INFLUENCE OF THE SOUTHERN HEMISPHERE CIRCULATIONS ON THE ACTIVE-BREAK CYCLE OF THE INDIAN SUMMER MONSOON

Tetsuzo YASUNARI

The Center for Southeast Asian Studies, Kyoto University, 46, Shimoadachi-cho, Yoshida, Sakyo-ku, Kyoto 606

Abstract: During the northern summer monsoon period, the cloudiness fluctuation over and around India shows a predominant periodicity of 30 to 40 days as a major active-break cycle of monsoon activity, and this fluctuation appears as a northward phase shift of maximum (or minimum) cloudiness from the equatorial Indian Ocean toward the Himalayas (T. YASUNARI: J. Meteorol. Soc. Jpn, **57**, 227, 1979; *ibid.*, **58**, 225, 1980). It has also been revealed that the northward movement of the cloudiness with this periodicity is triggered by the cold air outbreak toward the equator, associated with the large-scale westerly wave motions such as an index cycle in the Southern Hemisphere mid-latitudes (T. YASUNARI: J. Meteorol. Soc. Jpn, **59**, 336, 1981). In addition, the analysis of the temperature fluctuation at 500 mb over Syowa Station, East Antarctica, showed the dominant periodicity of the same period range (30–40 days) especially in the winter season. These results lead to a tentative idea that the major active-break cycle of Asian summer monsoon is closely linked with the hemispheric-scale wave motions in the Southern Hemisphere including the circumpolar vortex over Antarctica.

1. Introduction

Through the analyses of satellite brightness data during the northern summer monsoon period of 1973, a dominant periodicity of about 40 days was found, which is associated with the major active-break cycle of monsoon activity over and around India (YASUNARI, 1979). The year-to-year stationarity of this mode was also confirmed by using the cloudiness data from 1966 to 1972 (YASUNARI, 1980). The cloudiness fluctuation of this mode shows a distinct northward propagation from the equatorial Indian Ocean toward the Himalayan region with the phase speed of about 1° latitude/day. This feature is most remarkable over the longitudinal sector to the south of the Indian Subcontinent and the Bay of Bengal (60°E–90°E). It was also noticed that the northward movement of the maximum cloudiness is initiated by the passage and development of the equatorial disturbances which progress eastward along the equatorial Indian Ocean, and that the development of these disturbances is triggered by the passage of the cold fronts and/or the penetration of cold air from

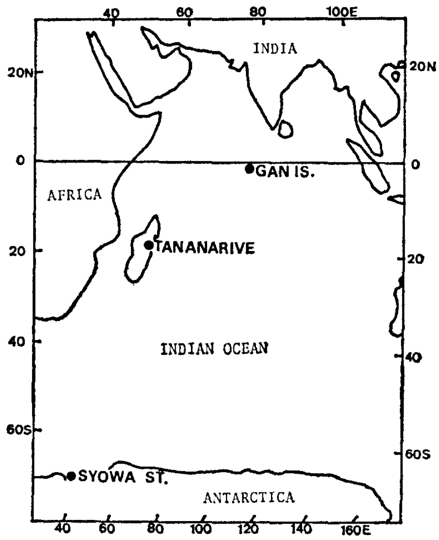


Fig. 1. The area for the analysis. The aerological stations used in the present analysis are also shown.

the Southern Hemisphere toward the equator (YASUNARI, 1981). In this paper, a preliminary analysis is made on the influence of the middle- and high-latitude circulations over the ocean in the Southern Hemisphere on the major active-break cycle of monsoon activity over and around India. The area for the analysis is shown in Fig. 1.

2. Analysis of the Southern Hemisphere Circulation over the Indian Ocean

The time-latitude section of the filtered cloudiness with about 40-day period along the longitudinal sector of India through the Bay of Bengal (70°E–90°E) is shown in Fig. 2. It is of interest to note that the maximum (or minimum) cloudiness over the equatorial zone occurs in phase with the maximum (or minimum) cloudiness in the Southern Hemisphere where nearly-standing oscillation is dominant over the area from the equator to 30°S. This may suggest that the formation or development of the major equatorial cloud disturbances over the Indian Ocean is closely linked with the mid-latitude westerly disturbances or fronts in the Southern Hemisphere which affect even the equatorial zone.

To verify the influence of the Southern Hemisphere circulation on the equatorial disturbances, the time series of some elements over Gan Island (0°41′S, 73°09′E) near the equator and over Tananarive (18°54′S, 47°32′E) in Madagascar Island were examined. Fig. 3 shows that the maximum cloudiness (associated with the eastward moving disturbances) and the maximum zonal wind cyclonic shear over the equator occur at the minimum stage of the geopotential height and temperature at 500 mb over Gan Island. The geopotential height shows nearly the same tendencies throughout the troposphere, which is also the case with southern India (not shown). In ad-

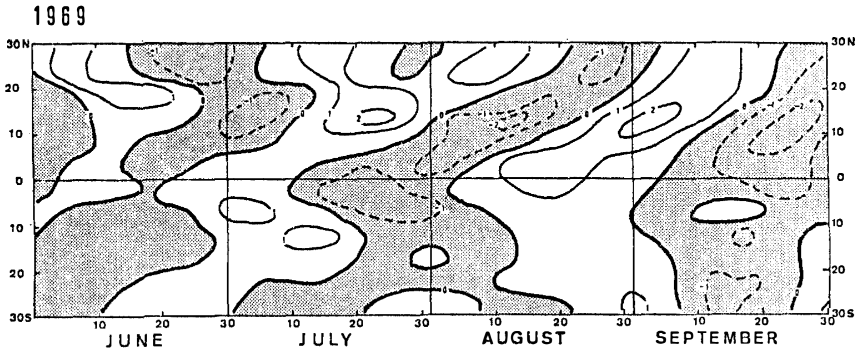


Fig. 2. Time-latitude section of filtered cloudiness for the 40-day period along the longitudinal sector of 70°–90°E. Unit of contour line is 1.0 and negative values are shaded (after YASUNARI, 1981).

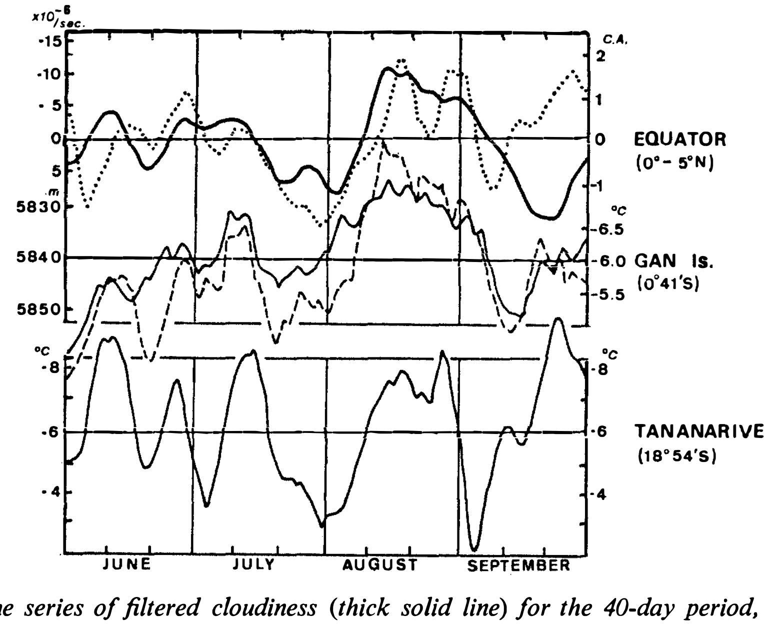


Fig. 3. Time series of filtered cloudiness (thick solid line) for the 40-day period, zonal wind shear (dotted line) over the equatorial zone (0°–5°N), temperature (solid line) and geopotential height at 500 mb (dashed line) over Gan Island, and temperature at 500 mb over Tananarive (solid line). Note that all the data except for the cloudiness are smoothed with 7-day moving average and are plotted upside down (after YASUNARI, 1981).

dition, it should be noted that the time series at 500 mb over Gan Island is highly correlated with that of the temperature over Tananarive, which has the predominant periodicity of the 40 days as shown in Fig. 4. That is, the formation or development of the major equatorial disturbances with about 40-day period seems to be triggered by the cold air penetration in the middle (and perhaps the upper) troposphere from

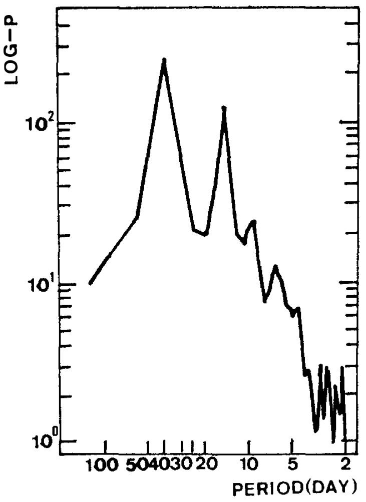


Fig. 4. *Power spectra of the temperature at 500 mb over Tananarive by using MEM method, units are* $(°C)^2 \cdot day$ *(after YASUNARI, 1981).*

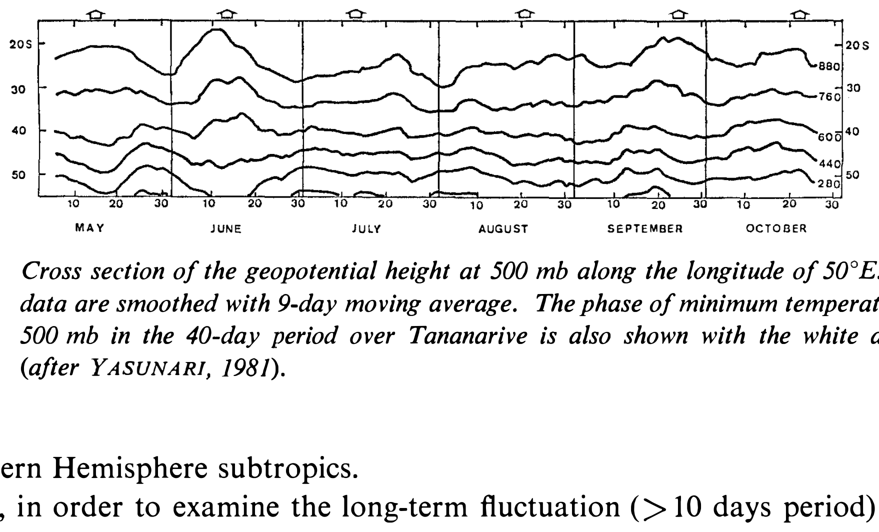


Fig. 5. *Cross section of the geopotential height at 500 mb along the longitude of 50°E. The data are smoothed with 9-day moving average. The phase of minimum temperature at 500 mb in the 40-day period over Tananarive is also shown with the white arrows (after YASUNARI, 1981).*

the Southern Hemisphere subtropics.

Here, in order to examine the long-term fluctuation ($>$10 days period) over the Indian Ocean sector, the cross section of smoothed 500 mb height for the mid-latitudes along 50°E from May to October is composed as shown in Fig. 5. The perturbation shows a distinct periodicity of 30 to 40 days especially at 20–30°S zone and the maxima of cold stage at Tananarive (shown with the white arrows in the figure) correspond well with the trough at around 20°S. It also seems that the regional index (as is supposed in the intervals of the contours between 30°S and 50°S) has the same periodicity and that the cold stage coincides with the low index phase.

The difference of the synoptic situations of the Southern Indian Ocean between the maximum cloudiness (*i.e.*, formation of cloud disturbances) and the minimum cloudiness (*i.e.*, no formation of cloud disturbances) over the equatorial zone can be seen contrastively in the satellite pictures as shown in Fig. 6. The successive 4 days during the maximum cloudiness stage (a; August 16–19, 1969) and the minimum

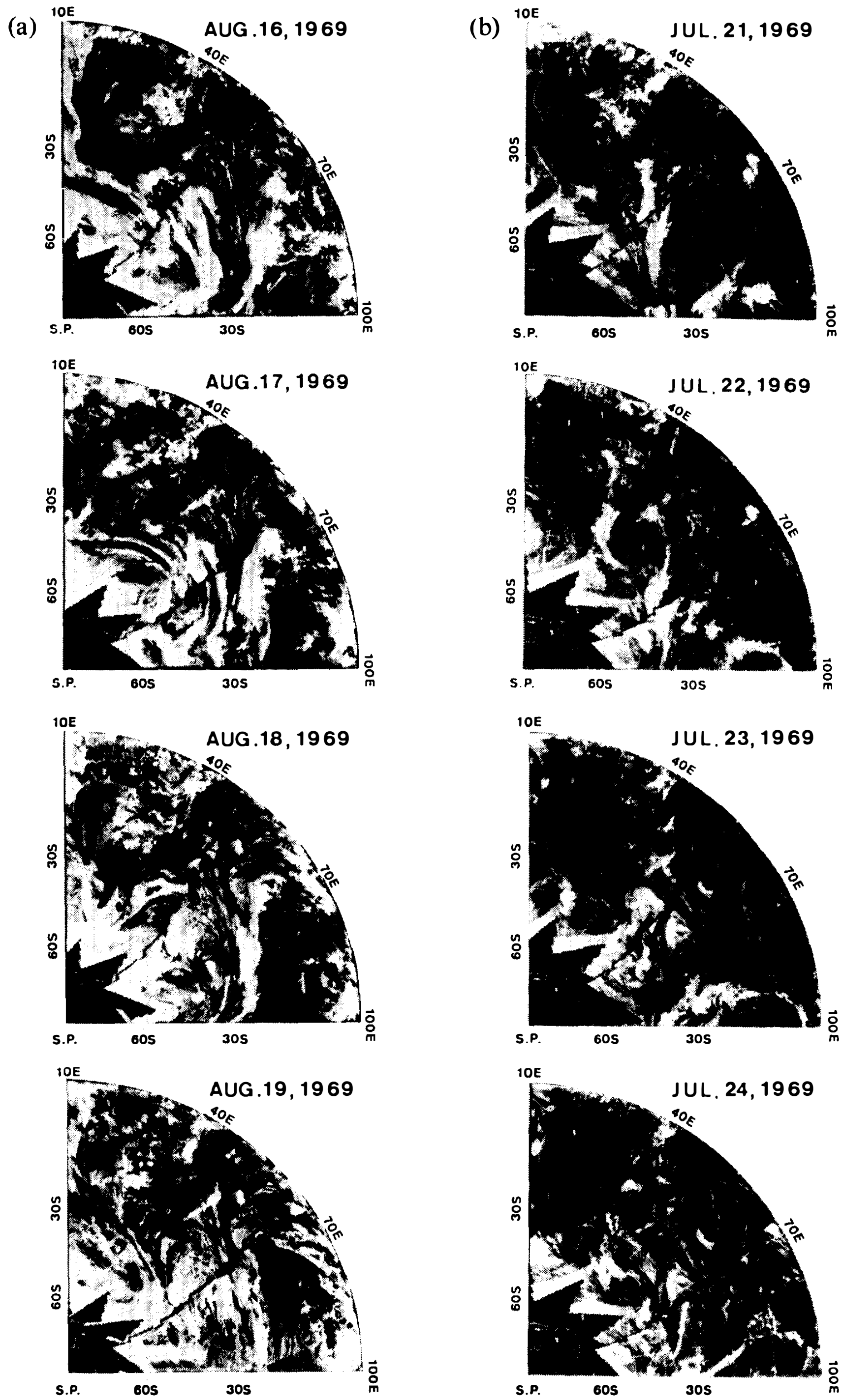


Fig. 6. Quadrant mosaic pictures (ESSA-9, visible) of the Southern Hemisphere over the Africa-Indian Ocean sector for the period of (a) the maximum cloudiness (August 16–19, 1969) and (b) the minimum cloudiness (July 21–24, 1969) over the equator (after YASUNARI, *1981).*

stage (b; July 21–24, 1969) were selected by referring to Fig. 2. In Fig. 6a cloud clusters (with the scale of 500–1000 km or more) are continuously formed or developed over the equatorial zone (0°–10°S), while in Fig. 6b cluster formation is rarely seen. It should be noted that the cold fronts (or frontal zones) are elongated toward the equator in Fig. 6a while they are relatively short and are limited in the mid-latitudes in Fig. 6b. The occurrence of cellular convective clouds is noticeable over a broad area at the back side of the fronts in Fig. 6a, but it is not seen or is limited in a small area in Fig. 6b. These features suggest that at the maximum cloudiness stage (Fig. 6a) the cold air outbreak from the polar region toward the tropics is remarkable associated with the extended trough of the westerly waves, while at the minimum stage (Fig. 6b) the cold air mass is not strong and the westerly waves are confined within the mid-latitudes. In other words, the maximum cloudiness stage may correspond with the low index phase, and the minimum cloudiness stage the high index phase of the westerly waves, respectively.

The increase of convective instability by the penetration of cold air in the middle (and upper) troposphere over relatively warm and moist air may facilitate the development of disturbances. In addition, it is strongly suggested from Fig. 6a (especially from the case for August 16 and 18) that some dynamical interaction between the extended troughs (or fronts) and the equatorial waves may be important for the formation and development of disturbances. The equatorial disturbances once developed may trigger the northward shift of monsoon cloudiness during the eastward propagation along the equator, as was already discussed by YASUNARI (1981).

Although the analysis made in this section is still preliminary, it is tempting to say that the major cold air outbreak toward the lower latitudes associated with the index cycle (or vacillations) of the mid-latitudes in the Southern Hemisphere should be a pacemaker of the 40-day period in the summer monsoon activity over India and Southeast Asia. Unfortunately, only a few studies have been made on the hemispheric-scale perturbations of the Southern Hemisphere mid-latitude circulation including the consideration of time and space scales, mostly because of the insufficiency of the aerological data over the oceans. ANDERSSEN (1965) analized the long waves of wavenumber 1 to 6 by using the 500-mb geopotential data. He commented that the waves of wavenumber 1 are quasi-stationary in a rough sense but their most frequent phase velocity at 50°S is nearly 10° longitude per day. This implies that the transient part of wavenumber 1 has the inherent periodicity of 30 to 40 days. He also noticed that there is some relationship between the amplitude variation of the wavenumber 1 and the development of cut-off lows over southern Africa. KAO *et al.* (1970) made analysis of the kinetic energy of large-scale motion in wavenumber-frequency space. Though they did not stress the dominant periodicity of each wave mode, their results show that the zonal and meridional kinetic energies of the longest waves (wavenumber 1 to 3) at the higher latitude (60°S) seem to concentrate at the spectral band of 30- to 50-day period especially in the winter season. By utilizing the EOLE satellite data set, WEBSTER and KELLER (1974, 1975) found the dominant periodicity of 18–23 days in zonal indices, momentum flux and mean and perturbation kinetic energies at 200 mb level. However, their results on the wavenumber-frequency domain also suggest a longer period (30 days), especially for ultra long waves (wavenumber 1 and 2). At all events, conclusive results have not yet been obtained on the time-space characteristics of the mid-latitude circulation in the Southern Hemisphere.

3. Analysis of Temperature Field over Syowa Station

It has been suggested in the previous section that the fluctuation of the monsoon activity with the 40-day period is triggered by the cold air outbreak from the southern polar region toward the equator over the Indian Ocean sector associated with the large-scale perturbation of the Southern Hemisphere westerly waves. Since the cold air outbreak treated here may be of large scale, the fluctuation of the circumpolar vortex over and around Antarctica should be closely connected with this phenomenon. From this viewpoint, the daily fluctuations of temperature field at 500 mb over Syowa Station (69°00′S, 39°35′E) were investigated during the years from 1969 to 1975. This station may be suitable for examining the cold air outbreak from Antarctica toward the Indian Ocean. The annual course of daily temperature for

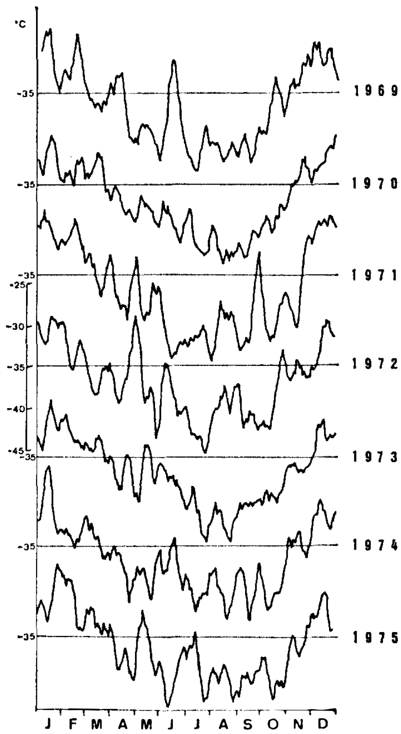


Fig. 7. Annual march of temperature at 500 mb over Syowa Station from 1969 to 1975. The data are smoothed with 11-day moving average. Scale of temperature is shown along the ordinate and the temperature of −35°C is indicated for each year.

each year is shown in Fig. 7. Since our main interest is the longer-period fluctuations than 10 days, the time series are filtered by operating 11-day moving average. In each year, a seasonal trend of gradual cooling in autumn and rapid warming in spring are apparent. These phenomena are very common in the southern polar region and were previously discussed by VAN LOON (1967). It is noteworthy that besides the seasonal trend the fluctuation of the time scale of several tens of days exists in each year with substantially large amplitudes. To examine the dominant periodicities of these fluctuations and their seasonal dependencies, the spectral analysis by the Maximum Entropy Method (MEM) was applied to the four-month data for each winter and summer season. MEM has an advantage of high resolution for short time series (*e.g.*, ULRICH and BISHOP, 1975; HINO, 1977). To eliminate the seasonal trend, the smoothed data by 90-day moving average were subtracted from the original data. The spectral distributions of winter and summer months for each year are shown in Fig. 8. In the winter months (June to September), the most prominent

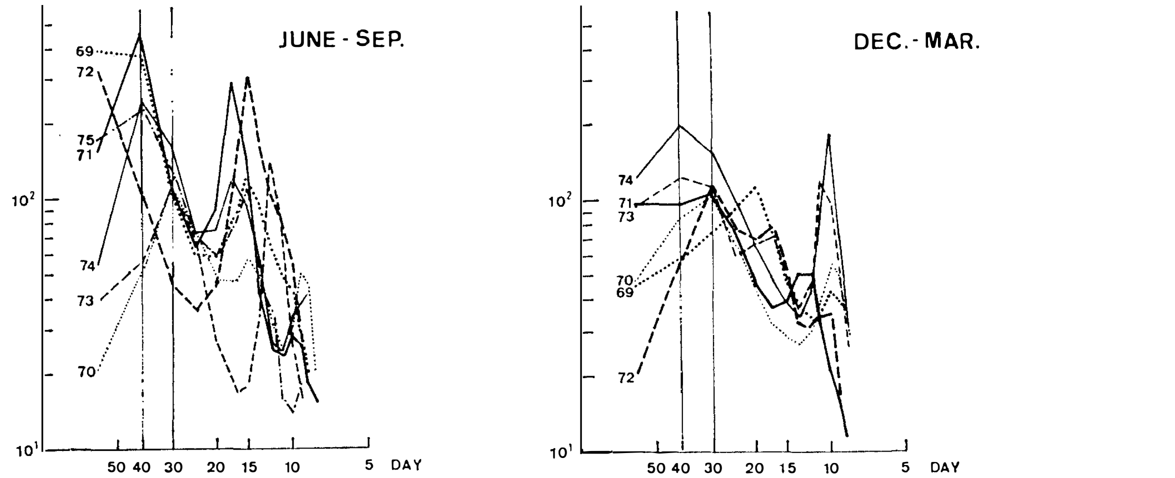
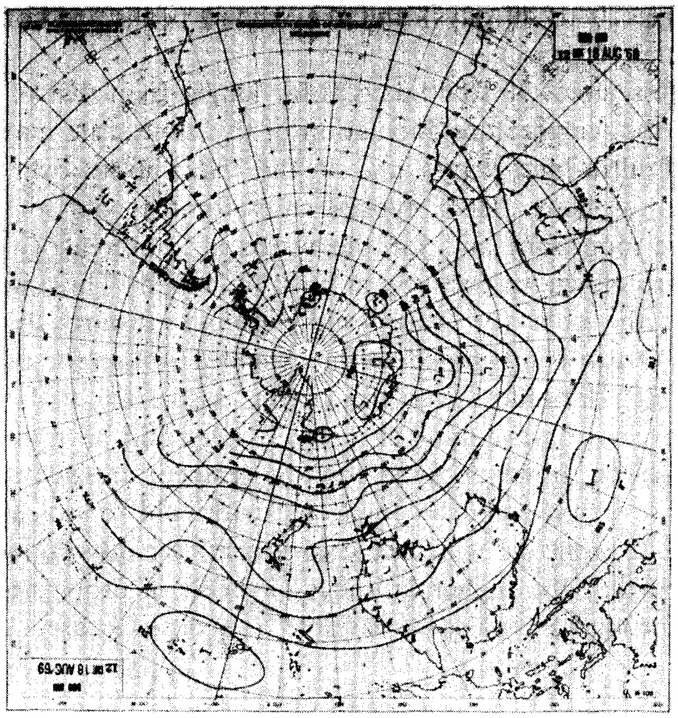


Fig. 8. Power spectra of temperature at 500 mb over Syowa Station by using MEM for the winter (June–September) and the summer (December–March) of the years from 1969 to 1975. The period range from 30 to 40 days is shown by the two solid lines. Units are (°C)^2·day.

peaks are distributed in most of the years over the period range of 30 to 40 days, and secondly at around 15 days. Uniquely in 1972 the predominant periodicity seems to shift to the period range longer than 50 days, as is obvious in Fig. 7. Interestingly, the unusual spectral feature in 1972 coincides well with that of the cloudiness over India in 1972 (YASUNARI, 1980), though more detailed analysis is necessary for determining the exact relation between these two results. In the summer months (December to March), the dominant periodicities are found in the same or a little

(a)



(b)

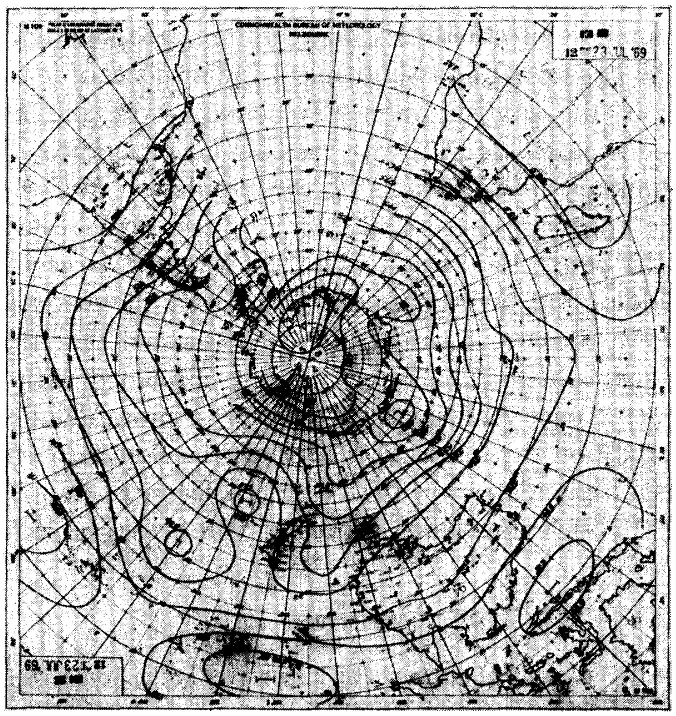


Fig. 9. 500 mb weather charts of the Southern Hemisphere for (a) the typical cold air outbreak (August 18, 1969) and (b) the typical warm air outbreak (July 23, 1969) toward the Indian Ocean.

wider period range (20 to 40 days) and the second peaks are concentrated on the period range around 10 days.

Since the time scale of 30 to 40 days is far longer than that of the normal planetary long waves, the temperature fluctuation of this time scale may correspond with the movement of ultra-long waves and/or the index cycle over and around the southern polar atmosphere. Here, typical cases for the cold air outbreak (which initiated the active monsoon) and for the warm air outbreak (which initiated the monsoon break) are shown, respectively in Figs. 9a and 9b. These weather charts (500 mb) suggest that the cold (or warm) air outbreak toward the subtropical and equatorial Indian Ocean is attributed to the extended trough (or blocking high) over the middle and high latitudes over the ocean, associated with the oscillation of the ultra-long waves (or wave-number 1 to 3) over and around Antarctica. The problem is still reserved, however, as to how the temperature fluctuation of this time scale over the polar region could be connected with cold (or warm) air penetration over the equator. In some cases, the cold (or warm) air advection from Antarctica may be confined within the higher latitudes. Process of propagation and modification of the polar air mass may also be variable from case to case.

4. Conclusion

Through the analysis of cloudiness, temperature, geopotential height and zonal wind shear over the equatorial and subtropical Indian Ocean, it is revealed that the active-break cycle of the summer monsoon activity over and around India with about 40-day period is closely related with the cold air penetration from the Southern Hemisphere. Preliminary investigations on the circulation over the southern Indian Ocean by using the upper air charts and satellite pictures suggested that the cold air outbreak toward the equatorial region is linked with the large-scale westerly wave motions in the middle- and high-latitudes. Moreover, the analysis of the temperature field over Syowa Station, East Antarctica, suggested that these wave motions are based on the hemispheric-scale wave motions combined with the oscillation of the circumpolar vortex over Antarctica. However, a more detailed analysis will be necessary for the study on the interaction between the Southern Hemisphere circulation and the monsoon circulation in the Northern Hemisphere. The complete data set of FGGE and MONEX now being processed will be desirable for this study.

References

ANDERSSEN, E. C. (1965): A study of atmospheric long waves in the Southern Hemisphere. Notos, **14**, 30–38.

HINO, M. (1977): Supekutoru kaiseki (Spectral analysis). Tokyo, Asakura Shoten, 300 p.

KAO, S. K., JENNE, R. N. and SAGENDORF, J. F. (1970): The kinetic energy of large-scale atmosphere motion in wavenumber-frequency space: II. Mid-troposphere of the Southern

Hemisphere. J. Atmos. Sci., **27**, 1008–1020.
ULRICH, T. J. and BISHOP, T. N. (1979): Maximum entropy spectral analysis and autoregressive decomposition. Pure Appl. Geophys., Spec. Issue, **115**, 1463–1491.
VAN LOON, H. (1967): The half-yearly oscillations in middle and high southern latitudes and the coreless winter. J. Atmos. Sci., **24**, 472–486.
WEBSTER, P. J. and KELLER, J. L. (1974): Strong long-period tropospheric and stratospheric rhythm in the Southern Hemisphere. Nature, **248**, 212–213.
WEBSTER, P. J. and KELLER, J. L. (1975): Atmospheric variations: Vacillations and index cycles. J. Atmos. Sci., **32**, 1283–1300.
YASUNARI, T. (1979): Cloudiness fluctuations associated with the Northern Hemisphere summer monsoon. J. Meteorol. Soc. Jpn, **57**, 227–242.
YASUNARI, T. (1980): A quasi-stationary appearance of 30 to 40 day period in the cloudiness fluctuations during the summer monsoon over India. J. Meteorol. Soc. Jpn, **58**, 225–229.
YASUNARI, T. (1981): Structure of an Indian summer monsoon system with around 40-day period. J. Meteorol. Soc. Jpn, **59**, 336–354.

(Received April 6, 1981; Revised manuscript received May 15, 1981)