

Local estimation of GMS-5 water vapour motion vectors and their application to Australian region numerical weather prediction

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Introduction

After the launch of the GMS-5 satellite, the capability to generate and assimilate winds estimated using sequential observations from the 6.7 μm water vapour absorption channel has been available in the Australian Bureau of Meteorology. Water vapour winds are currently available in real time at hourly intervals and, four times per day, half-hourly. They are routinely distributed to the National Meteorological Operations Centre, Regional Forecast Centres and Tropical Cyclone Warning Centres. Here, we briefly describe the history and characteristics of these absorption channel motion vectors, the method of estimation used in the Australian Bureau of Meteorology and their beneficial impact on an operational regional numerical weather prediction system.

Background

While winds derived from following cloud movement in infrared (IR) and visible satellite imagery have been estimated and applied in a number of ways since the early 1970s, the use of the water vapour absorption channel data to produce motion vectors only became prevalent in the early 1980s. In the early 1970s, pioneering work in this area was reported by Allison et al. (1972) and by Steranka et al. (1973). They both examined the application of the Nimbus 4 Temperature and Humidity Infrared Radiometer (THIR) 6.7 μm channel observations to the determination of the moisture distribution and wind flow near the 400 hPa level. Almost a decade later, Kästner et al. (1980) reported using overlapping swaths of consecutive Nimbus 5 orbits to derive wind velocities from water vapour imagery in a pre-Meteosat study. Their work demonstrated the feasibility of using sequential water vapour images for wind determination. Subsequent work by Fischer et al. (1981), Stewart et al. (1985), Hayden and Stewart (1987), Velden et al. (1992)

and Le Marshall et al. (1984, 1985) further refined the procedures for generating water vapour winds and gave an initial indication of their utility for numerical weather prediction (NWP), in particular for tropical cyclone track forecasting where they can provide important information around the 'steering level'.

The generation of water vapour motion vectors

Water vapour image based winds are generated routinely at upper and middle levels in the Bureau of Meteorology, every hour, using three successive GMS images taken one hour apart. Four times per day, around 05, 11, 17 and 2300 UTC, they are generated half-hourly, using three successive GMS images, separated by half an hour. At upper levels, the wind estimation method involves automatically identifying suitable targets from gradients (features) in the water vapour absorption channel imagery associated with upper-level clouds. These are tracked automatically, using a NWP model forecast of wind velocity to initiate the search for selected targets on subsequent images. Tracking uses three successive images and a lag correlation technique to provide an estimate of velocity. The target areas used for this procedure are 30 x 30 pixels in size. These were chosen because at upper levels (pressure less than 400 hPa) they provided similar accuracy to the 20 x 20 pixel areas used in the operational IR wind processing system, but for middle-level clear air vectors they were clearly superior, providing a greater number of more accurate vectors. The height assignment of these upper-level vectors uses a method similar to that associated with the determination of height with local cloud-drift winds (Le Marshall et al. 1994a) with some modifications to allow for changes in the spectral response functions and calibration for GMS-5. In essence, a normal distribution is fitted to the histogram of brightness values for pixels associated with the upper-level cloud, and the cloud height is then assigned using the coldest one per cent of

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the pixels to provide a representative temperature for the cloud-top height. For middle-level vectors associated with clear conditions, targets are again selected on gradient criteria and automatically tracked. The brightness temperature associated with the feature tracked is then used to assign a pressure altitude to the vector. Automatic quality control, using physically based tests and forecast model wind estimates, then provides wind vectors and associated error estimates (Le Marshall et al. 1994a). Testing through December 1996 and January 1997 showed the mean magnitude of vector differences, compared to radiosondes within 100 nautical miles, for middle and high-level water vapour winds, were of the order of 5.8 and 5.9 m/s, while those for middle and high-level IR cloud-drift winds were 5.7 and 6.2 m/s.

An example of the typical distribution of water vapour winds over the Australian Region is seen in Fig. 1. where the wind vectors are plotted over a 6.7 μm GMS-5 image for 0500 UTC on 31 March 1998. The stars (*) indicate the positions of features (tracers) used for tracking. The complementary nature of the clear-air water vapour motion vectors and cloud-motion vectors

is evident, with the clear air vectors providing middle-level wind information in areas devoid of cloud. Typical wind vector differences between water vapour motion vectors and radiosondes within 100 nautical miles are shown in Table 1. The mean magnitude of vector difference for water vapour winds available on the GTS from the Japanese Meteorological Agency (JMA), for example, during March 1998, over the extratropical southern hemisphere was 7.6 m/s for upper levels and 8.3 m/s for mid-levels. This is a clear indication that the local water vapour winds are of good quality.

Water vapour motion winds in regional NWP

The experiments

A series of real-time data assimilation experiments has been completed to examine the potential utility of water vapour winds in operational numerical weather prediction over the Australian region. In these experiments, the operational Limited Area Prediction System, LAPS

Fig. 1 Water vapour motion vectors generated from images around 0500 UTC on 31 March 1998. Stars (*) denote tracers available for tracking. Upper-level winds are white, middle-level winds are grey.

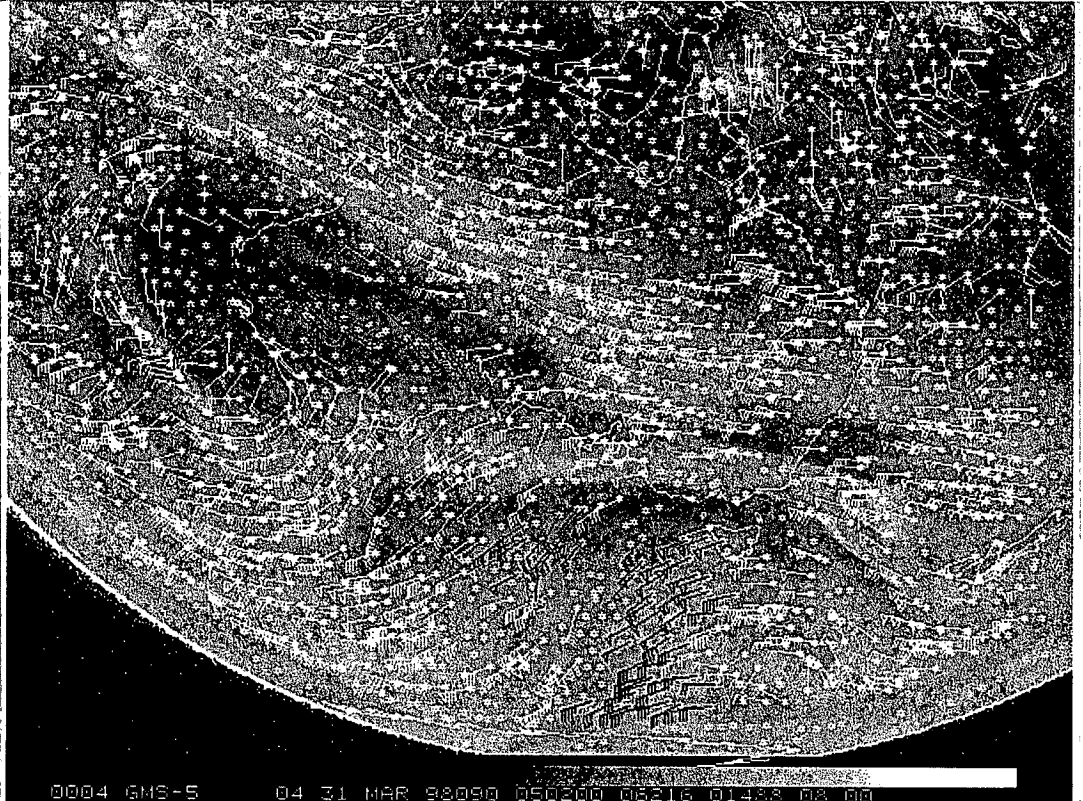


Table 1. Mean magnitude of vector difference (MMVD) (m/s) between water vapour motion vectors and radiosondes within 100 nautical miles (March 1998).

<i>Level</i>	<i>No. of cases</i>	<i>MMVD (m/s)</i>
High (150 - 399 hPa)	1520	6.34
Middle (400 - 699 hPa)	105	5.32

(Puri et al. 1998) has been used as the control. The experimental system was a duplicate near real-time Limited Area Prediction System, identical to the operational system except for the addition of real-time water vapour motion vectors to the input database. The forecasts in this real-time study were performed mainly during March 1998. The data were inserted into the system at six-hourly intervals. It should be noted that the database to which these water vapour motion vectors were added already contained local TOVS data (Le Marshall et al. 1994b) and local cloud-drift winds (Le Marshall et al. 1994a) generated by tracking features in 11 μm GMS-5 imagery.

The assimilation methodology

The analyses on which the forecasts reported here are based start with a Bureau of Meteorology global analysis, valid 12 hours prior to the forecast start time. This is used as a first guess to the regional analysis which then provides the base analysis for an initialised six-hour forecast, a subsequent analysis and a further initialised six-hour forecast. This forecast is then used as a first guess to the final analysis from which the twenty-four and forty-eight hour forecasts are run. Forecasts are nested in fields from the most recent Bureau of Meteorology global model forecast (Bourke et al. 1995).

The analysis and forecast models

The LAPS analysis and forecast model uses the same latitude/longitude/sigma coordinate system. The configuration consisted of 160 x 110 grid-points at 0.75° spacing in the horizontal, and 19 levels in the vertical, with an upper level of sigma 0.05. The analysis system is a limited area adaptation of the global multivariate statistical interpolation analysis (Seaman et al. 1995). The errors assigned to the water vapour motion vectors in the operational analysis scheme are 4 m/s and 5 m/s for middle and high-level vectors respectively. These values are consistent with the errors of 3 m/s assigned to middle and high-level radiosonde observations and the differences in Table 1. The forecast model is described in Puri et al. (1998) and is a hydrostatic model formulated in latitude/longitude/sigma coordinates on the Arakawa 'A-grid'. It uses high order numerics and includes a comprehensive physics package and the digital filter initialisation of Lynch and Huang (1992).

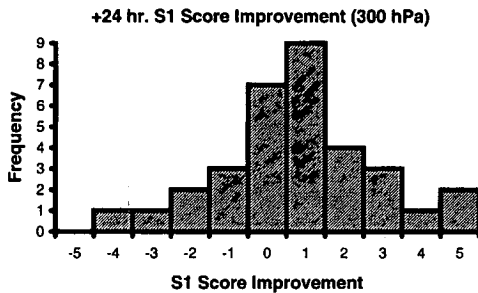
The experimental results

Thirty-three forecasts from this experiment were examined and the results are summarised in Table 2. The forecasts were performed in near real-time only when computing resources were available, with the majority of the forecasts (24) being in March 1998. The analysis and forecast charts were scrutinised manually and the forecast accuracy recorded. In much of the region, particularly over the oceans, the water vapour winds provide the majority of the upper and middle-level wind vectors to be analysed (see Fig. 1) and usually led to a small but discernible change in the analysed fields. Table 2 shows that, at both 24 and 48 hours, the addition of water vapour motion vectors to the operational analysis database (including local TOVS and cloud-drift winds) has provided, on average, at all levels examined, a modest improvement in the accuracy of regional forecasts of geopotential height as measured by the S1 skill-score (Teweles and Wobus 1954) tabulated on the official National Meteorological Operations Centre (NMOC) verification grid. In particular cases, however, the improvement can be quite significant (up to five points, for example, during this trial). Another view of the impact of these winds on the NWP system used for operational regional NWP is seen in Fig. 2 where S1 skill-score improvement versus frequency is plotted, showing that the general improvement in accuracy is not due to a few large impacts only. In some cases, the water vapour motion vectors can clearly be seen to contain important information for the analysis. Figure 3, for example, shows a GMS-5 water vapour absorption band image for 1700 UTC on 18 September 1997 overlain by the operational 400 hPa analysis for the same time. In this case, clear-air water vapour motion vectors can be seen to indicate that the low centre in the operational analysis at 400 hPa (which had no access to these water vapour motion vectors) should be further to the west.

Table 2. S1 skill-scores for the operational regional forecast system (LAPS) and LAPS with water vapour motion vectors (WVLAPS) for March 1998 - 33 cases.

<i>Level</i>	<i>LAPS (+24 hrs)</i>	<i>WVLAPS (+24 hrs)</i>	<i>LAPS (+48 hrs)</i>	<i>WVLAPS (+48 hrs)</i>
MSLP	25.2	25.1	35.3	34.8
850 hPa	25.9	25.4	34.7	33.4
500 hPa	20.1	19.4	29.9	29.2
300 hPa	17.3	16.8	29.7	29.4
250 hPa	16.3	15.8	26.8	26.7

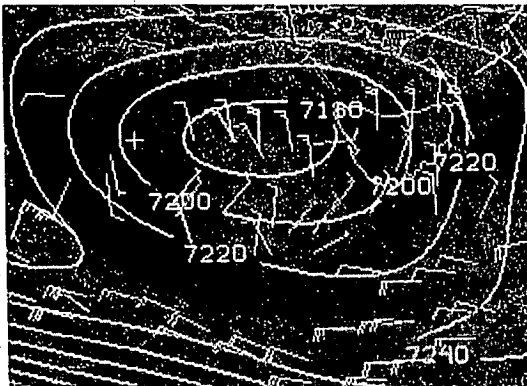
Fig. 2 A histogram showing S1 skill-score improvement versus frequency of occurrence for 24-hour forecasts of geopotential height at 300 hPa.



Summary and conclusion

Water vapour motion vectors are routinely generated on an hourly basis, in the Bureau of Meteorology Research Centre and transmitted routinely to NMOC, Regional Forecast Centres and Tropical Cyclone Warning Centres. Their application to regional numerical weather prediction in the (operational) Limited Area Prediction System, using six-hourly intermittent assimilation, has shown that the addition of these water vapour motion vectors to the real-time database has provided, on average, a modest improvement in skill as measured by the S1 skill-score. Their impact, on particular occasions, however, can be more significant. These impacts have been gained even though the regional forecast system already contains local TOVS data and local cloud-drift winds, estimated by tracking features in GMS-5 11 μm imagery. It

Fig. 3 Water vapour motion vectors generated from images around 17 UTC on 18 September 1997 over the analysis for 17 UTC on 18 September 1997.



may be noted that this is probably the first record of the beneficial impact of these water vapour absorption channel winds when used with an operational regional numerical weather prediction system.

As a result of these and other experiments, local water vapour motion vectors are now being considered for inclusion in the operational regional NWP system. It is important to note that the utility of water vapour motion vectors for tropical cyclone track forecasting is also well established (Le Marshall 1998; Velden et al. 1997). Hence, their addition to the NMOC real-time database should also be of benefit to operational tropical cyclone track forecasts in the Australian Region. In the longer term, it is anticipated that clear-air wind information used here may be extracted from the 6.7 μm images using 4-D variational assimilation of clear radiances, avoiding the problems of assignment of heights to the vectors using brightness temperatures from single absorption channel data. When multi-channel absorption imagery, such as that available from the current GOES satellites, becomes available, it will also provide wind-related information at a range of levels in clear air. In conclusion, it can be seen that water vapour absorption band winds have the capacity to enhance current analysis and prognosis accuracy, and with improving satellite technology and the developing variational NWP methodologies the ability to enhance NWP will increase into the next millennium.

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