

Operational Generation and Assimilation of Himawari-8 Atmospheric Motion Vectors

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Abstract

The Japanese Meteorological Agency (JMA) launched the geostationary satellite Himawari-8 in October 2014. The satellite provides 10 minute, sixteen band imagery over the Asian and Australasian region. The imagery has been navigated, calibrated and subsequently used in the Bureau of Meteorology (BoM) to generate Atmospheric Motion Vectors (AMVs) over the full earth disk viewed from the satellite every ten minutes. Each vector has been error characterised and assigned an expected error. In preparation for the operational assimilation of the 10-minute data, these high temporal and spatial resolution data were used in the BoM test operational database to provide forecasts from the next generation operational forecast model ACCESS APS2 using 4D Var. Results from these tests indicate these locally generated Himawari-8 10 minute AMVs are of high quality and density and have the potential to improve numerical weather prediction (NWP) model initialisation and forecasts. The forecasts undertaken include cases associated with high impact weather. The results also provided the appropriate times, data selection and application methods for the successful use of these high temporal resolution data. As a result of these studies these wind data have been approved for inclusion in the BoMs operational database and are used in operational forecasting.

Introduction

Atmospheric motion vectors have been generated in the Australian region for operational use from 1991 (Le Marshall et al. 1992). In the early nineteen nineties winds were generated from images separated either by one hour or by 30 minutes (around 00 UTC, 06 UTC, 12 UTC and 18 UTC). These hourly and half hourly winds have been demonstrated to have a beneficial effect on the operational Australian numerical analysis and forecast system (for example Le Marshall et al. 1992, 1993, 1994). The operational processing and use of hourly AMVs was first introduced into the Australian operational regional forecast system in the mid 1990's (Le Marshall et al. 1996) using intermittent data assimilation. It is of note such hourly winds have been introduced into the operational database of other numerical forecast centres (e.g. ECMWF) in this decade. The significant benefit of hourly data to current operational numerical weather prediction using four-dimensional variational assimilation (4DVar) was recently documented in Le Marshall et al. (2013), where noteworthy benefits were recorded. In addition, the benefit of hourly AMVs to tropical cyclone forecasts is well established. It was first demonstrated in Le Marshall et al., (1996a) and later in Le Marshall et al. (1998, 1999) and Leslie et al. (1998).

Here, results are provided from work directed towards operationally deriving AMVs from 10-minute Himawari imagery and subsequently assimilating them into the Bureau of Meteorology's next generation operational regional forecast system. The Bureau is currently updating its operational numerical weather prediction (NWP) suite and is further developing its capability to use 10 minute AMVs. As part of the preparation for this upgrade and for the operational assimilation of 10 minute wind data from Himawari-8, initial testing using 10 minute wind data was completed using Himawari-6 (MTSat-1R) observations. High temporal (10 minute) and spatial resolution wind data were generated over and around Australia from JMA rapid scan observations during the High Ice Water Content (HIWC) Study (see for example Le Marshall et al., 2016). These were combined with the Bureau's test operational database to provide forecasts using the next generation operational regional forecast model ACCESS APS2. This model was used during the introduction of operational Himawari-8 data. This work is summarised below. The work has been extended using Himawari-8 high temporal (10

minute) and spatial resolution (2km in the IR) data. The wind generation methods, error characterisation, data quality and data impact are delineated below.

Generation of 10 Minute Atmospheric Motion Vectors

Himawari-6

The general method used in the Bureau of Meteorology, to estimate AMVs from Himawari-6 (MTSat-1R) and Himawari-7 (MTSat-2) high-rate information transmission (HRIT) data is described in Le Marshall et al. (2008, 2011). Three sequential images from Himawari-6 and Himawari-7 were re-navigated using land features to ensure that there is consistency between images used for estimating cloud displacement. Target selection used orthogonal brightness temperature gradients and targets with suitable gradient features are subjected to a spatial coherence analysis (Coakley and Bretherton 1982) and tracked using lagged correlation. Height assignment methods are similar to those employed in Le Marshall et al. (2008) Each vector is associated with error indicators such as the expected error (EE; Le Marshall et al. 2004), the quality indicator (QI; Holmlund 1998) . Figure 1 is a sample of local Himawari-6 infrared (IR) image-based AMVs generated from JMA special test observation 10 minute imagery between 0010 UTC and 0050 UTC 28 January 2014 displayed over NE Australia. The usual operational database has insufficient imagery for AMVs to be generated during this period. In future, 10-minute imagery will be available operationally, so this Field Experiment data provided an opportunity to prepare for this new improved data base. The study period used was selected because it represented challenging cloud fields associated with wind generation and also a challenging meteorological situation.

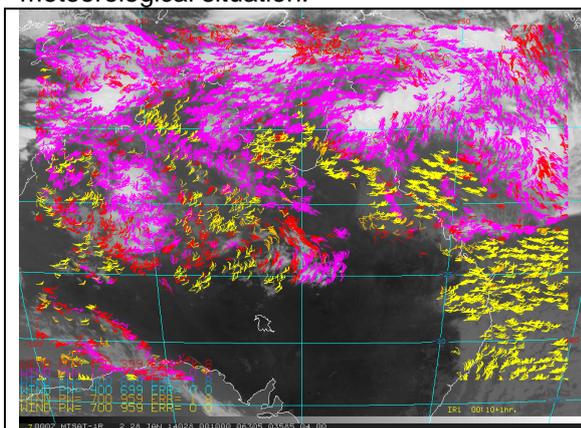


Fig. 1 A selection of Himawari-6 Atmospheric Motion Vectors over Eastern Australia generated from 10 min imagery between 0010 UTC and 0050 UTC 28 January 2014.

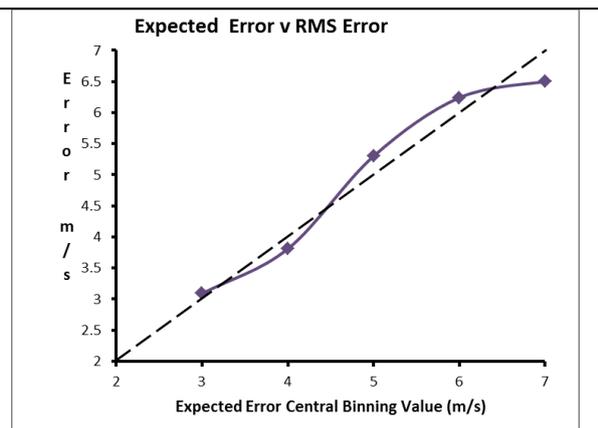


Fig. 2. Measured error (m/ s) vs Expected Error (m/s) for low-level Himawari-7 IR winds (1 January–31 January 2014).

In this study accurate error characterization and thorough quality control ensure that AMVs have a beneficial impact on NWP (Le Marshall et al. 2004). The AMVs were systematically thinned using a number of these error indicators, including the departure from a first guess provided by the Bureau's operational NWP model, a vector pair acceleration check, and a tracer constancy check, the QI (Holmlund 1998) and the Expected Error (EE) (Le Marshall et al. 2004) were also used.

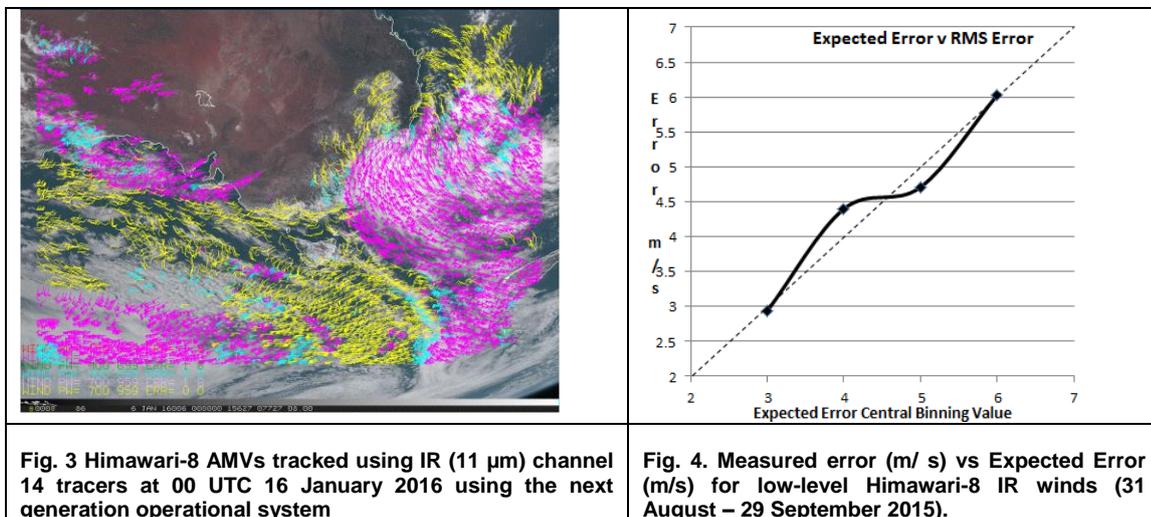
This reduced the volume of the data while maintaining good data coverage with average separations consistent with the length scale of the correlated error. The thinning methodology has also ensured that the average errors are generally no larger than the analysis background error field of the forecast model as measured at radiosonde sites. The approach is detailed in Le Marshall et al. (2004).

The total rms (root mean square) error component of the EE was used here. A typical comparison of the Expected Error (EE) with the measured error from radiosonde observations for low-level Himawari-6 and -7 IR winds is seen in Fig. 2. The quality of data from the operational Himawari-6 and 7 processing system can be made close to that from Himawari-8 but data from the latter is much more plentiful.

Himawari-8

The method used to estimate AMVs from Himawari-8 HSF (Himawari Standard Format) data (and in research mode from Himawari-7 HRIT [High-rate Information Transmission] data) employs GEOCAT (Geostationary Cloud Algorithm Testbed - Geocat Manual, 2016) software, modified in a number of areas, in its initial processing. The GEOCAT approach was employed because of the efficiencies gained in the BoM using a common satellite data initial processor for many operational applications (for example, volcanic ash detection and sea surface temperature calculation). The AMV estimation methodology is similar to that described in the GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Derived Motion Winds (Daniels 2010) with changes and additions which include elements of the BoM current operational system, particularly in the areas of error characterization and quality control. Three sequential navigated images from Himawari-8 are used for estimating cloud displacement. In this system, target selection uses orthogonal brightness temperature gradients and targets are tracked employing nested tracking (Daniels, 2010, Bresky et al. 2012). Height assignment methods employed in the GEOCAT algorithms are similar to those described in GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document For Cloud Height (Heidinger 2010). The error characteristics of these vectors are determined and each vector is associated with error indicators such as the expected error (EE; Le Marshall et al. 2004), the quality indicator (QI; Holmlund 1998), as well as with a correlated error and the length scale of the correlated error. Figure 3 is a mid-latitude sample of local Himawari-8 infrared (IR channel 14) image based 10 minute AMVs generated from 10 minute imagery around 0000 UTC on 16 January 2016 displayed over SE Australia.

As noted previously accurate error characterization and thorough quality control ensure that AMVs have a beneficial impact on NWP (Le Marshall et al. 2004). The error characterization employed here has again used the Bureau's initial error flagging procedure (ERR), which involved a number of basic checks. These include the departure from a first guess provided by the Bureau's operational NWP model, a vector pair acceleration check, and a tracer consistency check, the QI and the Expected Error (EE).



The AMVs are systematically thinned using these error indicators to reduce the data volume while maintaining good data coverage with average separations consistent with the length scale of the correlated error. The thinning methodology has also ensured that the average errors are generally no larger than the analysis background error field of the forecast model as measured at radiosonde sites. The total rms error component of the EE was again used here. A typical comparison of the Expected Error (EE) with the measured error from radiosonde observations for low-level Himawari-8 IR (channel 14) winds is seen in Figure 4.

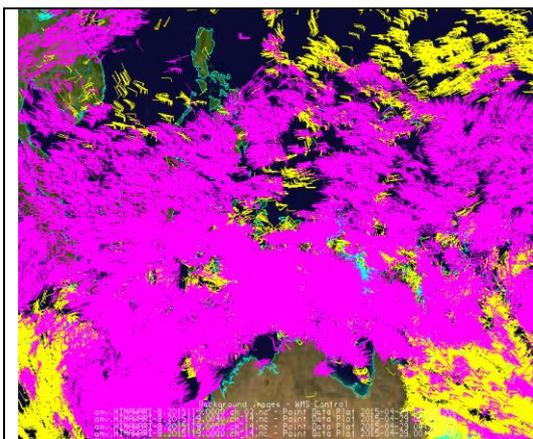


Fig. 5 Coverage of AMVs from Himawari-8 in the tropics to the north of Australia around 0000 UTC 29 April 2015

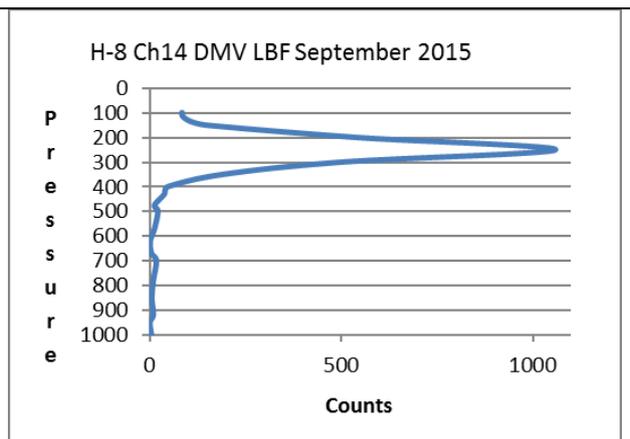


Fig. 6 Himawari-8 level of best fit height assignment statistics for CH.14 AMVs for September 2015 (see text)

The thick coverage of Himawari-8 winds over the tropics to the north of Australia around 0000 UTC 29 April 2015 is shown in Figure 5. In these images, low level vectors are coloured yellow (700-950 hPa), middle level cyan (400 - 699 hPa) and upper level (150 - 399 hPa) vectors magenta. An indication of the accuracy of height assignment in the new local Himawari-8 system AMV system is shown in Figure 6. Here for Channel 14 Himawari-8 AMVs height assigned between 230 hPa and 270 hPa, the number of winds (AMVs) at a level are plotted against the level of best fit (hPa) for September 2015. In general, the AMVs are associated with a height assignment accuracy which renders them suitable for NWP.

It is important to note that adjacent ten minute AMV data sets can provide different and at the same time important observations to the analysis system, an indication of the importance of continuous data sets for operational analysis. These continuous data can also help in quality control.

Verification data for real time vectors from Himawari-7 and Himawari-8 are shown below. In Table 1 and 2 MMVD is the mean magnitude of vector difference and RMSVD is the root mean square vector difference.

AMV Type	Category	m/s	NOBS
Low	MMVD	2.4	358
Sep.	RMSVD	2.8	
<50 km	BIAS	0.3	
High	MMVD	3.3	1460
Sep.	RMSVD	3.9	
<50 km	BIAS	-0.6	

Table 1 Verification Table for Himawari-8 IR (channel 14) AMVs compared to radiosondes 1 March – 31 March 2016

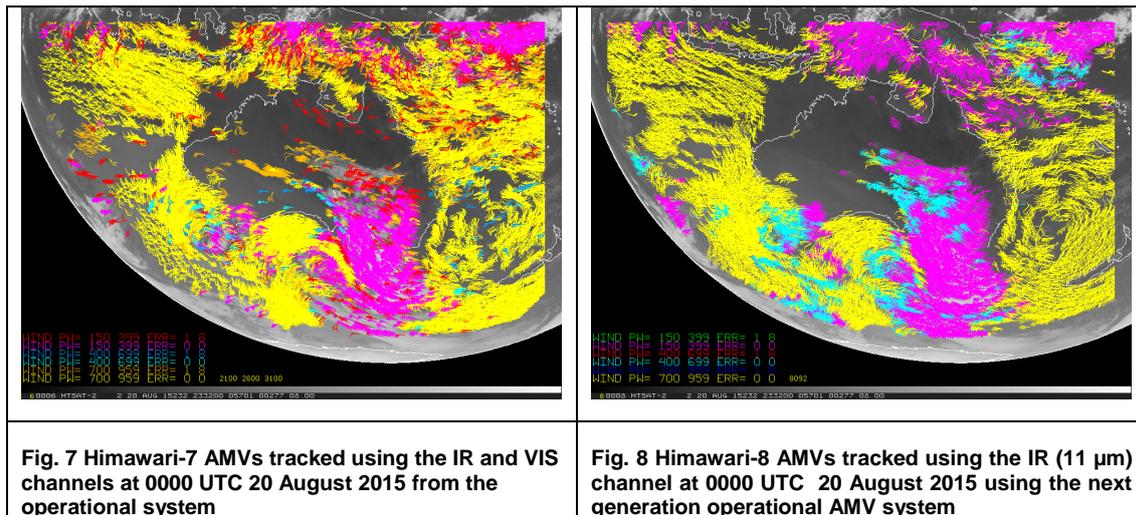
AMV Type	Category	m/s	NOBS
Low	MMVD	2.5	57
Sep.	RMSVD	2.9	
<50 km	BIAS	-0.6	
High	MMVD	3.5	291
Sep.	RMSVD	3.9	
<50 km	BIAS	-1.4	

Table 2 Verification Table for Himawari-7 IR (channel 4) AMVs compared to radiosondes 1 March – 20 March 2016

Although the initial wind error estimates for the Himawari-8 are near to those from Himawari-7, it should be noted that, due to the vast increase in wind data numbers in the case of Himawari-8, the Himawari-8 wind observations can be thinned using the Expected Error associated with each vector and other error characterisation data, to produce a far denser and more accurate wind field than previously available. This process provides fields suitable for assimilation in NWP, with errors being similar to or less than the errors of the NWP background field at radiosonde sites. It is expected that use of these data in operational NWP has the potential to provide improved analysis, reanalysis and numerical prediction. Studies examining full use of the data to this end are expanding as further denser data sets become available. Early work in this area has already been completed using 10 minute Himawari-6 special observations collected in 2014 and additional advanced sounder data in the Bureau of Meteorology's next-generation operational forecast model APS-2. Here we also report

on a study using locally generated 10 minute Himawari-8 AMV data in the BoM's next generation operational forecast model.

An insight into the relative data coverage of the current operational Himawari-7 and the next generation operational Himawari-8 AMV systems is seen below. Local Himawari-7 11 μm IR and Visible feature tracked winds at 0000 UTC 20 August 2015 are shown in Figure 7 and local 11 μm IR feature tracked winds for Himawari-8 over the same Himawari-7 image are shown in Figure 8. The increasing data density in the case of Himawari-8 due to a small reduction in times between the images used in AMV production and also due to the increased spatial resolution of the instrument, however, is clearly apparent.



Assimilation of the 10 Minute Atmospheric Motion Vectors

Ten-minute wind data have been generated from MTSat-1R data using the methods described above and subsequently converted into BUFR (Binary Universal Form for the Representation of meteorological data) format and passed through the Bureau's test next-generation operational regional forecast model. This model was the operational regional forecast model when Himawari-8 data became available during last half of 2015. The number of winds produced from the Rapid Scan MTSat-1R images in the test area was dependent on the synoptic situation but was typically over 4,000 infrared (IR) and 19,000 visible (VIS) higher quality vectors for each ten minutes within the Australian region test area. These winds have been combined with the local and also JMA MTSat-2 fifteen, thirty and sixty minute wind data and have been subsequently assimilated in hourly blocks using 4DVar into the new regional forecast system. The hourly blocks of data were developed to have good spatial and temporal coverage centred around the box middle time, with data density consistent with the analysis data selection methodology.

First Results - MTSAT-1R

The merged and quality controlled wind data sets from MTSAT-1R and MTSAT-2 (including 10 minute wind coverage over the Australian region between 0° and 42° S and 110° and 160° E) provided much improved coverage over the region. They were assimilated as hourly blocks of data in the next generation regional forecast system, ACCESS-R APS2 using 4DVar (see, for example, Le Marshall et al., 2013). The resolution of the new regional model is 12 km with 70 levels in the vertical. The high resolution data was assimilated between 1200 UTC 26 January and 1200 UTC 27 January 2014 and used to provide a 3-day forecast for 1200 UTC 30 January 2014. Bureau analyses for the Australian Region at these times are given in Figs. 9 and 10, respectively. The 3-day forecast from the Bureau's operational forecast system in 2014 and the forecast from the Bureau's next generation forecast system including the 10 minute winds are seen in Figures 9 and 10 respectively.

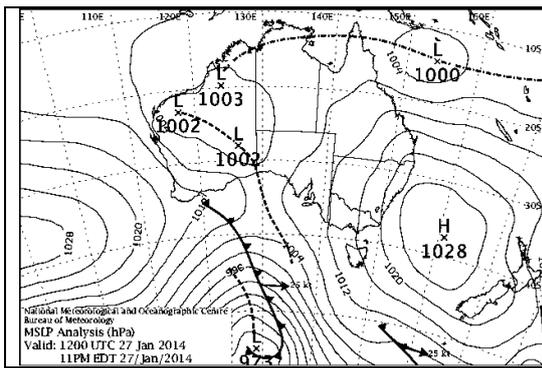


Fig. 9 Bureau of Meteorology Analysis for 12 UTC on 27 January 2014.

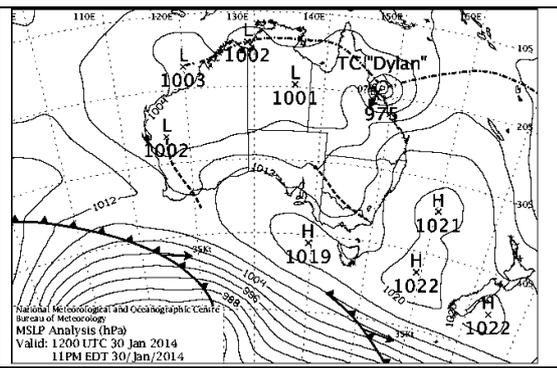


Fig. 10. Bureau of Meteorology Analysis for 12 UTC on 30 January 2014

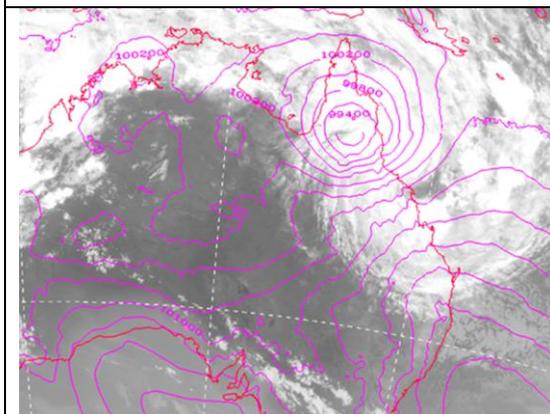


Fig.11 The Bureau of Meteorology operational three-day MSLP (hPa) forecast valid 1200 UTC 30 January 2014, shown remapped over an MTSat infrared image, valid at the same time.

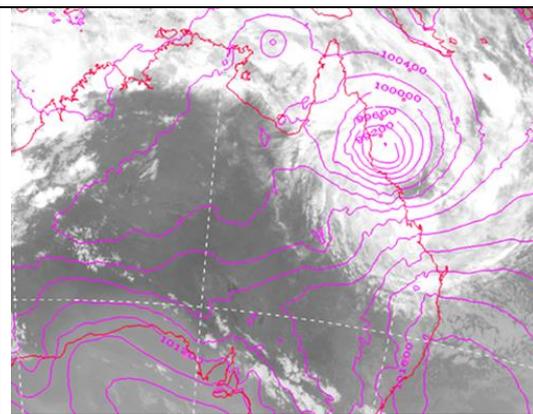


Fig.12 The Bureau of Meteorology three-day MSLP (hPa) forecast valid, 1200 UTC 30 January 2014 using the next generation operational regional forecasting system with ten, fifteen and sixty minute AMV data from MTSat-1R and MTSat-2. The forecast remapped over the 1200 UTC MTSat image.

It can be seen that the new forecast system with the inclusion of 10-minute wind data and data from the new enhanced forecast system, including a more expansive satellite data base has provided a significantly improved forecast. The genesis and final positioning of (Category two) Tropical Cyclone Dylan in relation to the coastline is greatly improved. What was a challenging operational forecast which proved difficult for some operational centres has in this case become a very good forecast of genesis and a very good three day forecast. It should be noted, this improvement has resulted from an improved wind field, resulting from the use of quality controlled ten minute winds, an improved mass field (additional sounding data – for example, Cross-track Interferometer Sounder [CrIS] data) and the next generation operational forecast model APS2. This first test of the next generation operational assimilation system with 10-minute winds, allowed observation of quality control and data selection for the new wind data and allowed effective integration of the data into the new operational data base.

Results – Himawari-8

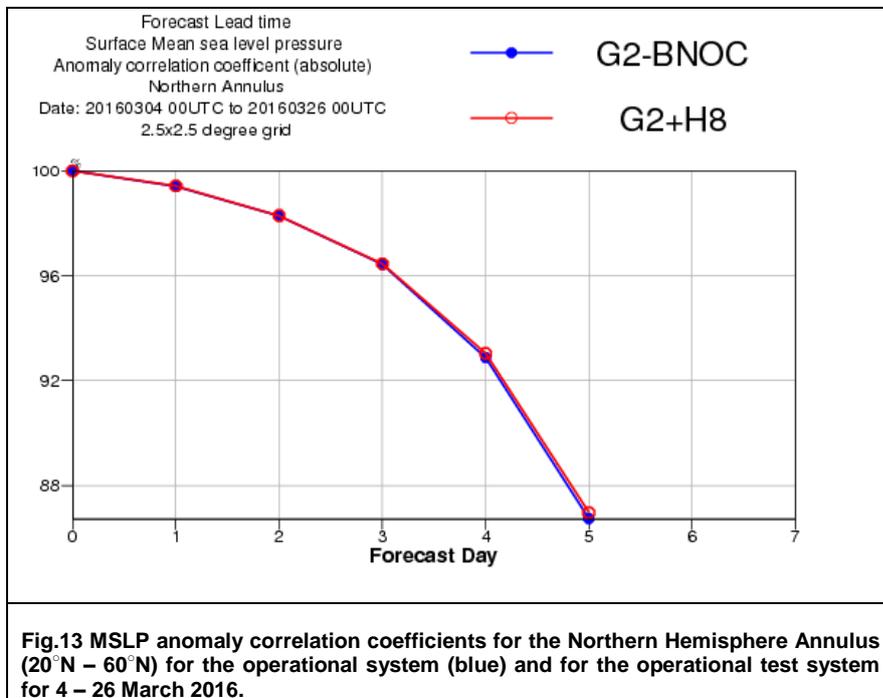
Himawari-8 winds have been produced in the Bureau of Meteorology from July 2015 and are currently being generated every 10 minutes in Real Time from image data collected via FTP from JMA. This FTP data is now the operational data source. The image and wind quality is continuously monitored. The locally-generated Himawari-8 10-minute wind data has also been used in data transmission and assimilation tests.

BUFR output containing AMV information from the Himawari-8 processing system is designed to be used by the current and future operational systems. Verification data for real time vectors from Himawari-7 and Himawari-8 have been shown in Tables 2 and 3 for March 2016. The quality and

number of Himawari-8 AMVs exceeds that of operational Himawari-7 AMVs which were generated and used operationally in the Bureau of Meteorology over previous years.

Locally produced Himawari-8 AMVs, generated using operational code on the BoM new virtual machines have been used in an assimilation test for a period during March 2016. The test ran from 4 March to 26 March 2016 and analysed the effect of adding local Himawari-8 AMVs to the operational data base then containing JMA MTSat-2 (Himawari-7) AMVs, Local BoM MTSat-2 (Himawari-7) AMVs and JMA Himawari-8 AMVs. The test system contained JMA MTSat-2 (Himawari-7) AMVs, Local BoM MTSat-2 (Himawari-7) AMVs, JMA Himawari-8 AMVs and local BoM high resolution Himawari-8 AMVs. The test not only involved assimilation but also transfer of the buffer data into the forecast system through the operational CMSS communications system.

The data transfer of this high resolution data was effective and the assimilation results show the successful use of the data by the operational NWP system. Typical impact is seen in Fig. 13. The impact is small but this is not surprising as the operational system at this stage had 3 complete and quite redundant sets of winds covering the same geographical area and the Test system had 4 complete and quite redundant sets of winds covering the same geographical area. After March only 2 AMV datasets were to be available as Himawari-7 data were no longer available, with the satellite going into backup mode.



It should be noted that the time period of the test involved use of redundant AMV data sets in operations. However, from April 2016 onwards, two data sets are available (JMA and BoM Himawari-8 data sets), providing a resilient database and during summer, for example, only local BoM winds will be available in time for the important 0000 UTC operational analysis.

Summary and Conclusions

A description has been provided of the generation of 10 minute Himawari-6 AMVs over a test area covering the Australian region. It used 10 minute MTSAT-1R imagery from a test period in January 2014. Tracer selection, height assignment and the quality control of the AMV's has been described. The quality of these data was near to that from the operational Himawari-8 processing system although the operational Himawari-8 system with the advantage of higher spatial and spectral density provides more high quality vectors for selection for assimilation.

In this first test of the future operational assimilation system with 10-minute winds, an initial effort to optimise data selection and gauge the utility of the data in the new operational database has been

described. The 10-minute data over the test area in the Australian region has been combined with the lower temporal resolution (hourly) data covering the MTSat full disc, present in the operational database. The resultant forecast from the next generation operational regional forecast system shows an improvement over the earlier operational product in this case for a tropical cyclone forecast that was challenging for a number of operational centres. Detailed quantification of the impact of these 10 minute data in numerical analysis and prediction will be provided now that 10 minute wind data become regularly available over the full disk area viewed by Himawari-8. However, these early results strongly suggested a potential for improvement which may be provided by the new operational forecast system. It is also interesting to note early tests of the science processing system now used with Himawari-8 also provided AMV data of a quality near that described above when being used with MTSat image data.

In summary, 10-minute winds were generated continuously for the first time in the Australian region and assimilated with 4D Var. This early evidence showed that 10-minute data from MTSat-1R provide a much improved spatial and temporal database for operational analysis and forecasting. Early indications suggest the new operational 4DVar system has the potential to extract additional information from this and other components of the improved next generation database with resultant improvement in forecast accuracy.

Following the launch of Himawari-8, AMVs were generated at the BoM from July 2015. We have described the generation of 10 minute Himawari-8 AMVs over the Australian region and beyond. This was performed using 10 minute imagery obtained in close to real time (RT) via FTP from JMA since July 2015. These data provided an improved spatial and temporal resolution database for analysis and forecasting. The quality of these higher spatial, temporal and spectral density data (see Table 2 and Table 3) is of a level which renders them beneficial for NWP. If the data is thinned to equal spatial density, the quality of the H-8 data exceeds that of the operational H-7 data. Locally produced Himawari8 AMVs have also been used in an assimilation test for a period during March 2016 where the effect of adding local Himawari-8 AMVs to the then, quite redundant operational AMV data base (then containing 3 complete different sets of data) was recorded. The test showed successful transfer of data and successful use of the data by the NWP system. Further quantification of the impact of these data in our current operational prediction system is underway. This includes use of all 10-minute data in the prediction of TC activity and severe weather.

In conclusion we have noted operational considerations related to the processing of Himawari-8 winds and have summarised the current status of the Himawari-8 wind processing system and the assimilation of these data. Overall the data provide an improved data base for operational NWP and are ready for full exploitation.

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