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A LIMITED TEST OF METHODS OF PRESSURE REDUCTION TO MEAN SEA LEVEL

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ABSTRACT

A limited test has been made of five methods of correcting pressures at high level stations to sea level. The mean sea level pressures were calculated using each of these methods and were compared with pressures found by interpolation on a mean sea level chart, which was drawn on the basis of the estimated mean sea level pressures at stations below 500 ft (calculated by the method at present being used in Australia) supplemented by estimates of pressure gradients assuming geostrophic flow at 3000 ft. The methods were compared on the basis of the means and root mean squares of the differences between the calculated and interpolated pressures over the period studied. In this test the method which most frequently gave the best results was that based on a constant monthly mean surface temperature and vapour pressure.

Mean sea level charts for the synoptic hours 0600 EST on 6.7.64 and 15.1.64 and 1500 EST on 3.1.64 and 14.7.64 were drawn for pressures reduced by three methods - the two most successful methods in the preceeding test and the method at present being used in Australia. This limited test again showed the superiority of these two methods but did not indicate any marked difference between them.

1. INTRODUCTION

Five methods of pressure reduction have been investigated at nine stations above 500 ft in eastern Australia over the period 2-14 January 1962 at 0900 EST and 1500 EST. The methods tested were:-

(i) The method at present being used in Australia, where the mean sea level pressure is given by,

$$\log_{10} \frac{p_o}{p_s} = \frac{Z'_p}{56525 + 123.1t' + 0.003\, Z'_p}$$

where p_s = station level pressure (mb),

p_o = mean sea level pressure (mb),

Z'_p = geometric altitude corresponding to the station altitude in feet, and

t' = air temperature at station at time of observation in ^{o}F.

In this method,

(a) the variation of gravity with height is neglected,

(b) the air temperature at station level (t') is taken as the effective temperature of the "column of air" between the station and mean sea level,

(c) the effect of water vapour on the density of the "column of air" is neglected.

(ii) A method following a suggestion by Gibbs (1952) using constant mean 900 mb temperature and a constant lapse rate, where the mean sea level pressure is given by,

$$\log_{10} \frac{p_o}{p_s} = \frac{0.0148275 H_p}{T_{900} + aH_{900} - \frac{aH}{2}_p}$$

where p_s and p_o are as defined in (i),

T_{900} = monthly mean 900 mb temperature at station (°K),

a = assumed lapse rate in the fictitious air column extending from sea level to the level of the station elevation (°C/gpm). The I.S.A. value of 0.0065°C/gpm was used. The mean lapse rates at nine coastal stations were calculated for January, April, July and October. The average over these months of these nine stations was 0.0063°C/gpm which is approximately equal to the value taken. Lapse rates for the same months were also calculated at some inland stations and mean values found were again close to 0.0065°C/gpm.

H_{900} = Monthly mean height of 900 mb surface at the station (gpm),

H_p = height of station above mean sea level (m).

(iii) A method recommended by the W.M.O. Working Group on Pressure Reduction (1954), where the mean sea level pressure is given by,

$$\log \frac{p_o}{p_s} = \frac{0.0148275\, H_p}{T_s + \frac{aH_p}{2} + e_s C_h}$$

with H_p, p_o, p_s and a as in (ii)

T_s = station temperature argument in °K = $\frac{T + T_{12}}{2} + F$

where T = station temperature at time of observation (°K)

T_{12} = station temperature 12 hours before observation (°K)

F = a function, in °K, which is non zero in orographic situations with frequent persistant ground inversions (i.e. inversions not disappearing during daytime). F was taken to be zero for all stations studied.

e_s = vapour pressure argument at the station (mb),

C_h = a function of H_p (°C/mb).

(iv) A method where the correction applied to the 0600 EST station level pressure to obtain the mean sea level pressure (using the present method) was also applied to the 0900 and 1500 EST station level pressures,

i.e. $P_{(\text{sea level})} = P_{(\text{station level})} + A$

where A = correction (mb) applied to 0600 station level pressure on the basis of method (i).

(v) A method using constant monthly mean surface temperature and vapour pressure, and a constant lapse rate. The mean sea level pressure is given by,

$$\log_{10} \frac{p_o}{p_s} = \frac{0.0148275 H_p}{T_m + a/2\, H_p + e_m\, C_h}$$

with p_o, p_s, H_p C_h and a as in (ii) and (iii),

T_m = monthly mean surface temperature ($^{\circ}$A), and

e_m = monthly mean vapour pressure (mb).

2. METHOD OF EVALUATION OF RESULTS

Estimates of the mean sea level pressure at high level stations were obtained by interpolation from mean sea level isobaric charts drawn on the basis of pressures at stations below 500 ft (corrected to M. S. L. by the present method) supplemented by estimates of pressure gradients assuming geostrophic flow at 3000 ft.

Because of the small number of low level stations in inland Northern Territory, South Australia and Western Australia interpolation cannot be made with sufficient accuracy to provide estimates for high level station's there, so the investigation was restricted to the stations in eastern Australia listed in Table 1.

Table 1. List of stations

Station	Number	Latitude S	Longitude E	Height of barometer above mean sea level (m)
Canberra	926	35°18'	149°12'	577
Coonabarabran	728	31°06'	149°17'	510
Mt. Surprise	277	18°09'	144°15'	458
Tambo	355	24°53'	146°15'	398
Dalby	542	27°11'	151°16'	351
Roma	515	26°35'	148°47'	301
Charleville	510	26°25'	146°17'	300
Broken Hill Aeradio	690	31°58'	141°27'	283
Cobar	701	31°30'	145°50'	241

3. RESULTS

Results are presented in tabular and graphical forms. Table 2 and Fig. 1 present the mean difference between the reduced and interpolated pressures (reduced minus interpolated) at 0900 and 1500 EST. Table 3 and Fig. 2 present the corresponding r.m.s. values.

Table 2. Mean departures (mb) of pressures found by reduction of station level pressure to mean sea level pressure from pressures found by interpolation

Station	Height (m)	Method									
		(i)		(ii)		(iii)		(iv)		(v)	
		0900	1500	0900	1500	0900	1500	0900	1500	0900	1500
Canberra	577	+0.6	-0.1	+0.5	+0.3	+0.1	-0.3	+0.2	+2.0	-0.4	-0.7
Coonabarabran	510	+1.3	+0.7	+1.1	+1.0	+0.7*	+0.8	+2.5	+2.6	+0.5	+0.4
Mt. Surprise	458	+0.9	-0.4	+1.1	+0.8	-	-	-	-	+0.3	-0.1
Tambo	398	+0.4	-0.7	+0.2	-0.7	-	-	-	-	-0.2	-1.0
Dalby	351	+0.8	+0.6	+0.6	+0.9	+0.4	+0.7	+1.2	+1.8	+0.1	+0.5
Roma	301	-0.3	-0.2	-0.5	-0.1	-0.6	-0.2	-0.1	+0.6	-0.9	-0.5
Charleville	300	+0.6	-0.3	+0.3	-0.2	+0.3	-0.2	+1.0	+0.6	-0.1	-0.6
Broken Hill Aeradio	283	+1.1	+0.3	+0.4	+0.5	-	-	+1.5	+1.8	-0.1	+0.2
Cobar	241	+0.4	+0.2	+0.5	+0.8	-	-	+0.7	+1.3	+0.1	+0.4

Notes: Where values are missing for methods (iii) and (iv) no values could be calculated as there were no 0900 or 1500 observations at the station for use in method (iii) and no 0600 observations for use in method (iv).

* The 0900 EST mean and r.m.s. values at Coonabarabran may be too low, as on two occasions when no pressure calculation could be made other methods gave large positive difference values; this suggests that method (iii) would have given large positive difference values, thus increasing the value of the mean and r.m.s. differences.

Table 3. r.m.s. departures (mb) of pressures found by reduction of station level pressure to mean sea level pressure from pressures found by interpolation

Station	Height (m)	Method									
		(i)		(ii)		(iii)		(iv)		(v)	
		0900	1500	0900	1500	0900	1500	0900	1500	0900	1500
Canberra	577	1.6	1.8	1.0	1.2	1.3	1.4	2.3	2.2	1.1	1.4
Coonabarabran	510	1.7	1.2	1.4	1.3	1.0*	1.0	2.7	2.7	1.1	0.9
Mt. Surprise	458	1.1	1.5	1.2	1.3	-	-	-	-	0.6	1.1
Tambo	398	0.8	1.9	0.6	1.7	-	-	-	-	0.6	1.8
Dalby	351	1.1	1.2	0.9	1.4	0.9	1.3	1.4	2.1	0.7	1.1
Roma	301	1.0	1.4	1.0	1.2	1.1	1.2	0.9	1.3	1.2	1.3
Charleville	300	1.2	1.6	0.9	1.4	1.1	1.5	1.9	1.6	0.9	1.5
Broken Hill Aeradio	283	1.3	1.0	0.9	1.1	-	-	1.7	2.1	0.8	1.0
Cobar	241	0.8	1.3	0.7	1.3	-	-	0.8	1.6	0.6	1.1

(See Notes below Table 2)

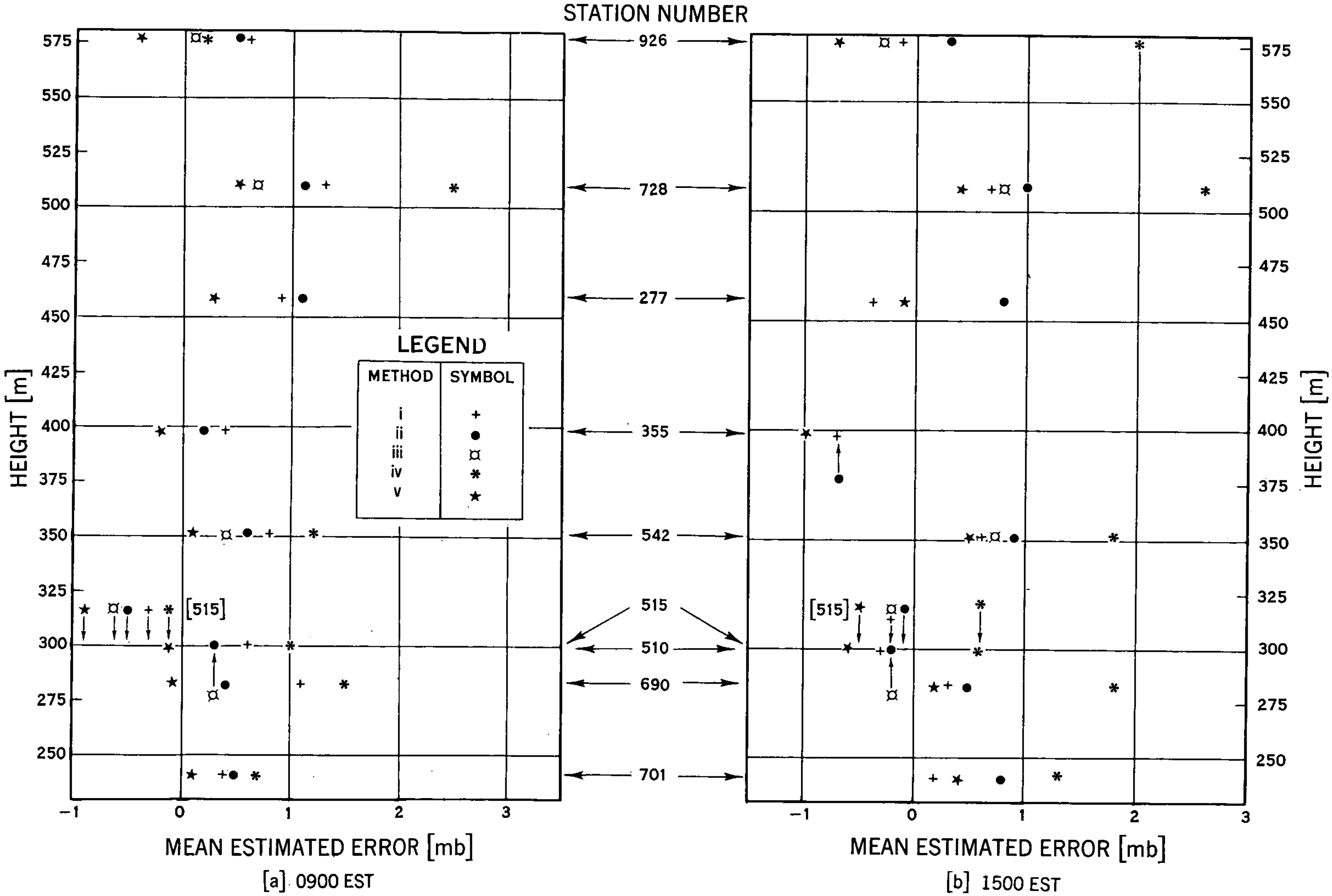


Fig. 1 Mean estimated errors [mb] for various methods of pressure reduction to mean sea level.

Values are plotted against height of barometer above mean sea level. Period 2–14 January 1962.

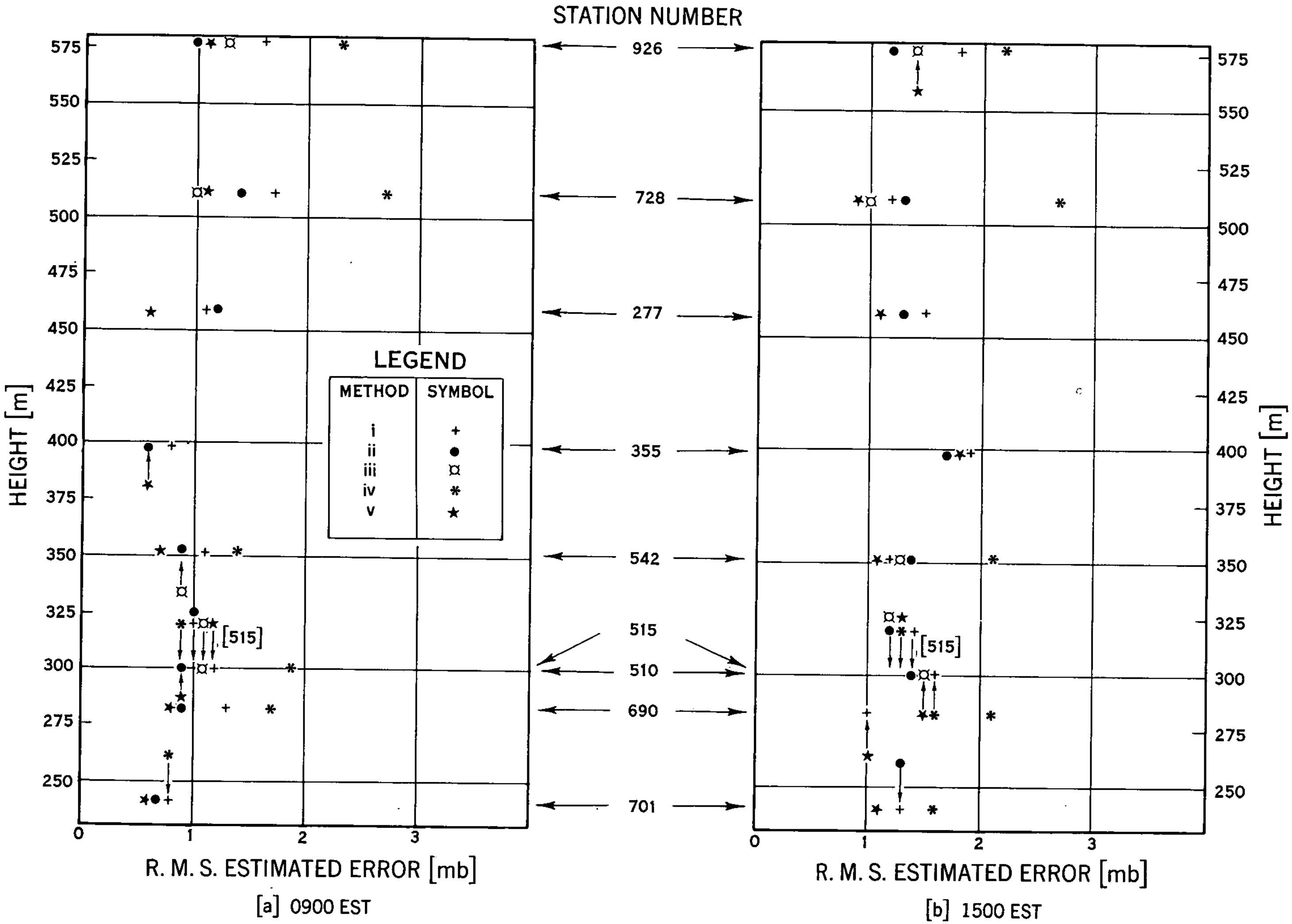


Fig. 2 R.M.S. estimated errors [mb] for various methods of pressure reduction to mean sea level.

Values are plotted against height of barometer above mean sea level. Period 2-14 January 1962.

Fig. 1 shows the variation of the mean errors with height. In Fig. 1(a) it is seen that in general, at 0900 EST the methods over-estimate the true mean sea level pressure. The constant mean surface temperature and vapour pressure method exhibits the smallest bias at most stations. The graph for 1500 hr (Fig. 1(b)) has more negative values than Fig. 1(a) but there is still a general positive bias.

Fig. 2 shows the variation of the r.m.s. values with height. In Fig. 2(a) the r.m.s. values generally tend to increase as the heights of the stations increase. Notable exceptions are the three methods studied at Tambo and method (v) at Mt. Surprise. The r.m.s. values in Fig. 2(b) are generally greater than the corresponding values in Fig. 2(a) with the low level stations showing the greatest increases. The only stations at which the r.m.s. values were lower at 1500 than at 0900 EST were Canberra (method iv), Coonabarabran (methods i, ii and v), Charleville (method iv) and Broken Hill Aeradio (method i).

Tables 4 and 5 show that method (v), which uses a constant monthly mean surface temperature and vapour pressure, is superior on a greater number of occasions for both 0900 EST and 1500 EST with method (ii) second best. No attempt has been made to make a general quantitative estimate of the success of the methods.

Table 4. Ranking of methods by mean values

Method	Position of mean value									
	0900					1500				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
i		3	2	3	1	3	4	2		
ii	1	$1\frac{1}{2}$	$5\frac{1}{2}$	1		2	2	3	2	
iii	1	$2\frac{1}{2}$	$\frac{1}{2}$	1			2	3		
iv	1	1		2	3				2	5
v	6	1	1		1	4	1	1	3	

Table 5. Ranking of methods by r.m.s. values

Method	Position of r.m.s. value									
	0900					1500				
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
i		1	4	4		1	1	4	$1\frac{1}{2}$	$1\frac{1}{2}$
ii	2	5	2			4	2	1	2	
iii	1		3	1			2	3		
iv	1			2	4				$3\frac{1}{2}$	$3\frac{1}{2}$
v	5	3			1	4	4	1		

It will be noted from Tables 2 and 3 that the ranking statistics in Tables 4 and 5 are based on fewer stations for methods (iii) and (iv) than for other methods. If the ranking is confined to the five stations for which all methods were assessed we obtain the results presented in Tables 6 and 7. These results do not alter the previous conclusions based on Tables 4 and 5.

Table 6. Ranking of methods by mean values at five stations.

	Position of Mean Value									
	0900					1500				
Method	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
(i)		1		3	1	1	$2\frac{1}{2}$	$1\frac{1}{2}$		
(ii)		$\frac{1}{2}$	$3\frac{1}{2}$	1		$1\frac{1}{2}$	1	$\frac{1}{2}$	2	
(iii)	1	$2\frac{1}{2}$	$\frac{1}{2}$	1		$\frac{1}{2}$	$1\frac{1}{2}$	3		
(iv)	1	1			3				$\frac{1}{2}$	$4\frac{1}{2}$
(v)	3		1		1	2			$2\frac{1}{2}$	$\frac{1}{2}$

Table 7. Ranking of methods by r.m.s. values at five stations

	Position of r.m.s. Value									
	0900					1500				
Method	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
(i)		$\frac{1}{2}$	$\frac{1}{2}$	4			1		$1\frac{1}{2}$	$1\frac{1}{2}$
(ii)	$1\frac{1}{2}$	$1\frac{1}{2}$	2			$2\frac{1}{2}$	$\frac{1}{2}$		2	
(iii)	1	$\frac{1}{2}$	$2\frac{1}{2}$	1		$\frac{1}{2}$	$2\frac{1}{2}$	2		
(iv)	1				4			$\frac{1}{2}$	1	$3\frac{1}{2}$
(v)	$1\frac{1}{2}$	$2\frac{1}{2}$			1	2	1	$1\frac{1}{2}$	$\frac{1}{2}$	

To further compare the two most successful methods ((ii) and (v)) with the present method of reduction, mean sea level charts have been drawn on the basis of the pressures obtained by each of these methods. Charts were drawn for each of the four synoptic hours, 1500 EST on 3.1.64 and 14.7.64, and 0600 EST on 15.1.64 and 6.7.64. These times are approximately the times of the maximum and minimum temperatures. In this comparison all station level pressures were corrected to mean sea level by each of the three methods irrespective of the height of the station. Isobars have been drawn to fit every value. The 1500 hr 3000 ft winds are shown on the 1500 hr diagrams. No 3000 ft winds were available at 0600 hr so the mean of the 0300 and 0900 hr 3000 ft winds have been used as an estimate of this wind. These winds were plotted with a view to comparing them with the geostrophic winds given by each method of correction.

On the 1500 EST charts for 3.1.64 and 14.7.64 the pressures at high level stations found using method (i) were generally lower than those found using the other two methods whose pressures were approximately the same. This is as expected on the basis of the higher mean temperature used in method (i).

On the chart for method (i) (Fig. 3(a)) at 1500 EST on 3.1.64 there is a heat low centred at 27°S 118°E. This low pressure area is weaker on the charts of methods (ii) and (v) (Figs. 3(b) and (c)). Another low pressure area centred at 20°S 139°E on Fig. 3(a) is also smaller in area on Figs. 3(b) and (c). Pressures at high level stations in south-east Australia are 1-2 mb higher on Figs. 3(b) and (c) than on Fig. 3(a). The low pressure area in this region on Fig. 3(a), centred at 35½°S 149½°E and the adjacent strong pressure gradient do not appear on Figs. 3(b) and (c). Looking at the winds on the charts in Fig. 3 there is little agreement for any of the methods between the 3000 ft winds and the geostrophic wind. Except on the coast temperatures everywhere were between 90°F and 105°F and hence geostrophic flow is not expected in the lower levels. However, the pressure gradients around the low pressure areas in Figs. 3(b) and (c) are more consistent with the light winds around these areas than the gradients in Fig. 3(a).

The pressure patterns for all three methods for 1500 EST on 14.7.64 (not reproduced) were similar but as in the summer case of Fig. 3(a) method (i) gave lower values than methods (ii) and (v) at most high level stations. On the Western Australian Plateau corrected pressures obtained by methods (ii) and (v) were about 1.0 and 1.5 mb higher than those obtained by method (i). Geostrophic winds over the plateau obtained from the pressure gradients from methods (ii) and (v) were in much closer agreement with the 3000 ft winds than in the case of method (i). Otherwise there was little difference in the patterns obtained from the three methods.

On the 0600 EST charts for 15.1.64 and 6.7.64 the pressures at the high level stations found using method (i) were generally higher than those found using methods (ii) and (v). This is again as expected on the basis of the lower mean temperature used in method (i).

On the chart of method (i) for 0600 EST on 6.7.64 (Fig. 4(a)) the pressure gradient around latitude 20°S from longitudes 119°E to 137°E is too strong compared with the gradient equivalent to the 3000 ft wind on the geostrophic assumption. Methods (ii) and (v) give more realistic pressure distributions for this region (see Figs. 4(b) and (c)). The anticyclonic centres at 30½°S 151°E and 26½°S 152°E are much weaker on the charts of methods (ii) and (v) than on the charts of method (i).

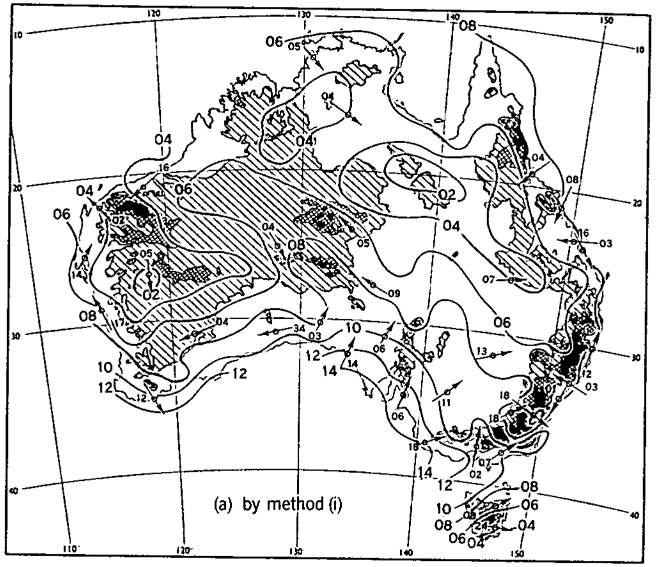
The 0600 EST charts on 15.1.64 have not been reproduced. The chart of method (i) shows a strong gradient in the region of Alice Springs (23°48'S, 133°53'E) caused by a high pressure value at this station. The other two methods eliminate this bad feature.

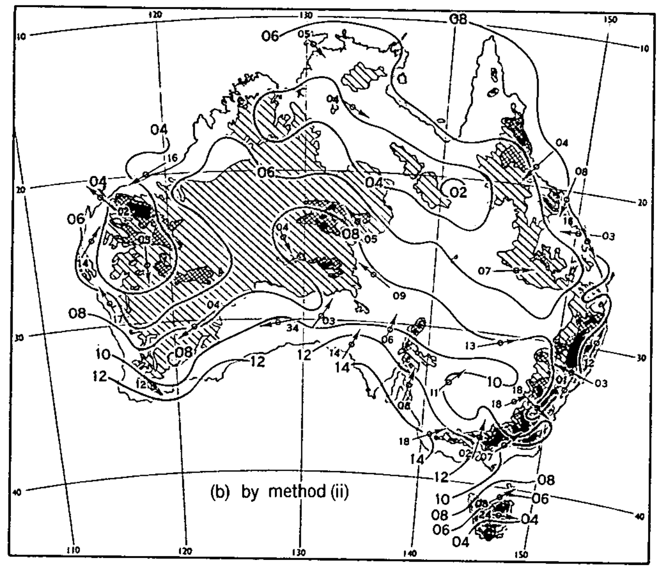
This limited study indicates that methods (ii) and (v) are an improvement on method (i) but there does not seem to be any appreciable difference between methods (ii) and (v).

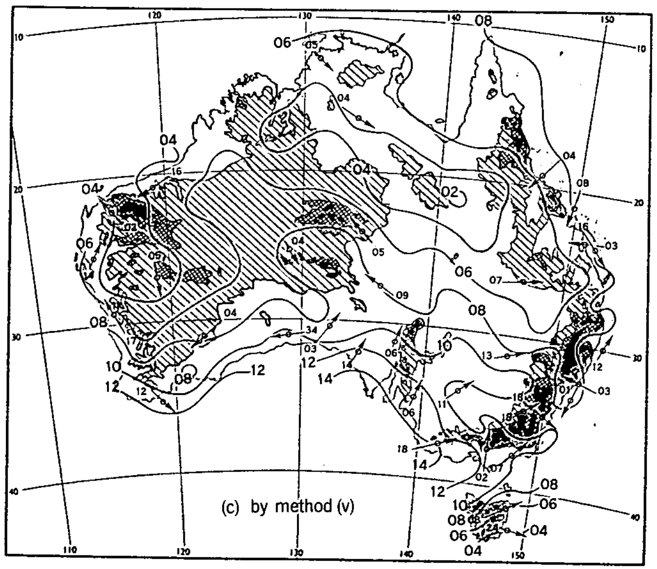
4. CONCLUSIONS

Although some interpolated estimates of the mean sea level pressures may be open to some doubt on particular days, the interpolation method of evaluation used should give a good overall estimate of the reliability of the particular methods of pressure reduction tested.

Of the five methods studied, the most successful is the constant mean surface temperature and vapour pressure method (v). The next most successful is the constant mean 900 mb temperature method (ii). Method (iv) consistently gives the worst results and does not appear to warrant further study. Method (iii), although only calculated for six stations, does not show a great deal of promise as it gives the best r.m.s. value on only one occasion. The method at present being used in Australia (i) also falls into this category.







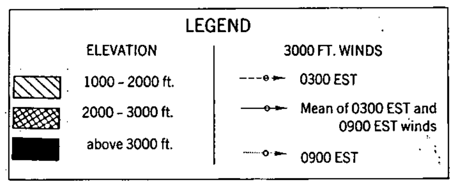


Fig. 3 MSL isobars mb (hundreds omitted) at 1500 EST 3 January 1964, based on pressures reduced by methods as indicated. 3000 ft. wind directions and speeds (kt) are also plotted.

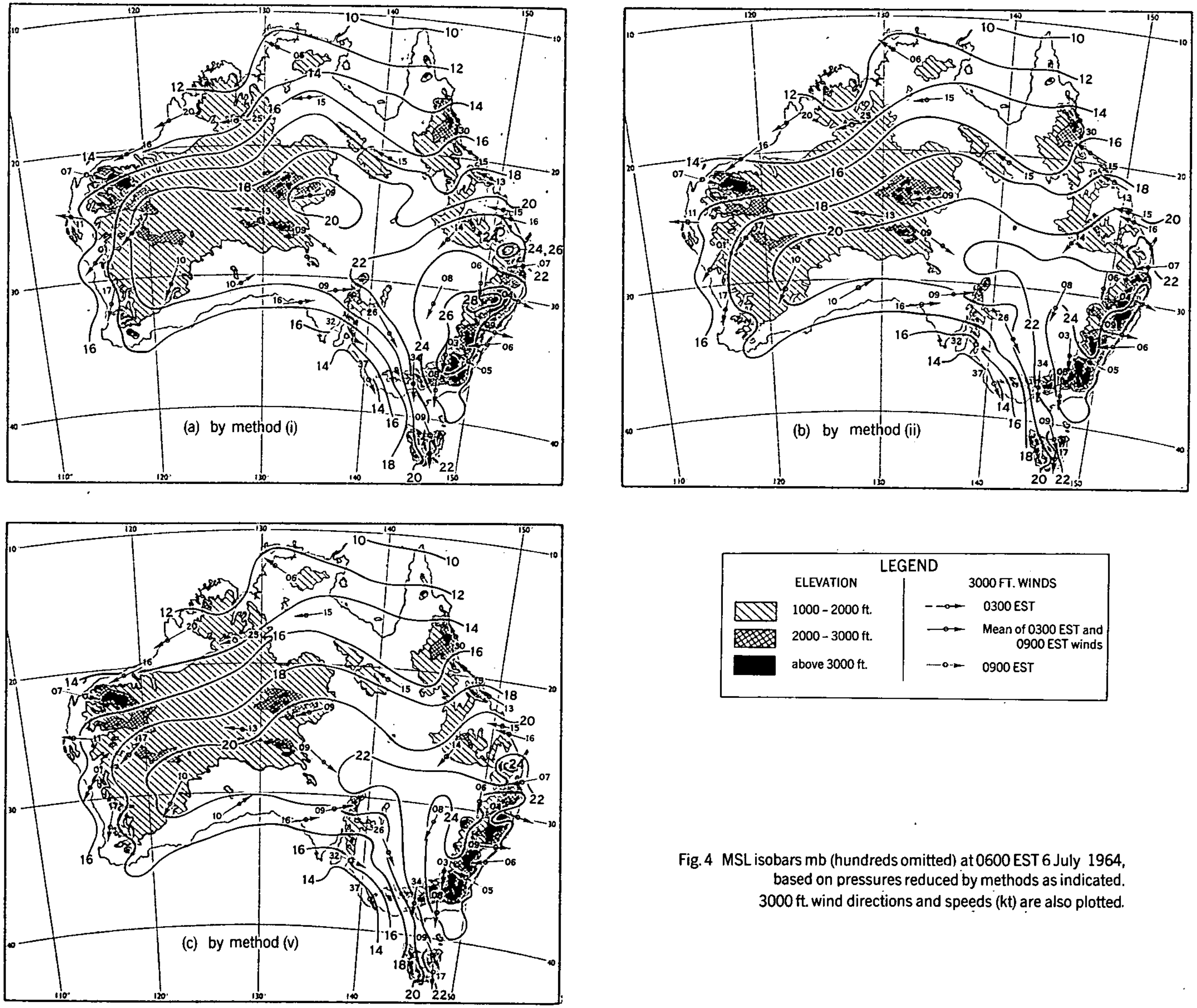


Fig. 4 MSL isobars mb (hundreds omitted) at 0600 EST 6 July 1964, based on pressures reduced by methods as indicated. 3000 ft. wind directions and speeds (kt) are also plotted.

Analysis of the mean sea level charts showed that methods (ii) and (v) are superior to method (i), but there was no obvious difference between methods (ii) and (v).

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