A Climatological Study of the Atmospheric Circulation in the Southern Hemisphere during the IGY, Part II

Harry van Loon
National Center for Atmospheric Research, Boulder, Colo.

(Manuscript received 30 June 1967)

ABSTRACT

The seasonal variations during the IGY of sea-level pressures, 500-mb heights, and 1000-500 mb thickness in the Southern Hemisphere are examined to see if they conform to patterns which are deemed intrinsic to the hemisphere. These are: 1) the arrangement of the annual temperature range in four concentric zones of alternating low and high range; 2) the coldness of the lower and middle troposphere over Australasia in winter compared with South America and Africa; 3) the positive temperature isanomals in middle and high latitudes over the South Pacific Ocean in both summer and winter; and 4) the sea-level pressure and 500-mb height variations of opposite sign in middle and high latitudes which give rise to a second harmonic of large amplitude in temperature and height gradients, and in winds and sea-level pressure.

The speed of movement of lows between 30 and 70S was, on the average, only slightly lower in the IGY summer than in the winter.

A comparison between the standard deviations of daily sea-level pressures and 500-mb heights in the two hemispheres shows that the variability is nearly the same in the northern and southern winters, but that the standard deviations in the latitudes near 50N in summer are only two-thirds of those in the same latitudes in the southern summer.

1. Introduction

The first part of this study (van Loon, 1965) dealt with zonal and meridional geostrophic winds, pressure systems and fronts, and the short waves at the 500-mb level during the first half of the IGY. This second part, which uses data from all of the IGY, examines the distribution of the 1000-500 mb thickness; its change from summer to winter and the response of the wind at the 500-mb level; the speed of movement of lows between 30S and 70S; and the seasonal change of pressure at sea level, of the height of the 500-mb surface, and of the standard deviations of both.

2. The change of 1000-500 mb thickness from February to August

It was demonstrated by van Loon and Taljaard (1958) and van Loon (1964, 1966) that the annual range of surface temperature and of 1000-500 mb thickness in the Southern Hemisphere does not everywhere increase with increasing latitude. Instead, it decreases from subtropical to middle latitudes. Such a poleward-decreasing annual range of temperature has definite consequences for the change of meridional temperature contrasts from summer to winter in the zone over which it takes place. If T_φ is the temperature in a latitude φ and $T_{\varphi+\Delta\varphi}$ the temperature in latitude $\varphi+\Delta\varphi$, the temperature difference is given by

$$\Delta T = T_\varphi - T_{\varphi+\Delta\varphi}.$$

For $T_\varphi > T_{\varphi+\Delta\varphi}$, the contrast ΔT across the latitude belt will decrease if T_φ drops by a larger amount than does $T_{\varphi+\Delta\varphi}$. A poleward-decreasing annual *range* of thickness (temperature) thus implies a larger meridional contrast in summer than in winter within the region of decreasing range, and consequently, a weaker vertical shear of the zonal component of the geostrophic wind in winter.

The decrease of thickness from February (summer) to August in 1958 is shown in Fig. 1, the distribution of the annual range in 1958 in the alternating rings of low and high values being similar to the long-term pattern (van Loon and Taljaard, 1958). In the subpolar belt of low range the values are below the long-term average, and in the areas of high range they are considerably above average over west Antarctica and central Argentina and Chile.

In Fig. 2 meridional profiles are given of the zonally averaged thickness gradients per 5° latitude in February and August 1958. The gradients in low and high latitudes are steeper in August, but between 35 and 55S they are steeper in February. Also in Fig. 2 are shown the zonally averaged profiles of the west-east component of the geostrophic wind at the 500-mb level in the two months. The west wind is stronger in middle latitudes in the summer month, mainly in accordance with the greater vertical shear, but also in accordance with the geostrophic wind changes at the 1000-mb level.

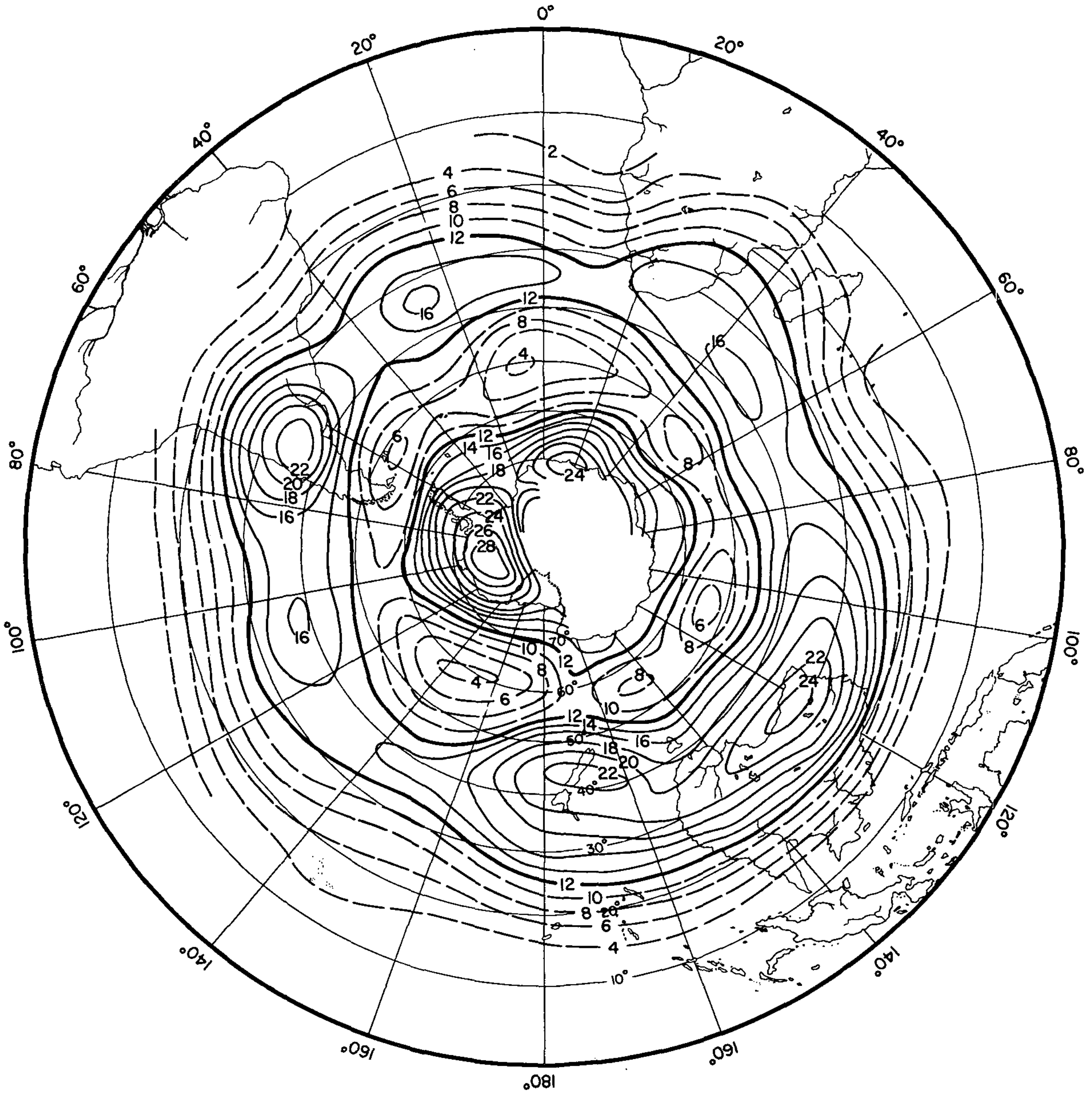

FIG. 1. Range of 1000–500 mb thickness (dekameters), February to August 1958.

3. Isanomalies of thickness

Figs. 3 and 4 are maps of the deviation of the 1000–500 mb thickness at each point from the mean of the latitude in January (summer) and July 1958. They may be compared with the similar maps for a longer period by van Loon and Taljaard. The thickness is proportional to the mean virtual temperature of the layer (2 dekameters≈1C). The long-term average characteristics appear with local modifications on the two maps. Common to both are the positive deviations in the South Pacific Ocean (in higher middle latitudes) and the negative deviations in the same latitudes of the South Atlantic and Indian Oceans. Where the difference between these positive and negative deviations is biggest, the column between 1000 and 500 mb is 7–8C warmer in the South Pacific. In January (Fig. 3), as in the means for the long period, there are positive deviations over Australia, South America and Africa, and

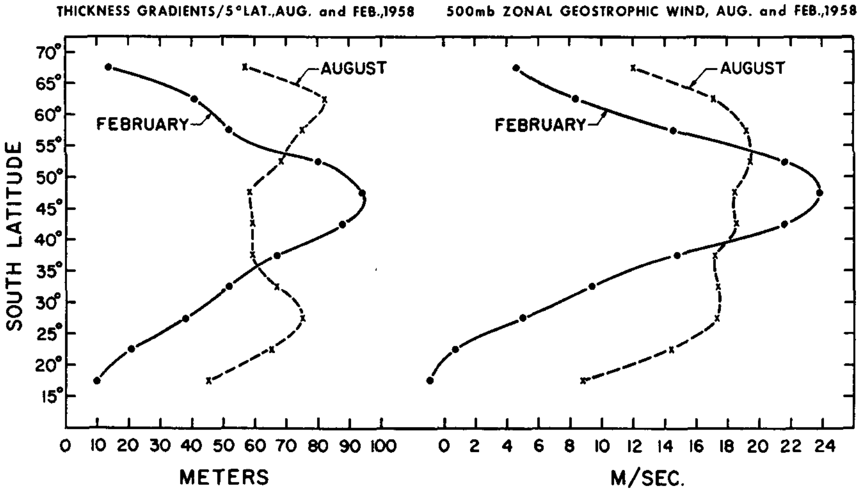

Fig. 2. Gradients per 5° latitude of 1000–500 mb thickness (dekameters), and zonal geostrophic wind (m sec^{-1}), February and August 1958.

negative or weak positive deviations over the oceans in subtropical latitudes.

In winter (July, Fig. 4) Australia and surroundings differ notably from South America and South Africa. Over the latter two, positive centers are found as in summer, but over Australasia the positive deviation of summer has been replaced by an equally marked negative deviation. Where the values in Fig. 4 differ most, the column of air is 7.5C colder over Australia than over the two other continents. According to the mean maps, this quality of the distribution of mean temperature in the layer between 1000 and 500 mb first appears in April and disappears in October.

4. Mid-season differences of sea-level pressures and 500-mb heights

It was shown by Reuter (1936) and by Schwerdtfeger and Prohaska (1956) that the annual march of pressure at the surface in middle and high southern latitudes has marked half-yearly components. In 45 to 55S the amplitude of the second harmonic, with maxima in March and September, equals or exceeds that of the first harmonic. A phase shift takes place near 60S so that in the polar region the second harmonic reaches its maxima in June and December. In 65 to 75S the amplitude of the second harmonic again becomes equal to or larger than that of the first. Schwerdtfeger (1960) further proved the existence of a dominant second harmonic with maxima in March and September in the middle-tropospheric height and temperature contrasts between 50S and the South Pole. A discussion of the origin of the large half-yearly variations and of their implications for the general circulation in the Southern Hemisphere was given by van Loon (1967).

The maps in Figs. 5–8 illustrate the change of sea-level pressure from September to December 1957, December 1957 to March 1958, March to June 1958 and June to September 1958. The variations of pressure of opposite sign in middle and high latitudes, which produce the second harmonics of opposite phase in the two regions, are conspicuous. In the Antarctic they are the generally rising pressures from September to December (Fig. 5) and from March to June (Fig. 7), and the falling pressures from December to March (Fig. 6) and from June to September (Fig. 8). In middle latitudes the pressures fall generally from September to December (Fig. 5) and from March to June (Fig. 7), and rise between December and March (Fig. 6) and between June and September (Fig. 8). In a single year the pressure will vary irregularly and thus, in that year, will show higher harmonics. But while the second harmonic recurs with the same phase in most years, the higher harmonics change phase from one year to another and so tend to be cancelled in the averaging over longer periods.

It has been shown (van Loon, 1967) that in the half hemisphere centered on Australia a rearrangement of the long waves takes place in the period around June. This consists of the formation or amplification of troughs on either side of Australia and a ridge over southeastern Australia. Data from 32 years between 1931 and 1964 show in nearly all the years a trough of large amplitude east of New Zealand in June which, in the mean, is replaced by a ridge in August, a sequence which is reflected in Figs. 7 and 8. The cellular arrangement of areas of rising and falling pressure in Fig. 7, superimposed on the pattern of falling pressure in middle latitudes and rising pressure in the polar region, is therefore not accidental.

For the 500-mb level only the maps of the difference

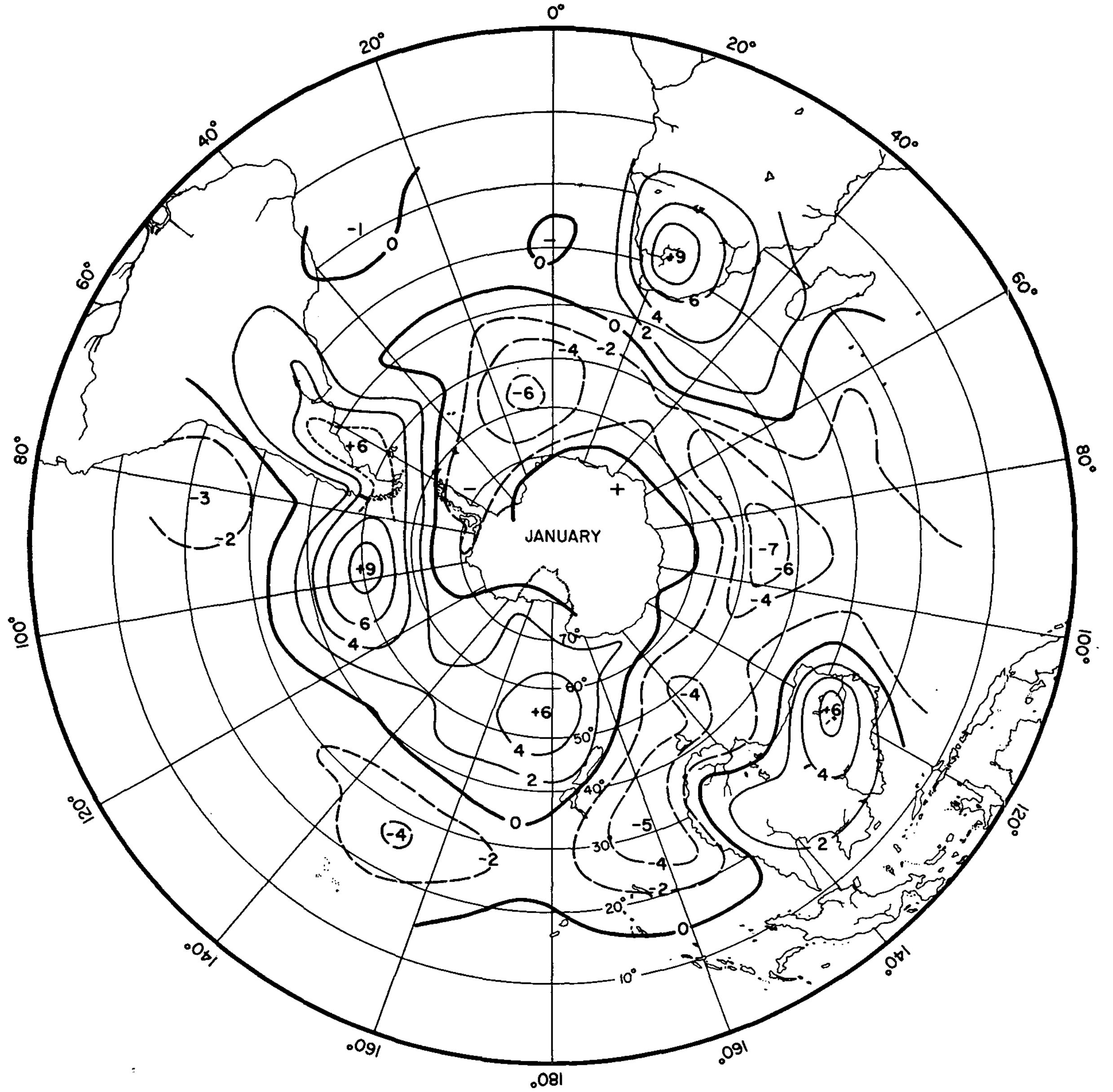

FIG. 3. Isanomals of 1000–500 mb thickness (dekameters), January 1958.

between December 1957 and March 1958 (Fig. 9), and between June and September 1958 (Fig. 10), are presented. Both clearly show the rises in middle latitudes and falls in high latitudes appropriate to their place in the half-yearly oscillation (compare Figs. 9 and 10 with Figs. 6 and 8).

As Schwerdtfeger demonstrated, the pressure and height changes of opposite sign in middle and high southern latitudes introduce a half-yearly oscillation in the gradients between the two regions, and thus also in the wind. An example of this is given in Fig. 11 where the amplitude of the second harmonic of the zonal component of the geostrophic wind in 1958 and its phase are drawn as a function of latitude for sea level and 500 mb. The amplitude is largest near 60S where the dates of the two maxima of the harmonic fall in the second half of March and September. This agrees with the variations in pressure and height in Figs. 5–10.

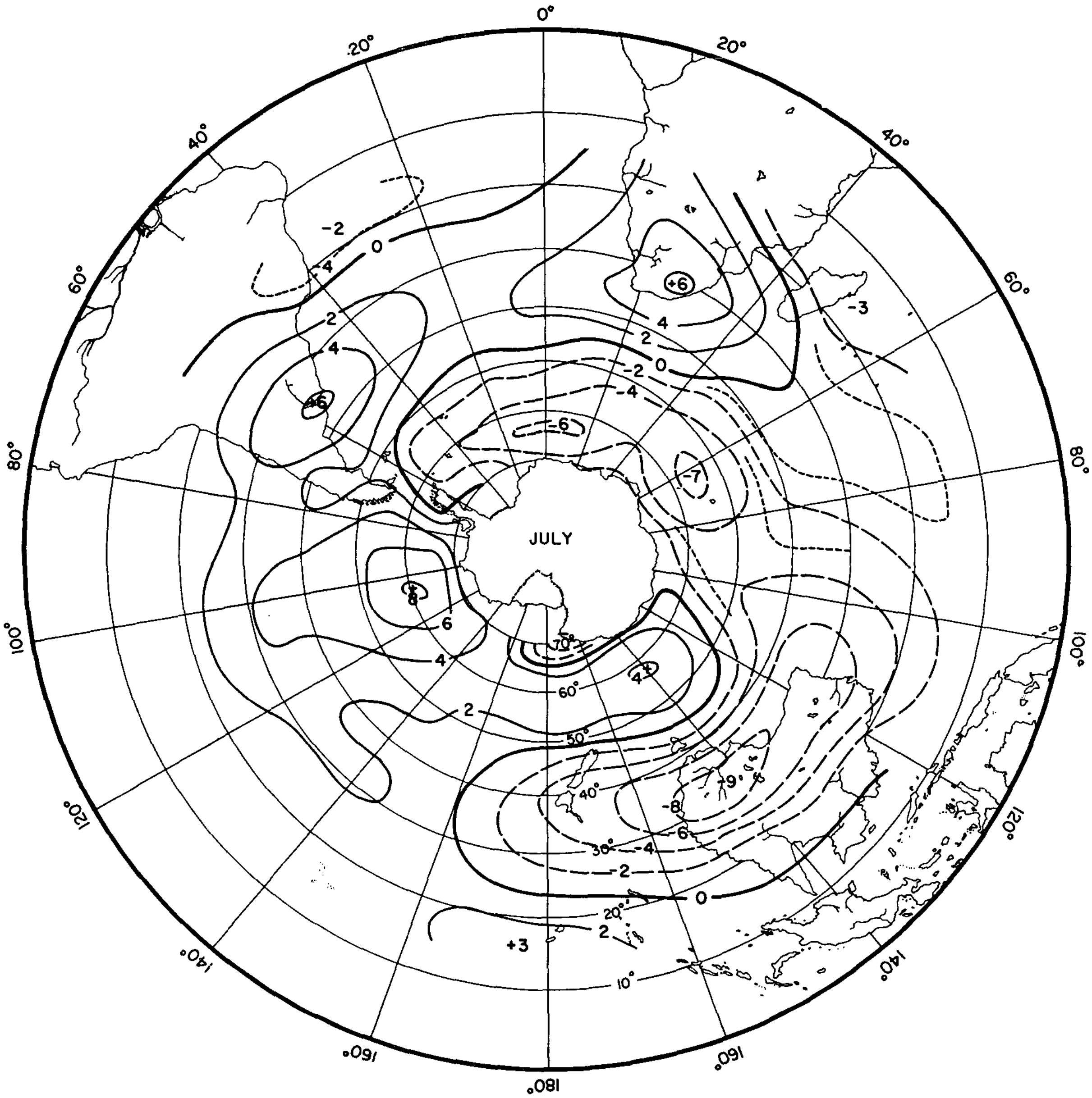

Fig. 4. Isanomals of 1000–500 mb thickness (dekameters), July 1958.

As a result of the pressure and height variations in middle latitudes, the amplitude of the second harmonic of the wind has another maximum in the subtropics in opposite phase to that of the subpolar region.

5. Standard deviations of daily sea-level pressure and 500-mb height

Zonally averaged standard deviations of the pressure at sea level and of 500-mb geopotentials are shown in Fig. 12. For the Southern Hemisphere they are based on daily values in a grid of 5° latitude by 5° longitude. The southern summer here includes December 1957, and January, February, March, December 1958, or 152 daily values at each point. The winter includes July, August, September 1957, and June, July, August, September 1958 or 214 daily values at each point. The standard deviations of pressure in the Northern Hemisphere were published by Schumann and van Rooy

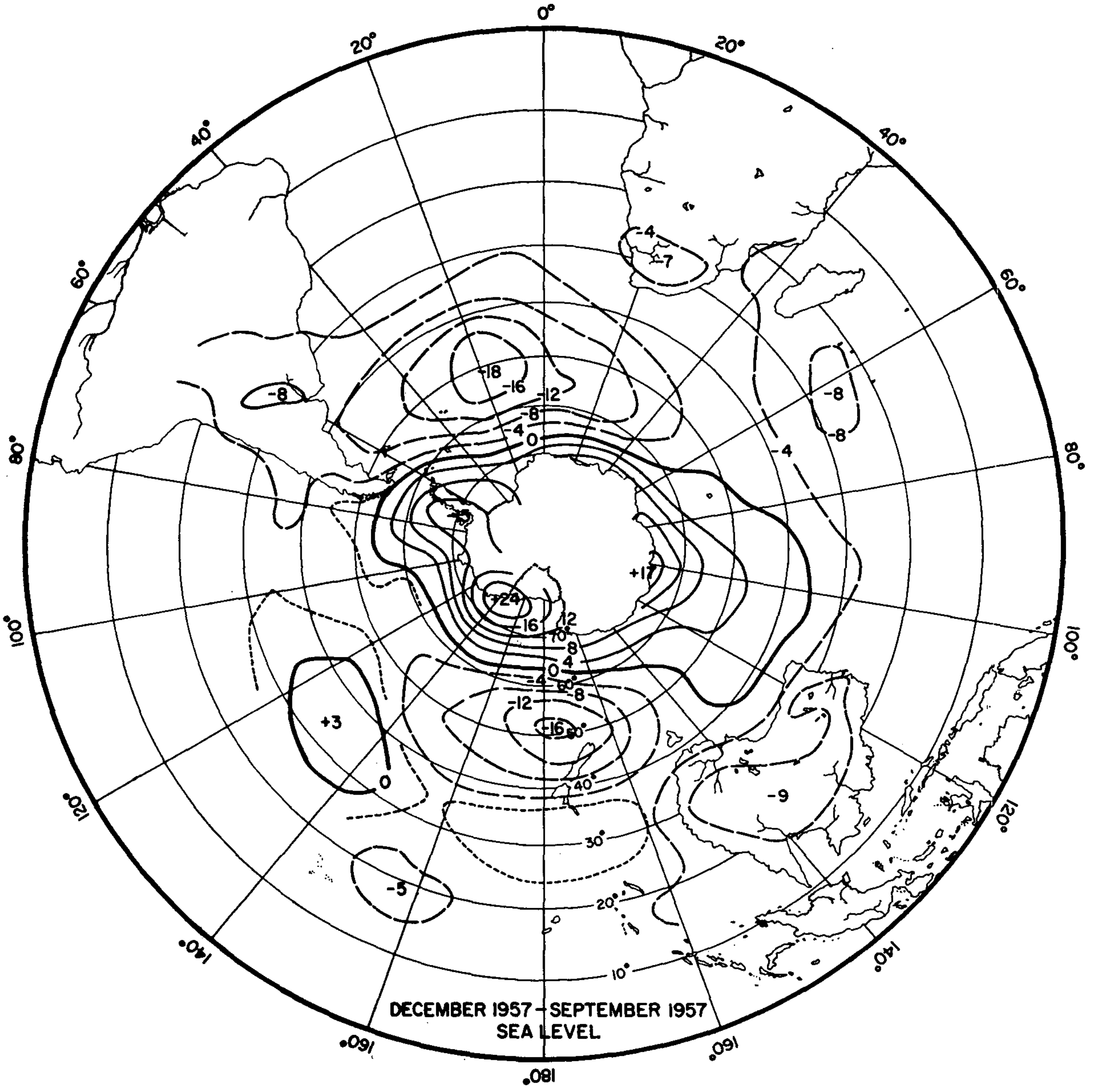

FIG. 5. Difference of sea-level pressure (mb), December minus September 1957.

(1951), and are for the period 1929 to 1938. Those for the 500-mb level are from Lahey *et al.* (1958), and cover the period October 1945 to January 1953.

The zonally averaged variability is nearly the same in the northern and southern winters, even in the latitudes between 40 and 65 where the difference in the distribution of land and sea is biggest. The variability is greater in the southern than in the northern summer, however. This is without doubt because of the dampening of meridional temperature contrasts by the heated land in middle and high northern latitudes, and thus the dampening of the large-scale turbulence of the atmosphere of which the standard deviation is a measure. The continents of the Southern Hemisphere lie in tropical and subtropical latitudes and around the pole, and in summer enhance meridional temperature contrasts.

At the 500-mb level the difference between the standard deviations of the southern winter and summer is

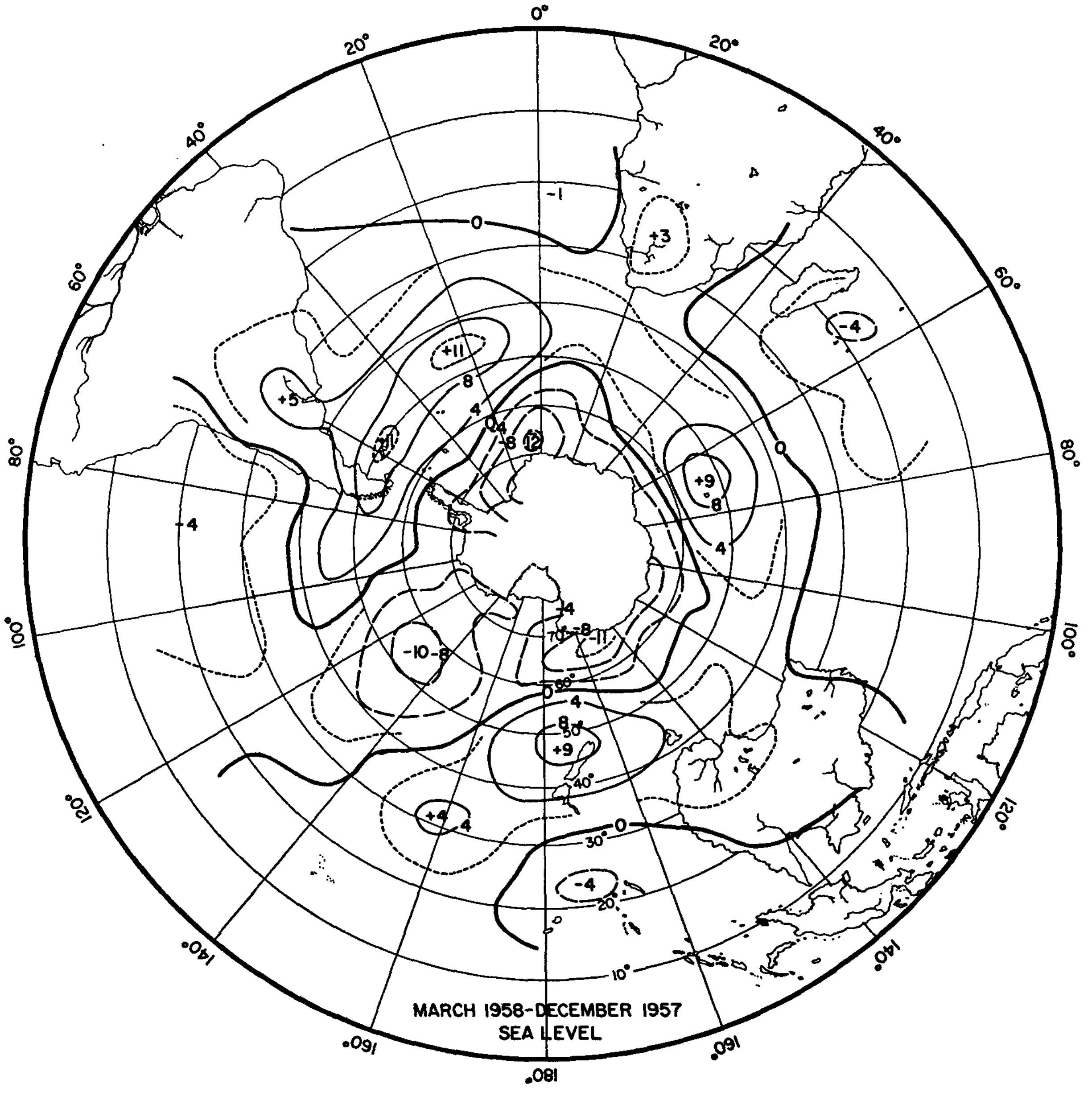

Fig. 6. Difference of sea-level pressure (mb), March 1958 minus December 1957.

smaller in 45 to 55S than in the latitudes to the south and north. This is associated with the increase of the meridional temperature gradients from summer to winter in the polar and subtropical regions in contrast with the middle latitudes (Fig. 2).

6. The speed of movement of lows

The distance over which the lows between 30 and 70S moved in 24 hr was measured for July, August and September 1957 (winter), and January, February and March 1958. In summer there are enough ships in the whaling grounds to permit an accurate tracking of the lows. In winter the daily analyses over most of the ocean south of 45S are uncertain, and in the central South Pacific Ocean, where there are no Antarctic coastal stations, the analysis in unreliable [see Taljaard and van Loon (1964), their Fig. 6]. The statistics for this ocean south of 40S in winter in Figs. 13 and 14 are

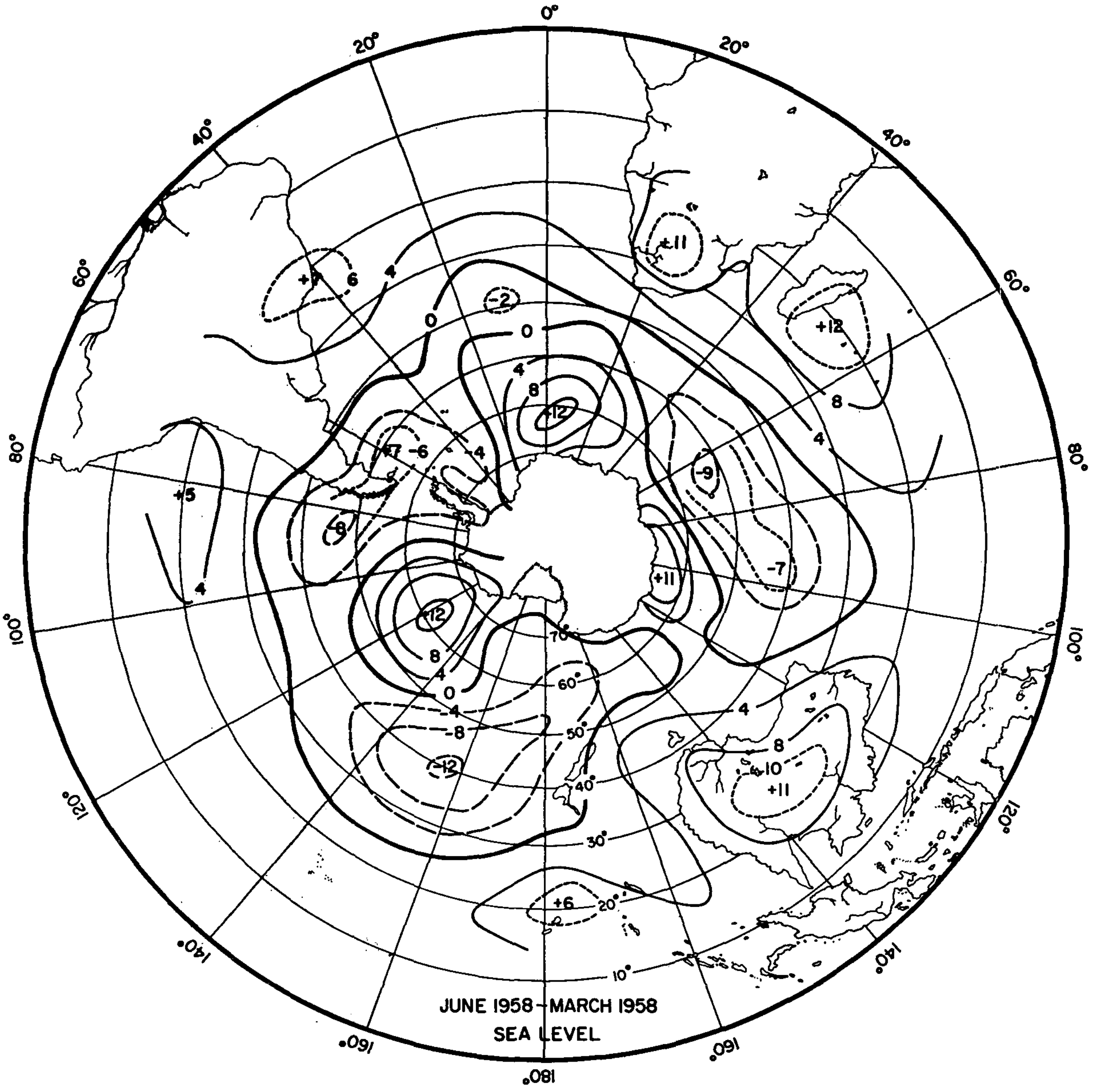

FIG. 7. Difference of sea-level pressure (mb), June minus March 1958.

therefore at best only qualitative indicators of the mean speed.

Since the zonal circulation in the South Pacific Ocean is weaker than in the South Atlantic and Indian Oceans (Meinardus, 1928; van Loon, 1964), and the average position of the subantarctic trough is closer to the pole in that ocean, the movement of lows was determined separately for the sector from 140E eastward to 60W and for the rest of the hemisphere. The average speeds in latitude belts of 10° for the two sectors, and for the whole hemisphere, are shown in Fig. 13. Apart from the region between 30 and 40S in the Pacific, the lows moved on the average faster in winter than in summer, though the difference between the two seasons is not great. Meinardus (*op. cit.*) found that between 40 and 50S the *west-to-east component* of the movement is

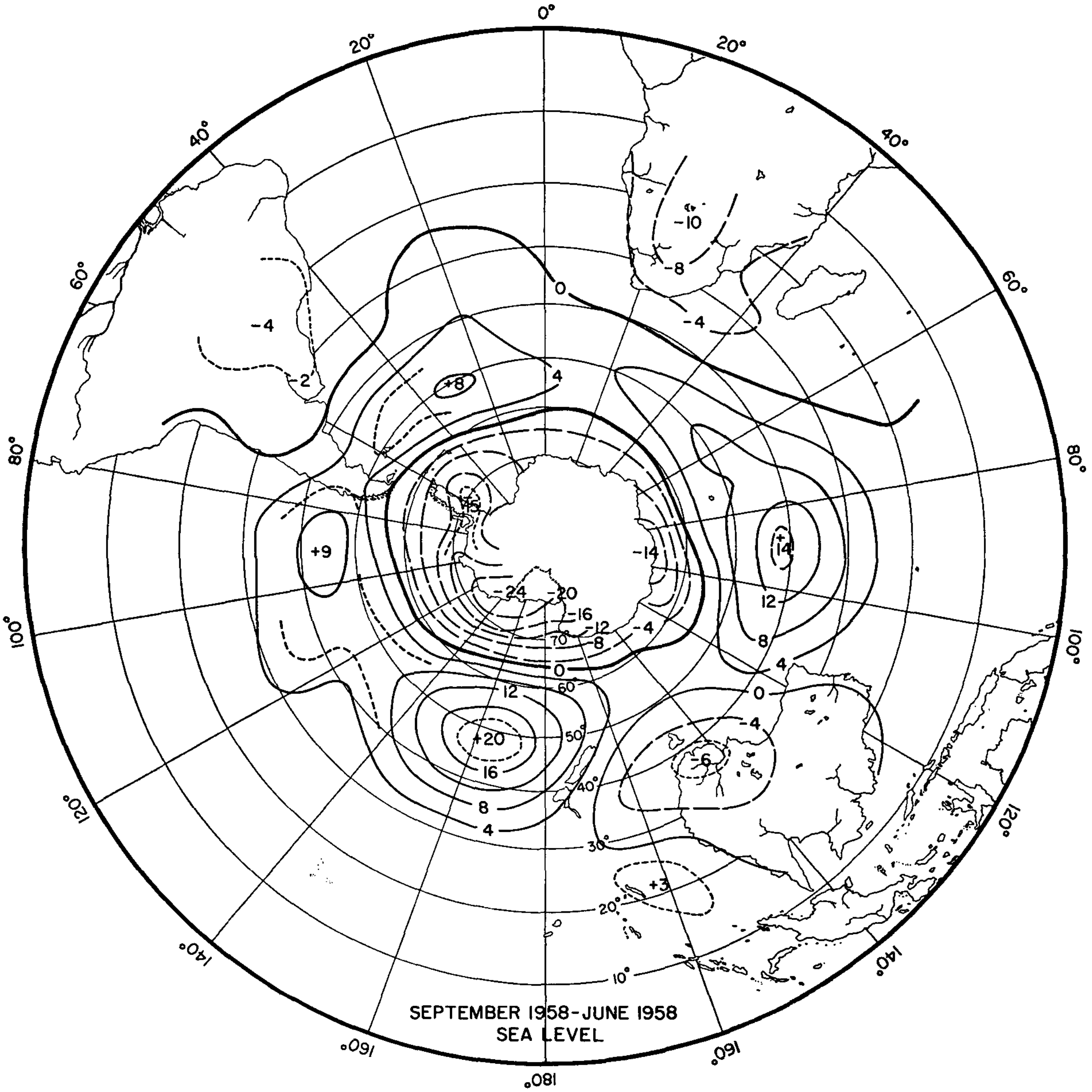

Fig. 8. Difference of sea-level pressure (mb), September minus June 1958.

slightly larger in summer than in winter. This does not necessarily contradict Fig. 13 which shows the total movement, that is, the combined west-east and south-north components. A hint of the reason for the difference is found in Table 1; the average zonal westerlies between 35 and 55S of the three summer months are indeed 9% stronger than those of the winter months. The average meridional index at 45S, however, is 17% higher in winter than in summer, pointing to a greater average meridional movement of lows in winter.

The quickest movement is in the zone between 40 and 60S, with the characteristic difference between the two sectors being that the highest values are over the southern half of this zone in the South Pacific, but over the northern half in the two other oceans.

The frequency distribution of speeds in intervals of 10 kt is given in Fig. 14. Because only one summer and

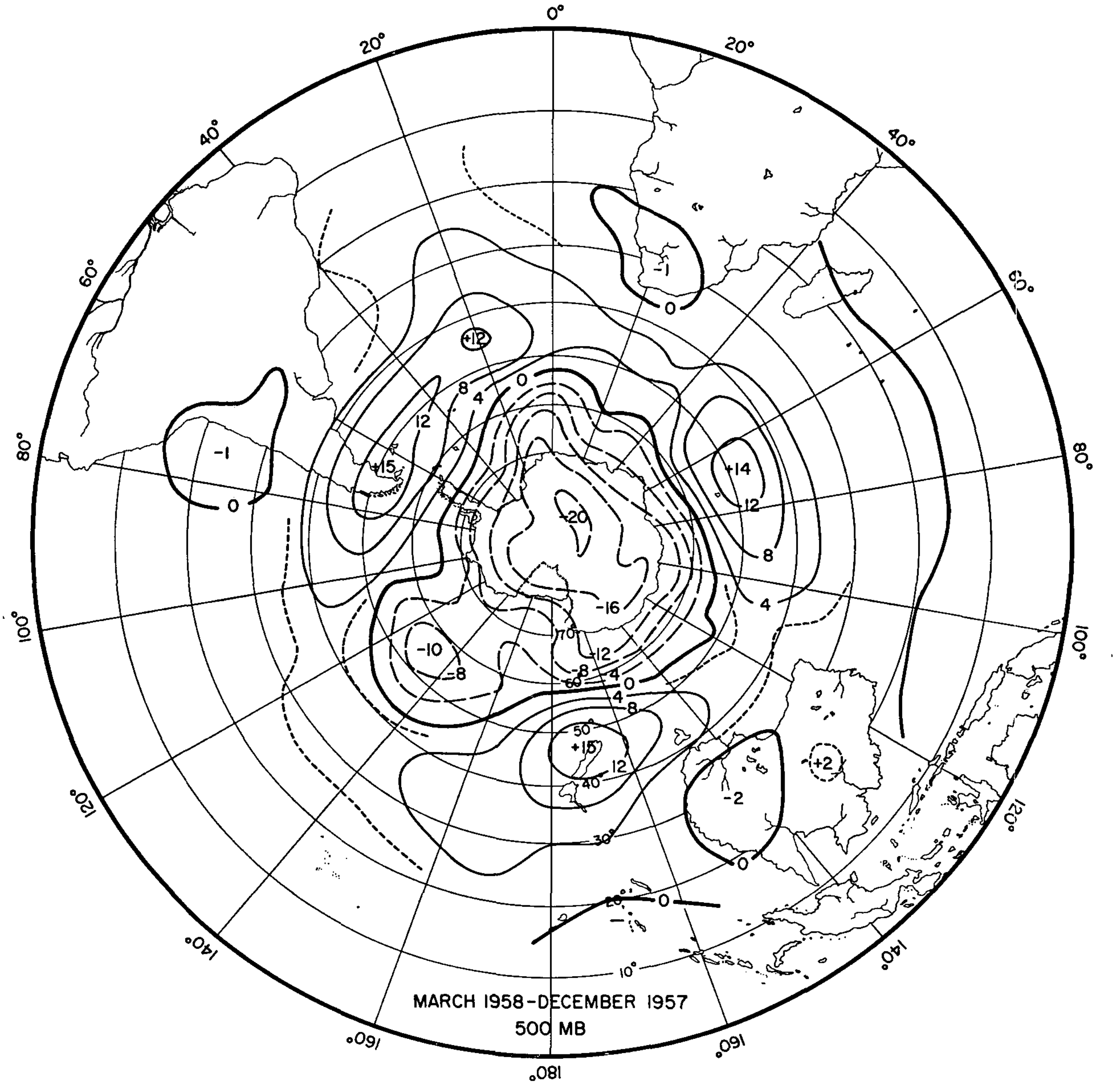

FIG. 9. Difference of 500-mb height (dekameters), March 1958 minus December 1957.

one winter were examined, the sample is too small to assure that the differences which appeared between the frequency distributions of the IGY summer and winter, are real seasonal differences. In any event, frequency distributions in the two seasons were rather similar, the average difference between summer and winter for all the speed intervals in the four latitude belts amounting to only 2.8%. Therefore, the frequencies for all six months are shown together.

The frequency distributions and the means for the zones 40–50S and 50–60S differ little. About 67% of the speeds fall in the two intervals between 20 and 40 kt. Few lows in these latitudes are stationary or slow-moving: only 5% are in the interval between 0 and 10 kt. Between 60 and 70S, which is where the circumpolar trough appears in the maps of sea-level mean pressures, 26% fall in the first interval, being either stationary or moving less than 4° latitude a day.

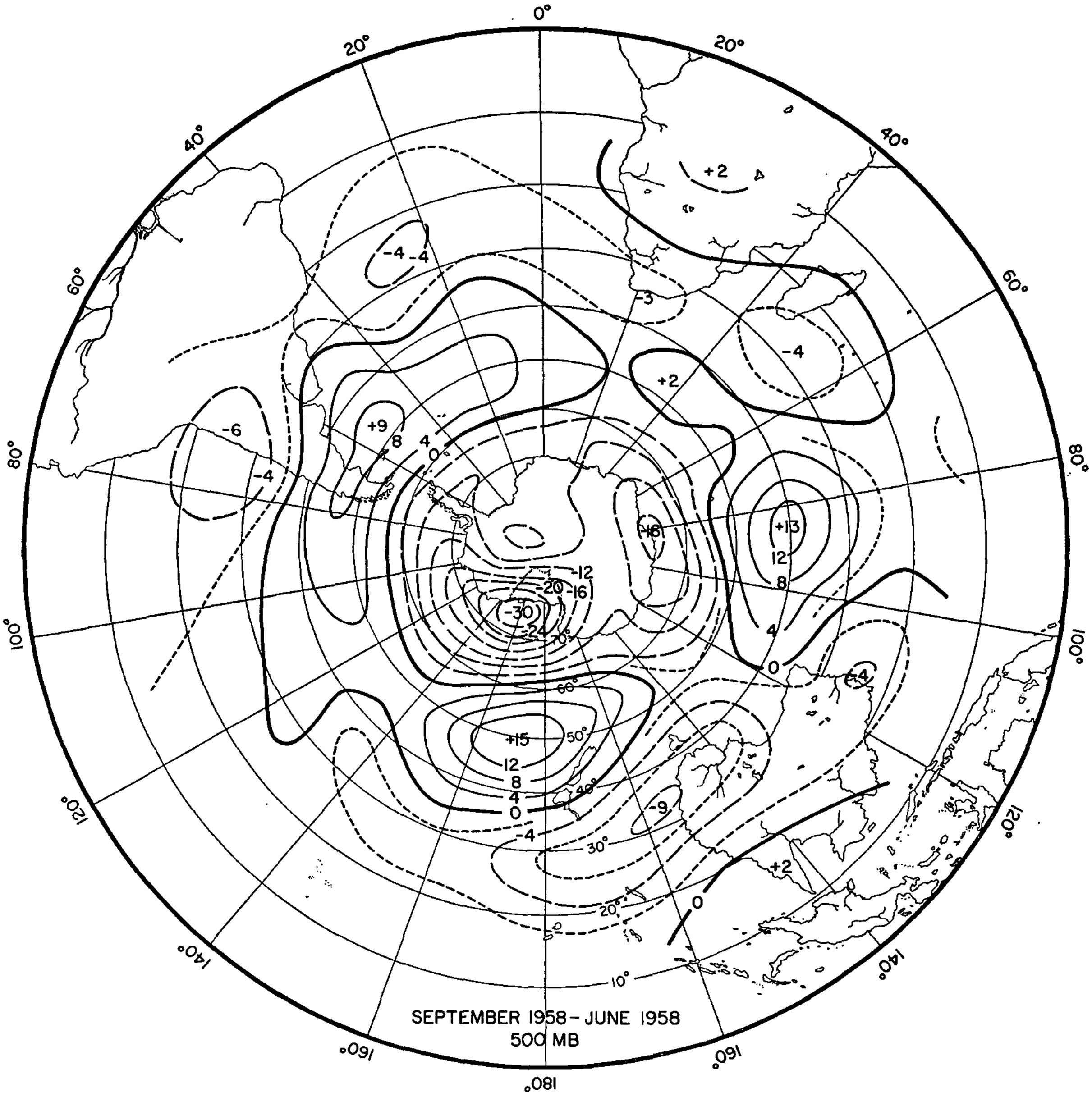

Fig. 10. Difference of 500-mb height (dekameters), September minus June 1958.

7. Summary

Averages for long periods reveal certain characteristics of the distribution and seasonal variation of pressures, heights, winds and temperatures in the Southern Hemisphere, which have been briefly examined here such as they appear in a single year. They are:

1. The higher annual range of temperature in subtropical than in middle latitudes, and the resulting greater temperature contrast and stronger vertical shear of the geostrophic west wind in summer than in winter in middle southern latitudes.

2. The coldness of the atmosphere over Australia in winter compared with Africa and South America, and the higher temperatures, both summer and winter, in the South Pacific than in the South Atlantic and Indian Oceans.

3. The mass variations of opposite sign in middle and

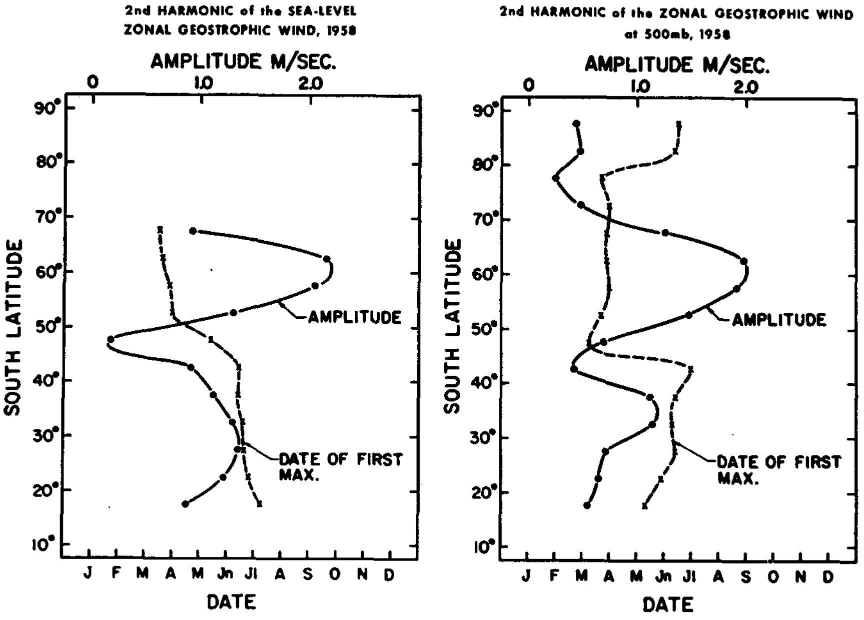

FIG. 11. Amplitude (m sec^{-1}) and date of first maximum of the second harmonic of the zonal geostrophic wind at sea level and 500 mb in 1958.

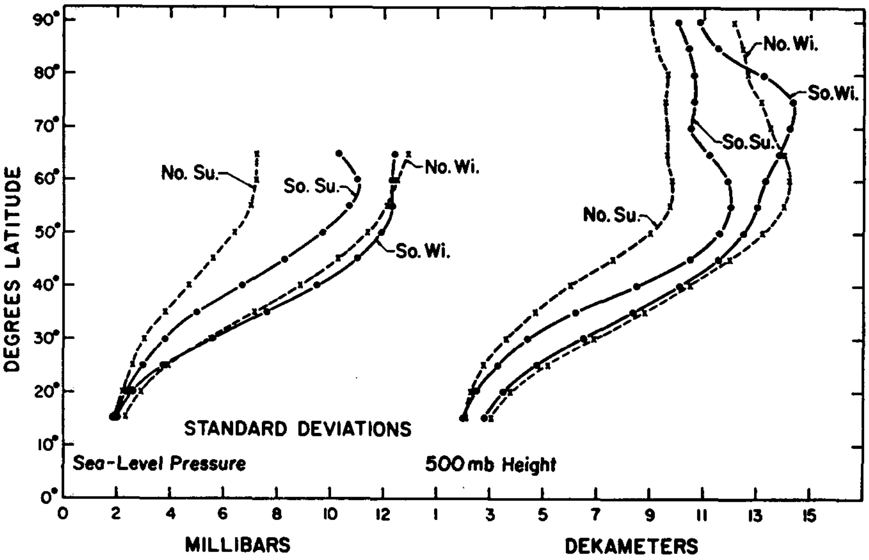

FIG. 12. Standard deviation of daily values of sea-level pressure (mb) and 500-mb height (dekameters).

TABLE 1. Zonal and meridional indices (m sec^{-1}).

	Summer, 1958 (Jan., Feb., Mar.)	Winter, 1957 (Jul., Aug., Sept.)
Zonal westerly index 35–55S	6.8	6.2
Meridional index 45S	5.5	6.6

high latitudes. These characteristics all appeared in the IGY.

4. The standard deviations of daily sea-level pressures and 500-mb heights differ little in winter in the two hemispheres. In the southern summer they are larger in middle latitudes than in the northern summer.

5. The average speed of movement of lows between 30 and 70S is only slightly greater in the southern winter than in summer.

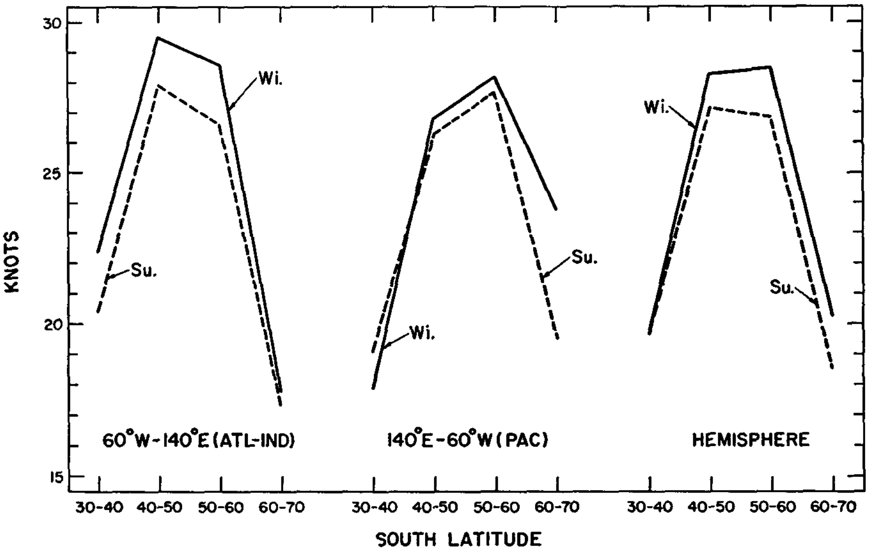

FIG. 13. Average speeds of movement (kt) of lows between 30 and 70S in July, August and September 1957 (winter), and January, February and March 1958 (summer).

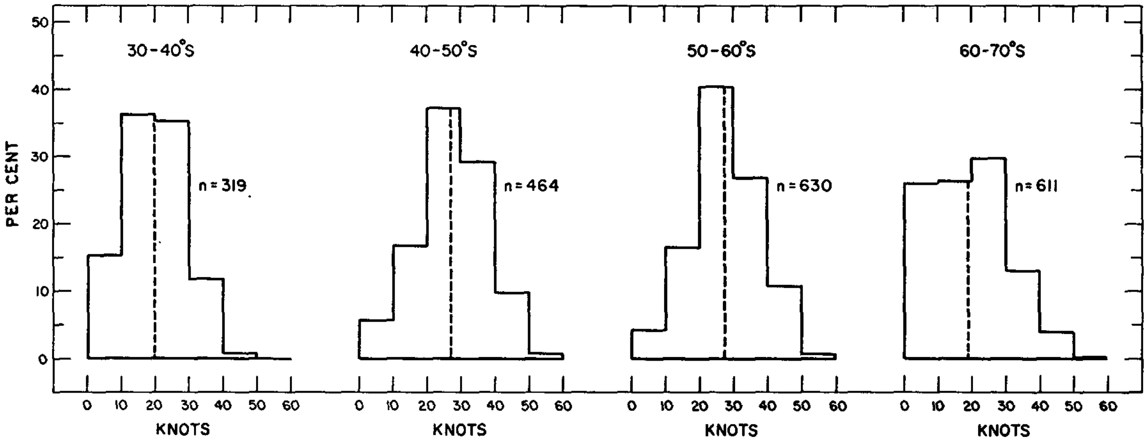

FIG. 14. Frequency distributions of the speeds of movement (kt) of lows between 30 and 70S in winter 1957 and summer 1958 combined.

REFERENCES

Lahey, J. F., R. A. Bryson, E. W. Wahl, L. H. Horn and V. D. Henderson, 1958: Atlas of 500-mb wind characteristics for the Northern Hemisphere. Sci. Rept. No. 1, U. S. Air Force Contract AF 19(604)-2278, The University of Wisconsin Press, Madison.

Meinardus, W., 1928: Deutsche Südpolar Expedition 1901–1903. Band III, *Meteorologie*. Berlin, Walter de Gruyter, 133–307.

Reuter, F., 1936: Die synoptische Darstellung der hälbjahrigen Druckwelle. *Veröff. Geoph. Inst. Leipzig*, 7, 257–295.

Schumann, T. E. W., and M. P. van Rooy, 1951: Analysis of the standard deviation of atmospheric pressure over the Northern Hemisphere. W. B. 16, Wea. Bur., Pretoria, 33 pp..

Schwerdtfeger, W., 1960: The seasonal variation of the strength of the southern circumpolar vortex. *Mon. Wea. Rev.*, **88**, 203–208.

——, and F. Prohaska, 1956: Der Jahresgang des Luftdrucks auf der Erde und seine halbjährige Komponente. *Meteor. Rundsch.*, **9**, 33–43.

Taljaard, J. J., and H. van Loon, 1964: Southern Hemisphere weather maps for the International Geophysical Year. *Bull. Amer. Meteor. Soc.*, **45**, 88–93.

van Loon, H., 1964: Mid-season average zonal winds at sea level and at 500 mb south of 25 degrees south, and a brief comparison with the Northern Hemisphere. *J. Appl. Meteor.*, **3**, 554–563.

——, 1965: A climatological study of the atmospheric circulation in the Southern Hemisphere during the IGY, Part I. *J. Appl. Meteor.*, **4**, 479–491.

——, 1966: On the annual temperature range over the southern oceans. *Geograph. 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.

——, and J. J. Taljaard, 1958: A study of the 1000/500-mb thickness distribution in the Southern Hemisphere. *Notos*, **7**, 123–158.