Proceedings for the 13th International Winds Workshop
27 June - 1 July 2016, Monterey, California, USA

ASSESSMENT OF AMVS FROM HIMAWARI-8 AND VIIRS

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Abstract

Detailed analysis of the Atmospheric Motion Vectors (AMVs) is presented for the Advanced Himawari Imager (AHI) instrument on Himawari-8 and the Visible Infrared Imager Radiometer Suite (VIIRS) instrument on the polar orbiting Suomi National Polar-orbiting Partnership (SNPP) satellite.

Himawari-8 replaced the geostationary Multifunction Transport Satellite - 2 (MTSAT-2). The assessment of first guess departures using Himawari-8 AMVs shows improved data quality compared to MTSAT-2, resulting from a combination of the new instrument capabilities and 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 the near surface AMVs but there was no clear benefit.

In the analysis of VIIRS AMVs, data quality in the first guess departures is similar to the Advanced Very High Resolution Radiometer (AVHRR) on Metop A although the spatial distribution is quite different. Assimilation experiments gave more 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.

INTRODUCTION

The launch of several satellites and the development of new products in the past two years has meant that many new Atmospheric Motion Vectors (AMVs) have become available. In these proceedings we present the assessment of AMV datasets from two new satellites: Himawari-8 (AHI instrument) and SNPP (VIIRS instrument). The successor of MTSAT-2, Himawari-8, (both operated by JMA) was launched in October 2014. 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 1). 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).

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

Table 1: **Wavelengths at which AMVs are available from MTSAT-2 and Himawari-8.**

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. The first part of this document focuses on the Himawari-8 assessment starting with the analysis of first guess departure statistics (difference between observation and model background values) to analyse the data quality. Comparison is primarily with MTSAT-2 although checks with SEVIRI instrument on Meteosat-10 are also carried out. The derivation of the observation errors for use in the assimilation system is discussed. From this analysis, channel selections and quality control choices were finalised to test the performance of the data in long term Numerical Weather Prediction (NWP) experiments. After the initial implementation, potential further refinements of channel use were explored.

In the second part of these proceedings, we focus on the analysis of the VIIRS AMVs which are available from one infrared channel (10.7µm). While this dataset does not immediately replace another satellite as for Himawari-8, VIIRS will be the successor of AVHRR, used to generate polar AMVs. 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). 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). AMVs from VIIRS have been similarly assessed using first guess departure statistics and assimilation experiments.

HIMAWARI-8

Distribution of observations

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. 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. It is surprising that there is such a difference since the features available to track must be the same. The pressure difference between observation and model best-fit pressure values (the model pressure which minimises the vector difference between AMV and model wind) can be used to indicate systematic problems with the AMV heights compared to the model wind fields. For the water channels there is a reduction of a positive pressure bias but for the infrared channel pressures 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.

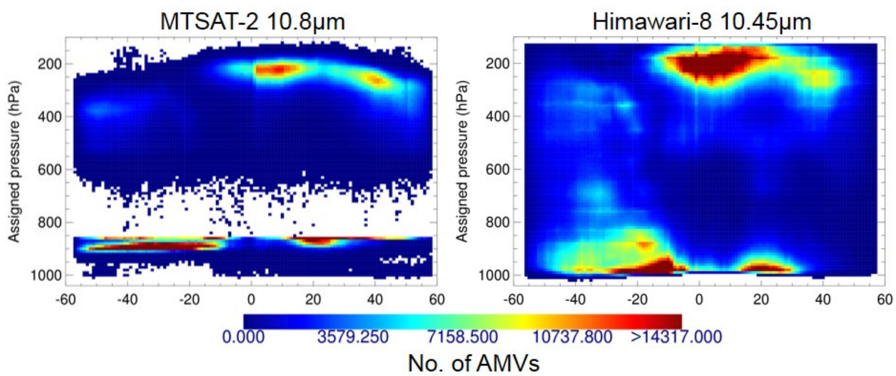

Figure 1: **Zonal dependence of the total number of observations for all available infrared AMVs 19th June - 31st August MTSAT-2 (left) and Himawari-8 (right).**

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 10-15N. Corresponding satellite images suggested these AMVs are occurring in situations of low, small clouds. There was no apparent dependence on the observation time or quality indictor (QI) values. Details from JMA (private communication, K. Shimoji) suggest that the reason for the low height assignment may be problems with separating the radiance from the cloud top and the surface radiance. This leads to the height being assigned roughly halfway between the cloud and surface resulting in unusually low AMVs.

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).

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, quality indicator 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 200x200km 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 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. 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. 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 (not shown) shows much improvement when compared to all the MTSAT-2 data available. 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.

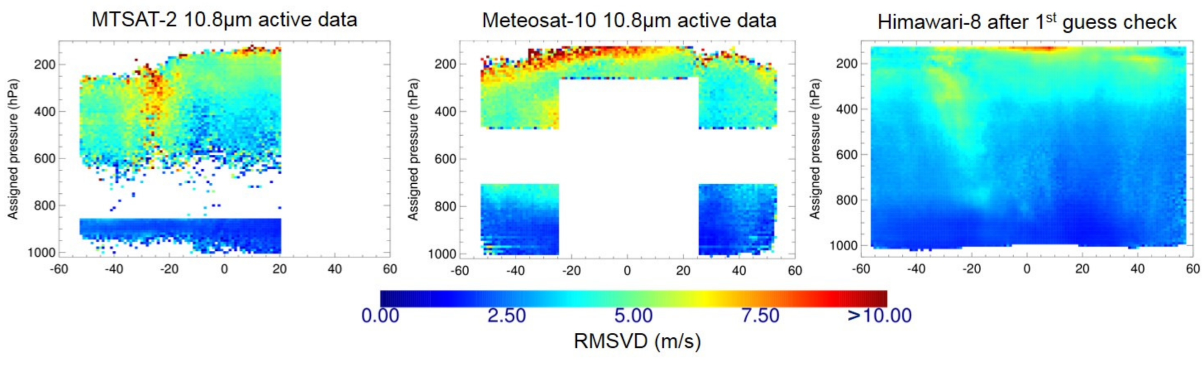

Figure 2: **Zonal dependence of RMSVD for MTSAT-2 using active data only (left), Meteosat-10 using active data only (middle) and Himawari-8 after application of first guess check (right).**

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. 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 suitable for Himawari-8.

Assimilation experiments

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 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 below 150hPa everywhere and in the tropics (±25˚) between 150hPa and 300hPa

Figure 3 illustrates the impact on the error in the vector wind forecast when verified against 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 than when using MTSAT-2 by around 40% throughout 500-200hPa.

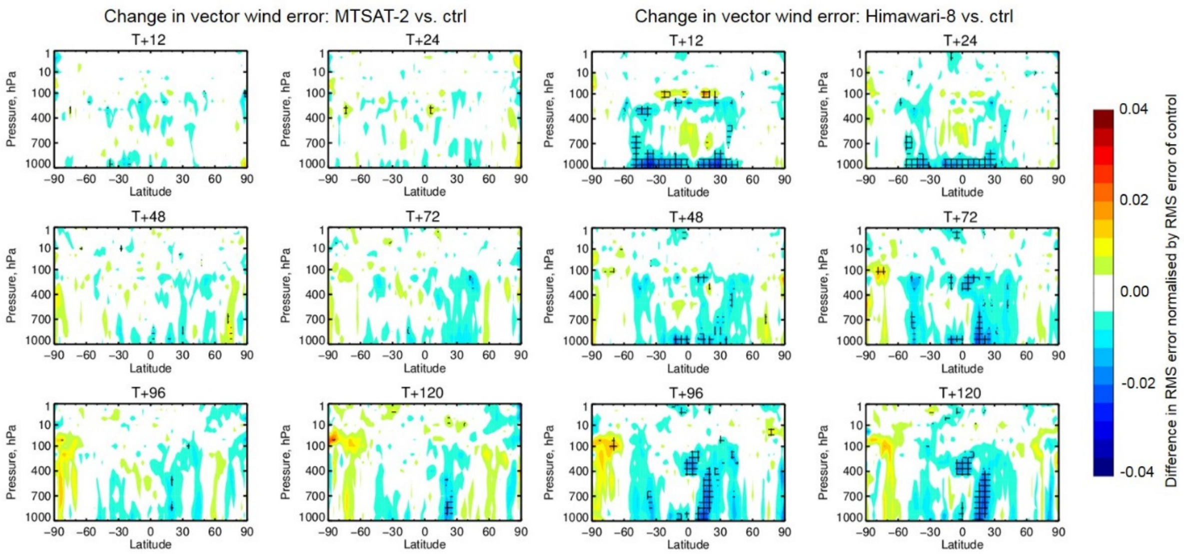

Figure 3: **Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons. Data are from MTSAT-2 (left) and Himawari-8 (right) experiment versus the control. Cross hatching indicates 95% confidence.**

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 these unusually 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.

A further experiment tested the addition of the two remaining water vapour channels. 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, one season experiment (27th April - 11th September 2016) was run for Meteosat-10 which compared the use of only one against two water vapour channels. Unlike Himawari-8, the results showed little impact on the vector wind forecast error and small (0.1%) but significant improvement for humidity sensitive channels on ATMS. However, the signal in the conventional wind observations shows similar, but smaller, negative impacts present again in the tropics (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.

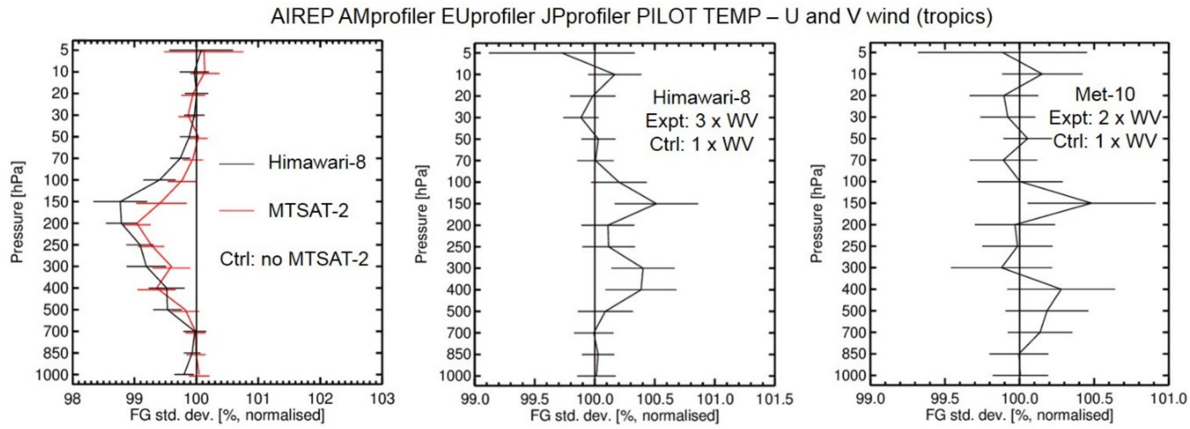

Figure 4: **Change in first guess departure standard deviation for conventional wind observations (U and V components combined) in the tropics. Left panel: addition of Himawari-8 (black) or MTSAT-2 (red) compared to a control with no MTSAT or Himawari-8 AMVs. Middle panel: addition of further two water 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).**

When considering a sample of data from Himawari-8 (5 days) and Meteosat-10 (10 days), there were many AMVs that appeared to be duplicated across the different water vapour channels. These are subsequently thinned out in assimilation and extra AMVs by adding another channel - “non-duplicate” data - were mostly found in the longer wavelength channel. Compared to the AMVs common between the channels, these non-duplicates were on average at a higher pressure and showed fewer AMVs with higher forecast independent QI values. For both satellites this also corresponded to slightly higher standard deviations of the first guess departures in the non-duplicate AMVs and for Meteosat-10 the wind speed bias was also larger in the non-duplicate AMVs. Where clouds are located beyond the sensitivity of the shorter wavelength channels, this may indicate 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.

VIIRS

Distribution of observations

Similar to assessing Himawari-8, AMVs from VIIRS have both a different instrument design and new derivation algorithm compared to wind from the current polar orbiters. 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 derivation. Compared to MODIS or AVHRR on the NOAA satellites (not shown) there are far more AMVs for VIIRS. 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 EBBT method for AVHRR. It is a little surprising that the differences are so large and it is not presently clear 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.

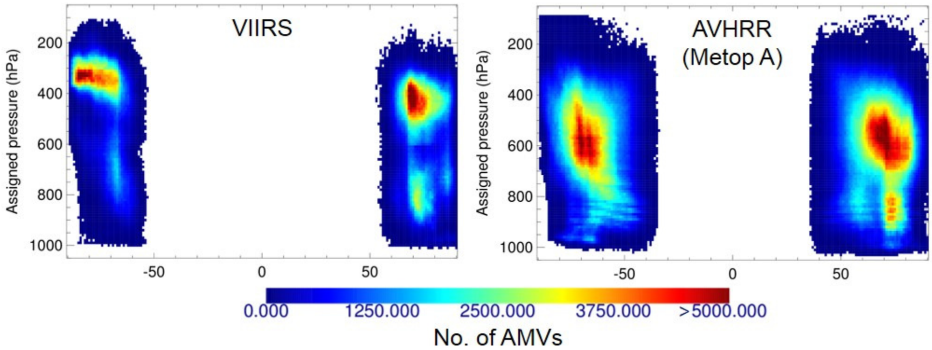

Figure 5: **Zonal dependence of the total number of observations for all available infrared AMVs for 1st October - 30th November 2016 for VIIRS (left) and AVHRR Metop A (right).**

Data quality

Overall the quality of the AMVs from VIIRS is comparable to Metop A. Figure 6 illustrates the RMSVD for both instruments 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 in the respective densest regions of AMVs. The dependence of the RMSVD on forecast independent QI (not shown) has a general decline in RMSVD as the QI value rises to around 65. There is 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.

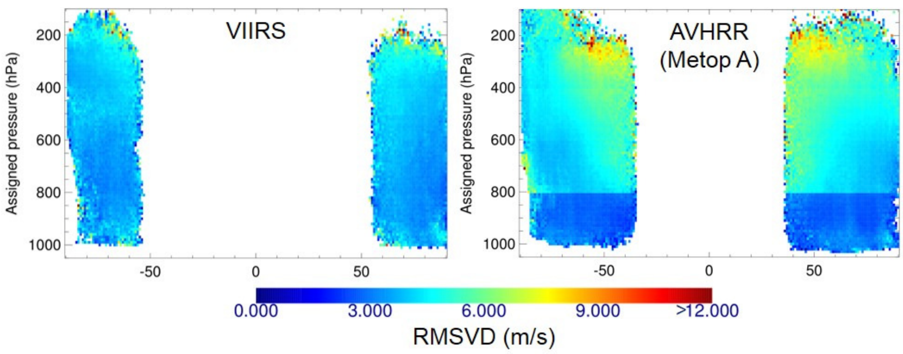

Figure 6: **Zonal dependence of the RMSVD for infrared AMVs after first guess check has been applied for 1st October - 30th November 2016 for VIIRS (left) and AVHRR Metop A (right). (Note that the sharp transition at 800hPa for AVHRR is due to the use of default observation errors in the screening calculation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

The speed bias (not shown) is slightly different in pattern between VIIRS and Metop A. 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. However, speed biases at higher, mid-level pressures are generally slightly positive for the VIIRS AMVs. Interestingly, the new AMV derivation algorithm applied to VIIRS especially tries to reduce slow biases (Bresky et al., 2012). In the best-fit pressure statistics the pressure bias around the dense areas of AMVs is similar although slightly more positive in regions of fewer AMVs for VIIRS compared to the equivalent areas for Metop A. The standard deviation of the best-fit pressure, which is an important indicator of the height assignment error (Salonen et al., 2012), is generally lower for VIIRS.

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 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 7) in the very short range forecast. Changes are more modest, especially compared to those seen earlier for Himawari-8, as in this experiment the data enhance existing 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° at pressures below 700hPa is mostly below 10%.

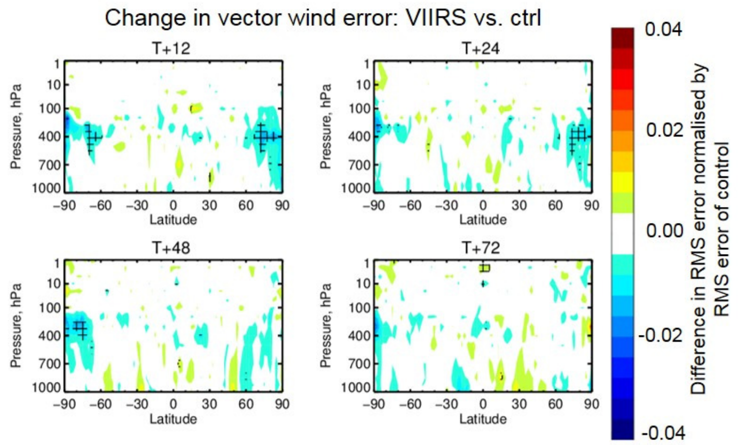

Figure 7: **Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons for VIIRS experiment versus the control. Cross hatching indicates 95% confidence.**

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. Changes that were significant were small (around 0.1%) and usually affected isolated pressure levels/channels rather than larger portions of the atmosphere. The winter season performed slightly better with a larger proportion of the small positive results. There was a consistent pattern across both seasons and for wind and humidity observations that the northern hemisphere has a tendency towards positive results while the southern hemisphere was more negative (though mostly not significant). The distribution of AMVs was more different in the southern hemisphere compared to the other polar orbiting satellites and perhaps the slower speed bias of these AMVs is causing a small negative interaction. However, results with a negative signal are small and do not appear to translate to larger medium-range forecast errors.

SUMMARY

AMVs from two new satellites have been introduced into the ECMWF operational forecast system. Himawari-8 replaced MTSAT-2 on 15th March 2016 while AMVs from the VIIRS instrument were added to enhance the current polar data on 11th August 2016. New instrument design and AMV algorithms gave both datasets different characteristics to other satellites currently in use. Good data quality was found through assessment with first guess departure statistics, and favourable forecast impacts led to the inclusion of the data.

Overall, the data quality of Himawari-8 was improved significantly from its predecessor, 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 unusually 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. An attempt to use all three water vapour channels resulted in negative impacts on the forecast system. Further experiments showed that Meteosat-10 produced a similar signal with the use of one or two water vapour channels. A preliminary assessment suggests that new data assimilated by adding a further channel may be of lower quality than AMVs common to different channels. 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.

AMVs from the VIIRS instrument were of comparable quality to AVHRR on Metop A. The distribution of observations differed from the other polar orbiting satellites but there were no issues apparent in the first guess departure statistics to indicate incorrect placement. 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 generally neutral. VIIRS data are a beneficial addition and provide resilience to polar orbiting AMVs which led to their operational implementation on 11th August 2016.

ACKNOWLEGDEMENTS

Katie Lean is funded by the EUMETSAT Fellowship Programme.

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