AN OPERATIONAL SYSTEM FOR GENERATING CLOUD DRIFT WINDS IN THE AUSTRALIAN REGION AND THEIR IMPACT ON NUMERICAL WEATHER PREDICTION

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ABSTRACT

The Australian Bureau of Meteorology (BoM) has, since June, 1992, produced cloud drift wind data for operational use. These data are used in the analysis cycle of the local operational Numerical Weather Prediction (NWP) system. This paper briefly describes the methodology used for automatically producing cloud drift winds and also for their application to numerical weather analysis and prediction. Local processing of Geostationary Meteorological Satellite (GMS) digital infrared data into cloud motion vectors has provided several advantages. It ensures timely availability of the data in the Australian National Meteorological Centre for the operational Regional Assimilation and Prediction (RASP) system. It allows quality control and, in particular, height assignment to be closely tied to the RASP system, which is consistent with the long-term requirement for the processing of these remotely sensed data to be done as part of the assimilation system. Importantly, use of the data has resulted in consistent improvements both in forecasts from the RASP system over the Australian Region in real time trials over several months and in forecasts over the Southern Hemisphere in a one month trial with the Bureau of Meteorology Research Centre (BMRC) Global Spectral Model.

1. INTRODUCTION

This paper briefly describes the operational cloud drift wind system in the BoM. It outlines the present methods employed for wind extraction, height assignment and quality control in the local CDW estimation system. It documents the accuracy of the local CDW's and shows their impact on operational numerical weather prediction in the Australian region in both the BoM's regional and global models. The system runs in an Australian Region McIDAS environment (Le Marshall et al., 1987).

2. THE CLOUD DRIFT WIND SYSTEM

a. Wind vector estimation

After reception at the BoM, the imagery is navigated using orbit, attitude and landmark data from the header of the GMS S-VISSR transmission together with some refinements which include statistical correction of the navigation information to fit the landmark data and horizon detection. The operational system uses 3 sequential IR images, separated by half an hour. These images are typically 2500 x 2500 pixels, with 256 brightness levels. The imagery is searched for potential target areas of 20 x 20 pixels by examining maximum and minimum pixel values and brightness temperature gradient maxima. Selected targets are tracked automatically using forecast winds from the RASP system as a first guess, then a lagged correlation technique which minimises root mean square (RMS) differences in brightness from successive pictures is used to estimate the vector displacement.

b. Height Assignment

CDW height assignment uses temperature profiles provided by the RASP. Determination of temperatures associated with various levels within the cloud is presently done by fitting Hermite polynomials to smooth raw histograms of brightness temperature (dashed line in Figure 1). This enables estimation of cloud base altitude from cloud base temperature using the RASP, (assuming that the temperature difference between cloud top and cloud base is twice the difference (ΔC) between cloud top and modal (M) cloud brightness temperatures) or one third of the cloud top height where the cloud base is not discernible. The cloud height assigned to the low level winds is that of the cloud base, determined as described above.

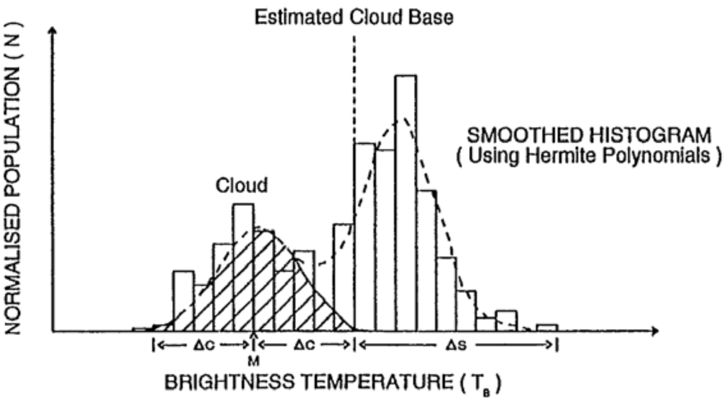

Figure 1 Schematic diagram of the methodology used to determine altitudes of cloud top and cloud base.

A typical indication of the utility of cloud base assignment can be gauged from the Mean Magnitude of the Vector Difference (MMVD) between BoM low level winds and radiosondes (within 100 nautical miles) after assignment to cloud base Pc and 850 hPa for October 1993 which is 4.21 ms^{-1} and 4.66 ms^{-1} respectively for 685 vectors.

Upper level cloud winds are assigned to the cloud top. The cloud top level is estimated by an examination of the cold tail of the upper cloud population (hatched area of Fig. 1), assuming the cloud temperature for the winds to be just above the coldest 5.5% of the cloud population. This methodology is still being refined using observational studies matching CDW's with radiosonde data. When using this method, a check is made to ensure that the brightness temperature distribution increases in a specified manner as the class temperature rises. The height assignment and this latter check is based on the smoothed histograms, obtained from the Hermite polynomials, which are used to distinguish the contributions from high cloud as opposed to those from lower levels. The height assignment level for the CDW's moves progressively from the estimated cloud base to the estimated level of the cloud top as one progresses from low to high cloud.

c. Wind Quality Control

Quality control is fully automatic. Wind data are accepted and errors assigned based on several criteria. These include the correlation between the brightness temperature arrays of the search and target areas which must exceed 0.65 and the differences in meridional (and zonal) wind components of the two vectors from a tracer tracked in two adjacent half-hourly images which are usually required to be less than 5 ms^{-1} for each component. The deviation of the calculated wind vectors from the first guess field is also examined and zonal and meridional wind tolerances of the order of 10 and 7 ms^{-1} respectively are used to assign error estimates to the vectors, (based on previous colocation statistics).

Quality control at the wind calculation stage is, to a significant degree, a practical compromise as an analysis system should be able to appropriately handle even poor data provided their error characteristics accompany the observation. In this system, the quality control is complementary to that in the data assimilation component of the regional and global forecast systems used within the Bureau of Meteorology. As a result, checking using neighbouring data for example is not done because this is performed as part of the analysis cycle. It should be noted that in a simplistic sense, however, this may increase RMS errors associated with the local CDW's. In practice, wind numbers generated and RMS errors are related and the number of error categorised winds produced needs to be optimal for both NWP and synoptic use.

The weights assigned to the wind data in analysis are dependent on their expected error. To facilitate the estimation of these weights, the quality control criteria cited above are used to provide a measure of velocity uncertainty with each wind observation. In future, it is also intended to use the uncertainty in height assignment (indicated by calculating height from all sequential images used for wind estimation) to help estimate wind errors.

d. Wind Accuracy

An example of winds generated by the operational system is shown in Fig. 2. The local system provides 400 to 600 wind vectors every six hours.

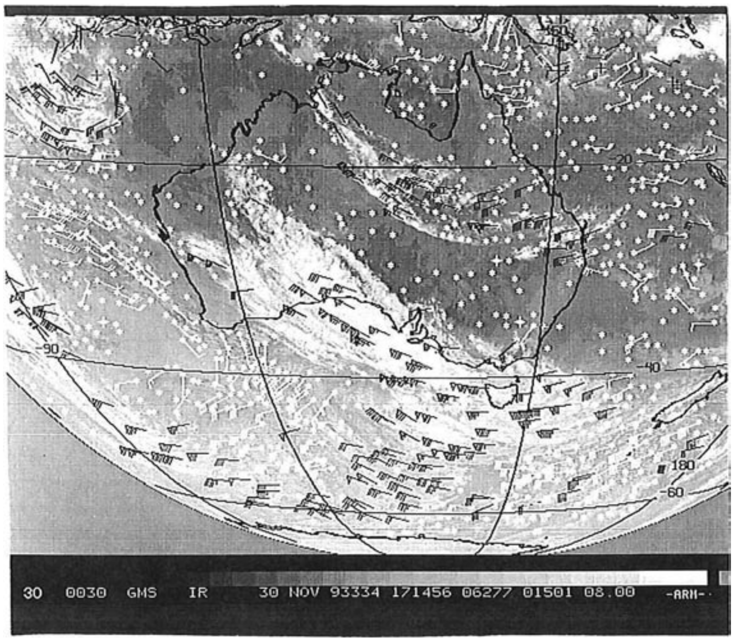

Figure 2 Local CDW's for 1700 UTC on 30 November 1992. White arrows denote low level, grey arrows denote middle level and black arrows denote upper level winds. Automatically selected tracers are denoted by *.

The performance of the local system by month is seen in Table 1, which shows the mean modulus of the vector deviation (MMVD) of the CDW's and the 6 or 12 hour forecast first guess field from radiosondes within 100 nautical miles for the period for lower error category vectors. The importance of providing error estimates for the first guess fields and winds in analysis is highlighted by their relative sizes at different levels in Table 1.

Month	Level	No.	Guess MMVD	CDW MMVD
Sept.	High	101	8.3	8.2
	Low	1452	4.6	4.0
Oct.	High	119	7.9	7.6
	Low	685	4.5	4.2
Nov.	High	110	7.8	7.8
	Low	362	4.3	4.0

Table 1 Mean Magnitude of vector difference (MMVD) between Bureau of Meteorology CDW's and the first guess (RASP) forecast with respect to radiosondes (within 100 NM) for September, October and November, 1993 (ms^{-1}) for lower error category vectors.

3. DATA IMPACT IN THE AUSTRALIAN REGION

The regional data assimilation system used in these studies was the BOM operational limited area data assimilation system which has been described in detail by Mills and Seaman (1990).

a. The 1991 Regional Trial (BoM Winds only)

To quantify the impact of winds from the now operational CDW system on short range, limited area prediction over the Australian Region, a series of real time analysis-forecast experiments were run in the Australian Region, using local CDW's instead of those available from JMA via the GTS at the operational cutoff time. Data was inserted every six hours, with JMA winds usually available for the 0600 UTC and 1800 UTC operational forecast cycles but, usually, no such winds were available in time for the 0000 UTC and 1200 UTC operational forecast cycles.

The data used in the real time assimilation trials were identical to those used by NMC except that the JMA winds, if available, were excluded and locally generated vectors were used. In this way, the NMC forecast was used as a control. The results from the real time trial during July, August and September, 1991 are shown in Table 2. The verification statistics were derived using the operational NMC verification grid.

The forecast periods examined were 2300 UTC 1 July 1991 to 2300 UTC 13 July 1991, during which 14 assimilation forecasts were performed, 2300 UTC 23 August 1991 to 1100 UTC 29 August 1991, during which 12 assimilation forecasts were performed and 1100 UTC 6 September 1991 to 2300 UTC 28 September 1991, during which 17 assimilation forecasts were performed. The forecasts were only verified in this trial if at least 36 hours of cycling with the local CDW data had been completed to ensure that the impact of the winds on the regional forecast system was being properly measured.

The forecasts were assessed by comparing S1 skill scores (Tewles and Wobus, 1954) for the control (NMC) forecasts and the corresponding forecasts using CDW's, using the NMC operational verification grid. The results for both 24 and 36 hour forecasts were verified against both the NMC and CDW assimilation analyses. For S1 skill scores, the lower the score, the better the skill of the forecast. In all cases, the mean S1 skill scores indicated a small but consistent improvement in skill at all levels for **local CDW's**. Examples of synoptic impact can be seen in Le Marshall et al., 1993.

Table 2 Mean S1 skill scores of forecasts using only local CDW's (local CDW's) and matching Control forecasts (operational) for the periods 2300 UTC 1/7/91 to 2300 UTC 13/7/91, 2300 UTC 23/8/91 to 1100 UTC 29/8/91, 1100 UTC 06/9/91 to 2300 UTC 28/9/91.

	Verifying Analysis OPERATIONAL RASP ANALYSIS						Verifying analysis CLOUD DRIFT WIND ANALYSIS					
	+24 hr			+36 hr.			+24 hr			+36 hr		
System	MSLP	500 hPa	300 hPa	MSLP	500 hPa	300 hPa	MSLP	500 hPa	300 hPa	MSLP	500 hPa	300 hPa
Operational	33.7	21.6	20.5	42.3	28.3	26.5	33.7	21.0	19.9	42.2	28.3	25.73
local CDW's	33.6	21.1	20.0	41.4	27.3	25.6	33.6	20.9	19.6	41.3	27.0	25.07

b. The 1992 Regional Trial (BoM plus JMA Winds)

As a result of the success of the trials referred to above, an operational trial with the local CDW data and JMA data was undertaken at the BoM. From 0000 UTC on 11 May 1992 to 0000 UTC on 31 May 1992, 40 test cases were run within NMC from base times of 0000 UTC and 1200 UTC on each day, to test the impact of the operational use of the local CDW's. In this trial, locally derived CDW's (which were available for most analysis cycles) were used in the real time RASP system and both synoptic and skill score assessment were undertaken for the resulting forecasts. During the trial, the local CDW data were added to the NMC database, which included any JMA winds that arrived before the operational cutoff. In this test, JMA data were usually available for the 0600 and 1800 UTC analyses but arrived after the operational cutoff for 0000 UTC and 1200 UTC analysis and forecast cycle run. The operational NMC run was used as the control. The rationale for using both BoM and JMA winds was that, if either were not available at the operational cut-off time, the analyses would still benefit from the available wind data coverage.

For the test period, a small but consistent positive impact on skill score for mean sea level pressure and all geopotential heights verified was demonstrated. This can be seen in Table 3, which shows S1 skill scores verified against both the operational analyses and the analyses using the local CDW's. These results were consistent with the improvements shown in 3a. In addition to the small improvements shown in Table 3, there were also visible changes in the forecast charts. One such change, which occurred on several occasions during the trial, was an enhancement of the forecast jet stream intensity at upper flight levels to the east of the Australian continent. Such an enhancement was illustrated in Le Marshall et al., 1992.

Table 3 S1 skill scores from the operational trial

	Verifying Analysis OPERATIONAL RASP ANALYSIS						Verifying Analysis CLOUD DRIFT WIND ANALYSIS					
SYSTEM	+24 hr.			+36 hr.			+24 hr.			+36 hr.		
	MSLP	500 hPa	300 hPa	MSLP	500 hPa	300 hPa	MSLP	500 hPa	300 hPa	MSLP	500 hPa	300 hPa
Operational	37.5	26.7	23.6	45.5	34.1	30.5	37.4	26.4	23.6	45.5	33.8	30.4
CDW's	37.3	26.2	23.3	45.3	33.7	30.0	37.2	26.0	23.0	45.4	33.4	29.9
Persistence	57.9	48.0	42.3	69.0	57.3	50.7	57.9	47.7	41.8	69.0	57.0	50.2

It should be noted that while this experiment was in progress, the usual provision of manual pseudo-observations over data-sparse areas south of Australia for mean sea level pressure was not assisted by access to the local CDW's and, as a result, the important 0000 UTC and 1200 UTC mean sea level pressure analyses did not benefit fully from the provision of CDW data during the operational trial.

4. DATA IMPACT IN THE GLOBAL SYSTEM

The Bureau's basic Global Assimilation and Prediction System (GASP) is described in Bourke et al (1990), and significant refinements since 1990 are summarised in Seaman et al (1993).

Tests of the impact of local CDW's on the Global system were conducted by means of daily (1200 UTC) forecasts to 5 days from parallel assimilation cycles for a period of 29 days in December 1992. The assimilation cycles performed were as follows.

- The cycle designated 'JMA' utilised incoming reports to the Australian NMC within cutoff times approximately 8 hours after 0000 and 1200 UTC, with the exception of local CDW's. It generally included all JMA CDW's.
- The cycle designated 'BOTH' utilised all incoming reports including both JMA and local CDW's.
- The cycle designated 'PREF' utilised all incoming reports, with the exception that a JMA CDW was not used if it was located within 150 km and 100 hPa of a local CDW. Such a methodology ensured preferential use of the local CDW's.

The forecasts were verified against independent analyses from the U.S National Meteorological Center 'aviation' run (3 hour data cutoff). Since the U.S analyses did not have access to the local CDW's, any bias in the verifications is likely to favour the JMA winds.

Forecasts from all three cycles were verified by means of the S1 score over the Australian region (the same verification area as in Tables 2 and 3), and by means of the anomaly correlation coefficient (ACC), scaled to range from 0 to 100, over the annulus from 20 to 60 degrees south. The differences between (i) the 'JMA' and the 'BOTH' cycle scores, and (ii) the 'JMA' and the 'PREF' cycle scores, were then computed, the sign of the difference being defined so that a positive difference corresponds to a positive impact of the local CDW's. The resultant impacts are summarised in Table 4.

Table 4 Mean differences of GASP forecast skill scores between (i) the BOTH and the JMA cycle and (ii) the PREF. and the JMA cycle. The means are based on 29 base times during December 1992. The forecasts were verified against analyses from the US NMC aviation run. A positive sign denotes positive impact of the local CDW's.

Score	Z500 S1 Aust. Reg					Z500 ACC 20 - 60 S				
Range (days)	1	2	3	4	5	1	2	3	4	5
BOTH - JMA	+0.2	+0.2	+0.2	+0.1	+0.3	0	0	+0.1	0	0
PREF. - JMA	+0.2	+0.1	+0.3	+0.5	+0.3	+0.1	0	+0.1	+0.2	+0.4
Score	MSL pressure S1 Aust. Reg.					MSL pressure ACC 20 - 60 S				
Range (days)	1	2	3	4	5	1	2	3	4	5
BOTH - JMA	0	+0.2	+0.5	+0.6	+0.7	0	0	+0.1	+0.3	+0.2
PREF. - JMA	0	+0.2	+0.7	+1.0	+0.5	+0.1	0	+0.9	+0.1	+0.6

The average impacts are without exception small ($\leq$ 1 point in S1 and ACC), but they are also consistently positive or zero. The sign and magnitudes of the S1 impacts appear consistent with those in Tables 3 and 4, obtained for the regional system in different months. Particularly in the case of the ACC, there is some suggestion of a greater impact of local CDW's when they are used preferentially.

5. SUMMARY AND CONCLUSIONS

As a result of the evidence provided by the 1992 regional operational trial and previous testing over a six month trial period in research mode, locally derived CDW's from Japanese GMS imagery were incorporated into the operational RASP system from 3 June 1992. From this date, analysts providing bogus observations for the numerical MSLP analyses have also been able to access these data before preparing the MSLP charts from which the bogus observations are derived. Senior analysts in NMC have indicated their importance for this task.

In addition, tests using the BMRC global assimilation scheme have indicated the utility of the locally derived CDW's in the GASP system where their addition to the data base has provided a small but consistent improvement in the accuracy of forecasts in the Australian sector.

In summary, testing, both in research and operational mode has indicated :

- Local CDW's can be generated, in a timely fashion, for the 0000 UTC and 1200 UTC operational regional analyses.
- The winds improved the operational RASP forecasts (the amount of improvement varied from month to month) and
- The use of the winds in the GASP system has provided a small but consistent forecast improvement.

The local CDW's are now also being used in the manual MSL pressure analyses prior to the generation of bogus observations in NMC.

In conclusion, the Bureau of Meteorology has joined the small group of organisations which process cloud drift wind data for use in operational numerical weather prediction. These winds are providing small but consistent improvement in NWP forecasts over the Australian region. Recently, the domain over which these winds are used operationally has been increased and it is intended to further augment the present system by deriving these data at intermediate times based on hourly imagery, and to make additional enhancements using bispectral imagery and improved height assignment and cloud tracking algorithms. The use of cloud classification for tracer selection is also under examination. Where possible, the wind calculations will be done in the presence of all data available to the local analysis and prognosis system to provide an optimal environment for wind data retrieval and utilisation.

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