THE ROLE OF TROPICAL CONVECTION IN VARIATION OF INTRASEASONAL TELECONNECTIONS OF TROPICAL AND EXTRATROPICAL CIRCULATIONS

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Received July 28, 1994; revised September 2, 1995

ABSTRACT

Based on ECMWF objective analysis data, the relationships between tropical convective activities and extratropical circulation, as well as the low frequency kinetic energy, have been investigated by making use of diagnostic analysis methods on the intraseasonal time scale in winters of 1983/1984 and 1986/1987. From this study, it is found that the different intensities of the tropical convective activities may bring about both the different intraseasonal teleconnection wave trains between the tropics and the extratropics and the different dispersions of the low frequency wave energy. Moreover, the tropical convection can be an important junction factor for the teleconnection effect of the tropical and extratropical circulations on the intraseasonal time scale.

Key words: 30—60 day low frequency domain, tropical convective activities, atmospheric circulation, low frequency kinetic energy

I. INTRODUCTION

Many modelling results indicate that interaction between the tropics and the extratropics plays an important role in the global atmosphere on the intraseasonal time scale (Lim and Chang 1983; Simmons 1982). Moreover, the relation between the extratropical circulation and the tropical convection on intraseasonal time scale was also closely studied by means of the correlative analysis skill (Liebmann and Hartmann 1984; Lau and Phillips 1986). Based on the outgoing longwave radiation (OLR) and 500 hPa geopotential height data, selecting the 10—90 day frequency band, it was found that there exists a strong effect of the extratropical disturbance on the tropical system; and a weak effect of the tropical system on the extratropical one, especially on relatively short time scale (Liebmann and Hartmann 1984). However, results described by Lau and Phillips (1986) show that there exists the coherent variation for the development of the extratropical wave trains and the tropical convection from analyzing the data in nearly the same period and taking the 20—70 day frequency band by making use of the bandpass filter. The most active tropical convective activities occur in the Indian Ocean and the Mid-Pacific regions; meanwhile, the extratropical circulations have the low frequency characteristics of three wave trains and correspondingly stationary wave guides, which are located in the extratropics. Because of the stationary characteristics of the low frequency variations of the tropical and extratropical systems, they may be considered as the normal modes in both the tropics and the extratropics, and the modes may couple with the stationary wave guides (Wang

1990).

Comparing the results of Liebmann and Hartmann and Lau and Phillips, it is found that the remarkable difference exists in intraseasonal interaction characteristics of circulations between the tropics and the extratropics. This may be caused by the different frequency bands of the data. It is a problem needing to be further explored. With regard to the important role of the 30—60 day periodic low frequency oscillation (LFO) in the global atmosphere, it is of importance to discuss the teleconnection between the tropical and the extratropical circulations on this time scale.

As described in Yu and Huang (1994), there exists a significant interaction between the tropical and the extratropical circulations on the intraseasonal time scale. Moreover, this interaction closely relates to the tropical convective activities. However, we wonder whether the interannual change of this intraseasonal interaction exists in the aspect of barotropical teleconnection. Furthermore, we wonder whether the change connects with the variation of the tropical convective activities. Meanwhile, most recent researches show that the transportation of the LFO perturbational energy is through the two dimensionally dispersive Rossby waves. Then, we may ask whether the transportation relates to the variation of the tropical convective activities. Those are also the problems needing to be explored.

The winter of 1983/1984 was in the resumed phase of the strong El Nino cycle of 1982/1983, and the winter of 1986/1987 was in the outburst phase of another El Nino cycle. From analysing the outgoing longwave radiation (OLR) data and the variation of SST in the eastern Pacific Nino 3 region, we find that there existed remarkable differences in the tropical convective activities between winters of 1983/1984 and 1986/1987 (Yu 1993). The tropical convective activities of the latter are stronger than those of the former, especially in the midwinter. Therefore, the OLR field and the 500 hPa winds and potential height data from ECMWF in the two winters are analyzed in the present study; meanwhile, the bandpass filtered skill is used to derive the 30—60 day periodic component (Krishnamurti and Gadgil 1985), and the diagnostic analysis method is employed to investigate the problems mentioned above. Moreover, the words "low frequency" used in this paper mean the "30—60 day periodic low frequency component".

II. LOW FREQUENCY RELATION BETWEEN THE TROPICAL CONVECTIVE ACTIVITIES AND THE EXTRATROPICAL STATIONARY WAVES

In order to show the relation between the extratropical stationary waves and the tropical convective activities, the correlations between the low frequency geopotential heights at every grid point in the 20—60°N zone at 500 hPa and the OLR values at every grid point in the tropical 10°S—10°N zone are calculated. In more detail, the maximum negative correlation between the geopotential height value at each grid point and the OLR field is plotted at every corresponding grid point of the geopotential heights; meanwhile, the maximum negative correlation between the OLR value at each grid point and the 500 hPa geopotential height field is plotted at the corresponding grid point of the OLR field. Figure 1 shows the correlation results from Dec. to the following Feb. in winters of 1983/1984 and 1986/1987.

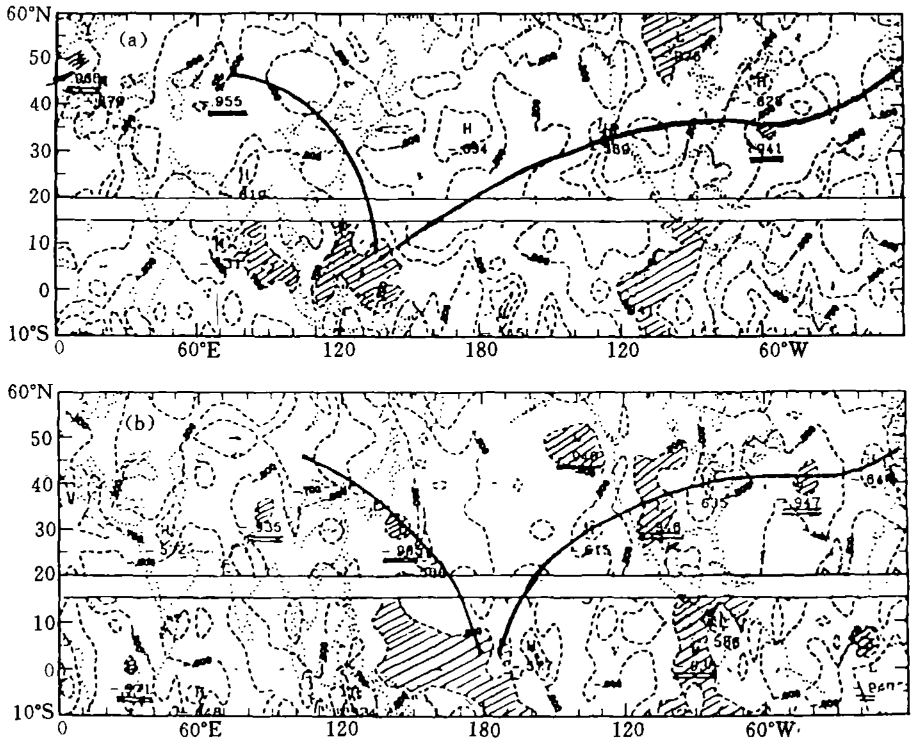

Fig. 1. The maximum negative correlation between the OLR field in the tropics and the geopotential height field at 500 hPa in the extratropics. (a) Dec. 1983 to Feb. 1984; (b) Dec. 1986 to Feb. 1987.

It can be found that there exist three pronounced wave trains in the tropics and the extratropics connected by the relatively high correlative value centres in the two winters. They are the EUP pattern from the Eurasian Continent to the Pacific Ocean, the PNA pattern from the Pacific Ocean to North America and the NA pattern in the northern Atlantic Ocean region. These results resemble to those described by Lau and Phillips (1986). Moreover, the main differences between the two winters are: (1) the more pronounced wave trains existed in the winter of 1986/1987 (Fig. 1b); (2) the maximum negative correlation in eastern Asia and the Pacific Ocean in the winter of 1986/1987 was mainly on the mid-Pacific, it was located eastwards in comparison with the maximum negative correlation on the tropical western Pacific in the winter of 1983/1984. This also relates to the distributive characteristics of the OLR field (Yu and Huang 1994).

Another feature can be seen in Fig. 1 is that the maximum negative correlative centers in the tropics are located to not only the east but also the west of the corresponding centers in the extratropics. That is to say, there exist both the meridional and zonal envelope velocities of the stationary Rossby waves. As is well known, the teleconnection mentioned above mainly means the transportation of linear Rossby waves, so the significant teleconnection in Fig. 1 indicates the interaction between the tropics and the extratropics. Moreover, the interaction in the winter of 1986/1987 was relatively strong.

III. LOW FREQUENCY RELATION BETWEEN TROPICAL CONVECTIVE ACTIVITIES AND EXTRATROPICAL CIRCULATIONS

From the preceding analyses, the tropical western Pacific 120°E and the Mid-Pacific 180°E may be considered as the typical regions of the active tropical convective activities in the winters of 1983/1984 and 1986/1987. The interaction characteristics in the two mid-winters, say Dec. to the following Feb., are studied further by means of the lag correlative skill.

Figure 2 shows the lag correlation between the low frequency geopotential height in (15—60°N) and the regional mean OLR in (10°S—10°N, 90—130°E) from Dec. 1983 to Feb. 1984. It can be seen that when the extratropical geopotential height is 6 days ahead of the tropical convective activities (denoted as Day—6), the main wave train is the EUP pattern with energy apparently propagating from the Eurasia to the western and middle Pacific. The propagation is indicated subjectively by the direction of the arrow connecting the individual centers. This wave train suggests that the energy propagate equatorwards and eastwards. In the Day—0 pattern, the EUP pattern still exists. Moreover, there appears the PNA pattern with energy propagation from Mid-Pacific to North America in the Western Hemisphere and the NA pattern in the northern Atlantic. That is to say, the energy transfers from the Mid-Pacific in the tropics, which relates to the tropical heating region, to the extratropics. After that, the anomalous wave train in the East Asia weakens and shifts eastwards, and the PNA and NA patterns turn into the dominant wave trains (see Day+6 in Fig. 2c). The feature persists till Day+12 (figure omitted). Furthermore, owing to the energy propagation from the Western to the Eastern Hemispheres through the NA pattern, the EUP pattern strengthens once again in the Eastern Hemispheres, and the PNA pattern weakens in the Western Hemisphere (see Day+16 in Fig. 2d). The Day +16 pattern is similar to that in Day—6 but with the sign reversed, meaning that that a half cycle of the phase variation of the wave trains has undergone.

Figure 3 shows the lag correlation between the low frequency geopotential height in (15—60°N) and the regional mean OLR in (10°S—10°N, 170°E—160°W) in Dec. 1986 to Feb. 1987. In Day—6, the EUP pattern is the pronounced wave train, and however, there also appears the PNA pattern in the Western Hemisphere. This differs from that in the winter of 1983/1984, although it is not so strong as the EUP pattern in the Eastern Hemisphere. After that, the wave train in the Western Hemisphere strengthens with its propagation eastwards, and the wave train in the Eastern Hemisphere weakens with its propagation eastwards (see Day 0 in Fig. 3b); meanwhile, there occurs the NA pattern in the northern Atlantic. Furthermore, the EUP pattern develops gradually with the NA pattern transferring its energy eastwards (see Fig. 3c). The Day+12 pattern is similar to that in Day—6 but with the sign reversed, meaning that a half cycle of the phase variation of the wave trains has undergone.

Results from the above-mentioned correlations between the low frequency extratropical geopotential heights and the tropical OLRs in the two winters show that there exist three pronounced wave trains from Eurasia across the Pacific to the Atlantic around the Northern Hemisphere in the intraseasonal 30—60 day periodic domain: (1) the EUP pattern, which mainly transfers energy to the maritime continent and the middle and western Pacific in the tropics; (2) the PNA pattern, which transfers energy from Mid-Pacific in the tropics to the extratropics and (3) the NA pattern, which realizes the energy transformation in the Western and the Eastern Hemispheres. Moreover, the teleconnections between the tropics and the extratropics also show their differences in the two winters. The more significant teleconnections of the wave trains appear in the winter when the tropical convective activities are relatively active. This illustrates once again that the tropical convection can be an important junction factor for the intraseasonal interaction between the tropical and the extratropical circulations (Yu 1993). Furthermore, although the wave

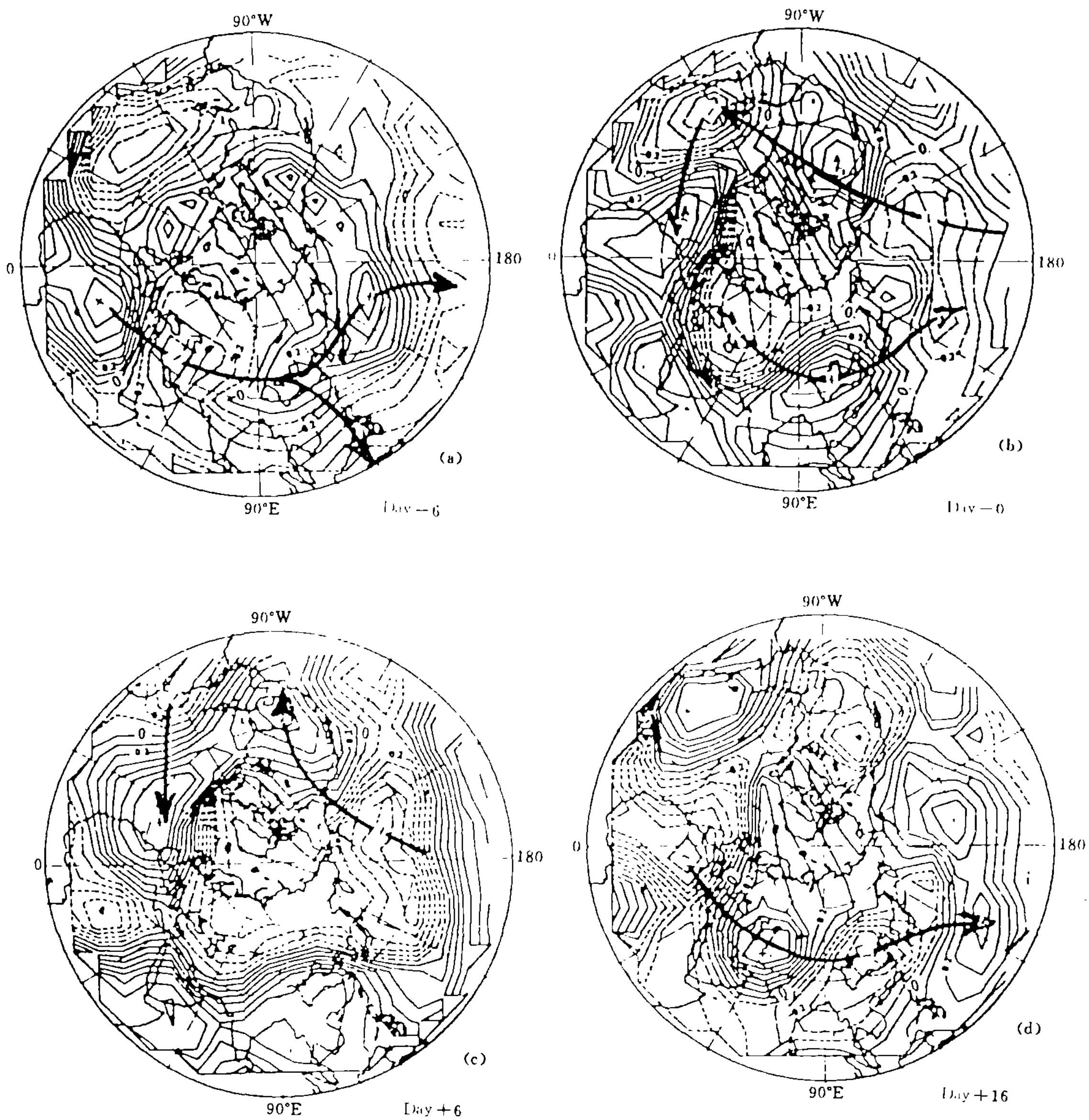

Fig. 2. The lag correlation between the low frequency geopotential height in (15—60°N) and the regional mean OLR in (10°S—10°N, 90—130°E) in Dec. 1983 to Feb. 1984.

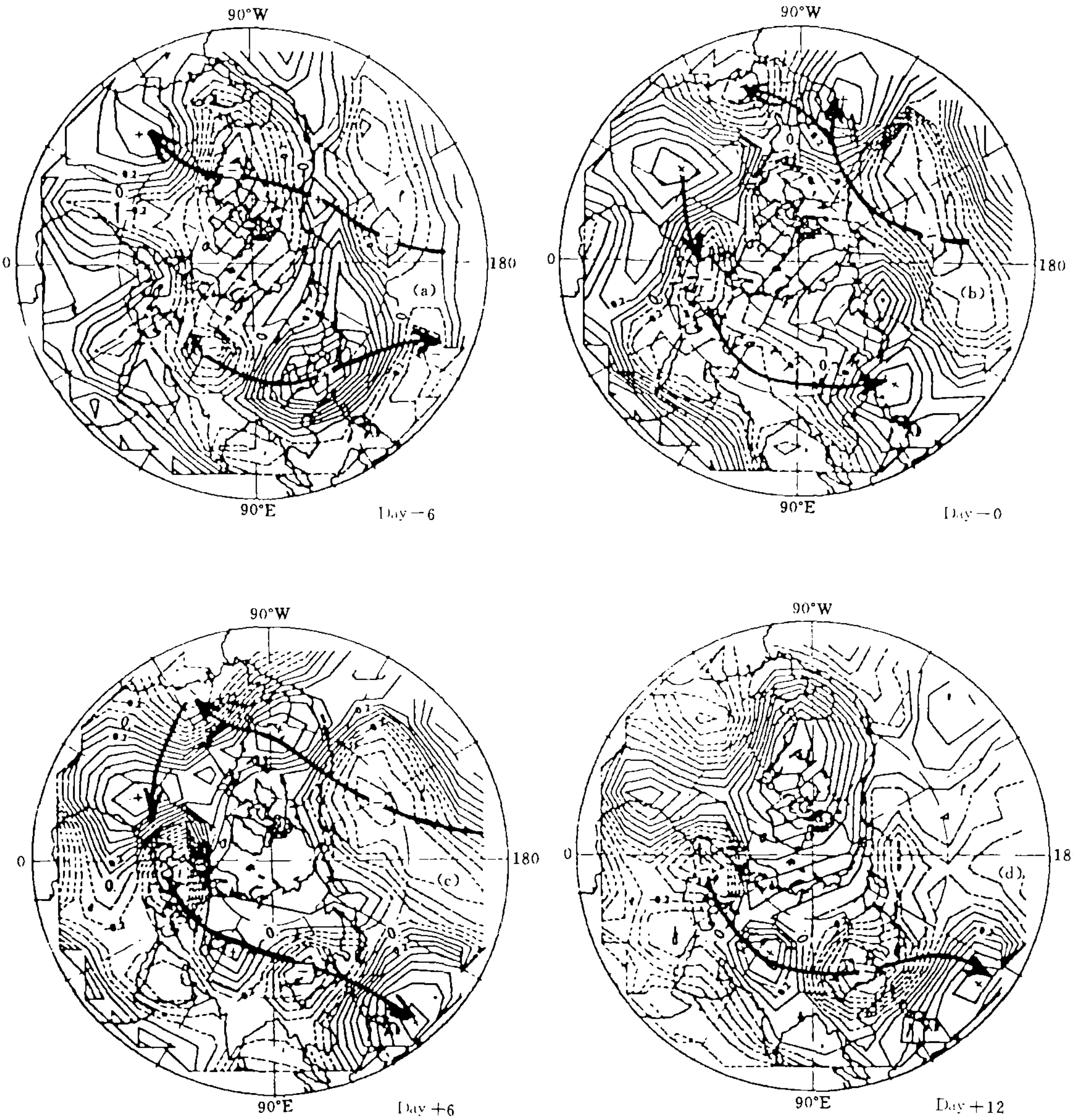

Fig. 3. As in Fig. 2, except for the regional mean OLR in (10°S—10°N, 170°E—160°W) and in the winter of 1986/1987.

energy can transfer between the tropics and the extratropics through the EUP and PNA patterns, there exists a significant break in the wave trains in Mid-Pacific in the tropics. Results from Webster and Chang (1988) indicate that the wave energy may accumulate in the tropics and disperse to the extratropics on account of the negative extension of the zonal flow along the equator. However, this result was obtained from the studies on the relatively long time scale, which did not explain the reason of the energy transformation in the equator. Therefore, a further study is needed on the "break" in the wave trains but with the energy propagation in the tropics on the intraseasonal time scale.

IV. EXPRESSION OF LOW FREQUENCY WAVE ENERGY TRANSFORMATION BETWEEN TROPICS AND EXTRATROPICS

Following Plumb (1985), the horizontal component of the effective flux of the stationary waves in the quasi-geostrophic approximation is as follows:

$$\boldsymbol{F}_S = \frac{P}{P_0}\cos\varphi\left[(V'^2 - \frac{1}{2\Omega a\sin 2\varphi}\frac{\partial(U\Phi')}{\partial\lambda})\boldsymbol{i} + (-U'V' + \frac{1}{2\Omega a\sin 2\varphi}\frac{\partial(U\Phi')}{\partial\lambda})\boldsymbol{j}\right].$$

where "′" means the deviation from the temporal and zonal means; P_0 equals 1000 hPa; a is the earth radius. The other notations are conventional. The flux $\boldsymbol{F}_S$ indicates the direction of the envelope velocity of the linear Rossby wave of the temporal mean inhomogeneous flow, which can be a useful analysis tool in investigating the effect of the temporal mean inhomogeneous disturbance and the energy propagation (Liu 1992).

Figure 4 shows the January monthly mean low frequency $\boldsymbol{F}_S$ in the winters of 1984 and 1987, when the most active tropical convective activities appeared. The maximum modes of $\boldsymbol{F}_S$ well relate to the maximum regions of the low frequency kinetic energy. It is also a reason for explaining the forming mechanism of the low frequency kinetic energy by means of the barotropic instability theory of the zonal inhomogeneous flow (Yu 1993).

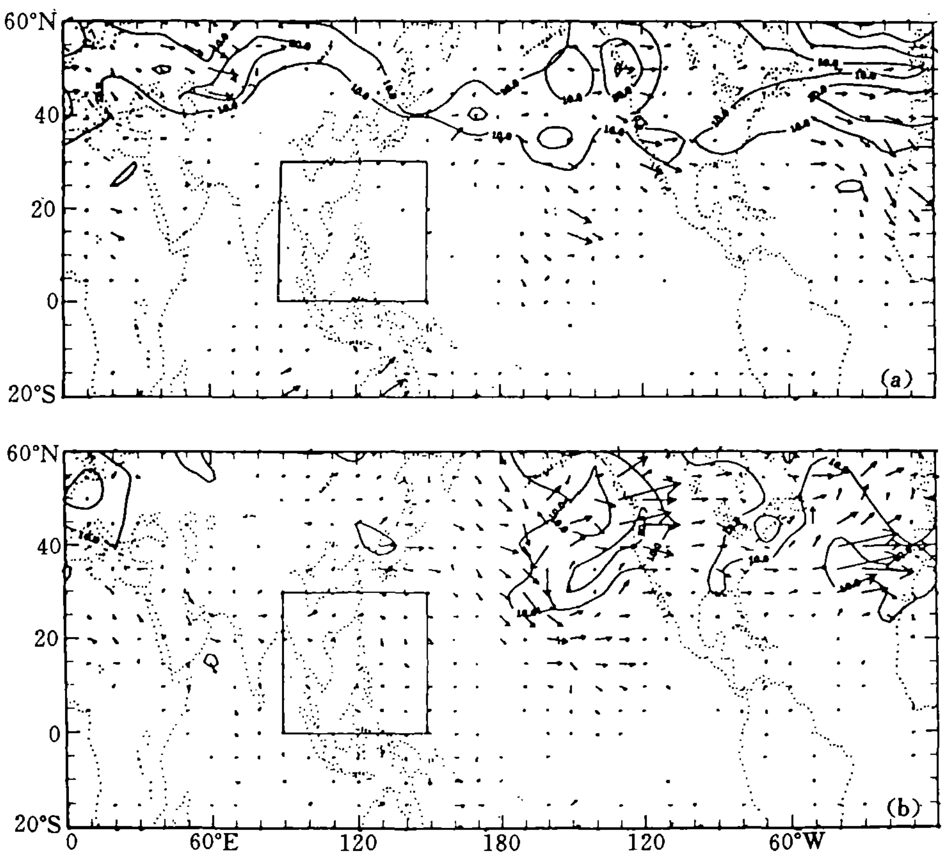

Fig. 4. Monthly mean low frequency $\boldsymbol{F}_S$ and the perturbational kinetic energy in mid-latitudes at 500 hPa, with unit in $m^{-2}s^{-2}$. (a) Jan. 1984; (b) Jan. 1987.

Moreover, the intraseasonal interaction between the tropics and the extratropics in the Pacific Ocean region is stronger in Jan. 1987 than that in Jan. 1984. This can be seen not only in the modes of the $\boldsymbol{F}_S$ in the middle and eastern Pacific, which indicate the transformations of the energy to their southeast and northeast parts, but also in the region near 150°E (the little box in Fig. 4), where the low frequency effect of the extratropics on the tropics is also stronger in Jan. 1987 (figure omitted). With regard to the result obtained from OLR analyses, it is seen that the relatively stronger interaction between the tropics and the extratropics in the winter of 1986/1987 corresponds well to the relatively stronger tropical convective activities.

V. LOW FREQUENCY RELATION BETWEEN THE CONVECTIVE ACTIVITIES IN THE TROPICS AND THE PERTURBATIONAL KINETIC ENERGY IN THE EXTRATROPICS

Similar to the analyses in Section II, Figure 5 shows the maximum negative correlation between the low frequency kinetic energy in 20—60°N zone at 500 hPa and the OLR field in 10°S—15°N.

In Yu and Huang (1994), we indicate that the maximum value centers of the low frequency kinetic energy in the extratropics were located mainly in the downstream regions of the corresponding jets in East Asia, North America and West Asia in the winters of 1983/1984 and 1986/1987. This also resembles to the results from data analyses in years 1984 and 1985 described by He et al. (1993). Moreover, it can

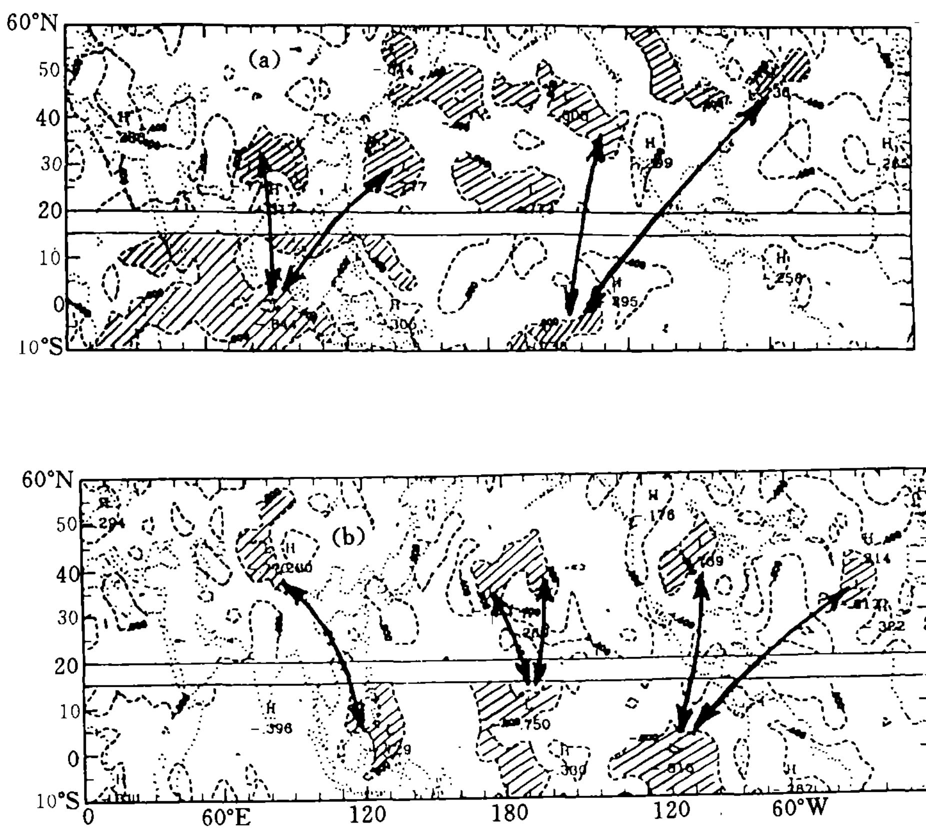

Fig. 5. The maximum negative correlation between the OLR field in the tropics and the low frequency kinetic energy field at 500 hPa in the extratropics. (a) The winter of 1983/1984; (b) the winter of 1986/1987.

be found from Fig. 5 that the maximum negative correlation centers in the extratropics correspond to the maximum value centers of the low frequency kinetic energy in the winter of 1983/1984; meanwhile, one of the main maximum negative correlation centers in the tropics is located on the Indian Ocean near 90°E, another is in 140—160°W, say the Mid-Pacific, both of them are the typical regions of the tropical convective activities. This means that there exists a relationship between the occurrence of the low frequency kinetic energy in the extratropics and the convective activities in the tropics.

The maximum value centers of the low frequency kinetic energy, which correspond to the maximum negative correlation centers, can also be found in the extratropics in the

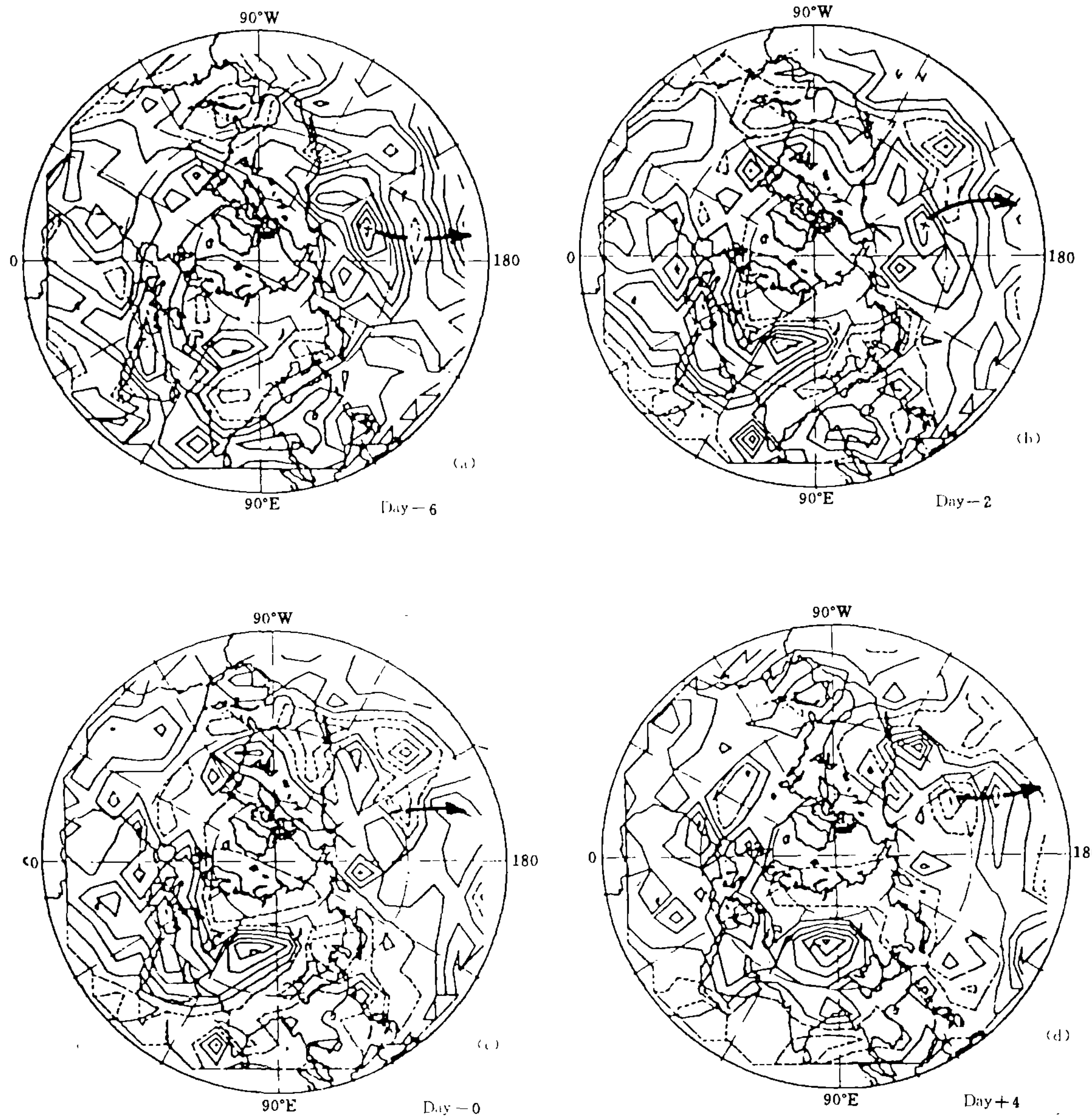

Fig. 6. As in Fig. 2, except for the low frequency kinetic energy instead of the low frequency geopotential height.

winter of 1986/1987. Meanwhile, three maximum negative correlation centers are located in the tropics, say the west, middle and east Pacific centers. In comparison with the results in the winter of 1983/1984, the maximum negative correlation centers are located eastwards in the tropics, which relate to the distribution of the tropical convective activities as shown in the OLR field. It once again indicates the close relationship between the tropical convective activities and the low frequency kinetic energy in the extratropics.

Similar to the analyses in Section III, the lag correlation between the low frequency kinetic energy in 15—60°N at 500 hPa and the regional mean OLR (similar to that in Section III) is calculated.

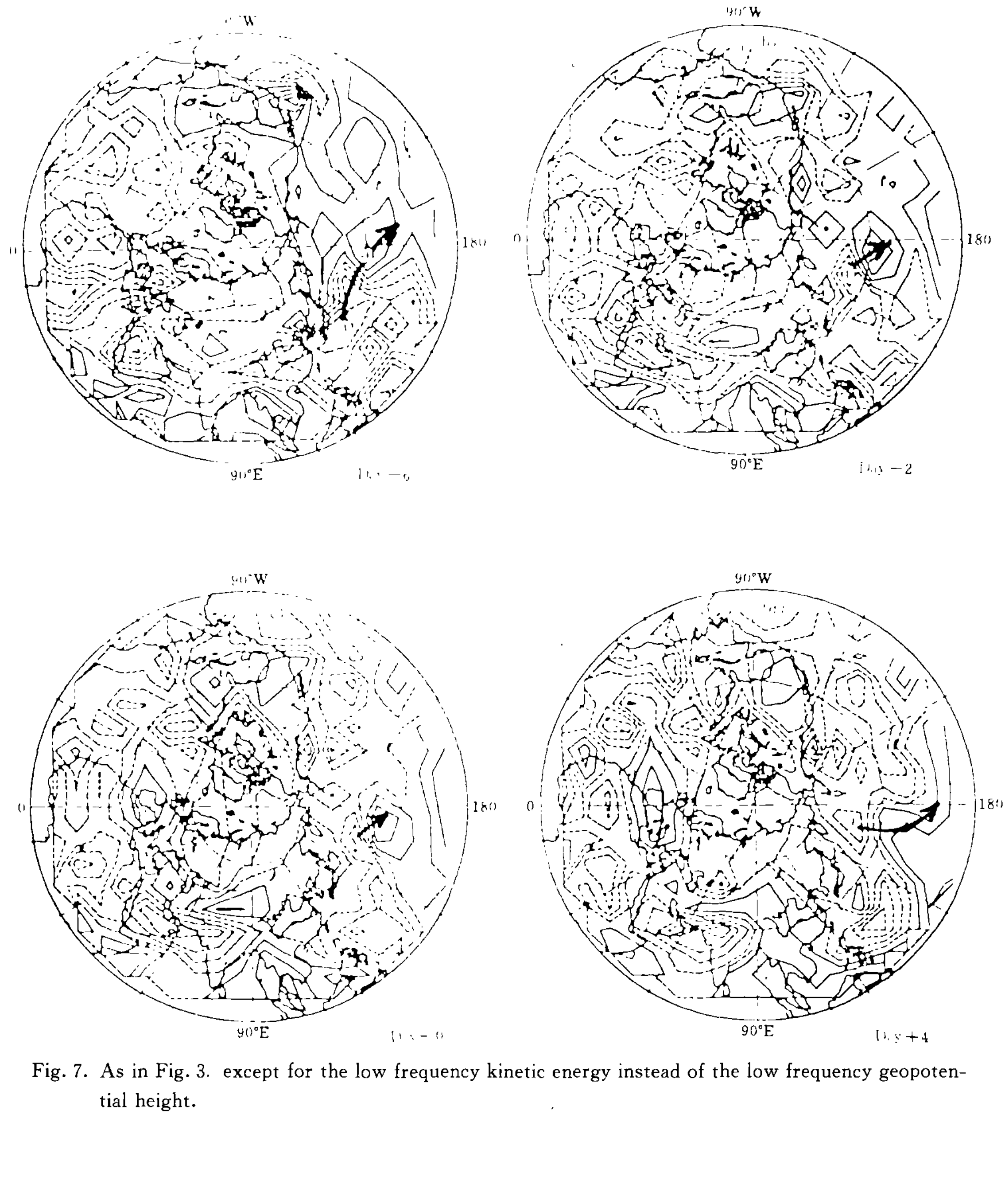

Fig. 7. As in Fig. 3. except for the low frequency kinetic energy instead of the low frequency geopotential height.

Concentrated on the eastern Asian and the Pacific regions, in the winter of 1983/1984, a pronounced meridional teleconnection wave train appears near 180° when the low frequency kinetic energy is 6 days ahead of the tropical convective activities, say Day−6. Through Day−6 to Day−0, the positive correlative center on the wave train weakens in the north of 30°N, and the negative center strengthens in 25−30°N (Figs. 6b and 6c). The Day+4 pattern is similar to that in Day−6 but with the correlative sign reversed. Moreover, the distribution variation of the wave train assumes an oscillation mode, which means that the southward propagation of the wave energy mainly assumes a fluctuation mode in East Asia and the Pacific region in the winter (Fig. 4).

Results from the winter of 1986/1987 differ from those in the winter of 1983/1984. It is seen from Fig. 7 that a zonal wave train appears in East Asia and the Pacific region in Day−6 pattern, and the positive and negative centers on the wave train are around 30°N, 180°E and 30°N, 140°E respectively. It corresponds to the result obtained from analysing the evolution of the low frequency vortex pairs in this winter (Yu 1993). After that (Figs. 7b and 7c), the wave train transfers to 180°E, with the strengthening of its meridional component; furthermore, in Day+4, there appears a meridional wave train near 180°E, which is favourable for the meridional dispersion of the wave energy. Therefore, the propagation of the wave energy from the extratropics to the tropics is stronger in this winter than that in the winter of 1983/1984 (Fig. 4).

Summing up the above results, it is evident that there exists a close relation between the tropical convective activities and the low frequency kinetic energy. Different intensities of the tropical convective activities will bring about both the different dispersion patterns from the extratropics to the tropics and the different intensities of the low frequency wave energy.

VI. CONCLUSIONS AND DISCUSSION

Results from analysing the intraseasonal teleconnection of the tropical and the extratropical circulations show that there exist three pronounced wave trains from the Eurasia across the Pacific to the Atlantic around the Northern Hemisphere: (1) the EUP pattern, which mainly transfers energy to the maritime continent and the middle and western Pacific in the tropics; (2) the PNA pattern, which transfers energy from Mid-Pacific in the tropics to the extratropics; and (3) the NA pattern, which facilitates the energy transformation in the Western and Eastern Hemispheres. These results resemble to those described by Lau Phillips (1986). Moreover, results from the present study further show that there exists a close relation between the intraseasonal teleconnection and the tropical convective activities and the relatively strong effect of the intraseasonal teleconnection corresponds to the relatively strong tropical convective activities. It once again verifies the result that the tropical convection can be an important junction factor for the intraseasonal interaction between the tropical and the extratropical circulations as mentioned in Yu and Huang (1994). Nevertheless, it is noted that the results in this paper are obtained from the analyses of only two winters. In order to get the more general results, more data need to be analysed.

Results from the study also indicate that the dispersion patterns of the low frequency energy are different in the different analysis periods. Moreover, the variation of the energy dispersion is connected with the variation of the tropical convective activities. Those differ from the modelling results of the response of the model atmosphere to the tropical forcing as described by Keshavamurty (1982) and Geisler et al. (1985) by means of GCMs.

REFERENCES

Chang, H. R. and Webster, P. J. (1990), Equatorial energy accumulation and emanation regions. Part I: Nonlinear response to strong episodic equatorial forcing, *J. Atmos. Sci.*, **47**: 2624—2644.

Geisler, J. E. et al. (1985), Sensitivity of January climate response to the magnitude and position of equatorial Pacific sea surface temperature anomalies, *J. Atmos. Sci.*, **42**: 1037—1049.

He Jinhai, Xu Jianjun and Zhang Yongxin (1993), The distribution of low frequency energy in Northern Hemisphere and its relation to the westerly jet, *J. Tropical Meteor.*, **9**: 28—35 (in Chinese).

Keshavamurty, R. N. (1982), Response of the atmosphere to sea surface temperature anomalies over the equatorial Pacific and the teleconnections of the southern oscillation , *J. Amos. Sci.*, **39**: 1241—1259.

Krishnamurti, T. N. and Gadgil, S. (1985), On the structure of the 30 to 50 day mode over the globe during FGGE, *Tellus.*, **37**: 336—360.

Lau, K. M. and Phillips, T. J. (1986), Coherent fluctuations of extratropical geophysical height and tropical convective in intraseasonal time scale, *J. Atmos. Sci.*, **43**: 1164—1181.

Li Chongyin (1991), *Atmospheric Low Frequency Oscillation*, Chinese Meteorological Press, 207pp. (in Chinese).

Liebmann, B. and Hartmann, D. L. (1984), An observational study of tropical-midlatitude interaction on intraseasonal time scale, *J. Atmos. Sci.*, **41**: 3333—3350.

Lim, H. and Chang, C. P. (1983), Dynamics of teleconnections and Walker circulations forced by equatorial heating, *J. Atmos. Sci.*, **40**: 1987—1915.

Liu Hui (1992), The maintenance of the blocking high in the Northern Hemisphere, Ph. D. Thesis, Inst. Atmos. Phys., Chinese Academy of Sciences.

Plumb, R. A. (1985), On the three-dimensional propagation of stationary waves, *J. Atmos. Sci.*, **42**: 217—229.

Simmons, A. J. (1982), The forcing of stationary wave motion by tropical diabatic heating, *Q. J. R. Met. Soc.*, **108**: 503—534.

Wang Guoming (1990), A review of researches on the variation of low frequency oscillation, *Metero. Sci. Tech.*, No. 1, 8—15.

Webster, P. J. and Chang, H. R. (1988), Equatorial energy accumulation and emanation regions: Impacts of a zonally varying basic state, *J. Atmos. Sci.*, **45**: 803—829.

Yu Bin (1993), Study of tropical-extratropical interaction on intraseasonal time scale, Ph. D. Thesis, Inst. Atmos. Phys., Chinese Academy of Sciences, 185pp.

Yu Bin and Huang Ronghui (1994), The intraseasonal interaction characteristics of the tropical and extratropical circulations: Parts: (I) and (II), *Sci. Atmos. Sin.* (to be published).