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RELATIONSHIPS BETWEEN DIFFERENT TROPICAL CONVECTIVE ACTIVITIES AND LOW FREQUENCY WAVE-MEAN FLOW INTERACTIONS

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ABSTRACT

Based on ECMWF objective analysis data, and with use of Batterworth bandpass-filtered skill and diagnostic analysis method, the interaction characteristics of low frequency wave and mean flow in mid-latitudes during the winter years of 1983 / 1984 and 1986 / 1987 have been studied in this paper. The main results point out the important role of the tropical convective activity on the above mentioned interaction process.

Key words: tropical convection activities, low-frequency fluctuation, wave-mean flow interaction

I. INTRODUCTION

Many studies have shown that the changes in tropical convective activity can bring about differences in global atmospheric teleconnection patterns (Huang, 1991). In the meantime, it also results in intraseasonal interaction between the tropical and extratropical areas (Yu and Huang, 1994a, b). Therefore, studies on the variations of the tropical convective activities and their forcing effects on the global atmospheric circulation have been an important research focus in the investigation of the variations of global atmosphere.

On the other hand, a series of studies on the atmospheric low frequency oscillation (LFO) indicate that LFO not only exists but also holds a considerable percentage in the whole layer of atmosphere (Li, 1991). For this reason, it is important to know the distribution and accumulation characteristics of the kinetic energy of LFO. Recent researches also show that there exists a certain mode of the relationship between the occurrence of the maximum value of LFO kinetic energy and the low-frequency wave-mean flow interaction (He et al., 1993). Thus the coming problems follow. How are the interannual changes of these relationships taking place? Whether or not the changes connect with the variations of the tropical convective activities? If there do exist the connection, are the effects of the variations of the tropical convective activities mainly on the intensity or on the characteristics of the low frequency wave and mean flow interactions? The study of these problems is the aim of the present research.

Ⅱ. DATA AND ANALYSIS METHOD

The winter of 1983 / 1984 is in the resumed phase of the strong El Nino cycle of years 1982 / 1983, and the winter of 1986 / 1987 is in the outburst phase of another El Nino cycle. By analysing the Outgoing Longwave Radiation (OLR) data and the variations of SST in the eastern Pacific Nino 3 region, we pointed out that there exist remarkable differences in the tropical convective activities of winter in years 1983 / 1984 and 1986 / 1987 (Yu, 1993) . The tropical convective activity of the latter is stronger than that of the former, especially in the midwinter. Therefore, the ECMWF objectively analysed data of the two winter periods are chosen for use in the present study. The time series of the data is from October to the following March, the analysed area is in the spherical zone of 60°N—30°S, with 5°× 5° in grid length. Moreover, the bandpass-filtered skill (Krishnamurti et al. , 1985) and the diagnostic analysis method are employed in this study.

Ⅲ. THE EVOLUTION CHARACTERISTICS OF THE EAST ASIAN WESTERLY JET AND THE LOW FREQUENCY KINETIC ENERGY

Analysing the evolution characteristics of the westerly jets and 30—60 day periodic low frequency perturbation kinetic energy (LKE) in the northern hemisphere in the winter of 1983 / 1984 and 1986 / 1987 it is shown that the centers of strong LKE appear with few exception in the downstream regions of the strong westerly jet centers (Yu, 1993), which is similar to the results in Li (1991) and He et al. (1993). As in Yu (1993), we further selected from the previous years of winter data two prime seasons (Jan. 1984 and Jan. 1987) with the most significant variations in the East Asian Jet and the LKE in its downstream region, and found that corresponding to the relatively weak / strong East Asian Jet in the former / latter period, there appear the maximum value centers of the relatively weak / strong LKE downstream. Furthermore, it is interesting to note that the occurrence of strong LKE occurs about 5—6 days lagging behind that of the westerly Jet center in both winters.

Results from the above case study show that there exists an important lag correlation between the East Asian Jet and the downstream LKE. Then, whether does it also exist statistically? With this question in mind, the lag correlation between the East Asian Jet and the downstream LKE is calculated for the relavant winter and the result is presented in Fig. 1.

It is obvious from Fig. 1 that the LKE is 5—6 days lagging behind the East Asian Jet in the winter of 1986 /1987 and 1983 /1984, though with a relatively weak value for the latter. This may be caused by the selection of the core of the East Asian Jet averaged in 145—155°E (similar to that in the winter of 1986 / 1987) in the calculation,

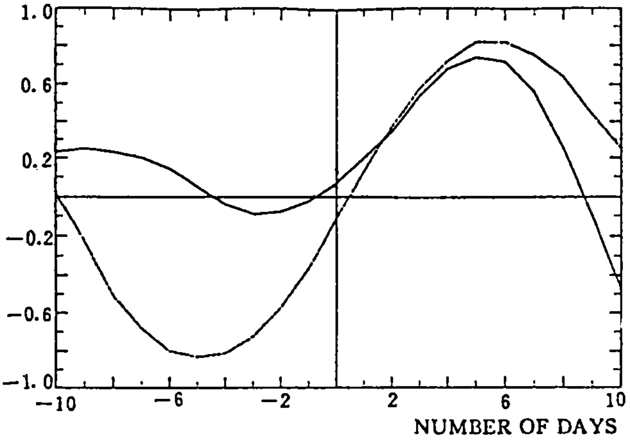

Fig. 1. The 200 hPa lag correlation between LKE high-value averaged in area (30—35°N, 140—160°W) and East Asian Jet averaged in area (30°N, 145—155°E). The solid (broken) line indicates the result in the winter of years 1983 / 1984 (1986 / 1987).

and the actual one was shifting eastward.

Ⅳ. LOW FREQUENCY WAVE ENERGY AND BAROTROPIC INSTABILITY OF ZONAL ASYMMETRIC FLOW

Simmons et al. (1982) and Hoskins et al. (1983) indicated that most of the low frequency variations of the atmospheric in the northern winter hemisphere is closely connected with the fluctuation of the energy obtained from the barotropically unstable flow. Therefore, the study of the relationship between the low frequency wave energy and the barotropic instability of the zonal asymmetric flow is of importance to further understanding of the forming of the former.

Following Simmons et al. and Hoskins et al. ,

$$\vec{E} = -\,(\overline{u'^2 - v'^2}, \overline{u'v'}) \tag{1}$$

$$\begin{aligned}\frac{\partial K_t}{\partial t} &= -\frac{\overline{u'^2 - v'^2}}{a}\left(\frac{1}{\cos\varphi}\frac{\partial \bar{u}_b}{\partial \lambda} - \bar{v}_b \mathrm{tg}\varphi\right) - \frac{\overline{u'v'}}{a}\left[\cos\varphi\frac{\partial}{\partial\varphi}\left(\frac{\bar{u}_b}{\cos\varphi}\right) + \frac{1}{\cos\varphi}\frac{\partial \bar{v}_b}{\partial \lambda}\right] \\ &\approx -\,(\overline{u'^2 - v'^2})\left(\frac{1}{\cos\varphi}\frac{\partial \bar{u}_b}{\partial \lambda}\right) - \overline{u'v'}\left(\frac{\partial \bar{u}_b}{a\partial\varphi} + \frac{\bar{u}_b \mathrm{tg}\varphi}{a}\right)\end{aligned} \tag{2}$$

$$CKX \equiv -\,(\overline{u'^2 - v'^2})\,\frac{1}{\cos\varphi}\cdot\frac{\partial \bar{u}_b}{\partial \lambda} \tag{3}$$

$$CKY \equiv -\,\overline{u'v'}\left(\frac{\partial \bar{u}_b}{a\partial\varphi} + \frac{\bar{u}_b \mathrm{tg}\varphi}{a}\right) \tag{4}$$

In the equations, u' and v' are low frequency components; "—" denotes mean over a time period; $K_E = \frac{1}{2}(\overline{u'^2} + \overline{v'^2})$ the kinetic energy of 30—60 day periodic oscillation,

$\bar{u}_b$, $\bar{v}_b$ the temporal mean zonal and meridional flows, and CKX and CKY two components of the function of the energy conversion, where the former (latter) is associated with the effect of the zonal inhomogeneity (meridional shear) of the time-mean flow.

1. *Results of Vector $\vec{E}$*

Fig. 2 is the composite results of mean $\vec{E}$ and zonal wind components for two periods of 11 days (23 Jan. —2 Feb. , 1984 and 24 Jan. —3 Feb. , 1987) centered on the day with maximal LKE values in the winter of interest. It indicates that in both corresponding periods, strong zonal winds mainly appear in East Asia, North America and West Asia, with the core of the East Asia jet being the most intense and vector $\vec{E}$ is also dominated by the zonal component in mid-latitudes, the maximal mode between the entrance of the East Asian jet and exit of the North American Jet. The direction of vector $\vec{E}$ in this area is mainly westward (There also exists the northward component in the winter period of 1984.), which means a feedback effect of the low frequency fluctuation

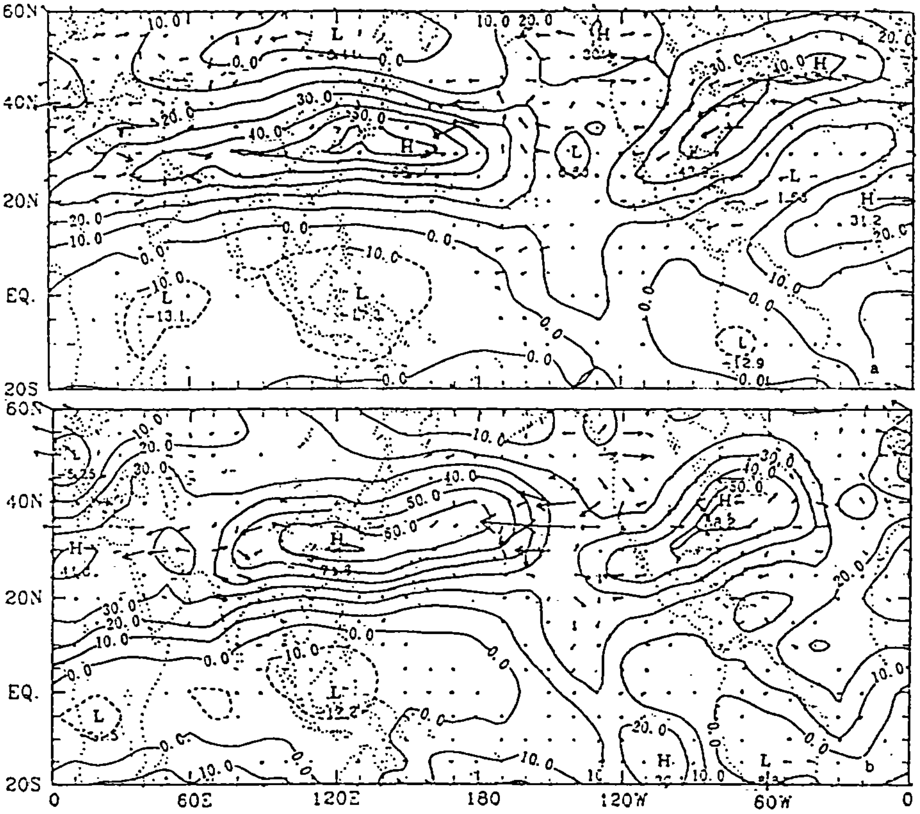

Fig. 2. Composition of zonal wind components at 200 hPa for the 11-day periods of Jan. 23—Feb. 2, 1984 (a) and Jan. 24 — Feb. 3, 1987 (b). The contour interval is 10 m·s^{-1}.

on the zonal mean flow. Moreover, in 160—180°W (see Fig. 2a) and 130—150°W (see Fig. 2b), there exist obvious meridional components of vector $\vec{E}$ pointing from mid-latitude to tropics, indicating the interaction between the tropical and extratropical atmosphere. Furthermore, the maximum mode of vector $\vec{E}$ in Fig. 2b is 223.5 $m \cdot s^{-2}$, which is about twice as much as that in Fig. 2a (108.8 $m \cdot s^{-2}$). It suggests that the interaction between the low frequency fluctuation and the zonal mean flow Jan. 24 through Feb. 3, 1987 is stronger than that Jan. 23 through Feb. 2, 1984.

Results from the monthly mean low frequency $\vec{E}$ and the zonal wind in January 1984 and January 1987 are similar to the above ones, except for the low values in the modes of $\vec{E}$ vectors.

2. *Relationship Between Low Frequency Wave Energy and Barotropic Instability of Zonal Asymmetric Flow*

Mean results of *CKX* and *CKY* in the two corresponding winter periods are discussed.

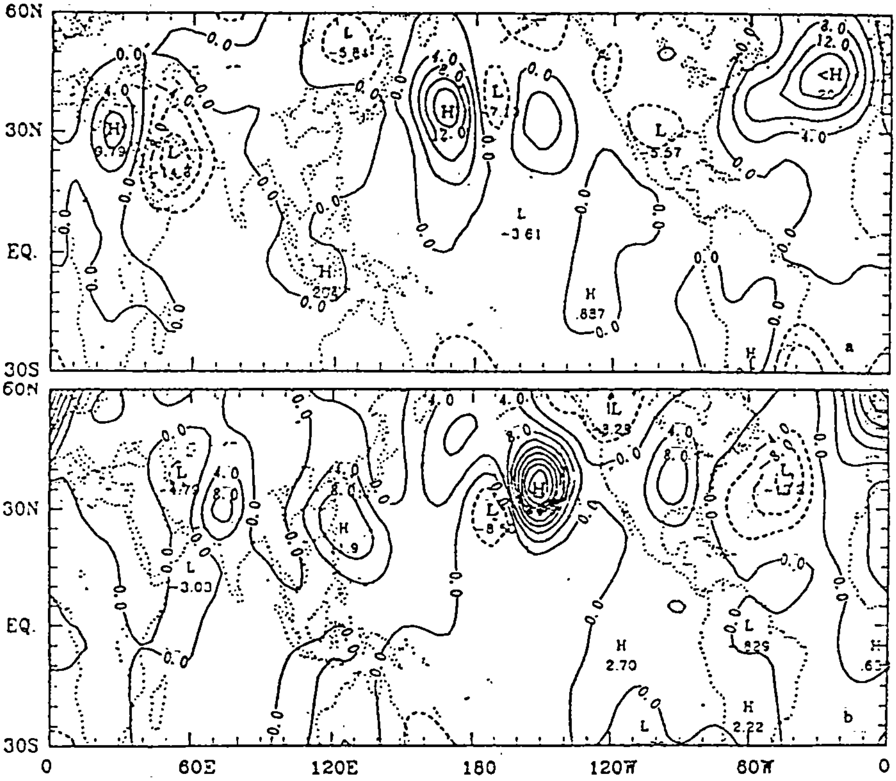

Fig. 3. Eleven-day mean low frequency conversion of barotropically unstable energy (*CKX* + *CKY*) at 200 hPa, contour spacing being $4.0 \times 10^{-4} \cdot m^2 \cdot s^{-3}$. a. Jan. 23—Feb. 2, 1984; b. Jan. 24 — Feb. 3, 1987.

Fig. 3a is the result of distribution of ($CKX + CKY$)conversion between LKE averaged over the period and the basic flow in 1984. It shows that the main energy conversion centers appear in (35 °N, 170°E), (45°N, 25°W) and (30°N, 25°E), with relatively higher values in the former two. Comparing with the above-mentioned evolution characteristics of Jets and LKEs in mid-latitude, it is interesting to find that all the positive centers of ($CKX + CKY$) are between the corresponding jets and downstream LKE. A positive conversion of energy means that low-frequency kinetic energy of perturbation gets supply from the basic flow so that barotropical instability will develop there. Thus the above results indicate that it is the mutual transformation between energy type that makes possible the conversion from the basic flow energy to low-frequency energy and further results in the formation of strong kinetic energy centers of perturbation downstream the jet areas. Further study also shows that, during this period, the energy conversion component CKY is stronger than CKX, which indicates that the energy conversion is more dependent on the barotropically unstable effect of the meridional shear of the zonal flow. This is also consistent with the results concluded in the present discussion of the evolution characteristics of the low frequency vortexes during this process (Yu, 1993).

The result for the winter period of 1986 / 1987 shows that the highest positive center of ($CKX+CKY$) is in North Pacific region (35°N, 150°W), with its value at $36.9\times10^{-4}\mathrm{m}^2\mathrm{s}^{-3}$. It is about twice as much as that of the maximum positive center in the corresponding period of 1984. Fig. 4 is the difference between them. Meanwhile, the strong positive center of ($CKX+CKY$) is also right between the corresponding jet and the LKE downstream. Moreover, the appearance of the stronger center of low-frequen-

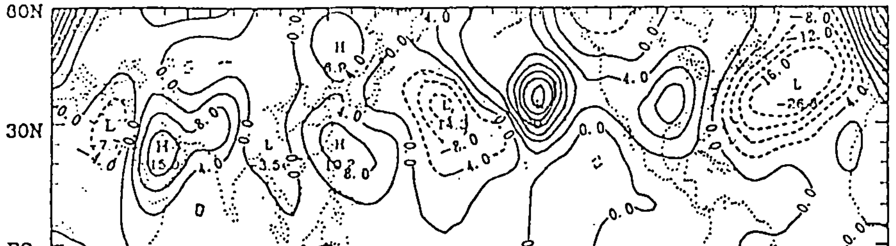

Fig. 4. Difference of low frequency conversion terms of barotropically unstable energy at 200 hPa between two 11-day periods of Jan. 24—Feb. 3,1987 and Jan. 23—Feb. 2, 1984, contour spacing being $4.0\times10^{-4}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-3}$.

cy perturbation as compared to 1984 in the period selected in the downstream of East Asia Jet also linked closely with the strong simultaneous conversion of energy (*CKX*+*CKY*) in 1987. Further research shows that the *CKX* term is the dominant factor in forming the positive center of composition (Yu, 1993), which suggests that, during Jan. 24 to Feb. 3, 1987, it is the effect of the zonally inhomogeneous time-mean flow that brought about the increase of barotropically unstable energy in North Pacific, so as to further cause the concentration of low frequency energy in the downstream region of the East Asian Jet.

Monthly results of *CKX*, *CKY* and (*CKX*+*CKY*) for Januaries 1984 and 1987 are similar to those averaged over the corresponding 11-day periods, except for low values of maxima of energy conversion for the former (as shown in Fig. 5). Meanwhile, this similarity can well explain the reason for the more stable locations of the low frequency perturbation kinetic energy in the winter of 1983 / 1984 and 1986 / 1987 as pointed out by Yu (1993). Furthermore, it once again shows the important role of the conversion of the barotropically unstable energy in the concentration of low frequency energy of perturbation.

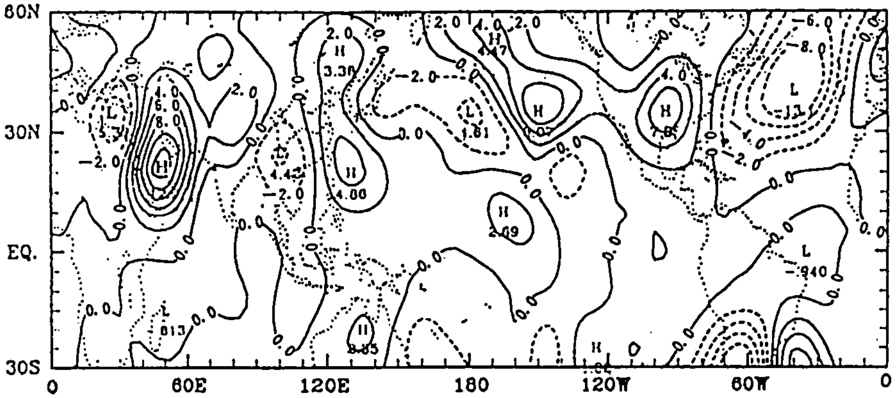

Fig. 5. Difference of monthly mean low frequency conversion of barotropically unstable energy at 200 hPa between Jan. 1987 and Jan. 1984, contour spacing being $4.0\times10^{-4}\cdot\mathrm{m}^2\cdot\mathrm{s}^{-3}$.

V. ACCELERATION OF ZONAL BASIC FLOW AND LOW FREQUENCY WAVE

Let
$$\nabla^2 S_m = -\nabla\cdot\vec{E} \tag{5}$$

Then
$$S_m = \nabla^{-2}(-\nabla\cdot\vec{E} \tag{6}$$

and
$$\frac{\partial\bar{u}}{\partial t} = \nabla\cdot\vec{E} = -\nabla^2 S_m \tag{7}$$

Therefore, the effect of disturbance on the zonal mean flow would accelarate the westerly (easterly) wind as S_m reaches its maximum (minimum) value.

It is known from Fig. 6 that S_m is situated in the North Pacific (35°N, 165°W) in the winter period of 1983 / 1984, which is also where the center (noted in the previous section) of maximum ($CKX+CKY$) is averagely located. Moreover, the two negative minimum centers at 47° N, 135°W and 35°N, 170°W, are also respectively corresponding to the two maximum value centers of low frequency kinetic energy previously discussed. Similar results can also be found in the period of winter in 1986 / 1987.

Fig. 6. Distribution of S_m at 200 hPa averaged over the corresponding 11-day periods of Jan. 23—Feb. 2, 1984 (a) and Jan. 24—Feb 3, 1987 (b), at contour intervals of $4.0\times10^6\cdot m^3\cdot s^{-2}$.

In the above-mentioned results, all of the minimum centers of S_m right correspond to the maximum centers of low frequency perturbation kinetic energy, suggesting that the westerly wind decelerates and the easterly wind accelerates there, which is also reflection of the low frequency fluctuation gaining from the westerly flow. Moreover, the maximum positive centers of S_m correspond to the maximum centers of ($CKX+CKY$) and there exist minimum centers of S_m in the upstream regions of the maximum centers of S_m, indicating that the weakened westerly Jet is favourable for the energy transformation to its downstream region, which should have caused the corrresponding westerly wind to accelerate. However, results from analyses of the evolution characteristics of the westerly wind in mid-latitude in Section 3 do not show any such acceleration. On the other hand, the downstream is where the maximum ($CKX+CKY$) occurs. Therefore, to sum up the previous results, it is just through the strong effect of the barotropically unstable energy conversion that the energy obtained from the upstream of the westerly Jet is transported to the region further downstream and cause the maximum center of low frequency perturbation kinetic energy to appear, or, the energy to concentrate.

Furthermore, another significant result is obtained by analysing S_m: The distribution characteristics of S_m in Figs. 6 and 7a are very much the same. (The similarity is found between Figs. 4 and 5.) It is indicated that the transient forcing plays an important adjusting role in the interaction between the westerly jet and low frequency kinetic energy of perturbation, so that the transformation of the energy in the upstream basic flow towards the downstream and thus the concentration of strong low frequency kinetic energy of perturbation in the downstream are made possible. In fact, the interannual difference of the transient forcing mainly brings about the difference in the intensity of the energy conversion. However, it seems much likely that the tropical convective activity, which has been stressed by us, plays an important role in forming the zonal flow in extratropical areas in the two respective years.

Fig. 7. Distribution of S_m difference at 200 hPa in two respective winter periods with contour intervals of $4.0\times10^6\cdot m^3\cdot s^{-2}$. a. 11-day mean; b. January mean.

Results from the January monthly mean of S_m are similar to that of the 11— day mean, except for the low value there. It once again verifies the conclusions mentioned above.

VI. CONCLUSIONS

Based on this study, we can conclude as follows:

a. Results from analysing the variations of westerly Jets and low frequency kinetic energy (LKE) in the winter of 1983 / 1984 and 1986 / 1987 indicate that, in spatial distribution, the strong centers of LKE mainly exist in the downstream regions of the Jets; in temporal distribution, the maximum of LKE appear about one week after the occurrence of the East Asian Jet. These results also exist in the statistical sense.

b. The variations of the intensity of tropical convective activity can result in the different intensities of the interaction between low frequency fluctuation and zonal flow in mid-latitude. Moreover, results from the frequency wave-mean flow energy conversion show that, by virtue of the low frequency wave-mean flow energy conversion, zonal flow can transfer its energy to low frequency fluctuation, thus results in the concentration of low frequency kinetic energy in the downstream region of the Jet.

c. The transient forcing plays an important adjustment role in the interaction between the westerly Jet and low frequency kinetic energy in the winter of 1983 / 1984 and 1986 / 1987. It also mainly affects the intensity of the energy conversion. However, it seems likely that the tropical convective activity plays the most important role in forming the zonal flow in extratropical areas.

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