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SEASONAL AND INTRA-SEASONAL FLUCTUATIONS OF POLAR ANTICYCLONE AND CIRCUMPOLAR VORTEX OVER ANTARCTICA

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Abstract: Fluctuations of the polar anticyclone at sea level and the circumpolar vortex at 500 mb are examined by using daily sea level and 500-mb weather maps of 1983. In addition to the seasonal cycle, a remarkable intra-seasonal fluctuation with the period of about 30 days is noticed in the intensity of polar anticyclone and in the circumpolar vortex. It is also noticed that in the seasonal time scale the intensity of polar anticyclone and circumpolar vortex shows a positive correlation while in the intra-seasonal time scale these two are negatively correlated.

1. Introduction

In the sea level weather maps of the Southern Hemisphere, there is a quasi-stationary anticyclone over Antarctica called the polar anticyclone. Occasionally, this anticyclone is split into some pieces over the Antarctic Continent, or is extented over the Antarctic Ocean. The polar anticyclone seems to be closely connected with the variations of the circumpolar vortex at middle or upper levels of the troposphere. It has been speculated that when the westerly flow around the vortex is zonally-oriented, the cold surge from the polar anticyclone toward lower latitudes is weak. But the heat exchange between the high and the low latitudes takes place on a large scale when the polar anticyclone links up with the middle-latitude high pressure belt associated with the meridionally-meandering upper westerly flow (MORITA, 1971).

In the larger time-scale, the fluctuations of the polar anticyclone may be controlled by the Antarctic ice sheet and the sea ice extent, which may be associated with the hemispheric-scale or global-scale climate change (KATO and HIGUCHI, 1979).

In this study, to understand the relations between the fluctuation of the polar anticyclone of surface level and that of the circumpolar vortex at 500-mb level in the daily and intra-seasonal time scale, the time series of the sea level pressure and the 500-mb geopotential height over the Antarctic region are analyzed.

2. Data and Method of Analysis

The data used in this study are daily sea level weather maps and 500-mb weather maps of the Southern Hemisphere at 1200 GMT during 1983 adopted from Daily Global

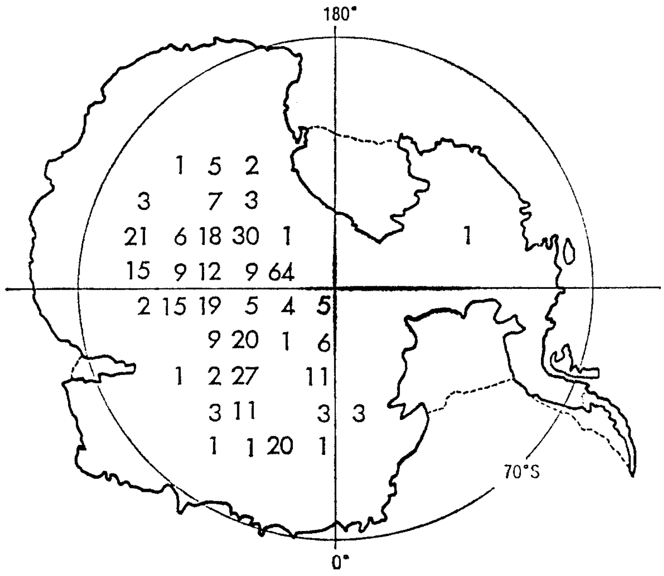


Fig. 1. Frequency distribution of center of the polar anticyclone.

Analysis from European Centre for Medium Range Weather Forecast (ECMWF).

Polar anticyclone is defined as the anticyclone whose center exists over Antarctica in the sea level weather map. If more than one anticyclones exist over Antarctica at the same time, the anticyclone which has the maximum central pressure is defined as the polar anticyclone.

The zonal mean 500-mb height (average of 18 grid points) along 70°S is used as the index of the circumpolar vortex, since Antarctica is almost enclosed by this latitude and the migrating polar anticyclone is always located inside this latitude circle (Fig. 1). When the zonal mean height decreases (increases), the circumpolar vortex is defined to be intensified (weakened).

Harmonic wave analysis was also applied to the 500-mb height along 70°S, to examine the fluctuation of the ultra-long waves and their association with the circumpolar vortex intensity.

3. The Fluctuation of Polar Anticyclone and Circumpolar Vortex

The time series of the central pressure of polar anticyclone is shown in Fig. 2a. Each dot denotes the daily value, and the solid line indicates smoothed values with 5-day moving average. The central pressure of the polar anticyclone increases in the winter season and decreases in the summer season as a seasonal cycle. The plateau-type (or reversed coreless-type) fluctuation is remarkably shown, probably related to the coreless-type seasonal trend of temperature over Antarctica (VAN LOON, 1967). It is interesting to note that the intra-seasonal variation whose periodicity is about 30 days is also distinct. The amplitude of this fluctuation seems to be almost as large as that of the seasonal cycle.

As an index of the circumpolar vortex over Antarctica, time series of the zonal mean height along 70°S is shown in Fig. 2b. It tends to decrease in the winter season

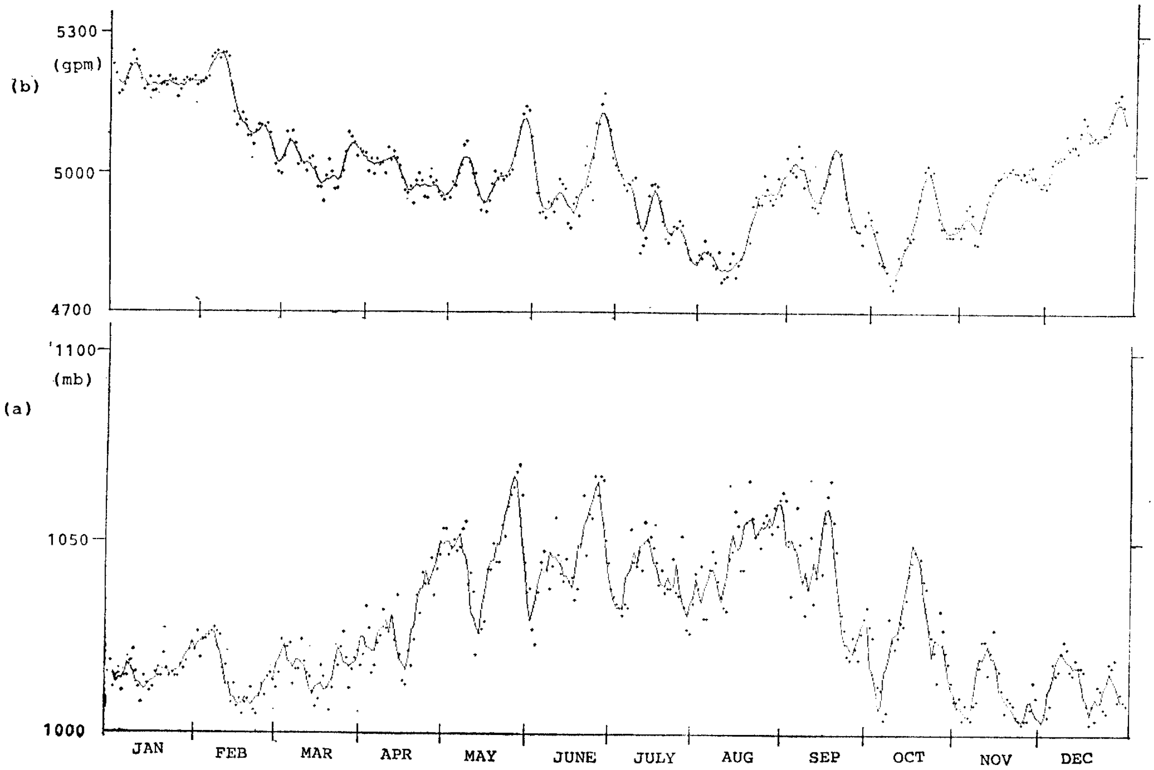


Fig. 2. Time series of (a) center pressure of polar anticyclone, and of (b) zonal mean height along 70°S. Solid line indicates smoothed value with 5-day moving average.

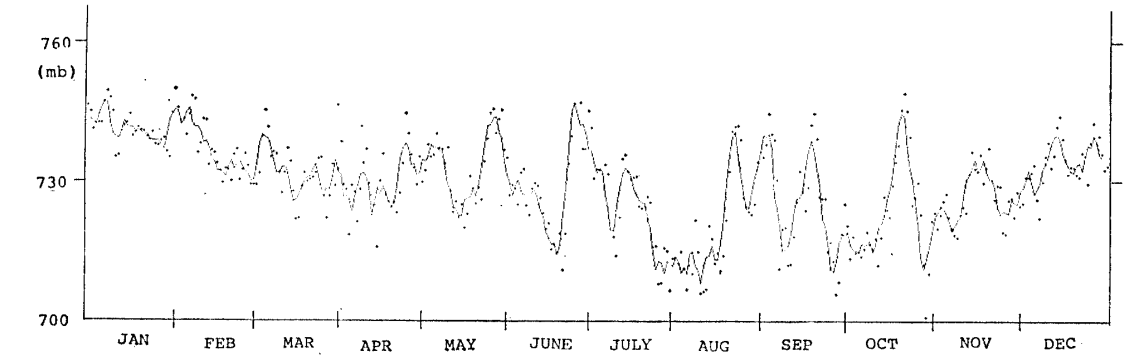


Fig. 3. Time series of surface pressure at Mizuho Station (70°42′S, 44°20′E). Solid line indicates smoothed value with 5-day moving average.

and increase in the summer season with the opposite sense to the sea level pressure (polar anticyclone intensity), but the coreless-type trend is not so prominent. It is noteworthy to state, however, that its intra-seasonal fluctuation with the period of about 30 days shows a nearly in-phase relation with that of the polar anticyclone intensity (Fig. 2a). This intra-seasonal fluctuation seems to be amplified in winter through spring (May to October).

In the intra-seasonal fluctuation with the period of about 30 days, the circumpolar vortex becomes weak (strong) when the polar anticyclone becomes strong (weak). In general, when the anticyclone in the sea level is strong (weak), the circumpolar vortex over the anticyclone is also strong (weak) as shown in the seasonal cycle.

One problem of the sea level pressure over Antarctica may be the effect of a large amount of reduction from the surface pressure over the ice sheet. To examine this problem, the polar anticyclone intensity (Fig. 2a) is compared with the surface pressure at Mizuho Station (70°42′S, 44°20′E; 2230 m height) over East Antarctica as shown in Fig. 3. Although this station is not located near the center of the anticyclone, the daily (intra-seasonal) fluctuation of the pressure is well correlated with that of the polar anticyclone intensity and the circumpolar vortex (Fig. 2b). However, the seasonal trend of the sea level is just opposite to that of surface pressure. These facts suggest that the seasonal trend of the sea level pressure is due to the seasonal change of reduction rate which is decided mainly by the mean virtual temperature. But this rule cannot be applied to intra-seasonal fluctuation. Therefore, the intra-seasonal fluctuation of the sea level (as well as the ice-sheet surface) pressure is highly coherent with that of the 500-mb height.

4. Longitude-time Section of 500-mb Height along 70°S

To examine the zonal structure of the intra-seasonal fluctuation with the period

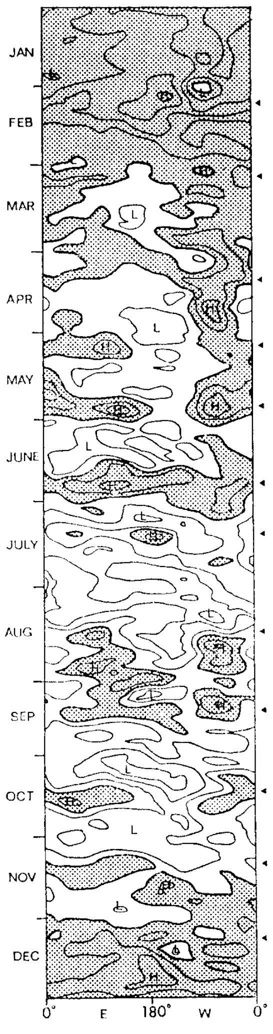


Fig. 4. Longitude-time section of 500-mb height along 70°S. Unit of contour is 100 gpm, the areas of values more than 5000 gpm are shaded. L (H) denotes minimum (maximum) height.

of about 30 days and its association with the polar anticyclone and the circumpolar vortex, the longitude-time section of 500-mb height along 70°S is produced as shown in Fig. 4.

A notable feature is a quasi-contemporaneous fluctuation of height throughout the longitudes. The eastward propagation of high and low areas is also noted, especially during February through November. The amplitude seems to increase during winter through spring and decrease during summer. It is interesting to note that the maximum stages of the polar anticyclone (as denoted with ▶ in Fig. 4) seem to correspond particularly with high values over East Antarctica. This feature is remarkably seen during winter through spring.

Thus, the fluctuation of the polar anticyclone (or circumpolar vortex) with the intra-seasonal time scale may be associated particularly with the height fluctuation over East Antarctica.

5. Harmonic Analysis of 500-mb Height along 70°S

5.1. The amplitude fluctuations

The 500-mb height at 70°S tends to change nearly simultaneously for the whole longitude belt but with some zonal asymmetry as shown in Section 4. In other words, the circumpolar vortex embeds some trough and ridge structure. It sometimes extends towards low latitudes and/or splits into some pieces. In this section, to examine the relationship between the polar anticyclone and the circumpolar vortex in more detail, harmonic analysis is applied to 500-mb height anomalies from the zonal mean along 70°S.

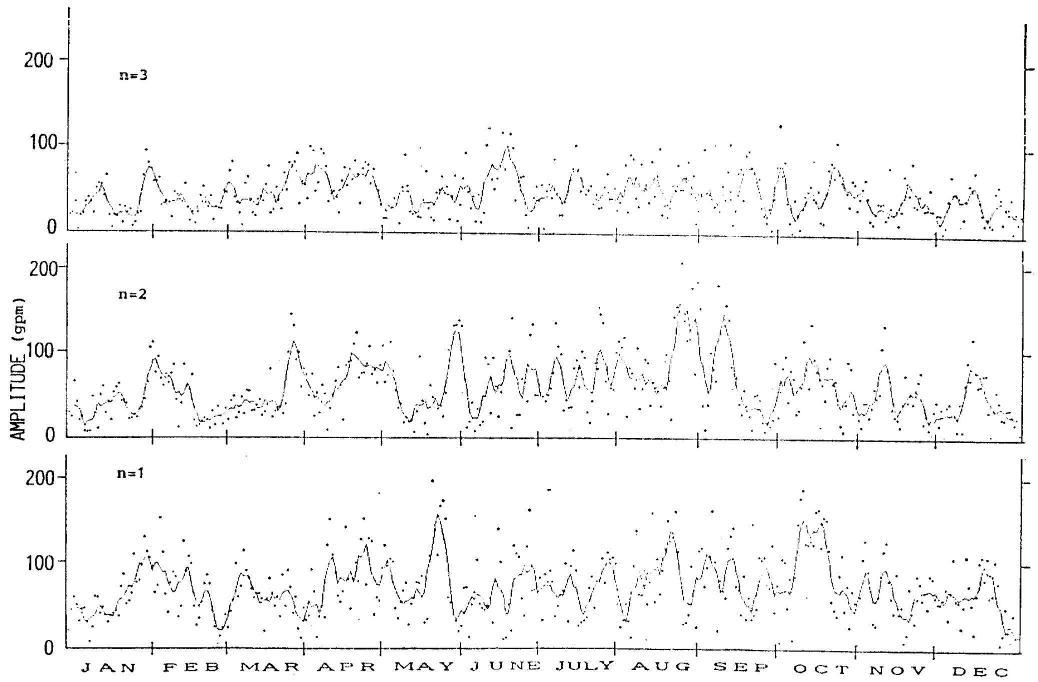


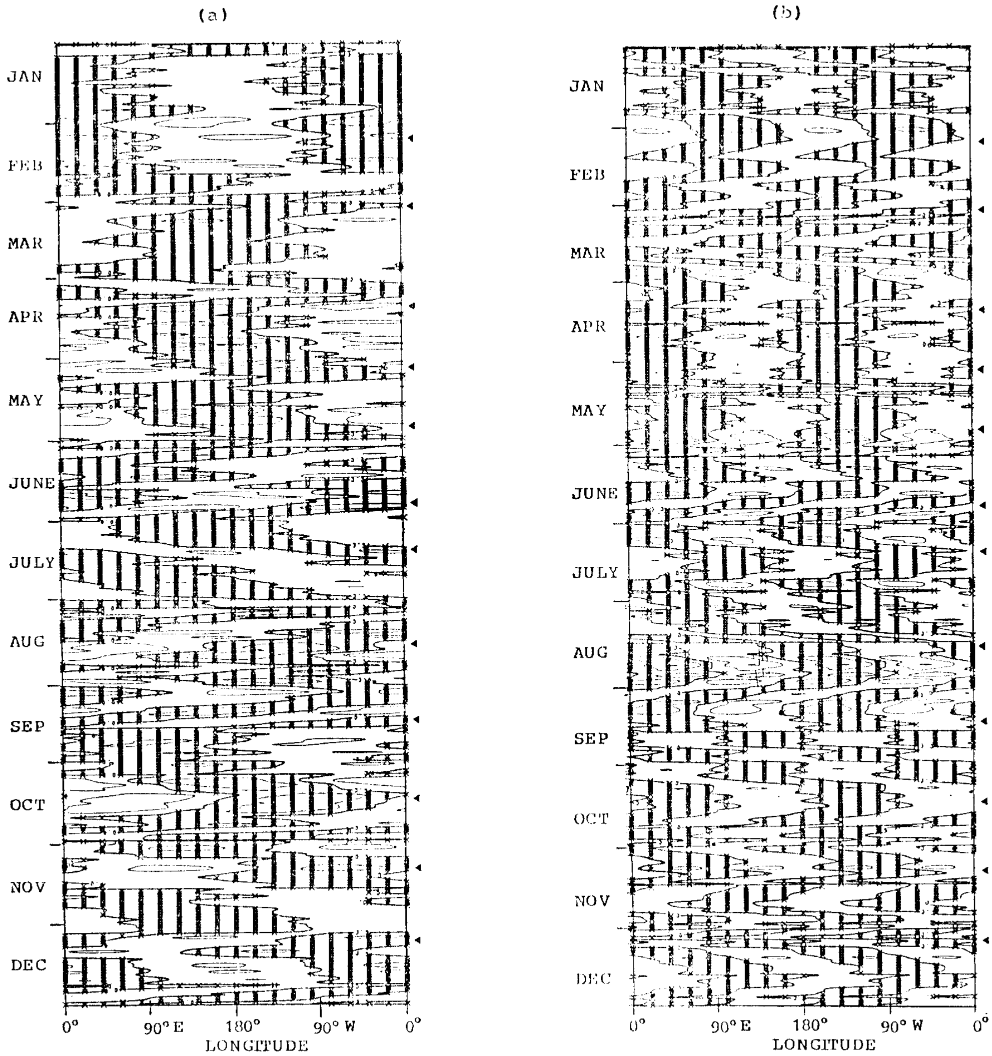
Fig. 5. Time series of the amplitude of each harmonic wave (wave number 1 to 3). Solid line indicates smoothed value with 5-day moving average.

Time series of the amplitude of each harmonic wave (wave number from 1 to 3) is shown in Fig. 5. It is noted that the amplitude of wave number 1 is correlated well to the intensity of the polar anticyclone (Fig. 2a). This implies that when the amplitude of wave number 1 is large (small), the polar anticyclone tends to be strong (weak) though the polar anticyclone is dominantly correlated to the zonal mean height (*i.e.*, wave number 0 mode of the circumpolar vortex). Wave number 2 also seems to be partly responsible for the intensity of the polar anticyclone.

5.2. Longitude-time section of each harmonic wave

To examine the zonal fluctuation of each harmonic wave, a longitude-time section of each wave is reconstructed from the phase and amplitude of each harmonic wave (Fig. 6). The areas of negative values are shaded.

The stationary parts seem to be dominant for all the three waves, particularly for wave number 3. The transient part is relatively large for wave number 1 particularly from February through November. It is interesting to note that there seems to be an abrupt phase change of the stationary part of wave number 1 in February and around



November through December. That is, during summer the ridge of wave number 1 tends to be located quasi-stationarily around 180°, but during spring through autumn it tends to be located around 0°.

Moreover, to see the relationship between the intra-seasonal fluctuation of each wave and the polar anticyclone, the maximum phase of polar anticyclone is indicated with the triangle mark (▶) in the right hand side of Fig. 6. It is noteworthy to state that when the polar anticyclone reaches its maximum the trough (ridge) of wave number 1 tends to be in West (East) Antarctica. As wave number 1 is considered to express the eccentricity of the circumpolar vortex, the circumpolar vortex seems to shift toward West (East) Antarctica when it is weak (strong).

6. Synoptic Examples of Polar Anticyclone and Circumpolar Vortex

Two extreme cases of polar anticyclone and circumpolar vortex are examined in the synoptic maps of October 4 when the central pressure of the polar anticyclone is minimum, and of October 17 when it is maximum. The difference between the two

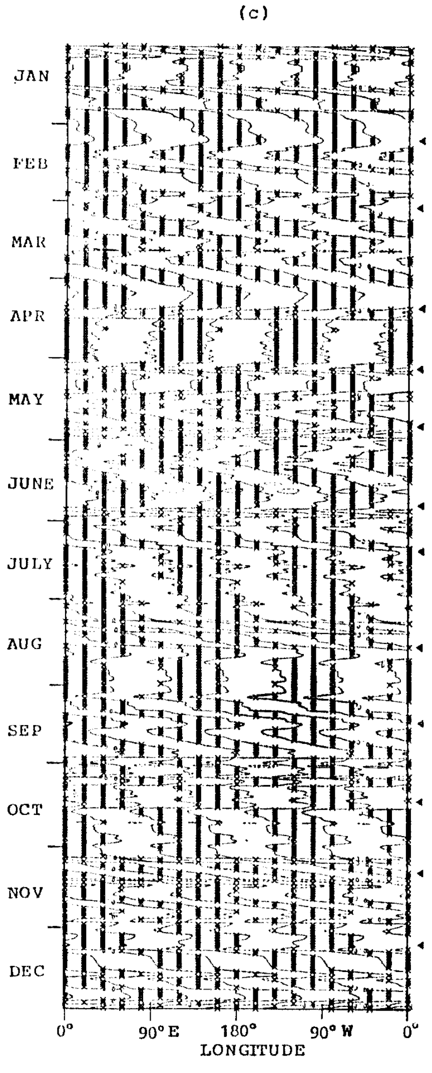


Fig. 6. Longitude-time section of harmonic wave for (a) wave number 1, (b) wave number 2 and (c) wave number 3. Unit of contour is 100 gpm and areas of negative value are shaded.

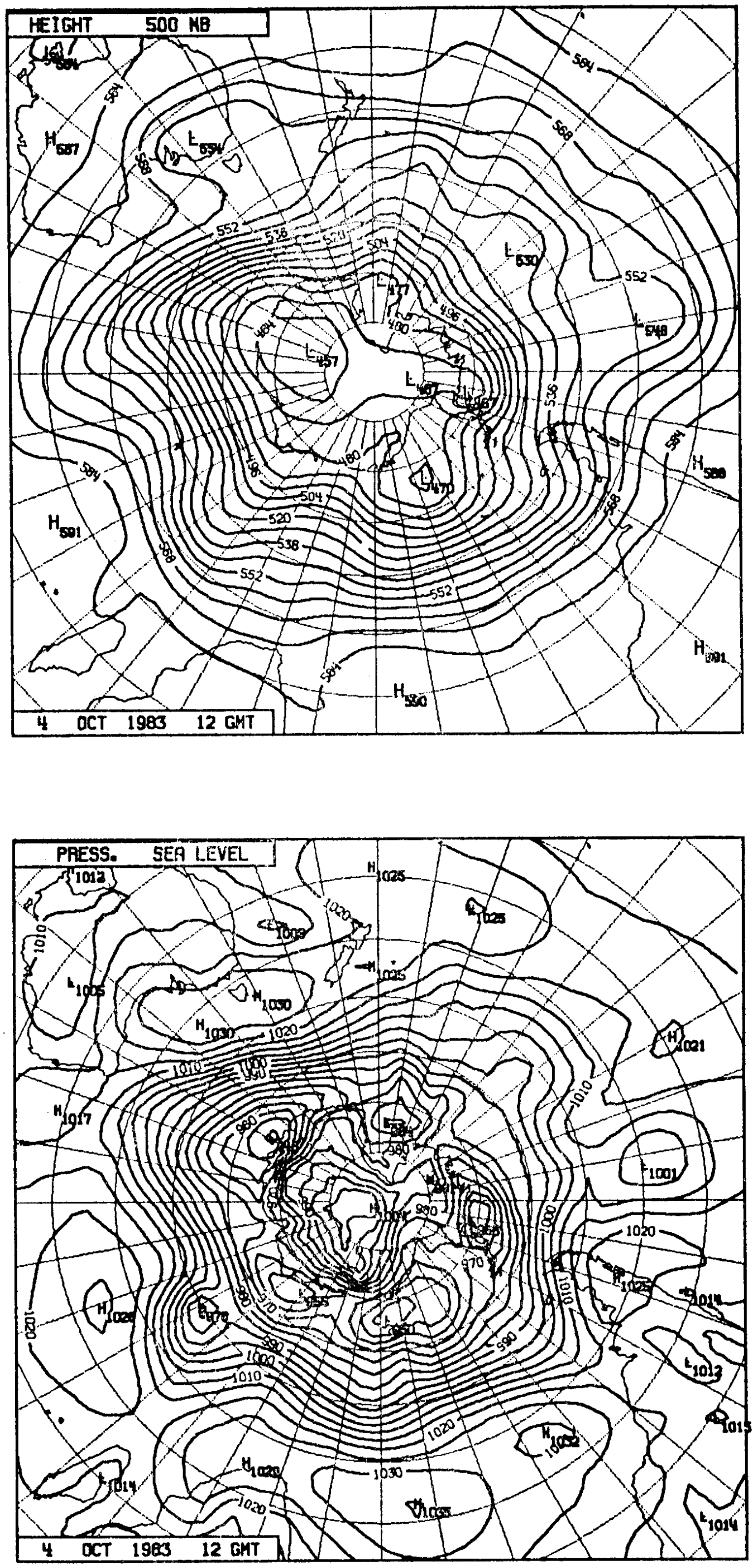


Fig. 7. *Synoptic examples of sea level and 500-mb weather map when the center pressure of the polar anticyclone is minimum (1200 GMT October 4, 1983).*

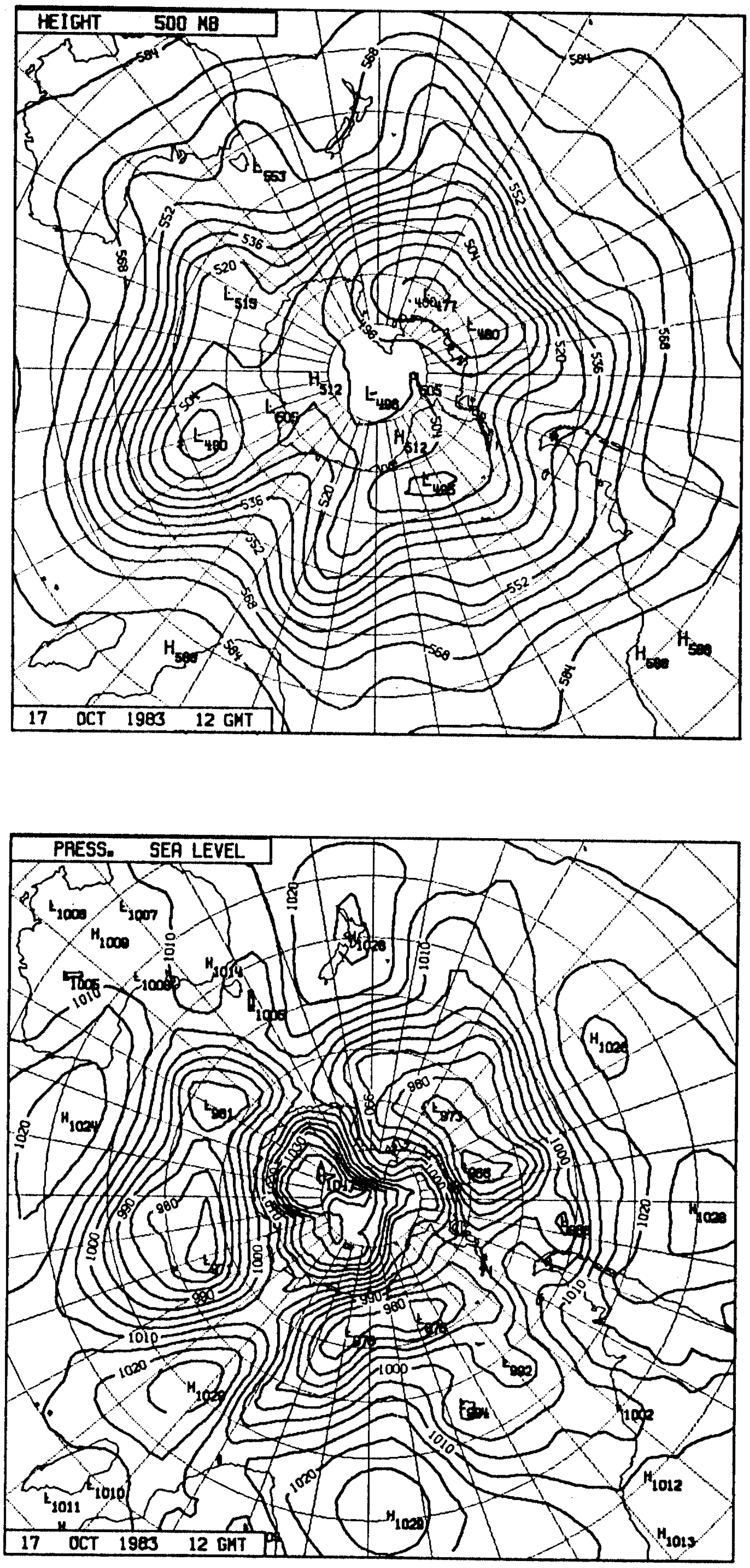


Fig. 8. Synoptic examples of sea level and 500-mb weather map when the center pressure of the polar anticyclone is maximum (1200 GMT October 17, 1983).

dates is 13 days which is almost equal to one-two of the intra-seasonal fluctuation with 30 days.

On October 4 (Fig. 7) when the central pressure of the polar anticyclone shows a minimum value (1004 mb), the center of the circumpolar vortex at 500 mb is located at about 76°S, 110°E over East Antarctica. The center of the circumpolar vortex is located nearly over the polar anticyclone.

Figure 8 shows the weather maps when the central pressure of the polar anticyclone is a maximum (1047 mb). The coastal cyclone, which moves eastward along the edge of the Antarctic Continent or rarely over it, is separated from it and shifts toward the low latitude as far as 55°S in East Antarctica. In the 500-mb weather map, the center of the circumpolar vortex is located at about 71°S, 150°W over West Antarctica.

In summary, these cases show that the circumpolar vortex is located in East Antarctica comparatively and is strong when the polar anticyclone is weak, and that the circumpolar vortex is located in West Antarctica and is weak when the polar anticyclone is strong. In addition, it is noted that the location and tracks of coastal cyclones are considerably different between the two cases.

In any case, the problem remains whether the 30-day period fluctuation of the circumpolar vortex derives its origin from the low-latitudes (MADDEN and JULIAN, 1972) or from the inherent mechanism in the polar region.

7. Conclusion

Time series analysis of the central pressure and the zonal mean 500-mb height of polar 70°S was performed respectively as the index of the polar anticyclone and circumpolar vortex over Antarctica for 1983. Harmonic analysis was also applied to the 500-mb height along 70°S. The results show the interrelations among the fluctuations of the polar anticyclone, the circumpolar vortex, and of ultra long waves along 70°S as follows:

(1) It is evidenced that in addition to the seasonal cycle there is a prominent intra-seasonal fluctuation with the period of about 30 days. This intra-seasonal fluctuation shows a negative correlation between the polar anticyclone and the circumpolar vortex, while the seasonal fluctuation shows a positive correlation between the two. It is considered that the correlation in the seasonal cycle may be related to the reduction of pressure to mean sea-level by using seasonally-varying virtual temperature.

(2) The 500-mb height of 70°S in each longitude tends to change nearly simultaneously. The zonal mean value tends to decrease when the circumpolar vortex shifts toward East Antarctica, and to increase when it shifts toward West Antarctica. This fluctuation is associated with the intra-seasonal fluctuation mentioned in (1).

(3) The ultra long waves (wave number 1–3) show nearly standing type oscillation.

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