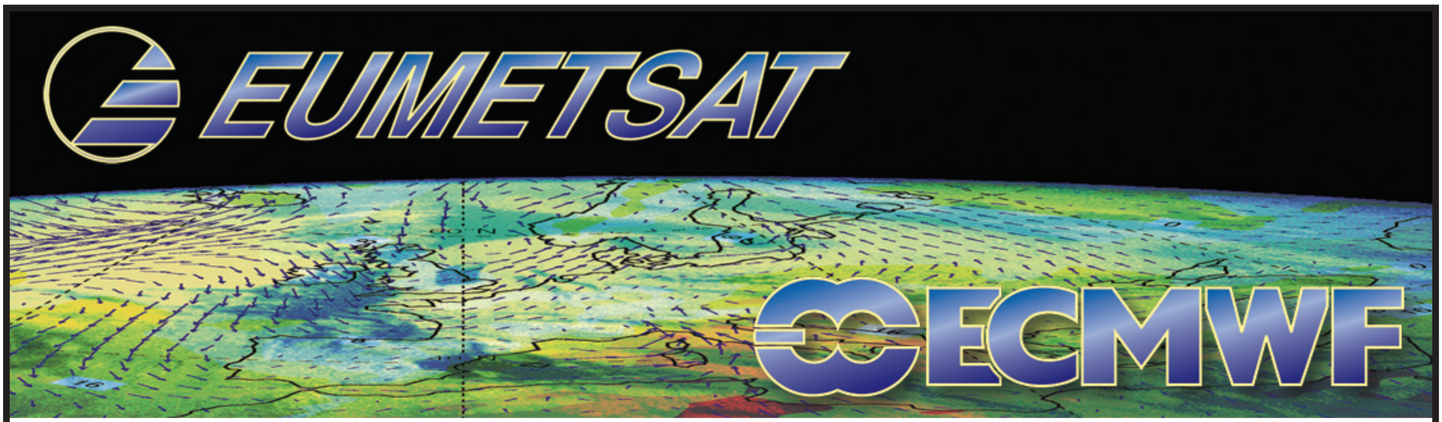

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Assessment of Himawari-8 AMV data in the ECMWF system

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Contents

Abstract

This report evaluates Atmospheric Motion Vectors (AMVs) from Himawari-8 in the ECMWF system and compares the results to findings for its predecessor, Multifunction Transport Satellite - 2 (MTSAT-2). Himawari-8, carries a more advanced imaging instrument and a new method has been developed for the AMV derivation. AMVs from the new satellite were first analysed using first guess departure statistics, followed by assimilation trials.

The quality of Himawari-8 data exceeds that of MTSAT-2 and even prior to any screening it is comparable to MTSAT-2 data that has passed through the strict quality control applied for assimilation. Many more AMVs are available due to changes both in the instrument and algorithm with significant changes found in the geographical and height distribution. A large number are also assigned heights at unusually high pressures, most likely a result of surface contamination of the cloud top radiance, however there were no obvious detrimental effects.

The assimilation of Himawari-8 AMVs gives positive impacts on the forecast vector wind fields exceeding the effects of MTSAT-2, especially at low levels and in the tropics. There are also significant improvements in the fit of conventional wind observations (around 1% reduction in error in the tropics). The final channel selection is similar to the configuration for MTSAT-2 AMVs, and in particular makes use of data from only one of the three available water vapour channels, but still increases the global total number of AMVs assimilated by around 40% compared to MTSAT-2. Further refinements were attempted with the addition of remaining water vapour channels and the removal of the near surface AMVs, but these modifications showed no clear benefits. Himawari-8 AMVs have been assimilated at ECMWF since 15th March 2016.

1 Introduction

The imaging instrument on board the geostationary MTSAT-2 satellite provided AMVs which have been used in the ECMWF assimilation system since August 2010. The successor of MTSAT-2, Himawari-8, was launched in October 2014 and is also operated by the Japan Meteorological Agency (JMA). It carries the Advanced Himawari Imager (AHI) which provides data allowing the derivation of AMVs. The new satellite covers almost the same area of the globe, being positioned at 140°E (5° further west then MTSAT-2). AHI is more advanced than the MTSAT-2 Imager instrument with higher spatial resolution (up to two times higher). There is also the capability to produce full-disk images every 10 minutes (Shimoji, 2014), reduced from 24 minutes, allowing better tracking of cloud features. The AMVs are provided hourly for both MSTAT-2 and Himawari-8. AHI has an extended set of channels, 16 channels compared to 5 on the MTSAT-2 imager allowing AMVs from two further water vapour channels (Table 1) and also providing more information for the AMV height assignment.

As well as improvements in the imaging instrument, new tracking and height assignment algorithms have been developed by JMA for the Himawari-8 AMVs (further details can be found in Shimoji (2014)). The tracking method now incorporates small (7x7 pixel) and large (31x31 pixel) target boxes (private communication, K. Shimoji). The cross correlation calculation in the tracking is still the same as for MTSAT-2 but now the computation is carried out first with averaged correlation surfaces using the small and large boxes. Two vectors, one used in forward matching and one for backward matching, are derived for each of the small and large boxes. These are used as a consistency check to quality control the final output wind vector which is derived using an average of the two averaged correlation surfaces (small and large boxes) previously used. For the height assignment method, a new approach has been developed based on optimal estimation which combines both radiance and motion vector information. This is a complex statistical procedure which gives a multi-layer solution for the height assignment. Generally, the top layer is used for the AMV height but lower layers will be used in the case of small amounts of cloud (defined by an empirical threshold) in the highest layer.

Dissemination of the MTSAT-2 AMV product ceased on 24th March 2016. To ensure full and continuous

Table 1: 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

coverage, the Himawari-8 AMVs replaced MTSAT-2 in the operational system at ECMWF on 15th March 2016. With the extra channels available on Himawari-8 and new processing techniques, a thorough assessment of the new AMVs needed to be carried out before using the data operationally. After the initial implementation, further refinements of channel use were tested which were developed based on earlier experiences. The method and results of this assessment are presented in this report. After initial discussion about the Himawari-8 data sources in section 2, section 3 considers first guess departure statistics (difference between observation and model background values) to analyse the performance of the Himawari-8 data with regard to the quality indicator (QI) values, time and spatial patterns. Initial comparison is primarily with MTSAT-2 although a check with the quality of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) instrument on Meteosat-10 is 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 in section 3. From this analysis, choices about quality control are made and suitable configurations constructed to test the performance of the data in long term Numerical Weather Prediction (NWP) experiments. The experiments for the operational implementation and later refinements are discussed in section 4 and finally section 5 summarises the report and future plans.

2 Data

For the initial analysis, the Himawari-8 data were introduced passively into the ECMWF system i.e. they were included in the first trajectory calculation in 4D-Var but did not contribute any increments to the assimilation scheme. The operational model (cycle 41r1) at the time of testing was used as a base for this monitoring experiment, employing a 12-hour 4DVAR system at T_L639 spatial resolution, with 137 levels in the vertical. MTSAT-2 data were still actively used - this must be kept in mind as it is possible that in the comparison with the model values, MTSAT-2 could receive a slight advantage as the data were being assimilated and thus affecting the model fields. Unless otherwise stated, data for the following analysis are taken from 00Z 19th June - 12Z 31st August. Statistics using the observations minus model background values (first guess departures) are analysed where the background values are provided by the short range forecast from the model cycle 12 hours previous.

For our evaluation we obtained Himawari-8 AMVs from JMA in real time, via FTP during the period 18th June 2015 - 31st August 2015 and via the GTS for later dates (used in winter assimilation experiments). Unfortunately, the timeliness of the FTP data was found to be fairly poor and therefore a significant portion of AMVs did not reach ECMWF before the operational cut-off time. While most AMVs arrived in time for the first 6 hours of the 12-hour delayed cut-off assimilation window, up to 50% of the AMVs were missed for the last hours of the window. In contrast, almost all AMVs arrived before the cut-off time for the GTS data, and

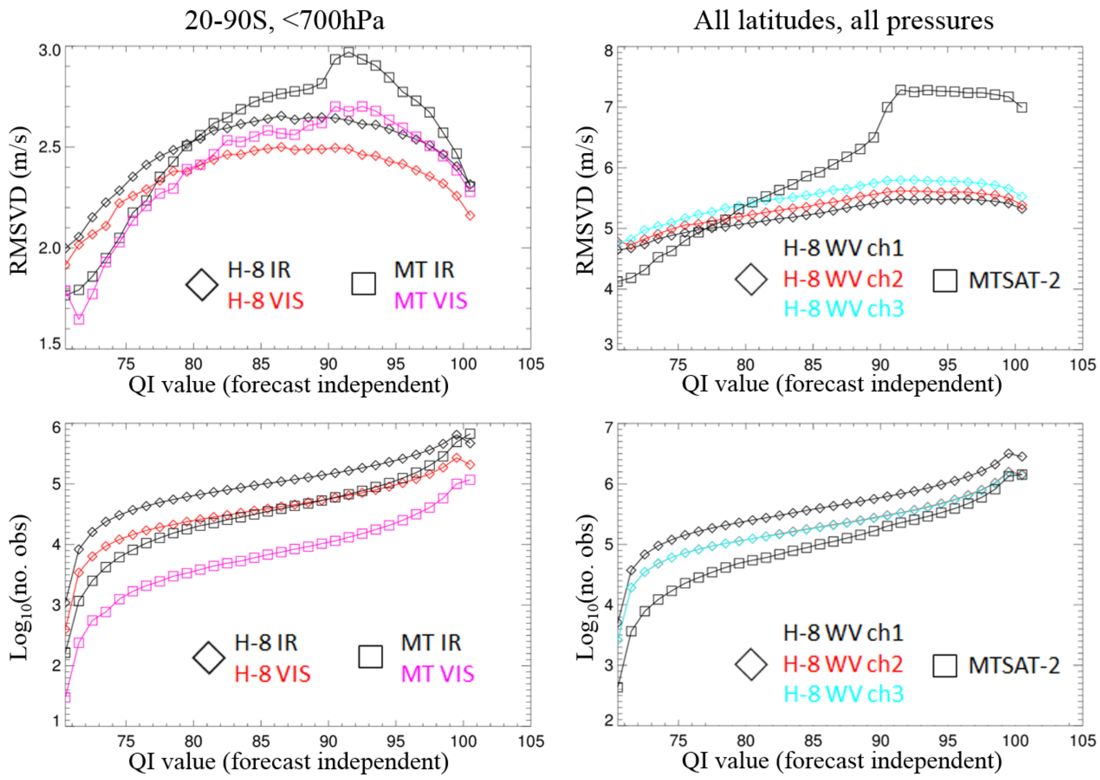


Figure 1: Dependence of the root mean square vector difference on the forecast independent QI (top row) and $\log_{10}$*(number of observations) (bottom row) for the visible and infrared channels (left) for the Southern hemisphere and high pressure band and the water vapour channels (right) for MTSAT-2 and Himawari-8 using all latitude and height bands available.*

timeliness is not an issue. This initial analysis uses Himawari-8 AMVs from the FTP site however, subsequent analysis of the GTS data showed that the conclusions about the data quality presented in section 3 are the same regardless of data source. Timing of observations within the assimilation window has been shown to affect the forecast impact with those towards the end of the window having most influence (e.g. Peubey and McNally, 2009). This means that the impact of Himawari-8 will be greater in the winter season assimilation experiments.

3 Data Quality Analysis

3.1 Quality indicators and screening

Both the Himawari-8 and MTSAT-2 AMVs are provided with two QI types: forecast dependent and forecast independent. While a variety of tests can be incorporated into the QI generation, the forecast dependent version will also include information from a NWP model used at the AMV processing centre (Holmlund, 1998). Generally a threshold is placed on the QI value for data used in the assimilation scheme (MTSAT-2 data are screened with a threshold of 85 on the forecast dependent QI). Note that for the disseminated Himawari-8 data JMA already apply an initial threshold of 70 and 75 for the forecast independent and the forecast dependent QI respectively. In the following we aim to establish whether it is useful to use a tighter threshold to eliminate data of obvious poor quality from Himawari-8 before calculating further statistics.

The dependence of the root mean square vector difference (RMSVD) on the QI value for the different channels shows that there is more consistency in Himawari-8 across the channels. There is also less variation and generally smaller RMSVD values than MTSAT-2 across the range of both QI types. For the forecast dependent QI there is a small ($\sim$1m/s for the water vapour channels) but consistent pattern of improvement in the RMSVD as the QI value increases. However, this may be slightly misleading as for high forecast dependent QI values the AMVs are by design a better fit to the forecast model and this result may only be demonstrating agreement between the ECMWF and JMA short-range forecasts (Holmlund, 1998). For the forecast independent QI, Figure 1 (top row) illustrates that the RMSVD does not show a trend for improvement as the QI value increases making a threshold for screening difficult to establish. The number of AMVs assigned each QI value (Figure 1, bottom row) shows that especially for QI $>$ 75 there are sufficient data to give confidence in the pattern of RMSVD. The cause for the poorer performance of the forecast-independent QI is not known, and it is in contrast to the behaviour seen, for instance, for Meteosat satellites (e.g. Delsol et al., 2007).

The dependence of the Himawari-8 RMSVD on either QI type is quite small and use of the forecast dependent QI is less desirable so it was decided that there would be little advantage to use a threshold on the data prior to further assessment. Later results will be used to develop other blacklisting measures to apply before assimilation. When we compare our results to those for MTSAT-2, we will show results for all available MTSAT-2 AMVs, but also for a quality-controlled sub-sample, referred to as active data. The active data are the quality controlled data set used in assimilation and must pass three selection steps before use:

1. Blacklisting: data are subject to quality control through spatial and temporal screening, use of QI thresholds and channel selection.
2. First guess check: data are rejected if the difference between the observation and model first guess is too large. A strict threshold is used in this criterion leading to the removal of a significant number of AMVs (e.g. Salonen and Bormann, 2012).
3. 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.

Through all the analysis presented here it should also be kept in mind that MTSAT-2 has far fewer observations and the large reduction in the assimilation process means that the active only dataset is very small in comparison to the Himawari-8 data volumes.

3.2 Spatial statistics

3.2.1 Distribution of observations

The number of AMVs produced for Himawari-8 per hour time slot is much higher not just due to having more channels but equivalent channels have many more winds available (especially for the infrared (2-3 times larger) and visible (up to 10 times higher)) largely due to the new derivation algorithm (Shimoji, 2016). As well as having more AMVs, their distribution has changed significantly between Himawari-8 and MTSAT-2. Figure 2 shows a map of the total number of observations for the high level AMVs for a water vapour channel. The AMVs at high levels in Himawari-8 are now concentrated much more around the tropics. There is also an unusual symmetrical ring pattern in the numbers of observations present in Himawari-8 (Figure 2). The cause was explained by JMA (private communication, K. Shimoji) as an artefact of the conversion between

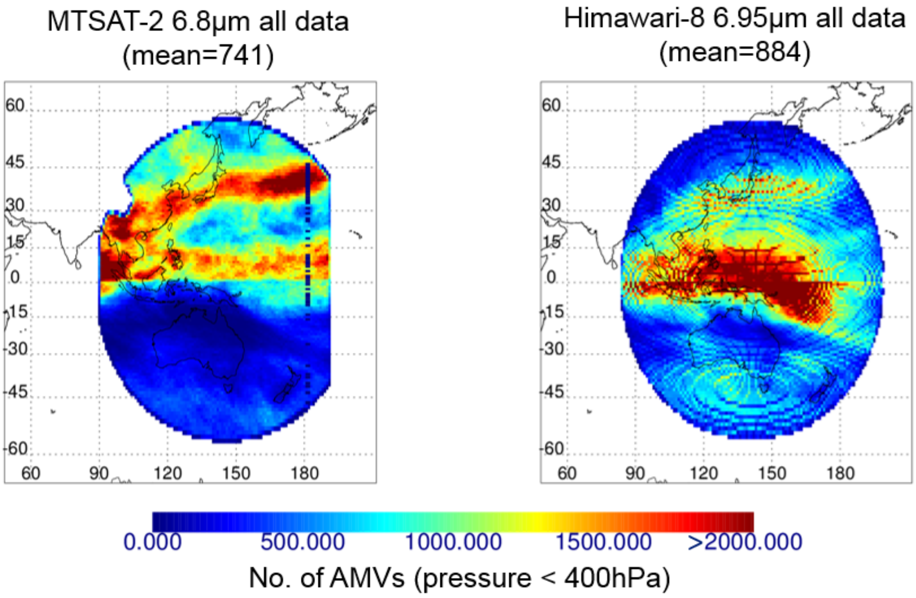


Figure 2: Total number of observations at high level (<400hPa) using all available MTSAT-2 6.8µm data (left) and Himawari-8 6.95µm data (right)

co-ordinate systems when processing the data. For Himawari-8, calculations are initially carried out on a pixel-line grid (imager co-ordinates) in order to avoid issues with strong correlations. Then there is a later projection to regular latitude/longitude (geophysical co-ordinates) which introduces the pattern seen here. For MTSAT-2 the projection to the geophysical co-ordinates has already been carried out before the AMVs are calculated.

Zonal maps in Figure 3 show changes in the height distribution as well as latitudinal differences. AMVs are now available from a greater range of pressures including visible winds at pressures less than 700hPa where they are unavailable for other satellites. For high level winds, the highest densities, particularly for the water vapour channels, 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 bias in the difference between observation and model best-fit pressure values can be used to indicate systematic problems with the AMV heights compared to the model wind fields (discussed further in section 3.4). For the water vapour channels there is a reduction of a positive pressure bias (where the AMV assigned pressure is too high compared to the model background wind profile) 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 3) and the visible channel (not shown), AMVs are now 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 values of low level cloud bases and hence appear questionable (Medeiros et al., 2010). Other satellites such as Meteosat-10 tend to have very few AMVs at such high pressures.

Investigations using a sample period 15th March - 5th April 2016 of AMVs found that the near surface winds are mostly confined to specific regions. In particular, there are two smaller areas to the west and east of Australia and a large band across the Pacific Ocean centred around 10-15°N. Corresponding satellite images suggested these AMVs are occurring in situations of small broken stratocumulus clouds. Details from JMA

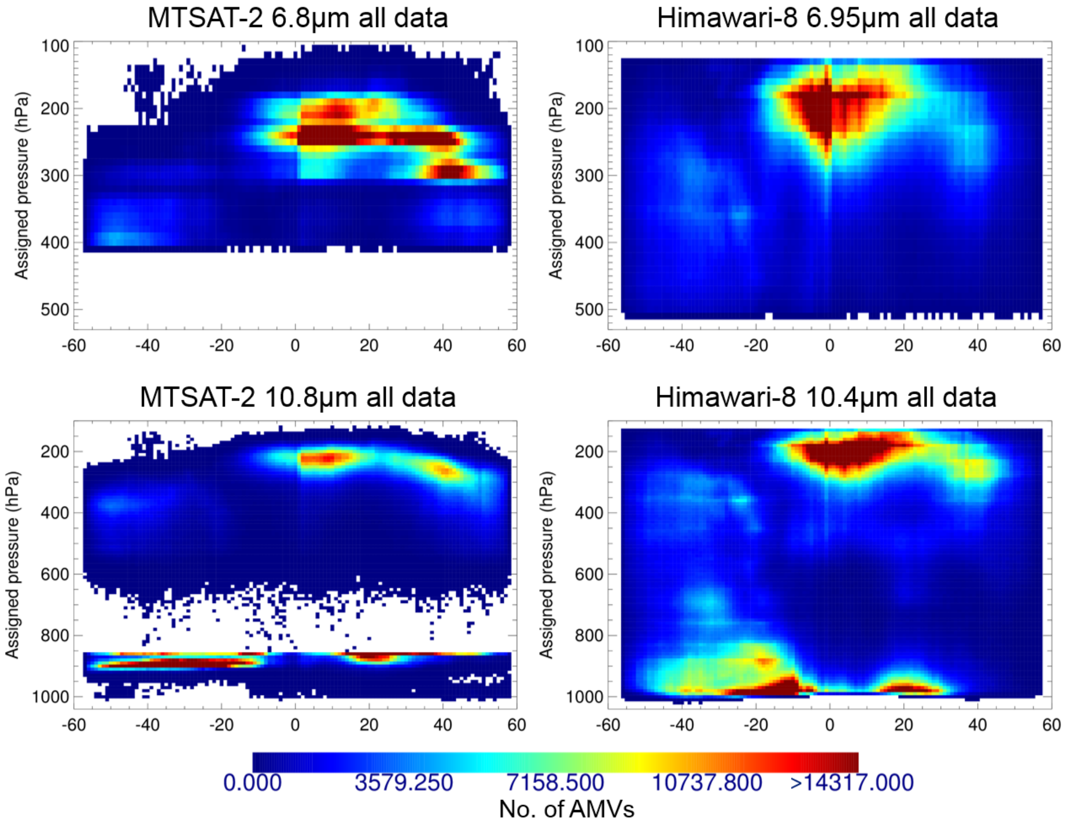


Figure 3: Zonal dependence of the total number of observations for MTSAT-2 using all data (left column) and all data from Himawari-8 (right column). The top row is for a water vapour channel (6.95µm) and the bottom row for the infrared channel.

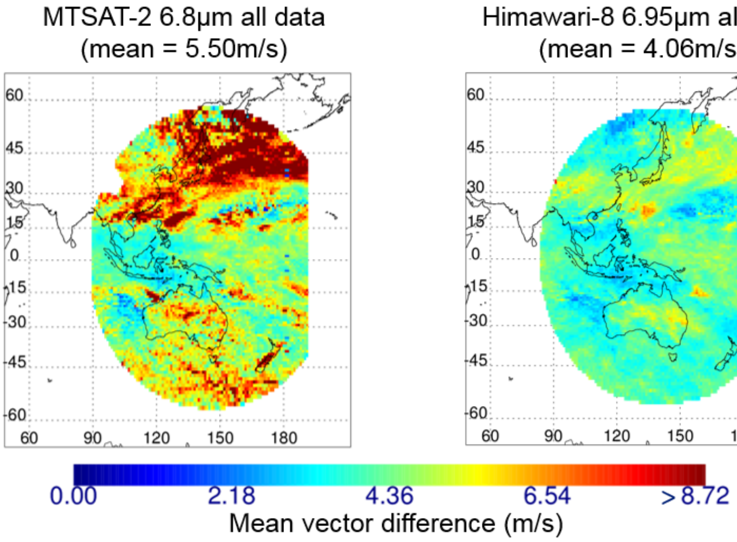


Figure 4: Mean vector difference for water vapour channel at high level (<400hPa) using winter data (17th Nov - 13th Dec) with all MTSAT-2 data (left) and all Himawari-8 data (right). Note that in order to illustrate the winter period, the Himawari-8 AMVs come from the GTS data stream.

(private communication, K. Shimoji) propose 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 unusually low AMVs.

Interestingly, the statistics such as the RMSVD, speed bias (discussed further in section 3.2.2) or best-fit pressure analysis (discussed further in section 3.4) did not confirm any large scale errors across this low level region. Since the quality of these near surface AMVs was not obviously degraded there was initially no attempt to exclude them in further analysis or in testing the longer term forecast impacts. In fact, experiments showed the effects of assimilating these AMVs were quite favourable (discussed later in section 4).

3.2.2 Data quality

Overall there is a clear improvement in the Himawari-8 departure statistics compared to MTSAT-2. Figure 4 shows the mean vector difference for high levels winds from one of the water vapour channels. The large seasonal differences introduced during winter in the northern hemisphere in MTSAT-2 have been removed so this area will no longer require blacklisting in the Himawari-8 data. In both seasons the vector difference appears much more homogeneous for Himawari-8 and the average difference of the 1°x1° gridded data in the summer season is the same as the active only MTSAT-2 data value of 4.5m/s (not shown).

Even when comparing to the assimilated MTSAT-2 data only, with the advantage of quality control, the Himawari-8 data with no screening are generally already of similar quality. Figure 5 illustrates the zonal dependence of the RMSVD for one water vapour channel and one infrared channel comparing all data from Himawari-8 to the active data only from MTSAT-2 and also the active data only from the SEVIRI instrument on Meteosat-10. The RMSVD values are broadly similar to the statistics of the active data of both MTSAT-2 and Meteosat-10 and much improved when compared to all the MTSAT-2 data available (not shown). Similar to the other two satellites, Himawari-8 shows elevated values of RMSVD ($\sim$8m/s compared to 4-6m/s) at very low pressures. The speed bias is also more negative in the same region (Figure 6) although similar in magnitude

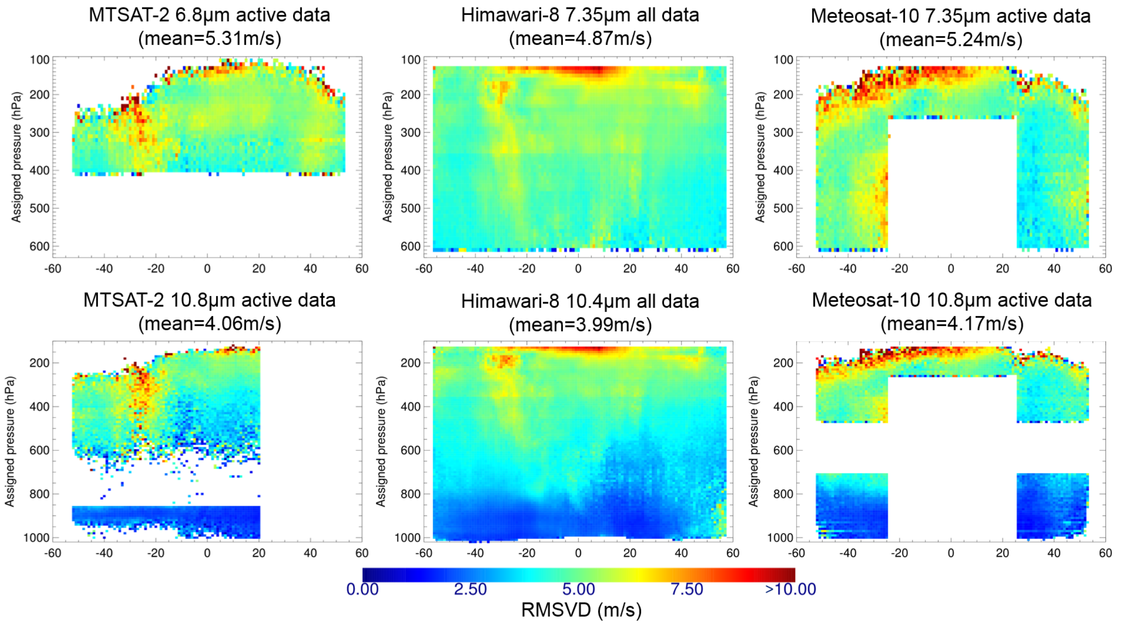


Figure 5: Zonal dependence of RMSVD for MTSAT-2 using active data only (left), Himawari-8 (centre) and Meteosat-10 using active data only (right). The top row is for a water vapour channel and the bottom row for the infrared channel.

(up to about 2.5m/s) compared to AMVs at high pressure. As for the RMSVD, the speed bias for Himawari-8 is considerably improved from MTSAT-2 prior to quality control. Note that around the regions of unusually near-surface AMVs discussed in section 3.2.1 there is no obvious degradation across the various statistics.

3.3 Time Dependence

Both MTSAT-2 and Himawari-8 AMVs are distributed as an hourly product. For MTSAT-2, there was a dip in the hourly total number of AMVs every six hours. This pattern has been investigated in earlier studies and attributed to the scanning pattern of the imaging instrument (Bormann et al., 2012). Himawari-8 no longer has this feature and has a more stable number of AMVs across the whole 24 hours. For the two shorter wavelength water vapour channels the number of observations for each hour appears to be capped and does not vary in the more natural way of the other channels. Although it is not clear why the limit is imposed, a cap on the observation count has been noted in other AMV data sets e.g. INSAT-3D (Salonen and Bormann, 2015).

Figure 7 illustrates the RMSVD and speed bias as a function of the hour recorded for the Himawari-8 and MTSAT-2 data (without quality control) for the time period 19th June - 31st August 2015. The Himawari-8 data show a much smaller range e.g. the bias for each channel varies less than 0.5m/s whereas for the water vapour channel on MTSAT-2 there are differences up to 1m/s. A six hourly cycle is also clear in the statistics for MTSAT-2 coinciding with the pattern in the number of observations mentioned earlier. The water vapour channels of both satellites show an overall positive speed bias, larger for MTSAT-2. The visible winds from Himawari-8 appear to have a much larger RMSVD (around 4m/s compared to 2-3m/s on MTSAT-2). However, this is a result of different pressure coverage in the data used in the calculation - for Himawari-8 the visible winds extend throughout the troposphere while MTSAT-2 visible winds are restricted to below 700hPa. In the equivalent pressure range, the Himawari-8 RMSVD is actually slightly lower than MTSAT-2.

For the Himawari-8 data, the values of RMSVD and the speed bias show a saw tooth pattern where the values

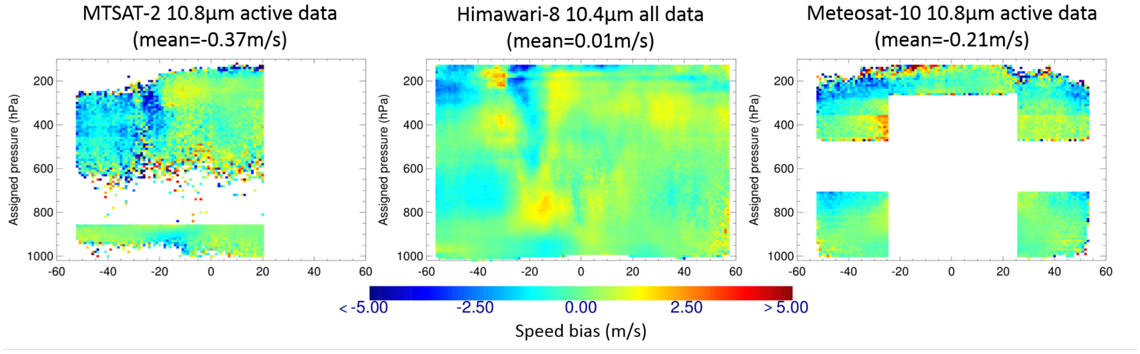


Figure 6: Zonal dependence of speed bias for MTSAT-2 using active data only (left), Himawari-8 (centre) and Meteosat-10 using active data only (right) from the infrared channel.

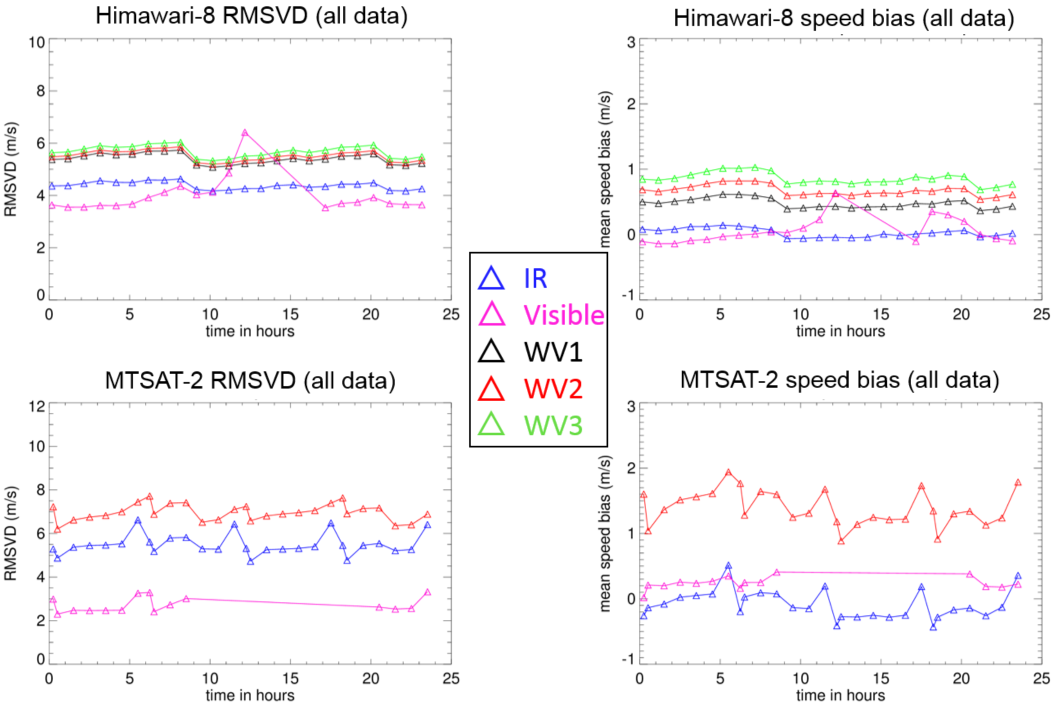


Figure 7: Time dependence of the RMSVD (left column) and speed bias (right column) for Himawari-8 (top row) and from MTSAT-2 (bottom row) for the time period 19th Jun - 31st Aug 2015

gradually increase to 08/20Z before a step decrease in the following hour which also corresponds to the start of the assimilation time window. The mean speed recorded for each hour (not shown) is relatively unchanged across the 24 hours so this pattern in speed bias suggests that the model wind may be getting slower by the end of the assimilation window. There is also a rise in RMSVD throughout the time period of the assimilation window. A coincidental change in the quality of the AMVs would be unlikely and further to this, a similar though less pronounced pattern is present for Meteosat-10 (not shown). This result most likely highlights the growth of error in the background field through the time window after the increments are applied at the start of the 12 hour window (at 9Z and 21Z). This error growth has not been observed with AMV data before, and the finding is a reflection of the high quality and good temporal consistency of the Himawari-8 AMVs.

3.4 Observation errors

Before use in the assimilation system, the AMV observation errors must be defined. The total observation error is situation dependent and combines the error in the tracking with the error in the speed due to the error in the height. The use of these situation dependent errors has already been successfully implemented at ECMWF and the Met Office (Forsythe and Saunders, 2008; Salonen et al., 2012; Salonen and Bormann, 2013). These are calculated for each channel, each available height assignment method and for pressure bands of width 200hPa from 0 to 1000hPa. For Himawari-8, all AMVs use the same height assignment method, so no distinction by height assignment method is required.

3.4.1 Height errors

The wind error caused by an error in the height assignment is estimated by using the variation in the wind profile of the model background about the assigned height, assuming the error in the assigned pressure is Gaussian with a standard deviation of E_p. This is calculated separately for u and v components of the wind. E_p is estimated by the standard deviation of the (assigned - best-fit pressure). The best-fit pressure is the pressure at which the vector difference between the observed AMV and model background wind is the smallest (Salonen et al., 2012).

The standard deviation and bias of these best-fit pressure statistics have been calculated using all the available AMVs (Figure 8). Across all of the channels, Himawari-8 standard deviations are lower than MTSAT-2. The water vapour channels show the best agreement between satellites in magnitude of values and the pattern of general increase as the pressure increases. The positive systematic pressure bias suggests that the AMVs are placed too low compared to the model in both cases with a greater effect for MTSAT-2. For visible channel AMVs, the bias and standard deviation is comparable for Himawari-8 at high and the newly available low pressures. Meanwhile, the infrared channel shows the greatest difference between satellites. A zonal plot (not shown) of the standard deviation reveals that values are elevated in the tropic regions for Himawari-8 at mid and low levels which is not a feature present in the MTSAT-2 data.

When using all the data, problems with MTSAT-2 at low levels are highlighted by the large values in statistics in the 800-1000hPa band. Here, the Himawari-8 visible AMVs have a standard deviation around 50hPa lower than MTSAT-2. For Himawari-8, the 800-1000hPa band is dominated by the unusually low level winds but does not show elevated values of pressure bias or standard deviation. Focusing on just the dense regions of near surface AMVs, values of height error are not particularly elevated and comparable to AMVs at other heights suggesting there no high sensitivity to a misspecification of height in these situations. Pressure statistics were also calculated with a subset of quality controlled data screened using a forecast dependent QI threshold of 85 and the first guess check (not shown). Values of bias and standard deviation for MTSAT-2 are much closer after quality control but continue in most cases to be slightly larger in magnitude (around 10-20hPa). For use

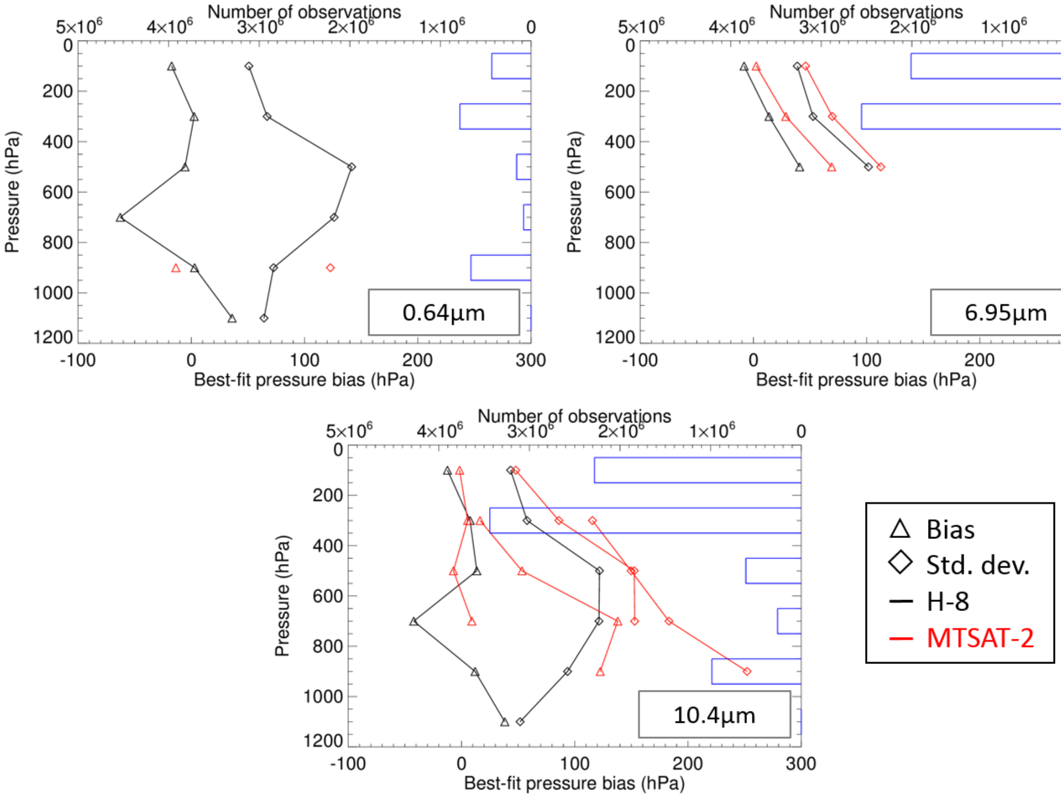


Figure 8: Assigned - best-fit pressure bias and standard deviation for each 200hPa band for (clockwise from top) visible, water vapour and infrared channels. The values are calculated from all the data. Bars show the number of observations for Himawari-8 data. Multiple points for MTSAT-2 at the same pressure level represent the different height computation methods.

in assimilation, values of height assignment error using all the data as shown here were used for Himawari-8 making the estimates used generally lower than the operationally used values for MTSAT-2.

3.4.2 Tracking errors

The tracking error can be estimated by considering the standard deviation of the observed - background wind speed for cases where the error in height assignment is small (Salonen and Bormann, 2013). This is considered separately for the u and v components and for pressure bands of 200hPa. In practice, all geostationary satellites have been assigned the same tracking errors which vary between 3m/s at low pressure and 2m/s at high pressure. It was found for all the different pressure bands that the current errors used for all other geostationary satellites were sensible for application to Himawari-8.

4 Assimilation experiments

Initial analysis shows promising results for Himawari-8 AMVs. As well as improved data quality, there is a large increase and new distribution in observation numbers. The changes are sufficient that assimilation experiments of Himawari-8 are required to find the most beneficial use of the data in the forecast system. To assess the impact on the forecast, a control was run which closely mimics the current operational system at the time (cycle 41r1) but with a model resolution reduced to T_L639. MTSAT-2 was also removed in the control as this would be the situation when introducing Himawari-8 data. The experiments then add different configurations of the Himawari-8 data without changing anything else. An experiment that introduces MTSAT-2 back into the system was also carried out for comparison.

Experiments were run over two seasons, covering the period 19 June to 30th September 2015 and 17th November 2015 to 28th February 2016. Note that for the first period we use Himawari-8 data obtained from the FTP-site and hence the data availability is not as good as for the second period, as discussed in section 2. The thinning procedure (200km horizontal, 50-175hPa vertical and 30 minutes thinning) and the first guess departure check for the Himawari-8 data remained the same as for MTSAT-2. While different channel specific blacklisting is trialled, general restrictions across all channels e.g. on zenith angle are also 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. Observation errors calculated using all the available Himawari-8 data were used.

4.1 Operational configuration

The final channel selection chosen for operational use is more conservative and similar to MTSAT-2. In particular, only one of the three water vapour channels is used. The spatial blacklisting allows Himawari-8 AMVs to be used 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 ($\pm 25°$) between 150hPa and 300hPa

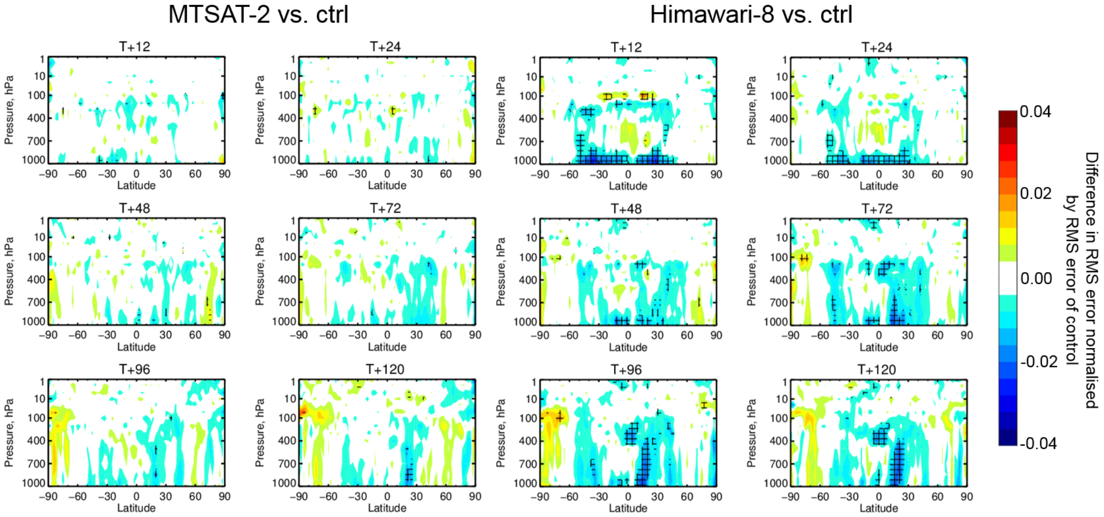


Figure 9: Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons. Data are from (left) MTSAT-2 and (right) experiment versus the control. Cross hatching indicates 95% confidence.

Results from experiments with more relaxed data usage showed that the exclusion of AMVs above 150hPa was necessary due to significant degradation in the short range forecast errors for vector wind. Similarly, mid-level infrared winds were excluded in the tropics due to poor short-range forecast impact, combined with unfavourable departure statistics and larger height assignment biases in these areas. Results from testing the addition of the further two water vapour channels are discussed in section 4.2.

Despite the similar channel selections, the assimilation of Himawari-8 compared to MTSAT-2 increases the global number of AMVs by around 40% for 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). Figure 9 illustrates the impact on the zonal verification against own analysis of vector wind for the operational configuration. For Himawari-8 there is significant improvement at low levels and up to 100hPa in the tropics that persists to day 5 of the forecast. MTSAT-2 generally shows similar patterns in the areas of improvement and degradation however, changes are generally smaller and not significantly positive. In the overall global changes in forecast score for vector wind, the high pressures showed significant reduction in error compared to the control and to MTSAT-2 which was more neutral. In other variables such as temperature and humidity, changes were more aligned with MTSAT-2 and generally neutral.

For the changes in the fits of independent observations to the model background, significant reductions in the standard deviation exceeding MTSAT-2 of up to around 1% in the upper troposphere are seen in the fit of conventional wind observations in the tropics (Figure 10). In the winter season, where even more Himawari-8 data are available particularly in the latter half of the assimilation time window, this improvement is even more pronounced for Himawari-8 at the level of about 100hPa. For the humidity sounding channels (18-22) on Advanced Technology Microwave Sounder (ATMS) both satellites mostly show a neutral to slightly positive impact (0.1-0.2% reduction) (Figure 10) with better results again in the winter season. More generally the impacts on temperature and humidity observations are more modest and mostly neutral as might be expected from adding data only directly providing wind information.

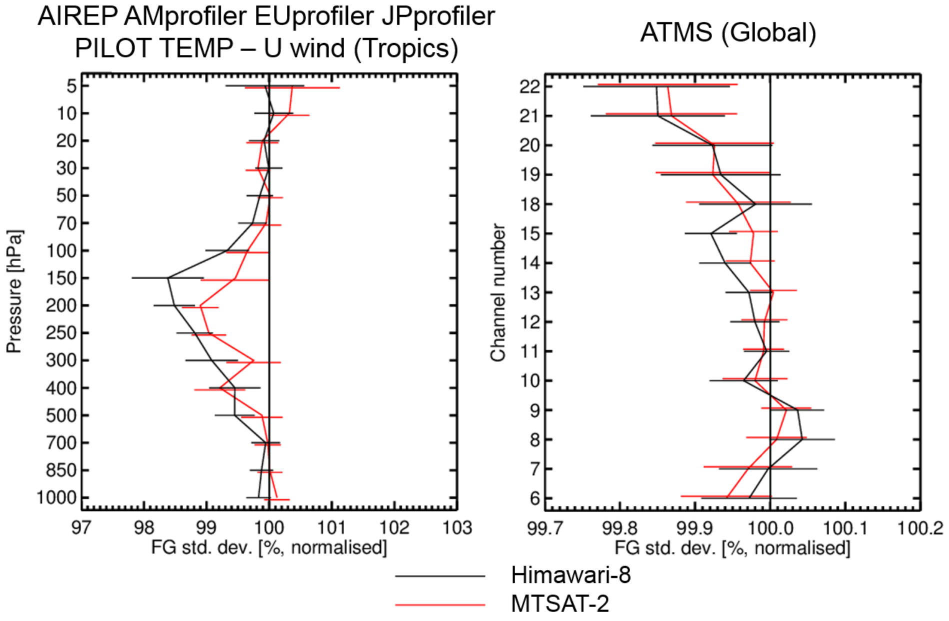


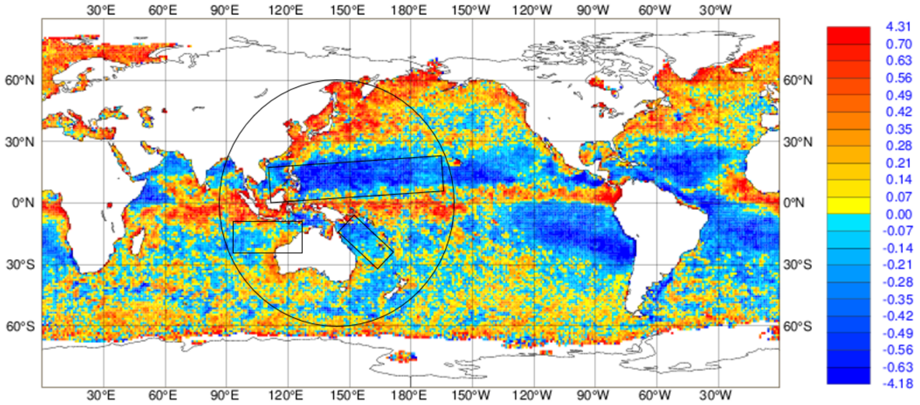
Figure 10: Change in the standard deviation of the first guess departures for the U component of wind from conventional observations in the tropics (left) and for ATMS globally (right) for summer and winter seasons combined.

As there is some uncertainty regarding potential negative effects from including the near surface AMVs, the fit of the 10m scatterometer winds to the model background was also investigated. Figure 11 (lower panel) shows the difference in the 10m wind speed bias (observed - background) for scatterometer winds between the experiment using the final operational configuration for Himawari-8 and the control. For reference, the top and middle panels of Figure 11 also show the actual values of the bias for the control and with use of the Himawari-8 AMVs respectively. When introducing Himawari-8, the pattern of the bias is very similar. However, small but positive differences seen particularly around 10°N and off the east coast of Australia mean a bias closer to zero (improvement) when the Himawari-8 AMVs are used.

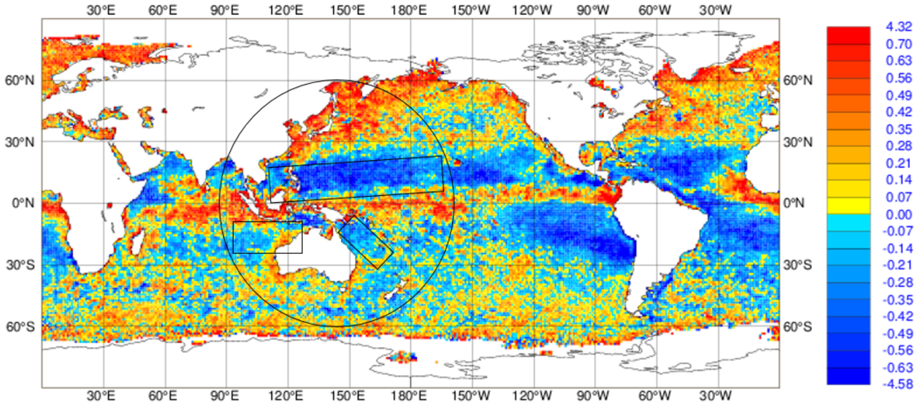
The impact on the mean wind analysis from the introduction of MTSAT-2 and Himawari-8 is shown in Figure 12 (changes in upper level winds at 200hPa) and Figure 13 (changes in lower levels at 850hPa). The impact for both satellites is relatively large as the control has no AMV data in the same region. For upper level winds significant changes are mostly confined to the tropics for both satellites. Data from both satellites have an effect of increasing the wind speed, mostly strengthening the existing wind pattern and introducing a slightly larger eastwards component. Their agreement suggests that both are trying to correct a model bias in this region. The changes are slightly larger for Himawari-8 which may be due to increased number of AMVs concentrated in the tropics as well as the densest area of high level AMVs placed at a lower pressure.

In Figure 13 the change in wind analysis at low levels has less agreement between introducing MTSAT-2 or Himawari-8. Between the two satellites, the differences in the distribution of AMVs in height and latitude/longitude are even greater at higher pressures. Off the north coast of Japan, the Himawari-8 AMVs have the effect of slowing the wind. In the tropical western Pacific, the Himawari-8 AMVs act mostly to strengthen the existing circulation while MTSAT-2 AMVs also increase the wind speed but introduce more of a southward component. Both satellites have a similar effect of increasing the northward flow off the west coast of Australia while slowing the winds along the south coast (the effect is slightly stronger for Himawari-8).

Scatterometer wind speed bias (O-B) at 10m (m/s):
control



Scatterometer wind speed bias (O-B) at 10m (m/s):
Himawari-8 as operationally used



Difference in scatterometer speed bias (O-B) at 10m (m/s):
(Himawari-8 operational – control)

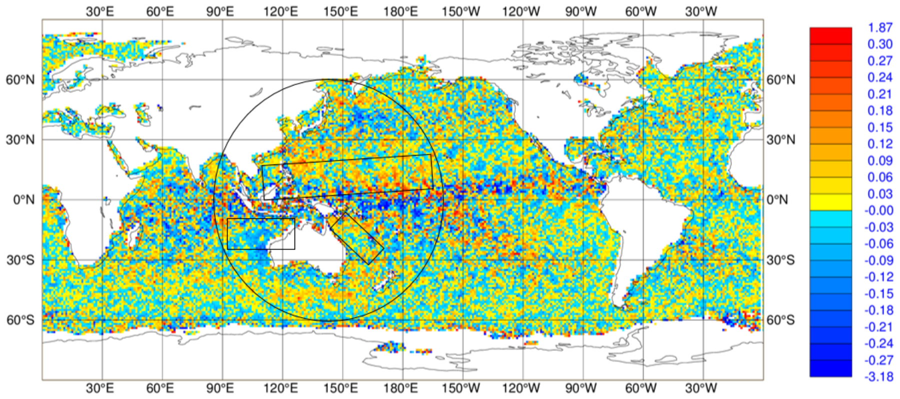


Figure 11: 10m wind speed bias for scatterometer winds in the control (top panel), with the new operational configuration using Himawari-8 (middle panel) and the difference in bias between the new operational and control (no west Pacific geostationary satellite) (lower panel). Circle shows approximate location of Himawari-8 disc and boxes give approximate locations of dense areas of near surface AMVs. Data calculated from 18th Nov 2015 - 18th Jan 2016.

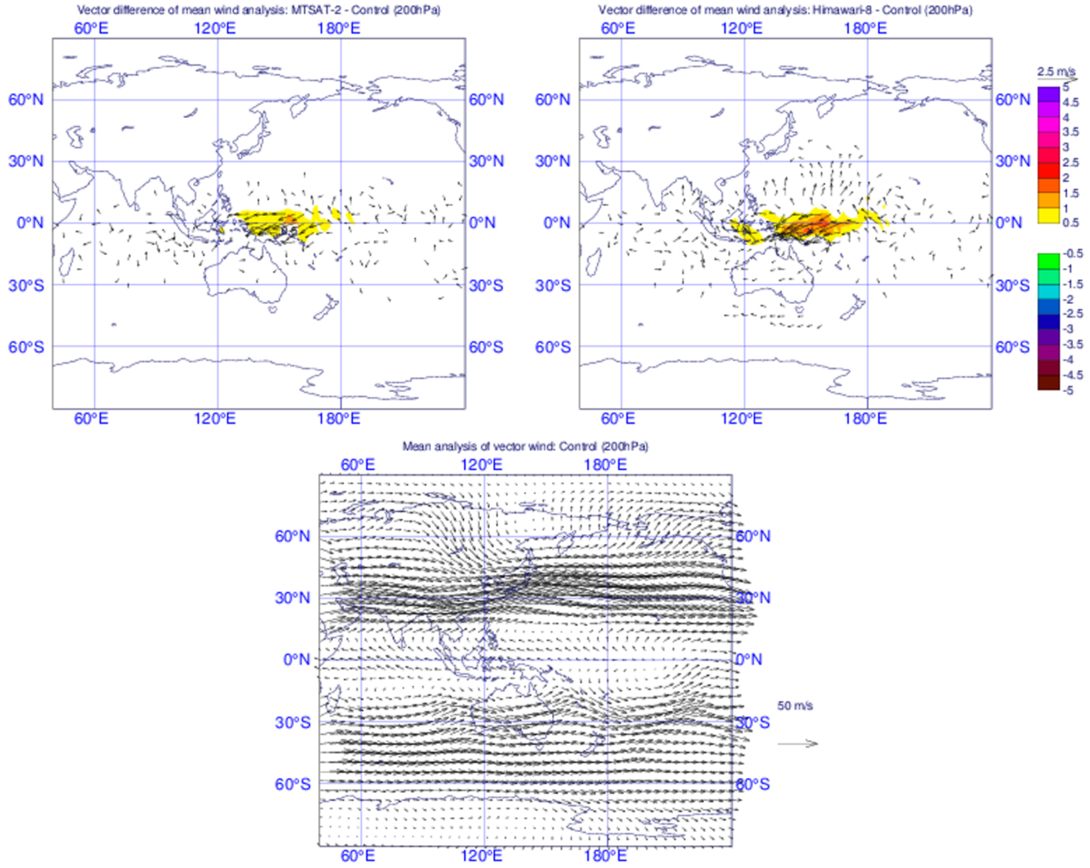


Figure 12: Vector difference of mean wind analysis between MTSAT-2 experiment and control (top left), vector difference of mean wind analysis between Himawari-8 experiment and control (top right) and mean wind analysis for the control (bottom panel). All at 200hPa for 1st Dec 2015 - 31st Jan 2016.

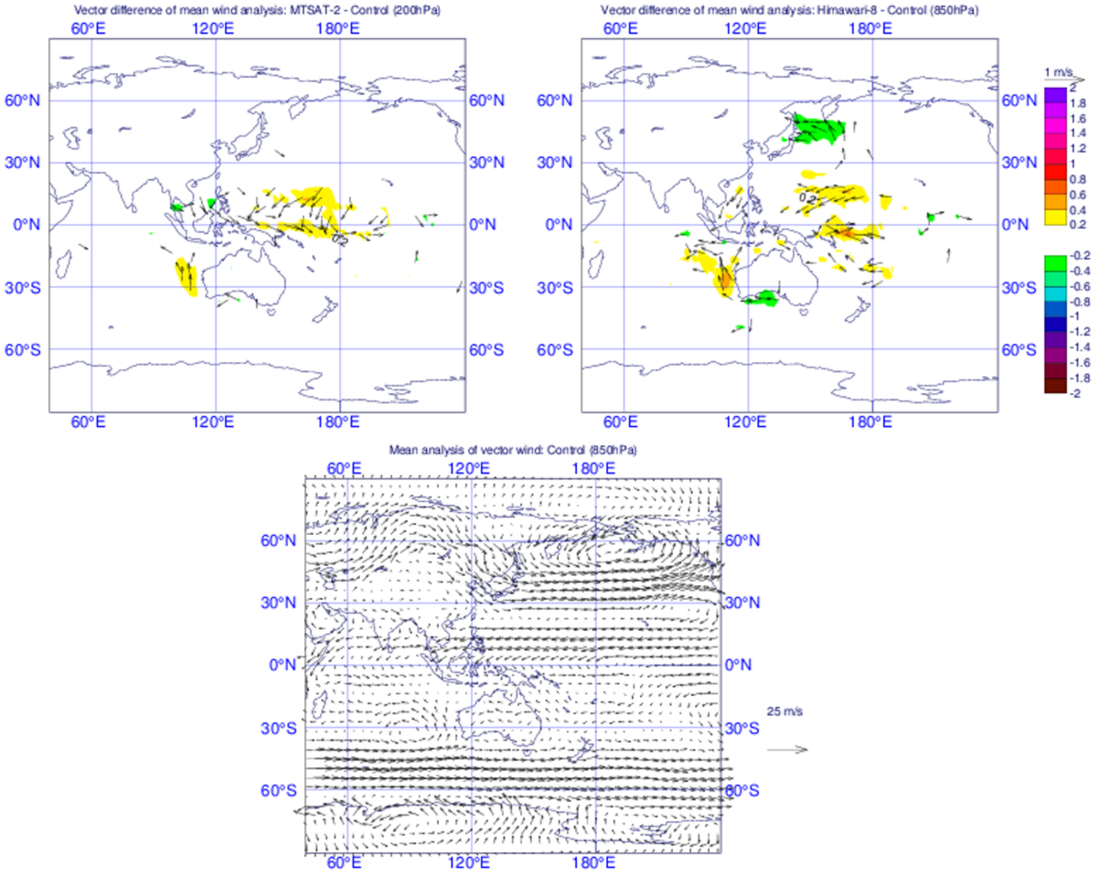


Figure 13: Vector difference of mean wind analysis between MTSAT-2 experiment and control (top left), vector difference of mean wind analysis between Himawari-8 experiment and control (top right) and mean wind analysis for the control (bottom panel). All at 850hPa for 1st Dec 2015 - 31st Jan 2016.

4.2 Experiments with modified data use

Since the operational implementation, two further configurations were proposed to try to extract more benefit from the data using experiences from the earlier tests:

1. Add the two further water vapour channels for the pressure range 150-400hPa
2. Remove the near surface winds in the infrared and visible channels (pressure $>$ 950hPa)

The same testing periods and experiment set up were used but the operational configuration with Himawari-8 becomes the control in order to more clearly see if there is a benefit over current use.

4.2.1 Adding water vapour channels

When adding the two remaining water vapour channels (using the Himawari-8 operational configuration as a baseline), these extra data unfortunately introduced negative effects in the mid-troposphere in the vector wind forecast errors (Figure 14). Further degradation was seen in the fit of independent wind observations (0.3%) (Figure 15, left panel) although there were neutral changes for humidity sensitive observations. The availability of AMVs from three water vapour channels on Himawari-8 is a new feature, and currently Meteosat-10 is the only other satellite in the ECMWF system where AMVs from more than one water vapour channel are actively used. For comparison, an experiment was run for Meteosat-10 (27th April - 10th October 2016) which compared the use of two water vapour channels against only one (6.25μm) as the control. 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 some negative impacts present again in the tropics especially at 150hPa (Figure 15, 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 water vapour 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. When the two further channels were added to the system, the percentage increase in the number of Himawari-8 AMVs actively assimilated was around 20% in the mid-upper troposphere. So despite the similar characteristics and data quality in the three channels, the presence of duplicate information means that there is a relatively small rise in AMV number compared to the introduction of Himawari-8 with only three channels in total.

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.

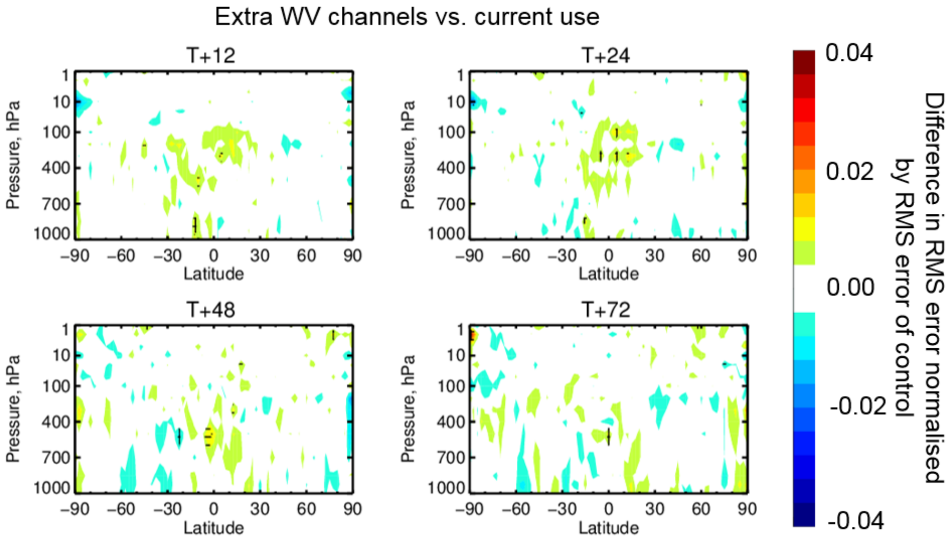


Figure 14: Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons. Experiment: operational use of Himawari-8 plus two additional water vapour channels. Control: system with initial operational use of Himawari-8. Cross hatching indicates 95% confidence.

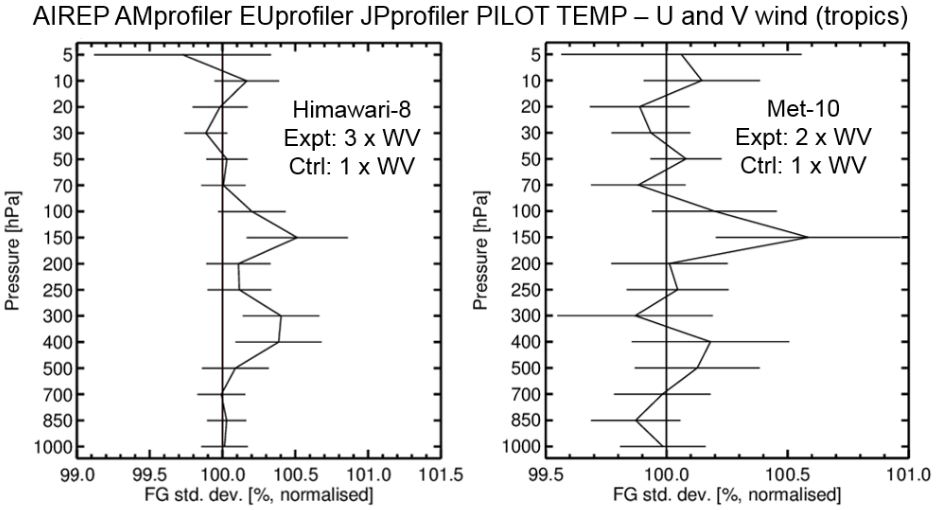


Figure 15: Change in the standard deviation of the first guess departures for the combined U and V component of wind from conventional observations in the tropics (summer and winter seasons) for the addition of the Himawari-8 water vapour channels (control: initial operational use of Himawari-8). Right panel: addition of further water vapour channel for Meteosat-10 (one season). Both experiments are compared to respective controls using one water vapour channel (in addition to infrared and visible).

A contributing factor may also be strong error correlations between the AMVs from 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 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 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.

4.2.2 Removing near surface AMVs

As noted earlier, a relatively large number of low-level Himawari-8 AMVs are assigned to unexpectedly low levels. An experiment was carried out which rejected any Himawari-8 AMVs with pressures higher than 950hPa in order to isolate any potential detrimental impact from the inclusion of the AMVs placed too low.

Figure 16 shows that the removal of these winds causes a small negative impact on the vector wind field near the surface in the tropics. Similarly, in the fits of conventional wind observations, there is also a small but significant degradation (around 0.2%) at 1000hPa in the tropics (not shown), indicative of a small degradation in the quality of the short-range forecast. Figure 17 shows that the positive effect on the speed bias (O-B) for scatterometer winds is also removed. In the region of densest, near surface AMVs the difference in bias without these AMVs compared to the operational use of Himawari-8 is now negative. As the absolute values are also negative, this indicates a return to larger magnitude biases when the near surface AMVs are removed. This conclusion is reinforced by the presence of neutral changes (not shown) when the experiment removing the low AMVs is compared directly with the original control with no geostationary satellite in the region.

A short (two month) sensitivity experiment was run which made a systematic subtraction of 50hPa to any AMVs assigned pressures higher than 950hPa. In the fit to conventional wind observations changes were mostly close to neutral but mixed between tropics and north/south hemisphere. Negative impacts on the wind vector error at 1000hPa at short forecast lead times were clear around the area covered by the Himawari-8 disk. However, the experiment is run over a relatively short time period so at this stage the signals cannot be confirmed as significant.

Despite the potential errors in the low level AMVs, their inclusion does have a positive impact. While the height errors do not suggest a high sensitivity to misspecification in this region, larger scale simplistic reassignment potentially has an impact. Their removal is not considered necessary at present however it may be possible to extract more benefit through a more sophisticated height correction.

5 Summary and future work

Himawari-8 was launched as the replacement for MTSAT-2 carrying a more advanced imaging instrument, AHI, and using a significantly different AMV processing method. An initial assessment of the data focused on first guess departure statistics while assimilation experiments investigated longer term forecast impacts.

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. A lack of significant dependence of data quality on the quality indicator values led to the decision not to use a

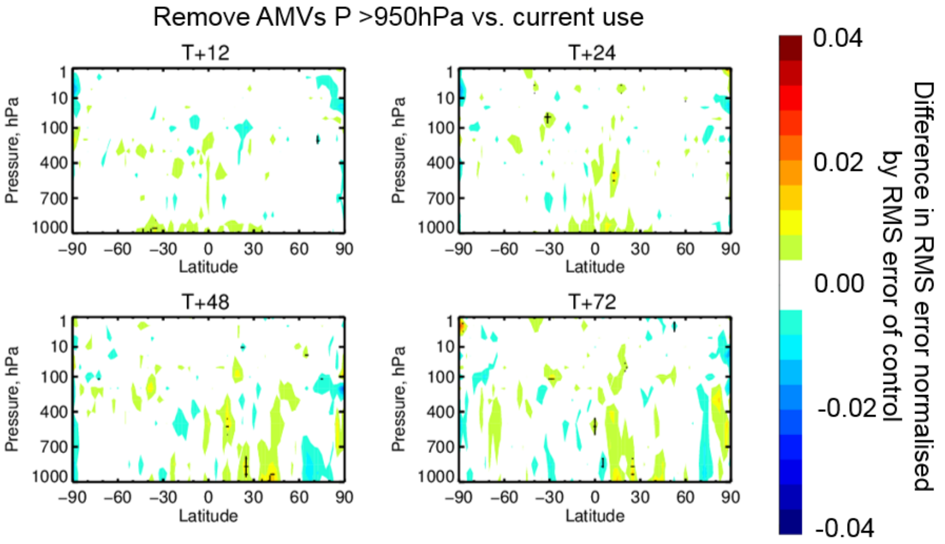


Figure 16: Normalised change in forecast RMS error verified against analysis for vector wind using results combined from both summer and winter seasons. Experiment: operational use of Himawari-8 with Himawari-8 AMVs at pressures > 950hPa removed. Control: system with initial operational use of Himawari-8. Cross hatching indicates 95% confidence.

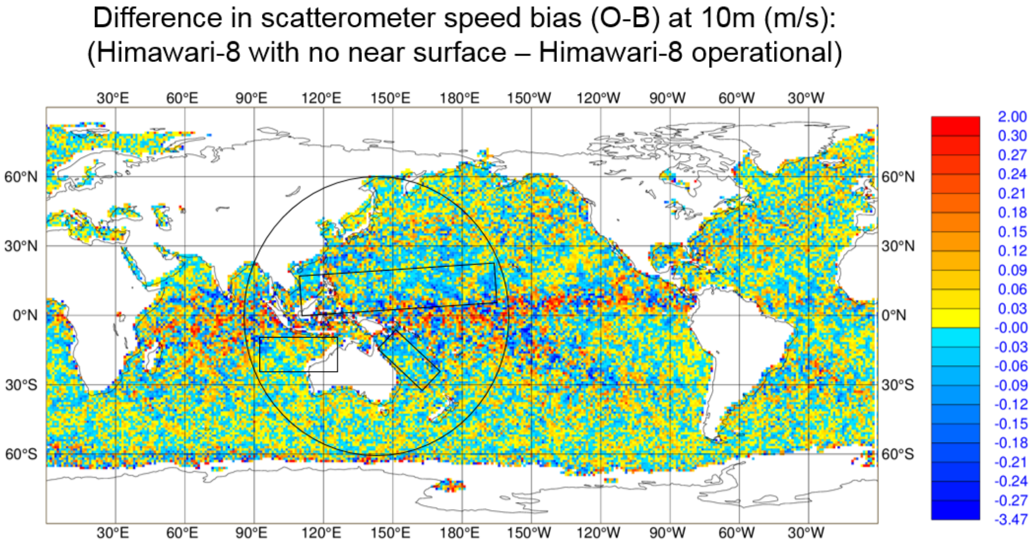


Figure 17: Difference in 10m wind speed bias for scatterometer winds between the new operational system with the near surface Himawari-8 winds removed and the new operational with all Himawari-8 data as before. Circle shows approximate location of Himawari-8 disc and boxes give approximate locations of dense areas of near surface AMVs. Data calculated from 18th Nov 2015 - 18th Jan 2016.

threshold for additional screening. New height assignment errors were derived and found to be generally lower than values for MTSAT-2 while the tracking errors currently used at ECMWF across all geostationary satellites were sensible for Himawari-8 as well.

A notable change was the large increase in the number of AMVs e.g. about 2-3 times higher for the infrared channel and also a different distribution. 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.

In the assimilation experiments, early tests using Himawari-8 led to more conservative screening of the data based on areas of degraded statistics in the initial analysis. This resulted in a channel selection similar to MTSAT-2 where data were used from:

- Water vapour channel (6.95μm only): 150hPa $<$ pressure $<$ 400hPa
- Visible channel: pressure $>$ 700hPa
- Infrared channel: if latitude $> 25^\circ$ then use pressure $>$ 150hPa, if latitude $< 25^\circ$ then use 150hPa $<$ pressure $<$ 300hPa

This configuration led to 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. These changes were significantly larger compared to using the MTSAT-2 AMVs where changes were more neutral. AMVs from MTSAT-2 were no longer disseminated after 24th March 2016 so to give continuous data coverage, on 15th March 2016, AMVs from Himawari-8 replaced MTSAT-2 in active assimilation.

While the channel selection is similar to MTSAT-2, the total, global number of AMVs assimilated is higher than before (around 40% in the pressure range 500-200hPa). The total number of Himawari-8 AMVs added far exceeds the number of AMVs typically assimilated from any of the other geostationary satellites in the system. The number of AMVs available prior to any screening is similarly much larger for Himawari-8 but the reasonably consistent quality across the QI range means that no blacklisting is carried out using the QI. For other geostationary satellites the threshold on QI removes a significant number of AMVs (up to around 50% for Meteosat-10). 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.

Two approaches were tested which tried to extract more benefit from the Himawari-8 AMVs through further optimising the channel selection however neither change was supported. An attempt to use all three water vapour channels resulted in negative impacts on the forecast system. Further experiments for comparison 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 for Himawari-8 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 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.

At ECMWF, Clear Sky Radiances (CSRs) from the water vapour channels on Himawari-8 were also actively assimilated but in contrast, the positive impact of their inclusion was amplified with the addition of each channel (Letertre-Danczak, (In progress)). For CSRs the extra channels provide better resolution of the vertical structure of humidity in the atmosphere. However, for AMVs the distribution of cloud tracers dictate where new wind information can be added. For AMVs, 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).

The removal of the AMVs with pressures exceeding 950hPa was tested to isolate the impact from the AMVs with known height errors. The slightly negative results on forecast vector wind fields and independent wind observation fits support their continued inclusion. One area still relatively unexplored is the high level visible winds - with more understanding about their derivation, assimilation could be tested in the future.

Acknowledgements

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