THE MEAN FLOW AT THE BOUNDARY OF THE AUSTRALIAN CONTINENT

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ABSTRACT

An examination is made of the pressure anomaly from hemispheric means over the Australian continent in summer and winter. The flow across and the circulation around the coastline are found from observed winds up to 3 km, and also compared with hemispheric values. It is found that there is a large negative pressure anomaly in summer, and a smaller positive anomaly in winter. The annual range of pressure agrees with that calculated from a theory of Jeffreys (1929). In summer inflow, with a maximum of 1.5 ms^{-1} at 300 m and cyclonic circulation, is found up to about 1500 m, with outflow and a marked anticyclonic circulation above. In winter there is outflow, with a maximum of 1.6 ms^{-1} at 300 m, and anticyclonic circulation at all levels.

INTRODUCTION

The southern hemisphere is largely an oceanic hemisphere but the flow is perturbed by the three continents of Australia, southern Africa, and South America. Of these, the Australian continent is the most suitable for study of continental effects, as it is an island continent and has no very high mountains.

The perturbation in the pressure field has long been known; it has been observed that the continent is occupied by a low pressure centre in summer and a high pressure centre in winter. Considerations of the effect of friction on the geostrophic wind field would then indicate that there is inflow into the continent at the surface in summer and outflow in winter. These effects have not been expressed as departures from hemispheric zonal averages. However inferences from large-scale maps do not give the complete picture, which is complicated by smaller scale gradients near the coast giving rise to land and sea breezes. It is important to know the magnitudes of this inflow and circulation so that the effects of continental heating and cooling can be assessed. Moreover it is of importance for such considerations as the moisture balance.

The inflow and outflow near the boundaries of the continent were assessed from surface winds over the ocean by Arakawa *et al* (1952). From their results one can see that the influence of the continent extends well beyond its coastline. However, it would be desirable to determine to what height the influence extends, and this can only be done at the coastline itself, where there is a suitable network of upper air observations. We will first look, however, at the pressure perturbation.

THE PRESSURE PERTURBATION

The publication of Taljaard *et al* (1969) gives MSL pressures (monthly means of daily averages) at 5^o latitude and longitude grid points for the whole hemisphere and also the zonal averages. The zonal averages were subtracted from the individual grid point values for January and July, and the results are shown in Fig 1 and 2. It will be seen from Fig 1 that in January there is a maximum negative anomaly of 7 mb in the northwest of the continent, while in July the anomaly seems much smaller, of the order of +1 mb, and appears as an extension of the large positive anomaly to the south of New Zealand, which is presumably associated with the frequent blocking in this area. This New Zealand anomaly also exists in summer. In summer a high pressure system normally exists south of the Bight, but the anomaly chart suggests that the negative anomaly over the continent is not compensated locally, *ie*, there is not a comparable positive anomaly in the Bight.

It is of interest to determine whether any of the pressure perturbation can be derived theoretically. Jeffreys (1929) derived an expression for the amplitude of the monsoonal annual pressure variation, p'_s, where the horizontal extent of the warmed area is small compared with undisturbed conditions over the hemisphere:

$$p'_s = -Q/h$$

where

$$Q = g \int_0^\infty \rho_o \int_o^z \frac{T'}{T_o}\,dz\,dz$$

$$h = \frac{1}{p_{so}} \int_0^\infty p\,dz$$

where the undisturbed or mean conditions are denoted with subscript zero, and departures from this are primed. The subscript s denotes surface conditions. Thus p'_s is effectively the ratio of an integral mass anomaly and a scale height.

Use was made of Alice Springs radiosonde data taken from Maher and McRae (1966). The range of temperature at different levels between January and July was found, and corrected for the seasonal hemispheric variation of temperature from Taljaard *et al* (1969). This corrected range falls to zero at about 600 mb and is small and variable above. Evaluating the above expression gives a pressure range of 7.2 mb. The range at Alice Springs from Fig 1 and 2 is about 6.4 mb, and the maximum range over the continent is about 9 mb. Thus Jeffreys' theory gives reasonable agreement with the observed values, if Australia can be regarded as small compared with the hemisphere.

WIND PERTURBATION

Data used

The data used were principally four times daily upper-winds, taken from the Bureau of Meteorology tabulations at standard height levels of surface, 300, 900, 1500, 2100 and 3000 m. The stations used are shown in Fig 3. The periods chosen were December 1969, January and February 1970, December 1970, January and February 1971 for summer; and for winter, June, July and August 1970 and 1971. Observations were supplemented with those of four additional stations (taken from synoptic charts) which operated during the Second World War. Three times daily observations were available, there being no 1100 GMT ascent. The periods used were December 1943, January and February 1944, December 1944, January and February 1945 for summer, and June, July and August 1944 and 1945 for winter.

Computations

The winds were resolved into zonal and meridional components, and these were averaged at each level for summer and winter. The averaging was a straightout averaging, and generally took no account of missing observations. One exception was at

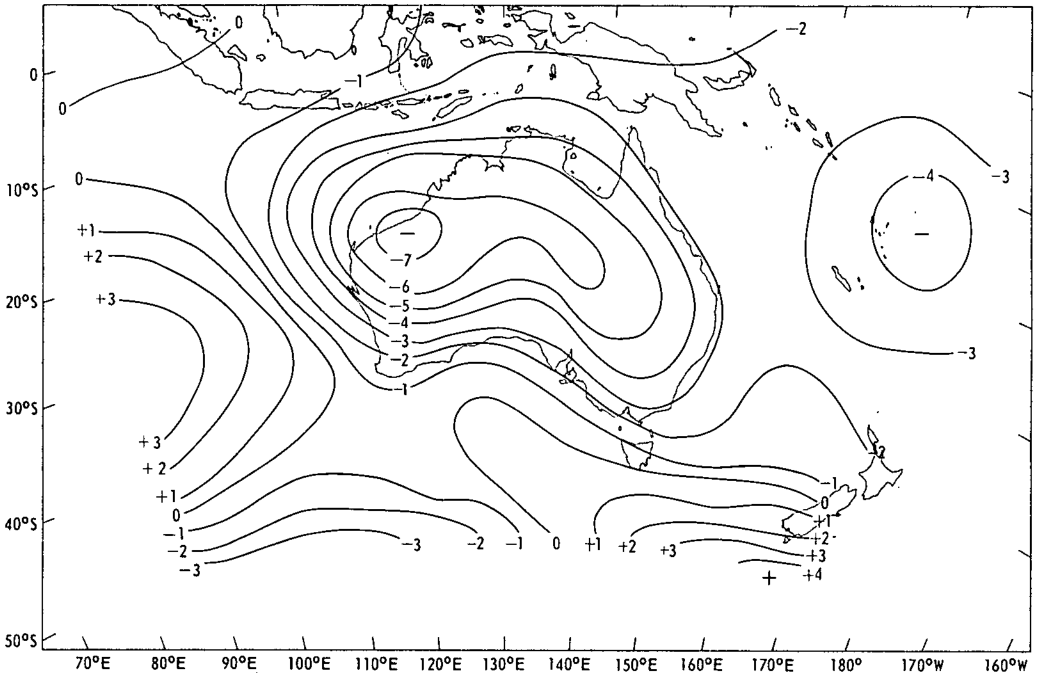

Fig 1 Departure of pressure from zonal averages for January

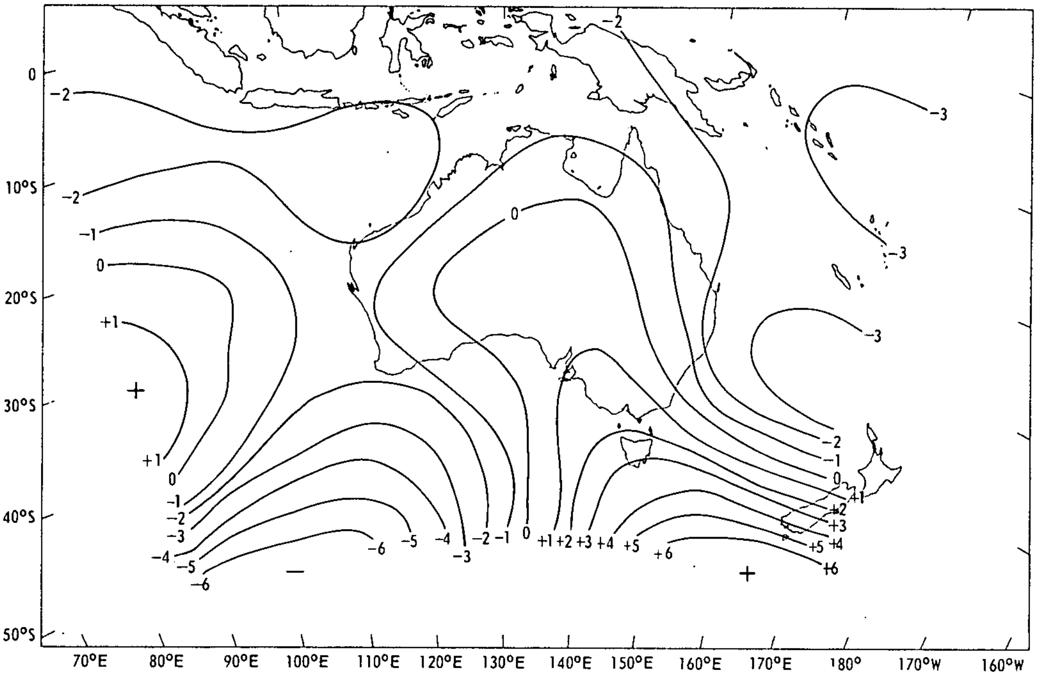

Fig 2 Departure of pressure from zonal averages for July

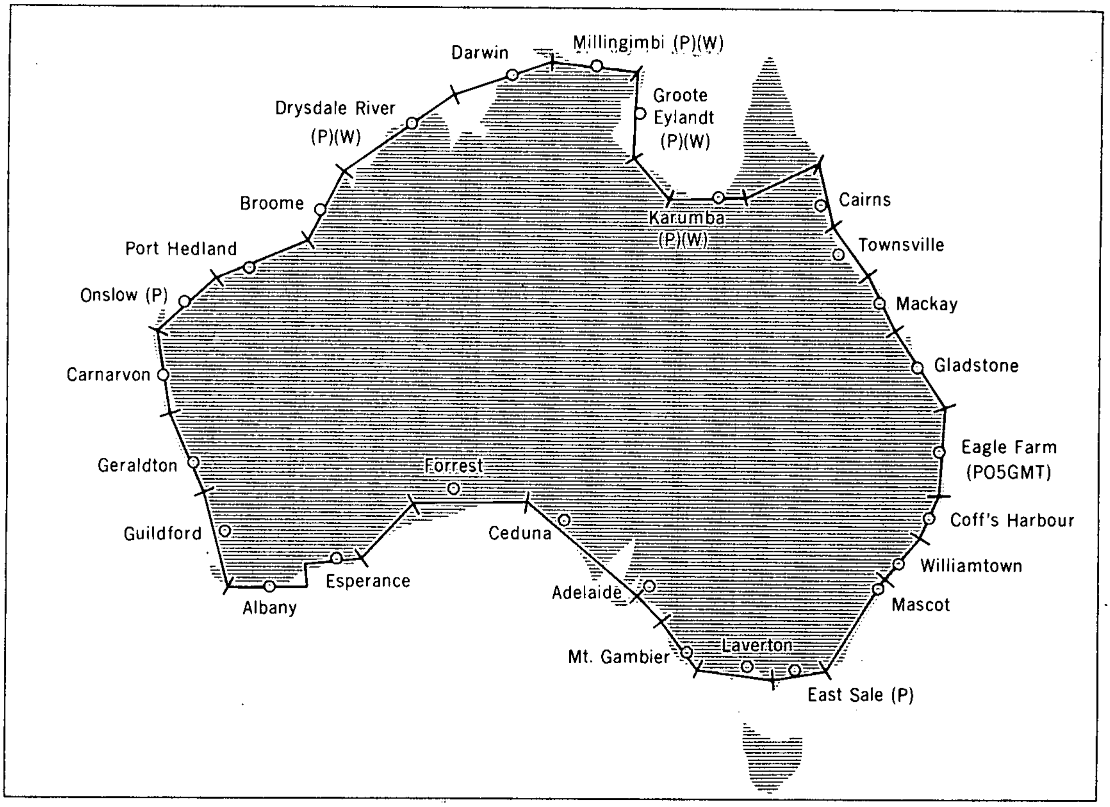

Fig 3 Stations and smoothed coastline used for wind computations. Pilot-balloon stations indicated by (P), otherwise stations are rawin stations. Wartime stations indicated by (W)

Esperance, where 1100 GMT observations were interpolated from the 0500 and 1700 GMT observations, using corrections for diurnal variation derived from Forrest and Albany. Also for winter observations at Drysdale River and Karumba, 1100 GMT observations were estimated using the diurnal variations at Broome and Darwin. No surface winds were extracted for the wartime stations: these were estimated from the 1000 ft wind by comparison with Broome, Darwin and Cairns. For the summer for the wartime stations, in some months observations were more frequent at one time of day than others. Daily averages were then taken before forming the monthly mean, and the monthly means were then averaged.

Vector mean winds at each level for summer and winter were found. The coastline of the continent was smoothed by drawing a number of straight lines, with each station approximately in the centre of each line. These lines are shown in Fig 3. The vector mean winds were then resolved normal to and parallel to each line, with cyclonic (parallel) flow positive and inflow positive. In a few cases it was decided to take a a suitable line and to average two adjacent stations to give an appropriate wind. These lines, which have no stations marked, are evident in Fig 3. The length of the lines was also measured. The product of the length of the lines and the components was then found, summed, and divided by the total length of the lines, to give a mean inflow into and circulation around the continent.

In order to obtain a comparison with hemispheric values, the same procedure was used for surface wind values of zonal and meridional components, and for the 850 and 700 mb levels from the values tabulated by Newell *et al* (1972). The components are tabulated at 10° latitude intervals; the zonal component was supplemented at 850 and 700 mb from the charts also presented at intermediate 5° latitude intervals and values interpolated linearly for the values at each station. This then gives us the corresponding inflow and circulation for an area of the same shape and latitudinal position as Australia. This will be called the hemispheric flow.

Table 1 Mean components (m s^{-1}) normal (n) and parallel (p) to the Australian coastline. Inflow and cyclonic circulation positive

	Summer				Winter			
	Observed		Hemispheric flow		Observed		Hemispheric flow	
	n	p	n	p	n	p	n	p
Surf	+1.1	+1.0	-0.2	-0.5	-0.7	-1.0	-0.6	-0.9
300 m	+1.5	+1.8			-1.6	-2.6		
900 m	+0.6	+0.9			-1.0	-4.0		
1500 m	0	-0.6	-0.2	-1.0	-0.8	-4.0	-0.6	-2.2
2100 m	-0.3	-1.8			-0.6	-3.6		
3000 m	-0.6	-2.9	-0.1	-1.5	-0.2	-2.8	-0.2	-1.2

RESULTS

The results of these computations are shown in Table 1. We see that in summer there is inflow up to 1500 m and cyclonic circulation up to about 1200 m, while the hemispheric flow gives outflow and anticyclonic circulation. Above, there is also outflow and anticyclonic circulation at the edge of the continent, both of which are stronger than the corresponding hemispheric flow at 3000 m; this reflects the strong heating over the continent. The maximum inflow and cyclonic circulation occur at 300 m, and correspond to a convergence of 2 × 10^{-6} s^{-1} and a cyclonic circulation per unit area of 3 × 10^{-6} s^{-1}. At 3000 m the outflow corresponds to a divergence of 10^{-6} s^{-1}, and the anticyclonic flow corresponds to a circulation per unit area of 4 × 10^{-6} s^{-1}. The total inflow up to 1500 m corresponds to an inflow of 1.6 × 10^{11} tonnes per day, using the NACA standard atmosphere from the Smithsonian Meteorological Tables, and this gives an upward vertical velocity of 20 m per day over the whole continent. This inflow is of course compensated by the outflow aloft, which presumably extends above 3000 m. The computations were not extended above this level because of the necessity to use pilot-balloon data at some stations; otherwise the total outflow could have been used as a check on the accuracy of the inflow computation.

From the figures given by Arakawa *et al* (1952) a mean value of surface inflow of 1.6 m s^{-1} can be deduced. This is surprisingly large compared with the value given in Table 1, as their observations were well out over the oceans; although allowances must be made for the fact that the presumably peak month of January was used instead of the December-February season.

In winter there is outflow and anticyclonic circulation at all levels which is stronger than the hemispheric values except at the surface. However it is probable that the 300 m values over the continent are greater than those on the large scale.

An estimate of the large-scale values at 300 m can be obtained in the following way: it is recommended for example by Atkinson (1970) that to obtain the gradient wind (at about 1 km) the wind at the surface over the ocean be backed (in the southern hemisphere) by 10^{o} and increased by 30%. Thus the 300 m wind should be backed by about 3^{o} and increased by about 10%. This direction change would make very little difference to inflow and circulation values, so that the surface values may be directly increased by about 10% to estimate the 300 m values. This gives outflow of 0.7 m s^{-1} and circulation of 1.0 m s^{-1}, considerably less than the continental values.

The maximum outflow from the continent is found to be at 300 m, and corresponds to a divergence of $2 \times 10^{-6}\ s^{-1}$, of similar magnitude to the cyclonic inflow in summer. The maximum circulation is at 900 and 1500 m and corresponds to a circulation per unit area of $6 \times 10^{-6}\ s^{-1}$. The outflow is 2.8×10^{11} tonnes per day, with a downward vertical velocity at the 3000 m level of 42 m per day. It must presumably be balanced by a corresponding inflow at higher levels.

The figure for surface outflow obtained from Arakawa *et al* is, as in the case for summer inflow, larger than the continental values, being $1.2\ m\ s^{-1}$.

CONCLUSIONS

The continent produces a marked anomaly of the pressure field and flow from the hemispheric or oceanic mean. This effect is more marked in summer than in winter. In summer the maximum inflow and cyclonic circulation are found at 300 m. In winter maximum outflow is also at 300 m, but the maximum anticyclonic circulation is at about 1200 m. The effect of the continent extends up to 3000 m and presumably higher in both seasons, and also extends beyond the coastline, where surface inflow or outflow out to sea is even greater than at the coastline.

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