the currently used AMV observation errors which vary only with height, a

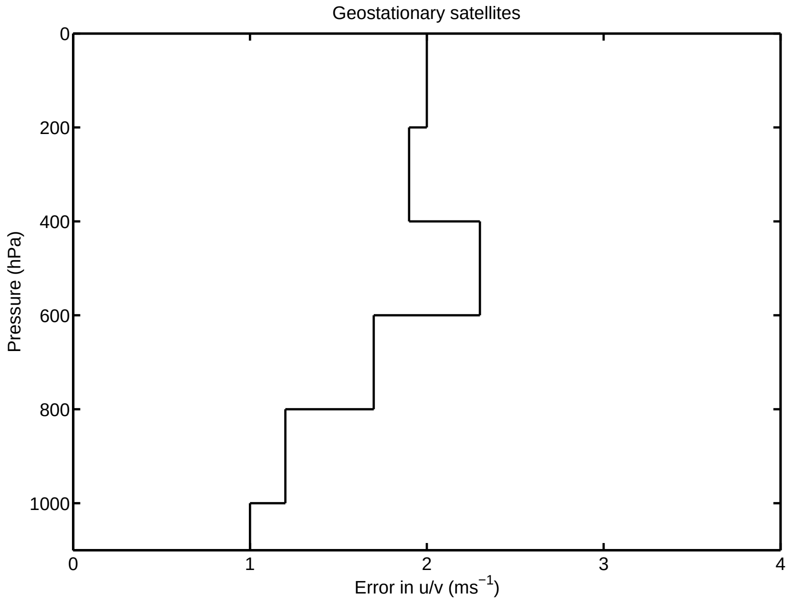

Figure 14: Tracking error estimates for AMVs from geostationary satellites.

two-month (February - March 2010) monitoring experiment has been performed. The results indicate that on average the situation dependent observation errors are of the same magnitude, or slightly larger, than the current observation errors.

Figure 15 shows the observation minus background (OmB) standard deviation as a function of the situation dependent (open circles) and the current (black circles) observation errors for u wind component for Meteosat-9 cloudy water vapour AMVs applying CO2 height assignment method at levels 100 - 400 hPa. The grey histograms show the number of observations. There is a good agreement between the situation dependent observation errors and the OmB standard deviation. In an ideal case the observation errors would lie above the one-to-one line as the OmB standard deviation has a contribution from the background error as well. Thus, Fig. 15 indicates that the new observation errors are slightly overestimated. This behaviour is quite typical for other satellite, channel, and height assignment combinations as well. However, at the moment the spatial and temporal correlations of the AMV observation errors are not taken into account, but only compensated by inflating the observation errors. From that point of view the magnitude of the new observation errors is justified.

Figure 16 displays the mean OmB (upper panel) and the mean observation error (lower panel) for cloudy water vapour AMVs (u component) at levels 100 - 400 hPa at 1st August 2010 12 UTC. Comparison of the panels indicates that when there are significant differences between the observed and model wind speed, also the situation dependent observation errors reach higher values at the same locations. Thus, the behaviour of the new observation errors is consistent with expectations.

5.3 Preliminary results on impact studies

An important part of the evaluation of the situation dependent observation errors is to perform impact studies. The main questions to be answered are:

- What is the impact of using the new observation errors on model analysis and forecasts?

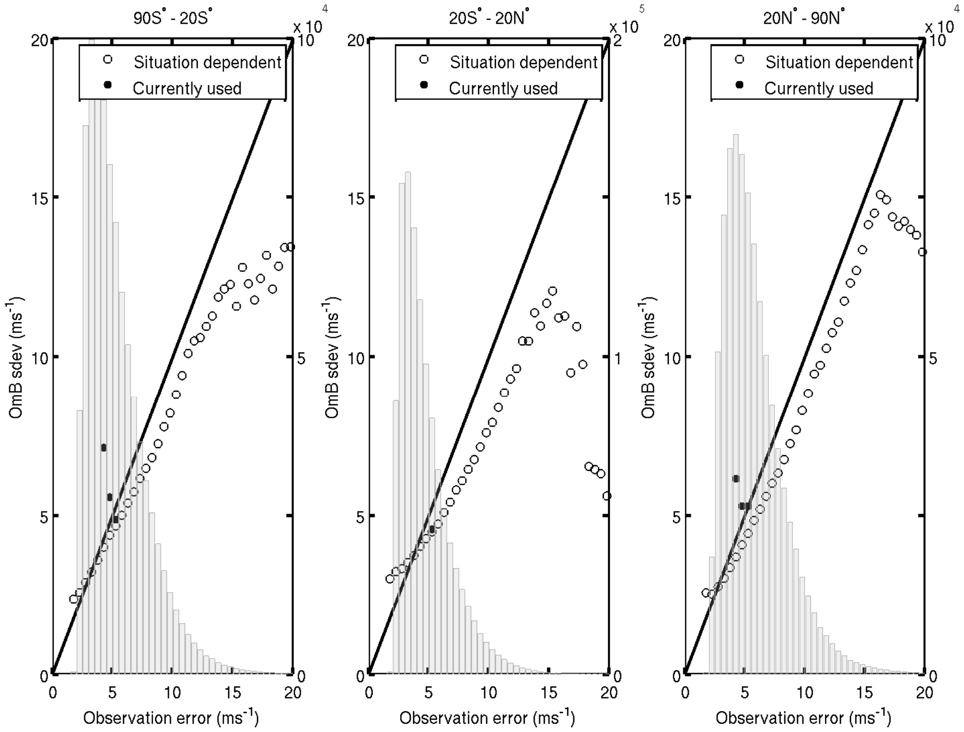

Figure 15: Situation dependent (open circles) and current (black circles) observation errors as a function of OmB standard deviation for southern hemisphere extra tropics (left panel), tropics (middle panel), and northern hemisphere extra tropics (right panel) Meteosat-9 cloudy water vapour AMVs applying CO2 height assignment method at levels 100 - 400 hPa. The grey histograms show the number of observations.

- Does the first guess check need to be modified?
- Can the observation error due to the error in height be used to exclude suspicious observations?

In order to answer these questions, a set of model experiments for July - August 2010 have been performed with the ECMWF Integrated Forecasting System cycle 37r2 at T511 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 situation dependent observation errors are used, and modifications to the first guess check are tested.

The model first guess check compares observations with the model background information. Observations which deviate notably from the background are rejected based on pre-defined criteria. Traditionally the first guess check has been very strict for AMV observations. In the operational ECMWF system tight rejection limits are applied, and the check is assymmetric, i.e. additional penalty is applied to AMV observations that under-report wind speed when compared with first guess field.

The new situation dependent observation errors allow to down-weight observations in areas where wind shear is strong and the error in 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 relaxed. Preliminary results indicate that the assymmetric check can be removed without degradation in the analysis and forecast quality. However, more experimentation and detailed analysis of the results is required before formulating the new rejection criteria and

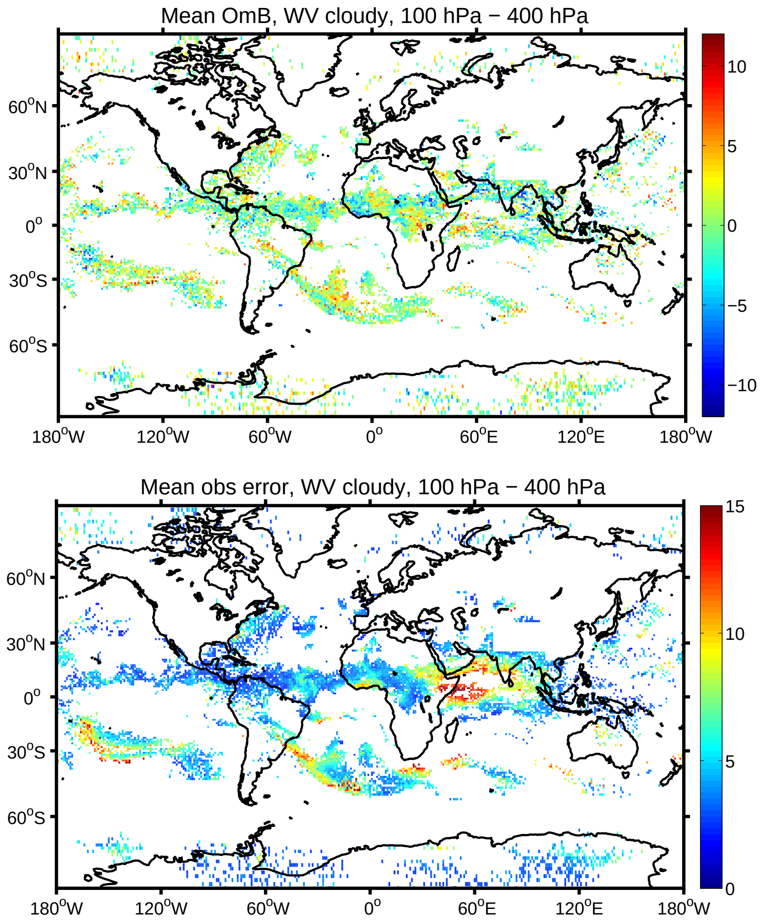

Figure 16: Mean OmB (upper panel), and mean observation error (lower panel) for cloudy water vapour AMV u-component at levels 100-400 hPa, 1st August 2010, 12 UTC.

limits.

Another aspect under investigation is how the observation error due to the error in height could be used to exclude bad quality observations. A first trial has been to limit the magnitude of the observation error due to height error to be smaller than twice the tracking error. 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 17 shows the OmB (solid line) and observation minus analysis (OmA; dashed line) standard deviation (left panel) and bias (right panel) for AMVs at southern hemisphere midlatitudes. The control run is indicated with black, and the experiment utilising the situation dependent observation errors and the above mentioned criteria for the error due to height error is indicated with red. The OmB and OmA standard deviations are clearly decreased for the experiment compared to the control run. This indicates that the applied criteria seem to detect and reject suspicious AMV observations with large departures well. The drawback is that the number of accepted observations is decreased considerably. Changes in the bias are relatively small. Further work is required to determine how best to exclude observation for which the height assignment error is considered too large.

Figure 18 shows normalised difference in RMS error for 24-hour wind forecasts at 700 hPa level verified against its own analysis. The difference is calculated as experiment minus control, thus blue shades indicate a positive impact and green and red shades a negative impact from using the situation dependent observation errors and

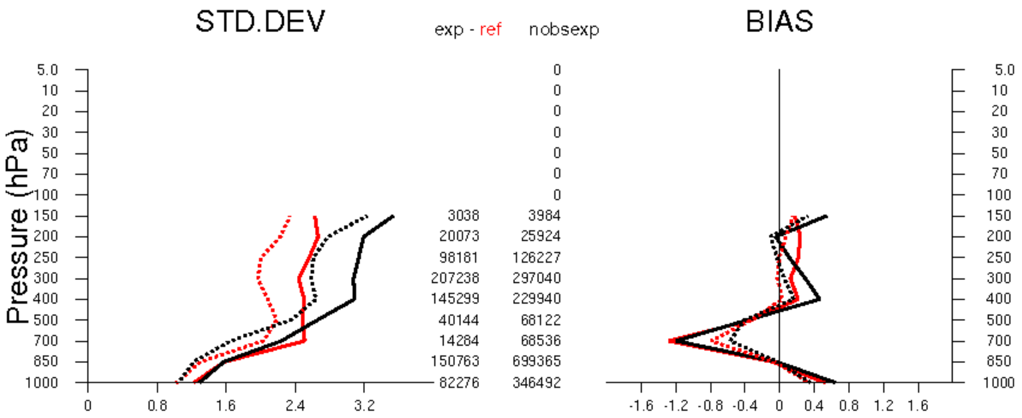

Figure 17: OmB (solid line) and OmA (dashed line) standard deviation (left panel) and bias (right panel) for AMVs at southern hemisphere midlatitudes. Control run is indicated with black, and the experiment is indicated with red.

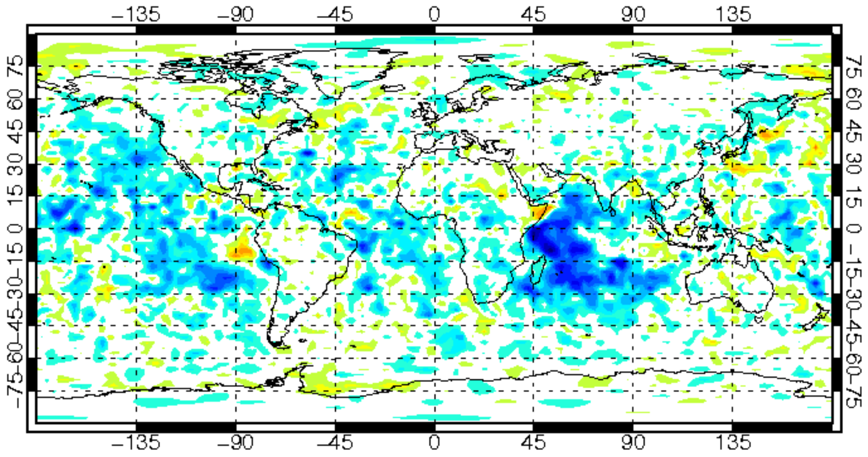

Figure 18: Normalised difference (experiment - control) in RMS error for 24-hour wind forecasts at 700 hPa level.

the limiting criteria for the error due to the height error. The overall impression is that using the situation dependent observation errors, and the limiting criteria have a positive impact on the forecast. Positive impact can be seen for longer forecast ranges, and on other levels as well, except 200 hPa level where more mixed impact is found.

Preliminary results from the impact studies are positive and encouraging but further analysis of the results is still required.

6 Ongoing activities

The work towards using situation dependent AMV observation errors in the ECMWF system continues. As mentioned in the previous section, the preliminary results are encouraging. However, to confirm the realism of the magnitude of the estimated observation errors, to make deliberate decisions how to modify the first guess check, and how to use the error due to error in height assignment as an additional criteria to accept observations, more detailed analysis of the results is required. AMV denial experiment will also be included to the set of experiments to confirm the overall benefits of using AMV observations in the model analysis.

An ongoing work is to contribute to a winds impact study co-ordinated by Met Office and Météo-France in the framework of the International Winds Working Group (IWWG). The aim of the study is to learn more about the impact of satellite-derived wind data on NWP. Two 6-week periods have been chosen. The periods cover the 2010 Atlantic hurricane season, and the 2010-11 northern hemisphere winter season. AMV denial experiments are performed for both of the 6 week periods, and a scatterometer denial experiment to the Atlantic hurricane period.

The next significant change in the operational use of AMVs will be the replacement of GOES-11 with GOES-15 in December 2011. The ECMWF system will be prepared for this change, and the new data will be carefully monitored before operational assimilation of the data.

Acknowledgements

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