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AMV RESEARCH ACTIVITIES AND PROGRESS AT ECMWF

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Abstract

This paper summarises the status of AMV assimilation and research at ECMWF, giving an overview of new data that has been assessed and added since the last workshop. The paper focusses particularly on the activation of Metop AMVs and the assessment of a new height assignment method provided by EUMETSAT.

There has been a long-standing gap in the spatial coverage of Atmospheric Motion Vectors (AMVs) between the geostationary and polar orbiting satellites. The past two years have been rich in new satellites and products which provided the opportunity to close the gap with the use of Advanced Very High Resolution Radiometer (AVHRR) Metop data. Single and dual Metop products derived by EUMETSAT were assessed using first guess departures and assimilation experiments. Data quality for the single product was slightly higher in the Polar Regions and the dual product exhibited large speed biases in the tropics. A combination - single product polewards of 60° and dual product between 40° and 60° - gave positive impacts on the vector wind forecast error in the Polar Regions and neutral changes elsewhere. Operational use began on 4th Feb 2016.

Improving the height assignment and better understanding the associated errors is also an ongoing challenge. Recently, Meteosat-10 AMVs have been distributed with alternative height estimates derived using Optimal Cloud Analysis (OCA). Statistics from first guess departures have been produced using the new technique and compared with the current operational method. Initial results show changes in the AMV distribution and areas of improvement especially in the high level winds such as a reduction in the speed bias of the high level jet off West Africa.

STATUS OF AMV ASSIMILATION AND MONITORING

Several new satellites have been added recently to the ECMWF system with many of these AMVs progressing to operational assimilation. Table 1 gives an overview of the data in use with the newer data indicated. The most recent additions are the replacement of MTSAT-2 AMVs with data from Himawari-8, and the activation of AMVs from the VIIRS instrument on Suomi-NPP. Details on these are given in a separate proceedings paper (see Lean et al., 2016). A key development has been closing the gap in coverage between geostationary and polar AMVs, primarily achieved through the activation of Metop AMV products, and an overview of this is provided in the present paper, with more details available in Salonen and Bormann (2016). On 8th Mar 2016, the use of existing data was updated by relaxing the threshold of accepted zenith angle for the geostationary satellites from 60° to 64° while Meteosat-10 data are no longer rejected in the mid-latitudes from 460-700hPa (Salonen and Bormann, 2016). New products are being monitored routinely, and results from the assessment of INSAT-3D (Salonen and Bormann, 2015) and COMS-1 (Lee et al., 2015) are available in separate reports.

Assessments of AMV product developments are also routinely performed at ECMWF, and here we provide first results of the assessment of a new height assignment method provided with EUMETSAT-derived Meteosat AMVs.

Satellite	Infrared	Cloudy WV	Clear WV	Visible
Meteosat-7	Used	Used	Monitored	Used
Meteosat-10	Used	Used	Monitored	Used
GOES-13	Used	Used	Monitored	Used
GOES-15	Used	Used	Monitored	Used
Himawari-8	Used	Used	-	Used
FY-2E	Monitored	Monitored	Monitored	-
FY-2G	Monitored	Monitored	Monitored	-
INSAT-3D	Monitored	Monitored	Monitored	Monitored
COMS-1	Monitored	Monitored	Monitored	Monitored
AQUA	Used	Used	Used	-
TERRA	Monitored	Monitored	Monitored	-
NOAA-15, -18 and -19	Used	-	-	-
Metop A and B single	Used	-	-	-
Metop A/B dual	Used	-	-	-
S-NPP	Used	-	-	-

***Table 1*: Summary of use of AMV data in ECMWF system at end August 2016. Satellites in italics have been added to operational monitoring or activated in assimilation within the past two years.**

ADDITION OF METOP AMVS

The spatial coverage of the geostationary and polar orbiting satellites has left a long-standing gap of 10-15° in the dynamically active polar jet region. A change in the threshold of accepted zenith angles for the geostationary satellites reduced but could not completely fill the gap. Metop AMV products derived by EUMETSAT have the capability to fill this gap: The Metop single AMV products extend to lower latitudes than other satellites due to their use of image pairs (same satellite, two consecutive orbits) compared to the image triplets (same satellite, three consecutive orbits) traditionally used in tracking the cloud feature. In addition to the single Metop product, EUMETSAT more recently developed a dual Metop product which derives AMVs using image pairs from consecutive overpasses from the different Metop satellites. Due to the use of image pairs, no temporal consistency check using a third image is available for quality controlling the AMVs. However, the time difference between images is reduced to around 50 minutes and allows global coverage from polar orbiting satellites. The combination of these two Metop products gives high density coverage of the gap in AMV data described. The single and dual products were assessed using first guess departure statistics (difference between observation and model background values) and using assimilation experiments to test longer term impacts on the forecast.

Data quality

The quality of the single Metop product has improved significantly in recent years allowing consideration for assimilation (Salonen and Bormann, 2015). With the availability of the dual product with global coverage, the assessment aimed to find the optimal combination of both products. Figure 1 compares the wind speed bias and root mean square vector difference (RMSVD) calculated from first guess departures for the Metop A single AMVs (statistics for Metop B AMVs are very similar) and the dual product. The total number of AMVs is also given (note that there are different scales on the plots). A forecast independent quality indicator (QI) threshold of 60 was applied to the AMVs prior to plotting. As well as the reduced time difference, the dual Metop product can be calculated with either satellite providing the first image. This leads to a substantial increase in the number of the AMVs in addition to the greater coverage compared to the single Metop A AMVs. Towards the Polar Regions, the two products have quite similar data quality although generally values of bias and RMSVD are slightly higher in magnitude for the dual Metop winds. However, in the tropics the dual product exhibits large positive speed biases that extend throughout most of the troposphere.

When considering the dependence of the data quality on the forecast independent QI, there is a decrease in RMSVD for both single and dual winds as the QI value increases. This led to the decision to keep a threshold of 60 for quality control screening as applied to AVHRR instruments on the Metop satellites.

Prior to assimilation, height assignment errors and tracking errors are estimated for use in the situation dependent observation error calculation (Salonen and Bormann, 2013). For both error components, the Metop products showed higher values than both the AVHRR instruments on NOAA and Moderate Resolution Imaging Spectroradiometer (MODIS) on the AQUA satellite. While the Metop products use a different AMV derivation technique to the other polar orbiting instruments, the difference between using image pairs rather than image triplets will be a large contributor to the elevated errors, especially in the tracking.

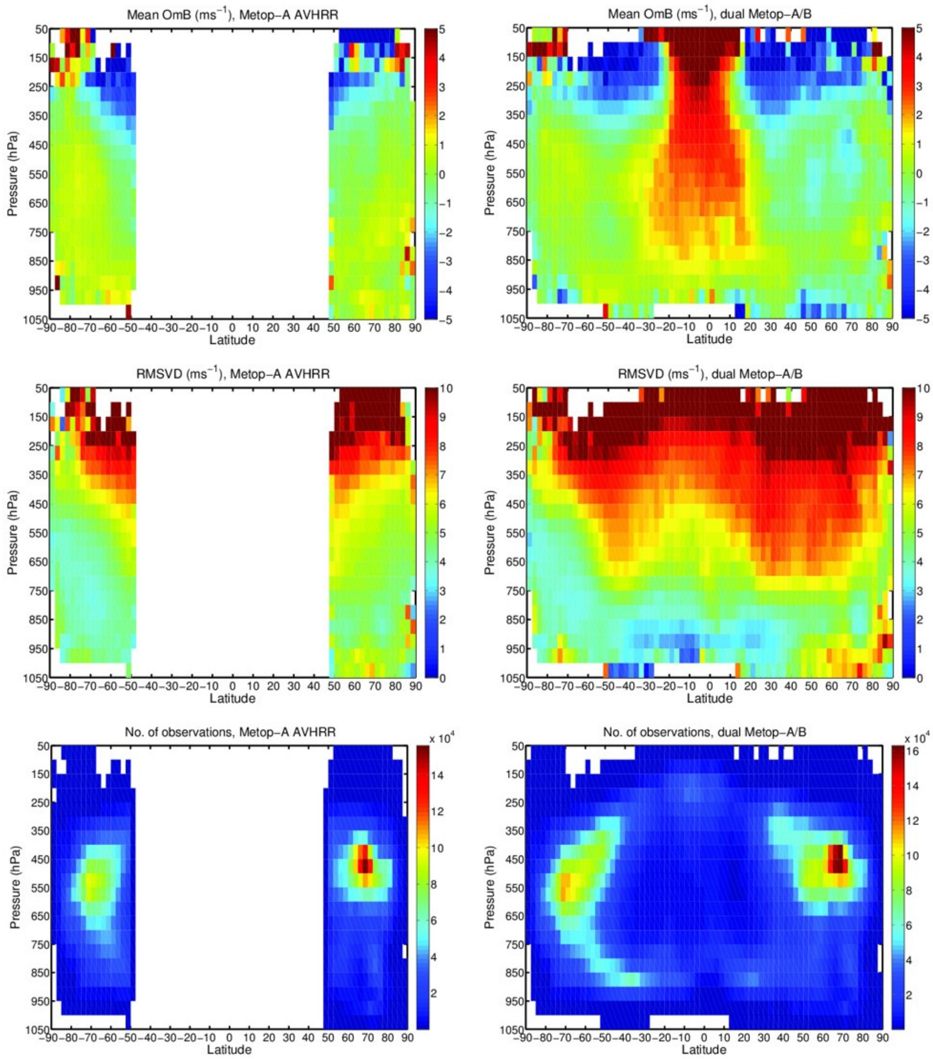

Figure 1: **Zonal plots of the wind speed bias (top row), RMSVD (middle row) and number of observations (bottom) row for the single Metop A product (left column) and dual Metop product (right column) using data from 19th April - 18th May 2015.**

Assimilation experiments

In light of the results from the first guess departure analysis and the potential better quality of the single Metop winds, two assimilation experiments were proposed which would add the data in two ways:

1. Single only: use single Metop product for latitudes greater than 50°
2. Single and dual combination: use single Metop product polewards of 60° and use dual product at latitudes between 40° and 60°.

The test period was over six months (1st Jan - 30th June 2015) with the control experiment a lower resolution version of the operational system. Metop data are then added to this configuration. Blacklisting choices (screening by height, pressure and QI) used across the other polar satellites were applied to the Metop AMVs.

The longer term impact on the forecast was investigated through the verification of each experiment against their respective analyses. Figure 2 shows the reduction in the vector wind error when using the combination of single and dual Metop winds. There is significant improvement in the Polar Regions out to day two of the forecast. Forecast impacts on other atmospheric variables and at longer lead times were more neutral as would be expected for the addition of these polar wind data. Results from using just the single Metop AMVs were similar.

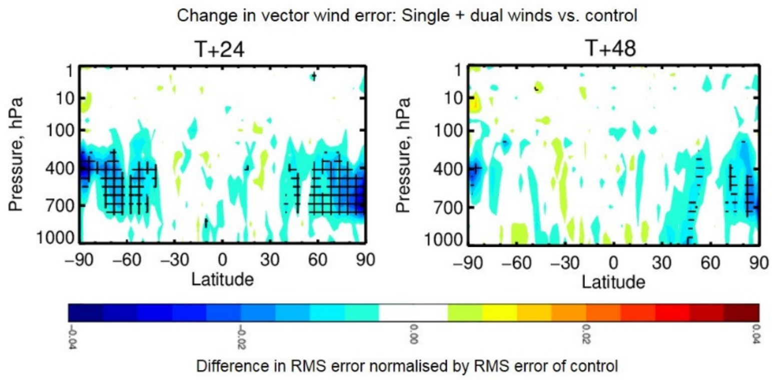

Figure 2: **Zonal plots of normalised change in forecast vector wind error (experiment - control) for forecast lead times of 24 hours (left) and 48 hours (right) with the experiment containing a combination of dual and single Metop winds. Test period 1st Jan - 30th June 2015. Hatching indicates significance at a level of 95%.**

The impact of new observations in assimilation is also measured by the change in fit of independent observations to the model background. For both Metop experiments, neutral effects were seen for the conventional wind and humidity sensitive observations.

Results from both experiments were quite similar however, the inclusion of dual Metop data provides full coverage of the gap between geostationary and polar orbiting satellites and with a higher density of AMVs. Figure 3 illustrates the change in coverage by including the dual and single Metop products along with the increase in allowed zenith angle for the geostationary satellites. A particular benefit is the new presence of AMVs south of the GOES-13 and GOES-15 geostationary satellites over the Americas and Eastern Pacific where the coverage for these satellites does not extend to the full disk. The global total of AMVs increases significantly with this configuration. The combination of dual and single Metop AMVs was operationally assimilated from 4th Feb 2016 and more detailed information about the analysis can be found in Salonen and Bormann (2016).

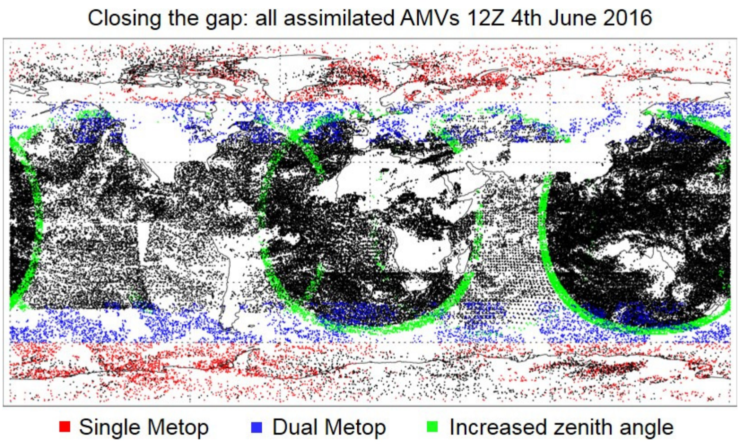

Figure 3: **All AMVs assimilated for one 12 hour cycle on 4th June 2016 showing the typical increase in coverage due to the addition of the single Metop winds (red), dual Metop winds (blue) and extension of zenith angle for geostationary satellites (green).**

OPTIMAL CLOUD ANALYSIS (OCA) HEIGHT ASSIGNMENT

An active area of research is the improvement of the height assignment and understanding the associated errors. The error in the height assignment is recognised as a dominant source of error for the AMVs (e.g. Jung et al., 2010). Research conducted at ECMWF and elsewhere includes also the development of bias corrections for the height assignment (Salonen and Bormann, 2016) although this has not yet led to operational applications of such schemes.

In April 2016, Meteosat-10 data were operationally disseminated from EUMETSAT with an alternative height estimate available. This new assignment method is the OCA product which uses an optimal estimation technique to extract parameters such as cloud top height (Optimal Cloud Analysis: Product Guide, 2016). An important benefit of this method is the ability to detect and treat situations with multi-layer (two layer) cloud. OCA is a potential replacement of the current height assignment schemes (such as CO_2 slicing or the water vapour intercept) which are applied depending on the cloud characteristics (e.g. high or low level). A preliminary assessment of the OCA heights has been made using first guess departure statistics calculated using the new assignment and comparing to the operational method.

First guess departure statistics were generated using data from each method separately for a period of one month (27th April - 26th May 2016). Figure 4 shows an example of the zonal distribution of the AMVs using the infrared channel. Post-processing on the operational product means that there are pressure limits imposed leading to the artificial cut off at low pressure. When using OCA the AMVs are concentrated into a thinner pressure band (indicated by the red arc in the difference plot on the right) with fewer very low pressure AMVs. The lower numbers in the mid-troposphere might be an indication of multi-layer cloud situations where, with the new OCA product, the height is assigned to the top layer rather than between the two. For the low level infrared and visible AMVs differences are smaller with slightly fewer AMVs using OCA.

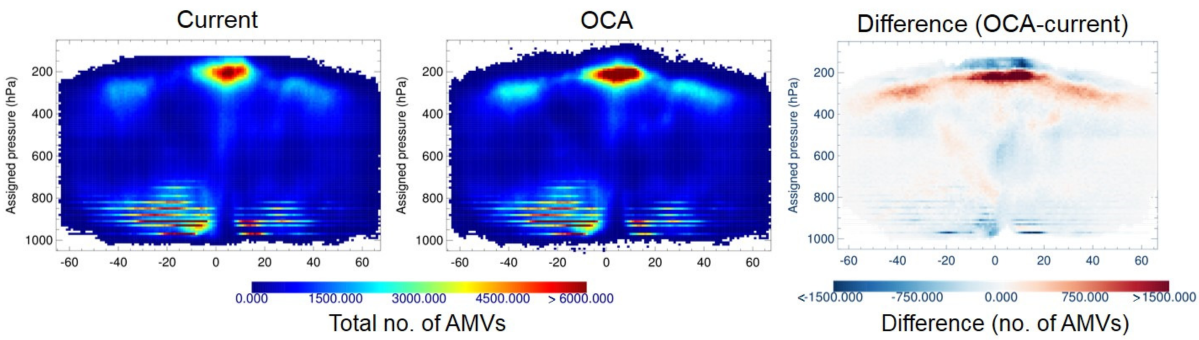

Figure 4: **Zonal plots showing distribution of the total number of Meteosat-10 infrared channel AMVs using the currently operational height assignment (left), new OCA assignment (middle) and the difference between the two (OCA - current) (right). Data from 27th April - 26th May 2016.**

The forecast independent quality indicator is tuned to the AMVs using the operational height assignment. However, the dependence of statistics such as RMSVD are very similar when using OCA. It would be reasonable to screen poorer quality data using a threshold of 85 (as operationally used in ECMWF assimilation) for both products before further comparison. Figure 5 shows the zonal RMSVD using both height assignments and the difference between them. In the region of densest high level AMVs there is a small improvement using the OCA product. Similarly at low levels the change is mostly in favour of OCA. At mid-levels, where there are fewer observations the impact is more mixed with some large, improved areas (around ±20°N and above 500hPa) but also degraded areas mostly between 500-800hPa. The data can also be screened using the first guess departure check (rejecting AMVs too far from the model background wind field). Taking the difference with this alternative quality control retains favourable changes for OCA in the AMV dense areas and gives a less extreme picture at mid-levels (not shown). With the smaller number of AMVs in this region, perhaps statistics over an even longer time period would help give a clearer signal.

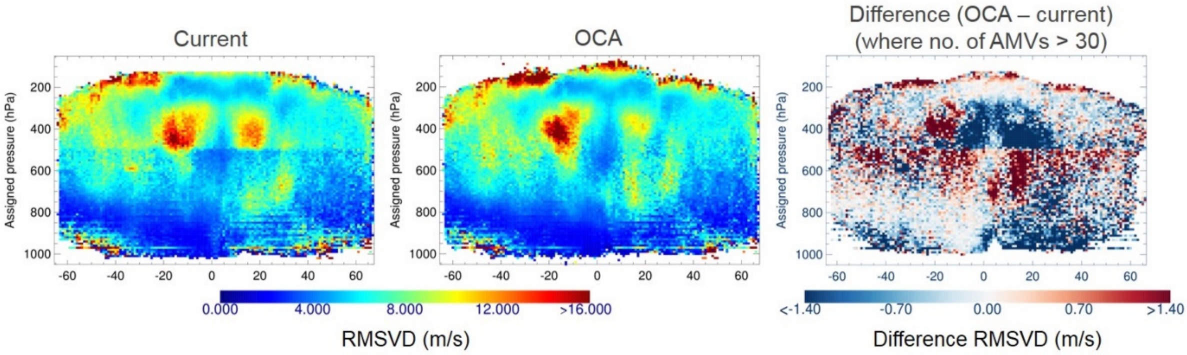

Figure 5: **Zonal plots showing RMSVD of Meteosat-10 infrared channel AMVs using the currently operational height assignment (left), new OCA assignment (middle) and the difference between the two (OCA - current) (right). Data from 27th April - 26th May 2016 with QI > 85.**

More of the faster AMVs are located in the region coinciding with the increase in observation numbers in the OCA product seen in Figure 4. This has led to corresponding changes in the observed - background speed bias which are mostly shifted towards more negative values. In some cases this has resulted in an improvement such as reducing the previously positive bias of the high level jet off the coast of West Africa (Figure 6). However, especially at mid-levels the speed bias in the extra-tropics is now further from zero (more negative) than when using the operational product.

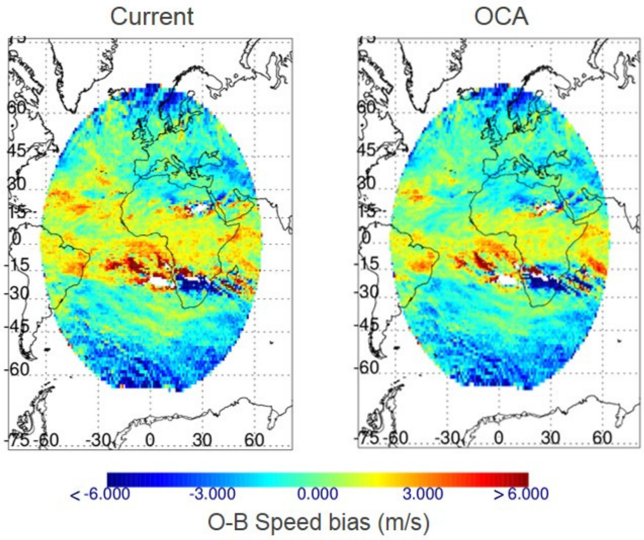

Figure 6: **O-B speed bias for the high level (pressure < 400hPa) winds in the 7.35µm water vapour channel using the currently operational height assignment (left) and OCA (right). Data from 27th April - 26th May 2016 with QI > 85.**

Best-fit pressure statistics can also give important information about the impact of a height assignment change where the AMV assigned pressure is compared with the model pressure that minimises the vector difference between observation and model wind. Figure 7 shows the pressure bias (assigned - best-fit pressure) using the current height assignment, OCA and the difference between the absolute values which indicates whether the value is closer to zero. As a solution for estimating the best-fit pressure reliably cannot always be found, the number of AMVs is slightly lower leading to the gaps in the tropics where there were too few AMVs to calculate the difference. These areas coincide with regions of very high positive pressure biases which are reduced overall in OCA but there are very few AMVs.

Around dense regions of AMVs at high levels the difference in bias is small but generally slightly negative (Figure 7) suggesting that OCA agrees better with the model. At low levels, outside the tropics the pressure biases are quite similar between the two methods. However, at mid-levels (450-800hPa) especially in the southern hemisphere and at low level in the tropics the bias is more negative in the OCA product i.e. compared to the model the AMV pressure is too low and the winds are placed too high in the troposphere. At mid-levels this could be an indication of the two-layer process selecting a level that is too high while issues at low levels in the tropics suggest that the inversion correction is not as effective. For mid-levels this also corresponds with an area of more negative speed bias in the OCA product.

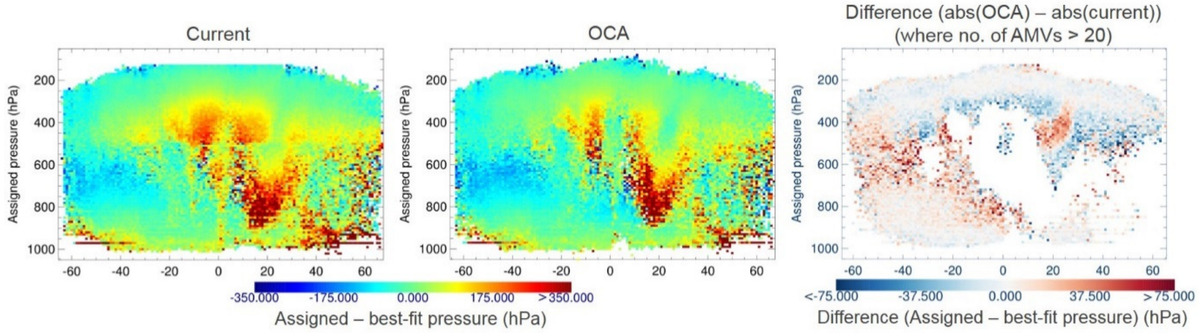

Figure 7: **Zonal plots showing pressure bias (assigned pressure - best-fit pressure) of Meteosat-10 infrared channel AMVs using the currently operational height assignment (left), new OCA assignment (middle) and the difference between the absolute values of the two methods (OCA - current) (right) i.e. blue values indicate OCA has a pressure bias closer to zero in magnitude. Data from 27th April - 26th May 2016 with QI > 85. Note that there are fewer AMVs due to the need for having a valid best-fit pressure estimation.**

The standard deviation of (assigned - best-fit pressure) is used as an estimate of the error in the height assignment and values estimated for 200hPa intervals throughout the atmosphere are used in the overall observation error calculation (Salonen and Bormann, 2013). The values for these 200hPa bins are comparable (within about 10hPa) for the two height assignment techniques except for the low level infrared AMVs (800-1000hPa) where the OCA value is around 40hPa lower. The small differences in standard deviation imply that the random error is actually similar between the two height assignment techniques. The more visible changes in bias suggest that OCA may have more influence on the systematic errors in the height assignment. Reducing biases can have positive effects on longer term forecast quality as no bias correction is currently applied to the AMVs during assimilation (where observations are treated as unbiased). Further consideration of aspects such as whether the cloud top is most representative level to assign to the wind vector might be required to improve the random error.

SUMMARY

There have been several AMV datasets from new satellites and products added in the ECMWF monitoring and operational assimilation system in the past two years and a relaxation applied to quality control using the zenith angle and the mid-level Meteosat-10 AMVs. In these proceedings the focus has been on the addition of the Metop single and dual AMVs to close the long-standing gap in coverage between geostationary and polar satellites and investigating new developments in the height assignment provided by the OCA product.

The quality of the single Metop AMVs have improved recently leading to their consideration for assimilation. The availability of the dual product with its global coverage provided an opportunity to attain full closure of the gaps around 40-60°N/S. Testing considered both products in order to introduce the optimum configuration of the datasets. In the Polar Regions, our analysis suggests that the quality of the dual product is now acceptable and only slightly poorer than that of the single winds. Meanwhile, in the tropics the dual product contained large speed biases that discouraged use of the AMVs in this area. The slightly poorer data quality in the Polar Regions can be taken into account by assigning larger height assignment and tracking errors. Assimilation tests showed positive impacts on the vector wind error in the Polar Regions for a combination of the dual (between 40°N/S and 60°N/S) and single (polewards of 60°) products with neutral changes on the fit of independent observations to the model background. While tests using only the single product showed similar results, the gap in coverage could not be totally filled by these AMVs alone leading to the choice of implementing AMVs from both products operationally.

The study of height assignment bias has been ongoing at ECMWF - this aspect of the AMV derivation is one of the leading areas of uncertainty. AMVs using the new OCA product for height estimation, provided by EUMETSAT, have been analysed using first guess departures and compared with statistics from the current operational method. The distribution of AMVs has changed with a higher concentration of observations in a band at high level. Statistics in this region were generally improved with small decreases in RMSVD and pressure bias. At low levels the change was smaller but also slightly positive overall. For mid-level AMVs the number of observations is lower but changes have been more mixed with some areas of degradation, particularly in the southern hemisphere. After these encouraging first results, the next step will be to test the longer term impact on the forecast through assimilation experiments.

ACKNOWLEGDEMENTS

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