Decadal Variation of the Annual Cycle in the Australian Dataset

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ABSTRACT

During the 1970s and 1980s, elements of the atmospheric circulation over the Southern Hemisphere changed markedly from their state in the two previous decades. The change was evident in the zonal asymmetry, especially in the zonal harmonic wave 3 at higher latitudes, and in the semiannual wave in pressure and wind. The semiannual wave changed in the same sense in all three southern oceans, but by the largest amount in the South Pacific Ocean. The second harmonic in a 12-month series, by which we describe the semiannual wave, dominates the shape of the *long-term* mean annual curve of sea level pressure in mid- and high latitudes; this harmonic weakened during the period, and its midlatitude peak disappeared in the South Pacific Ocean.

As part of the low-frequency changes during the 18 years from 1972 to 1988, the central pressure in the subantarctic trough fell, the trough moved northward, and the subtropical ridge moved south. The meridional movement of the trough and the ridge, and the concurrent trend in their central pressure, weakened the semiannual wave in midlatitudes.

1. Introduction

The set of daily maps of sea level pressure and 500-hPa height that we have used begins in May 1972, ends in December 1989, and consists of operational analyses from the Australian Bureau of Meteorology. It is an indispensable basis for studies of the meteorology of the Southern Hemisphere, such as those by Trenberth (1981), Rogers and van Loon (1982), Lejenäs (1984), Le Marshall et al. (1985), and Karoly and Oort (1987), to name only a few who have used the maps. Interannual variations in the dataset have been examined before [e.g., Swanson and Trenberth (1981); Kidson (1988)], but our approach is different in that it looks at trends in the data on the background of longer records at stations and through changes in the components of the annual cycle.

The paper demonstrates that a quite sudden change at middle and high south latitudes, which occurs in the data after 1977, was real and not a result of the improved analyses that began with the First GARP Global Experiment (FGGE) in 1979; and also, that periods of a few decades do not in all respects yield representative statistics.

2. Zonal asymmetries

The time–longitude section in Fig. 1 contains three-month running means of deviations at 60°S, from the zonally averaged pressure at sea level (SLP). There are two recurring, large-scale features in the section: the trough (negative deviations) southwest of Australia and the ridge (positive deviations) southeast of New Zealand. Both appear throughout the period. In the eastern part of the section, at about 30°W–80°W, a ridge, which was either weak or absent in the first years, gains strength in 1978 and stays as strong as, or stronger than, the ridge southeast of New Zealand. The negative anomalies near 90°E tend to amplify at the same time. The corresponding time section for the 500-hPa level (not shown) indicates the same pattern of changes, which are thus almost barotropic.

Because there were more, and better distributed, observations during and after FGGE (1979), one is apt to attribute the change after 1977 to improved analyses. It is a credit to the Australian dataset that this would be a wrong assumption, for as shown below, a change did take place after the first third of the period covered by the Australian analyses.

There are no stations near 60°S situated such that they can be used to verify the enhancement of the positive anomalies in Fig. 1; but the corresponding time–longitude section at 50°S (not shown) contains the same trend, but weaker, and there are stations near this latitude that can be used to validate the enhancement of the latitude anomalies: Kerguelen Island (49°S, 70°E) near the trough in the eastern Indian Ocean, and Comodoro Rivadavia (46°S, 68°W) in the South

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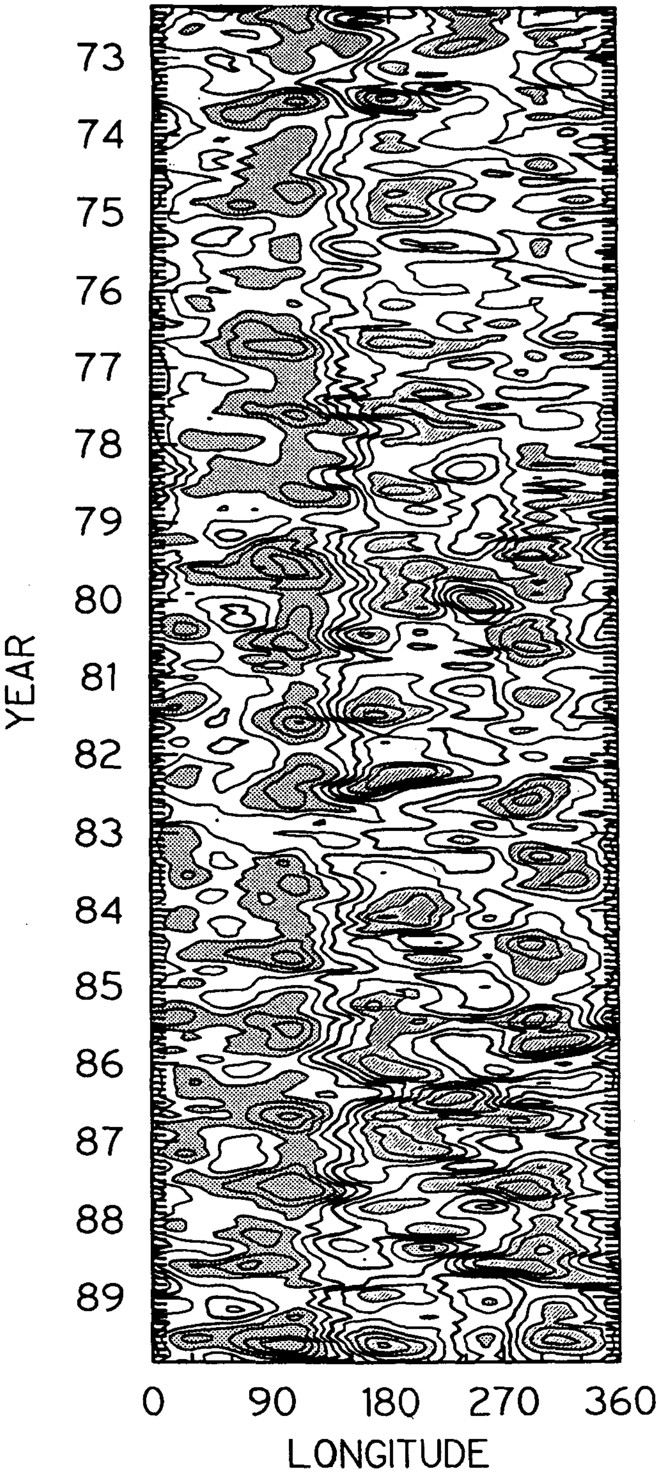

FIG. 1. Three-month running means of sea level pressure deviations (hPa) from the mean of the latitude at 60°S. Contour interval 2.5 hPa. Heavy contour denotes the mean, and stippling (hatching) marks areas where negative (positive) deviations exceed 5 hPa.

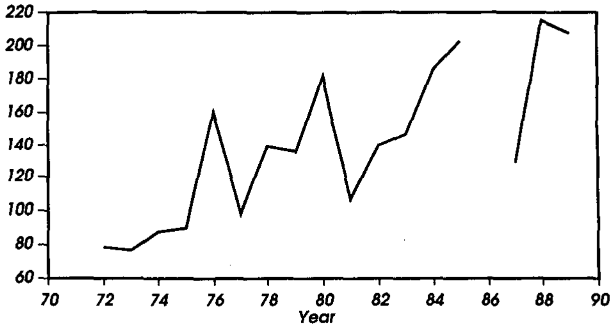

FIG. 2. Time series of the difference of 500-hPa height (m) between Comodoro Rivadavia and Kerguelen Island in June–July–August.

American ridge. The time series in Fig. 2 shows that the difference in 500-hPa height between the two stations in winter (Rivadavia minus Kerguelen) grew appreciably during the period. The SLP (and 500-hPa height) at Rivadavia rose in the 1970s and 1980s (Fig. 3); but in an equally long period before, 1956–1972, the trend was negative. The widening difference in SLP between South America and the Indian Ocean in the 1970s and 1980s is evident in Fig. 3; but this figure also shows that in the years before, the difference was narrowing as Kerguelen's pressure rose while Comodoro Rivadavia's fell.

Campbell Island's pressure (52.5°S, 169°E) had the same upward trend before 1972 as Kerguelen's, and the same downward trend afterward (Fig. 3). There was, therefore, an increasing southerly/decreasing northerly wind component at 50°S–60°S between South America and the date line before the Australian analyses began, and an increasing northerly/decreasing southerly component between South America and the central Indian Ocean. These trends in the meridional wind reversed after 1972.

Useful as the Australian analyses are, not all conclusions that can be drawn from them are necessarily representative of other periods. Some of the behavior of the atmosphere in time and space that has been derived from them would have been different if the analyses had been for the period prior to 1972. For instance, one can deduce from Fig. 3 that the changes in the zonal asymmetries would have been different in the two periods because of the opposite changes in the

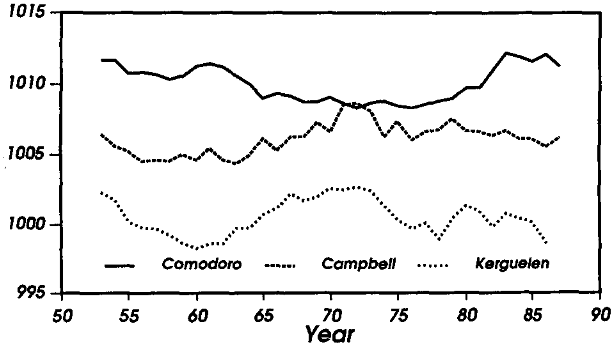

FIG. 3. Five-year (1953–1987) running means of sea level pressure (hPa) at Comodoro Rivadavia and Kerguelen and Campbell Islands in June–July–August.

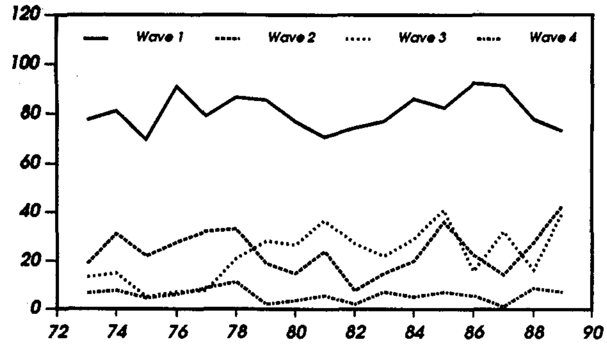

FIG. 4. Time series of the annual (January–December) mean amplitudes (m) of the first four zonal harmonic waves at 500 hPa and 60°S.

meridional component of the geostrophic wind during the two periods. Some of this decadal difference is apparent in wave 3, Fig. 4, which quadrupled after 1977. The three other quasi-stationary waves in the figure varied irregularly during the period in question.

3. The annual and semiannual waves

The annual wave (here defined as the first harmonic in a 12-month series) was described in van Loon (1972, Figs. 4.5 and 4.6), using the long-term climatological means in Taljaard et al. This source and the 18-year Australian dataset yield similar first harmonics in the SLP. The first harmonic explains more than 95% of the mean annual variance in the subtropical SLP, but its share of the variance sinks below 50% over most of the area south of 40°S. This does not mean that the first harmonic is always small in middle and high south latitudes; large first harmonics are found in single years, but their phase varies so that the maximum can occur in any month of the year. The single-year first harmonics in a given place therefore tend to cancel each other in the long-term mean.

Figure 5 shows a time–latitude section of the amplitude of the first harmonic in the zonally averaged SLP. The series has been smoothed such that at each point the value is the mean amplitude for the two years centered on the point. The harmonic was weak and variable south of 30°S, but amplified in the Antarctic toward the end of the period.

Where the mean annual wave is weak, in middle and high latitudes, the semiannual wave dominates. An earlier analysis of the semiannual wave in van Loon (1972, Figs. 4.7–4.9) was based on the climatological means in Taljaard et al. 1969. The second harmonic in the latter and that in the Australian analyses have the same distribution of phase, but the amplitude is smaller in the Australian data, especially in the South Pacific Ocean.

Between 35°S and 60°S the second harmonic on an average reaches its maximum in the transition seasons, the phase reverses near 60°S, and in the Antarctic the maxima are in the extreme seasons (van Loon 1967, 1972). The largest amplitudes in the belt with maxima in the transition months are in 45°S–50°S; south of 60°S the peak of the harmonic follows the coast. A time series of the semiannual wave in the zonally averaged SLP is shown in Fig. 6a, smoothed in the same way as the annual wave in Fig. 5. In both phase regimes the second harmonic reached a peak in 1976–1977, and then waned to low values in the early 1980s. Although it recovered somewhat afterward, it did not attain its former size.

The semiannual wave weakened in each of the southern oceans, but the change was most marked in the South Pacific Ocean. The time series in the Pacific (Fig. 6b) is similar to those in the two other oceans until 1982; but after the disappearance of the second harmonic in the early 1980s the midlatitude peak with maxima in the transition seasons did not reappear in the Pacific, and the phase of the antarctic peak (maxima in summer and winter) reached as far north as 45°S toward the end of the period (Fig. 6c).

The observations at Chatham Islands (44°S, 177°W) in Fig. 7 confirm the weakening of the second harmonic in the Australian analyses. The five-year running mean (averaged without regard to phase) of the amplitude at Chatham Island undergoes large changes during the three decades shown: falling from a peak in 1958 to a valley in 1963, rising to a peak in 1975/1976, and then dropping to the lowest values since observations began in 1930. In single years, 1986 and 1988, the harmonic almost disappeared at Chatham Island, with values as low as 0.25 hPa and 0.38 hPa. Such large changes in an inherent and dominant component of the mean annual cycle, in addition to the change of trends described in section 2, point out that even a relatively long series cannot represent the full spectrum of the circulation. Both at sea level and 500 hPa the changes in the semiannual component were bigger than in the annual one, and the change after 1977 described in section 2 was thus largely due to variations in the second harmonic.

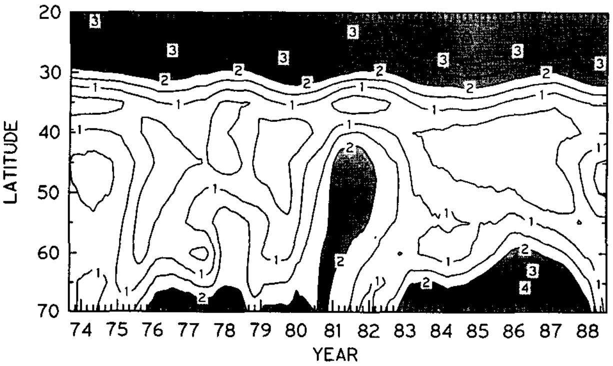

FIG. 5. Time series of the amplitude (hPa) of the first harmonic in the zonally averaged sea level pressure in the Australian dataset. The series has been smoothed such that the value at each point is the amplitude of the two-year mean centered on the point.

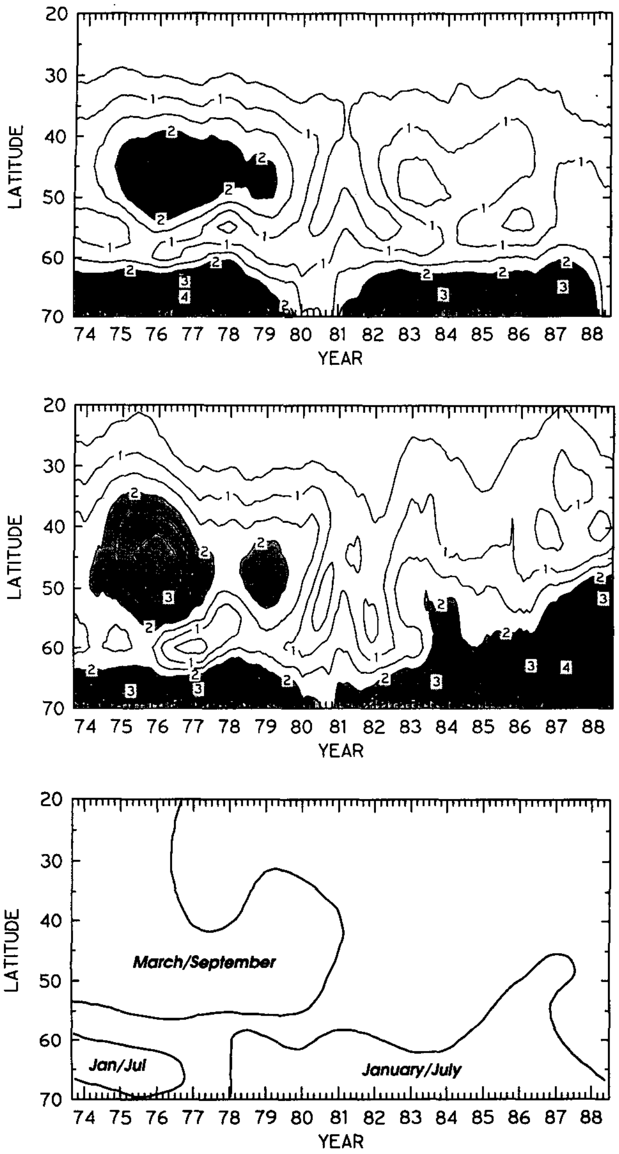

FIG. 6. As Fig. 5 but for (a) the second harmonic in the zonal average, (b) for 170°E–80°W. (c) The phase (months of maxima) of the second harmonic in 170°E–80°W.

4. Discussion and conclusions

During the second half of the 1970s, elements of the atmospheric circulation changed markedly from their state during the two previous decades. The change was evident in the zonal asymmetry, especially as described by wave 3 at 50°S–60°S, and in the change in the first two harmonic components of the annual cycle in SLP and geopotential height. The second harmonic (semiannual wave) is an intrinsic component of the annual cycle in middle and high south latitudes, forced by the different surface heat balances in middle and high latitudes (van Loon 1967; Meehl 1991), and dominating the mean annual cycle. The phase of the first harmonic in sea level pressure and wind of these latitudes is variable and only weakly tied to the solar forcing (van Loon 1966, 1972).

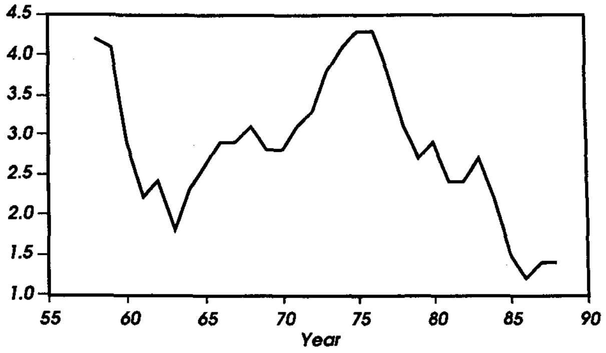

FIG. 7. Five-year running means of the amplitude (hPa) of the second harmonic in the sea level pressure at Chatham Islands.

The main change in the annual cycle after 1977 happened in the semiannual wave's peak at midlatitudes. The change was in the same sense in the three southern oceans, but it was largest in the South Pacific Ocean, where the second harmonic with extreme-sea-

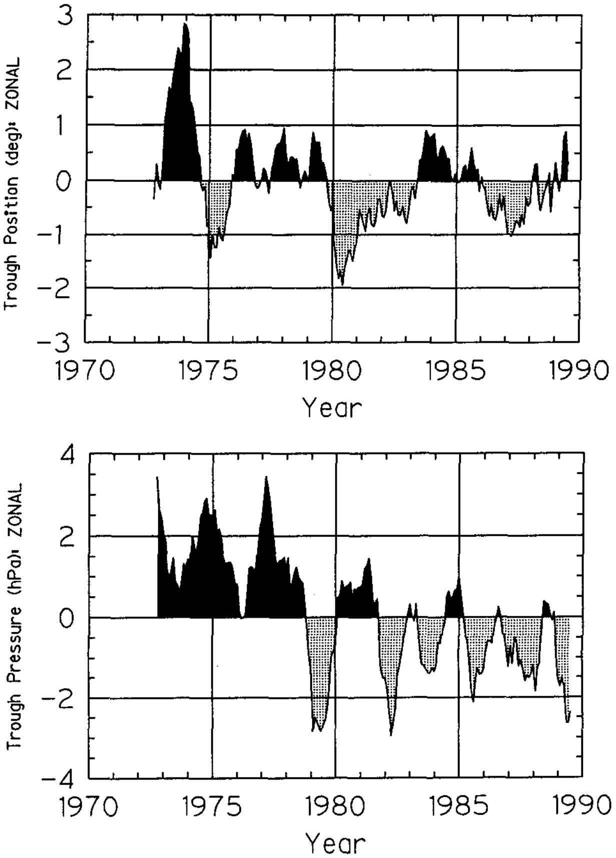

FIG. 8. (a) Twelve-month running means of the zonally averaged position of the center of the subantarctic trough of low pressure at sea level, relative to the 1973–1989 mean of 65.9°S. A negative value means the trough has moved to lower latitudes (northward). (b) Twelve-month running means of the zonally averaged lowest pressure (hPa) in the trough; 1973–1989 mean: 983.3 hPa.

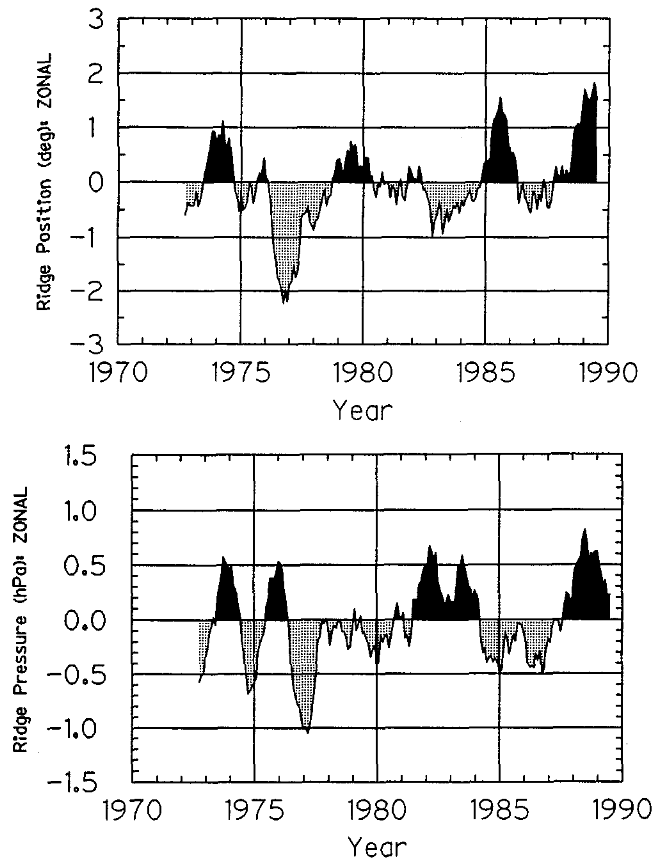

FIG. 9. The same as Fig. 8 but for the zonally averaged subtropical ridge.

son maxima at midlatitudes weakened and disappeared after 1977. In the two other oceans it weakened. The semiannual wave in the SLP is associated with the interseasonal changes in the subantarctic trough and concomitant changes of its central pressure. On an average, the pressure falls in midlatitudes when the trough moves north in the extreme seasons, and rises when the trough moves south in the transition seasons the reverse holds in the Antarctic. When the trough is farthest north (June and December) it is also weakest, and when it is farthest south (March–April and September–October) it is deepest (van Loon 1972, Fig. 4.10). A weakening or disappearance of the second harmonic at midlatitudes is likely related to a change in the movement or intensity of the subantarctic trough, or both.

Figures 8a,b show the 12-month running mean of the zonally averaged lowest pressure in the trough and of its zonal mean latitude. The trough was often north of its mean position and its central pressure lower in the 1980s. The trend in the SLP immediately to the north of the trough was therefore negative (Kerguelen and Campbell Islands in Fig. 3).

The average central pressure in the trough has a marked semiannual oscillation with the highest pressure in May–June–July and November–December–January (van Loon 1972, Fig. 4.10). During the 1970s and 1980s the central pressure in the trough fell steadily in *these* months, and this was largely responsible for the negative trend in Fig. 8b. The weakening of the semiannual wave between 1972 and 1989 is linked to these changes in the subantarctic trough, but also to low-frequency changes in the subtropical ridge which intensified and moved southward (Figs. 9a,b). Because the pressure fell at the same time in the northward moving trough, the meridional pressure gradient between trough and ridge increased.

In summary, the major changes observed during the winter months over this period were:

- The sea level pressure fell in high latitudes of the Southern Hemisphere in association with strengthening and northward displacement of the subantarctic trough.
- The pressure rose in lower latitudes, particularly near New Zealand and South America as the subtropical highs strengthened and moved southward.
- The three-wave pattern intensified from Antarctica to midlatitudes.

The pattern was similar, but weaker, in summer and a widespread fall in pressure was observed over the tropical and subtropical Indian Ocean.

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REFERENCES

Karoly, D. J., and A. H. Oort, 1987: A comparison of Southern Hemisphere circulation statistics based on GFDL and Australian analyses. *Mon. Wea. Rev.*, **115**, 2033–2059.

Kidson, J. W., 1988: Interannual variations in the Southern Hemisphere circulation. *J. Climate,* **1**, 183–194.

Lejenäs, H., 1984: Characteristics of Southern Hemisphere blocking as determined from a series of observational data. *Quart. J. Roy. Meteor. Soc.*, **110**, 967–979.

Le Marshall, J. F., G. A. M. Kelly, and D. J. Karoly, 1985: An atmospheric climatology of the Southern Hemisphere based on ten years of daily numerical analyses (1972–1982). *Austr. Meteor. Mag.*, **33**, 65–85.

Meehl, G. A., 1991: A reexamination of the mechanism of the semiannual oscillation in the Southern Hemisphere. *J. Climate,* **4**, 911–926.

Rogers, J. C., and H. van Loon, 1982: Spatial variability of sea level pressures and 500-hPa height anomalies over the Southern Hemisphere. *Mon. Wea. Rev.*, **110**, 1375–1392.

Swanson, G. S., and K. E. Trenberth, 1981: Interannual variability in the Southern Hemisphere tropospheric circulation. *Mon. Wea. Rev.*, **109**, 1879–1889.

Taljaard, J. J., H. van Loon, H. L. Crutcher, and R. L. Jenne, 1969: *Climate of the Upper Air: Southern Hemisphere.* Vol. I, NAVAIR 50-1C-55, Chief Naval Ops., 135 pp.

Trenberth, K. E., 1981: Observed Southern Hemisphere eddy statistics at 500 hPa: Frequency and spatial dependence. *J. Atmos. Sci.*, **38**, 2585–2605.

van Loon, H., 1966: On the annual temperature range over the southern oceans. *Geogr. Rev.*, **56**, 497–515.

——, 1967: The half-yearly oscillations in middle and high southern latitudes and the coreless winter. *J. Atmos. Sci.*, **24**, 472–486.

——, 1972: Temperature, pressure, and wind in the Southern Hemisphere. *Meteorology of the Southern Hemisphere, Meteor. Monogr.*, No. 35, Amer. Meteor. Soc., 25–100.