MERIDIONAL PROPAGATION OF EAST ASIAN LOW-FREQUENCY MODE AND MIDLATITUDE LOW-FREQUENCY WAVES*

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ABSTRACT

Based on June to September 1981 ECMWF grid datasets analysis is done of the characteristics of the propagation and structure of low-frequency (quasi 40 day) oscillation over eastern Asia. Results show a separating (confluence) belt for the meridional propagation of low-frequency zonal (meridional) winds at higher (lower) levels over subtropical latitudes at 120°E, revealing that the oscillation of the zonal winds is quasi-geostrophic in nature and in phase in the high- and low-level. It is also found that the eastward propagation of the high-level zonal winds around 35°N in East Asia is the result of eastward march of midlatitude low-frequency waves with 60—90 longitude wavelength and speed of 1.5—2.0 longitudes per day. In addition, such low-frequency vortices, when moving over the coastwise region, tend to develop, accompanied by sharp oscillation in the westerly jetstream over eastern Asia.

I. INTRODUCTION

30—50 day periodic oscillation (hereafter designated LFO) is marked by propagation as one of its basic features. Any theories of its essence and origin must be able to interpret the propagation. Madden and Julian (1972) and Murakami et al. (1974) indicated that as a rule, LFO travels eastward at equatorial latitudes and northward in summer monsoon area. Lau and Peng (1987)documented that the eastward propagation of near-equatorial LFO is accounted for in terms of the response of Kelvin waves on the east side of the disturbing heat source after the introduction into their study the mobile wave CISK mechanism. They, however, failed to explain its northward propagation and the travelling of extratropical LFO either.

Obviously, the meridional propagation of LFO should be viewed as an equally important feature, and however, study in this respect is relatively insufficient. Some researchers (e.g., Yasunari, 1980; Krishnamurti, 1982; and Webster, 1983) reported the meridional march of LFO in South Asia together with its relation to Indian summer monsoon. In contrast, still fewer papers were published concerning the meridional propagation over eastern Asia. In their numerical study of the effect of the Southern Hemisphere midlatitude low-frequency cold air activity on Asian summer monsoon using 1982 data, He et al. (1988) indicated that low-level meridional wind anomalies due to the impact of the cold air on the south side of Australian high have influence upon eastern Asian summer monsoon and China's Meiyu during

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its northward march from the NW side (around 10°S) of the high via 100°E. On the other hand, is there any limit to this northward march? Is there any difference in travelling between higher and low levels, and what are the characteristics of the propagation for other years in view of interannual variability?

LFO is of global nature,i.e.,it occurs both in tropics and in extratropics.It is safe to say that tropical LFO has been much examined compared to its counterpart. In his study of global LFO using FGGE datasets,Krishnamurti (1985) proposed the concept of "low-frequency storms" indicating that many of the "storms" either cyclonic or anticyclonic, are stationary, with the exclusion of part of them characterized by meridional movement,which, as anomalous systems, all tend to move eastward in the neighborhood of annually-averaged vigorous westerlies. However, the wave characteristics of these "storms" remain obscure.

Chen and Xie (1988) analysed fully the characteristic propagation of LFO in terms of day-to-day OLR data of 1975—1983, indicating that statistically LFO travels dominantly westward over 15—30°N and eastward around 37.5°N and at 120°E in tropics/subtropics (extratropics) LFO propagates northward (southward), resulting in the meeting about the subtropical belt. Obviously, the following questions are of interest. Do such propagation characteristics continue to be in wind field? What is the cause of the eastward travel of midlatitude (around 37.5°N) LFO?

East Asia is a place of the co-existence and vigorous display of tropical and subtropical monsoons (Zhu et al.,1986)and a region where LFO shows evident meridional propagation as well. Apparently,investigation of propagation features, particularly the meridional behaviors, of eastern Asian LFO is of much consequence to the appreciation of the properties of LFO at tropical and midlatitudes, to the exploration of the interaction between LFO of mid and low latitudes, and to the understanding of the nature of midlatitude LFO. This paper aims at the examination of LFO travelling meridionally in this area, and relevant features of midlatitude low-frequency waves together with its relation to eastern Asian LFO.

For this study, the ECMWF grid datasets of June—September 1981 were used. The filtered wind and height field data were obtained by means of the band-pass filtering (in the range of 35—45 days) technique used in the raw wind and height data from which the seasonal trend had been removed. For the details see He et al. (1984).

II. MERIDIONAL PATTERN AND PROPAGATION OF LFO

East-Asia (120°E) is a well-known monsoon area marked by the co-existence of tropical and subtropical monsoons. Therefore, LFO has the characteristics of its pronouned regionality and hence complexity in its distribution and propagation.

Fig. 1 is the 120°E cross section of 200-hPa time-varying zonal wind for June through September. It can be seen that between 60°N and 40°S there are 5—6 LFO centers of the wind, with the maximum amplitude of 10m/s, especially notable being the centers over 30—40°N, 5—10°N and 30—40°S. One can also find that these centers are arranged almost in a crosswise fashion, showing the pronounced component of standing wave oscillation, a characteristic pattern associated with the particular meridional distribution of eastern Asian summer large-scale circulation systems. The first center in the midlatitude westerly wind on the north side of the South-Asian high (SAH) is related to the changing intensity and position of eastern Asian westerly jetstream, and it is also the result of the jet oscillation in association with the development of midlatitude low-frequency vortices that move eastward to this area, as will be discussed in Section III. The second center in tropical easterly jetstream on the south side of the SAH reflects quasi-40-day variation of the jet in this area and the periodic change in the southward-spreading flow over the monsoon trough in the South-China Sea. The third center is none other than the manifestation of low-frequency variation in the Australian westerly jet-stream. In addition, a weaker oscillation center is seen both at 50°N and at the Southern Hemisphere tropical-subtropical latitudes. Noticeable is the fact that after June 20, the centers on both sides of the SAH become farther apart (which is caused mainly by the northward shift of the oscillation center over China's mainland), followed by another weaker center between 20—30°N around July 20 that is located in easterly flow on the south side of the SAH, with propagation in various directions, indicating remarkable features of standing waves.

Another feature exhibited by Fig.1 is that north of 30°N LFO propagates northward (after the first decade of September the course is reversed), and the easterly jet oscillation moves systematically equatorward to 20—30°S, at times even to midlatitudes, with the propagation separating belt in 20—30°N. In association with this is a meeting belt of meridional propagation of meridional wind LFO between 20—30°N at 850 hPa level. Inspection of Fig. 2 shows that this LFO around 10°S can travel poleward to South China where the equatorward meridional wind LFO of the NH extratropics can reach, too. The discovery of the meeting and separating belt is a fact of consequence, which bears relation to the findings of Chen and Xie (1988) and He et al. (1989). Perhaps the existence of low-level confluence and high-level separating belts is somewhat associated with the orientation of basic flow about 120°E. We may just as well take the 20—30°N belt as the division of LFO between tropical and extratropical latitudes. It can therefore be assumed that the LFO characteristics should be considerably different on both sides of this belt.

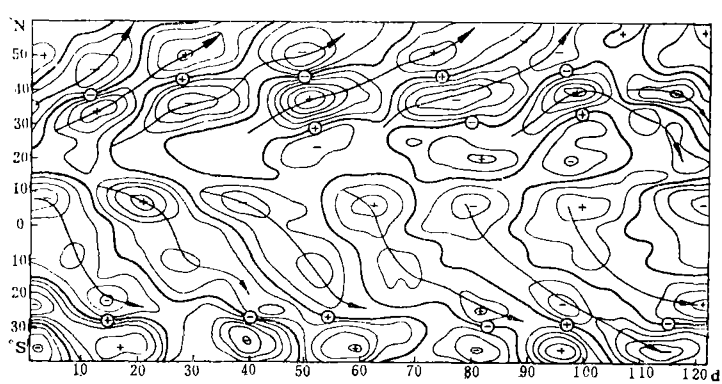

Fig. 1. 120°E time cross-section of 200 hPa zonal wind LFO.Signs + and – denote the positive and negative center in the height field, respectively. Arrows indicate the direction the LFO moves. Heavy sold line is the zero valued with isopleth interval of 2m/s.

Fig. 3 displays the time cross-section of u component at 850 hPa, showing 5 weaker LFO centers zonally, with maximum amplitude of 4 m/s. Three out of the five centers are notable, two situated around 30—35°N and 20°N, separately, which move farther equatorward after 70 days, i.e., the first decade of August, but with no other center coming into view as in the case of 200 hPa. The third center is between 30—40 °S, indicating less regular propagation than that at 200 hPa but the Southern Hemisphere midlatitude LFO still has quite significant equatorward propagation. As for the NH, the extratropical LFO travels equatorward to around 30°N prior to the second decade of August, followed by chaotic propagation. Overall, the meridional propagation of LFO if opposite in direction at high- and low-levels of extratropical latitudes for both the hemispheres.

Comparison of positions of high- and low-level zonal wind LFO centers on the cross section (Fig. 4) indicates that for the SH midlatitude high- and low-level,the centers always remain unchanged in relative position, and for the NH north of 30°N, they are roughly unaltered. both with more or less meridional deviation in September: south of 30°N, strong LFO centers at both levels show great difference in phase, even in opposite phase with each other. One can see that the LFOs at both levels for extratropics are essentially in phase with each other, a result in agreement with the conclusion of Krishnamurti et al. (1982).

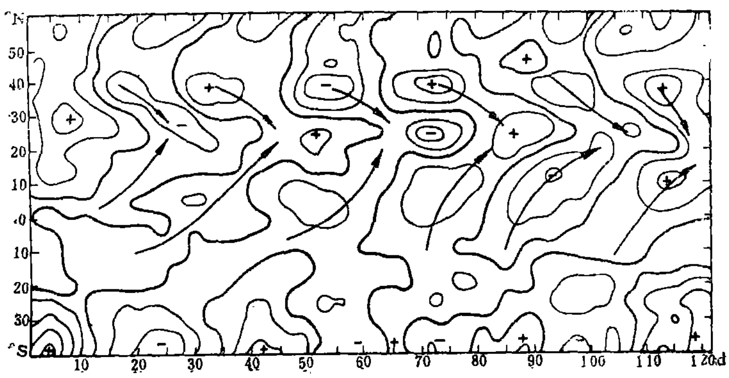

Fig. 2. 120°E time cross-section of 850-hPa meridional wind LFO. Arrows and heavy solid lines denote the same as in Fig. 1, but with the isopleth interval of 1m/s.

Further inspection of Figs. 1 and 3 indicates that the zonal wind LFO centers are characteristic of appearance in pairs zonally, quite distinct at high and low levels. To elucidate this, we have to examine features of the height oscillation.

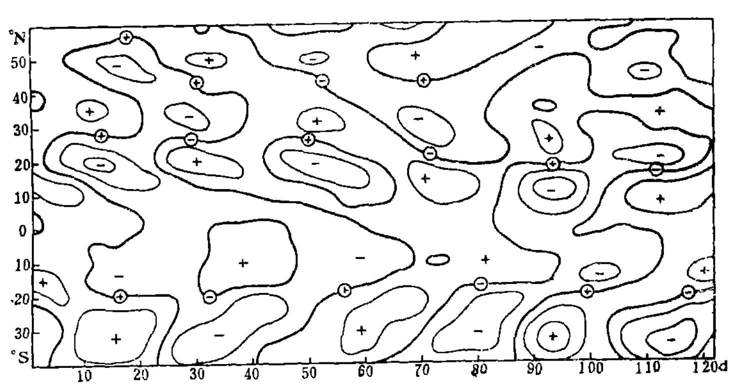

Fig. 3. 120°E time cross-section of 850-hPa zonal wind LFO. Otherwise as in Fig. 1.

Figs. 5 and 6 illustrate time cross-sections of LFO height at 200 and 850 hPa, respectively. Fig.5 shows a row of noticeable height oscillation centers at midlatitudes for both hemispheres. Interestingly, after July 20, i.e. 50-day integration, a row of height oscillation centers shows up along 30°N, which is a match for zonal wind LFO centers (refer to Fig. 1). The propagation of height oscillation, albeit less regular than that of zonal wind, is evident in its northward march north of 30°N with equatorward travel south of 30°N. That is, a separating belt is available for height oscillation meridional propagation as well. Another fact of interest is

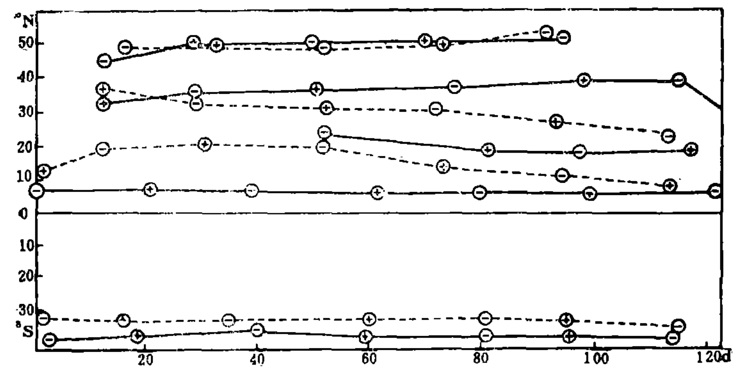

Fig. 4. Positions of zonal wind LFO centers at high and low levels on the cross-section. Solid (broken) line connects centers at high (low) levels.

that north of 30°N the axis lines of maxima and minima of the height oscillation coincide with the E-W zero-value line of zonal wind oscillation with the negative(positive) center of the wind oscillation located on the south (north) side of the positive (negative) center of the height oscillation (see Figs. 1 and 3), an allocation that reflects that the LFO in this area is quasi-geostrophic in character. So is the SH midlatitude oscillation. No such a pattern is, however, seen around the equator. The 850-hPa zonal wind and height fields show a similar pattern. Of particular interest is the fact that between 20—30 °N there is a row of centers of height oscillation with zonal wind oscillation centers appearing in pairs on both sides of the height oscillation centers, in agreement with the quasi-geostrophic relation. It is worth noting that the row of centers had important effect on the low-frequency variation in China's mainland weather for the summer of 1981. Preliminary analysis indicates that it bears intimate relation to the southward advance of the LFO cold air in the land and variation in the position of the subtropical high.

To summarize, around 120°E of East Asia there is a separating and a confluent belt for LFO meridional propagation at high and low levels, respectively, the division being at 20—30°N, with marked different vertical structure and properties of the oscillation on either side. On the north side the zonal wind LFO's at high and low levels are in phase and quasi-geostrophic in nature, while on the south side the LFOs are remarkably out of phase for both the levels,

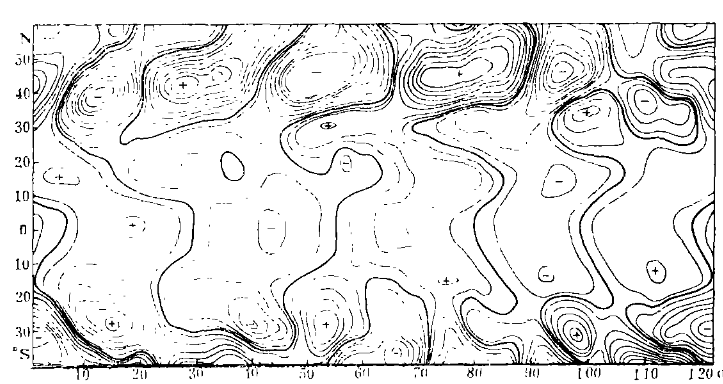

Fig. 5. 120°E time cross-section of 200-hPa height LFO. Heavy solid line is the zero-value line. Isopleth interval is 80 gpm.

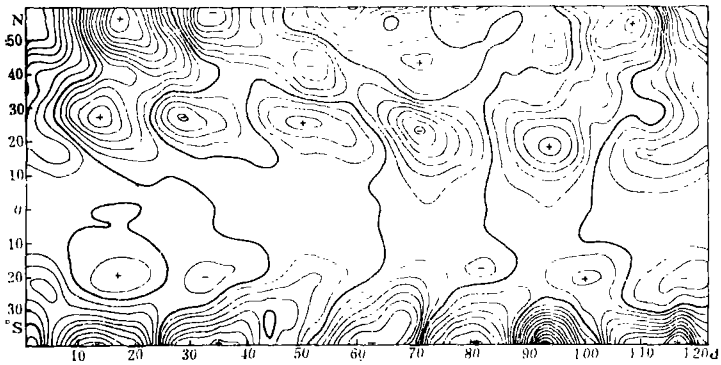

Fig. 6. As in Fig. 5 but for 850 hPa and the interval is 40 gpm.

even in opposite phase with each other, and the LFO around the equator loses its quasi-geostrophy.

III. EASTWARD PROPAGATION OF ZONAL WIND LFO AND MIDLATITUDE LOW-FREQUENCY WAVES

Chen and Xie (1988) indicated the eastward travel of LFO north of 37.5°N. However, they did not make further discussion of the propagation features of midlatitude oscillation, perhaps in view of the applicability of the OLR datasets to extratropics. In fact, the mid-latitude LFO propagation is an essential problem concerning the dynamics and origin of the oscillation. Unfortunately, little is studied of the issue.

Fig. 7 depicts temporal variation in the 35°N zonal wind LFO.One can see in the Eastern Hemisphere two noticeable LFO centers, generally more than 6m/s, the maximum reaching over 10 m/s, and they move westward over a great distance as the time goes on. For instance, they are about 30—40°E and 130°E, respectively, in the second decade of June and move to around 10°E and 80°E for the same-decade of September, accompanied at the time by another stronger oscillation center between 130—140°E, whose intensity tends to grow and which travels westward.

Inspection of Fig. 7 shows that the oscillation travels basically eastward to the west of 130—140°E with a break (around 50°E) in the eastward march between the centers. And the oscillation east of 130—140°E is featured by westward propagation. Such a transition or break band in zonal propagation is also found in other zonal belts. This transition band is noteworthy because it shows that LFO does not travel east- or westward all the way around the globe but has striking regionality. Causes may be many. Preliminary analysis indicates that the transition band in zonal propagation is associated with the meridional movement of low-frequency waves. We can possibly say that the zonal transition band serves as the passage for LFO meridional propagation or interaction between mid- and low-latitude LFO.

"Regionality" implies not merely the association of the direction the LFO progresses in a particular area, but that the existence of an oscillation center in a certain zone as the standing wave component of LFO should be related to the existence of the quasi-stationary circulation system or the center of atmospheric activity. Within a certain geographic locality, the regular propagation of oscillation is merely the manifestation of its progressive wave component, whose speed must be dependent on the period of local change of LFO. Only in this way can we explain the quasi-40-day period of LFO. Then the following questions arise: What is the process by which such coordination occurs? What are the system and dynamic mechanism responsible for the change?

Careful inspection of all eastward propagating processes in Fig. 7 indicates that they have many in common. Therefore we select one eastward propagating process from the Mediterranean to East Asian coast as marked by heavy-lined arrows to discuss the problems mentioned above (refer to Fig. 7).

Fig. 8 illustrates the horizontal pattern of the LFO wind field at 5 intervals of time for the process. Since the filtered wind field is slow-changing, the horizontal wind distributions at 5 different times are used to represent the respective fields at the five intervals.

It is evident from Fig.8 that there lies a nearly E-W train of cyclones and anticyclones at 30—50°N of the Eastern Hemisphere, with mean wavelength about 60—90 degrees of longitudes. By closely following the track, one can notice that they all move eastward fairly uniformly, with speed of 1.5—2.0 longitudes per day, suggesting that the period of oscillation in

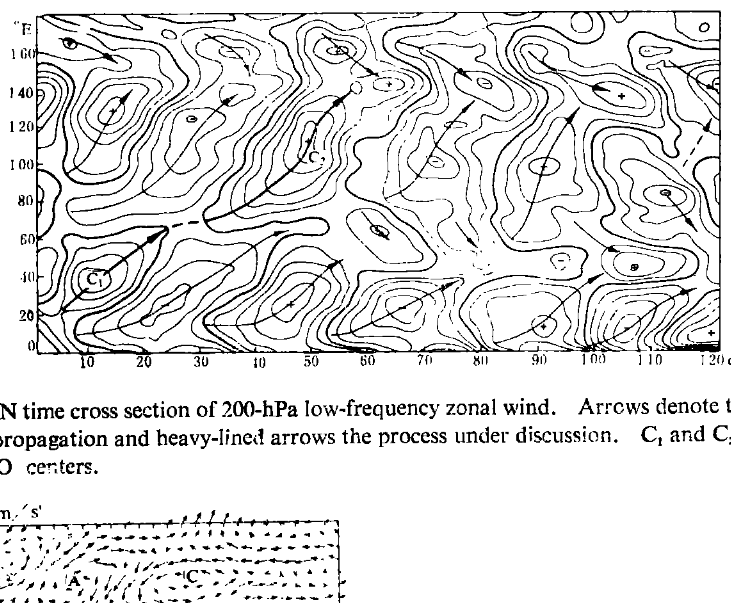

Fig. 7. 35°N time cross section of 200-hPa low-frequency zonal wind. Arrows denote the direction of propagation and heavy-lined arrows the process under discussion. C_1 and C_2 are strong LFO centers.

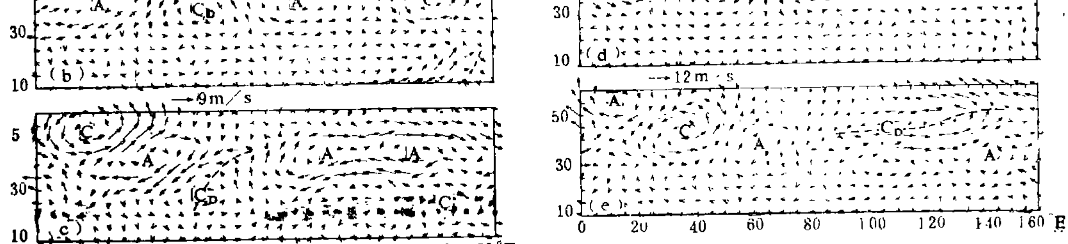

Fig. 8. 200-hPa horizontal distribution of the LFO wind at five different times. C denotes the cyclone, A the anticyclone and C_D the cyclone under consideration. (a) on day 10; (b) on day 20; (c) on day 30; (d) on day 40; (e) on day 50.

the local wind field caused by the eastward wave system is roughly 40 days. This characteristic time scale is naturally in agreement with the result of the wind field treated by band-pass filtering. One important discovery in our analysis is what circulation system gives rise to the quasi-40-day oscillation in the local wind field.

To examine the way the zonal wind travels eastward and quasi-40-day oscillation of the local zonal wind due to the movement of low-frequency vortices we consider the eastward shift of a vortex C_D and the west wind on the south side.

It can be seen that on day 10 (i.e., June 10, and the other day can be inferred from June 10 for day 10) C_D is around 40°N, 40°E, with a strong west wind in 30—40°E on its south side (35°N), which is the locality of the first center C_1 in Fig. 7. Subsequently, as the train keeps on moving eastward on day 20, C_D is west of 60°E, accompanied by the west wind going in the same direction, but with decreased intensity.On day 30, the center of C_D moves southward to around 25°N, with a considerable trough stretching out in the NE direction from it, but the midlatitudes are still covered by the pronounced wave train. Because of the southward advance of C, the westerly wind is suddenly veered to the easterly, resulting in the break in the eastward travel of the west wind shown in the cross section. Later, the trough in the north gets apart from the center in the south and continues to move eastward and starts to develop. On day 50 it develops into a vigorous low-frequency vortex between 90—140°E, and the strong west wind on its south side corresponds to the second center C on the cross section and also to the vigorous center formed on day 50 in 30—40°N (Fig. 1). The development of the low-frequency vortex is related to the wet season of North China. The eastward travel of the west wind as seen in Fig. 7 happens to be at the speed of 1.5—2.0 longitudes per day in agreement with the speed of the low-frequency vortex,suggesting that the eastward travel of the west wind is indeed caused by the eastward advance of the vortex.

Above analyses show that in a certain area at midlatitudes, the propagation properties of the oscillation are associated with the movement of low-frequency waves and the standing wave nature of the oscillation, i.e., the existence of the oscillation center with development of the low-frequency waves. The growth of low-frequency vortices indicated above is probably related to the supply of barotropic instability energy in the jetstream area. Xu (1989)* showed that the barotropic instability in the neighborhood of jetstream is really a possible mechanism for providing low-frequency disturbance with energy. From the above we can arrive at the conclusion that midlatitude low-frequency waves are quasi-geostrophic high- and low-level waves roughly in phase. Study of these waves is of consequence to the understanding of the essence of midlatitude LFO.

IV. RESULTS AND DISCUSSIONS

(1) For 120°E of East Asia a confluent (separating) belt is available for the meridional travel of low-frequency meridional (zonal) wind perturbance at low (high) levels. The belt is found in 20—30°N inside which the propagation is more changeable in direction, and the LFO systems on both sides of the belt greatly differ in properties. Therefore we take the belt as the division between midlatitude and tropical LFOs.

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* Xu Jianjun (1989), Observation and analysis of 30—50 day periodic oscillation in atmospheric motions and diagnostic study of the effect upon disturbances of the variation in the kinetic energy and basic flow, M.S. thesis, Nanjing University.

(2) The eastward travel of zonal wind LFO is evident along 35°N in East Asia, with a pronounced oscillation center in the Mediterranean and eastern Asia, respectively. This characteristic demonstrates that the zonal wind LFO at this belt is featured by the components of both progressive and standing waves. Successive analyses of the horizontal wind fields indicate ttha the characteristic oscillation propagation depends on the eastward advance of low-frequency waves and that the properties of standing waves are the result of the low-frequency vortices developing over the belt, which may be associated with the supply of barotropical instability energy in the central area of the jetstream.

(3) Midlatitude low-frequency waves are Ca. 60—90 longitudes in wavelength, with the eastward speed of 1.5—2.0 longitudes a day. The two features are good enough to account for the quasi-40-day periodicity of the local wind fields. The midlatitude waves are quasi-geostrophic in dynamics and approximately in phase for high and low levels. Numerical study shows (Luo and He, to appear) that nonlinear solitary Rossby wave travels westward and the linear Rossby mode including basic flow goes eastward, with the composite pattern kept quasi-stationary, travelling eastward at 1.3—1.5 longitudes per day and having wavelength of roughly 60 longitudes. This agrees well with the diagnostic result.

The important discovery in the study of midlatitude low-frequency waves helps to appreciate their essence and origin.Evidently,the diagnostic result needs to be verified in terms of even more comprehensive datasets.

REFERENCES

Chen Longxun and Xie An (1988), Westward propagation low-frequency oscillation and its teleconnections in the Eastern Hemisphere, *Acta Meteorologica Sinica*, **2**:300—312.

He Jinhai and Chen Lizhen (1988), The SH midlatitude Quasi-40-day Periodic Oscillation with its effect on the NH summer monsoon circulation, *Acta Meteorologica Sinica*, **2**:331—339.

He Jinhai, Li Jun and Li Yongping (1989), Numerical experiment with processes for effect of Australian cold air activity on East-Asian summer monsoon, *Acta Meteorologica Sinica*, **4**:51—59.

He Jinhai et al. (1984), Circulation with 40—50 day oscillation and changes in moisture transfer over monsoon Asia in the summer of 1979, *J. Nanjing Inst. of Meteor*, 163—175 (in Chinese).

Krishnamurti, T.N. and Subrahmanyam, D. (1982), The 30—50 day mode at 850 mb during MONEX, *J. Atmos. Sci.*, **39**: 2088—2095.

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

Lau, K.M. and Peng, L. (1987), Origin of low frequency (intraseasonal) oscillations in the tropical atmosphere, Part I: The basic theory, *J. Atmos. Sci.*, **44**: 950—972.

Luo Zhexian and He Jinhai, A numerical study of low-frequency oscillation of midlatitude flow pattern, to appear.

Madden, R.A. and Julian, P.R. (1972), Description of global scale circulation cells in the tropics with a 40—50 day period. *J. Atmos. Sci.*, **29**:1109—1123.

Murakami, T., Nakazawa, T. and He Jinhai (1984), On the 40—50 day oscillations during the 1979 northern hemisphere summer, Part I: Phase propagation, *J. Meteor. Soc. Japan*, **62**:440—468.

Webster, P.J. (1983), Mechanism of monsoon low frequency variability: Surface hydrological effects, *J. Atmos. Sci.* **40**: 2110—2124.

Yasunari, T. (1980), A quasi-stationary appearance of 30—40 day period in the cloudiness fluctuations during the summer monsoon over India, *J. Meteor. Soc. Japan*, **58**:225—229.

Zhu Qiangen, He Jinhai and Wang Panxing (1986), A study of circulation differences between East-Asian and Indian summer monsoon with their interaction, *Adv. Atmos. Sci.*, **3**:466—477.