Article ID: 1006-8775(2005) 02-0169-09

DECADAL CLIMATE VARIABILITY OF RAINFALL AROUND THE MIDDLE AND LOWER REACHES OF THE YANGTZE RIVER AND ATMOSPHERIC CIRCULATION

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ABSTRACT: This study examined the rainfall around the middle and lower reaches of the Yangtze River and related atmospheric circulation by using NCEP reanalysis data. The purpose of this study is to analyze their decadal variation and the relationship among rainfall, atmospheric circulation around East Asia and the ENSO episodes. Current results are presented as follows: (1) Very clear increasing trend of the rainfall around the middle and low reaches of the Yangtze River during the Meiyu period and June to July is found in the recent 15 years. Meanwhile, the geopotential height at 500 hPa around the Okhotsk Sea also holds similar increasing trend. It is noticeable that ENSO episodes tend to occur more frequently in the recent 15 years. (2) An index describing East Asian summer monsoon is well correlated with the SST in the Nino-3 region in preceding autumn in the recent 20 years but is not prior to the period. This means that the El Nino phenomenon exerts more impacts on East Asian summer monsoon recently. (3) The warm phase of PDO in the recent 20 years basically coincides with the increasing trend of the atmospheric circulation in East Asia.

Key words: East Asian summer monsoon; decadal variation; Meiyu

CLC number: P426.62.3 **Document code:** A

1 INTRODUCTION

Summer climate plays an especially important role in the people's daily life around East Asia, one of the most populated regions in the world, for most of the regions receive more than 70% of the annual precipitation in summer due to the effect of monsoon climate. Global climate change caused by mankind activities have become a hot topic in recent years, though it is still not clear how these activities result in the climate change around East Asia. Successive studies (Qin[1], Ding et al.[2], Zhai[3]) pointed out an outstanding rising trend of precipitation in areas south of the Yangtze River in the recent 10 – 20 years. Other related studies on the interdecadal variation of precipitation are also noticeable, e.g. Ju et al[4]. Particularly, using numerical simulations, Menon et al[5]. made a convincing demonstration that the interdecadal variation of drought-in-the-north versus floods-in-the-south pattern in the eastern part of China was caused by regional atmospheric circulation anomalies that are resulted from large absorption of solar rays due to persistent growth of black carbon aerosols over cities. Thus successfully explains why mankind activities have not led to significant warming in the summer of southern China. On the other hand, Wang et al.[6] show that the East Asian summer monsoon corresponds well with the onset of preceding El Niño episodes and much better with the precipitation in the Yangtze River and the

Received date: 2004-12-08; **revised date:** 2005-09-07
Foundation item: Research Fund for Tropical Oceans; Project 973 of the Ministry of Science and Technology (2004CB418300); No. 2002DIB20067 from the Ministry of Science and Technology.
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areas south of it. When the SST is higher in the Niño-3 area in the preceding autumn, the East Asian summer monsoon gets anomalously strong and precipitation to the south of the Yangtze River also increases. These abnormal phenomena remind one of the tendencies of frequent occurrence of the El Niño episode in the past more than 10 years. Evidences show that atmospheric warming due to human activities is one of the main causes for the frequent occurrence of the El Niño episode (Kito[7]). Wang et al. [6] pointed out an important impact of the El Niño phenomenon on the atmospheric circulation in the East Asian summer. In other words, when a strong El Niño event reaches to its mature phase in the autumn or winter, blocking highs tend to appear over northeastern Asia while the subtropical high anomalously extends to the west in the next summer. This pattern plays an important role in strengthening the summer monsoon over East Asia to lead to more precipitation in the regions to the south of the Yangtze River (which agrees with the composite analysis by Ye and Huang[8]). Therefore, if similar interdecadal variation can be found in preceding El Niño phenomenon and East Asian monsoon, one can say that an essential effect of the El Niño event on the interdecadal variation of the East Asian monsoon and an important effect on the interdecadal variation of the Meiyu in the Yangtze River basin are true. It is necessary to study extensively the interdecadal variation of precipitation in this area, which is one of the most populous parts of China, for it holds very important significance to the long-term drought/flood forecast. In view of the possibility that the interdecadal variation resulted from the El Niño phenomenon should affect the changes in the atmospheric circulation to cause anomalous precipitation, it is the effect on the variation of the general circulation that the current work attempts to work on, with special focus on those that are associated with the interdecadal precipitation anomalies in areas of the middle and lower reaches of the Yangtze River

2 DATA

The work uses the rainfall data during the Meiyu period in the Yangtze River from 1958 to 1999 measured at five weather stations of Nanjing, Wuhu, Shanghai, Hankou and Jiujiang, CMAP's June – August precipitation data from 1979 to 1999 (Xie-Arkin[9]), NCEP reanalysis data for geopotential height and wind fields at 850 and 500 hPa from 1958 to 2002 and Pacific Decadal Oscillation (PDO) time series as provided by Climate Diagnostic Center of the United States.

3 PRECIPITATION TENDENCIES AND CIRCULATION PATTERNS IN YANGTZE AND HUAIHE RIVER BASINS

It is generally accepted that the Meiyu rainfall is defined using the precipitation record at the five stations mentioned in Section 2. Fig.1 shows that the annual variation of precipitation at the stations and East Asian Monsoon Index (EAMI) over the period 1958 – 1999. EAMI is an index used by Wang et al. [6] to measure the intensity of East Asian monsoon. They once pointed out that there were close relationship between the index and rainfall in the raining season south of the Yangtze River and during the Meiyu period. We can see a clear rising trend of the monsoon index and rainfall in the Meiyu period beginning from the mid-1980's, with the coefficient of correlation between them being 0.353, which is above the 0.02 confidence level. In contrast to the monsoon index, the rising trend of the Meiyu rainfall seems more noticeable, indicating that the Meiyu rain front, a subsystem of the East Asian monsoon, is playing the most active role in the interdecadal rising trend. Additionally, satellite precipitation data that was provided by Xie-Arkin[9] were compared with the rainfall at the five stations. Fig.2 shows the rainfall averaged over June and July in the area of 27.5°N – 30°N, 110°E – 120°E, composed with the CMAP data.

Due to limited satellite data, rainfall was not available until 1979. The area covers most of the middle reach of the Yangtze River and matches the location of the mean Meiyu frontal zone for June and July (Wang[10]). It is then easy to find some differences in precipitation trends between the area and the five stations, though they agree in general tendencies (with the correlation coefficient being 0.51, exceeding the 0.02 confidence level). It is known from Fig.2 that the interdecadal rising trend of precipitation is more obvious in this area. As there were obvious trends of rising after the mid-1980's, only the pattern for this period will be discussed. Figures3a and 3b are the composite charts of geopotential height and wind field at 500 hPa and 850 hPa for June and July in 1971 – 1985, which are subtracted from those for the same months in 1986 – 2000. The figures show that the southerlies and northerlies at the level of 850 hPa obviously converge near the middle and lower reaches of the Yangtze River (about 30°N), with the strong anticyclonic circulation over Mongolia, the Okhotsk Sea and Ogasawara Islands versus deep cyclonic circulation off the east coast of Japan. The East Asian monsoon is very active around the Yangtze River (Wang et al. [6]). The circulation pattern is much a favorable condition for the precipitation in the middle and lower reaches of the Yangtze River but not for that in North China. Similar patterns are identified at the 500-hPa level: The ridge of the subtropical high is further southward than usual and extends much to the west; there is a strong ridge near the Okhotsk Sea, accompanied by a positive anomaly center. Comparing the 850-hPa composite in the paper of Wang et al. [6] for the situation of a strong summer monsoon in East Asia, we find that the distribution in Fig.4 is quite similar to that in Fig.3b. For example, there are also anticyclonic circulation and centers of high anomalies north of the Okhotsk Sea and near the Ogasawara Islands and convergence of southwesterly anomalies near 30°N. What is different is that there is no anticyclonic circulation from North China to Mongolia in Fig. 4. It indicates that the East Asia monsoon has been quite active in the recent 15 years and associated with a pattern of circulation in which the Okhotsk high and the ridge around Ogasawara Islands become stronger. The anticyclonic circulation from North China to Mongolia as shown in Fig.3 is apparently linked with the atmospheric circulation pattern associated with drought in northern China as pointed by Menon et al. [5]. Wang[10], Wang and Song[11] have pointed out that the blocking high aorund the Okhotsk Sea was very important for stabilizing the Meiyu front. Wang et al. [10] also illustrate the important role played by the propagation of the Rossby wave which was associated with the Okhotsk Sea high in suppressing the northward progression of the subtropical high. It is therefore seen that the Okhotsk Sea high is an important factor in the precipitation in the Yangtze River valley and areas south of it. Future study about the physical mechanism for the formation of the Okhotsk Sea high, apart from the location of the subtropical high, is desirable.

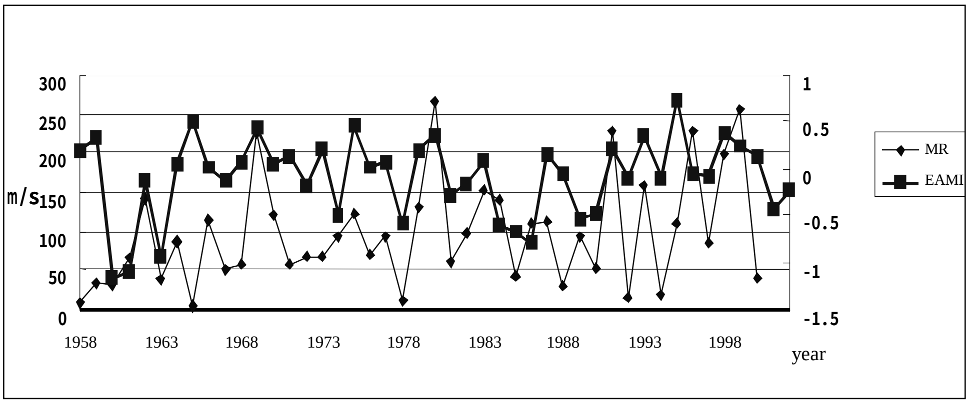

Fig.1 Interannual variation of precipitation in the five stations in the valley of the Yangtze River and the East Asian Monsoon Index (EAMI).

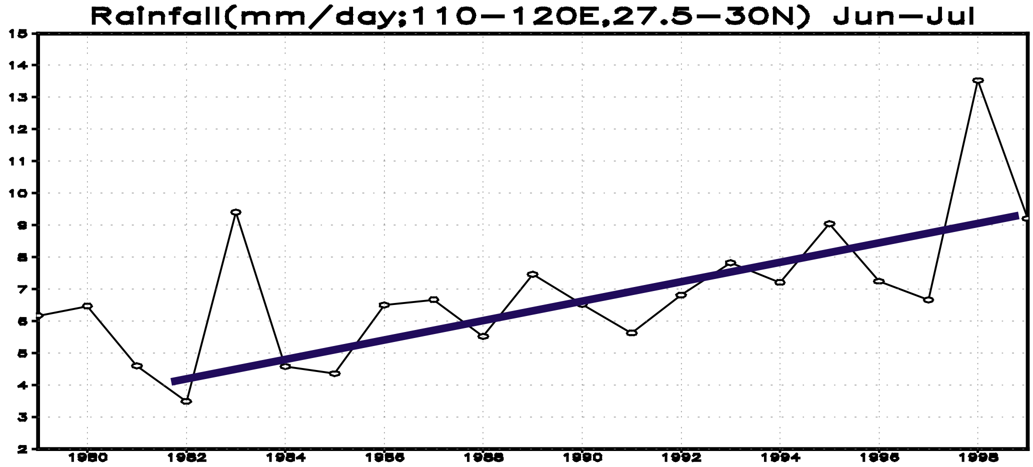

Fig.2 Time series of mean rainfall at 27.5°N – 30°N, 110°E – 120°E averaged over June and July 1979 – 1999.

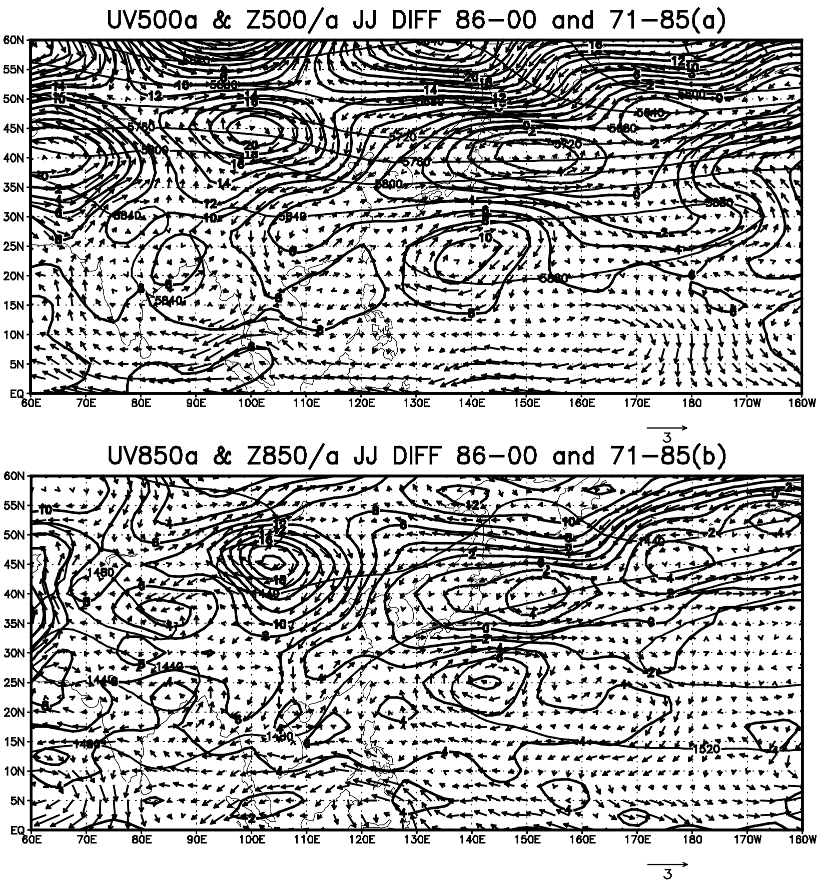

Fig.3 Geopotential height fields, their anomalies and wind field anomalies at 500 hPa (a) and 850 hPa (b) averaged over June and July 1986 – 2000, which are subtracted from those for 1971 – 1985.

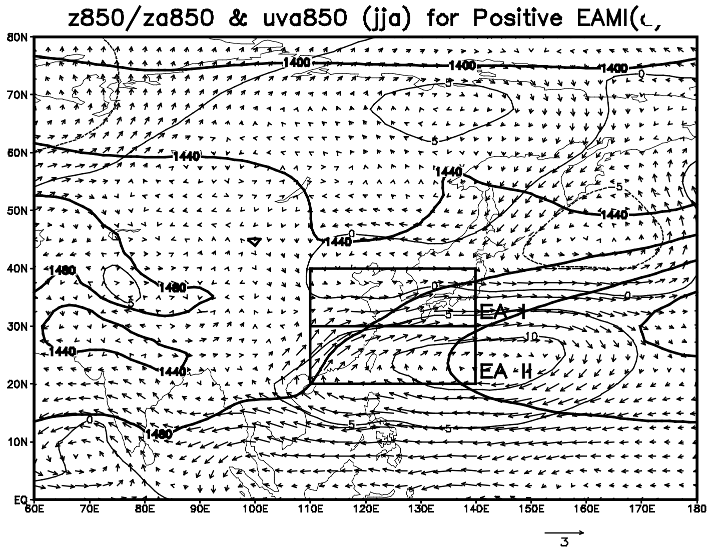

Fig.4 Summertime geopotential height fields, their anomalies and wind field anomalies at 850 hPa with strong East Asian monsoon (Wang et al[10]).

4 INTERDECADAL VARIATION OF SST AND MAIN CIRCULATION SYSTEMS IN EAST ASIA

Wang et al.[6] pointed out that ENSO episode usually develops maturely in autumn, which is well responded to the atmospheric circulation around East Asia in the following summer. Figure 5 shows the temporal variation of SST in the Niño-3 region during September – November. It is seen from Fig. 5 that there are only 4 years after the mid-1980's in which SST is a little lower than –0.5°C, but with quite a number of positive, wide-amplitude SST anomalies. It shows much more frequent occurrence of the El Niño events after the 1980's. Correlation between SST in preceding autumn in Niño-3 region and EAMI in the current summer is 0.45 over the recent 20 years (1981 – 2000) while it is 0.17 for another 20 years (1961– 1980), implying more significant impact of the El Niño phenomenon on the general circulation in recent years. Another remarkable phenomenon of air-sea interaction is PDO, which is an anomalous SST event similar to ENSO but with larger temporal and spatial scales. The index is defined as the first EOF component of the SST over Northern Pacific ocean. Therefore, PDO is a signal of North Pacific SST rather than tropical eastern Pacific, though it is well correlated with the SST in the Niño-3 region (with the correlation coefficient at 0.36 for 677 samples). It is because positive SST anomalies in the equatorial eastern Pacific is usually associated with negative one in North Pacific. The decadal variation is also the most significant feature of PDO. PDO's first period cycle is between 15 and 20 years and the second one even longer. It is interesting that the SST distribution in the warm phase of PDO is similar to that of the onset of the El Niño episode. This explained why the warm phase of PDO is accompanied by the El Niño events frequently occuring over the past 10 plus years. A persistent warm phase of PDO from 1977 to 1997 as shown in Fig. 6 implies that El Niño episodes with the cool water over North Pacific frequently occur in the recent 20 years. Thus, the composite chart (Fig.3) roughly represents how the atmospheric circulation looks like with the warm phase of PDO. Figure 7 shows the composite map of 850-hPa geopotential height anomalies in the years when El Niño episodes decay (Wang et al. [6], composite includes the summers of 1966, 1973, 1983, 1988 and 1998. Similar to Fig.4, Figure 7 shows that anomalous anticyclonic circulation also exists over the Ogasawara Islands and the region to the north of the

Okhotsk Sea. This shows that the ENSO event and air-sea interactions resulted from the warm PDO phase are much associated with the abnormally westward extending subtropical high and the Okhotsk high.

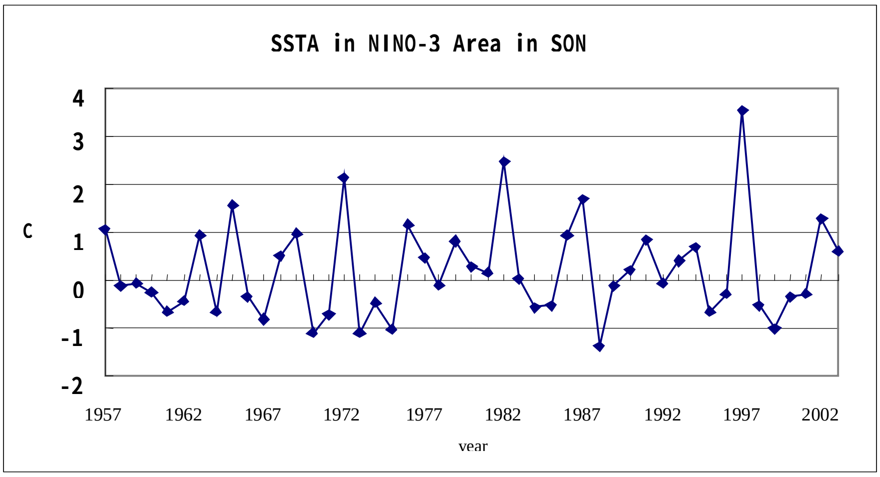

Fig.5 Temporal variation of seawater in September – November in the Niño-3 area.

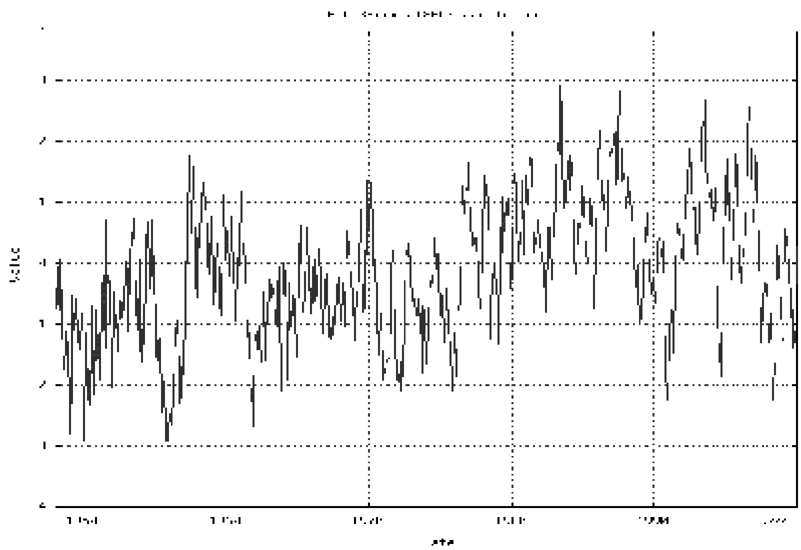

Fig.6 Time series of PDO from 1948 to 2002.

As mentioned above, El Niño episodes are related to the strong East Asian monsoon in the following summer. From the composite charts of Fig.3 and Fig.4, we have known that a strong East Asian monsoon is linked with the strengthening of highs over the Okhotsk Sea and Ogasawara Islands. We will examine the two systems in detail. Figure 8 shows the temporal variation of anomalies from zonal mean geopotential height near the Okhotsk Sea (55°N – 60°N, 135°E – 140°E) and the Ogasawara Islands (22.5°N – 27.5°N, 132.5°E – 142.5°E) at 500 hPa in June and July from 1958 to 2002. The anomaly not to be one of temporal variation is to show how active troughs and ridges are in the same latitudes. The geopotential height anomalies for the two areas can also be viewed as the indicators of activity of the Okhotsk high and the subtropical high. The figure shows that there is a significant rising trend of the geopotential height after the

1980's around the Okhotsk Sea, which reaches the maximum in 1998, while the subtropical high does not increase so much. It is seen that the trend for the Okhotsk Sea high to be more active is quite consistent with the interdecadal trend of precipitation in the middle and lower reaches of the Yangtze River. This implies that the frequent occurrence of the Okhotsk Sea blocking high may exert impacts on the persistent increase of rainfall during the Meiyu period in the Yangtze River

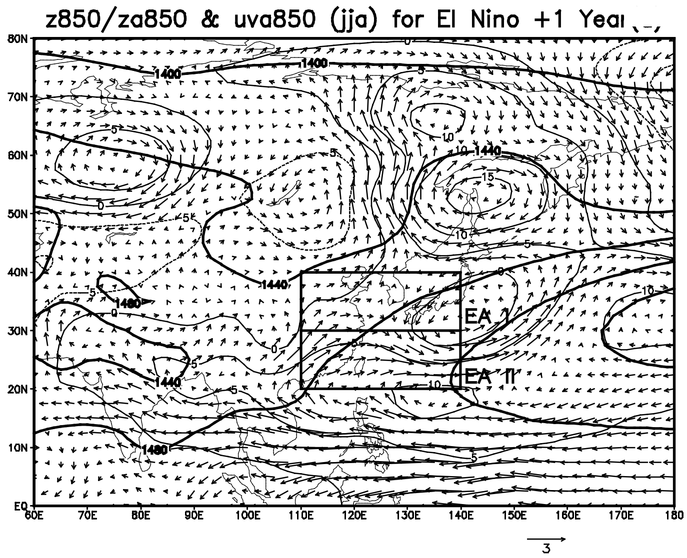

Fig.7 Composite chart of 850-hPa geopotential anomalous wind field in years with weakened El Niño phenomenon (Wang et al. [6]).

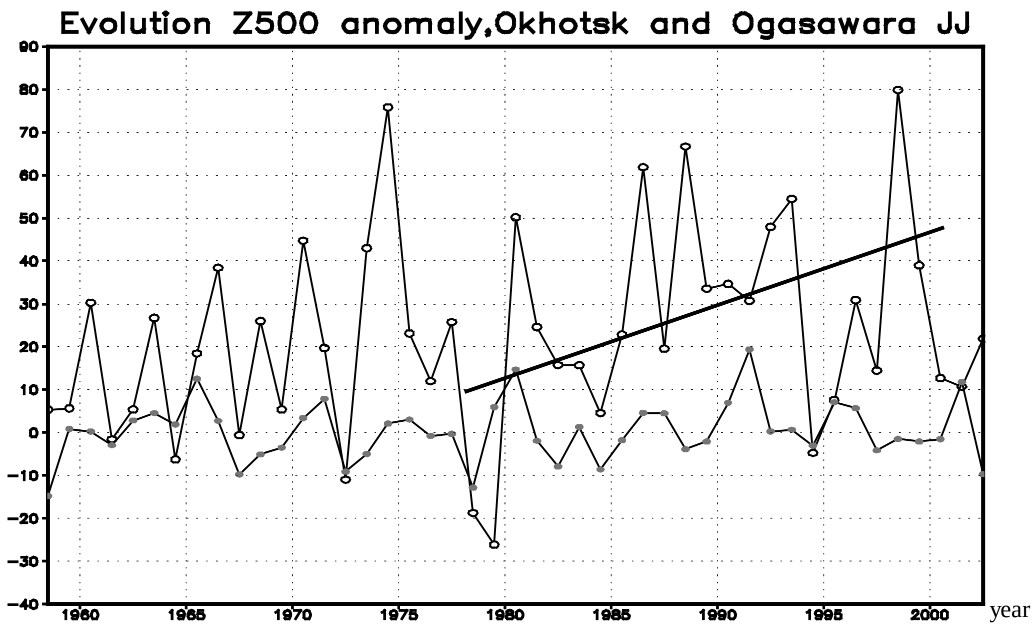

Fig.8 Temporal variation of mean anomalies of zonal geopotential height field near the Okhotsk Sea (55°N – 60°N, 135°E – 140°E) and the Ogasawara Islands (22.5°N – 27.5°N, 132.5°E – 142.5°E) at 500 hPa in June and July from 1958 to 2002.

5 CONCLUSIONS AND DISCUSSIONS

We, using 42 years data, examined the decadal variation of precipitation around the Yangtze River. We found:

a. Very clear increasing trend of the rainfall around the middle and low reaches of the Yangtze River during the Meiyu period and June to July is found in the recent 15 years. Meanwhile, the geopotential height at 500 hPa around the Okhotsk Sea also holds similar increasing trend. It is noticeable that ENSO episodes tend to occur more frequently in the recent 15 years.

b. An index describing East Asian summer monsoon is well correlated with the SST in the Nino-3 region in preceding autumn in the recent 20 years but is not prior to the period. This means that the El Nino phenomenon exerts more impacts on East Asian summer monsoon recently.

c. The warm phase of PDO in the recent 20 years basically coincides with the increasing trend of the atmospheric circulation in East Asia.

Though the relationship between the East Asian general circulation and the El Niño phenomenon is basically known, new observational data show that the former is increasingly affected by the air-sea interaction. For the warm phase of PDO, North Pacific is of persistent negative SST anomalies, which may have large contribution to the development of the Okhotsk high. This is because when rapid warming occurs over the continent to the west of the Okhotsk Sea in early summer, a strong east-west temperature gradient is formed, which favors to form the Okhotsk High, so that the Meiyu front becomes more steady. More numerical simulations about the physical mechanism for the air-sea interaction are needed. In addition, the interdecadal rising trend of precipitation in most of the South China regions should be affected by the growth of black carbon aerosol, which is, in some extent, different from the El Niño phenomenon. As a matter of fact, it is known from Fig.3 (Menon et al. [5]) that the contribution of increased black carbon aerosol is mainly seen in the increasing trend of precipitation in the southern parts of Guangdong and Guangxi provinces in China while that of the El Niño phenomenon in areas south of the middle and lower reaches of the Yangtze River, especially Hubei, Hunan and northern Jiangxi provinces in China. Though not the focus for the current work, how to distinguish effects of black carbon aerosol from those of El Niño phenomenon should also be studied in the future.

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