Article ID: 1006-8775(2011) 01-0018-09

NUMERICAL EXPERIMENT ON IMPACT OF ANOMALOUS SST WARMING IN KUROSHIO EXTENSION IN PREVIOUS WINTER ON EAST ASIAN SUMMER MONSOON

WANG Xiao-dan (王晓丹)[1, 2], ZHONG Zhong (钟　中)[1], TAN Yan-ke (谭言科)[1], DU Nan (杜　楠)[3]

(1. Institute of Meteorology, PLA University of Science and Technology, Nanjing 211101 China; 2. Institute of Aeronautical Meteorology, Air force Academy of Equipment, Beijing 100085 China; 3. Meteorological Center in Chengdu Air Command, Chengdu 610041 China)

Abstract: The impact of anomalous sea surface temperature (SST) warming in the Kuroshio Extension in the previous winter on the East Asian summer monsoon (EASM) was investigated by performing simulation tests using NCAR CAM3. The results show that anomalous SST warming in the Kuroshio Extension in winter causes the enhancement and northward movement of the EASM. The monsoon indexes for East Asian summer monsoon and land-sea thermal difference, which characterize the intensity of the EASM, show an obvious increase during the onset period of the EASM. Moreover, the land-sea thermal difference is more sensitive to warmer SST. Low-level southwesterly monsoon is clearly strengthened meanwhile westerly flows north (south) of the subtropical westerly jet axis are strengthened (weakened) in northern China, South China Sea, and the Western Pacific Ocean to the east of the Philippines. While there is an obvious decrease in precipitation over the Japanese archipelago and adjacent oceans and over the area from the south of the Yangtze River in eastern China to the Qinling Mountains in southern China, precipitation increases notably in northern China, the South China Sea, the East China Sea, the Yellow Sea, and the Western Pacific to the east of the Philippines. North China is the key area where the response of the EASM to the SST anomalous warming in the Kuroshio Extension is prominent. The surface air temperature shows a warming trend. The warming in the entire troposphere between 30ºN and 50ºN increases the land-sea thermal contrast, which plays an important role in the enhancement of the EASM. Atmospheric circulation and precipitation anomalies in China and its adjacent regions have a close relationship with the enhancement of the Western Pacific subtropical high and its northward extension.

Key words: East Asian summer monsoon; numerical experiment; anomalous warming; Kuroshio Extension

CLC number: P462.4 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2011.01.003

1 INTRODUCTION

Driven by the thermal contrast between the Asian continent and the surrounding oceans[1, 2, 3], the subtropical East Asian summer monsoon (EASM) affecting China, Japan, and the Korean peninsula (20ºN–45ºN, 100ºE–140ºE) is one of the active components of the global climate system. Therefore, the formation and development of the EASM is directly affected by anomalous variations in the sea surface temperature (SST). The relationship between anomalous SST and the EASM has been identified in numerous studies. For example, in different phases of the El Niño-Southern Oscillation (ENSO) cycle, the EASM and the precipitation exhibit different features[4-9], and the ENSO affects the precipitation in East Asia considerably via moisture transportation during the monsoon[10]. It has been found that an increase in the SST in the north Atlantic, accompanied by a decrease in the south Atlantic, results in the intensification of the EASM[11] . It has also been noted that the response to El Niño leads to the sea-basin-scale warming of the Indian Ocean; this has important effects on the summer climate in the Indian Ocean and the western Pacific Ocean[12]. It has been shown that the Asian summer monsoon is closely related to the Indian Ocean Dipole (IOD), an anomalous SST pattern in the Indian Ocean. A normal (late) South China Sea summer monsoon onset is associated with the previous positive (negative) IOD. In the summer after an IOD year, a positive (negative) IOD tends to induce a stronger (weaker) South Asian

Received 2010-05-30; **Revised** 2010-11-17; **Accepted** 2011-01-18

Foundation item: National Program on Key Basic Research Project of China (973 Program) (2007CB411805; 2010CB428505); National Natural Science Foundation of China (40830958)

Biography: WANG Xiao-dan, Ph.D., mainly undertaking the study on air-sea interactions.

Corresponding author: ZHONG Zhong, e-mail: zhongzhong@jsmail.com.cn

High, with a more (less) eastward-extending high ridge as well as an enhanced (a weakened) western Pacific subtropical high (WPSH) versus a westward-advancing (an eastward-retreating) high ridge. Influenced by the anomalous Asian monsoon circulations and the longitudinal position of the 500-hPa subtropical high ridge, summer rainfall in China also exhibits different patterns corresponding to different phases of the IOD in the previous year[13]. By analyzing the interannual changes in the onset and northward extension of the EASM and its relationship with the thermal state of the tropical western Pacific, Huang et al.[14] showed that an increase in the convection adjacent to the Philippines, with the tropical western Pacific being in the warm phase in spring, is associated with the eastward-extension of the WPSH and the early onset of summer monsoon in the South China Sea. Furthermore, if the warm phase of the tropical western Pacific is maintained throughout the summer, strong convection can be sustained in the Philippines and there is little precipitation in the Yangtze River-Huaihe River basin and the lower and middle reaches of the Yangtze River, whereas greater precipitation would appear in the Huanghe River basin, northern China, and northeastern China.

The Kuroshio is a strong western boundary current in the western North Pacific. It begins off the east coast of Taiwan and flows northeastward past Japan, where it merges with the easterly drift of the North Pacific Current. After separating from the coast of Japan at about 35ºN, 140ºE, the Kuroshio Current enters the open basin of the North Pacific and becomes the Kuroshio Extension (KE). Free from the constraint of coastal boundaries, the KE has been observed to be an eastward-flowing inertial jet flow accompanied by large-amplitude meanders and energetic pinched-off eddies[15, 16]. Due to the abundance of mesoscale eddy variabilities, it was recognized more than two decades ago that the KE region has the highest eddy kinetic energy level in the Pacific Ocean[17].

It has been shown that there exists a large-scale variability in transport and path migration on the interannual and interdecadal time scales in the KE[18-20]; the KE usually exhibits a large-scale oscillating pattern between an elongated mode and a contracted mode. In the former mode, the KE has a stronger eastward surface transport, a more northerly mean position, and an intensified southern recirculation gyre. In the latter mode, it has a weaker eastward surface transport, a more southerly mean position, and a less intense southern recirculation gyre (Fig. 1). The transition of the KE pattern would influence the surface ocean heat balance and generate wintertime SST anomalies. As noted by Qiu[18, 19], the wintertime SST in the KE increases and decreases in the elongated and contracted mode, respectively, and the anomalous variability of the SST ranges from -1ºC to 1ºC on an interannual time scale.

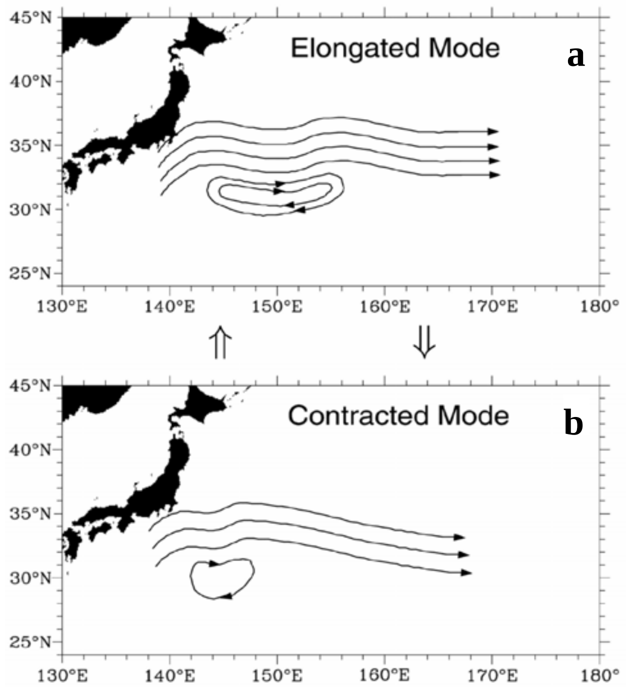

Fig. 1. Schematic of the KE system in the elongated mode (a) and contracted mode (b), adapted from Qiu[19]

In this paper, numerical experiments were conducted using the NCAR CAM3 in order to test the impacts of SST warming in the KE in previous winter (hereafter referred to as KEPW) on the components of the EASM, such as the general circulation, temperature, precipitation, and intensity and position of the WPSH; these are considered to be important for understanding how the precipitation over China in summer is related to the anomalous SST warming in the KEPW, as the precipitation pattern over China is closely related to the EASM.

2 MODEL DESCRIPTION AND EXPERIMENTAL DESIGN

2.1 *The model*

The model used in this study is the latest version of CAM3.0 (Community Atmosphere Model) of the global atmospheric general circulation model developed by the National Center for Atmospheric Research (NCAR, USA). It is a global spectral model with triangular spectral truncation. This paper applies its Euler dynamic framework T85 at a resolution of about 1.4°, which corresponds to 256 grid points zonally and 128 Gaussian grid points longitudinally with a total of 26 layers in the η vertical coordinate. The semi-implicit time integration scheme was employed with a time step of 10 min. The model includes radiation processes, cloud effects, convection, land surface processes, boundary layer effects, and other physical processes[21]. A large number of numerical studies of the model have shown that it shows good performance in simulating global atmospheric general circulation and has been widely used for climate simulation studies[21].

2.2 *Experimental Design*

To study the effect of anomalous SST in the KE on the East Asian climate, two numerical experiments were conducted. One was the control run for the experiment from September of the zero model year to December of the tenth model year (hereafter referred to as CTRL). The other was the SST sensitivity experiment of the KE (hereafter referred to as ABNO), which was designed to add 1°C to the SST from January to March in the KE area (140°E–180°E, 31°N–37°N) according to the definition of Qiu[19], for the experiment from the sixth model year to the tenth model year. The differences between the ABNO and CTRL averaged over the last 5 model years were considered as the influence of warmer SST in KEPW on the general circulation. In this paper, we will focus on the response of the lower and middle troposphere from June to August over East Asia to the anomalous SST warming in previous winter.

2.3 *Observation data*

The monthly Global Ocean Surface Temperature (GISST) of the 1948–2007 data at a horizontal resolution of 1°×1°, and the National Center for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR, USA) reanalysis data at a horizontal resolution of 2.5°×2.5° are used as the oceanic external forcing and the observational general circulation fields, in the integration of the model and the comparison study, respectively.

3 RESULTS

3.1 *Verification of the simulation results*

In order to make a comparison with the simulation results, a composite analysis of NCEP/NCAR reanalysis data was conducted to evaluate the performance of CAM3 in simulating the East Asian general atmospheric circulation as well as the response to anomalous SST in KE. The procedure was as follows: from the years 1948–2007 select the years as anomalous warming years in which the regional average anomalous SST in the KE in winter (January–March) was larger than 0.4°C, then perform the composition against the geopotential height anomalies in the summer（June–August）of these years. This composition shall be regarded as the response of the observed East Asia general atmospheric circulation to the SST anomaly in the winter. The years selected according to the above standard as years of anomalous warming of the KE in the winter were 1949, 1950, 1951, 1954, 1956, 1969, 1979, 1988, 1989, 1993, 1999, 2000, and 2002.

Figure 2 shows the observed and simulated distribution of geopotential height anomalies in the East Asia-Pacific in summer at 200 hPa, 500 hPa, and 850 hPa. It can be found that the observed geopotential height anomalies associated with the SST warming in the KE increase with altitude in the middle latitudes for the entire troposphere. This is described well by the model simulation results, whereas the anomalous decreasing geopotential height in the higher latitudes is also represented basically, although the center of the height anomalies differs somewhat between the observation and simulation. Therefore, CAM3 is a suitable model for studying the impact of the sea temperature anomaly of the KE on the general atmospheric circulation of East Asia. Moreover, the negative anomaly of the simulated geopotential height is generally enhanced, which may be related to the mean SSTA in the KE over the previous winter being set too high in the simulation. In addition, other factors may affect the East Asian climate; the observation results obtained by composition analysis cannot fully reflect the response of the East Asian general atmospheric circulation to the anomalous warming in the KE.

3.2 *Horizontal circulation*

Figure 3 shows the wind flow and geopotential height at 200 hPa and 850 hPa in the East Asia–Western Pacific in the summer, simulated by the CTRL experiment, as well as the difference in the distribution between the ABNO run and the CTRL run. It can be seen that the CTRL gives a good simulation of the large-scale circulation features in the summer over East Asia, i.e., the prevailing southwest wind in the lower level, the subtropical westerly jet stream in the higher level, and the tropical easterly jet stream. In the summer, following the warming in the KEPW, weak cyclonic circulation anomalies prevail at 850 hPa (the lower troposphere) in the regions of the Bay of Bengal and south of Taiwan, while a strong anticyclonic circulation anomaly prevails over Northeastern China. The existence of these three anomalous systems significantly strengthens the westerly winds in the Western Pacific to the east of the Philippines and at low levels over the South China Sea, and the southerly wind near Northern China. At the upper level of the troposphere, at 200 hPa, the warming in the KEPW has generated a large-scale anomaly area of positive geopotential height near the subtropical westerly jet axis (40°N) against the anticyclonic anomalous circulation. It is generally bordered by the jet axis; the westerly wind to the north is enhanced, while the westerly wind to the south is weakened, but the strength of the tropical easterly jet remains almost unchanged. According to the above analysis, the anomalous warming of sea surface temperature in the KEPW may have a significant impact on the high- and low-level circulation trends over East Asia in the summer, which may lead to a strengthening of the northern part of the high-level subtropical westerly jet and a weakening of its southern part. It may also strengthen the low-level southwest monsoon in the Western Pacific to the east of the Philippines and the South China Sea, thereby intensifying the East Asian summer monsoon.

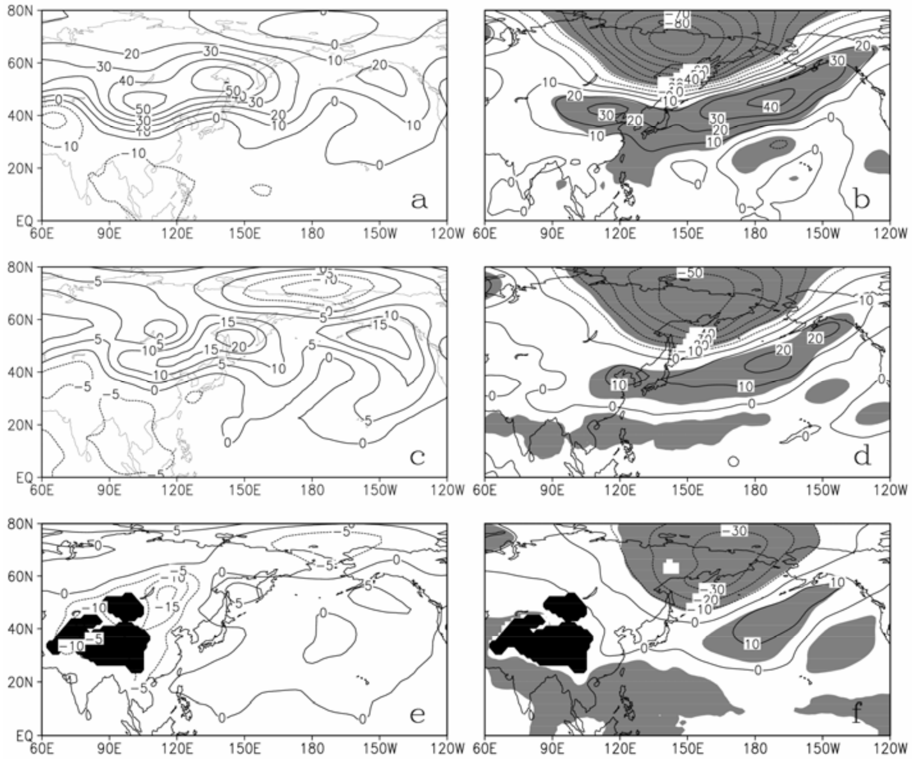

Fig. 2. Observed (a, c, e) and simulated (b, d, f) distribution of anomalous geopotential heights in summer over the Asia-Pacific region at 200 hPa (upper panels), 500 hPa (middle panels), and 850 hPa (lower panels). (The shaded area represents values greater than the 95% significant levels)

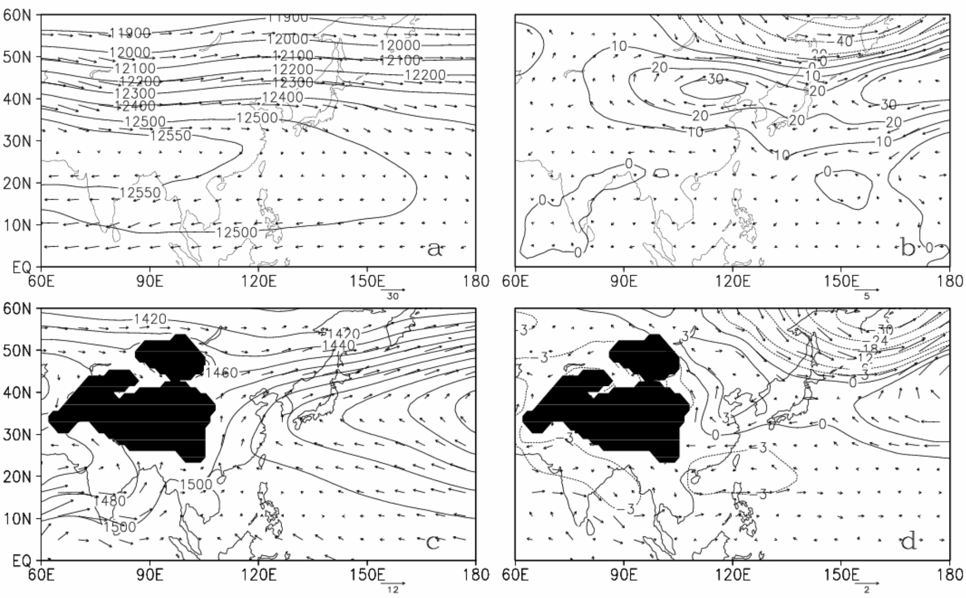

Fig. 3. Distribution of wind (arrows, unit: m/s) and geopotential height (contours, unit: gpm) at 200 hPa (a, b) and 850 hPa (c, d) in summer, for CTRL run (a, c) and ABNO-CTRL (b, d)

3.3 *Changes in precipitation and temperature*

The difference between the distributions of the 105°–122°E average temperature and meridional circulations on the latitude-height cross section obtained from CTRL and ABNO for the summer is shown in Fig. 4. The anomalous temperature disturbance shows a trend toward the north with increasing height, leading to reverse phase characteristics of the upper troposphere against that of the lower troposphere temperature fields between 45°N and 55°N. In addition to the small scale temperature reduction in the upper troposphere and the lower stratosphere between 35°N and 50°N in the southern area, there is generally an increase in temperatures, with big temperature increases mainly between 35°N and 45°N against an area of increasing anomalous ascending flow centered between 400 hPa and 200 hPa. To the north by 45°N, the temperature generally decreases with the anomalous descending flow. In the troposphere of East Asia between 30°N and 50°N there is generally an anomalous southerly wind, and in the north around 50°N mainly an anomalous northerly wind, from the low level to the high level. The above analysis indicates that a large scale temperature increase between 30°N and 60°N in East Asia and a temperature reduction in the upper troposphere in the north may induce an increase in the temperature gradient meridionally, strengthening the summer monsoon in the area.

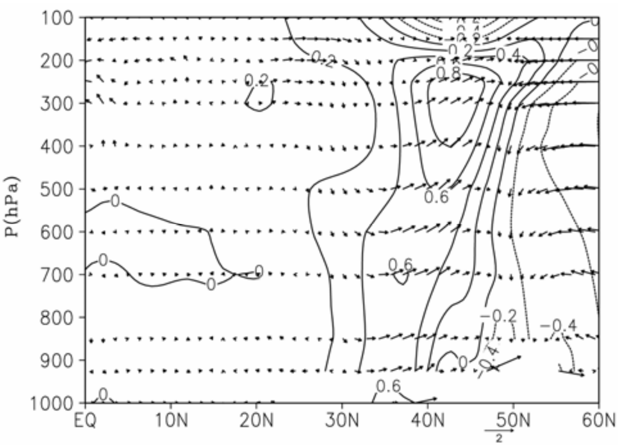

Fig. 4. Cross-section of mean anomalous temperature (contours, unit: °C) and meridional circulation (arrows, unit: hPa/s, the vertical velocity is magnified by 40.)

Figure 5 shows the anomalous distribution of summer precipitation and ground surface temperature. As shown in Fig. 5, after the anomalous warming in the KEPW, the precipitation over the Bay of Bengal, South China Sea, East China Sea, the Yellow Sea, and the Western Pacific east of the Philippines is significantly increased; but the precipitation over the Japanese archipelago and surrounding areas is decreased; there is an area of strong positive precipitation anomaly in the inland areas of Eastern and Northern China, but in most other areas, the precipitation anomaly is negative, with the negative anomalies centered at the lower and middle reaches of the Yangtze River and Qinling Mountains being the most significant. Therefore, the northward movement trend of the East Asian summer monsoon was caused by anomalous warming in the KEPW. Influenced by this winter warming of the KE, the temperature in East Asia in the summer tends to increase, with relatively large changes apparent in inland areas. The two centers of anomalous temperature rise are located near the Qinling and Tanggula Mountains, with the biggest anomalous value over 1.2 °C.

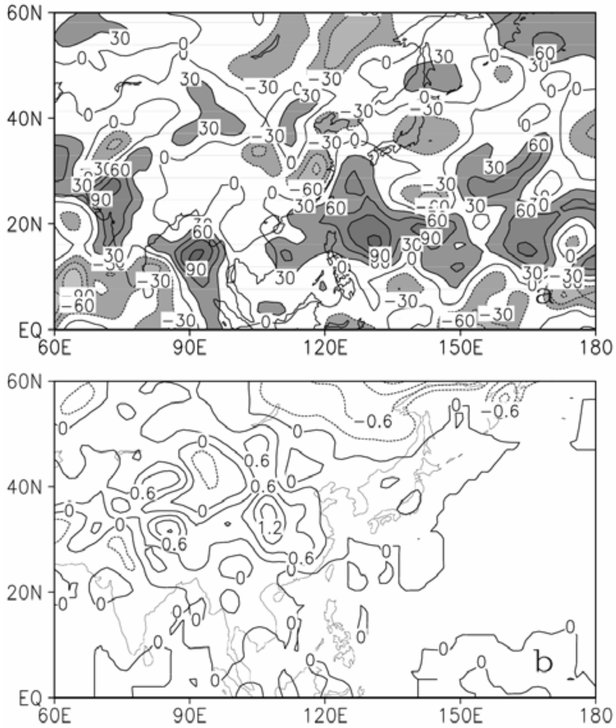

Fig. 5. Distribution of anomalous precipitation (a, unit: mm) and ground surface temperature (b, unit: °C) in summer

3.4 *Changes in the East Asian summer monsoon index*

In order to quantify the impact of surface anomalous warming in the KEPW on the strength of the East Asian summer monsoon, monsoon indexes such as EASMI (East Asian summer monsoon index) and LSTDI (land-sea thermal difference index) are used. EASMI describes the strength of the monsoon from the aspect of the wind field, based directly on the monsoon circulation, according to the definition of Han and Wang[23] . EASMI uses the standardized value of the shear between the average zonal wind at 850 hPa and 200 hPa in the East Asia region (110°E–140°E, 20°N–40°N). LSTDI[24] is based on the land-sea thermal difference and uses the difference between the ground temperature (T_{EC}) within the scope of the East Asian monsoon region (the eastern mainland along 105°E, 27°N–35°N）and the sea surface temperature (SST_{STNWP}) over the subtropical Northwest Pacific (120°E–150°E, 15°N–30°N) to indicate the land-sea thermal difference in the east-west direction. To define the land-sea thermal difference index in the north-south direction in the East Asian region, it uses the difference between the ground temperature (T_{EC}) within the scope of the South China region (eastern mainland to 105°E, south coast to 27°N) and the SST of the South China Sea (105°E–120°E, 5°N–18°N).

$$LSTD = (T_{EC} - SST_{STNWP}) \times 0.8 + (T_{SC} - SST_{SCS}) \times 0.2 \quad (1)$$

LSTDI is obtained after carrying out standardized treatment on the LSTD.

Figure 6 shows the temporal variation in the East Asian summer monsoon index EASMI and LSTDI obtained by the CTRL and ABNO experiment. Previous studies have indicated that the East Asian summer monsoon usually breaks out in the middle of May[25, 26].

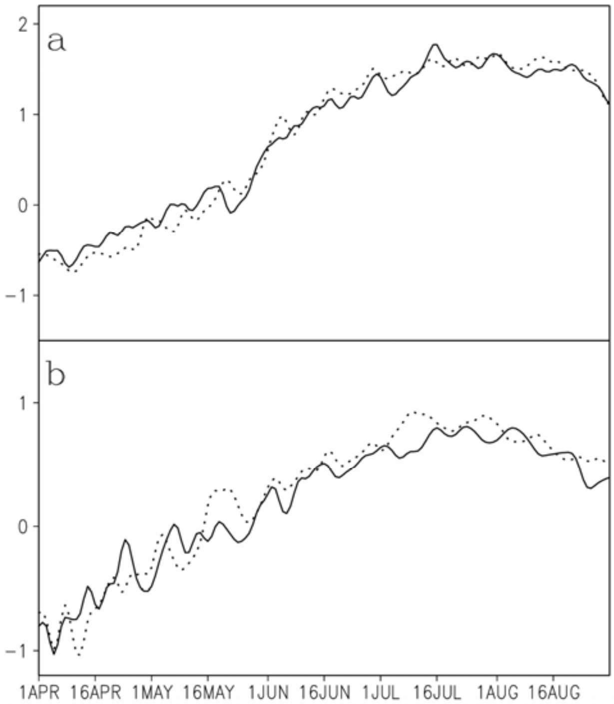

Fig. 6. Temporal variation in the East Asian summer monsoon indexes EASMI (a) and LSTDI (b) for the CTRL run (solid lines) and ABNO run (dashed lines)

It can be seen from Fig. 6 that the EASMI captures the beginning of the East Asian summer monsoon well, but LSTDI is obviously showing it a little earlier. The changing trends of these two indexes are generally consistent. Following the increase of the SST in the KEPW, from early April to early May, EASMI and LSTDI show a reduction trend in the early stages of the summer monsoon, but from middle and late May until August, the two indexes show enhancement trends after the summer monsoon onset, in which the increase in LSTDI is bigger, i.e., the land-sea thermal difference will increase significantly due to the SST warming in the KEPW, which is the main reason for the strengthening of the Asian summer monsoon. Therefore, the anomalous warming of KEPW promotes and strengthens the East Asian summer monsoon, which is consistent with the results presented in the previous section.

To summarize, based on the above results, the anomalous warming in the KEPW will cause the East Asian summer monsoon to intensify, resulting in a reinforced southwest monsoon in the lower troposphere and more precipitation in Northern China. This indicates that Northern China is most sensitive to summer monsoon changes due to the anomalous SST warming in the KEPW. In order to further verify the above conclusions, we have prepared an evolution chart to describe the summer monsoon index in Northern China (110°E–122°E, 34°N–42°N) and the SST anomaly in the KE during 1948–2007, based on observation data and using the EASMI (Fig. 7).

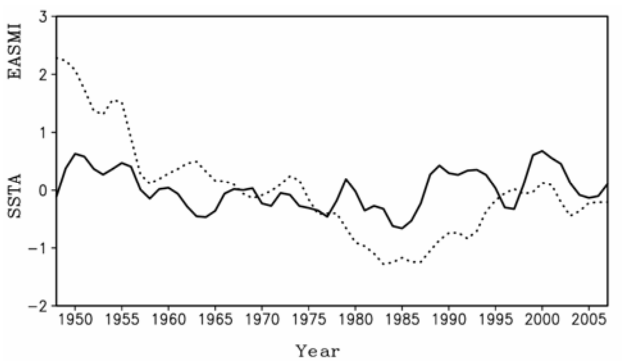

Fig. 7. Temporal variation in EASMI (dashed line) and anomalous SST in Kuroshio Extension in winter (solid line, unit: °C) from 1948 to 2007

It can be seen from Fig. 7 that the changes of the summer monsoon index and SST anomaly are relatively consistent as a whole, which is obvious during the two time periods of 1950–1960 and 1980–1990. The correlation coefficient is 0.2551, and they both passed the test at the 95% significance level. This indicates that the anomalous SST warming in the KEPW will induce a significant enhancement of the summer monsoon in Northern China. Furthermore, the summer monsoon index and the anomalous SST showed an anti-phase variation trend during the periods of 1963–1970 and 1995–2000. However, during those two periods, the atmospheric general circulation at the middle and high latitudes was influenced by continuous ENSO conditions, which suggests that the changes of summer monsoon index in Northern China during 1963–1970 and 1995–2000 may be due more to the effect of ENSO than to other factors.

3.5 *Changes in the western Pacific subtropical high*

The Western Pacific subtropical high (WPSH) is one of the main components in the East Asian summer monsoon system, which affects the evolution of the rain belt, the drought and floods in China, as well as the track and intensity of tropical cyclones in the Western Pacific[27, 28] . In order to compare the impact of the SST anomaly in the KE on the WPSH, we have used two indexes representing the intensity and position of WPSH: the strength index and the northern boundary index, proposed by Zeng et al.[22] The WPSH in this paper is defined as the simulated anticyclonic circulation surrounded by the 5910 gpm isoline in the geopotential height field at 500 hPa. The intensity index I_i is defined as the sum that is bigger or equal to the average height value code (the code of 5910 is 1, 5920 is 2 and so on) within the scope of (0°–50°N, 80°E–180°E) at 500 hPa. The northern boundary index I_{nb} is defined as the average value of the latitude intersected by the 5910 gpm isoline on the north side of the subtropical high and the longitude between 80°E and 180°E. The larger the I_i, the stronger the subtropical high will be; the bigger the I_{nb}, the more northerly the position of the subtropical high will be, and vice versa.

The simulated temporal variation in the intensity index and northern boundary index of WPSH is shown in Fig. 8. It can be seen from Fig. 8 that compared with the index variation in the CTRL run, the intensity index of the ABNO run generally shows an enhancement trend, in which the increases in index strength in late July and mid-to-late August are the most significant. For the northern boundary index, we see that the difference between the results of the two experiments is also obvious and the changes in the northern boundary index in the ABNO run mainly reflect the consistent northerly characteristics from May to September. Therefore, the impacts of the anomalous warming in the KE on the WPSH can be expressed as an increase in strength and an extension to the north.

The difference in seasonal geopotential height at 500 hPa in summer between the ABNO run and the CTRL run is given in Fig. 9. It clearly shows that there are two areas with significant geopotential height anomalies: a large area of negative anomaly centered over eastern Russia, and a positive anomaly belt in the middle and high latitudes centered over the Northern Pacific, enclosing the negative anomaly area. The distribution of the 500 hPa anomalous geopotential height is favorable to the enhancement and northward displacement of the WPSH.

It can be summarized that following the anomalous warming in the KEPW, the WPSH is strengthened and moves northward. As a result, the westerly flow in the lower troposphere over the South China Sea and the Western Pacific to the east of the Philippines is significantly enhanced, which is closely related to the variation in WPSH caused by the anomalous warming in the KEPW. This causes the low-level southerly flow over eastern China between 30°N and 50°N to increase, bringing more precipitation to northern China, whereas the precipitation from the south of the Yangtze River to the Qinling Mountains is reduced.

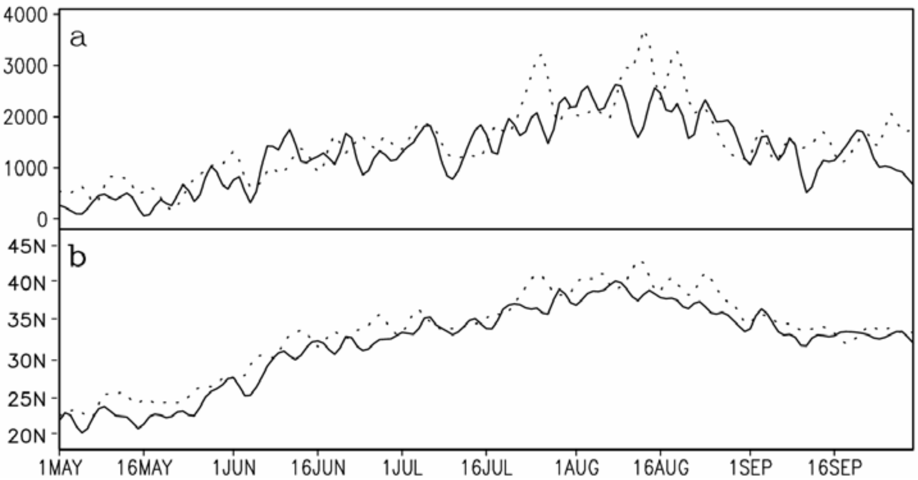

Fig. 8. Temporal variation in intensity index (a) and north boundary index (b) of WPSH for the CTRL run (solid line) and ABNO run (dashed line)

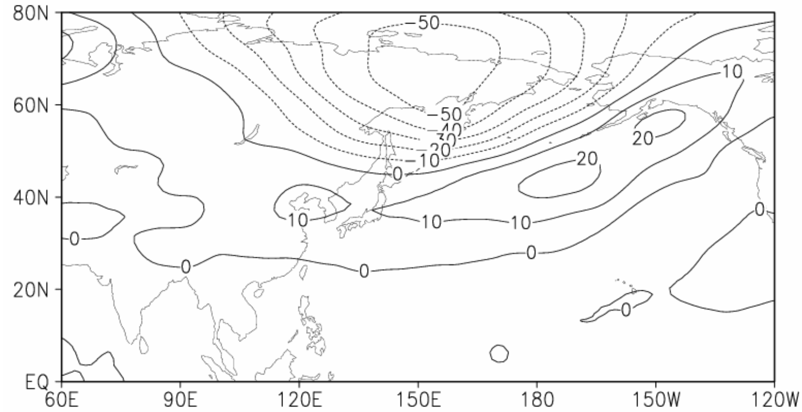

Fig. 9. Distribution of anomalous geopotential height (unit: gpm) in summer

4 CONCLUSIONS

This paper describes the impact of anomalous warming in the KEPW on the East Asian summer monsoon. The conclusions of the study are as follows:

(1) It is feasible to use the CAM3 model to study the response of the East Asian general atmospheric circulation to the anomalous warming of the SST in the KEPW. The model can reproduce the anomalous distribution features and the behavior of the overall change in geopotential height over East Asia and the Western Pacific in the summer following an anomalous warming in the KEPW.

(2) Indicating the strength of the East Asian summer monsoon, the summer monsoon indexes, EASMI and LSTDI, showed a reduction trend before the onset of the East Asian summer monsoon but a significant enhancement after the onset of the monsoon. LSTDI was more sensitive to SST anomalous warming in the KE. The features of these two indexes indicate that the anomalous warming in the KEPW strengthens the East Asian summer monsoon.

(3) The anomalous warming in the KEPW causes the East Asian summer monsoon to move northward. In the summer, the southwest flow in the lower troposphere over Northern China, the South China Sea, and the Western Pacific east of the Philippines is significantly strengthened, and the westerly winds to the north and south of the subtropical westerly jet axis are strengthened and weakened, respectively. There is more precipitation over Northern China, the South China Sea, East China Sea, the Yellow Sea, and the Western Pacific east of the Philippines; however, the precipitation over the Japanese archipelago and the surrounding oceans and south of the Yangtze River in eastern China to the Qinling Mountains decreases. The near-surface temperature in East Asia showed a consistent increase, and the warming appeared in the entire troposphere between 30°N and 50°N. The overall warming of the troposphere over the East Asian continent shows increased land-sea thermal difference, which is the main reason behind the strengthening of the East Asian summer monsoon. Northern China is most sensitive to the East Asian summer monsoon change caused by the SST anomaly in the KEPW.

(4) The anomalous warming in the KEPW causes the enhancement of the WPSH in the summer, pushing it northward, resulting in high- and low-level circulation anomalies and precipitation anomalies in the east of China.

This paper describes the response characteristics of the East Asian summer monsoon to the SST anomalous warming in the KEPW and presents a brief analysis of the possible reasons behind the enhancement of the East Asian summer monsoon. The mechanism of anomalous warming in the KE affecting the East Asian summer monsoon will be presented in another paper.

REFERENCES:

[1] WU R, WANG B. A contrast of the East Asian Summer monsoon-ENSO relationship between 1962-77 and 1978-93 [J]. J. Climate, 2002, 15(22): 3 266-3 279.
[2] HE Jin-hai, YU Jing-jing, SHEN Xin-yong, et al. Research on mechanism and variability of EAST ASIAN monsoon [J]. J. Trop. Meteor., 2004, 20(5): 449-459.
[3] WANG Li-juan, HE Jin-hai, GUAN zhao-yong, et al. Review of the Chinese research on the East Asian tropical and subtropical monsoons [J]. J. Trop. Meteor., 2008, 24(6): 724-731.
[4] ZOU L, NI Yun-qi. Impact of ENSO on variability of summer monsoon over ASIA and summer rainfall in China [J]. J. Trop. Meteor., 1998, 4(1): 30-37.
[5] WANG B, WU R, FU X. Pacific-East Asian teleconnection: How does ENSO affect East Asian climate [J]. J. Climate, 2000, 13(9): 1 517-1 536.
[6] PENG Jia-yi, SUN Zhao-bo. Influence of spring equatorial eastern Pacific SSTA on the seasonal change from spring to summer of eastern Asian circulation [J]. J. Trop. Meteor., 2001, 17(4): 398-404.
[7] CHEN Hai-shan, SUN Zhao-bo, NI Dong-hong. Possible impacts of Niño C SSTA on winter atmospheric general circulation over East Asia [J]. J. Trop. Meteor., 2002, 18(2): 148-156.

[8] HUANG R, CHEN W, YANG B, et al. Recent advances in studies of the interaction between the East Asian winter and summer monsoons and ENSO cycle [J]. Adv. Atmos. Sci., 2004, 21(3): 407-424.
[9] LIM Y, KIM K. ENSO impact on the space-time evolution of the regional Asian summer monsoons [J]. J. Climate, 2007, 20(11): 2 397-2 415.
[10] ZHANG R H, SUMI A. Mositure circulation over East Asia during El Niño episode in northern winter, spring and autumn [J]. J. Meteor. Soc. Japan, 2002, 80(2): 213-227.
[11] LU R Y, DONG B W, DING H. Impact of the Atlantic multidecadal oscillation on the Asian summer monsoon [J]. Geophy. Res. Lett., 2006, 33(24): 24 701-1-24 701-5.
[12] YANG J L, LIU Q Y, XIE S P, et al. Impact of the Indian ocean sst basin mode on the Asian summer monsoon [J]. Geophy. Res. Lett., 2007, 34(2): 2 708-1-2 708-5.
[13] YUAN Y, YANG H, ZHOU W, et al. Influences of the Indian ocean dipole on the Asian summer monsoon in the following year [J]. Int. J. Climatol., 2008, 28(2): 1 849-1 859.
[14] HUANG Rong-hui, GU Lei, XU Yu-hong, et al. Characteristics of the interannual variations of onset and advance of the East Asian summer monsoon and their associations with thermal states of the tropical Western Pacific [J]. Chin. J. Atmos. Sci., 2005, 29(1): 20-36.
[15] KAWAI H. Hydrography of the Kuroshio Extension. Kuroshio-Its Physical Aspects [M]. Stommel H, Yoshida K (Eds.), University of Tokyo Press, 1972, 235-354.
[16] YASUDA I, OKUDA K, HIRAI M. Evolution of a Kuroshio warm-core ring-variability of the hydrographic structure [J]. Deep-Sea Res., 1992, 39: 131-161.
[17] WYRTKI K, MAGAARD L, HAGAR J. Eddy energy in the oceans [J]. J. Geophys. Res., 1976, 81: 2 641-2 646.
[18] QIU B. Interannual variability of the Kuroshio extension system and its impact on the wintertime SST field [J]. J. Phys. Oceanogr, 2000, 30(6): 1 486-1 502.
[19] QIU B. The Kuroshio Extension system: Its large-scale variability and role in the midlatitude ocean-atmosphere interaction [J]. J. Oceanogr., 2002, 58(1): 57-75.
[20] QIU B, CHEN S M. Variability of the Kuroshio Extension jet, recirculation gyre and mesoscale eddies on decadal timescales [J]. J. Phys. Oceanogr., 2005, 35(11): 2 090-2 103.
[21] COLLINS W D, RASCH P J, et al. Description of the NCAR Community Atmosphere Model (CAM3.0) [M]. Technical Report NCAR/TN-464+STR, National Center for Atmospheric Research, Boulder, Colorado, 2004, 210pp.
[22] ZENG Gang, SUN Zhao-bo, WANG Wei-qiang, et al. Interdecadal variation of East Asian summer-monsoon simulated by NCAR Cam3 driven by global SSTs [J]. Climat. Env. Res., 2007, 12(2): 211-224.
[23] HAN J, WANG H. Interdecadal variability of the East Asian summer monsoon in an AGCM [J]. Adv. Atmos. Sci., 2007, 24(5): 808-818.
[24] SUN Xiu-rong, CHEN Long-xun, HE Jin-hai. Index of land-sea thermal difference and its relation to interannual variation of summer circulation and rainfall over East Asia [J]. Acta Meteor. Sinica, 2002, 60(2): 164-172.
[25] WU G X, ZHANG Y S. Tibetan Plateau forcing and the timing of the monsoon onset over South Asia and the South China Sea [J]. Mon. Wea. Rev., 1998, 126(4): 913-927.
[26] MAO J, CHAN Y J, WU G X. Relationship between the onset of the South China Sea summer monsoon and the structure of the Asian Subtropical Anticyclone [J]. J. Meteor. Soc. Japan, 2004, 82(2): 845-849.
[27] TAO S Y, CHEN L X. The East Asian summer monsoon [C]// Proceedings of International Conference on Monsoon in the Far East, Tokyo, 1985, 1-11.
[28] HUANG Xiao-dong, LUO Hui-bang. Seasonal coupling features between the East Asian summer monsoon rainband and West Pacific subtropical high [J]. J. Trop. Meteor., 2004, 20(2): 122-128.

Citation: WANG Xiao-dan, ZHONG Zhong, TAN Yan-ke et al. Numerical experiment on impact of anomalous SST warming in Kuroshio Extension in previous winter on East Asian summer monsoon. *J. Trop. Meteor.*, 2011, 17(1): 18-26.