Quasi–40–Day Oscillation and Its Teleconnection Structure together with the Possible Dependence on Conversion of Barotropic Unstable Energy of Temporal Mean Flow

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ABSTRACT

A study is made of the distribution of the diagnostic quantity vector $\vec{E}$ and the teleconnection structure of 30–50 (quasi–40) day oscillation, together with the dependence on the conversion of barotropic unstable energy of mean flow in terms of ECWMF daily 500 hPa grid data in winter, indicating that the energy transportation is closely associated with the westerly jet position, with zonal (meridional) propagation in the strong (weak) wind region, that considerable conversion of barotropic energy occurs at the jet exit region where low–frequency oscillation gains energy from the mean flow, leading to maximum kinetic energy for the oscillation observed there, which is marked by evident barotropy in striking contrast to the baroclinicity at low latitudes and that the teleconnection core is related to the center of action in the atmosphere and bound up with the pattern of the west wind.

I. INTRODUCTION

In recent years the study of the teleconnection of the atmospheric circulation and low–frequency oscillation has been a subject of much concern. By teleconnection we mean that the variation and anomaly in the circulation of a region may give rise to those in another locality. Viewed from the perspective of waves, some types of teleconnection show that a progressive wavetrain follows a specified course and possesses characteristic two–dimensional Rossby waves with the knots and anti–knots of the wave pattern at fixed geographic positions and wave dispersion in a ray way, resulting in a new set of centers formed and intensified in order at a place far away from forcing (Wallace and Blackmon, 1983). Recently, it is discovered that the oscillation displays characteristics of teleconnection train of 2D Rossby waves (Lau and Lau, 1986; Xu and Lin, 1991a) with the result that there exist two principal teleconnection patterns, i.e., EUP and PNA, which are generally related to low–frequency oscillation at mid and low latitudes (Lau and Phillips, 1986).

Evidently, the energy propagation of the oscillation plays an important role in teleconnection. The transfer is studied mainly in virtue of zonally–averaged E–P flux as the diagnostic quantity (Edmon, 1980) but the diagnosis is not so perfect because of zonal inhomogeneity of low–frequency oscillation. Hoskins et al. (1983) obtained vector $\vec{E}$ as the diagnostic quantity able to approximately characterize wave propagation on a horizontal plane under quasi–geostrophic and nondivergent condition, which may serve as an effective means to investigate the horizontal behavior of low–frequency oscillation. Simons et al. (1983) indicated that the teleconnection pattern of the atmospheric circulation is caused by barotropic instability of zonal inhomogeneous flow by the combination of teleconnection

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with time mean flow, which is used in the study of 30–50 day periodic oscillation, arriving at the conclusion that low–frequency oscillation gets developed at the jet exit region by virtue of the conversion of barotropic unstable energy of mean flow (Xu and Lin, 1991b; Xu and He, 1991).

The teleconnection structure of the oscillation at scale of 30–50 days and the teleconnection patterns of Wallace et al. (1981) have their own features and studies of the past (Xu and Lin, 1991a, b; Xu and He, 1991) treated wave propagation, teleconnection structure and conversion of barotropic unstable energy of mean flow in a separately fashion. And on this basis the author attempts to explore the inherent relation among these aspects and make further study of the problem of kinetic energy of the low–frequency oscillation for a more complete understanding of it. This work draws on the ECMWF data of the 1984 / 85 winter (November–February) with the aid of a band–pass filter.

II. THE DISTRIBUTION OF VECTOR $\vec{E}$ OF 30–50 DAY OSCILLATION AND MEAN FLOW

Following Hoskins et al., vector $\vec{E}$ can be given as

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

where u' and v' denote the transient perturbation of the related mean flow and the components of band–pass filtered low–frequency oscillation. For the filtering the reader is referred to Murakami (1979). Since the oscillation in question is marked by the quasi–geostrophy relation of large–scale motion, vector $\vec{E}$ is able to reflect the propagation characteristics. The 500–hPa level is chosen for the use in this present work.

From Fig. 1 one can see that around the center of the strong west wind, the E–W directed distribution of vector $\vec{E}$ indicates that the wave energy there is transferred in the same orientation, featured by a zonally elongated structure showing that zonal propagation is

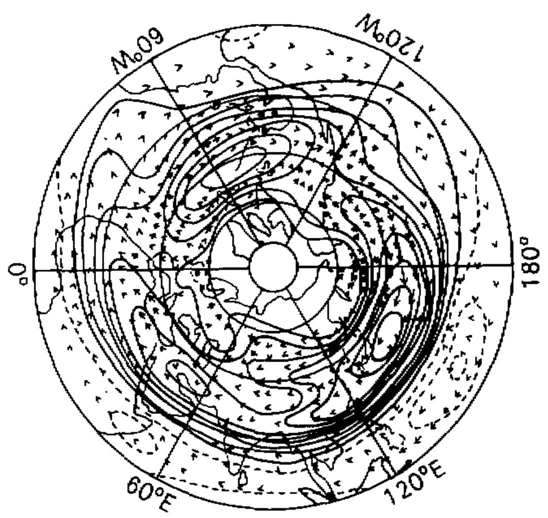

Fig. 1. Distribution of 500–hPa vector $\vec{E}$ and temporal mean flow in the 1984–85 winter (November–February). Arrowheads indicate vector $\vec{E}$ and contours the mean flow with spacing of 4 ms^{-1}.

stronger than the meridional transfer. Also, we see that in the exit region of the robust west wind over the central part of the subtropical Pacific the westward energy transportatin is most intense and the process is less strong equatorward of the exit region eastward of North America than the former. Moreover, in the break of three centers of quite robust west wind (regions of weak wind), i.e., western coastal belts of North America and the Eurasian continent, and between the Iranian Highland and the Qinghai–Xizang Plateau, an evident meridional distribution of $\vec{E}$ is observed, with wave energy coming from mid to low latitudes.

It is obvious that the transfer of low–frequency oscillation energy depends heavily in position on the temporal mean flow. It is seen that the energy goes westward along the latitude circle in the strong wind area, maximizing at the exit, a result that bears resemblance to that of Wallace and Lau (1985) regarding the propagation of waves at scale of > 10 days, and equatorward in the gaps aforementioned meaning that the mid–latitude oscillation has effect on the low–latitude counterpart.

III. RELATION BETWEEN THE BAROTROPIC UNSTABLE ENERGY OF MEAN FLOW AND KINETIC ENERGY OF LOW-FREQUENCY OSCILLATION

1. *Two–Dimensional Conversion of Barotropically Unstable Energy*

Following Simons et al. (1983), the kinetic energy of the oscillation and vector $\vec{E}$ are related as

$$\partial K_E / \partial t = \vec{E} \cdot \nabla \overline{U}_b ,$$

which, after evolution, has the form

$$\partial K_E / \partial t = (\overline{v'^2 - u'^2}) \cdot \frac{1}{a\cos\varphi} \frac{\partial \overline{U}_b}{\partial \lambda} - \overline{u'v'} \left(\frac{\partial \overline{U}_b}{a \partial \varphi} - \frac{\overline{U}_b \operatorname{tg}\varphi}{a} \right) ,$$

$$CK_x = -(\overline{u'^2 - v'^2}) \cdot \frac{1}{a\cos\varphi} \frac{\partial \overline{U}_b}{\partial \lambda} ,$$

$$CK_y = -\overline{u'v'} \left(\frac{\partial \overline{U}_b}{a \partial \varphi} + \frac{\overline{U}_b \operatorname{tg}\varphi}{a} \right) ,$$

where $K_E = \frac{1}{2}(u'^2 + v'^2)$, U_b= the temporal mean flow, a= the earth's radius, λ= the longitude, φ= the latitude, CK_x= the zonal component of the conversion (indicative of effect of zonal inhomogeneous flow) and CK_y= the related meridional component (suggestive of the barotropically unstable effect of meridional shear of the zonal flow).

Fig. 2 shows that the zonal asymmetric component of the conversion CK_x (see Fig. 2a) has two positive centers of highly appreciable conversion in the Northern Hemisphere midlatitudes, one located in the central Pacific (25–40 ° N) and the other over the western Atlantic east of North America (20–30 ° N), with the former much greater in size than the latter. Reference to Fig. 1 indicates that this center is right between the exit region of the eastern Asian strong west wind and the equatorward side of the intense wind over North America.. The meridional component of the conversion CK_y (Fig. 2b) is close to the wind axis over eastern Asia with the conversion of positive unstable energy occurring in the Aleutian region on the poleward side of the current and at the exit around the Hawaiian Islands, compared to the conversion of negative energy in the neighborhood of the exit of the strong wind (140 ° E). As to the North–American case, conversion of positive unstable energy takes place on either side of the wind axis in contrast to the conversion of negative energy in the exit region.

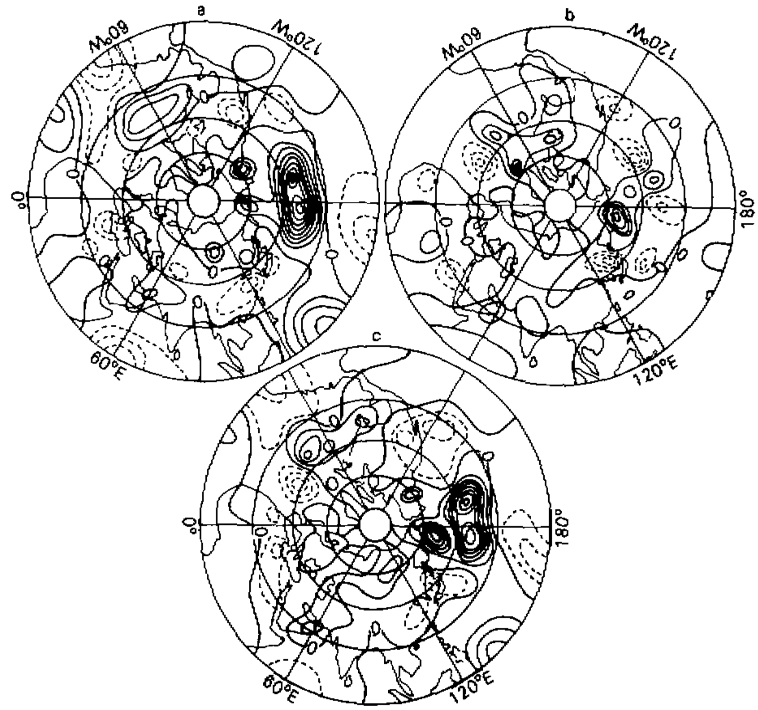

Fig. 2. Horizontal distribution of 2D conversion of barotropically unstable energy. a) zonal component CK_x ; b) meridional component CK_y ; c) CK_x+CK_y .Contour spacing is 40 m^2 s^{-3}.

It is clear that the two components differ from each other in distribution and strength but act together in the realistic atmosphere and their importance could be judged in the 2D conversion with the aid of Fig. 2c, where we see that the total effects, peaks and signs of the conversion agree roughly with the pattern of CK_x and considerably differ from that of CK_y , indicating that the conversion of midlatitude zonal asymmetric barotropically unstable energy is dominant in the 2D conversion. This suggests that zonal asymmetry of mean flow, zonal elongation and propagation of low–frequency oscillation are of great significance to the maintenance of the system.

From the physical implication of the signs "plus" and "minus" of the energy conversion one can see that maximum conversion happens in the exit region over the Northern Hemisphere midlatitudes where low–frequency waves gain energy from basic flow for development.

2. *Kinetic Energy of Low–Frequency Oscillation with Its Barotropy*

In the exit region of strong west wind the wave energy propagation and conversion of barotropic unstable energy of basic flow are most significant. Then a problem arises: what does the distribution of kinetic energy of low–frequency oscillation look like? As illustrated in Fig. 3, the maximum center of the kinetic energy (44 m^2s^{-2} at the core) covers the Hawaiian Islands, Aleutains and Gulf of Alaska, with the secondary center located over the Atlantic

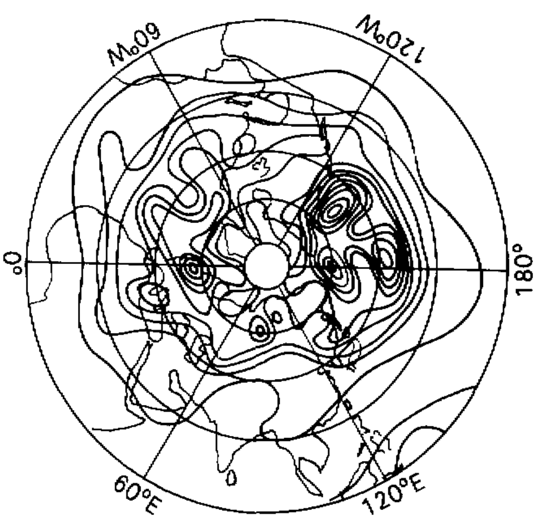

Fig. 3. Distribution of kinetic energy for low-frequency oscillation. Coutour interval is 4 m^2s^{-2}.

eastward of North America. From the analysis made earlier one can see that the peak area of the kinetic energy is related to the exit region of the west gale and that generation of the kinetic energy there is bound up with the conversion of barotropic unstable energy. Following the nature of wave energy propagation, this peak area may be the source of the oscillation.

The extratropical low-frequency oscillation (LFO) is marked by an equivalent barotropic structure and the problem of barotropy and baroclinicity of LFO kinetic energy deserves further exploration. By the definition of Wun-Neilsen (1962), the barotropic and baroclinic components of a meteorological element X can be given as

$$X_m = \frac{1}{p_0}\int_0^{p_0} x dp \text{ and } X_s = X - X_m,$$

where p is the pressure, p_0 the surface pressure, X_m and (X_s) the barotropic (baroclinic) component of X. Thus, the horizontal wind field treated by a 30–50 day band-pass filter $\vec{V}$ is in the form

$$\vec{V} = \vec{V}_m + \vec{V}_s,$$

in which $\vec{V} = U\vec{i} + V\vec{j}$, $\vec{V}_m = U_m\vec{i} + V_m\vec{j}$ and $\vec{V}_s = U_s\vec{i} + V_s\vec{j}$, so that the components of barotropic and baroclinic kinetic energy can be written, respectively, as

$$K_m = \frac{1}{2}\vec{V}_m \cdot \vec{V}_m \quad \text{and} \quad K_s = \frac{1}{2}\vec{V}_s \cdot \vec{V}_s .$$

For X_m the following expression (Huang et al., 1990) is used

$$X_m = 0.17X(1000) + 0.28X(700) + 0.33X(500) + 0.22X(100),$$

where the brackets denote the isobaric level in hPa's.

The baroclinic component X_s for each of the levels is found by

$$X_s(P) = X(P) - X_m .$$

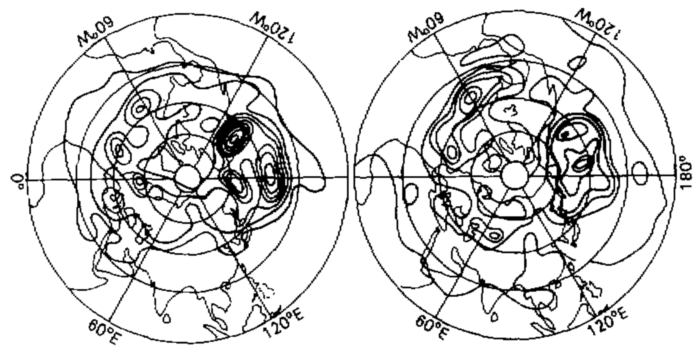

Fig. 4. Distribution of barotropy of LFO kinetic energy. a) pattern of barotropic kinetic energy K_m with contour interval of 4 m^2/s^2, and b) pattern of the K_m/K_s ratio at contour spacing of 1.0.

One can see from Fig. 4 that the pattern of LFO barotropic kinetic energy (Fig. 4a) bears resemblance to that of LFO kinetic energy (see Fig. 3) and two peak areas of barotropic kinetic energy correspond to those of the kinetic energy, separately, i.e., one located in part of the North Pacific and the other in the North Atlantic. From the 500-hPa K_m/K_s ratio (Fig. 4b) we see the ratio <1 in tropics with the exclusion of the part east of 110 ° W in the Pacific and part of the Atlantic, suggesting that the LFO is marked by intense baroclinicity in the low-latitude mid troposphere but by the ratio>1 for extratropics except part of East Asia, with the value possibly reaching 4 where LFO kinetic energy is considerable.

It can be seen that the midlatitude LFO kinetic energy has conspicuous barotropy, which is displayed particularly evident in the jet exit region where LFO barotropic behaviors get developed by virtue of the 2D conversion of barotropic unstable energy of temporal mean flow. Moreover, it is apparent that appreciable difference exists in LFO at mid and low latitudes, with barotropy and significant baroclinicity shown, respectively. Here, for illustrative purpose, a characteristic line of $K_m/K_s=1$ is used that is intuitive compared to other methods. This implies that the mechanism is different for the LFO at mid and low latitudes, the former related to the 2D conversion of barotropic unstable energy and the latter to the baroclinic effects of convection there.

IV. LFO TELECONNECTION STRUCTURE

From the foregoing analysis we see that the LFO is characterized by zonal propagation around the jet axis and meridional transfer in the break of the strong west wind (weak flow), and its generation is associated with the 2D conversion of barotropic unstable energy of temporal mean flow. Then a problem arises: What relation exists between these aspects and the structure of low-frequency teleconnection wavetrain?

As illustrated in Fig.5, the pattern of percentage variance of 500-hPa 30-50-day oscillation (Fig. 5a) is very similar to that of LFO kinetic energy with the maximum in the central North Pacific and North Atlantic at midlatitudes and a quite big value in the tropical oceans except the cold-water region in the eastern Pacific and a limited area in the eastern Atlantic, a pattern that bears close resemblance to that of the K_m/K_s ratio, leading to the conclusion that LFO of different meteorological elements is quite analogous. The region of the height field where LFO behaves most strongly is where maximum conversion of unstable energy occurs.

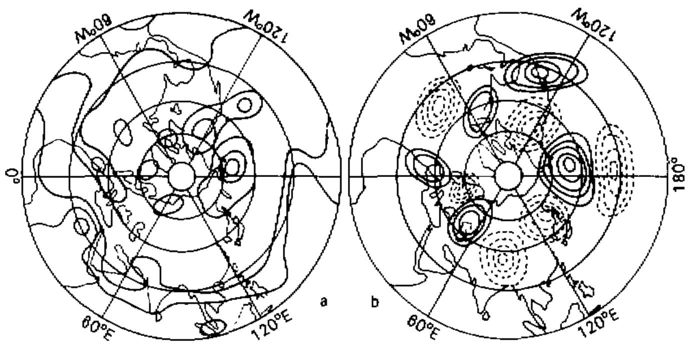

Fig. 5. The characteristic structure of 500–hPa LFO teleconnection. a) pattern of percentage variance, and b) correlation with the point (50 ° N, 175 ° W) as the reference and coutour interval of 0.2.

Fig. 5 presents the single–point correlation analysis with the area of maximum LFO (50 ° N, 175 ° W) as the reference. Therein we see that LFO at this point is in quite strongly negative correlation with the 500–hPa LFO around the Aleutains, in the neighborhood of the Midway Islands, east of Alaska in the subtropic Pacific, over the central Atlantic, the Baltic Sea, the Qinghai–Xizang Plateau and the Sea of Okhotsk and in positive correlation with LFO over the Gulf of Maxico, west of Newfoundland and Spain, and north of the Iranian Highland. With the reference point (50 ° N, 120 ° W) of Fig. 5b for calculation (figure not shown), we see that the pattern is quite analogous to that based on computation from the former point except that the correlation center has an opposite sign and slightly different coefficient so that the teleconnection structure of the quasi–40–day oscillation is marked by steadiness.

The pattern shows that the correlation centers are in the areas with most frequent activities of troughs / ridges and closed systems of high / low pressure, suggesting that the stationary centers of action in the atmosphere are probably the entities of 30–50–day LFO and related by teleconnection with the structure of zonal wavenumber 3–4.

Beyond that, the distribution of the correlation centers is bound up with the locations of mean flow at different strength and positioned mainly on either side of the strong west wind axis line with meridionally arranged correlation centers always in the break (weak west wind). Comparison of the distribution of these centers to those of vector $\vec{E}$ and 2D conversion of barotropic unstable energy indicates that in the break (gap) the quasi–40–day oscillation develops by the energy conversion with the energy dispersion, as a planetary–scale wavetrain, eastward along westerly jet and equatorward in the gaps of the westerly jet, thus exerting effects on tropical LFO.

V. CONCLUSIONS

1. The LFO energy propagation is intimately related with the position of temporal mean flow. In the strong west wind area the propagation is westward along the latitude circle with respect to the west flow and strongest at the exit and it is equatorward in the gaps of the westerly jet.

2. Maximum energy conversion occurs in the exit region of the strong west wind so that LFO develops with the energy from basic flow. In the 2D energy conversion, the zonally asymmetric barotropic energy CK_x is dominant.

3. In the westerly jet exit region LFO kinetic energy is quite strong, displaying considerable barotropic characteristics, and with the aid of the characteristic line of $K_m / K_s = 1$, the

difference in the LFO behavior at mid and low latitudes is revealed, showing that the midlatitude LFO depends strongly on the conversion of barotropic unstable energy of basic flow.

4. The LFO teleconnection centers situated chiefly on both sides of the westerly jet and in the gaps are associated with the atmospheric centers of action, marked by a quasi–stationary wavetrain, and these centers may be the LFO entity and in teleconnection. The teleconnection centers constitute a planetary–scale wavetrain with energy dispersion eastward along the westerly jet and equatorward in the jet gaps.

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