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The impact of increased TOVS data on numerical forecasts of a case of cyclogenesis

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In December 1987 an intense extratropical cyclone passed through southern Australia causing considerable damage, economic loss and forecast difficulty. This case was examined by Velden and Mills (1990), who showed that a limited area data assimilation system captured many of the features of the intensification and movement of the low. Their analyses used TOVS data at 500 km resolution, as received on the Global Telecommunication System in Australia. In this paper, their forecasts are repeated, but using TOVS data with a horizontal resolution of 250 km in the assimilation. It is shown that during the intensification phase of the low's evolution the additional TOVS data produced better forecasts of the low's shape, and also had the low moving slightly faster — an improvement in forecast accuracy. It is also shown that during the low's precipitation phase, the distribution of precipitation was more faithfully reproduced, with a double rainfall centre forecast, as was observed.

Introduction

In spite of what is probably a universally held belief that the temperature and moisture profiles from the TIROS Operational Vertical Sounder (TOVS data) have a significant impact on operational global medium-range weather forecasts, relatively little appears in the literature documenting their impact. This has been partly due to the difficulty of measuring this impact over the already (at least at the synoptic scale) well-observed northern hemisphere. Vergin et al. (1984) and Thomasell et al. (1986) showed a small positive impact of TOVS data on hemispheric forecasts, and found that most of the impact was in the less well-observed areas. Baker et al. (1984) found that positive or negative impact of these data depended on the choice of retrieval algorithm, while Tracton et al. (1981) argued that TOVS data could only positively impact an inferior analysis system. In spite of these mixed results in early data systems tests (note that all these references are at least five years old), all global operational numerical weather prediction systems now routinely input TOVS data to their data assimilation systems.

In the southern hemisphere, where conventional observations are more sparse, positive impact on hemispheric forecasts was demonstrated by Bourke et al. (1982). Of the few limited area studies, possibly the most definite positive impact of TOVS data on numerical forecast accuracy was that described by Kelly et al. (1978), although other more recent studies have been reported (e.g. Mills and LeMarshall 1987; LeMarshall et al. 1990). One of the possible reasons why the positive impact of these data has not been widely reported in the northern hemisphere is that the full horizontal resolution capabilities (see Smith et al. 1979) of these data have not been exploited. In at least one case over the United States the use of high resolution TOVS data improved the short-term numerical forecast of a severe weather event (Mills and Hayden 1983), and Gustafsson and Svensson (1988) also show small positive impact of these data over an already well-observed area of northern Europe.

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In Australia the TOVS retrievals received on the Global Telecommunications System (GTS) from the National Oceanic and Atmospheric Administration (NOAA) in Washington DC are used in the operational global (Bourke et al. 1982) and regional (Mills and Seaman 1990) data assimilation systems. Because of technological limitations, only the 500 km resolution retrievals are passed to Australia via Tokyo, rather than the 250 km resolution which is transmitted from Washington to other parts of the world. Velden and Mills (1990) (hereafter VM90) reported a case of unusually intense extratropical cyclogenesis over southeastern Australia which occurred in December 1987, and demonstrated that forecasts from the BMRC regional data assimilation system (RASP) showed a useful level of skill. These assimilation experiments used the 500 km resolution TOVS data from the GTS. Since then, tapes containing the 250 km resolution data for this period were obtained from the European Centre for Medium Range Weather Forecasts (ECMWF), and it is the purpose of this paper to report on the impact of adding these higher-resolution TOVS data to the Australian observation files, repeating the data assimilation and comparing the two sets of forecasts. This will be termed the HITOV assimilation in this paper.

The event under study was described in detail by VM90. A Southern Ocean low moved northeast towards the Western Australian coastline on 28 November 1987, and as it approached the coastline another low developed to its northeast, over the Nullarbor Plain. This new low moved eastward, then southeastwards through South Australia. The low intensified rapidly as it moved through South Australia and on 1 December brought heavy rain and strong cold winds to much of Victoria.

The design and performance of the RASP system has been described in detail by Mills and Seaman (1990). It has a 150 kilometre grid spacing, 11 analysis pressure levels (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, and 50 hPa), and 15 forecast model sigma levels (0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.70, 0.78, 0.85, 0.90, 0.95, and 0.98). In the experiments reported here data were inserted each six hours. After each data insertion the analysis changes on pressure surfaces were interpolated to the forecast model sigma surfaces before the model was initialised for the subsequent forecast.

The assimilation reported by VM90 (termed the LOTOV assimilation hereafter) commenced at 0000 UTC 29 November 1987, and two 24-hour forecasts were described in detail. The first was based at 0000 UTC 30 November, after 24 hours (four cycles) of assimilation, and was intended to examine the skill of the forecast system in predicting the track and intensification of the developing cyclone. The second, based at 0000 UTC 1 December, was intended to examine the forecasts of precipitation during the low's passage across Victoria. In this study four forecasts from the HITOV and the LOTOV analyses were prepared, based at 12-hour intervals from 1200 UTC 29 November to 0000 UTC 1 December. The next section of this paper will show the comparative data coverage and compare the analyses for the LOTOV and HITOV data sets and the following section will compare the forecasts from the two systems.

Data and analysis comparisons

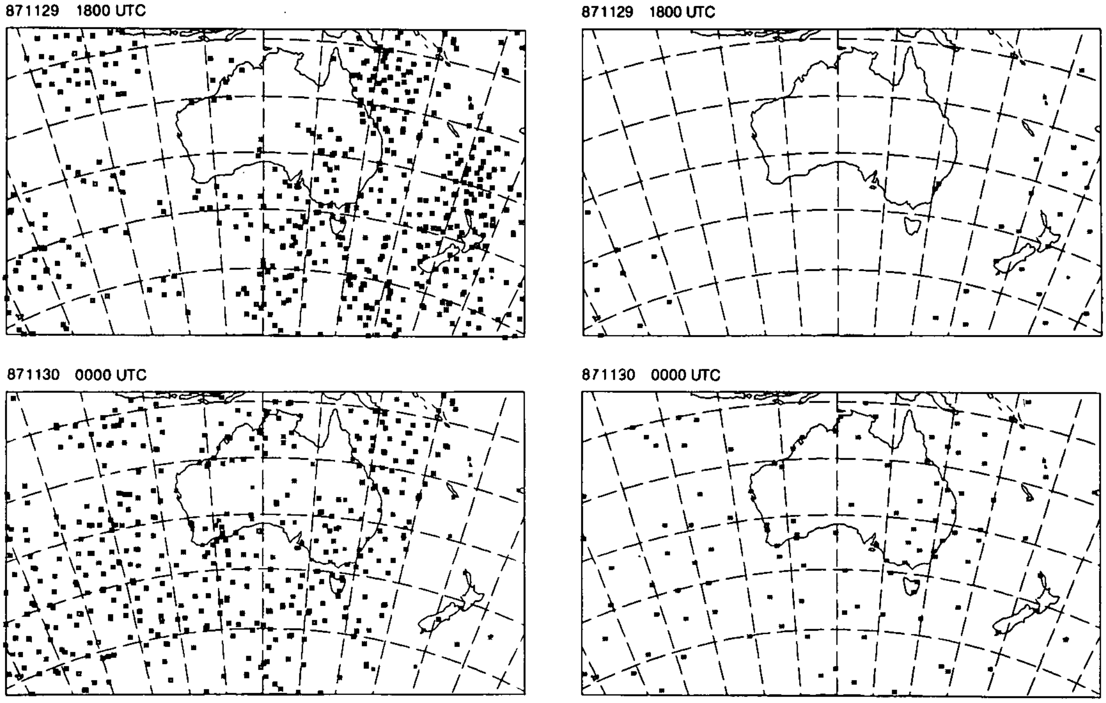
The number of TOVS profiles available to each six-hourly analysis from 0600 UTC 29 November for the LOTOV and HITOV assimilations is shown in Table 1, and Fig. 1 shows examples of the TOVS data distributions for these two data sets. Table 1 shows a vast increase in number of the TOVS data on the European Centre (EC) tapes, and Fig. 1 shows that this is not only a greater density of data, but also that more orbits were received. The additional orbits were mostly at the 0600 and 1800 UTC analysis times, with extra orbits (usually east of Australia) occasionally available at the 0000 and 1200 UTC analysis times. (At the time of writing this paper, this behaviour is no longer noticed in operational practice and so must be ascribed to changes in data handling practice since that time.)

Table 1. Number of TOVS data profiles available for the LOTOV and HITOV analyses for each analysis time.

Analysis time	*LOTOV No.*	*HITOV No.*
29/0600	18	252
29/1200	72	544
29/1800	25	496
30/0000	79	436
30/0600	10	421
30/1200	50	511
30/1800	23	400
01/0000	86	386

Because the EC data contain more orbits than do the Australian archive tapes as well as having a higher density of data in those orbits, any impact of the EC TOVS data will have components due to both increased resolution of the data and increased coverage. After the first cycle of assimilation the guess field will differ if a different data base is used, so a subsequent analysis will differ. Thus the differences between the LOTOV and HITOV analyses are partly the direct effects of

Fig. 1 LOTOV (right) and HITOV (left) TOVS data distributions for the analyses at 1800 29 November and 0000 UTC 30 November 1987.



differing data bases (in this case TOVS data density) at the analysis time, and partly the effects of the resulting differences in the guess fields resulting from differing data coverage and density at earlier analysis times. At the major forecast base times the same orbits are received so some reasonable conclusions can be reached, and some assessment of the effects of the differing guess field will be made by using the HITOV data with the LOTOV guess fields to generate what will be termed HONLY analyses.

In comparing the analyses, two fields will be assessed: the first is the 1000–500 hPa thickness field, and the second the 250 hPa wind speed. These will be compared for the analyses at the four forecast base times, and Figs 2 to 5 show these fields and their differences for analyses at 12-hour intervals from 1200 UTC 29 November to 0000 UTC 1 December 1987. Concentrating on the trough system approaching Western Australia, Figs 2 and 3 show that at 1200 UTC 29 November the LOTOV thickness analysis had a lower centre than the HITOV system, but its centre was slightly further south. The difference field shows the higher thickness values of the HITOV analysis on and west of the axis of the thermal trough, however values are lower to the southeast of the cold pool. The 250 hPa wind analyses reflect these differences with the main isotach maximum near the head of the Bight similar in each analysis, but with a much stronger southerly jet on the western flank of the trough in the HITOV analysis.

At 0000 UTC 30 November, the two analyses show identical positions for the cold pools, but those of the HITOV analysis have slightly higher thickness values on the axis of the trough over Western Australia, and lower values to the east and west of the trough. Wind speeds at 250 hPa are again up to 10 m s^{-1} stronger over southwest Western Australia in the southwesterly flow just west of the trough apex. At 1200 UTC 30 November (Figs 4 and 5) the differences in the trough structure are subtle, but with the HITOV analysis having the thermal trough slightly narrower and slightly further east and with a more pronounced thermal ridge over New South Wales than the LOTOV analysis. At 0000 UTC 1 December the HITOV analysis shows lower thickness values in the thermal trough over central South Australia and slightly higher thickness values in the thermal ridge over southern New South Wales. In spite of this implied stronger thermal wind on the eastern flank of the trough, the HITOV 250 hPa wind analysis shows slightly lower speeds in the northwesterly jet over New South Wales than are seen in the LOTOV analysis.

Fig. 2 Analyses of 1000–500 thickness (dam) at 1200 UTC 29 November and 0000 UTC 30 November 1987. HITOV analyses top, LOTOV analyses middle, and the difference fields (HITOV minus LOTOV) bottom. Contour interval 60 dam for analyses, 10 dam for difference fields.

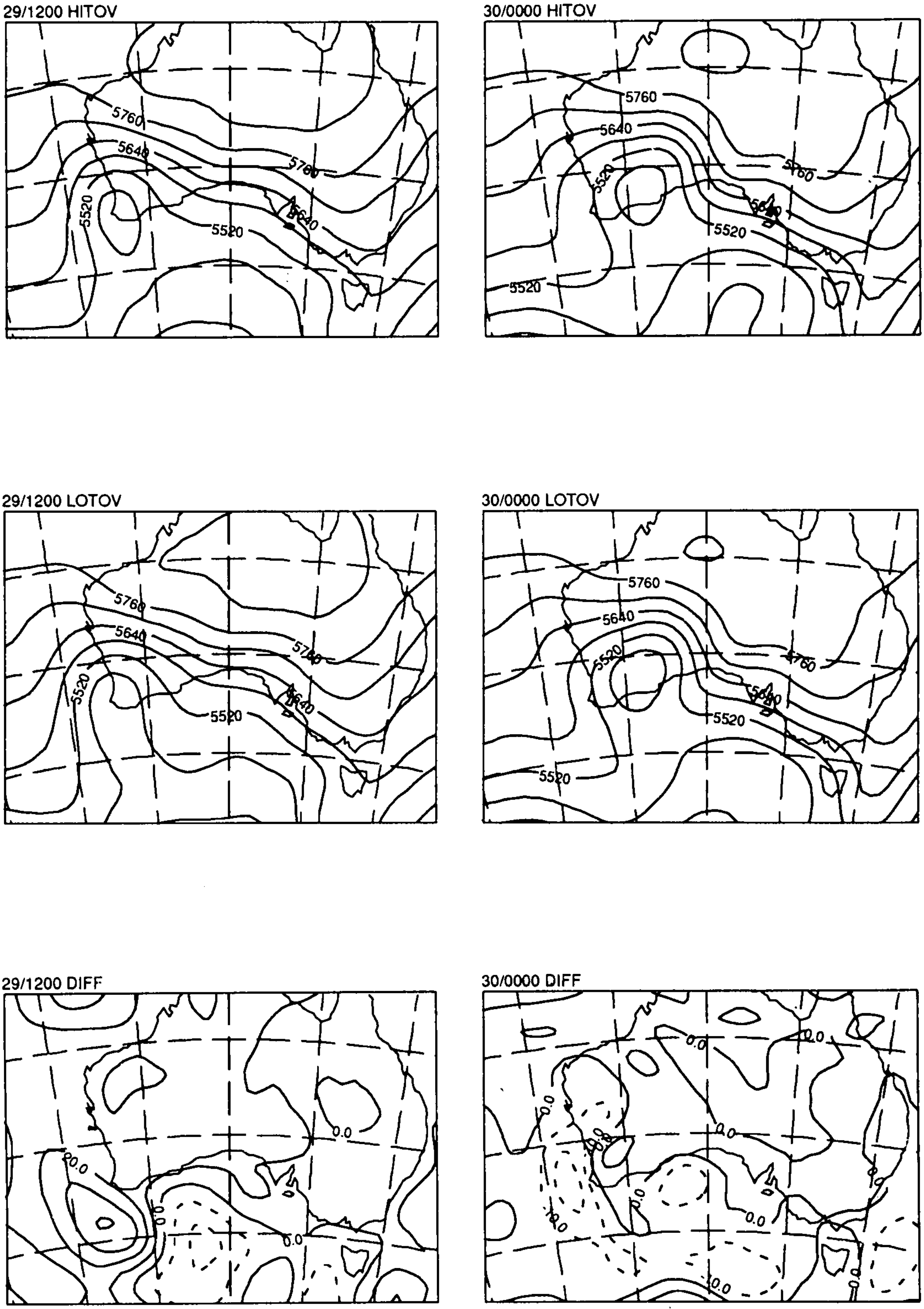


Fig. 3 Analyses of 250 hPa wind speed (m s^{-1}) at 1200 UTC 29 November and 0000 UTC 30 November 1987. HITOV analyses top, LOTOV analyses middle, and the difference fields (HITOV minus LOTOV) bottom. Contour interval 10 m s^{-1} for analyses, 5 m s^{-1} for difference fields.

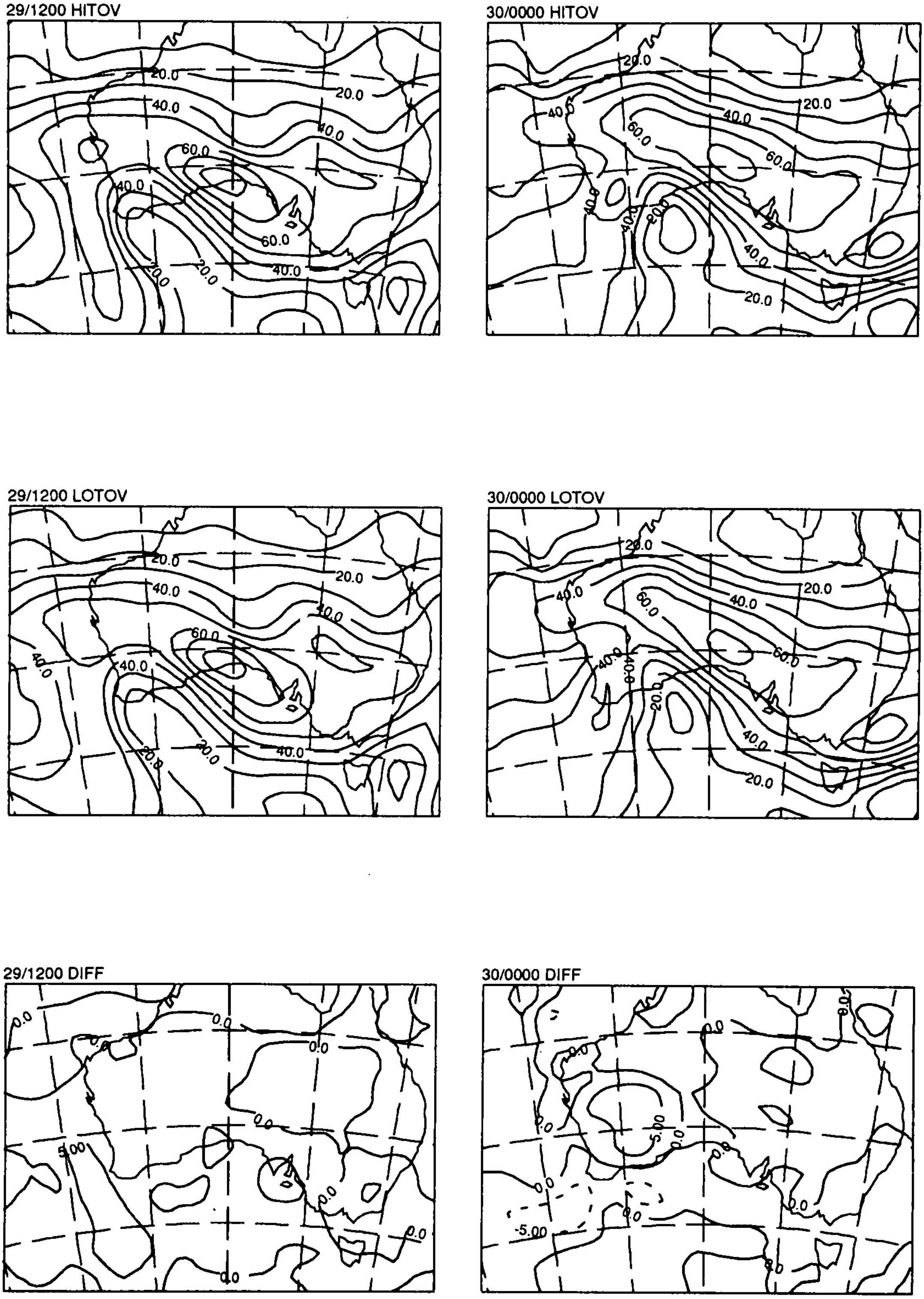
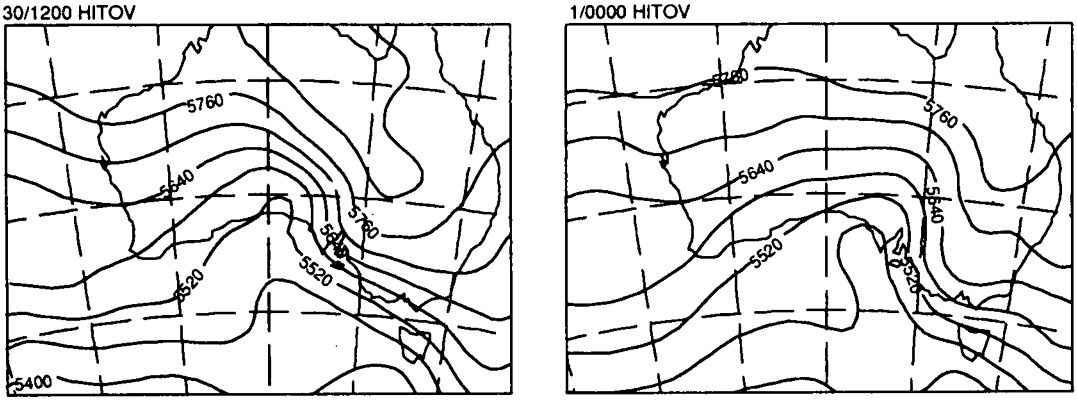
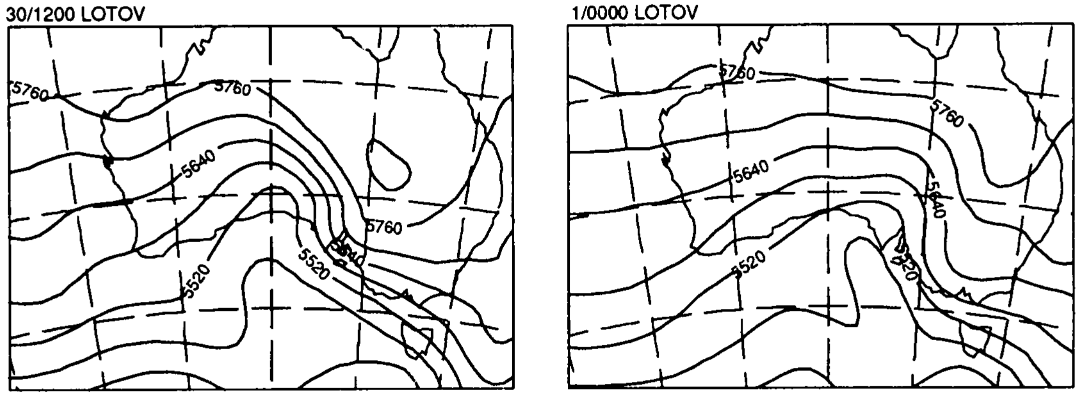


Fig. 4 Analyses of 1000–500 thickness (dam) at 1200 UTC 30 November and 0000 UTC 1 December 1987. HITOV analyses top, LOTOV analyses middle, and the difference fields (HITOV minus LOTOV) bottom. Contour interval 60 dam for analyses, 10 dam for difference fields.



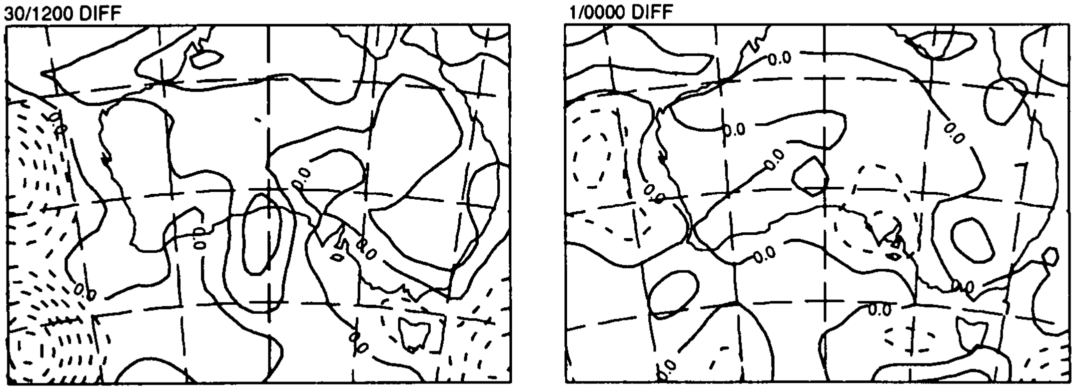
30/1200 HITOV

1/0000 HITOV



30/1200 LOTOV

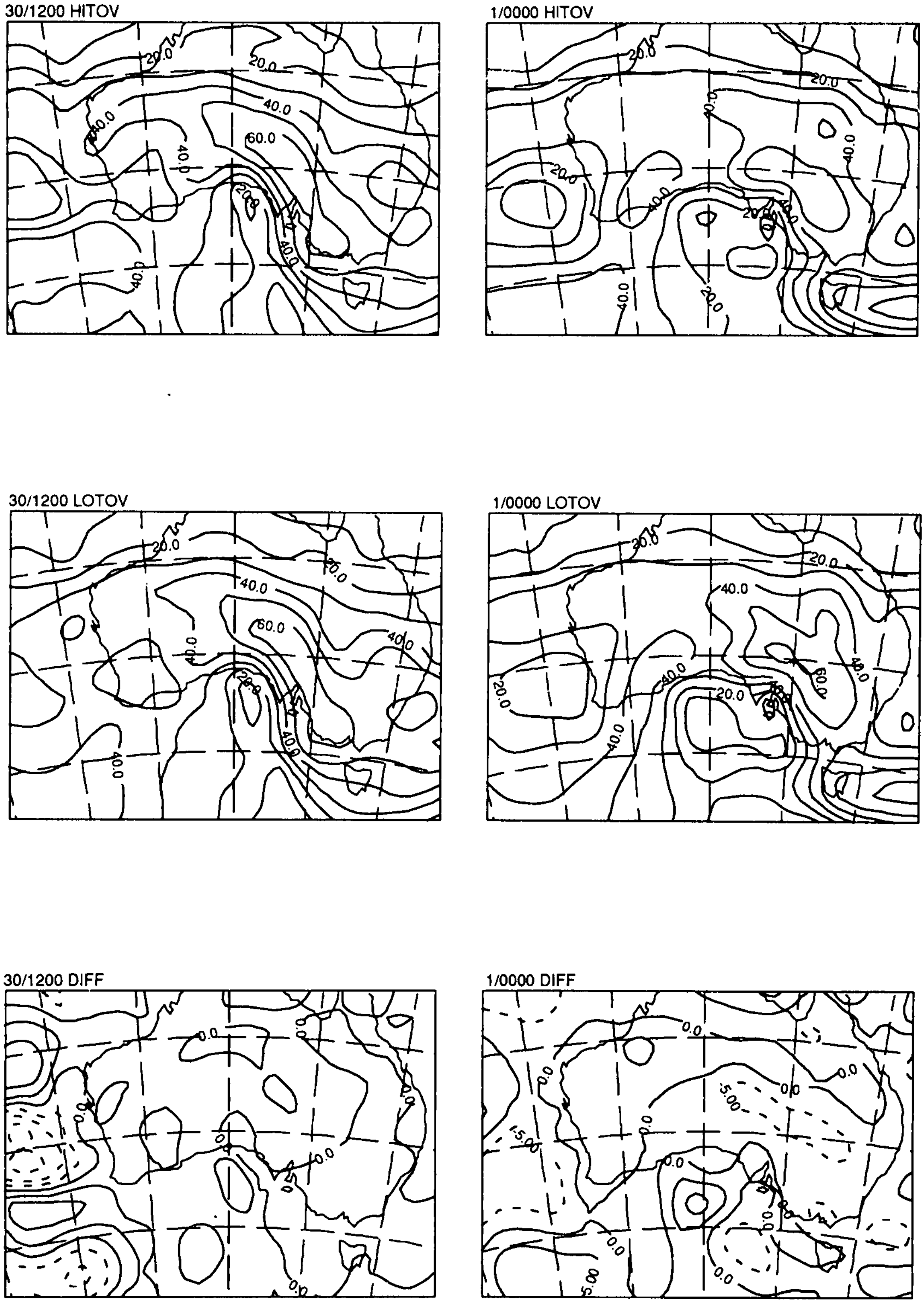
1/0000 LOTOV



30/1200 DIFF

1/0000 DIFF

Fig. 5 Analyses of 250 hPa wind speed (m s^{-1}) at 1200 UTC 30 November and 0000 UTC 1 December 1987. HITOV analyses top, LOTOV analyses middle, and the difference fields (HITOV minus LOTOV) bottom. Contour interval 10 m s^{-1} for analyses, 5 m s^{-1} for difference fields.


30/1200 HITOV

1/0000 HITOV

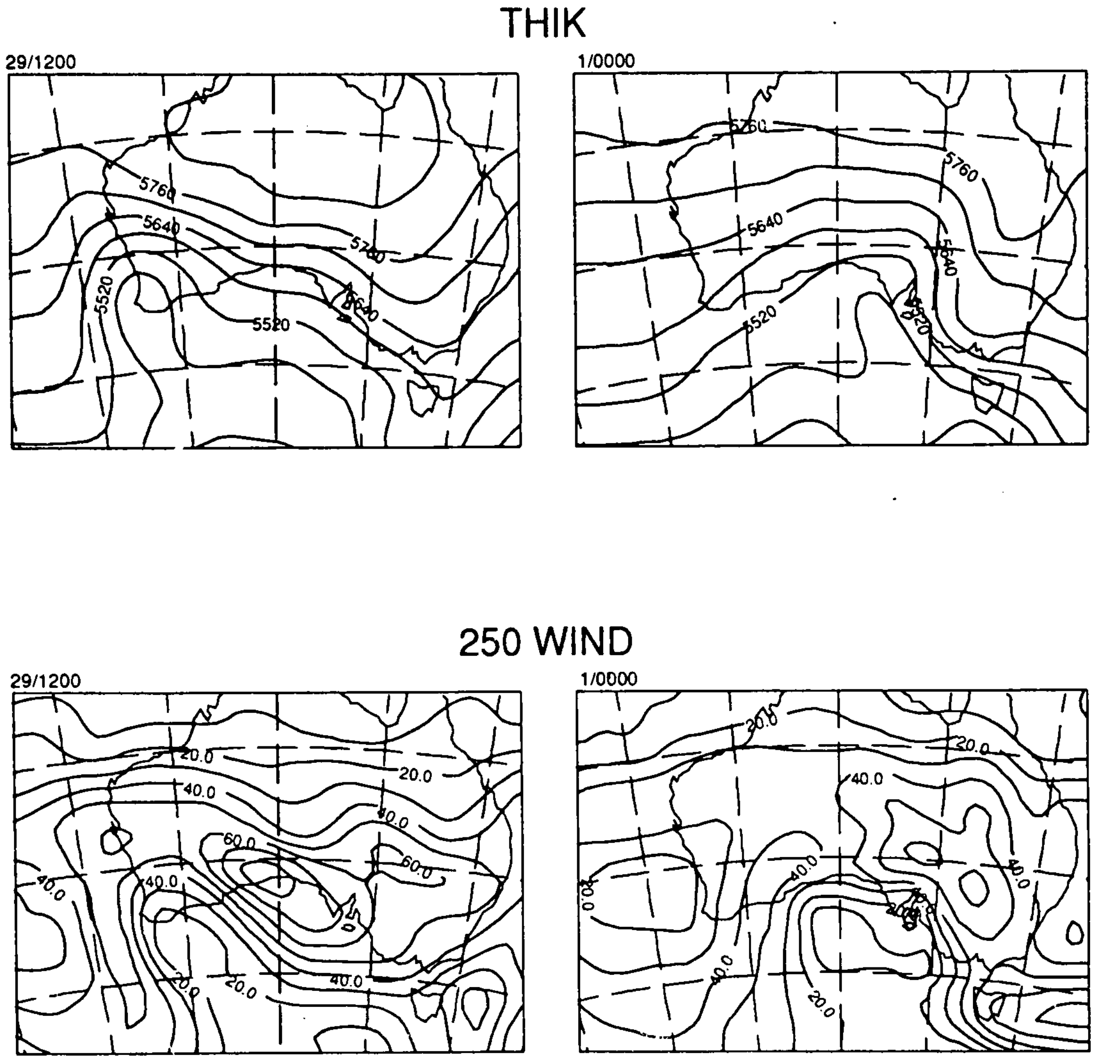
30/1200 LOTOV

1/0000 LOTOV

30/1200 DIFF

1/0000 DIFF

Fig. 6 Analyses of 1000–500 hPa thickness (dam) and 250 hPa wind speed (m s^{-1}) at 1200 UTC 29 November and 0000 UTC 1 December using the HITOV data base and the LOTOV guess fields.



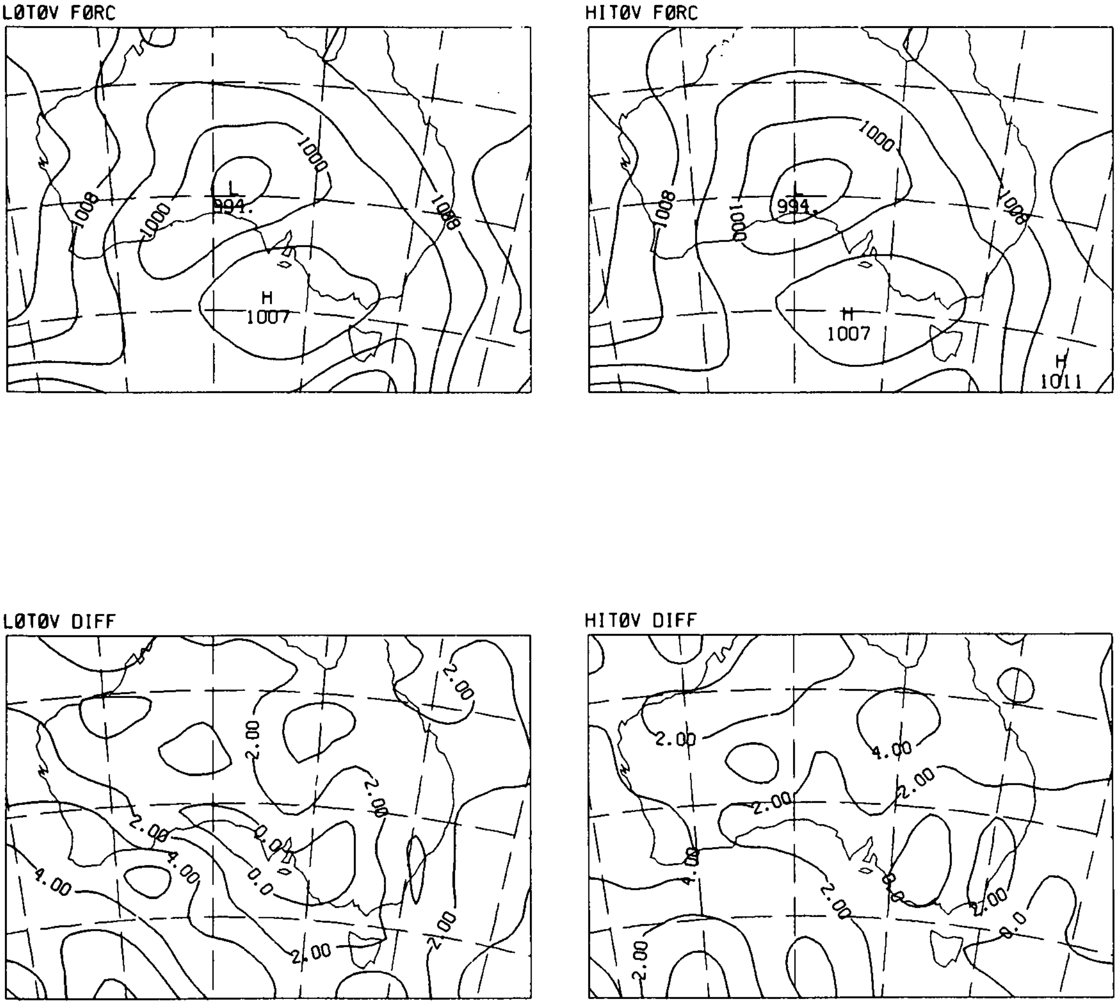
In order to make some assessment of the relative effects of different guess fields and different data coverages, new analyses at 1200 UTC 29 November and 0000 UTC 1 December were prepared using the HITOV data base, but the guess fields from the LOTOV assimilation. These 1000–500 thickness and 250 hPa wind analyses are shown in Fig. 6, and will be termed the HONLY ('high only') analyses. Interestingly, at 1200 UTC 29 November the HONLY analyses are closer to the HITOV analyses than the LOTOV analyses, however the opposite is the case at 0000 UTC 1 December. This suggests that in the second case the data coverage at the earlier time changed the guess field, thus having an impact on the analysis, while in the first case the increased data density at the analysis time was the chief cause of the changed analysis.

The subtle interactions of different guess fields and the detail of the different data distributions are obviously critical, but this shows that the differences in the analyses are not simply due to the different data bases at the analysis time, but also due to differences in the guess fields caused by differing data bases at earlier times.

Comparison of prognoses

Four 36-hour forecasts were prepared from both the HITOV and the LOTOV analyses based at 12-hour intervals from 1200 UTC 29 November.

Fig. 7 LOTOV and HITOV 12-hour MSLP forecasts based at 1200 UTC 29 November 1987 and their error fields (HITOV analysis minus forecast, lower panels).

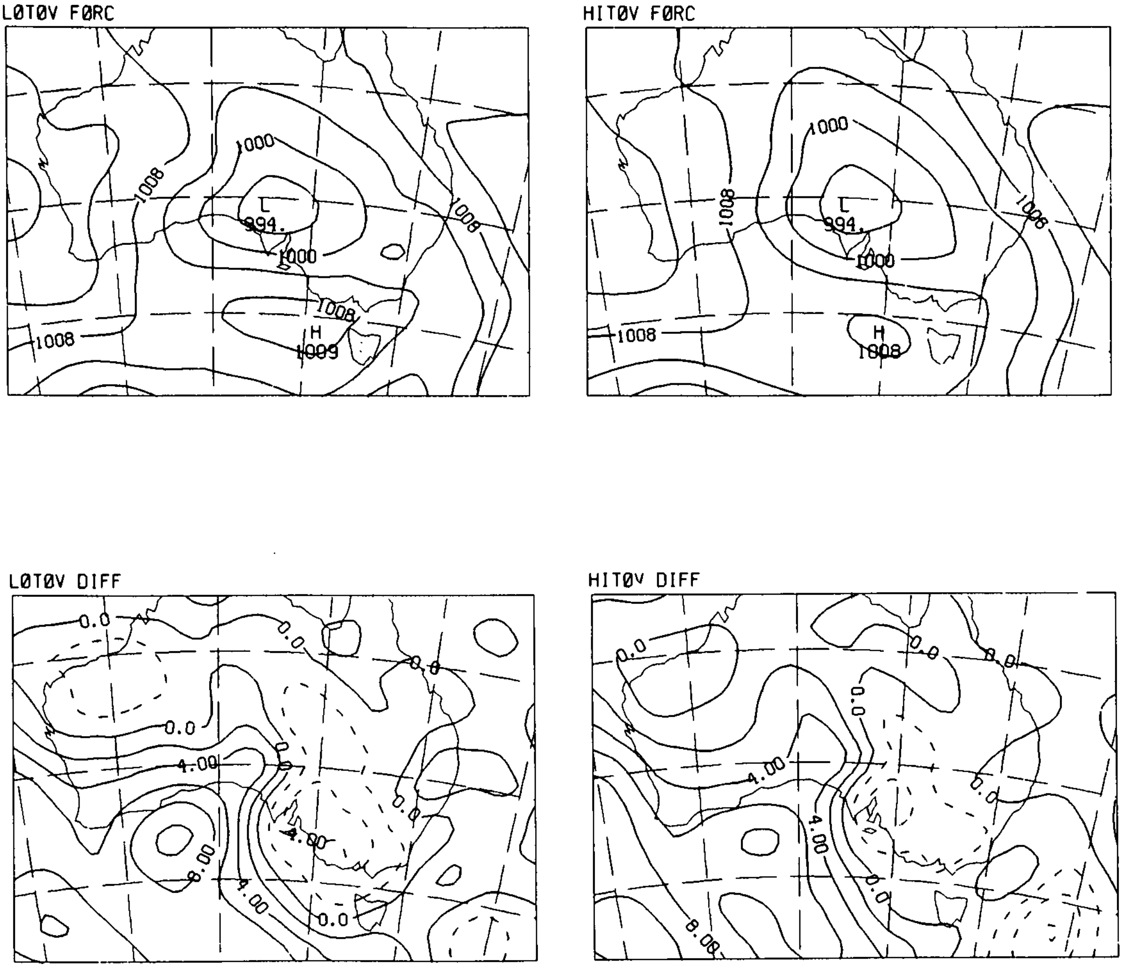


Lateral boundary conditions were obtained from the archived operational hemispheric forecast (Bourke et al. 1982) and duplicated operational practice. The first three forecasts show the low's development and movement through southern Australia, and only the first will be shown in detail as the general character of the differences between these three pairs of forecasts are quite similar. The last forecast, based at 0000 UTC 1 December, is intended to assess the impact of the HITOV data on the rainfall forecasts over Victoria on that day.

Forecast based 1200 UTC 29 November

Figures 7, 8 and 9 show the 12, 24 and 36-hour MSLP forecasts from this time, with the error fields below each forecast. The error fields are relative to the HITOV analyses, however, with the same data base for each of the MSLP analyses, and the use of operationally produced bogus data over the ocean at 0000 and 1200 UTC, the surface field is well specified and the error patterns are relatively insensitive to choice of verifying MSLP analyses. There are two main points to be made. First, the low-pressure system in the HITOV forecast is centred slightly west of the LOTOV low at 12 hours, but is centred to the east (a better forecast) by 36 hours. Thus the HITOV forecast moves the low more quickly. Second, it was pointed out in VM90 that there was a tendency for the forecasts to elongate the low northwest-southeast, rather than to have the more circular

Fig. 8 **LOTOV and HITOV 24-hour MSLP forecasts based at 1200 UTC 29 November 1987 and their error fields (HITOV analysis minus forecast, lower panels).**



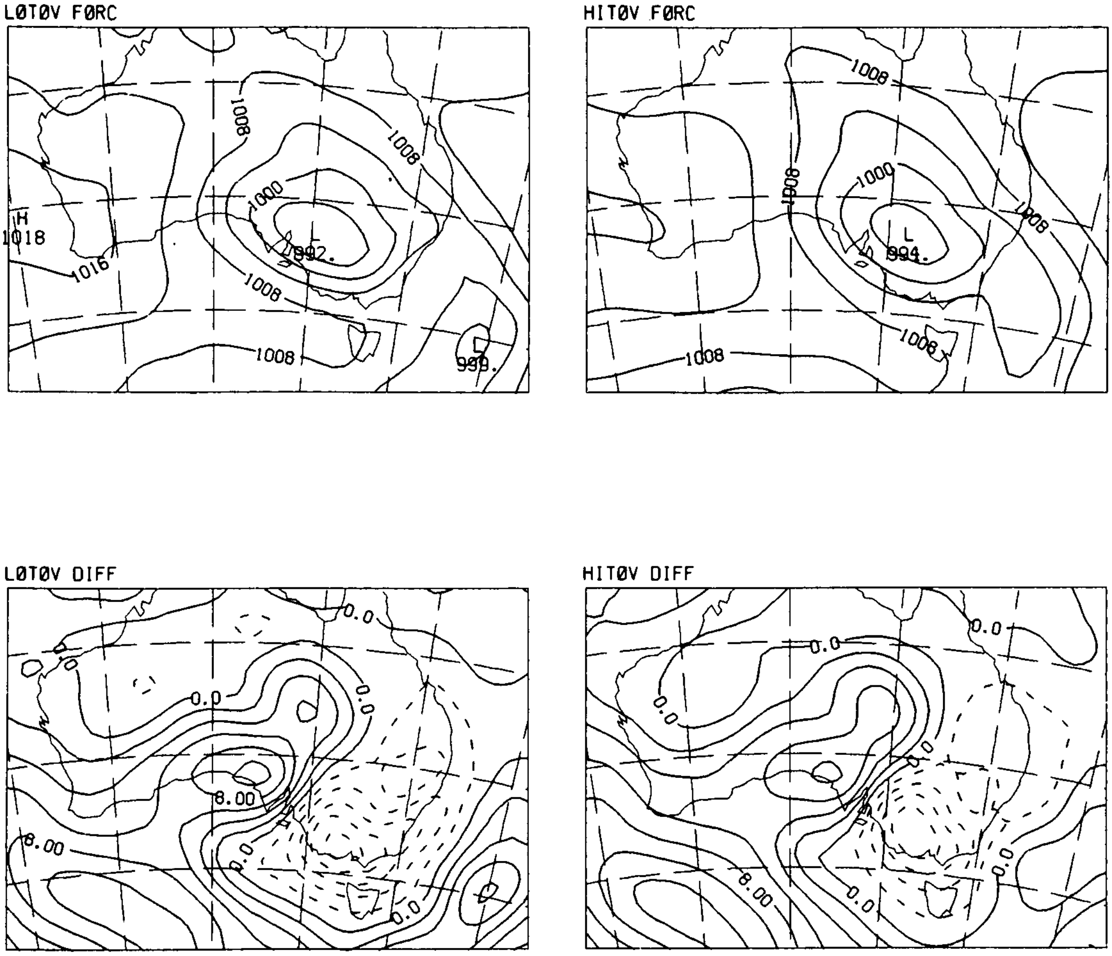
shape which was observed. The difference fields show that while this error has not been eliminated, it has been reduced in the HITOV forecast. The forecasts based at 0000 and at 1200 UTC 30 November each show this more rapid movement and reduced pressure error to the west of the low centre, and thus these forecasts will not be presented in detail.

Forecast based 0000 UTC 1 December

The primary purpose of this forecast was to assess the quality of the rainfall forecasts for 2 December. As described in VM90, the rain over Victoria fell in two distinct episodes on that day, one associated with the cloud east of the low centre, and the second associated with the comma-head cloud southwest of the surface low. It was the rain associated with this second rainfall episode, in conjunction with the strong, cold southeasterly winds southwest of the surface low, which led to the deaths by hypothermia of thousands of sheep in western Victoria.

Figure 10 shows the 12-hour and 24-hour forecast precipitation from the HITOV and LOTOV assimilations, and Fig.11 shows the subjective verifying analysis over Victoria. The HITOV forecast has forecast two clear rainfall maxima, one west of Melbourne and one to the east, much more in line with the verifying analysis than the LOTOV forecast, and also giving much better forecast guidance to the structure of the precipitation over Victoria.

Fig. 9 LOTOV and HITOV 36-hour MSLP forecasts based at 1200 UTC 29 November 1987 and their error fields (HITOV analysis minus forecast, lower panels).

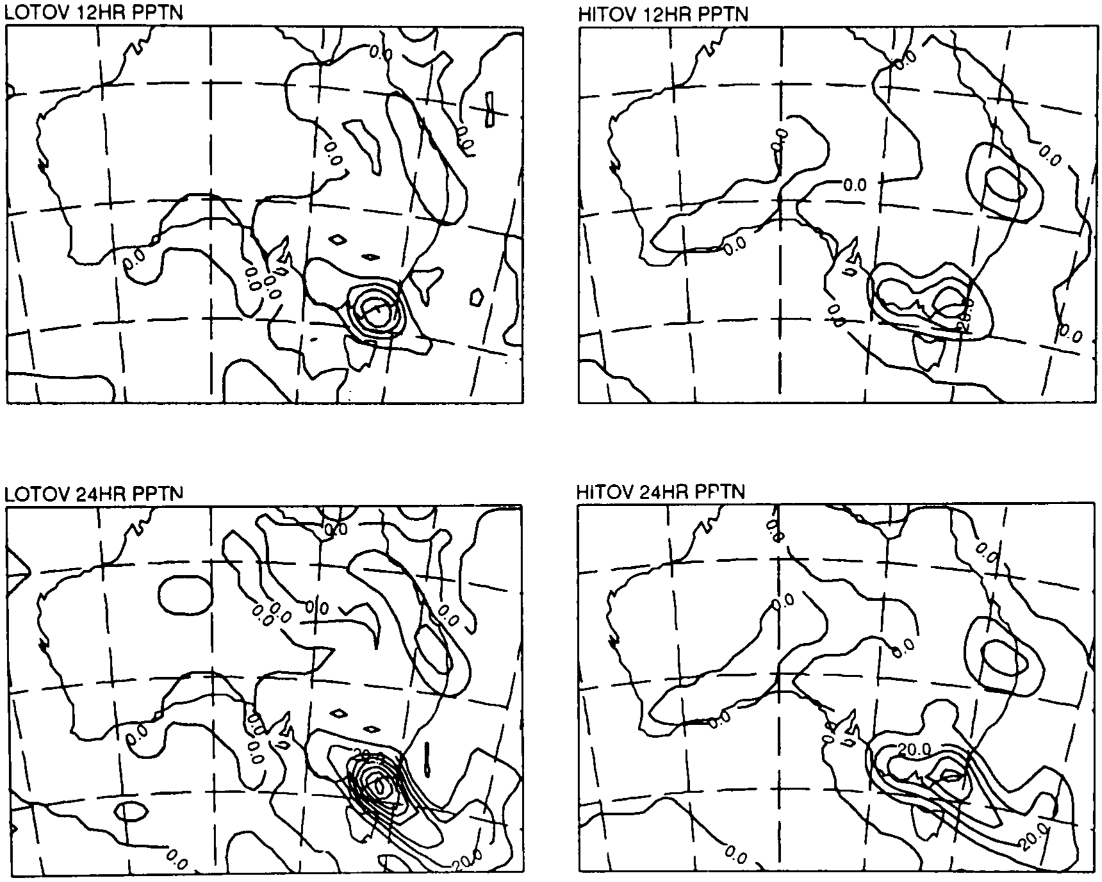


Conclusions

Studies demonstrating the positive impact of TOVS data on numerical forecasts in Australia have been published since Kelly et al. (1978). This study has shown that increasing the density of TOVS data from 500 km to 250 km resolution *and* increasing the coverage of these data lead to improved forecasts of a cyclogenesis event over southeastern Australia. Specifically, the mean sea level pressure forecasts of the low's shape and movement were improved by the higher resolution TOVS data, and the double precipitation maximum over Victoria was forecast by the HITOV forecast, but not by the LOTOV forecast. (It should be noted that a higher resolution forecast from the LOTOV analysis did produce a double rainfall maximum, as shown in Fig. 27 of VM90, although not quite in the same place as here.)

It is worth noting at this point that the HONLY forecasts from 1200 UTC 29 November and from 0000 UTC 1 December produced forecasts (not shown) intermediate between the HITOV and LOTOV forecasts, suggesting that not only is extra information from the increased data resolution and coverage being passed through the assimilation system via the guess fields, but also suggesting that the density of data is having a positive impact on the forecasts at the analysis time. The results of Mills and Hayden (1983) support this conclusion as when they reduced the resolution of

Fig. 10 HITOV and LOTOV 12 and 24-hour rainfall forecasts (mm) based at 0000 UTC 1 December 1987.

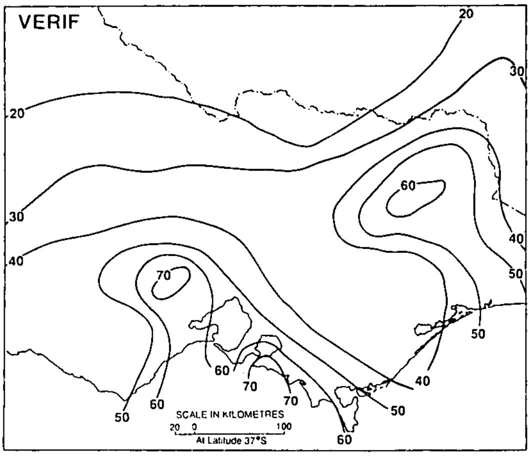


their data set, the subsequent short-term forecasts were degraded. The quote of Browing (1989) is pertinent here:

> '. . .in the case of mesoscale phenomena driven by their own internal dynamics, such as mesoscale convective systems and frontal rainbands, there can be no escaping the need for detailed observations to depict the mesoscale phenomena (or their precursors) within the initial data. It may be that the synoptic-scale forcing represented in the background field will lead to the development of these phenomena in the model, but in the absence of mesoscale input data it will not necessarily lead to a reliable mesoscale forecast of precisely when or where development will occur.'

While only one case study has been presented in this paper, these encouraging results add to the body of evidence from other Australian (e.g. Mills and LeMarshall 1987) and overseas (e.g. Mills and Hayden 1983; Gustafsson and Svensson 1988)

Fig. 11 Subjective analysis of observed 24-hour rainfall over Victoria to 9 am 2 December 1987 from the telegraphic rainfall network.



case studies of mesoscale weather events which show that use of high resolution TOVS data improves the mesoscale detail in numerical forecasts. In addition, the results from the quasi-operational parallel trials reported by LeMarshall et al. (1990) show that use of locally processed TOVS data at its full resolution produces a mean increase in forecast skill using objective verifications. This all leads to the expectation of this author that improved operational forecasts in Australia will be realised when either locally processed TOVS data or a higher resolution data set over the GTS become operationally available in the Australian National Meteorological Centre.

Acknowledgments

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