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The yearly wave in pressure and zonal geostrophic wind at sea level on the southern hemisphere and its interannual variability

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ABSTRACT

The yearly wave (first harmonic) in the sea level mean pressure on the southern hemisphere is largest at 30° S over and near the three continents, where it also explains most of the mean annual variance. In middle and high latitudes, the half-yearly wave dominates so that even in the Antarctic the yearly wave is mostly secondary. In single years, the amplitude of the yearly wave south of 40° S may be large, but as the phase varies widely from one year to another, the mean wave becomes small.

The yearly wave in the mean zonal geostrophic wind at sea level is largest in the tropics and subtropics. Like the pressure wave, it is second to the half-yearly wave over most of middle and high southern latitudes. The phase of the yearly wave appears in four concentric belts as follows: maximum westerlies/minimum easterlies in summer in the tropics outside the eastern Pacific Ocean; maximum westerlies/minimum easterlies in winter in the subtropics; maximum westerlies in summer in the latitudes round 50° S (unlike the northern hemisphere); and maximum westerlies/minimum easterlies in winter over most of the area covered by sea ice. Just as the pressure wave, the yearly wave in the zonal wind has a large interannual variation.

1. Introduction

The yearly wave in the sea level pressure (SLP) on the southern hemisphere is not an unknown quantity. Its main features north of 50° S were outlined by Spitaler (1901), and the picture was gradually completed as data became available: by Wahl (1942), Schwerdtfeger and Prohaska (1956), Hofmeyr (1957), and van Loon (1972). The analysis of the wave in this paper is based on the same daily synoptic maps for 12–13 years as we used to describe the half-yearly wave (van Loon and Rogers, 1984), whereas the earlier descriptions used monthly means. In addition to the analysis of the mean yearly wave, this paper will also give an idea of its interannual variation.

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The wave is defined as the first harmonic in a series of 12 monthly means:

$$y = a_1 \sin(x + A_1),$$

where a_1 is the amplitude (half range), and A_1 the phase angle which determines the value of x at which the extremes of y occur.

2. The yearly pressure wave

The wave does not necessarily reach its extremes in January and July, but mean SLP maps for these two months (Figs. 1A and B) are nevertheless shown so that a reader who is not familiar with the southern hemisphere can relate the phase and amplitude of the yearly wave to the features of the mean pattern.

The wave is conspicuous over and near Africa,

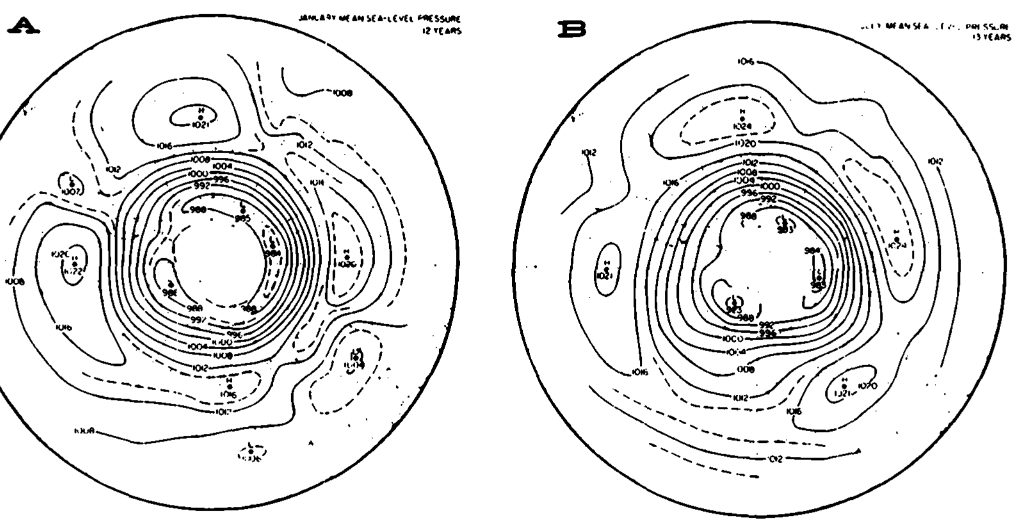

Fig. 1. (A) Sea level mean pressure in January based on 12 years of daily maps. (B) Sea level mean pressure in July based on 13 years of daily maps.

Australia, and South America (Fig. 2A), where it reaches its maximum about the middle of July (Fig. 2B); over the tropical-subtropical oceans, the maximum is about one month later. Note that the wave is weak in the central and eastern Pacific Ocean although it accounts for more than 95% of the annual mean variance, as it does over most of the circumference in these latitudes (Fig. 2C). The small amplitude in the Pacific Ocean is not owing to a lack of observations there, because the smallest amplitudes are in or near the shipping lanes from Australia–New Zealand to the Panama Canal and North America. The minimum even appears on Spitaler's (1901) map of lines of equal pressure difference between January and July on which the difference at 130° W is only just above 2 mb.

The yearly wave is less important in the south: its biggest amplitude is 3.6 mb in the westerlies of the South Pacific Ocean, and over wide regions it accounts for less than half of the annual variance. The amplitude is small even in Antarctica where it is only 1.5 mb to 2 mb on the coast. This does not of course mean that it is small in individual years, as one can see from the following example.

The mean yearly wave at Halley Bay in the Weddell Sea (Fig. 3A) is just below 2 mb, yet in 11 out of the 16 years the amplitude was between 3 mb and 7 mb. The phase, however, is variable and the single years thus tend to offset each other. The same happens, for instance, at Marion Island in the westerlies southeast of South Africa, and at Amsterdam Island at the northern border of the westerlies in the central Indian Ocean (Fig. 3B). The phase is especially variable in the latter position. On the other hand, the large mean amplitudes at the three continents in lower latitudes are owing to the small changes in phase from one year to another, as illustrated by Port Elizabeth in Fig. 3B. The constancy of phase in the subtropical pressure wave and the lack of same in the wave at higher latitudes have important consequences for the interannual variations of the yearly wave in the zonal geostrophic wind described below.

The amplitude of the mean wave at the stations in Fig. 3 is not necessarily of the same size as that in the same positions in Fig. 2A, because the map is based on only 12–13 years, whereas the number of years used at the stations ranges from 16 at Halley Bay to 28 at Marion Island. It is surprisingly close, however, at all four stations.

The annual pressure wave in the year of the First GARP Global Experiment (FGGE), 1979, has all the essential features of the mean wave (cf. Figs. 2A and D) such as the large amplitude with maximum in July on the lower-latitude continents, the amplitude minimum at lower latitudes in the Pacific Ocean, and the peak with summer maximum in the Pacific westerlies. The amplitude in

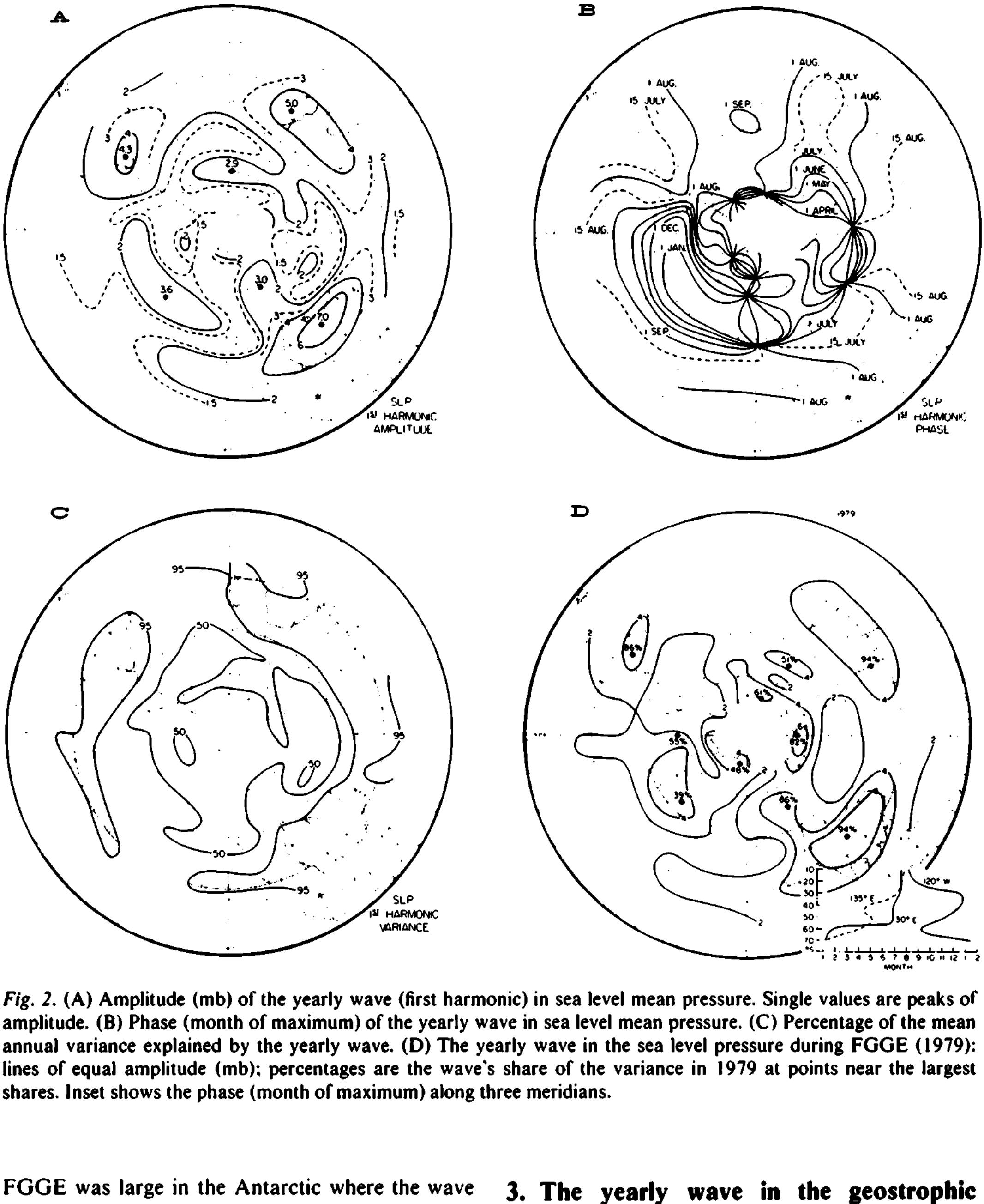

Fig. 2. (A) Amplitude (mb) of the yearly wave (first harmonic) in sea level mean pressure. Single values are peaks of amplitude. (B) Phase (month of maximum) of the yearly wave in sea level mean pressure. (C) Percentage of the mean annual variance explained by the yearly wave. (D) The yearly wave in the sea level pressure during FGGE (1979): lines of equal amplitude (mb); percentages are the wave's share of the variance in 1979 at points near the largest shares. Inset shows the phase (month of maximum) along three meridians.

FGGE was large in the Antarctic where the wave reached maximum in the southern summer. A feature of both the mean and the FGGE map is the extension toward the south from Australia of a peak with maximum in the southern winter. There is a distinct node near New Zealand between this peak and the one with summer maximum in the Pacific Ocean.

3. The yearly wave in the geostrophic zonal wind

The mean zonal geostrophic wind in January and July may be inferred from Figs. 1A and B. The yearly wave in the wind is shown in Fig. 4. The wave has four concentric amplitude peaks: in the tropics outside the eastern Pacific with minimum

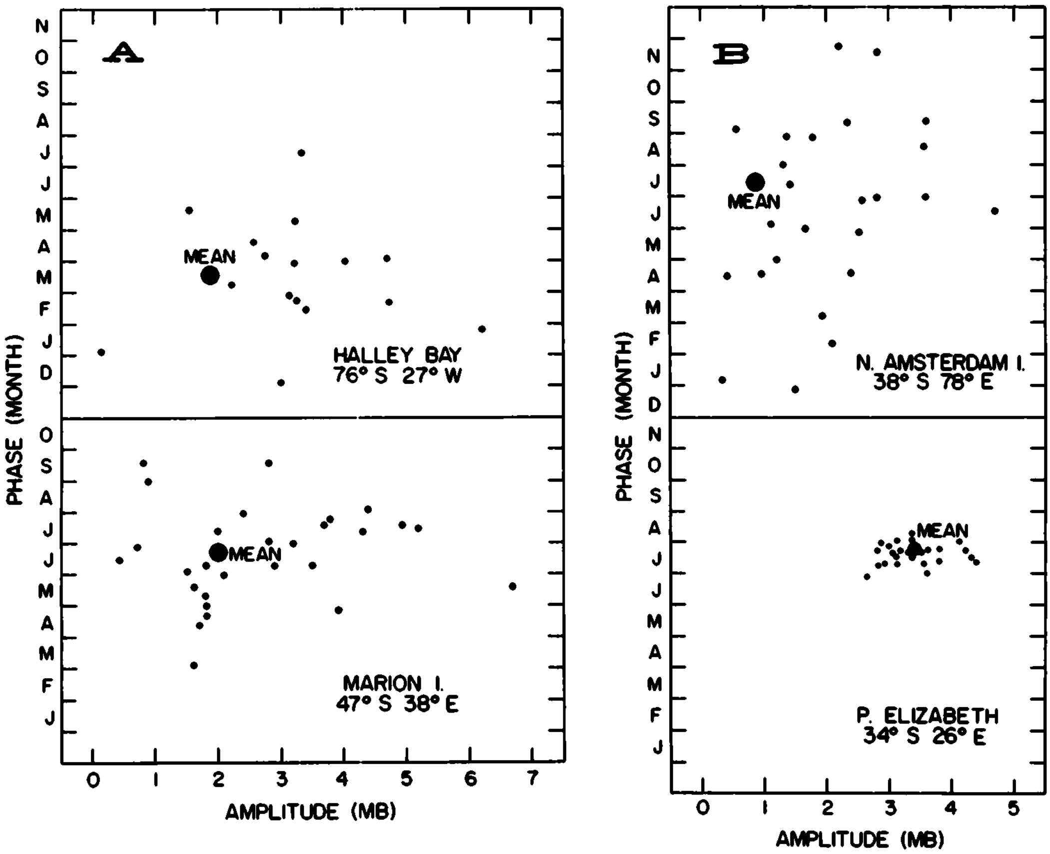

Fig. 3. (A) Amplitudes of the yearly wave in sea level mean pressure in single years plotted against phase (month of maximum) at Halley Bay (16 years) and Marion Island (28 years). The large dot is the amplitude versus phase of the long-term mean. (B) Same as (A) but for New Amsterdam Island (25 years) and Port Elizabeth (25 years).

easterlies/maximum westerlies in the southern summer; in the subtropics with maximum westerlies/minimum easterlies in the southern winter; in the latitudes about 50° S with maximum westerlies in summer; and in the subantarctic with maximum westerlies/minimum easterlies in winter. The amplitude is small in the last two zones where the half-yearly wave dominates over vast regions (van Loon and Rogers, 1984). The summer maximum in middle latitudes is in contrast to conditions on the northern hemisphere, and can be explained as an effect of the almost unbroken water surface between the subtropics and the Antarctic (van Loon, 1966).

The distribution of amplitude and phase in the FGGE year (Fig. 4C) does not differ much from that of the long-term mean (Fig. 4A), but the size of the amplitude and the wave's share of the annual variance are quite different from the mean in many places.

The daily analyses of sea level pressure over the southern hemisphere improved after 1954 when several antarctic stations were established in preparation for the International Geophysical Year. The years before 1955 were therefore not used in Fig. 5. The year of 1974 was chosen from the series of Australian analyses owing to the large yearly wave in the subtropics. Otherwise, three successive years including FGGE were used. Practical considerations, such as how many curves can be discerned from each other in one drawing, set a natural limit to the number of years which could be

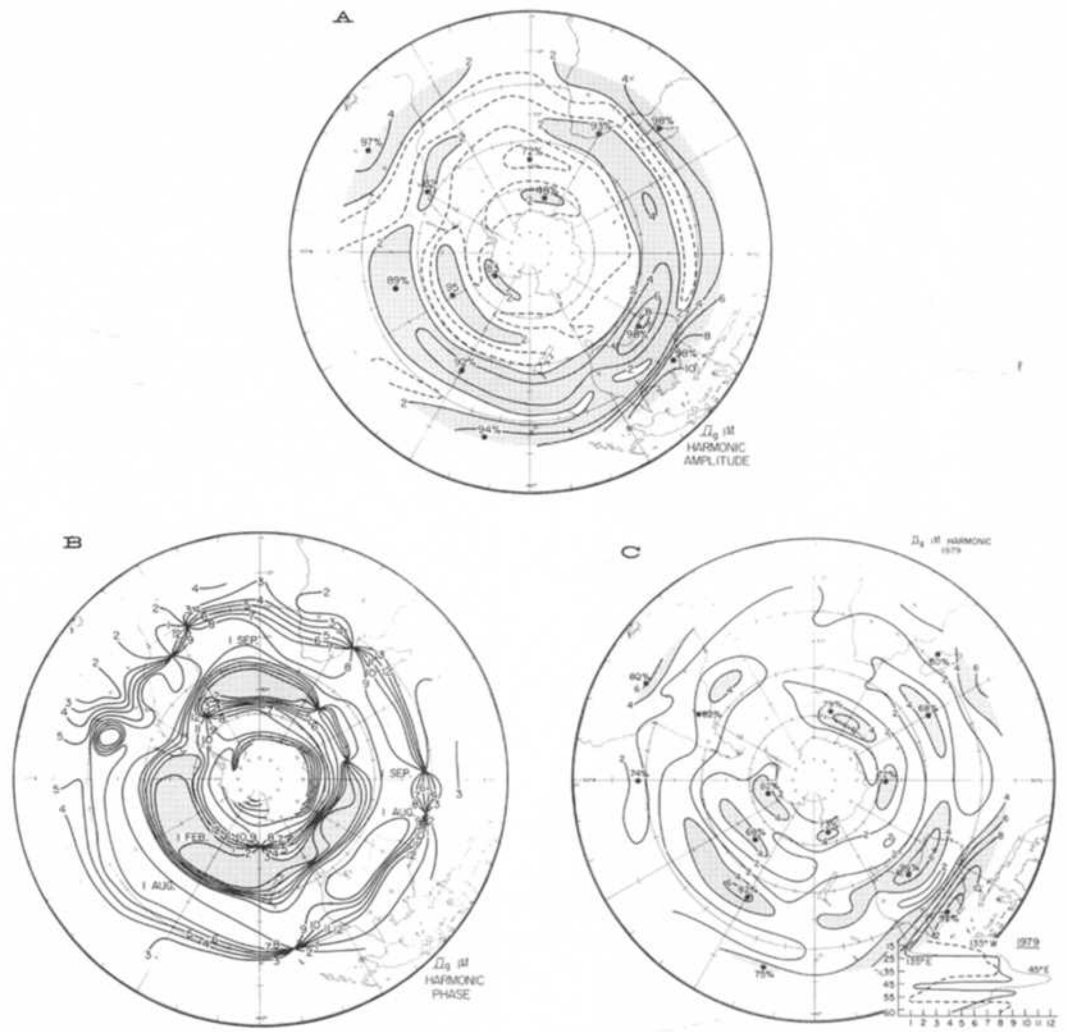

Fig. 4. (A) Amplitude (m s^{-1}) of the yearly wave of the mean zonal geostrophic wind at sea level based on 12–13 years of daily maps of sea level pressure. The dots with percentages denote the wave's share of the mean annual variance at points near the largest shares. (B) Phase (month of maximum) of the yearly wave in the zonal geostrophic wind at sea level. (C) The yearly wave in the zonal geostrophic wind during FGGE (1979); percentages are the wave's share of the variance during 1979 at points near the largest shares. Inset shows the phase (month of maximum) along three meridians.

shown in Fig. 5. This illustration, like Fig. 3, is in any event meant only to give an idea of the limitations of mean maps such as Figs. 2 and 4.

The large differences of the yearly wave in the zonal geostrophic wind from one year to another at the two longitudes in Fig. 5 are striking. In 1978, for instance, there was hardly a peak in the subtropics (Fig. 5A); in the other years, when the peak was pronounced, its latitude varied markedly. The variability is particularly large south of about 45° S.

In the zonal mean, (Fig. 5B), the peaks and valleys north of 40° S are in the same position every year, within the resolution of 5° latitude, which testifies to the constancy of the phase, and the interannual differences are generally below 1 m s^{-1}. In middle and high latitudes, the diagram is chaotic as the extremes of the amplitude seemingly

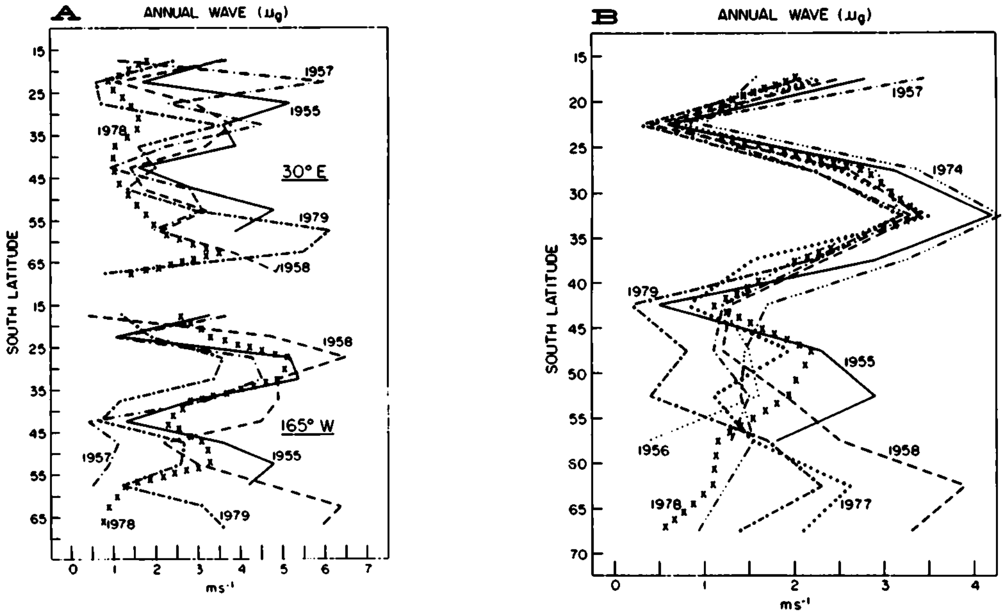

Fig. 5. (A) Amplitude (m s⁻¹) of the yearly wave in the zonal geostrophic wind at sea level along 30° E and 165° W in five single years. (B) Meridional vertical section of the amplitude (m s⁻¹) of the yearly wave in the zonally averaged geostrophic wind in eight single years.

occurred randomly from one year to another. The size of the summer maximum near 50° S and the winter maximum at higher latitudes is thus far from being as stable in the zonal means of single years as is that of the summer maximum in the tropics and the winter maximum in the subtropics.

4. Conclusion

North of about 40° S, and in the South Atlantic Ocean at all latitudes, the mean yearly wave in the pressure at sea level reaches its maximum in the southern winter. Elsewhere, its phase varies over short distances, apart from the wide summer maximum in the westerlies of the South Pacific Ocean. As noted by others (e.g., Hofmeyr, 1957), the mean yearly pressure wave is small in the Antarctic, and it does not have a winter maximum. The highly variable phase of the wave in middle and high latitudes from one year to another is responsible for the small mean amplitude. In single years, large amplitudes occur in these regions; in FGGE, for instance, the amplitude was large along most of the Antarctic coast (Fig. 2D), with a summer maximum; in places it was four times the long-term mean. This was due to the unusually low pressure in Antarctica in the winter of 1979 (van Loon and Rogers, 1981).

The yearly wave in the wind is strongest at lower latitudes where there are maximum westerlies/minimum easterlies in summer in the tropics and maximum westerlies/minimum easterlies in winter in the subtropics. In contrast to the northern hemisphere, the westerlies near 50° S reach their maximum in summer within the yearly wave. Over the region which is covered with pack ice in winter, the wave has maximum westerlies/minimum easterlies in winter.

Just as the pressure wave, the yearly wave in the wind has a large interannual variation. North of 40° S where the phase is fairly constant from one year to another, the peaks and valleys of the wave in the zonal average are in the same latitude every year (Fig. 5B), but to the south the distribution of the extremes is disorderly. Over most of this region the half-yearly wave plays an extraordinarily large rôle, which we have described in a previous paper (van Loon and Rogers, 1984).

5. Acknowledgement

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