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First results from the generation and assimilation of 10-minute atmospheric motion vectors in the Australian region

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Ten-minute interval infrared and visible satellite images, available from MTSAR-1R (Himawari-6) for a limited period over and around Australia, have been used to generate atmospheric motion vectors. These vectors—which were available every 10 minutes—have been quality controlled, error characterised and assimilated into the Australian Bureau of Meteorology's next generation operational regional forecast model as part of the new operational database. Results from this study indicate that this high temporal resolution imagery has the ability to produce high spatial and temporal density atmospheric motion vectors, and the quality of these vectors is such that they have the potential to improve numerical analysis and prognosis.

1. Introduction

In late 2013 and early 2014 the Japanese Meteorological Agency (JMA) provided several months of MTSat-1R rapid scan imagery in support of the 2014 High Altitude Ice Crystal (HAIC) – High Ice Water Content (HIWC) field campaign in the Darwin area. This 10-minute imagery was also provided in support of activities in preparation for Himawari-8. The imagery was renavigated, calibrated and used to generate atmospheric motion vectors (AMVs) over much of the Australian region including the HAIC-HIWC test area. Each vector was error characterised and assigned an expected error. In preparation for the operational assimilation of 10-minute data from the full disk footprint of Himawari-8, these high temporal and spatial resolution data generated over the Australian region test area were combined with the operational database—including high spatial but lower temporal density local Bureau and also JMA AMV data from MTSat-2—to provide forecasts using the next generation operational regional forecast model ACCESS APS2. This model will be used during the introduction of operational Himawari-8 data. First results from these tests indicate the 10-minute data have the potential to produce high density, high quality AMVs which will improve model initialisation and forecasts. This includes cases associated with extreme weather. The results have also provided indications of appropriate timing, data selection and application methods for the effective use of these high temporal resolution data. The quality and density of the 10-minute MTSat-1R data have also been compared to that available from imagery using a new processing paradigm which is to be used in future for the operational Himawari-8 AMV generation.

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2. Background

Cloud drift winds have been generated in the Australian region for operational use from 1991 (Le Marshall et al. 1992). In the early 1990s winds were generated from images separated by either 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, 2013). The operational processing and use of hourly AMVs was first introduced into the Australian operational regional forecast system in the mid nineteen nineties (Le Marshall et al. 1996a) using intermittent data assimilation. It is of note such hourly winds have only been introduced into the operational database of other numerical forecast centres (e.g. ECMWF) in the last few years. The significant benefit of hourly data to current operational numerical weather prediction using four dimensional variational assimilation (4DVar) was most recently documented in Le Marshall et al. (2013), where significant 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. (1996) and later in Le Marshall et al. (1998, 1999) and Leslie et al. (1998).

Here, we briefly describe results from the preparatory work directed towards operationally deriving AMVs from 10-minute imagery (soon to be available from Himawari-8) and subsequently assimilating them into the Bureau of Meteorology's next generation operational regional forecast system. This activity was undertaken as the Bureau is currently updating its operational numerical weather prediction (NWP) suite and needs to test its capability with 10-minute AMVs. As part of the preparation for this upgrade and in particular for the operational assimilation of 10-minute data from the full disk footprint of Himawari-8 when available, these high temporal and spatial resolution data generated over the Australian region test area were combined with the operational database. This included high spatial but lower temporal density local Bureau and also JMA AMV data from MTSat-2 to provide forecasts using the next generation operational regional forecast model ACCESS APS2. This model will be used during the introduction of operational Himawari-8 data.

3. The generation of 10-minute atmospheric motion vectors

In the Bureau of Meteorology, the general method used to estimate AMVs from MTSAT-1R and MTSAT-2 high-rate information transmission (HRIT) data is described in Le Marshall et al. (2008, 2011). Three sequential images from MTSAT-1R and MTSAT-2 were renavigated using land features to ensure that there is consistency between images used for estimating cloud displacement. In this system, 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. 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. Figure 1 is an example of local MTSAT-1R infrared (IR) 10-minute AMV wind spatial density.

The AMVs shown were generated using 10-minute imagery between 00:10 UTC and 00:50 UTC on 28 January 2014 and are displayed over eastern Australia. Magenta barbs are upper level AMVs and yellow barbs are lower level AMVs. In the current normal operational environment, there is insufficient imagery for AMVs to be generated during this period. In the future however this 10-minute imagery will become available operationally, so these field experiment data have provided an opportunity to prepare for this new significantly improved database. The study period used here was selected because it represented challenging cloud fields associated with wind generation and also a challenging meteorological situation.

In this study accurate error characterisation and thorough quality control (QC) ensure that AMVs have a beneficial impact on numerical weather prediction (NWP; Le Marshall et al. 2004). The error characterisation employed here has 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 constancy check, the QI (Holmlund 1998) and the expected error (EE) (Le Marshall et al. 2004).

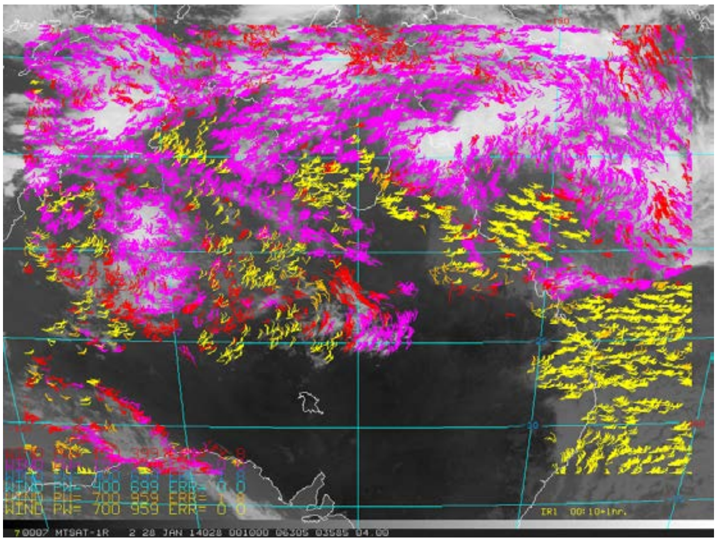

Figure 1 A selection of atmospheric motion vectors over eastern Australia generated from five triplets 10-minute imagery between 00:10 UTC and 00:50 UTC on 28 January 2014.

The AMVs are systematically thinned using these error indicators to reduce the volume of 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 root mean square (RMS) error component of the EE is used here. A typical comparison of the expected error (EE) with the measured error from radiosonde observations for low-level MTSAT-1R and MTSAT-2 IR winds is seen in Figure 2.

The quality of these data are expected to be close to that expected in future from the operational Himawari-8 processing system.

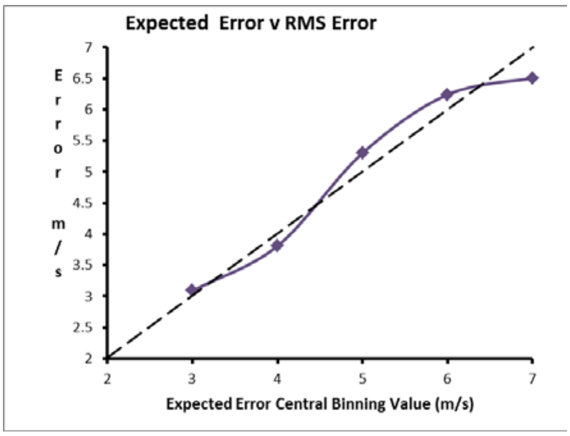

Figure 2 Measured error (m/ s) vs expected error (m/s) for low-level MTSAT-2 IR winds (1 January–31 January 2014).

4. The assimilation of the 10-minute atmospheric motion vector data

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 operational communication system into the Bureau's test operational database and subsequently assimilated into the Bureau's next-generation operational regional forecast model. This model will be the operational regional forecast model when Himawari-8 data becomes available in mid to late 2015. The number of winds produced from the MTSat-1R rapid scan images in the test area is dependent on the synoptic situation but is indicatively over 4000 infrared (IR) and 19 000 visible (VIS) higher quality vectors for each 10 minutes within the HIWC test area. These winds have been combined with the local and also JMA MTSat-2 15, 30 and 60 minute wind data and have been subsequently assimilated in hourly blocks using 4DVar into the new regional forecast system. The hourly blocks 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.

5. First results

The merged and quality controlled wind datasets from MTSAT-1R and MTSAT-2 (including 10-minute wind coverage over the Australian region) 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 12 UTC 26 January and 12 UTC 27 January 2014 and used to provide a 3-day forecast for 12 UTC 30 January 2014. Bureau analyses for the Australian Region at these times are given in Figures 3 and 4, respectively.

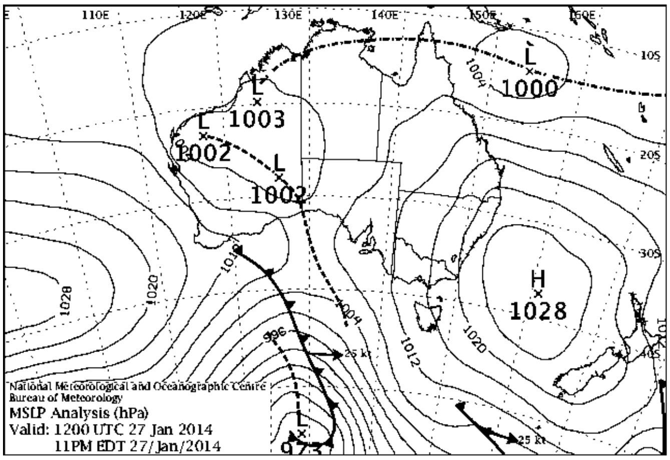

Figure 3 Bureau of Meteorology analysis for 12 UTC on 27 January 2014.

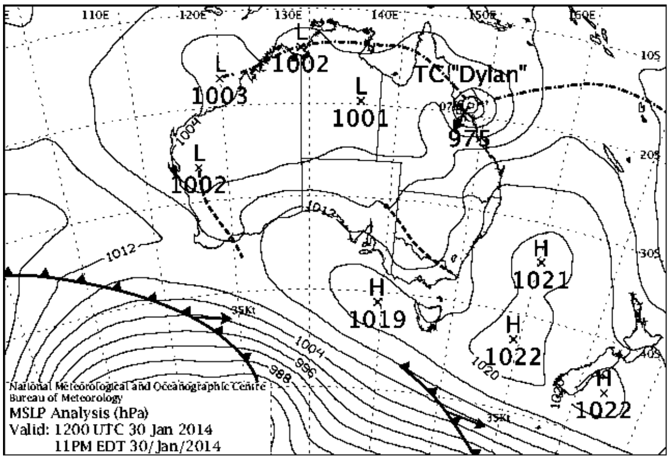

Figure 4 Bureau of Meteorology analysis for 12 UTC on 30 January 2014.

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 5 and 6, respectively. It can be seen that the new system with the inclusion of 10-minute wind data and data from the new enhanced forecast system, including a more expansive database, has provided an improved forecast, with the genesis and final positioning of (category two) tropical cyclone *Dylan* in relation to the coastline being greatly improved. What was a challenging operational forecast, which proved difficult for some operational centres, has in this case become a good forecast of genesis and a good 3-day forecast. It should be noted, this improvement has resulted from an improved wind field (resulting from the use of quality controlled 10-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.

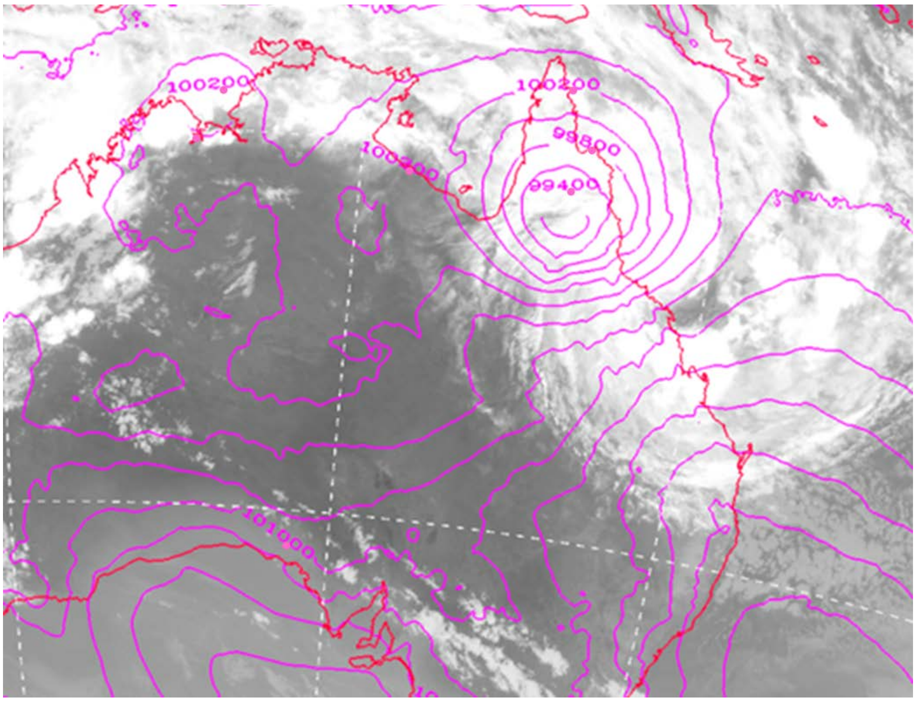

Figure 5 The Bureau of Meteorology operational 3-day mean sea level pressure (MSLP; hPa) forecast valid 12 UTC on 30 January 2014, shown remapped over an MTSat infrared image, valid at the same time.

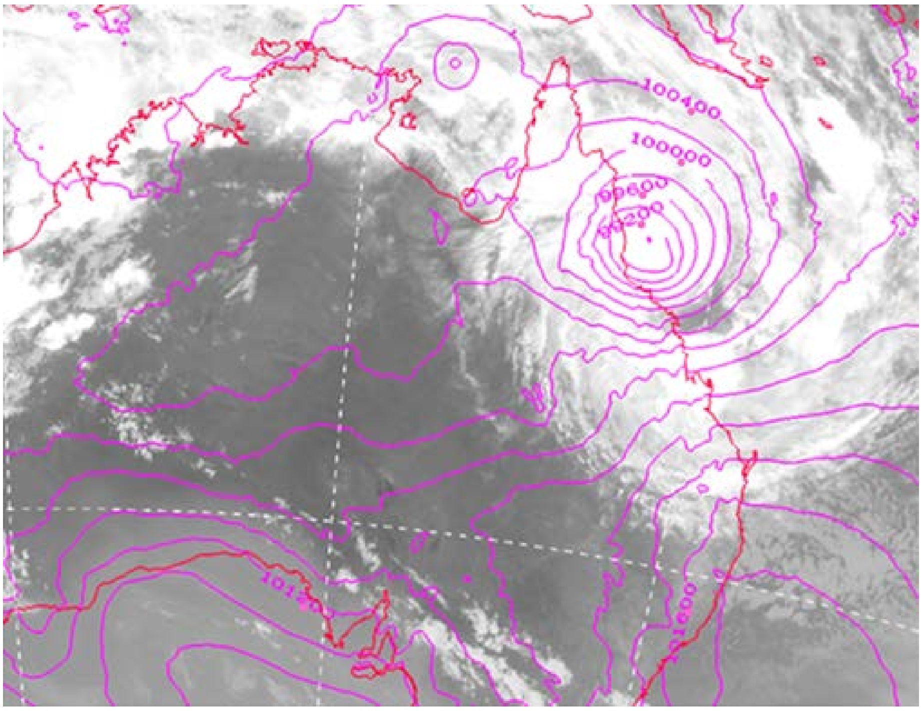

Figure 6 The Bureau of Meteorology 3-day MSLP (hPa) forecast valid, 12 UTC on 30 January 2014 using the next generation operational regional forecasting system with 10, 15 and 60 minute AMV data from MTSat-1R and MTSat-2. The forecast is again remapped over the 12 UTC MTSat image.

6. Conclusions

We have described the generation of 10-minute AMVs over a test area covering the Australian region. It was done using 10-minute MTSAT-1R imagery from the HAIC-HIWC period in January 2014. Tracer selection, height assignment and the quality control of the AMV's has been described. The quality of these data is expected to be 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—will provide 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 forecast that was challenging for a number of operational centres. Detailed quantification of the impact of these data in numerical analysis and prediction will be provided after 10-minute wind data become regularly available over the full disk area viewed by Himawari-8. However, these early results strongly suggest a potential for improvement which may be provided by the new operational regional system. It is also interesting to note early tests of the science processing system to be used with Himawari-8 have also provided AMV data of a quality near that described above when being used with MTSAT image data.

In conclusion, 10-minute winds have been continuously generated for the first time in the Australian region and assimilated with 4DVar. Early evidence suggests that 10-minute data from MTSat-1R and Himawari-8 have and will respectively 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.

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