Characteristics of Zonal Propagation of Atmospheric Kinetic Energy at Equatorial Region in Asia *

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ABSTRACT

Based on the daily NCEP/NCAR reanalysis dataset from 1980 to 1997, the zonal propagations of 850 hPa kinetic energy (K_{E}) and meridional wind (v) at equatorial region are examined respectively. Results show that the strongest center of K_{E} in the tropical Asian monsoon region is located at 75°-90°E, with the secondary over the Somalia low-level jet channel, i.e., about 50°E. East to 90°E, disturbances of both K_{E} and v observed are mainly coming from the western Pacific Ocean and propagating westward to the Bay of Bengal (BOB) passing through the South China Sea. But the propagation directions of both K_{E} and v are rather disorderly between the BOB and the Somalia jet channel. Therefore, the East Asian summer monsoon and the Indian summer monsoon are different in the propagating features of the disturbances of K_{E} and v. Above facts indicate that East Asian monsoon system exists undoubtedly even at the equatorial region, and quite distinct from the Indian monsoon system, it is mainly affected by the disturbances coming from the tropical western Pacific rather than from the Indian monsoon region. The boundary of the two monsoon systems is around 95°-100°E, which is more westward than the counterpart as proposed in earlier studies by 5-10 degrees in longitude.

Key words: kinetic energy, zonal propagation, East Asian monsoon system, Indian monsoon system

1. Introduction

As early as in the 1980s, Chinese scientists had first proposed that there exist two summer monsoon systems in Asia, namely the East Asian summer monsoon (EASM) and the Indian summer monsoon (ISM) (Chen and Jin, 1982; Jin and Chen, 1982; Chen, 1984; Tao and Chen, 1987). These two monsoon systems are quite different in characteristics but interactional. The low-level EAMS is mainly composed of the Australian high, the cross-equatorial flow (CEF), the western Pacific subtropical high, the Meiyu front, and the cold air activities from high latitudes of the Northern Hemisphere. Since then, such issues and conclusions have been documented and approved by a lot of studies in the past two decades, and were applied in the guideline of the South China Sea summer monsoon experiment (SCSMEX), which was undertaken in 1998. However, the earlier concept of EASM was mainly based on the analyses of their meridional interactions in summer monsoon regions and only a few studies focused on exploring the zonal differences in the two monsoon systems and their interactions. In fact, some studies argued that the circulation and disturbances in Asian monsoon regions should be eastward propagating because the tropical Asian summer monsoon is southwesterly. Therefore, the EASM is affected by the eastward moved disturbances from the Somalia low-level jet channel, whenever in early summer or mid-summer (Tang and Huang, 1983; Huang and Tang, 1987). But there also exist evidences that the low frequency oscillation (LFO) has a westward propagation along 22.5°N (Chen and Xie, 1988; Jiang and Qian, 2000). This conclusion was approved by an observed propagation from West Pacific to the Bay of Bengal (BOB) through SCS during the SCSMEX (Mu

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and Li, 2000; Chen et al., 2001). However, other analyses suggested that the sources of the 30-60 day LFO in the SCS are originated from the BOB (Liang and Wu, 2000).

From above arguments we can see, there still have disputes on the propagating directions of the disturbances in the Asian monsoon regions. It is a basic question for Asian monsoon research because it is not only related to the interactions between the two monsoon systems, but also to the influencing path of the external factors on summer climate of China. Based on the daily geostationary meteorological satellite (GMS) equivalent black body temperature (TBB) and the horizontal wind fields from NCEP/NCAR dataset from 1980 to 1997, the zonal propagation of kinetic energy (K_{E}) and convection in the SCS and ISM areas are examined in the study by Chen et al. (2004). Results suggest that the disturbances of K_{E} at 850 hPa and convection in the EASM are mainly from the West Pacific Ocean (140°-150°E), after passing through the SCS, and then westward propagating into the BOB (90°-100°E). While in the ISM region, mostly disturbances of K_{E} are found to be mainly coming from the Arabian Sea and eastward propagating into the Bay of Bengal. Therefore, the SCS and the ISM are quite different in zonal propagation. The analysis also suggests that the interaction boundary between the SCS and the ISM systems is about 90°-95°E, rather than 105°E as proposed by earlier studies.

As an important member of Asian monsoon system, the CEF plays a significant role in the exchanges of mass, vapor, momentum, and energy in the two hemispheres. Therefore, the analyses of the propagation south of 5°N will also help us understand the characteristics and their interactions of the two monsoon systems.

2. Kinetic energy propagation in the equarorial region of NH

In this paper, the equatorial region of NH (Northern Hemisphere) is defined as 0°-5°N and the kinetic energy K_{E} is $(u^2+v^2)/2$, where u and v represent the zonal and meridional wind components, respectively. As we know, the wind is one of the best variables indicating the generation, development, and movement of synoptic systems in the equatorial region. However, only partial figures are presented due to limited space though all the datasets have been analyzed year by year.

Figure 1 is the time-longitude section of 850 hPa K_{E} averaged between 0°-5°N from 1986 to 1991. From it one can see, there exist two maximal value centers of K_{E} from 40°E to 170°E, with the stronger at 80°-90°E (west to the BOB) and the secondary at 40°-50°E (Somalia low-level jet channel). No clear propagation can be found between these two centers. But in the EASM region, disturbances have distinct westward propagation from the West Pacific (140°-150°E) to the BOB through the SCS. Hence the characteristics of the zonal propagation of kinetic energy are quite different in the two systems. In the EASM, the propagation is westward though the basic flow is westerly. That means that the generation and propagation of K_{E} in the EASM are independent instead of being affected by the ISM.

To testify this conclusion, lagging correlation method is used with a sample length of 92 days, i.e., from 1 June to 31 August in each year. The lagging time is from ±1 day to ±7 days. The area (0°-5°N, 110°-120°E) is chosen as a base point (Fig.2). Obviously, in most years, the kinetic energy arises from the West Pacific and spreads to the BOB through the SCS, which is consistent with the results of Fig.1.

While in the lagging correlation figures in the ISM with the base point located at 0°-5°N, 60°-70°E (Fig.3), the propagation of kinetic energy is not very clear, and in some years the propagation is eastward. There also exist westward propagation cases, such as 1985 and 1987. Therefore Figs.2 and 3 indicate that the disturbances of K_{E} originating from the Somalia jet channel can hardly have influences on the EASM, which is consistent with the results of 5°-15°N in terms of TBB and K_{E} (Chen et al., 2004).

3. Zonal propagation of the cross-equator flow

As we know, the 30-60 day LFO of OLR is quite significant along the equator with a westward

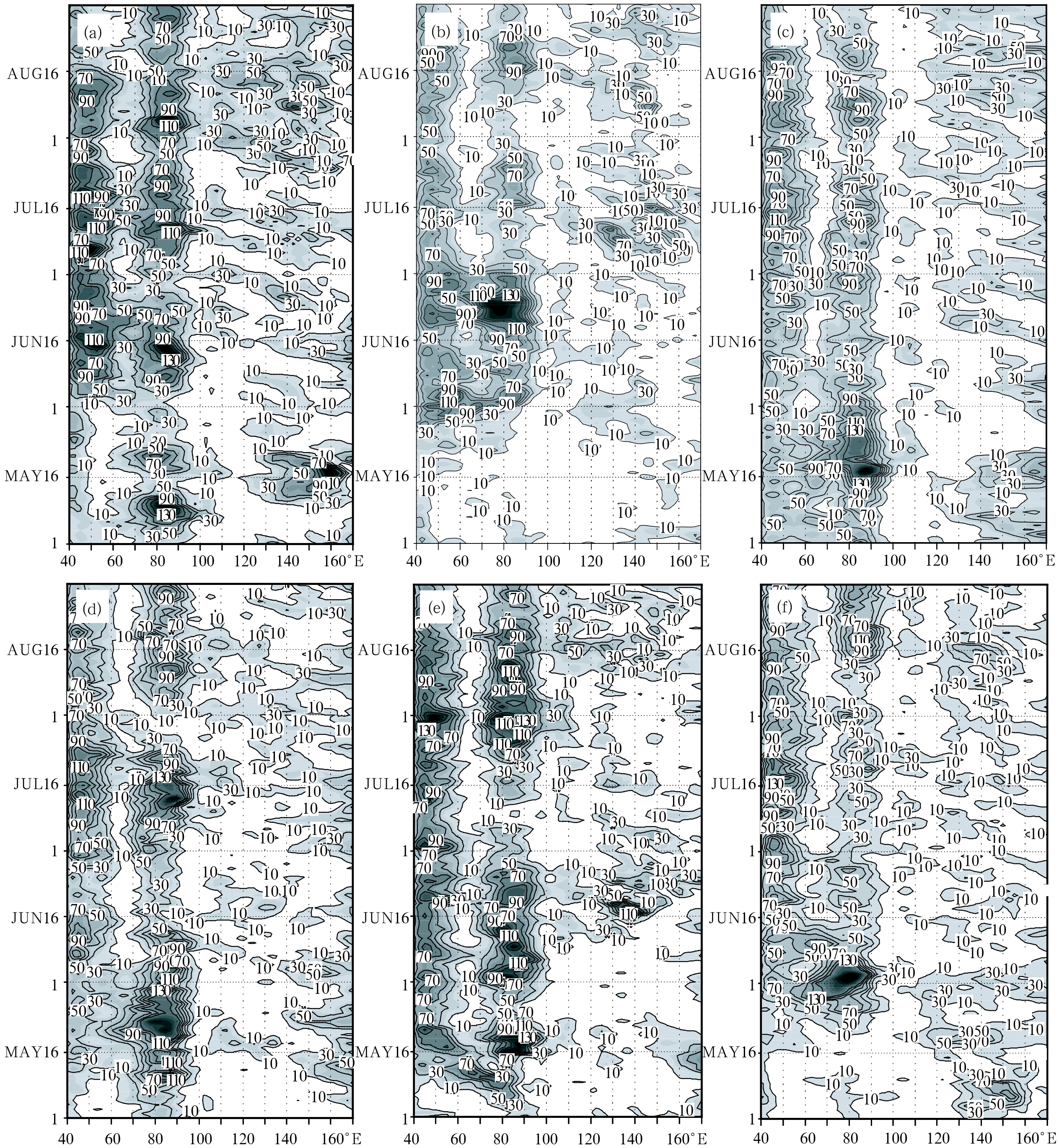

Fig.1. Time-longitude section of daily 850 hPa K_{E} ($\mathrm{m}^2\ \mathrm{s}^{-2}$) averaged between 0°-5°N during May to August in years (a) 1986, (b) 1987, (c) 1988, (d) 1989, (e) 1990, and (f) 1991. Regions above 10 $\mathrm{m}^2\ \mathrm{s}^{-2}$ are shaded.

propagation, especially in the West Pacific. But what is the characteristics of the zonal propagation for other variables, such as the meridional wind, or named as the cross-equatorial flow (CEF). The summer CEF channel in East Asia was firstly found by Chen and Zhang (1976). In their study, the main channel is located at 125°E and the secondary at 145°-150°E, i.e., near the New Guinea. It also can be seen at 105°E (Chen, 1982). Figure 4 is the time-longitude section of 850 hPa v averaged between 2.5°S-2.5°N from 1

May to 31 August in 1986-1991. Clearly, there are five CEF channels in the Eastern Hemisphere in summer, namely, the Somalia CEF channel (40°-50°E), the East Asian channel (125°-135°E), the SCS

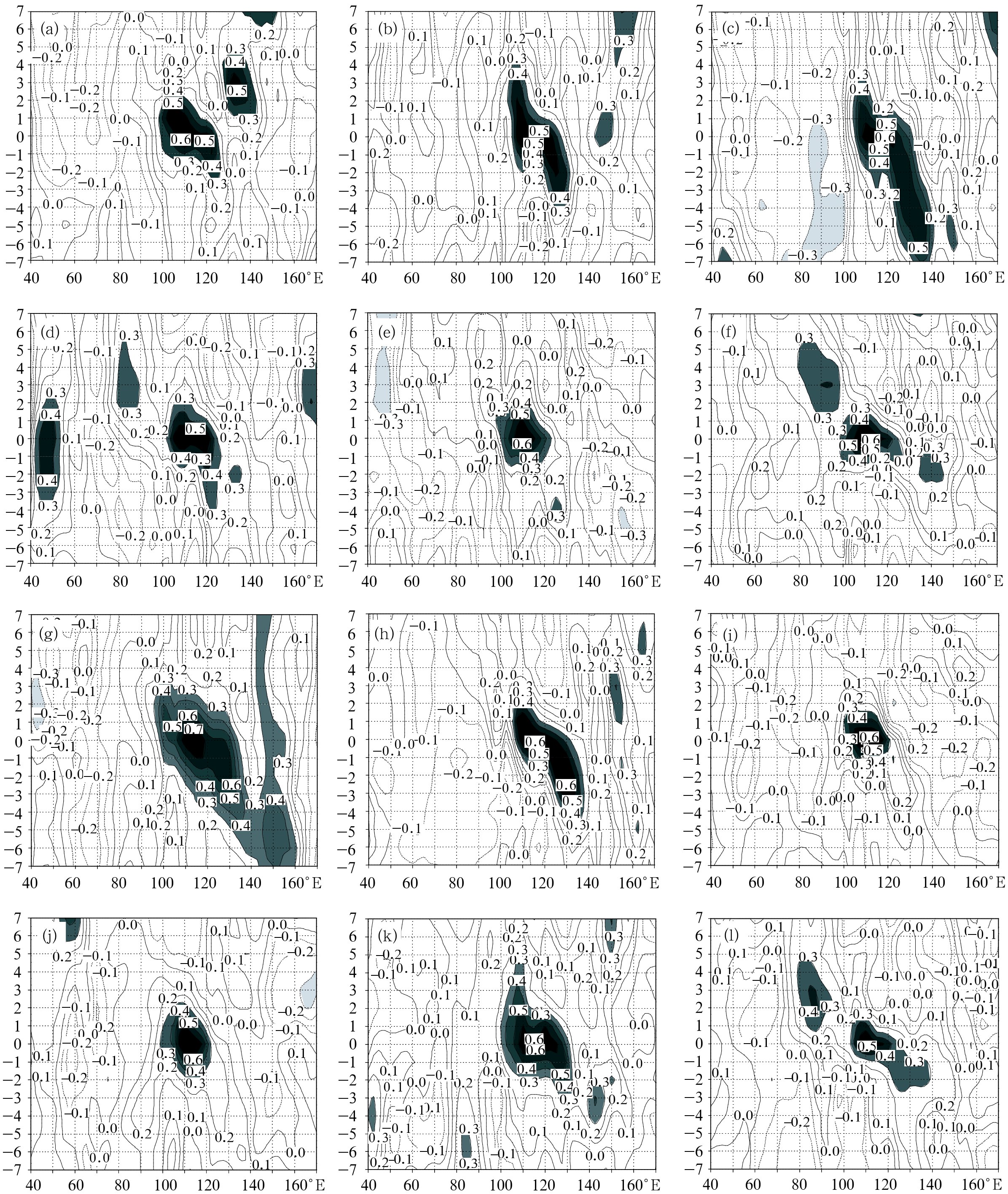

Fig.2. Time-longitude cross-section of lagged correlations of 850 hPa K_{E} averaged between 0°-5°N for day -7 to day +7 in summer during 1980-1991 with the center located at 0°-5°N, 110°-120°E. Positive numbers in the ordinate mean the leading day (s) to the base point, negative mean the lagged day(s). Regions above the 99% significance level are shaded. (a) 1980, (b) 1981, (c) 1982, (d) 1983, (e) 1984, (f) 1985, (g) 1986, (h) 1987, (i) 1988, (j) 1989, (k) 1990, and (l) 1991.

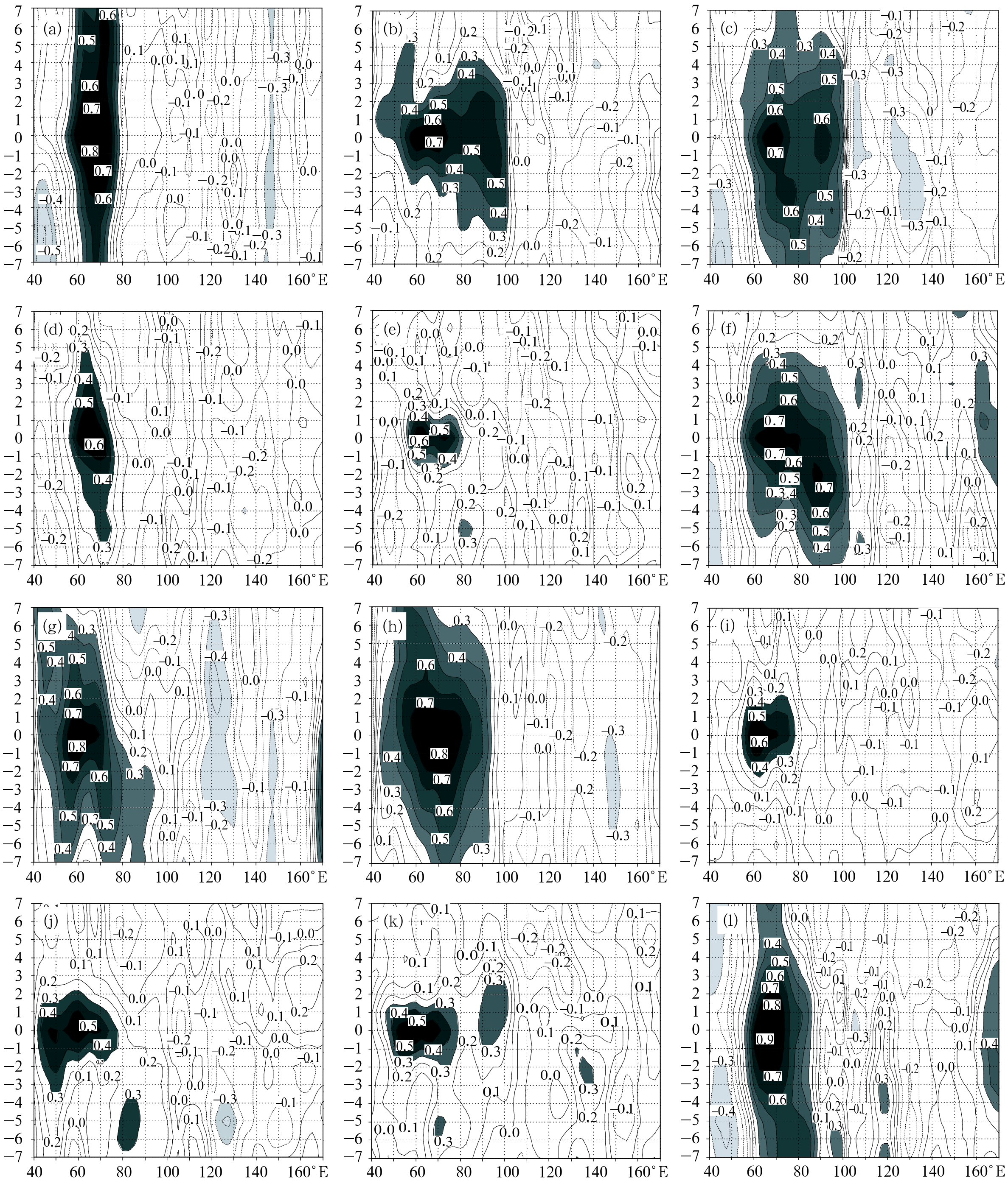

Fig.3. As in Fig.2, but for the center located at 0°-5°N, 60°-70°E.

channel (100°-105°E), the BOB channel (80°-90°E), and the New Guinea channel (145°-155°E) according to their intensities.

From Fig.4 we can also find that the meridional wind has no obvious zonal propagation between the Somalia CEF channel and the BOB channel. But on the contrary, it is very clear east to 105°E. The disturbances can be pursued to the middle Pacific, from where the meridional wind spreads westward and passes through the New Guinea, East Asia, and the SCS in turn. Some of the disturbances can also reach the BOB.

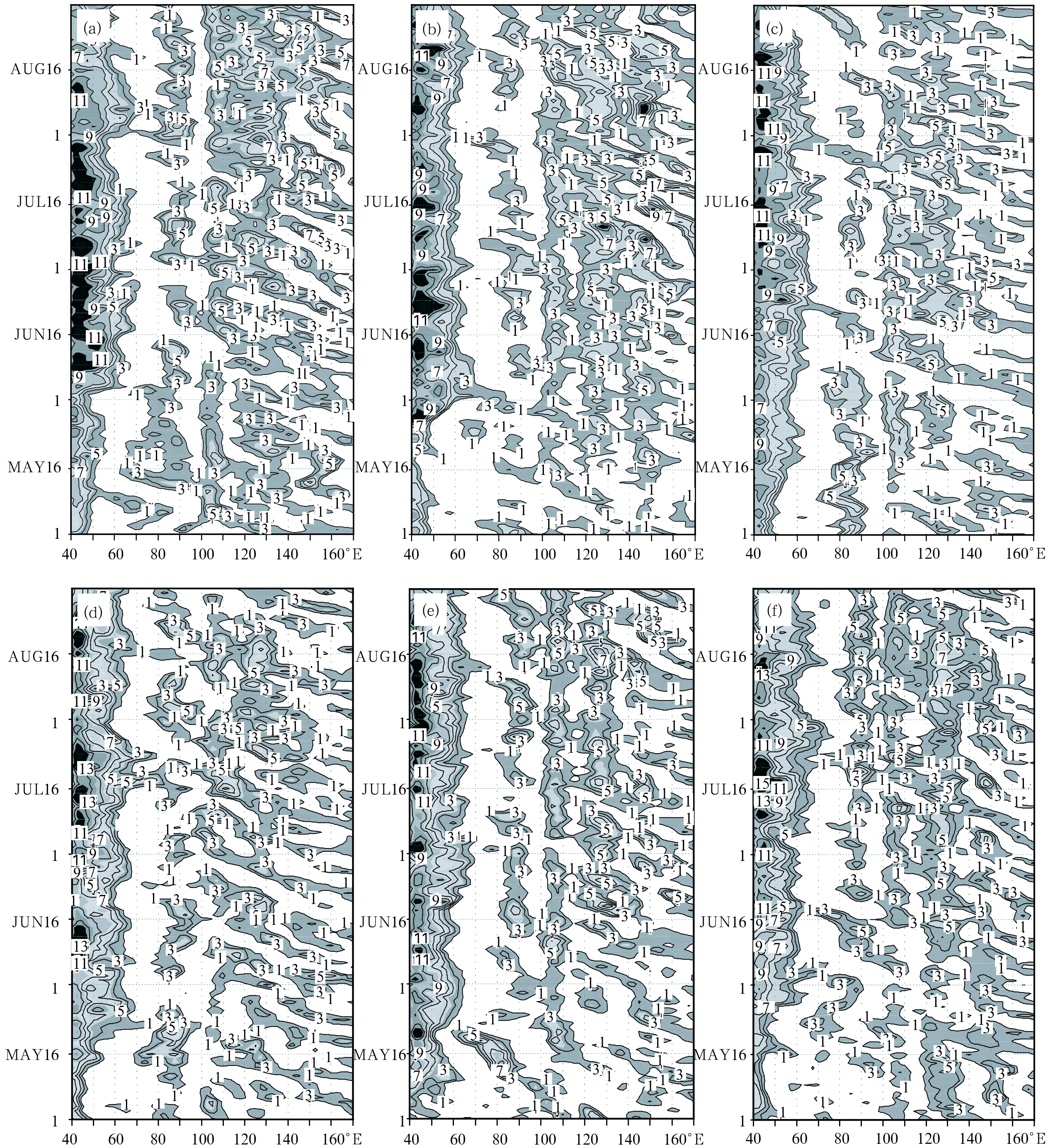

Fig.4. Time-longitude section of daily 850 hPa v averaged between 2.5°S-2.5°N during May to August in years (a) 1986, (b) 1987, (c) 1988, (d) 1989, (e) 1990, and (f) 1991. Regions above 1 m s^{-1} are shaded.

The lagging correlation method is also used here to understand the zonal propagation of the meridional wind (Fig.5). The disturbances of v at the SCS can be seen originating from 130°-150°E and propagating westward to 100°E. In some cases, it can even reach 90°E, such as in 1981 and 1984. A propagating period is about 7 days from -4 d to 3 d, which belongs to the quasi-one-week oscillation prevailing along the equatorial area.

But in the lagging correlation figures with a base

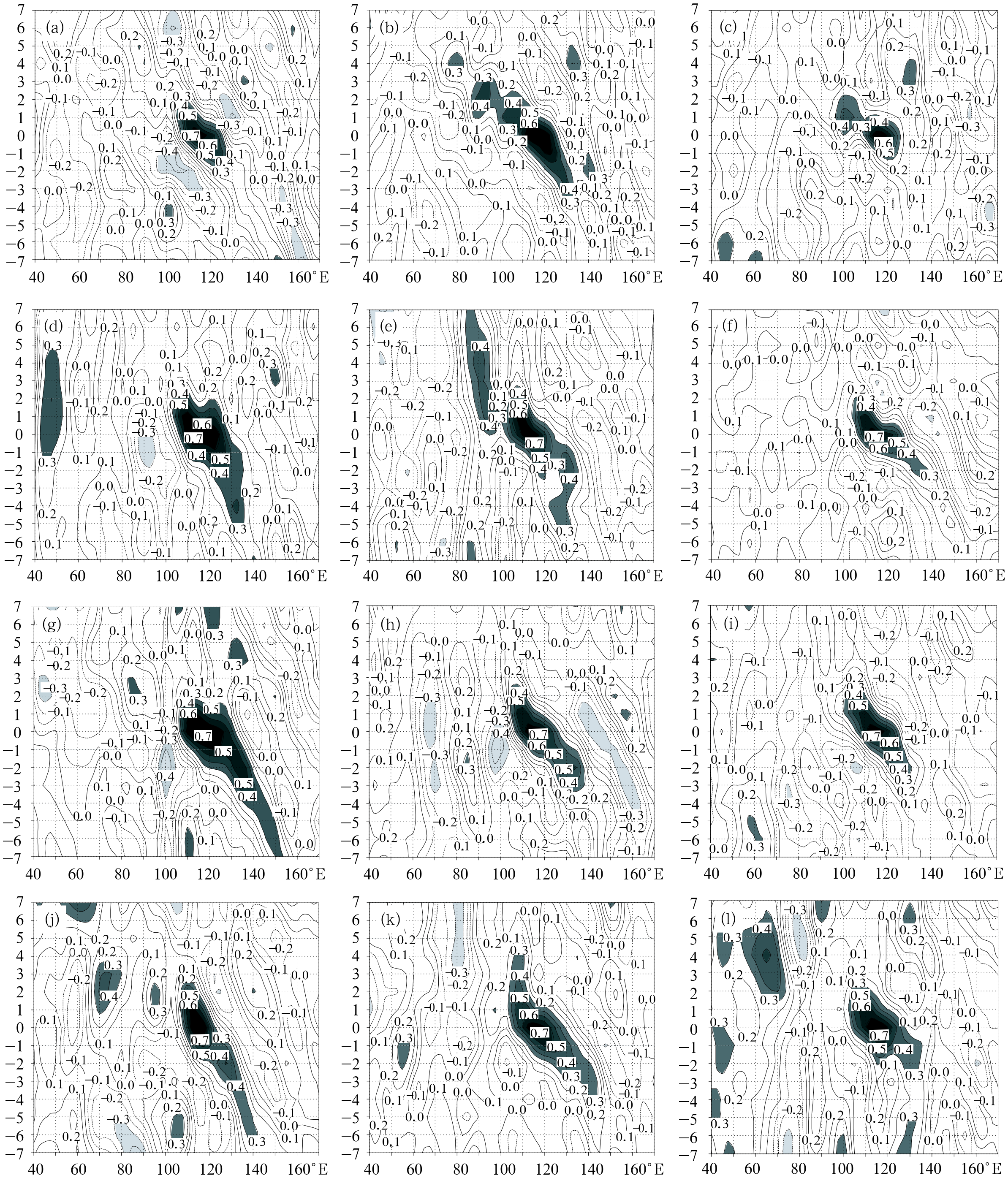

Fig.5. As in Fig.2, but for v, and the center located at 2.5°S-2.5°N, 110°-120°E.

points at 2.5°S-2.5°N, 40°-50°E and 2.5°S-2.5°N, 80°-90°E respectively, clear zonal propagation can hardly be seen (figures omitted). These also indicate that the EASM and ISM are quite different and should be independent.

4. Summary and discussion

We have examined the zonal propagation of disturbances of kinetic energy and convection in the domain region (5°-15°N) of Asian summer monsoon system (Chen et al., 2004). Results show that most of the disturbances of both K_{E} and convection come from the western Pacific Ocean (140°-150°E) and propagate to the BOB (95°-100°E) through the SCS in the EASM. While in the ISM, disturbances have been observed originating at the Arabian Sea and expanding to the BOB in about 1/3 cases, or propagating westward from the BOB in other 1/3 cases, or no clear propagation in the rest years. Therefore, the EASM and the ISM are quite different in zonal propagation of both K_{E} and convection and should be regarded as independent.

Based on the daily NCEP/NCAR reanalysis dataset from 1980 to 1997, the zonal propagation of 850 hPa kinetic energy and the meridional wind south of 5°N in the NH are examined respectively in this paper. East to 90°E, disturbances of both K_{E} and v observed are mainly coming from the West Pacific and propagating westward to the BOB passing through the SCS. But the propagation directions of both K_{E} and v are rather disorderly between the BOB and the Somalia low-level jet channel. Therefore, the East Asian summer monsoon and the Indian summer monsoon are also different in the propagation features of the disturbances of K_{E} and v in the equatorial region, which is similar to that of 5°-15°N. Above facts indicate that, East Asian monsoon system exists undoubtedly even at the equatorial region, and quite distinct from the Indian monsoon system, it is mainly affected by the disturbances coming from the tropical western Pacific rather than from the Indian monsoon region. The boundary of the two monsoon systems is around 95°-100°E, which is more westward than the counterpart as proposed in earlier studies by 5-10 degrees in longitude.

As we know, there also exists eastward propagation in the equatorial region, such as the zonal wind. It has already been recognized that the zonal wind over the tropical Indian Ocean has important influences on the onset of the SCS summer monsoon (Li and Wu, 2002). But for meridional wind or kinetic energy, we can hardly see the eastward propagation. Does the direction depend on the variables? What is the characteristic of the propagation for other variables? This is a basic question for Asian monsoon research but has not been resolved thoroughly.

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