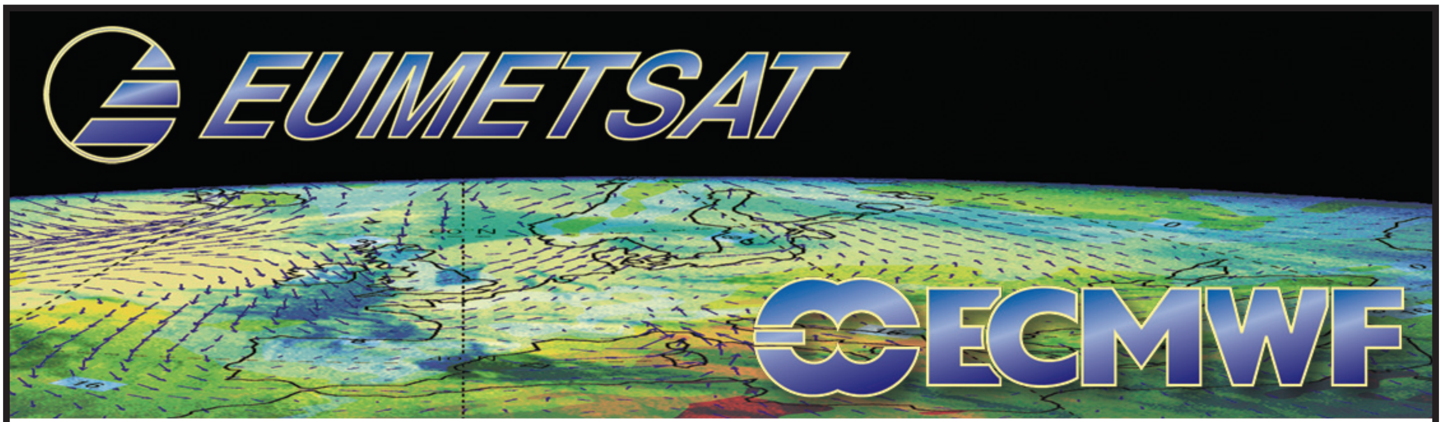

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Assessment of new AMV data in the ECMWF system: First year report

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1 Executive summary

Many more Atmospheric Motion Vectors (AMVs) have recently become available with the launch of new satellites and the release of new products enhancing existing datasets. Characterisation of these new datasets has been a key focus of the first year of the AMV fellowship. At the European Centre for Medium-Range Weather Forecasts (ECMWF), AMVs are currently assimilated from five geostationary satellites and seven polar orbiting satellites. Table 1 summarises the status of the monitored and assimilated AMVs as of the end of November 2016. AMVs from the Metop satellites (Salonen and Bormann, 2016), Himawari-8, carrying the Advanced Himawari Imager (AHI), and the Visible Infrared Imager Radiometer Suite (VIIRS) instrument on the polar orbiting Suomi National Polar-orbiting Partnership (S-NPP) satellite have all progressed to operational use in 2016. In this report we will discuss four AMV datasets that have been assessed in the ECMWF system from Himawari-8, VIIRS, Meteosat-11 and a new product from the Metop satellites.

On 15th March 2016, Himawari-8 replaced the geostationary Multifunction Transport Satellite - 2 (MTSAT-2). The assessment of first guess departures (difference between observation and model background values) using Himawari-8 AMVs shows improved data quality compared to MTSAT-2, resulting from a combination of new instrument capabilities and a new derivation algorithm developed at the Japan Meteorological Agency (JMA). There is a substantial increase in the number of AMVs available with a new spatial distribution including many low level winds assigned to unusually high pressures. A more conservative channel selection, similar to MTSAT-2 (with only one water vapour channel), was chosen for operational implementation. However, this configuration significantly increased the number of AMVs assimilated and positive impacts were found exceeding the effects of MTSAT-2 on the forecast vector wind fields and fit of conventional wind observations to the model background. Further refinement of the channel selection was attempted with the addition of remaining water vapour channels and the removal of AMVs particularly close of the surface but there was no clear benefit. A short summary is presented here in section 2 but complete details of the evaluation can be found in Lean et al. (2016a).

The analysis of the polar Visible Infrared Imager Radiometer Suite (VIIRS) AMVs is discussed in section 3. AMVs are available from one infrared channel (10.7μm) and while this dataset does not immediately replace another satellite, VIIRS will be the successor of the Advanced Very High Resolution Radiometer (AVHRR), used to generate polar AMVs. Data quality in the first guess departures is similar to AVHRR on Metop-A although the spatial distribution is quite different which can be attributed to a different instrument design and derivation algorithm. Assimilation experiments gave modest but positive impacts on the forecast vector wind fields in the Polar Regions with more neutral changes in the fit of conventional wind observations. Operational assimilation of the VIIRS AMVs began on 11th August 2016.

In addition to datasets that have been added to the operational system, two further quality assessments were conducted and feedback provided to EUMETSAT. The first, presented in section 4, considers data from the Meteosat-11 satellite, launched on 15th July 2015, carrying the same instruments as Meteosat-10. A test dataset was disseminated prior to the satellite entering in-orbit storage. Analysis was carried out using first guess departure statistics and comparing with Meteosat-10. Data quality was found to be very similar but some time-dependent patterns were present in statistics such as the speed bias, thought to be caused by movement in the satellite position not fully accounted for in the product generation.

The second evaluation (section 5) discusses the new Metop triplet product (AVHRR Winds Product [Triplet processing mode] Validation Report, 2015). Previously, EUMETSAT generated a Metop single product (tracking features in two consecutive images from the same satellite) and a dual product (tracking features in two consecutive images from different Metop satellites). In the triplet product, three images are used with the first and third image from one satellite and the middle image from the other satellite. Comparison between the products using first guess departure statistics showed that the temporal consistency check provided by the availability

Table 1: Overview of the use of AMV data in the ECMWF system in November 2016.

	IR	Cloudy WV	Clear WV	VIS
Meteosat-7	used	used	monitored	used
Meteosat-8	monitored	monitored	monitored	monitored
Meteosat-10	used	used	monitored	used
GOES-13	used	used	monitored	used
GOES-15	used	used	monitored	used
Himawari-8	used	used	monitored	used
CMA FY-2E	monitored	monitored	monitored	-
CMA FY-2G	monitored	monitored	monitored	-
IMD INSAT-3D	monitored	monitored	monitored	monitored
COMS	monitored	monitored	monitored	monitored
MODIS on Aqua	used	used	used	-
MODIS on Terra	monitored	monitored	monitored	-
AVHRR on NOAA-15, -18 and -19	used	-	-	-
AVHRR on Metop-A, Metop-B and dual Metop-A,B	used	- -	- -	- -
VIIRS on Suomi NPP	used	-	-	-

of a third image improved the overall quality of the AMVs. However, applying stricter quality control using the forecast independent quality indicator (QI) (provided with the AMVs) to the dual Metop-AMVs achieved comparable results in terms of data quantity and data quality. The benefits of the triplet product over the dual product are hence presently not clear.

While this report will discuss the analyses of the four AMV datasets described, it is worth noting that a further, ongoing activity is the investigation of a new height assignment developed at EUMETSAT and made available for Meteosat-10 AMVs. The new assignment comes from the Optimal Cloud Analysis (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). Work is still ongoing and a partial evaluation will not be presented here however an overview of the results so far can be found in Lean et al. (2016b).

2 Assessment of Himawari-8

The successor of MTSAT-2, Himawari-8, (both operated by JMA) was launched in October 2014 and is located at 140°E. The imaging instrument, AHI, is more advanced than the MTSAT-2 Imager instrument (Shimoji, 2014) with up to two times higher spatial resolution; full-disk images over two times faster; 16 channels compared to 5 on the MTSAT-2 imager. AMVs are now available from two further water vapour channels (Table 2). As well as improvements in the imaging instrument, new tracking and height assignment algorithms have been developed by JMA for the Himawari-8 AMVs which are provided hourly as for MTSAT-2 (further details in Shimoji (2014)).

Table 2: Wavelengths at which AMVs are available from MTSAT-2 and Himawari-8.

Channel	MTSAT-2 wavelength (μm)	Himawari-8 wavelength (μm)
Water vapour	6.8	7.35
		6.95
		6.25
Infrared	10.8	10.45
Visible	0.63	0.64

Dissemination of the AMV product from MTSAT-2 ceased on 24th March 2016. To ensure full and continuous coverage, the Himawari-8 AMVs replaced MTSAT-2 in the ECMWF operational system on 15th March 2016. Before using the data operationally a thorough assessment of the new AMVs was carried out. In the following, we will give a brief summary of this assessment; a more detailed report can be found in Lean et al. (2016a). The Himawari-8 assessment starts with the analysis of first guess departure statistics to analyse the data quality using the period 19th June - 31st August 2015. Comparison is primarily with MTSAT-2 although checks with the Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument on Meteosat-10 are also carried out. Note that Meteosat-10 is a geostationary satellite centred over 0° longitude so covers a different area which may have different problems particular to the geographical region. However, the comparison allows another indication of the relative quality of the Himawari-8 data. The derivation of the observation errors for use in the assimilation system is also discussed. From this analysis, channel selections and quality control choices were finalised to test the performance of the data in long term assimilation experiments. After the initial implementation, potential further refinements of channel use were explored. In particular, the operational channel selection includes AMVs from only one of three water channels so a test investigating the impact of adding further water vapour winds was carried out.

2.1 Distribution of AMVs

The distribution and volume of AMVs has changed significantly between MTSAT-2 and Himawari-8. There are many more AMVs available due to a combination of extra channels but also with the introduction of the new derivation method (Shimoji, 2016). Zonal maps (Figure 1) show changes in the height distribution as well as latitudinal differences. For high level winds, the highest densities, particularly for the water vapour channels (not shown), are located at pressures about 20-50hPa higher in the atmosphere. The features available to track must be the same for both satellites but the two different processing methods disagree for these high level water vapour and infrared winds. The pressure difference between observation and model best-fit pressure values (the model pressure which minimises the vector difference between AMV and model wind e.g. Forsythe and Saunders (2008)) can be used to indicate systematic problems with the AMV heights compared to the model wind fields. For the water vapour channels there is a reduction of a positive pressure bias but for the infrared channel pressure biases are very similar and near to zero for high levels.

For the low level AMVs in the infrared channel (Figure 1) and the visible channel (not shown), AMVs are assigned more towards the edges of the tropics and much lower. It should be noted that MTSAT-2 has difficulties at low levels which is reflected in poorer quality statistics prior to quality control so a change might be expected for Himawari-8. However, the assigned heights are now so close to the surface (many at pressures $>$ 950hPa) that they are lower than typical heights of low level cloud bases (Medeiros et al., 2010). Other satellites such as Meteosat-10 tend to have very few AMVs at such high pressures. The near surface AMVs are mostly confined to specific regions. In particular, there are two smaller areas to the west and east of Australia and a large band of about 10° width across the Pacific Ocean centred around 10-15°N. Corresponding satellite images suggested these AMVs are occurring in situations of low, small clouds. There was no apparent dependence on the observation time or QI values. Details from JMA (private communication, K. Shimoji) suggest that the reason for the low height assignment may be problems with separating the radiances from the cloud top and the surface. This leads to the height being assigned roughly halfway between the cloud and surface resulting in AMVs at unexpectedly high pressures.

Interestingly, the statistics such as the root mean square vector difference (RMSVD), speed bias or best-fit pressure analysis did not confirm any large scale errors across this low level region. Estimates of the error in wind speed due to errors in height were also reasonably low for these winds. Initially the near surface AMVs were not excluded from further analysis or in assimilation experiments. In fact, experiments showed the effects of assimilating these AMVs were quite favourable (discussed later).

2.2 Data Quality

Overall there is a clear improvement in the Himawari-8 statistics compared to MTSAT-2. Even when using the assimilated MTSAT-2 data only, with the advantage of quality control, the Himawari-8 data are already comparable with no screening. In the case of actively used data, there are three steps that have been applied:

- Blacklisting: quality control through spatial and temporal screening, QI thresholds and channel selection
- First guess check: data are rejected if the difference between the observation and model first guess is too large.
- Thinning: AMVs are thinned spatially in 200 x 200km by 50-175hPa boxes with the vertical extent varying according to nearest standard pressure level. A temporal thinning of 30 minute windows is also used. The thinning gives preference to AMVs with higher QI values.

Only a small dependence of the data quality on QI value was found so no threshold was applied to the Himawari-8 AMVs to eliminate obviously unsuitable data. Figure 2 illustrates the zonal dependence of the RMSVD

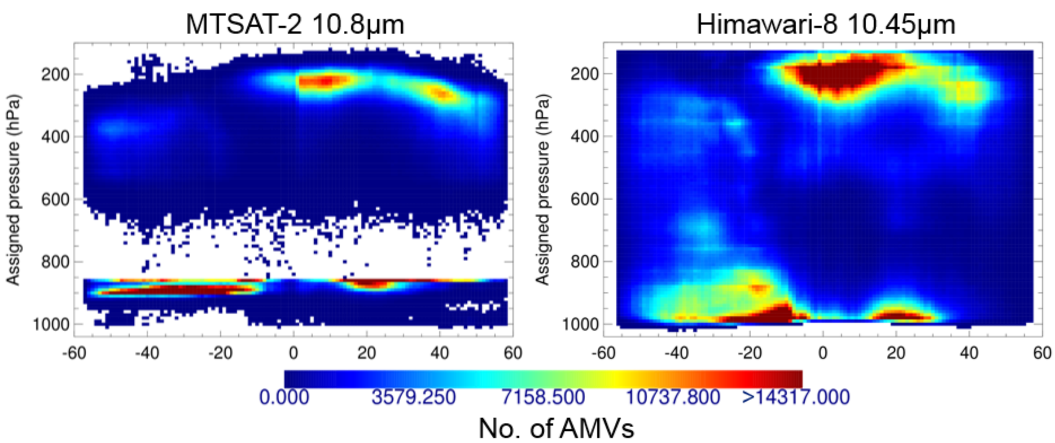

Figure 1: Zonal dependence of the total number of observations for all available infrared AMVs 19th June - 31st August MTSAT-2 (left) and Himawari-8 (right).

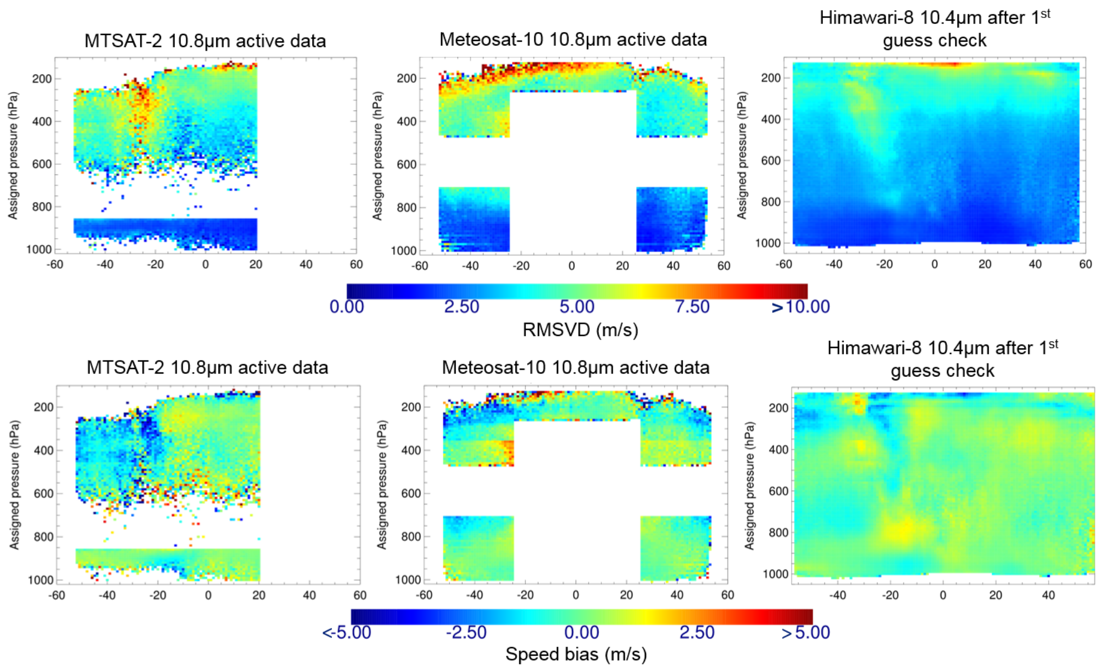

Figure 2: Zonal dependence of RMSVD (top row) and speed bias (bottom row) for MTSAT-2 using active data only (left), Meteosat-10 using active data only (middle) and Himawari-8 after application of first guess check (right).

and speed bias for the infrared channel comparing Himawari-8 data (after screening with first guess check) to the active data from MTSAT-2 and the active data from the SEVIRI instrument on Meteosat-10. After application of the first guess check, the Himawari-8 data are clearly achieving a good quality comparable or even exceeding the other satellites. The unscreened Himawari-8 dataset shows much improvement when compared to all the MTSAT-2 data available (not shown). In both seasons the mean vector difference appears much more homogeneous for Himawari-8 and the large seasonal biases introduced during winter in the northern hemisphere in MTSAT-2 have been removed.

To assimilate the AMVs, observation errors must be defined. The total observation error assigned at ECMWF is situation-dependent and combines an estimate of the error in the tracking with estimates of the error in the speed due to the error in the height (Forsythe and Saunders, 2008; Salonen et al., 2012; Salonen and Bormann, 2013). Height assignment errors have been estimated using best-fit pressure statistics (following Salonen et al. (2012)). Across all of the channels, the height assignment error for Himawari-8 is lower than the operational values used for MTSAT-2 even prior to applying any quality control. Tracking errors applied to all geostationary satellites were also found to be suitable for Himawari-8.

2.3 Assimilation experiments

2.3.1 Operational configuration

To assess the impact on the longer term forecast, assimilation experiments were run with a control run that closely mimics the operational set up (but at a lower model resolution of T_L639). MTSAT-2 was also removed as this would be the situation when introducing Himawari-8 data and experiments were run over two seasons (19th June to 30th September 2015 and 17th November 2015 to 28th February 2016). General quality control for Himawari-8 across all channels (e.g. thinning, maximum zenith angle) remains the same as for MTSAT-2. However, no threshold on quality indicator was placed on the Himawari-8 data and there is no Northern hemisphere latitude restriction (rejecting infrared channel AMVs for latitudes $\geq 20°$N) after the removal of the large seasonal biases.

Early experiments tried to exploit the new channels and pressure coverage previously unavailable on MTSAT-2. However, mixed results for the forecast vector wind errors and fit of conventional observations to the model background led to a more conservative channel selection, similar to MTSAT-2, motivated by degraded areas of statistics seen in the first guess departures. The final configuration allows Himawari-8 AMVs from:

- Visible channel winds below 700hPa
- Water vapour (6.95μm only) channel winds between 150hPa and 400hPa
- Infrared channel winds between 150hPa and 300hPa in the tropics ($\pm 25°$) and below 150hPa elsewhere

Figure 3 illustrates the impact on the error in the vector wind forecast when each experiment is verified against its own analysis for the separate additions of Himawari-8 and MTSAT-2 AMVs. There are clear positive impacts for Himawari-8 that exceed those for MTSAT-2 in the tropics near the surface and in the mid-troposphere extending out to day 5 of the forecast. Despite a similar channel selection, adding Himawari-8 to the assimilation system increases the global total of AMVs compared to using MTSAT-2 by around 40% throughout 500-200hPa. This is a very large increase and such significant changes are rare and hard to achieve. The total number of assimilated Himawari-8 AMVs alone is roughly the same as the sum of all the AMVs used from the other four geostationary satellites in the system (GOES-13,-15, Meteosat-7 and -10). The number of AMVs available prior to any screening is also much larger for Himawari-8 but the reasonably consistent quality across the QI range means that no blacklisting is carried out using the QI. Good agreement with the model background as demonstrated in the data quality should also ensure that the percentage rejected by the first guess departure check is not dissimilar to other satellites.

Improvements were also seen in the fit of conventional winds observations to the background field. There were reductions of up to 1% in the mid-troposphere in the standard deviation of first guess departure for conventional wind observations which was a larger impact than for MTSAT-2 (Figure 4, left panel). Changes to the humidity sensitive observations remained more neutral. Reductions in the 10m wind speed bias (observed - background) for the scatterometer winds were identified in the dense areas of near surface (pressure $>$ 950hPa) AMVs.

To more clearly isolate the impact of the unexpectedly low AMVs, an assimilation experiment was run which excluded any Himawari-8 winds assigned pressures larger than 950hPa. The positive impact on the vector wind forecast error was reduced and the positive effects on the scatterometer winds were removed. The decision was taken to continue with use of these data although in the future it may be useful to consider the development of a height correction to these winds.

2.3.2 Additional water vapour channels

A further experiment tested the addition of the two remaining water vapour channels in the pressure range 150-400hPa. However, when using the Himawari-8 operational configuration as a baseline, these extra data introduced negative effects in the mid-troposphere in both the vector wind forecast errors and fit of independent wind observations (0.3%) (Figure 4, middle panel) although there were neutral changes for humidity sensitive observations. For comparison, a one season experiment (27th April - 15th October 2016) was run for Meteosat-10 which compared the use of only one (6.25μm) against two water vapour channels. Unlike Himawari-8, the

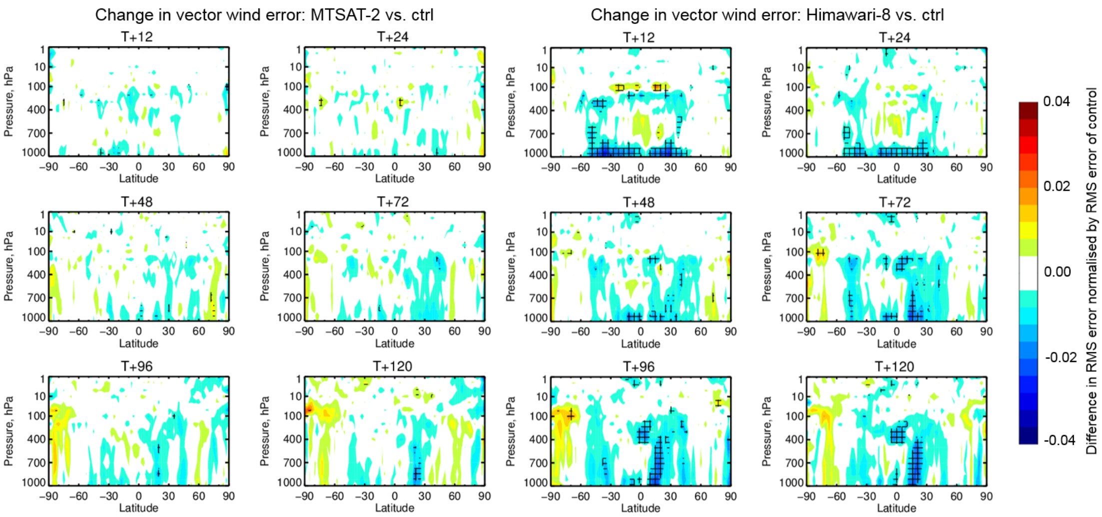

Figure 3: Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons. Data are from MTSAT-2 (left) and Himawari-8 (right) experiment versus the control. Cross hatching indicates 95% confidence.

results showed little impact on the vector wind forecast error and small (0.1%) but significant improvement for humidity sensitive channels on the Advanced Technology Microwave Sounder (ATMS). However, the signal in the conventional wind observations shows similar, but smaller, negative impacts present again in the tropics particularly at 150hPa (Figure 4, right panel). The difference in strength of signal could be that in Himawari-8 we add two channels leading to far more additional AMVs compared to one extra channel with Meteosat-10. In any case, the benefit of the additional WV channel(s) appears less clear for both satellites.

Using a sample of data from Himawari-8 (5 days) and Meteosat-10 (10 days) an investigation showed that there are many AMVs common across the three water vapour channels - i.e. the same feature is tracked in the different channels. These 'duplicates' are subsequently thinned out during assimilation. Once the duplications across the three channels have been removed, the new information actually used in assimilation - "non-duplicate" data - was mostly found in the longer wavelength channel which peaks lower in the atmosphere. As a consequence, these non-duplicated AMVs were on average at a higher pressure where there is less overlap in sensitivity for the different channels. However, compared to the AMVs common between the channels, the non-duplicates showed slightly higher standard deviations of the first guess departures. For Meteosat-10 the wind speed bias was also larger and a smaller proportion of non-duplicate AMVs were assigned the high forecast independent QI values. If the characteristics of a cloud feature are such that an equivalent AMV cannot be produced from each of the water vapour channels (e.g. the cloud is too low for sufficient sensitivity in the shorter wavelength channels), perhaps this indicates a more challenging situation for AMV derivation. This leads to the hypothesis that by adding further water vapour channels, there is a tendency for the extra AMVs to be of lower quality leading to negative impacts in the forecast system.

A contributing factor may also be strong error correlations between the three water vapour channels causing damage when used together (K. Shimoji, personal communication). Such error correlations are currently neglected in the assimilation, but the thinning strategy (horizontal, vertical and in time) and inflated observation errors should reduce their impact. There are virtually no instances of two winds from different water vapour channels derived at different pressures within the same target box. However, there is a significant percentage of winds that have a distance well below the horizontal thinning requirement but are permitted due to being in

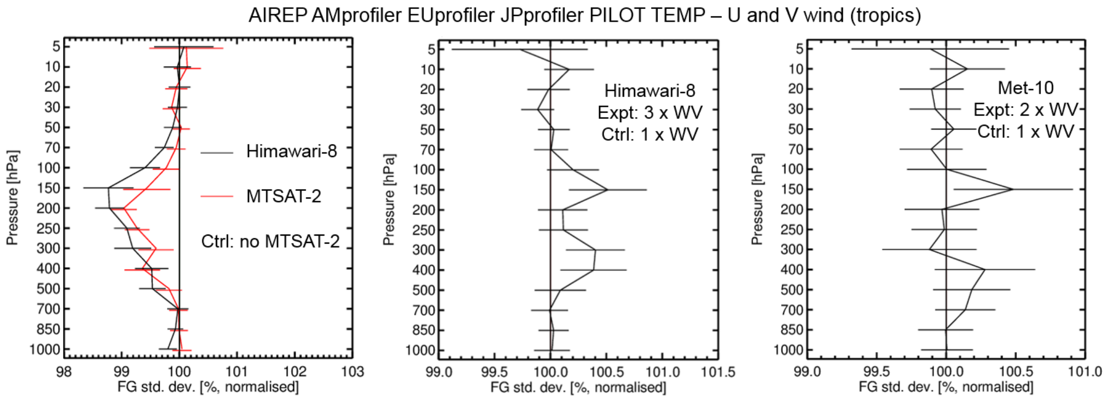

Figure 4: Change in first guess departure standard deviation for conventional wind observations (U and V components combined) in the tropics. Left panel: addition of Himawari-8 (black) or MTSAT-2 (red) compared to a control with no MTSAT or Himawari-8 AMVs. Middle panel: addition of further two water vapour channels for Himawari-8 (2 seasons). Right panel: addition of further water vapour channel for Meteosat-10 (one season). In the middle and right panel the experiments are compared to respective controls using one water vapour channel (in addition to infrared and visible).

different thinning boxes in the vertical. All three water vapour channels exhibit a positive speed bias so there is also a possibility that reinforcing the signal with more AMVs contributes to a negative forecast impact. With the degradation discussed here, the extra Himawari-8 water vapour channels are not recommended for inclusion in this configuration.

2.4 Summary

Overall, the data quality of Himawari-8 was improved significantly from MTSAT-2, including lower RMSVD, the removal of large seasonal biases and better agreement with best-fit pressure values. Assimilation experiments revealed significant positive impacts on the forecast vector wind field in the tropics at mid-troposphere levels that persisted out to five day lead times. Improvements were also clear in the fit of independent wind observations to the model background. The new algorithm led to a large number of the low level infrared and visible winds assigned heights unexpectedly close to the surface. However, data quality of these very low winds did not appear to be degraded. Conversely, their inclusion had positive impacts on the vector wind forecast error in the near surface region as well as reducing the 10m wind speed bias for scatterometer winds. Despite a more conservative channel selection, many more AMVs are assimilated compared to MTSAT-2. Good data quality found through assessment with first guess departure statistics combined with favourable forecast impacts led to the operational replacement of MTSAT-2 on 15th March 2016.

An attempt to use all three water vapour channels resulted in negative impacts on the forecast system. Further experiments showed that Meteosat-10 also did not produce a positive signal with the use of two water vapour channels compared to one. A preliminary assessment suggests that there are many AMVs that are duplicated across the different water vapour channels. Once the duplications have been removed by the thinning process in the assimilation system, the new data actually assimilated by adding a further channel may be of lower quality in comparison to the AMVs common between the channels. In light of the issue of duplication, a future experiment could be the substitution of the 6.95μm water vapour channel with 7.35μm, which has sensitivity over the greatest pressure range. This should allow more information while still using one channel although we may need to consider the development of higher observation errors for the subset of AMVs not common

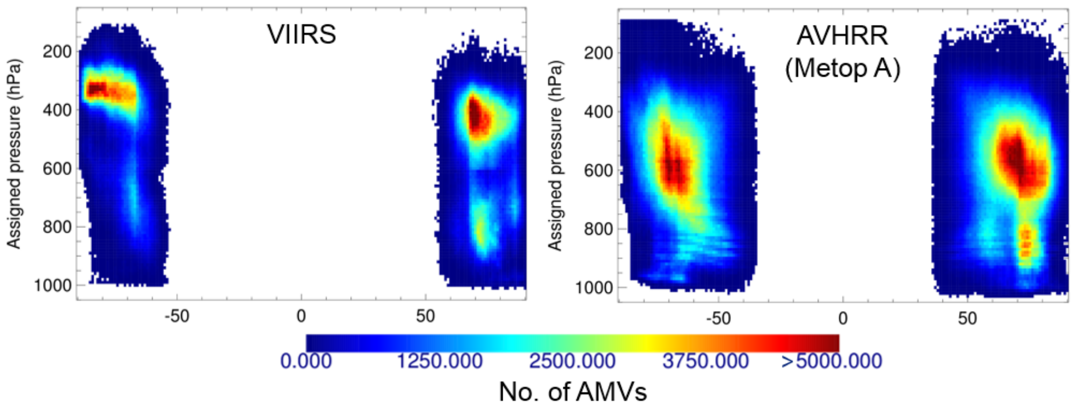

Figure 5: Zonal dependence of the total number of observations for all available infrared AMVs for 1st October - 30th November 2016 for VIIRS (left) and AVHRR Metop-A (right).

between the three channels. For pursuing the use of multiple channels, if the error correlation in these channels is indeed stronger for Himawari-8 and in addition to reinforcing a fast speed bias, perhaps more aggressive thinning would be required to use them together. It would be very useful to better understand the benefits of one versus multiple water vapour channels for selection choices for current and future satellites such as Geostationary Operational Environmental Satellite - R (GOES-R).

3 Assessment of VIIRS

AMVs from VIIRS on S-NPP are based on a new instrument, using a new derivation algorithm compared to winds from the other current polar orbiters. VIIRS is the successor of AVHRR on the US polar satellites, providing data in 22 spectral bands in the visible and infrared, with a constant spatial resolution of 750m for the infrared channels. The constrained pixel growth on VIIRS means that compared to other instruments such as AVHRR, the resolution is higher at the swath edges. The swath width is also wider than the Moderate Resolution Imaging Spectroradiometer (MODIS). Like AVHRR, VIIRS does not include a WV channel, so AMVs are only available from a long-wave infrared channel, and the height assignment capabilities are not as good as for the MODIS instrument. AMV derivation from VIIRS uses a new method developed for the Geostationary Operational Environmental Satellite - R (GOES-R) which employs a new nested tracking algorithm and an optimal estimation method for the height assignment (further information in Key et al. (2014)).

As for Himawari-8, AMVs from VIIRS have been similarly assessed using first guess departure statistics and assimilation experiments. The first part of the analysis uses data received via the Global Telecommunication System (GTS) network from 1st October - 30th November 2016. The comparison presented here is principally with AVHRR on Metop-A although the agreement with other polar orbiting satellites was considered.

3.1 Distribution of AMVs

Figure 5 compares the distribution of observations from VIIRS and AVHRR on the Metop-A satellite. The coverage does not extend quite as far equatorwards for VIIRS, largely a result of using image triplets for VIIRS (i.e. three overlapping orbits) versus image pairs for Metop-A in the feature tracking step of the AMV

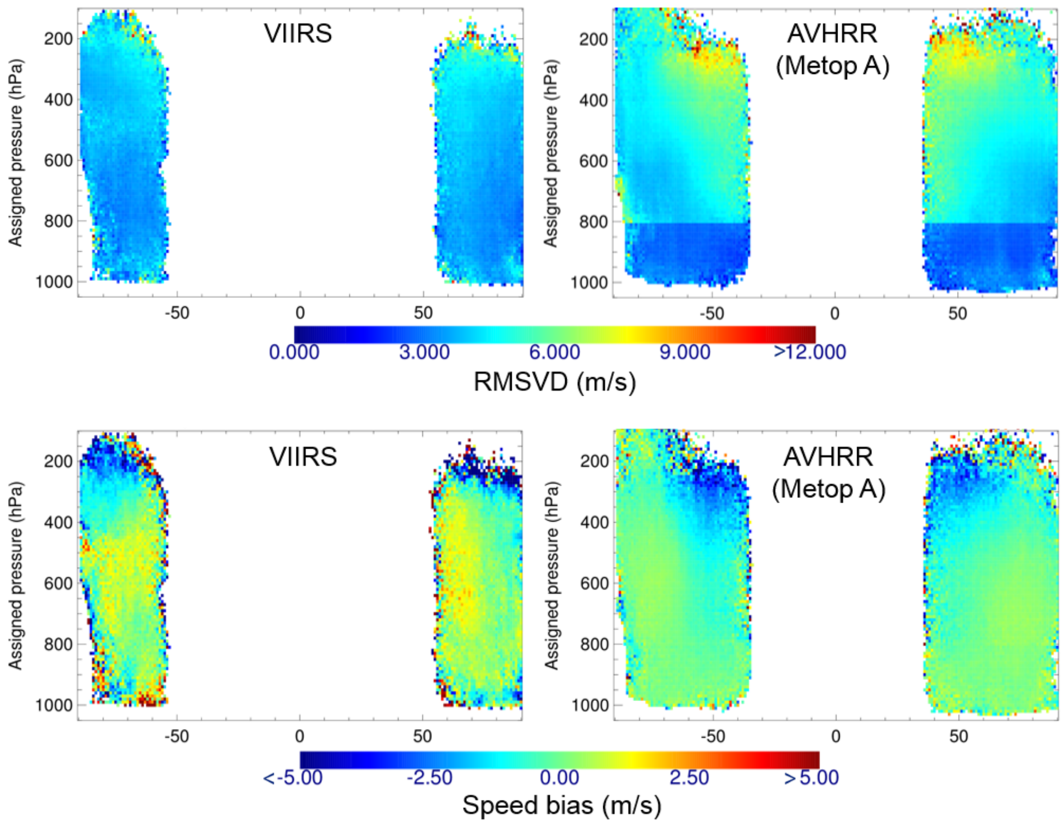

Figure 6: Zonal dependence of the RMSVD (top row) and mean speed bias (bottom row) for infrared AMVs after first guess check has been applied for 1st October - 30th November 2016 for VIIRS (left), AVHRR Metop-A (middle) and MODIS AQUA (right). (Note that the sharp transition in RMSVD at 800hPa for AVHRR is due to the use of default observation errors in the screening calculation for the 800-1000hPa band as the data are not actively used at pressures higher than 700hPa)

derivation. Compared to MODIS or AVHRR on the NOAA satellites there are far more AMVs for VIIRS which will be due to both the instrument and algorithm differences. The distribution of AMVs is quite different for VIIRS than the other polar orbiting satellites with the highest density areas generally at lower pressures and closer to the pole in the southern hemisphere. This is likely to be the result of using an optimal-estimation-based height assignment algorithm for the VIIRS AMVs, as opposed to the Equivalent Black-Body Temperature (EBBT) method for AVHRR. It is a little unexpected that the differences are so large and not presently clear exactly why the AMVs from VIIRS favour this new pattern. However, the data quality (discussed later) from first guess departure statistics and comparison of AMV assigned pressure with model best-fit pressure do not show obvious indications that one distribution is incorrect compared to the other.

3.2 Data quality

Overall the quality of the AMVs from VIIRS is comparable to Metop-A and MODIS. Figure 6 (top row) illustrates the RMSVD for VIIRS and Metop-A after the first guess check has been applied (i.e. outliers rejected after comparison with model background wind fields). This shows slightly lower values for VIIRS than Metop-A in the respective densest regions of AMVs. The dependence of the RMSVD on forecast independent

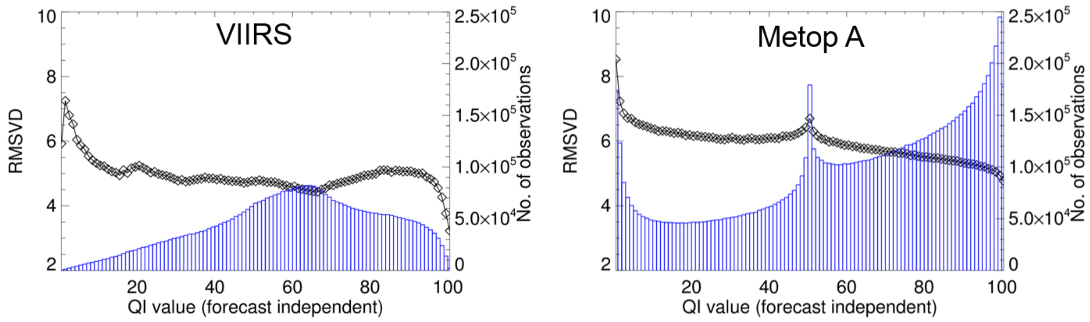

Figure 7: RMSVD dependence on forecast independent QI and number of AMVs per QI value for VIIRS (left) and AVHRR Metop-A (right). Data are from 1st October - 30th November 2016 and cover all available pressure levels and latitudes.

QI (Figure 7) has a general decline in RMSVD as the QI value rises to around 65. There is a relatively small increase of around 0.5m/s up to QI values approaching 85 and a sharp drop for higher QI. In line with other AMVs from other polar orbiting satellites a threshold of 60 was chosen to screen lower quality data for assimilation. Figure 7 also reiterates the lower number of AMVs due to the differences in processing.

The speed bias is slightly different in pattern between VIIRS and Metop-A (Figure 6, bottom row). For VIIRS, the high level AMVs (around 250-400hPa) in the southern hemisphere display negative speed bias around 1-1.5m/s whereas biases in the equivalent region for Metop-A are close to zero. Interestingly, the new AMV derivation algorithm applied to VIIRS especially tries to reduce slow biases (Bresky et al., 2012). At higher pressures the speed bias tends to be more positive for VIIRS although these heights have far fewer AMVs present.

In the best-fit pressure statistics the pressure bias around the dense areas of AMVs is similar between VIIRS and Metop-A while the standard deviation of the best-fit pressure, which is an important indicator of the height assignment error (Salonen et al., 2012), is generally around 20-40hPa lower for VIIRS (Figure 8). However, the Metop AMVs exhibit the largest height assignment errors of the polar orbiting satellites diagnosed in the ECMWF system (Salonen and Bormann, 2016). The values for VIIRS are comparable to the other AVHRR instruments and MODIS (Figure 8), both processed with heritage algorithms developed at CIMSS. Tracking errors for VIIRS are also diagnosed as smaller than Metop-A and remaining closer to other polar orbiting satellites.

3.3 Assimilation experiments

To investigate the longer term impact on the forecast due to the addition of VIIRS AMVs two seasons of assimilation experiments were run (1st June - 30th August 2015 and 1st October 2015 - 30th January 2016). The control mimics the operational system (cycle 41r2) but at lower resolution (T_L511) and includes polar orbiting AMVs from the Metop satellites as well as the NOAA satellites and AQUA. Due to similarities with the other satellites, VIIRS AMVs are subject to the same screening/quality control procedures as the other polar data. Blacklisting includes removing AMVs with pressures greater than 700hPa over ocean and greater than 400hPa over land as well as a minimum QI value of 60.

The addition of the VIIRS AMVs reduces the error in the vector wind forecast in the Polar Regions (Figure 9) in the very short range forecast. Changes are more modest as in this experiment the data enhance existing

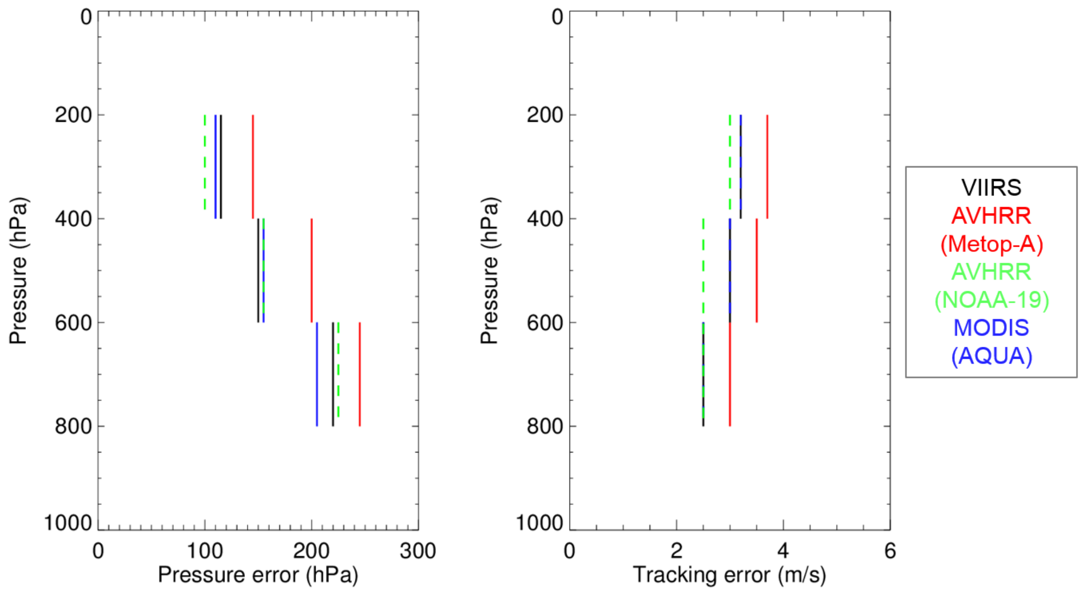

Figure 8: Values of the error in height assignment (left) and tracking error (right) proposed of operational use for VIIRS, AVHRR (Metop-A and NOAA-19) and MODIS (AQUA).

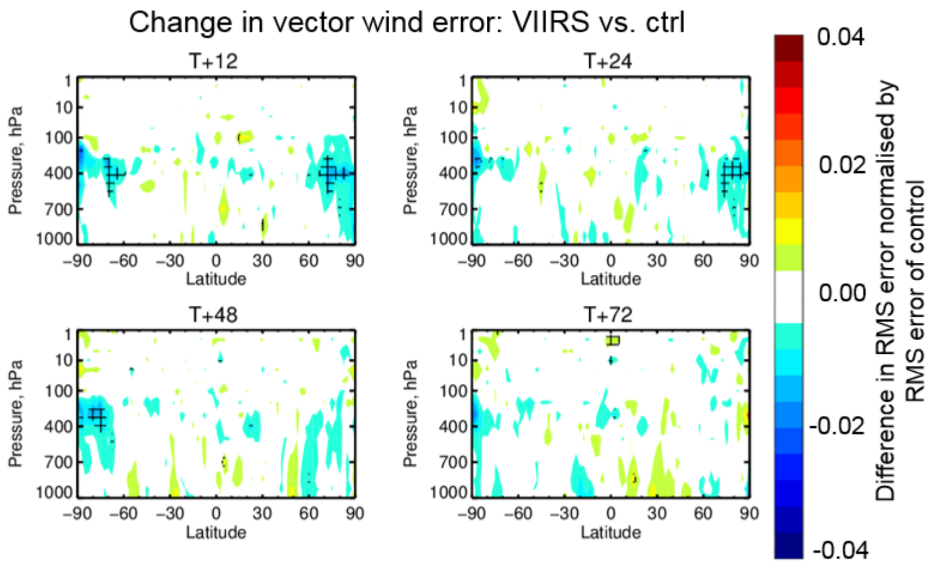

Figure 9: Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons for VIIRS experiment versus the control. Cross hatching indicates 95% confidence.

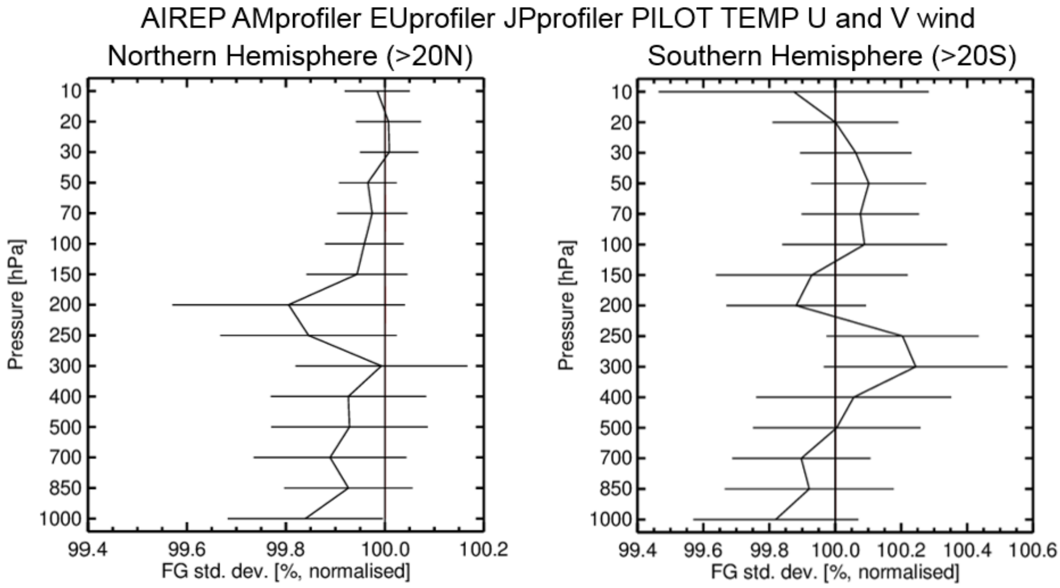

Figure 10: Change in first guess departure standard deviation for conventional wind observations (U and V components combined) in the Northern hemisphere (left panel) and Southern hemisphere (right panel). Results are combined from both summer and winter seasons for VIIRS experiment versus the control.

coverage. However, their presence will become more important in the future with the gradual retirement of AVHRR. The increase in the total number of AMVs polewards of 20°N/S at pressures below 700hPa is mostly below 10%.

In the fit of independent observations to the model background, the changes (within 95% significance) are largely neutral for both wind and humidity sensitive observations. Any significant changes were small (around 0.1%) and usually affected isolated pressure levels/channels rather than larger portions of the atmosphere (Figure 10). The northern hemisphere and winter season performed slightly better with a larger proportion of the small positive results with the Southern hemisphere appears less positive. However, results with a negative signal are small and do not appear to translate to larger medium-range forecast errors.

3.4 Summary

In the assessment of the VIIRS AMVs, data were found to be of comparable quality to MODIS (AQUA) and similar or improved compared to on AVHRR (Metop-A). The spatial distribution of observations differed from the other polar orbiting satellites due to the difference in instrument and AMV derivation algorithm but there were no issues apparent in the first guess departure statistics to indicate incorrect placement. Best-fit pressure statistics suggested that the error in height assignment for VIIRS was slightly improved compared to Metop-A and comparable to the other polar orbiting satellites.

Comparing to AMVs from the other polar orbiters, it would be encouraging to see a clear improvement in the VIIRS winds due to a new instrument design and the different processing method based on GOES-R algorithm. This is also a good opportunity to assess the performance of the GOES-R algorithm before it is used in more satellites in the future. The results presented here suggest that when compared to other polar satellites using image triplets in the processing, there are more AMVs available for VIIRS but the data quality is not significantly different. It is difficult to make firm conclusions about the effect of the GOES-R processing alone but the experience with VIIRS suggests that in future satellites the changes in data quality due to the new algorithm are unlikely to be dramatic.

VIIRS AMVs were tested in assimilation experiments and gave positive impact on the vector wind forecast fields in the Polar Regions. Changes in the fit of humidity and conventional wind observations favoured the northern hemisphere but were small in magnitude and mostly not statistically significant. VIIRS data are a beneficial addition and provide resilience to polar orbiting AMVs which led to their operational implementation on 11th August 2016.

4 Assessment of Meteosat-11 test data

The fourth satellite in the Meteosat Second Generation (MSG) programme, Meteosat-11, has initially been placed in geostationary orbit at 3.4°W but is expected to eventually become the 0° service. Meteosat-11 carries the same instruments as Meteosat-10 including the imaging instrument, SEVIRI from which AMVs can be derived. Commissioning of Meteosat-11 was completed by mid-December 2015 (EUMETSAT press release, 16th Dec 2015, http://www.eumetsat.int/website/home/News/DAT_2880495.html?lang=EN) and during this phase AMV test data were released for a period of around two months. In December 2015 the satellite entered in-orbit storage for around two and a half years but it will be possible to quickly reactivate the satellite at any time if necessary to replace an earlier MSG platform.

An assessment of the early test data allows verification of the performance of instrument and processing and could potentially highlight issues that can be addressed before the satellite becomes operational. Currently, AMVs from Meteosat-10 and Meteosat-7 are operationally assimilated at ECMWF (although preparations have started to replace Meteosat-7 with Meteosat-8). The data quality of Meteosat-11 AMVs was evaluated through comparing first guess departure statistics with Meteosat-10. As this is a preliminary assessment for a short time period of data, assimilation experiments to test the forecast impact of the data were not conducted.

4.1 Data processing

Test data for the following assessment were disseminated via EUMETCast. Statistics have been calculated using a period from 26th September - 23rd November 2015. To generate the first guess departure statistics, two monitoring experiments were used to process Meteosat-10 and Meteosat-11 separately. These were run based on the configuration of cycle 42r1 of the forecast system but at a lower resolution of T_L511. Both Meteosat-10 and Meteosat-11 were used passively in the system in their respective experiments without the other satellite being present (passively or actively). The nadir points of the two satellites are a few degrees apart but Meteosat-11 imagery has been remapped to the Meteosat-10 projection prior to dissemination so the coverage is the same.

4.2 Data quality

4.2.1 Dependence on Quality Indicator

At ECMWF, a threshold on the QI is often used to screen poorer quality AMVs prior to assimilation. For Meteosat-10, a threshold of 85 on the forecast independent QI is used operationally. Only the infrared, lower

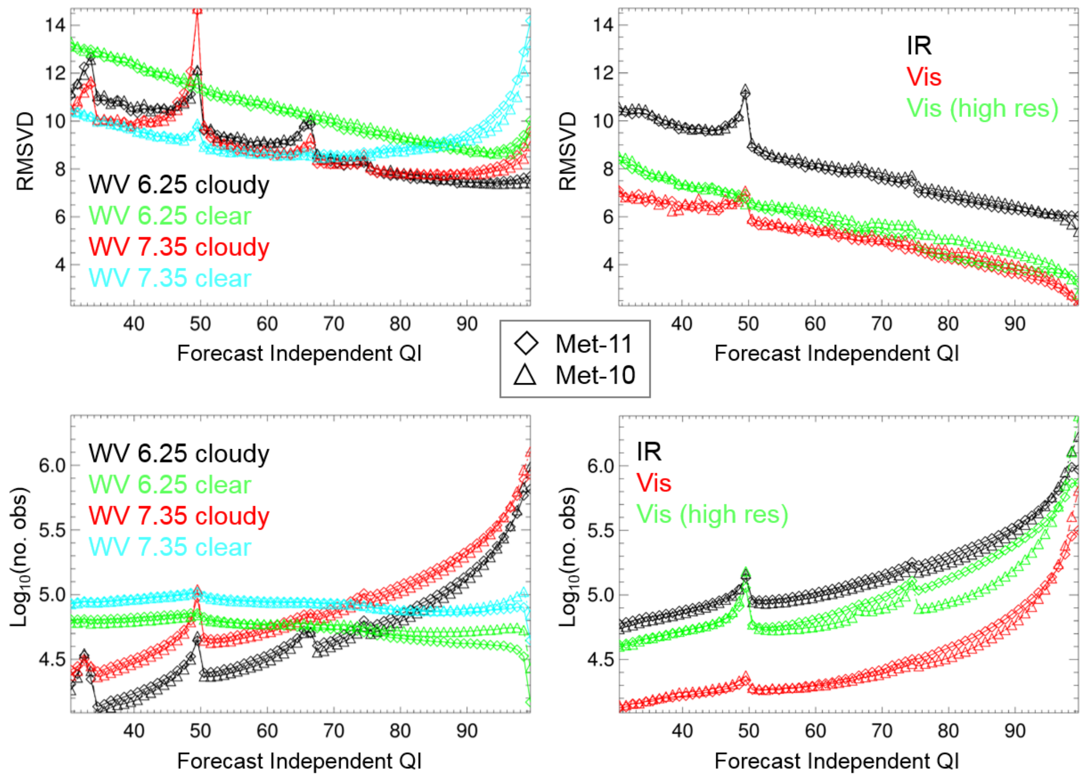

Figure 11: Dependence of RMSVD (top row) and log(number of AMVs) (bottom row) on the forecast independent QI for AMVs derived from cloudy and clear water vapour channels (left column) and infrared and visible channels (right column). Different symbols indicate the two different satellites while colours distinguish the different wind types.

resolution visible and cloudy water vapour AMVs are actively assimilated in the operational system. The dependence of the RMSVD, used mainly to determine the QI threshold value, on both the forecast dependent and independent QIs is very similar between Meteosat-10 and Meteosat-11 (Figure 11). However, there are some small differences such as slightly higher RMSVD (up to 0.5m/s) for Meteosat-11 water vapour winds at forecast independent QI values above 80. The speed bias (not shown) is also larger here for Meteosat-11. For the high resolution visible channel, there is instead a small improvement for Meteosat-11 at higher QI values. As the differences are mostly small, the QI threshold of 85 would be appropriate for Meteosat-11. For the analysis in subsequent sections, this threshold is applied as a basic quality control before calculation of the statistics.

In Figure 11 it is also clear that the number of AMVs assigned each forecast independent QI value differs between the satellites. At very high QI (above 95) there are fewer Meteosat-11 AMVs - as the logarithm of the total number is plotted, this actually corresponds to a large discrepancy. Apart from the high resolution visible channel, the number of AMVs for QI values less than 90 is closer between the satellites although slightly higher for Meteosat-11 in compensation for the smaller increase at higher QI.

4.2.2 Time dependence

Now applying a forecast independent QI threshold of 85 to the data, the time dependence of the AMV statistics was investigated. A time series of the RMSVD and speed bias for both satellites showed very similar results

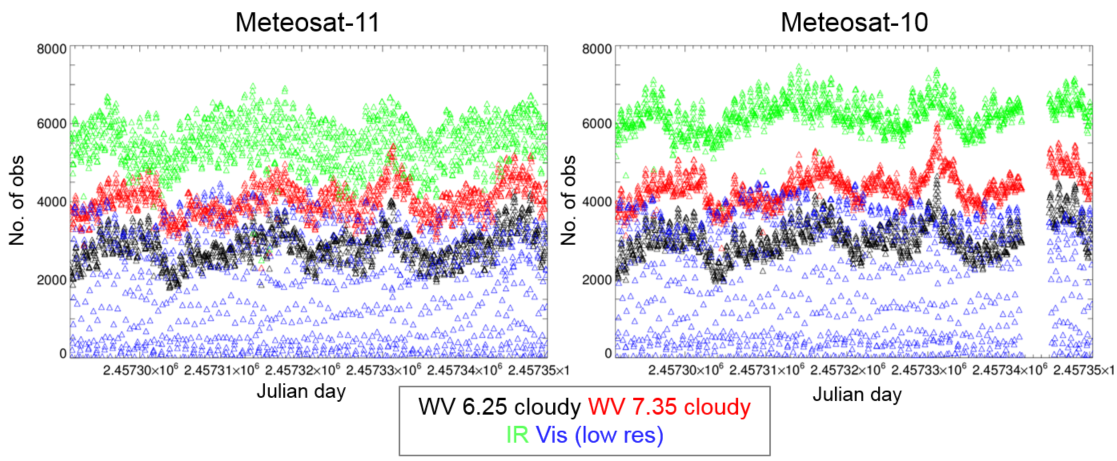

Figure 12: Time series of the number of observations with forecast independent QI > 85 received each hour for the time period 26th Sept - 23rd Nov 2015. Only a subset of channels are shown here - winds from the two cloudy water vapour, infrared and the low resolution visible channels.

(not shown). The time series of the number of observations (Figure 12) for the channels usually actively assimilated confirms the result shown in the previous section that the number of AMVs with high QI is smaller for Meteosat-11. However, it also reveals that there is more spread in the number of AMVs, especially apparent for the infrared channel.

Statistics were also calculated as a function of the time of day that the AMV is recorded. Figure 13 illustrates the variation of the mean speed for the two satellites. While the mean wind speed is relatively uniform throughout the day for Meteosat-10, Meteosat-11 exhibits a sinusoidal cycle with peaks every 12 hours in the speed around 03Z and 15Z. The pattern is most apparent in the cloudy water vapour channels where the departure from Meteosat-10 varies from 0.3m/s in the troughs to 1.5m/s in the peaks. A corresponding cycle in mean speed bias is also introduced (Figure 14). For RMSVD, the values are slightly higher for Meteosat-11 although the difference is mostly less than 0.4m/s. When looking at the difference in the assigned pressures there is generally good agreement (within $\pm$5hPa) between the two satellites apart from the infrared channel where a 12 hour cycle has been introduced in the Meteosat-11 data. This is causing the AMVs to be assigned up to 20hPa lower around 04Z and 16Z for Meteosat-11.

Figure 14 also illustrates that the reduction in the number of AMVs is not constant throughout the time period. The largest decrease for all channels of around 20% occurs between 10Z and 16Z. The clear sky water vapour winds display the largest percentage reduction with values generally between 20-40%.

Feedback regarding this unexpected time dependence of the statistics was provided to EUMETSAT. Subsequent investigation of the issue conducted at EUMETSAT determined that the effect was a result of movement in the location of the satellite that had not been correctly accounted for. Although the location of Meteosat-11 is given as 3.4°W above the equator, there is actually a small variation in satellite position. Due to external influences such as the gravity of the sun or the moon, a satellite in geostationary orbit will gently drift north-south in position on a daily basis. Small and regular station keeping adjustments mean that the variation of a geostationary satellite is typically kept to less than 1°N/S (e.g. Lee et al. (2012), EUMETSAT specific station keeping guidance can be found at `http://www.eumetsat.int/website/home/Satellites/LaunchesandOrbits/SatelliteOrbits/Satellitemanoeuvres/index.html`). This movement in the satellite produces a ground track in the shape of an approximate figure of eight. However, during this test phase Meteosat-11 had a slight inclination in the orbit leading to variation of around 6° (private com-

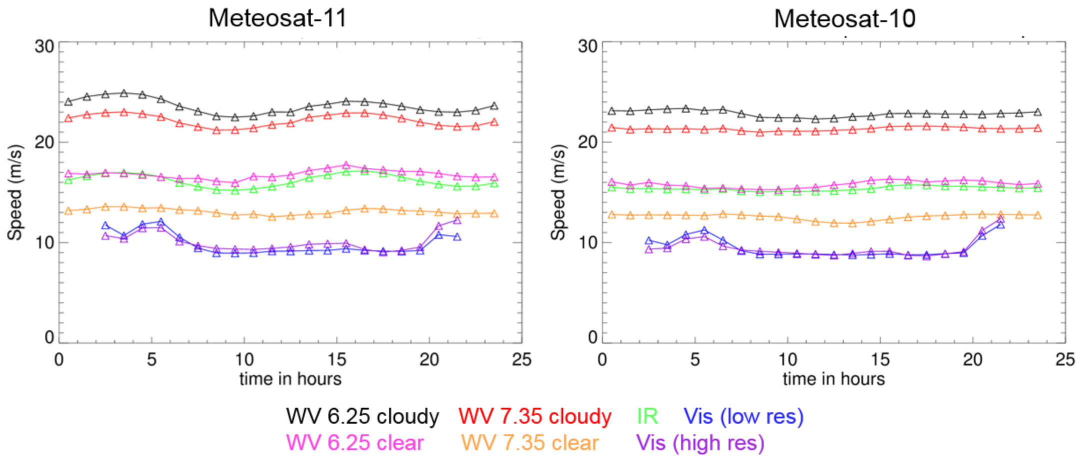

Figure 13: Mean wind speed as a function of time of day that the AMV is produced averaged over the time period 26th Sept - 23rd Nov 2015 (forecast independent QI > 85).

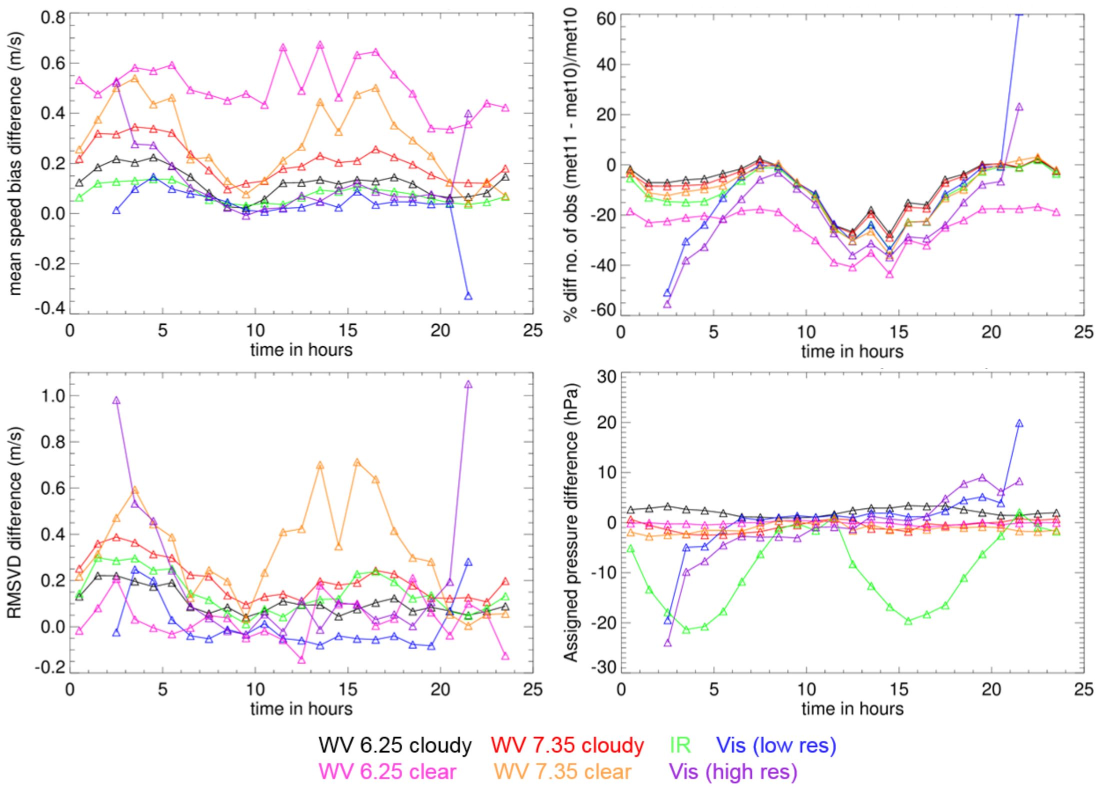

Figure 14: Clockwise from top right: Percentage difference of number of observation (relative to Meteosat-10), difference in AMV assigned pressure, RMSVD and mean speed bias calculated for (Meteosat-11 - Meteosat-10) all as a function of the time of day (data from 26th Sept - 23rd Nov 2015, forecast independent QI > 85).

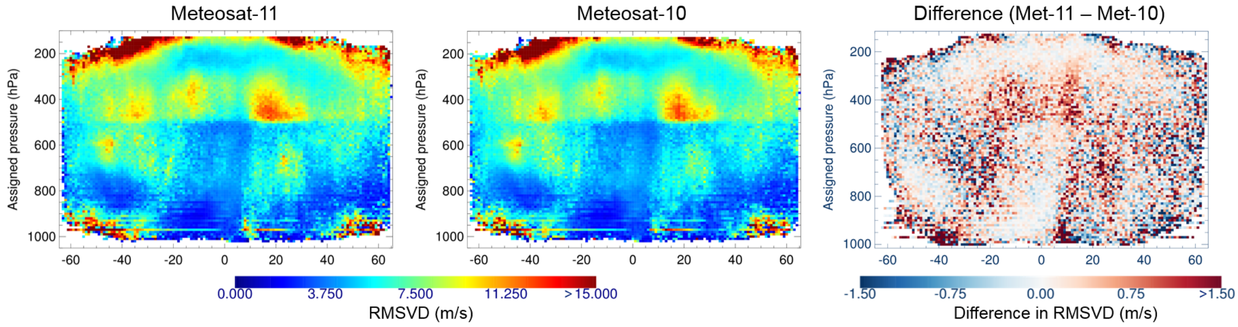

Figure 15: Zonal dependence of RMSVD for the infrared channel on Meteosat-11 (left), Meteosat-10 (middle) and the difference in RMSVD (Meteosat-11 - Meteosat-10) (right). Data from 26th Sept - 23rd Nov 2015, forecast independent QI > 85.

munication, O. Hautecoeur).

In July 2016, Meteorological Product Extraction Facility Release 2.3 was rolled out to Meteosat-9 and -10. Included in this release was a correction for how the sub-satellite position was used in product generation and will be especially relevant for satellites in a high-inclination orbit. This update is expected to remove the daily variation in data quality and therefore correct the Meteosat-11 data. Artefacts in the number of observations (fewer at high QI values and variation across the day) and the changes in statistics such as mean speed bias seen earlier should be absent in the future. The variation in best-fit pressure is also likely to be connected to this effect but it is not clear why only the infrared channel showed large variation. When Meteosat-11 is activated for operational use, the position will likely be more tightly controlled as for the current satellites so the effect should be less prominent anyway.

4.2.3 Spatial statistics

Having investigated how the statistics vary in time, the spatial patterns were also considered using zonal plots and maps of the winds. Again there is good agreement in the data quality between Meteosat-11 and Meteosat-10. Figure 15 gives an example of the zonal dependence of RMSVD which demonstrates the similarity in magnitude and pattern for both satellites. Where there are larger differences in RMSVD, this generally corresponds to areas where there are few AMVs. Overall, the small differences between the satellites highlighted in the time dependence do not appear to be linked to significant changes in a particular geographical region or height range.

4.3 Summary

For a period of around two months test data for Meteosat-11 were received at ECMWF. An assessment of the data has been made through comparison with model wind fields and considering the performance relative to Meteosat-10. Generally there is good agreement between the two satellites in all the channels with features remaining broadly similar in time and space. Given that both satellites carry the same instrument with near-identical processing, this result should be expected.

However, some smaller differences were found, particularly in terms of temporal consistency and a decrease in the number of AMVs assigned the highest quality in the EUMETSAT processing. A time dependent sinusoidal variation was introduced to the Meteosat-11 statistics in some way affecting AMVs from all the channels available. Overall, there was a slight elevation in RMSVD and speed bias as well (order of 0.1-0.5m/s). The most likely cause, especially for the time dependent behaviour, is the greater north/south variation in satellite position than typically seen for geostationary satellites. The correction regarding the use of the satellite position in the product generation subsequently developed at EUMETSAT should remove this effect.

At ECMWF, AMVs from Meteosat satellites have provided benefit to the forecast system for many years. As the main characteristics of Meteosat-11 are very similar to Meteosat-10, the introduction of the data to the forecast system should be a relatively straightforward process. When the satellite becomes active again another evaluation of the data quality will be required. However, there are indications from this preliminary assessment that in the future the data could be added to the forecast system as a routine change without the need for further assimilation experiments.

5 Assessment of Metop triplet product

Until summer 2015, EUMETSAT provided two operational AMV products from the Metop satellites - the single and dual products. For the AMV derivation, the single Metop product uses two images around 100 minutes apart from the same satellite on consecutive orbits. As a consequence the coverage of the AMVs is restricted to the polar regions but the extent is slightly larger than other polar orbiting satellites where the overlap of three consecutive images are used (as seen in the VIIRS assessment earlier). The dual product takes advantage of the overlapping field of view of the two Metop satellites to derive a global set of AMVs using consecutive images from different satellites, around 50 minutes apart. A combination of the single and dual products have been actively assimilated at ECMWF since 4th February 2016 (Salonen and Bormann, 2016).

For both products the use of only one image pair prevents a temporal consistency check (Holmlund, 1998) where consecutive vector pairs from three images can be used to quality check the acceleration. To address this, EUMETSAT now also produce a triplet Metop product (AVHRR Winds Product [Triplet processing mode] Validation Report, 2015) which does use three images - the first and third image are from one Metop satellite while the middle image is from the other satellite. This means that the triplet product can be thought of as an extension of the dual product with the third image used only for quality control purposes. Requiring the overlap from the three orbits restricts the product once more to the polar regions but more effective screening for poorer quality AMVs should be available. In this report we present a comparison between the three products using first guess departure statistics.

5.1 Data

EUMETSAT have developed a common algorithm to extract the winds from the Metop satellites (Hautecoeur et al., 2014) with adaptions to receive images from the different satellite combinations in the three products. Data for the single and triplet products were received in two different streams - Metop-A and Metop-B - corresponding to the origin of the last image used in the processing. Monitoring assimilation experiments were set up to process the AMVs from the three different products passively in the ECMWF system. The experiments used a lower resolution version (T_L511) of the cycle 41r1 operational configuration and were run from 25th August - 24th September 2015.

It was found that the AMVs for the single/triplet products extended from the poles up to latitudes of around 35° although the number of observations becomes very small in the region 35-50°. Statistics from these lower latitude regions are therefore unlikely to be robust for the period of one month however they have been included

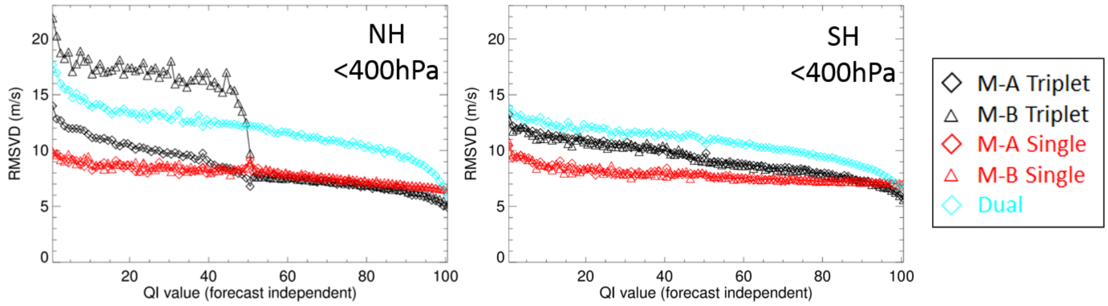

Figure 16: RMSVD dependence on the forecast independent QI values using AMVs above 400hPa and from the northern hemisphere (left) and southern hemisphere (right). Data labelled with the Metop-A and Metop-B have been treated separately for the triplet and single products.

for completeness in the following analysis. AMVs from the dual product have been restricted to polewards of 35° for comparison. Otherwise, no other spatial blacklisting has been applied to the data.

5.2 Data quality

5.2.1 Dependence on Quality Indicator

AMVs in the Metop products are provided with the full range of QI values from 0 to 100. For this initial assessment, data that are obviously of poorer quality can be ignored. So in addition to comparing the performance between the products, this part of the analysis also allows the choice of a QI threshold to apply as a basic filter for the calculation of further statistics. Operationally, a forecast independent QI threshold of 60 is used for the single and dual Metop products.

The dependence of the RMSVD and mean speed bias on both the forecast independent and dependent QI was considered. The main conclusions were very similar for both QI types. In particular, all three products show a consistent decrease in RMSVD as the QI value increases making a QI threshold feasible for quality control. The behaviour of all three products is illustrated in Figure 16 which shows the dependence on the forecast independent QI for high level winds. With better quality control available in the triplet product, for QI values > 60 the triplet winds generally show very similar RMSVD or even improved RMSVD compared to the single winds while being significantly lower than the dual winds.

One striking feature (also shown in Figure 16) is at low QI values only in the northern hemisphere there is a large disparity between the triplet winds depending on which satellite is used in the last image. The 'Metop-B' triplet winds show RMSVD values up to 5m/s higher than 'Metop-A'. The southern hemisphere is not especially affected with differences less than 0.5m/s. Feedback was provided to EUMETSAT who identified the source of the disagreement as incorrect treatment of a few small sections of each orbit where extracted vectors were assigned precisely the opposite direction to the correct solution (private communication, O. Hautecoeur). This was a previously unknown issue and highlights the value of data assessments at Numerical Weather Prediction (NWP) centres in discovering unexpected features. This has subsequently been fixed during the release of version 3.1 of the Metop processing on 2nd December 2015 (AVHRR Winds Product [Triplet processing mode] Validation Report, 2015). For further analysis presented in this report, a forecast independent QI threshold of 60 was applied so this poorer quality data is excluded.

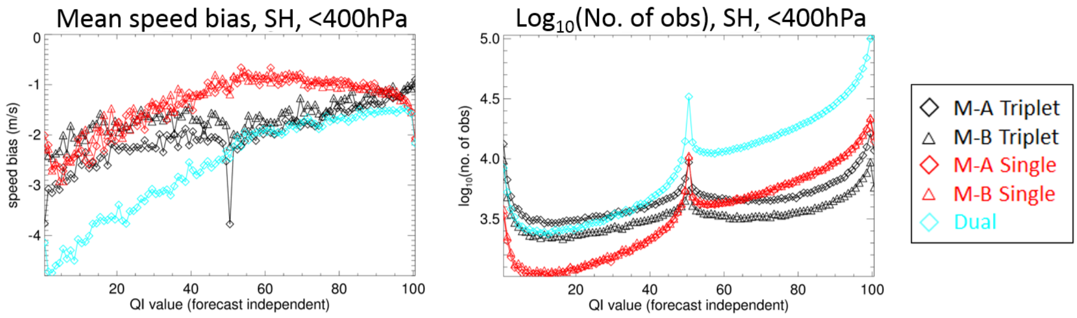

Figure 17: Dependence of the mean speed bias (left) and the logarithm$_{10}$(number of observations) (right) on the forecast independent QI values using AMVs above 400hPa and from the southern hemisphere only. Data labelled with the Metop-A and Metop-B identifiers have been treated separately for the triplet and single products.

The mean speed bias (Figure 17) is broadly similar across the three products and while there is no sudden jump as for the RMSVD, there are small differences throughout the QI range (up to 0.2m/s) between AMVs assigned the different satellite identifiers in the triplet product. The number of observations also shows a systematic difference between the identifiers with up to 500 more 'Metop-A' winds available for each QI value (Figure 17). The single product does not show this behaviour with the different satellite identifiers. During the months around the test period used here, a drift in position between the Metop satellites caused a change in the image overlap region available when processing the AMVs leading to the reduction in the triplet winds using Metop-B as the first image. At the beginning of December, an in-orbit satellite manoeuvre and an update to the processing removed the discrepancy (AVHRR Winds Product [Triplet processing mode] Validation Report, 2015). Overall the number of AMVs for the triplet product is decreased at higher QI values compared to the single product and much reduced from the dual product. A combination of the stricter quality control and change in spatial coverage (particularly when comparing to the dual winds) will be responsible for these changes.

5.2.2 Spatial statistics

After applying a forecast independent QI threshold of 60 there is good consistency in the data quality between the AMVs from the two Metop satellite streams in areas with a high density of observations. Differences are small enough that combining the 'Metop-A' and 'Metop-B' winds for further analysis with the single and dual products will still provide a sensible comparison.

A selection of zonal statistics is shown in Figure 18. The distribution of observations is similar across the products as might be expected from using a common processing technique. However, the density of the observations is generally slightly lower in the triplet product than the single product in line with the difference seen in the QI dependency plots. As for the single Metop winds, the number of triplet winds also decrease at lower latitudes compared to the globally available dual product.

The RMSVD (Figure 18, top row) shows lowest values for the triplet winds with reductions (around 0.5-1m/s) compared to the other two products in both hemispheres. While the general pattern remains the same, maps of the RMSVD (not shown) particularly highlight that closer to the poles ($> 70°$), where the AMVs are denser for the triplet product there is a larger improvement. A feature of higher RMSVD in the high level winds of the dual product around 60°N (corresponding to an area across North Europe/Russia) is not present in the triplet product and the reason for its existence only in the dual product is not clear.

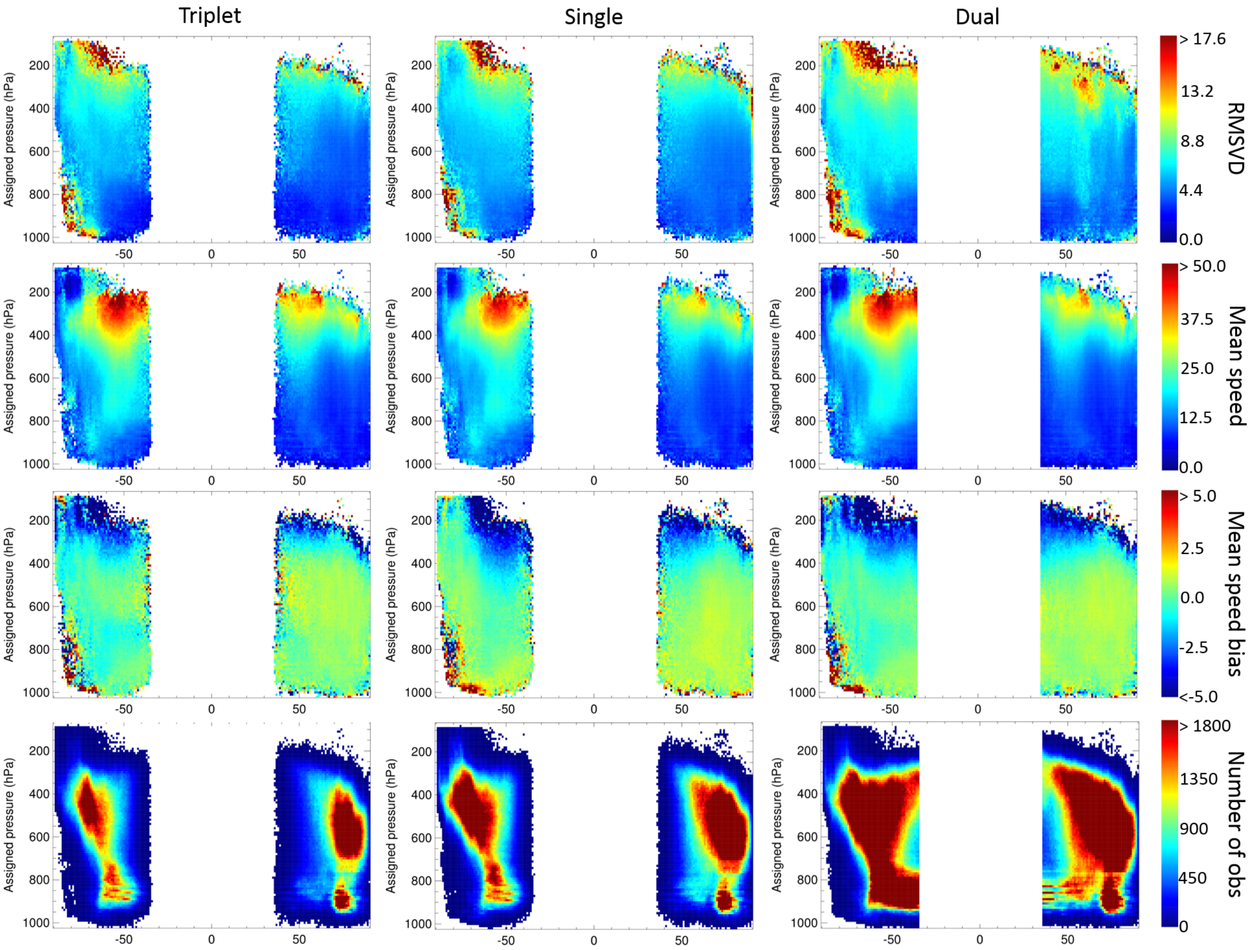

Figure 18: Zonal dependence of the RMSVD (top row), mean speed (second row), mean speed bias (third row) and number of observations (bottom row) for the triplet (left column), single (middle column) and dual (right column) products. QI ≥ 60 threshold applied.

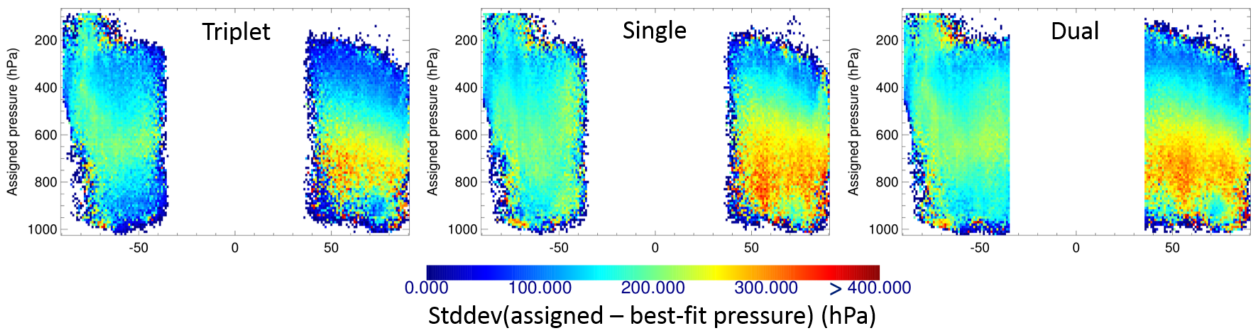

Figure 19: Zonal dependence of the standard deviation (assigned - best-fit pressure) for the triplet (left), single (middle) and dual (right) products. QI ≥ 60 threshold applied.

The overall wind speed (Figure 18, second row) is higher for the triplet product particularly at low pressures and slightly further away from the poles especially when compared to the single product. The corresponding speed bias in these regions (Figure 18, third row) is reduced suggesting that the faster wind better agrees with the model background values. With the shorter time difference between the consecutive images, the triplet and dual AMVs appear to better capture the speed of the high, fast jets. However, in the southern hemisphere the triplet wind speed bias is generally more negative (up to 2m/s) compared to the single product. Maps of the mean vector difference (not shown) show that the triplet product is performing better (1-2m/s) over sea ice regions.

5.2.3 Best-fit pressure statistics

As for the data quality analyses presented earlier in this report, best-fit pressure statistics have been considered for the Metop products to give an indicator of the height assignment error. Figure 19 shows the zonal dependence of the standard deviation of (AMV assigned pressure - best-fit pressure) for the different products. The standard deviation for the triplet product is generally lower (up to 30hPa) than the other products. The extra quality control seems to be impacting the best-fit pressure statistics through more effectively reducing the QI of the AMVs with less accurate height assignment. The height and latitude structure of the triplet product is otherwise similar.

5.3 Triplet winds as a subset of dual winds

In the comparison presented so far, the statistics show promising results for the triplet product but there is a caveat that there is a different sample of AMVs used for each product, and many more observations are available for the dual product. As noted earlier, the triplet product can be thought of as a subset of the dual product acquired through extra quality control from a third image. To confirm this idea, a three week sample (1st-20th September 2015) of triplet and dual winds were collocated using the 400-700hPa pressure band (which contains the majority of AMVs) and for latitudes $> 65^\circ$. A collocation was successful with the following criteria: within $\pm 0.1^\circ$ latitude, $\pm 0.1^\circ$ longitude and less than 30 minutes. Through collocation, the dual winds are sampled using the triplet AMVs so the extra quality control is indirectly applied. As expected, the data quality is almost identical and the advantage of the triplet product is lost. As the dual product contains more winds and the QI is not an absolute measure of AMV quality (see, for instance Figure 16), the question arises: Is it possible to recreate a dataset similar in quality to the triplet product by applying stricter quality control to the dual product using the QI values instead?

To achieve a similar sample size to the triplet AMVs with QI $\geq$ 60, the threshold on forecast independent QI for the dual product was increased until the total number of remaining AMVs was closest to the triplet product sample. Using the same three weeks of data, it was found that raising the threshold to 85 gave the most similar number of AMVs. Figure 20 shows maps that compare the mean speed bias, standard deviation of speed bias and number of observations for the triplet product and different samples of the dual product. Statistics have been calculated on a 1°x1° latitude/longitude grid. It is clear that by raising the QI threshold the standard deviation of the speed bias improves and becomes much closer to the magnitude and pattern of the triplet product. The difference between the triplet and dual (QI $\geq$ 85) product suggests that the triplet product is still slightly better especially around the lower latitudes. However, there are very few AMVs in this region so the signal is not necessarily significant. The mean speed bias changes very little with modifying the dual winds sample and stays in good agreement with triplet product. The investigation suggests that there is relatively little practical benefit from the triplet product.

5.4 Summary

First guess departure statistics from the new triplet wind product have been compared with the dual and single Metop products. When applying the same threshold on the forecast independent QI of 60 to all the products, the quality of the triplet winds, with the benefit of the third image for quality control, is generally similar or slightly improved from the single product while appearing to be significantly better than the dual product in aspects such as RMSVD. The extra quality control also means that the AMVs assigned higher QI values in the triplet product also have less error in their height assignment. The triplet winds also retain the faster wind speeds in the jet regions as seen in the dual product.

With the opportunity to investigate the performance depending on the order of the satellites used in the three images in the AMV derivation it was found that at lower QI values there was some anomalous behaviour in the northern hemisphere. Here, values for RMSVD diverged depending or whether AMVs were from the ‘Metop-A or ‘Metop-B streams. More widely, there were small, but not significant, differences in data quality between the two satellite streams. EUMETSAT have since identified the issues and corrections have been applied which remove these features. Shortly after this analysis, data were changed to dissemination in one stream as a composite satellite product so the order of the images is no longer differentiated.

An investigation was carried out into how the triplet and dual product statistics would compare if the sample sizes were similar. Using a collocation technique, the triplet winds were shown to be a subset of the dual winds. By raising the threshold on the QI to 85 for the dual product, the remaining winds did not have the same level of agreement as the direct collocation, but still showed very good agreement with the triplet data. This suggests that through more aggressive use of the QI provided with the dual product it is possible in the Polar Regions to achieve similar data quality to the triplet winds. Consequently, the additional benefit of the triplet winds in their current form is not very clear. In the derivation of a triplet wind there is more information available with the third image but while it is used only for quality control, it is changing the difficulty for the AMVs to achieve higher QI values relative to the formula used in the dual wind QI calculation. The underlying winds are still the same between the two products. Perhaps the second vector could be used not just for quality control but also in the generation of the final wind vector (similar to the use of three images in other polar products such as VIIRS). The direct use of the extra image in generating the wind has the potential to further reduce errors and provide new information not already present in the dual winds.

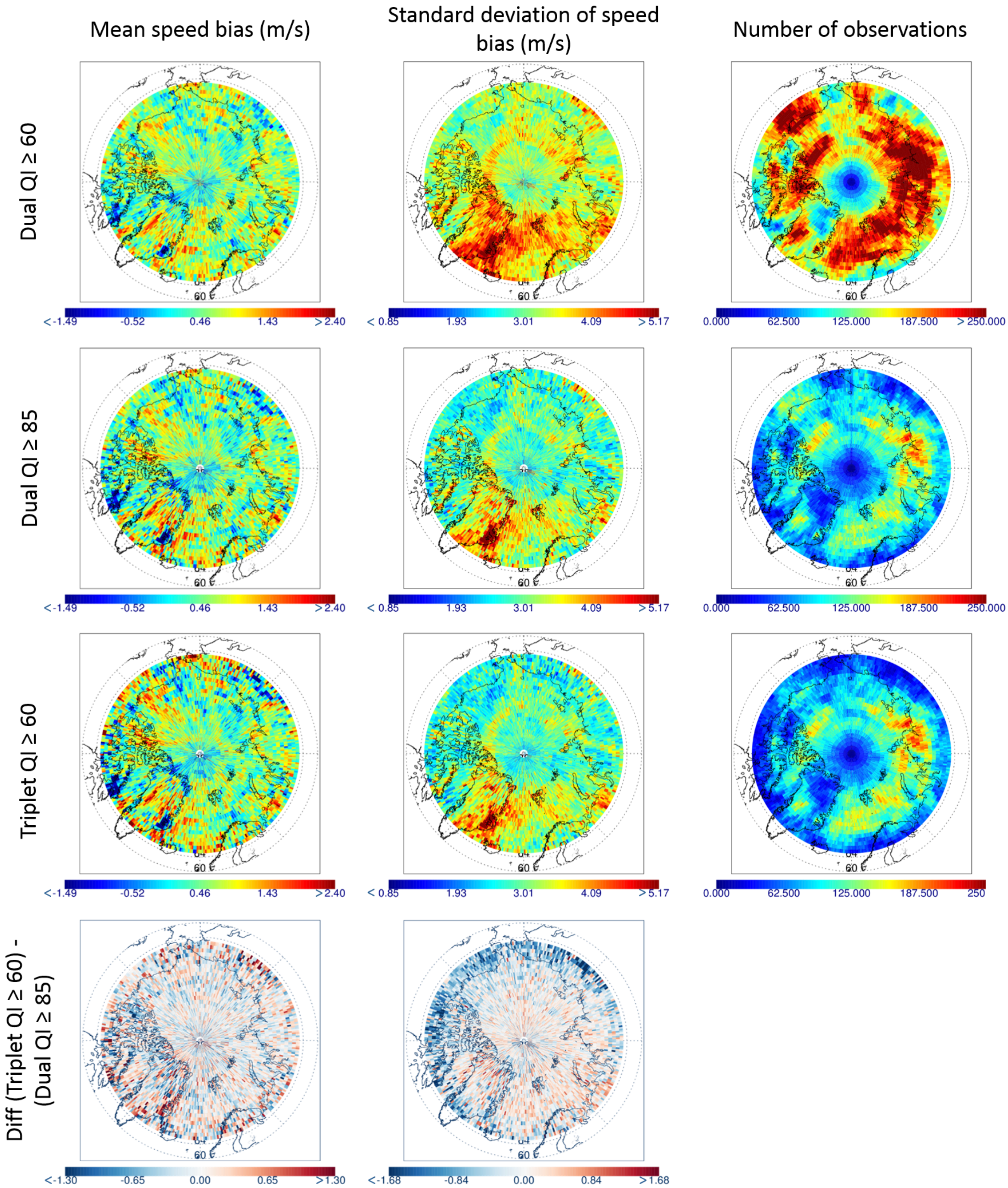

Figure 20: Comparison for the northern hemisphere of the mean speed bias (left column), standard deviation of speed bias (middle column) and number of observations (right column) for the dual product using QI $\geq$60 (top row), dual product using QI $\geq$ 85 (second row), triplet product using QI $\geq$60 (third row) and the difference between the triplet and dual (QI $\geq$ 85) products (bottom row). All QI thresholds are based on the forecast independent QI type and a minimum of 10 observations are needed before the calculation of the statistics is carried out.

6 Future work

The evaluation of new or enhanced AMV datasets will remain a large focus of the second year of the AMV fellowship. In early 2017, Meteosat-7 will be replaced with Meteosat-8 as the provider of the Indian Ocean Data Coverage (IODC). In moving to a new generation of Meteosat satellite, a larger number of AMVs will be available due to a second water vapour channel and the increased temporal resolution while improved data quality is also expected. Meteosat-8 AMVs will be assessed at the new location in order to find the optimum configuration to introduce the data operationally. The new satellite is positioned at 41.5°E, 16° further west than Meteosat-7 which increases the overlap with Meteosat-10 coverage and leaves a lower density on the eastern side of the disk. While the priority will be to use the Meteosat-8 AMVs, a subsequent investigation will explore the benefit of assimilating other satellites with good coverage of the Indian Ocean region such as FY-2G and INSAT-3D. This is also expected to provide guidance to EUMETSAT regarding the future continuation of the IODC mission.

GOES-R successfully launched in November 2016 (becoming known as GOES-16 after reaching geostationary orbit) and carries a more advanced imaging instrument than the currently operational GOES satellites (Schmit et al., 2008). Data will be evaluated when available in 2017 in preparation for operational use. As discussed in the VIIRS assessment presented here in section 3, a new derivation method has also been developed for GOES-R. This algorithm will eventually be applied across the other GOES satellites and MODIS/AVHRR instruments on the polar orbiting AQUA/NOAA satellites (Qi et al., 2016). Testing the existing satellites with the algorithm change will be required in preparation for the operational transition (likely to be in 2018).

AMVs from GOES-R will also be provided with extra information regarding the derivation and height assignment. As discussed in Salonen and Bormann (2016), benefits from the new parameters will include the ability to refine the quality control and observation errors. With changes to the file format in which AMVs are disseminated anticipated later in 2017, there will be space for data providers to add these parameters for wider use across all satellites. Also looking further ahead, the launch of Joint Polar Satellite System - 1 (JPSS-1) will allow polar AMVs from another VIIRS instrument. Analysis and potential operational use of these data will likely take place in early 2018.

As detailed in the summary of work at the beginning of this report, investigation is ongoing concerning the new Optimal Cloud Analysis height assignment currently available for Meteosat-10. Optimal analysis techniques are becoming more prevalent for AMV derivation so understanding the benefits and weaknesses of this method is valuable. Height assignment is an ongoing challenge for AMVs so advances in this area are of great interest. Related to this, a recent investigation considering a systematic correction for height assignment errors (Salonen and Bormann, 2016) showed promising results but with further work required. This study will be revisited to better understand the mixed impacts of applying the correction and aim to improve the results through suitable refinements.

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References

AVHRR Winds Product [Triplet processing mode] Validation Report, November 2015. EUMETSAT product guide. Eum/tss/rep/15/805961, v2a e-signed Edition.

Bresky, W. C., Daniels, J. M., Bailey, A. A., Wanzong, S. T., 2012. New methods toward minimizing the slow speed bias associated with atmospheric motion vectors. J. Applied Meteorology and Climatology 51, pp 2137–2151.

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.

Hautecoeur, O., Borde, R., Doutriaux-Boucher, M., Carranza, M., 2014. EUMETSAT operational dual-Metop wind product. Proceedings of the 12th International Wind Workshop, Copenhagen, Denmark, 16-20 June 2014.

Holmlund, K., 1998. The utilization of statistical properties of satellite-derived atmospheric motion vectors to derive quality indicators. Wea. Forecasting 13, 1093–1104.

Key, J., Dworak, R., Santek, D., Bresky, W., Wanzong, S., Daniels, J., Bailey, A., Velden, C., Qi, H., Keehn, P., Wolf, W., 2014. Polar winds from VIIRS. Proceedings of the 12th International Wind Workshop, Copenhagen, Denmark, 16-20 June 2014.

Lean, K., Bormann, N., Salonen, K., 2016a. Assessment of Himawari-8 AMV data in the ECMWF system. EUMETSAT/ECMWF Fellowship Programme Research Report No.42.

Lean, K., Bormann, N., Salonen, K., 2016b. Assessment of VIIRS AMV data and the Optimal Cloud Analysis product for AMV height assignment. Proceedings of the EUMETSAT Meteorological Satellite Conference, Darmstadt, Germany, 26-30th Sept 2016.

Lee, B.-S., Hwang, Y., Kim, H.-Y., Kim, B.-Y., 2012. GEO satellite collision avoidance maneuver strategy against inclined GSO satellite. Proceedings from 12th International Conference on Space Operations, Stockholm, Sweden, 11-15th June 2012.

Medeiros, B., Nuijens, L., Antoniazzi, C., Stevens, B., 2010. Low-latitude boundary layer clouds as seen by CALIPSO. J. Geophys. Res. 115, D23207, doi:10.1029/2010JD014437.

Optimal Cloud Analysis: Product Guide, April 2016. EUMETSAT product guide. Eum/tss/man/14/770106, v2a e-signed Edition.

Qi, H., Daniels, J., Key, J., Chang, P., Esposito, N., Bailey, A., Augenbaum, J., Zhu, Y., 2016. Operational wind products at NOAA/NESDIS: a status update. Presentation from the 13th International Winds Workshop, Monterey, California, 27th June - 1st July 2016.

Salonen, K., Bormann, N., 2013. Winds of change in the use of Atmospheric Motion Vectors in the ECMWF system. ECMWF Newsletter 136, 23–27.

Salonen, K., Bormann, N., 2016. Atmospheric Motion Vector observations in the ECMWF system: Fifth year report. EUMETSAT/ECMWF Fellowship Programme Research Report No.41.

Salonen, K., Cotton, J., Bormann, N., Forsythe, M., 2012. Characterising AMV height assignment error by comparing best-fit pressure statistics from the Met Office and ECMWF system. Proceedings of the 11th International Wind Workshop, Auckland, New Zealand, 20-24 February 2012.

Schmit, T. J., Li, J., Li, J., Feltz, W. F., Gurka, J. J., Goldberg, M. D., Schrab, K. J., 2008. The GOES-R Advanced Baseline Imager and the Continuation of Current Sounder Products. Journal of Applied Meteorology and Climatology 47 (10), 2696–2711.

Shimoji, K., 2014. Motion tracking and cloud height assignment method for Himawari-8 AMV. Proceedings from the 12th International Winds Workshop, Copenhagen, Denmark, 16-20th June 2014.

Shimoji, K., 2016. Current status of operational wind products in JMA/MSC. Presentation from the 13th International Winds Workshop, Monterey, California, 27th June - 1st July 2016.