Interannual to Interdecadal Variation of East Asian Summer Monsoon and its Association with the Global Atmospheric Circulation and Sea Surface Temperature①

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ABSTRACT

The East Asian summer monsoon (EASM) underwent an interdecadal variation with interannual variations during the period from 1958 to 1997, its index tended to decline from a higher stage in the mid–1960's until it reached a lower stage after 1980's. Correlation analysis reveals that EASM is closely related with the global atmospheric circulation and sea surface temperature (SST). The differences between the weak and strong stage of EASM shows that, the summer monsoon circulation over East Asia and North Africa is sharply weakened, in the meantime, the westerlies in high latitudes and the trade–wind over the tropical ocean are also changed significantly. Over the most regions south of the northern subtropics, both air temperature in the lower troposphere and SST tended to rise compared with the strong stage of EASM. It is also revealed that the ocean–atmosphere interaction over the western Pacific and Indian Ocean plays a key role in interannual to interdecadal variation of EASM, most probably, the subtropical Indian Ocean is more important. On the other hand, the ENSO event is less related to EASM at least during the concerned period.

Key words: East Asian summer monsoon, Inerannual to interdecadal variation, The global atmospheric circulation, Sea surface temperature

1. Introduction

Observational studies revealed that the global climate system has an interdecadal variation besides interannual variability associated with El Niño and South Oscillation (ENSO). The abrupt change of the global climate in 1960's–1970's is a typical interdecadal event, which can fully be depicted with the present observational data (Yan et al, 1990; Li and Li, 1999). In addition to the global climate, being accompanied with interannual variations, large interdecadal variation was found for the regional climate over East Asia (Ye and Huang, 1996; Hu, 1997), for instance, the northern China has been struck by a series of dry spells since 1965, rainfall over the yangtze and Huaihe river valley increased considerably after the end of 1970's, but the above studies focused mainly on rainfall and temperature, in particular, the physical cause of interdecadal variation of the regional climate is not very clear. Since EASM has an important influence on the regional summer climate, a further study from the view–point of EASM is helpful to understanding the long–term climatic change over East Asia.

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In this study, interannual to interdecadal variation of EASM and its relation to the global atmospheric circulation and SST are analyzed by using the NCEP/ NCAR (National Climate and Environment Prediction / National Center for Atmospheric Research) reanalysis data from 1958 to 1997, besides, the variations of the global atmospheric circulation and SST associated with interdecadal variation of EASM are studied through the differences between the weak and strong EASM. Based on this, the possible mechanism responsible for interannual to interdecadal variation of EASM is further discussed.

2. Data and methodology

Monthly mean data including wind, geopotential height and air temperature are provided by NCEP/ NCAR on a resolution of 2.5° × 2.5° during the period from 1958 to 1997 (Kalnay et al, 1996). Monthly mean SST data are provided by NCAR with a resolution of 2° × 2° from 1958 to 1992 and with a resolution of 1° × 1° from 1993 to 1997 respectively, which are only validated from 45°S to 69°N (Reynolds and Smith, 1994), the 1° × 1° SST data are matched to the 2° × 2° SST data using interpolation method on 2° × 2° grid box.

Correlation analysis and difference maps are combined together to study interannual to interdecadal variation of EASM and its relation with the global atmospheric circulation and SST, Student's t test is adopted to check the significance level.

3. Temporal variation of East Asian summer monsoon and its global correlation patterns

In order to quantitatively evaluate the strength of EASM, Wang (2000a) defined an index (M_I) that is represented by the anomaly of 850 hPa wind speed in summer (June–July–August) over the region of 110°–125°E, 20°–40°N. Figure 1 shows the temporal variation of this index from 1958 to 1997, M_I reached its maximum in the early 1960's, then it continued to decline with interannual oscillation and reached its minimum by the end of 1970's, after 1980, it exhibited a clear quasi-biennial oscillation with a relatively stable amplitude. It is evident that EASM underwent an interdecadal variation along with interannual variations during this period.

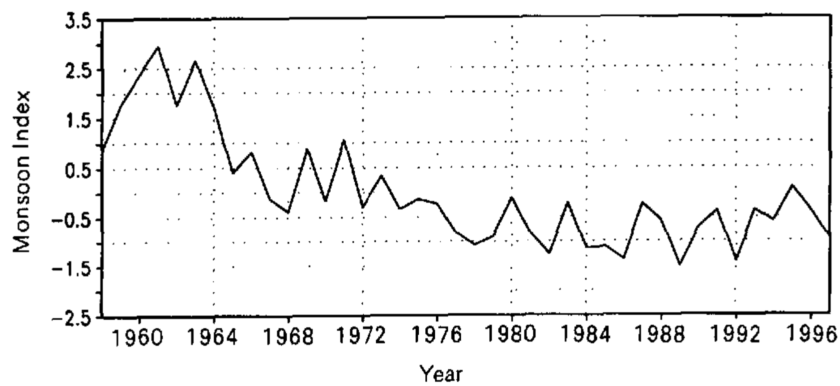

Fig. 1. Temporal variation of East Asian summer monsoon index (m / s), see text for its definition.

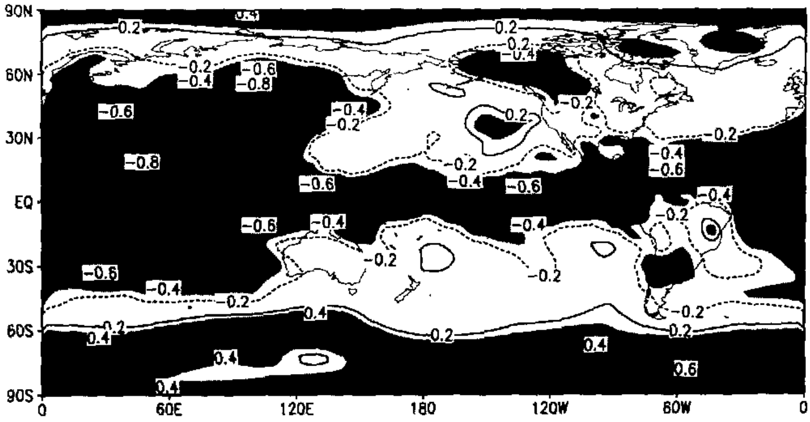

Fig. 2. Correlation coefficient between M_i and 850 hPa geopotential height in summer during the period of 1959–1997, regions over 95% significance level are shaded.

To illustrate the relationships between the global atmospheric circulation and EASM, Fig. 2 shows correlation coefficient between M_i and 850 hPa geopotential height (H_{850}) in summer during the period from 1958 to 1997. Over vast areas in the the Eastern Hemisphere west of 120°E between the southern subtropics and the northern midlatitudes, M_i is negatively correlated with H_{850}, indicating that EASM is closely related with the large–scale atmospheric circulation. Similar to that rainfall in northern China is significantly correlated with that in Sahel (Yan et al, 1990), the largest negative correlation regions with correlation coefficient over −0.8 are found in midlatitudes of East Asia and North Africa. Besides, M_i is negatively correlated with H_{850} over the other tropical regions from the western Pacific to Atlantic, the major positive correlation is found over the polar regions. Moreover, there is a trace of PNA (Pacific–North America) pattern arching from the eastern Pacific to North America, indicating that EASM circulation is somewhat related to the PNA pattern.

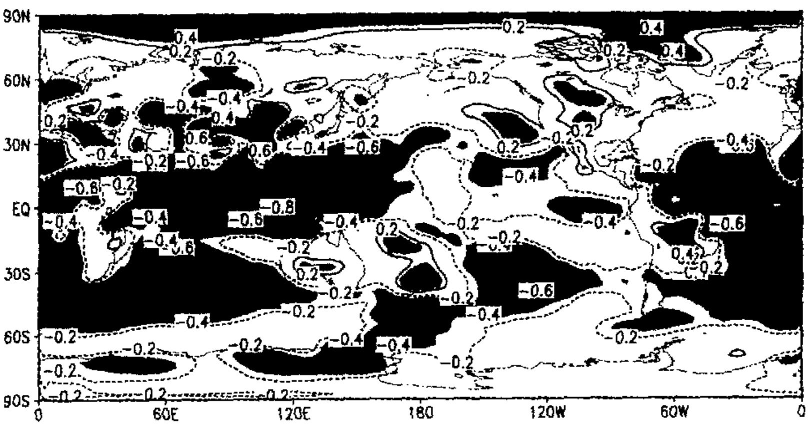

Fig. 3. As in Fig. 2, except for 850 hPa air temperature in summer.

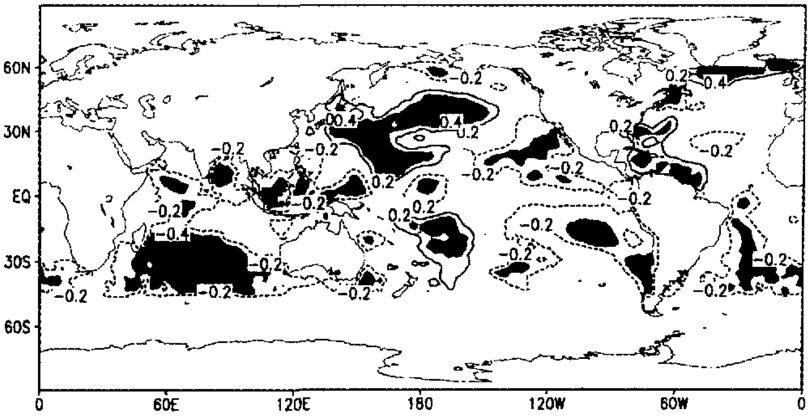

Fig. 4. As in Fig.2, except for sea surface temperature in summer.

Figure 3 shows correlation coefficient between M_i and 850 hPa air temperature (T_{850}) in summer. Except the positive correlation over the Arctic and midlatitudes of East Asia and North America, M_i is negatively correlated with T_{850} over most regions south of the northern subtropics with significant correlation over the western and southern Pacific, the Indian and Atlantic Ocean and several parts of the Antarctic. Overall, the highest correlation regions are mainly located over oceans, showing that the ocean–atmosphere interaction is important to EASM.

As shown in Fig. 4, the major negative correlation between M_i and SST are located in the Indian Ocean, the tropical western Pacific, the subtropical eastern Pacific and the subtropical southern Atlantic, the major positive correlation are located in the Northern Pacific and southern Pacific east of Australia and near the adjacent regions of the Caribbean Sea. In particular, in the subtropical Indian Ocean where the Mascarene high occupies, H_{850}, T_{850} and SST are all negatively correlated with M_i, implying that the ocean–atmosphere interaction over this region is of great importance to the variation of EASM during this period.

4. Differences of the global atmospheric circulation and sea surface temperature between weak and strong East Asian summer monsoon

As shown in Fig.1, EASM changed its strength from strong to weak monsoon with the transition occurring from the mid–1960's to the end of 1970's. To study the differences between the two stages, we simply take 1958–1965 as the strong monsoon stage and 1980–1997 as the weak one, the climatological mean differences of 850 hPa wind, T_{850} and SST in summer are shown in Figs. 5–7 respectively.

In Fig. 5, an anticyclone circulation is found over East Asia with the strong north wind along the coast, signaling the weakening of monsoon circulation especially the south wind over the coastal areas at the weak stage of EASM, the North Pacific subtropical high which has a close relationship to EASM is slightly weakened. In contrast, the tropical monsoon near Indonesia seems to enhance. In agreement with the result in Fig. 2, the African summer

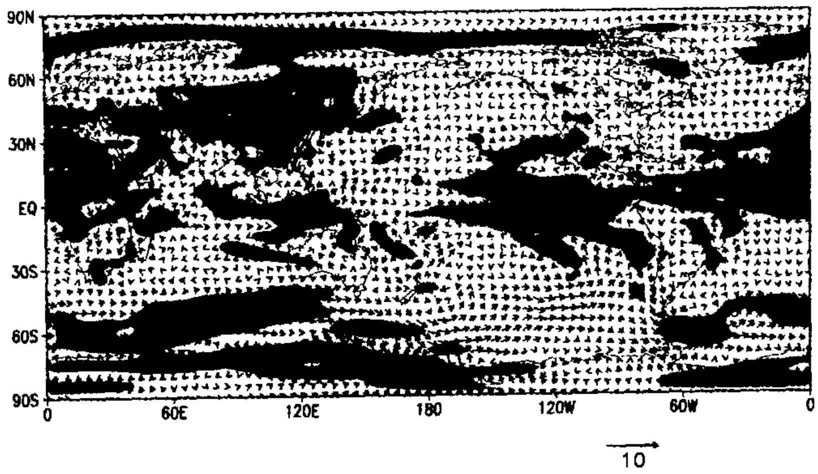

Fig. 5. Difference of 850 hPa wind in summer between 1980–1997 and 1958–1965, regions over 95% significance level are shaded.

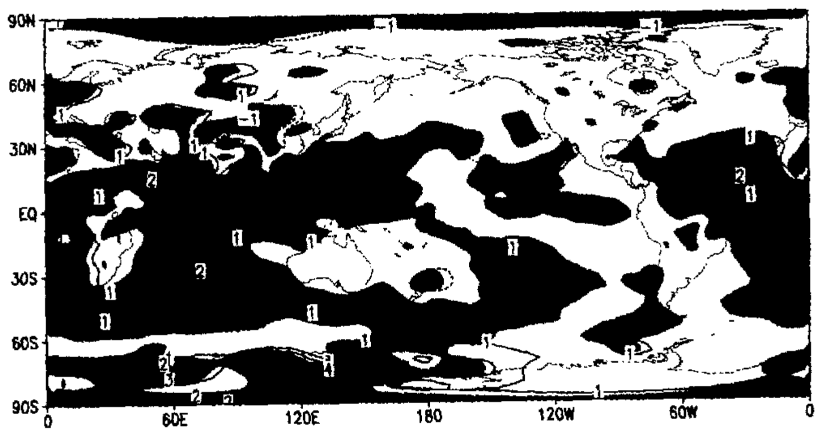

Fig. 6. As in Fig. 5, except for 850 hPa air temperature in summer (K).

monsoon is weakened in the meantime. Also evident is the weakening of the trade–wind in the eastern Pacific and the strengthening in the tropical Atlantic. In high latitudes of both hemispheres, the westerlies are strengthened especially in the Eastern Hemisphere.

The differences of T_{850} and SST are shown in Fig. 6 and Fig. 7 respectively. Over the oceanic regions, the distribution of T_{850} is similar to that of SST except for several parts of the North Pacific, both T_{850} and SST over the most regions south of 20°N rises evidently, T_{850} increases by 1–2 K with the greatest of 6K over the Antarctic and SST increases with a smaller amplitude of 0.2–0.6K, the temperature–increase with the largest range is found in the western Pacific and Indian Ocean especially the subtropical Indian Ocean. In contrast

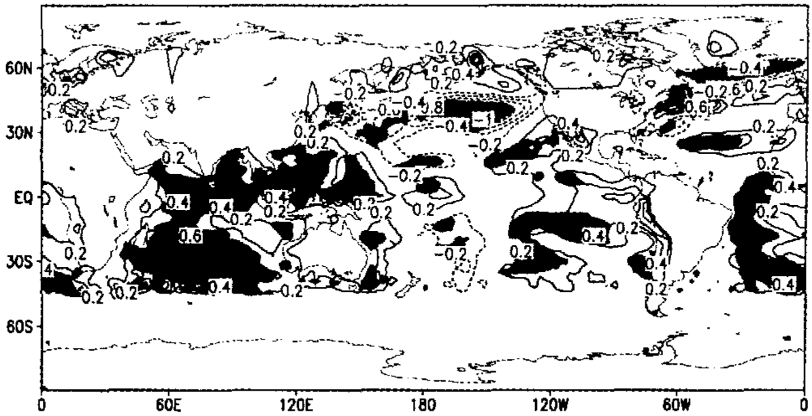

Fig. 7. As in Fig. 5, except for sea surface temperature (K).

with oceans, T_{850} over the Arctic and midlatitudes of East Asia tends to fall, for the latter it exists in the whole troposphere with the largest reduction at 300 hPa (not shown). Thus, because the land–sea temperature contrast in summer is reduced due to the common actions of temperature–increase over continents and temperature–increase over oceans south of East Asia, it is not difficult to understand why EASM is weakened. Nevertheless, considering the range and strength of temperature change, ocean plays a principal role in interannual to interdecadal variation of EASM.

5. Possible mechanism responsible for interannual to interdecadal variation of East Asian summer monsoon

The relationship between EASM and SST in particular the ENSO event has been studied exhaustively (e.g., Fu, 1991; Chen et al, 1991; Wang et al, 1999), the influences of SST and convective activity on EASM in other oceanic regions including the warm pool of the western Pacific and the tropical Indian Ocean are also emphasized (Huang and sun, 1992; Hu, 1997). Compared with the tropics, the extra–tropical regions have received relatively less attention up to now.

The study by Huang et al (1987, 1988) indicates that, as one of major sources of EASM, the Mascarene high over the subtropical Indian Ocean has great influences on EASM on seasonal scale. According to the above correlation analyses and difference maps, the influences of the subtropical Indian Ocean on EASM from interannual to interdecadal scale are also important. In order to further examine the influences of changes in SST over several oceanic regions mentioned above, Fig. 8(a) shows the temporal variation of SST anomalies in summer over the subtropical Indian Ocean (40°–90°E, 25°–35°S), the Equatorial Indian Ocean (60°–90°E, 5°N–5°S) and the western Pacific (110°–130°E, 5°–15°N), for the sake of comparison, Fig. 8(b) shows the corresponding results over Nino3 region (90°–150°W, 5°N–5°S), correlation coefficient between M_I and SST over the above four regions is −0.48, −0.27, −0.26 and −0.16 respectively (also shown in Fig.4). As it is well–known, in Fig. 8(b), SST anomaly over Nino3 region is dominated by interannual oscillation on 3–5 years scale although it

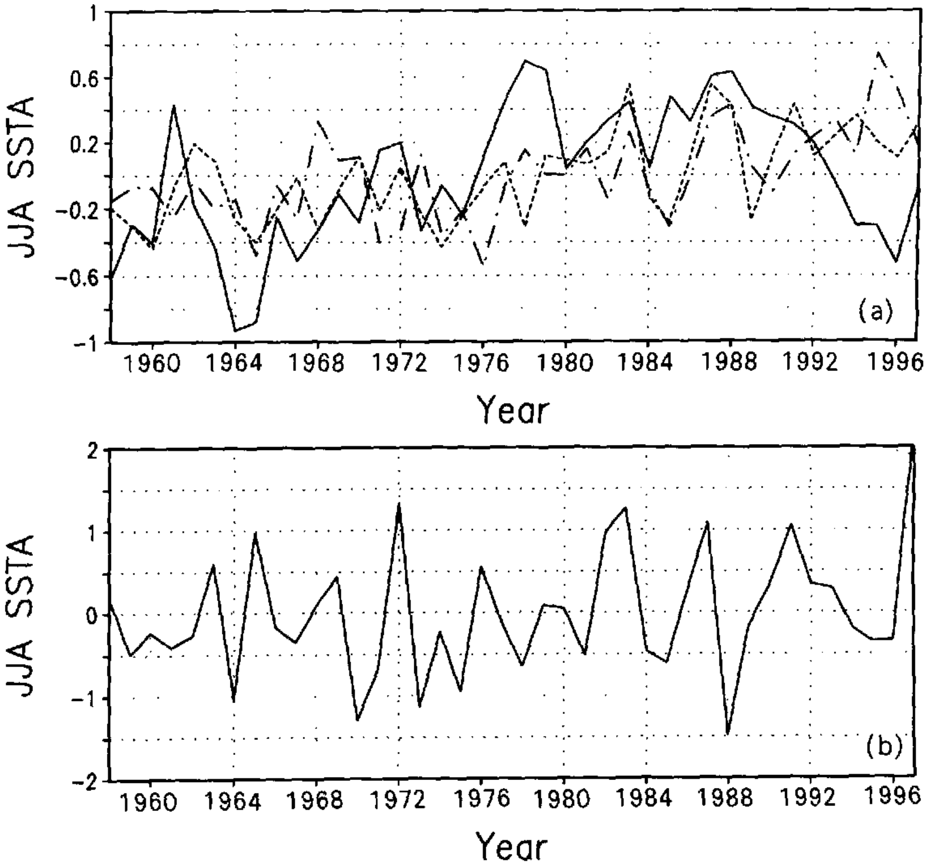

Fig. 8. Temporal variation of SST anomalies in summer (K), (a) subtropical Indian Ocean (40°–90°E, 25°–35°S), Equatorial Indian Ocean (60°–90°E, 5°N–5°S) and western Pacific (110°–130°E, 5°–15°N) denoted by solid, dashed and dot–dashed line respectively, (b) Nino3 region (90°–150°W, 5°N–5°S).

possesses the greatest amplitude, besides, it is less related to M_I with correlation coefficient of only −0.16. On the contrary, SST anomalies over the former three regions (Fig. 8a) have a clear interdecadal tendency although with a lower amplitude, in particular SST anomaly over the subtropical Indian Ocean varies in a generally opposite tendency of M_I (Fig. 1), its correlation coefficient with M_I is as high as −0.48 which is over significance level of 99.9%. Therefore, at least during the concerned period, it is not possible that interannual to interdecadal variation of EASM is mainly resulted from the ENSO event. On the other hand, the ocean–atmosphere interaction over the western Pacific and Indian Ocean in particular the subtropical Indian Ocean plays a crucial role in the variation of EASM.

6. Concluding remarks

The results in this paper shows that EASM underwent an interdecadal variation along with interannual variations from 1958 to 1997, the index of EASM continued to decline from a higher stage in the mid–1960's until it reached a lower stage after 1980's. Correlation analysis reveals that EASM bears a close relationship to the global atmospheric circulation and SST, the major significant correlation regions are found in the Eastern Hemisphere from the subtropics to the tropics, the tropical Pacific and Atlantic Ocean and the polar regions. The differences between the weak and strong stage of EASM show that, summer monsoon circulation over East Asia and North Africa is substantially weakened, the southwest wind along the coast of East Asia is also weakened, in the meantime, the trade–wind is weakened in the tropical Pacific while it is strengthened in the tropical Atlantic, also evident is the strengthening of the westerlies in high latitudes of both hemispheres. Furthermore, 850 hPa air temperature and SST over most regions south of the northern subtropics rise obviously, the largest temperature–increase is found over the Antarctic for 850 hPa air temperature and over the subtropical Indian Ocean for SST, however, 850 hPa air temperature in midlatitudes of East Asia and the Arctic falls.

Although SST in the equatorial eastern Pacific varies with the greatest amplitude on interannual scale, its interdecadal tendency is not so obvious as that in the western Pacific and Indian Ocean, moreover, it has a relatively lower correlation coefficient with EASM, therefore, it is unreasonable that the variation of EASM is mainly attributed to the ENSO event during the concerned period. Summarizing the results in this study, we believe that, as one of major sources of EASM, the ocean–atmosphere interaction in the western Pacific and Indian Ocean in particular the subtropical Indian Ocean plays a key role in the long–term variation of EASM. Yet, a numerical experiment is still needed to realize the detailed processes involved with the variation of EASM. In addition, the land–sea temperature contrast in summer is reduced by the temperature–decrease in midlatitudes of East Asia to a certain degree. Finally, the significant correlation between 850 hPa air temperature and EASM and the largest temperature–increase over the Antarctic reminds us that, the variation of EASM is possibly influenced by the changes in sea–ice over the Antarctic, however, the relation between EASM and sea–ice over the Antarctic is not studied due to lack of the observations before 1970's.

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东亚夏季风的年际到年代际变化及其与全球大气环流和海表温度的联系

薛 峰

摘 要

伴随着年际变化过程，东亚夏季风在1958年到1997年期间经历了一次年代际变化，其指数从60年代中期的高值期持续下降，80年代之后达到低值期。相关分析显示东亚夏季风与全球大气环流和海表温度有密切关系。东亚夏季风弱与强时期之差表明，东亚和非夏季风环流有很大减弱，同时，高纬西风带和热带海洋上的信风也有很大变化。在北半球副热带以南的大部分地区，对流层低层气温和海表温度均有升高趋势。研究结果还表明，西太平洋和印度洋地区的海气相互作用对东亚夏季风的年际到年代际变化起到关键作用，并且，副热带印度洋有可能更重要。但至少在上述时间尺度上，ENSO事件似乎与东亚夏季风关系不大。

关键词：东亚夏季风，年际到年代际变化，全球大气环流，海表温度