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# THE INFLUENCES OF SSTA OVER KUROSHIO AND ITS EXTENSION ON RAINFALL IN NORTHEAST CHINA UNDER THE BACKGROUND OF TWO DIFFERENT EL NIÑO CASES

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**Abstract:** By using the gauged rainfall in 160 stations within mainland China and the NCEP/NCAR reanalysis data, the impacts of anomalous SST in Kuroshio and its extension on precipitation in Northeast China were investigated. The results show that a difference in the meridional circulation such as the East Asia/Pacific teleconnection pattern (EAP) may be responsible for the difference in rainfall between 1998 and 2010. In comparison with 1998, the anomalous meridional circulation pattern in 2010 shifted northeastward, and then the western subtropical high, the mid-latitudinal trough and the northeastern Asia blocking high also shifted northeastward, causing intensified convergence of the cold and warm air masses at the southern region and thus more rainfall in the southwestern region and less in the northwestern region. In 1998, the anomalous cyclone, one component of the meridional pattern, located at the Songhuajiang-Nengjiang River basin, resulted in more rainfall in the majority of the area. The results of observation and the model show that the difference in SSTA in Kuroshio and its extension under the background of different El Niño events is the key point: (1) The anomalous warmth moved westward from the mid-Pacific to the east of the Philippine Sea during the central event, which led the heat resources shifting to the northeast in 2010; subsequently, a shift occurred to the north of the anomalous ascent and decent, followed by a warm SSTA in the region of Kuroshio's extension in 2010 and Kuroshio in 1998. (2) The warm SSTA in the Kuroshio extension causing the Rossby wave activity flux strengthened in 2010, and then the westerly jet shifted northward and extended eastward. A warm SSTA in Kuroshio and cold SSTA in its extension in 1998 caused the westerly jet to shift southward and weaken. As a result, the anomalous anticyclone and cyclone shifted northward in 2010, and the blocking high also shifted northward.

**Key words:** central El Niño; summer rainfall; Kuroshio extension; anomalous sea surface temperature

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## 1 INTRODUCTION

In the summer of 1998, the most severe flooding ever recorded occurred in a wild range of the Songhuajiang-Nenjiang Rivers basin (Tao et al.[1]; Zhang et al.[2]). A great deal of previous research shows that the disaster was caused by a combination of Western Pacific subtropical high, a low pressure over the Songhuajiang-Nengjiang Rivers basin (or the Northeast Cold Vortex) and an anomalous Okhotsk high (Zhang et al.[2]; Sun et al.[3]). Moreover, Huang suggested that the anomalous circulation in the northeastern part of the region in the summer of 1998 was related to the 1997/1998 eastern El Niño event[4]. In the summer of El Niño's decaying year, sea surface temperature anomalies (SSTAs) in the western Pacific were cold, which caused the convective activity over the Philippine area to weaken. Further, the Western Pacific subtropical high was stronger, and its position was southward, causing a significant amount of water vapor to be transported to the northeast region of China. Thus severe flooding occurred. In the summer of 2010, Northeast China suffered from significant flooding again, but the flood-affected area and the spatial distribution of precipitation were significantly different from that in 1998. Based on the climatological background, although the two years are both in the decaying phase of El Niño events, the 1997/1998 event is the traditional type of El Niño, and the 2009/2010 one is central El Niño. The following question thus arises: are the significant differences of the spatial distribution of precipitation in Northeast China related to the different types of El Niño?

As the climate abruptly changed in the late 1970s, central El Niño events with a maximum warm SSTA in the tropical central Pacific occurred frequently (Yeh et al.[5]; Qin and Wang[6]; Cao et al.[7]). This is significantly different from the eastern El Niño event with a maximum warm SSTA in the tropical eastern Pacific in

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terms of formation (Ashok et al.[8]; Weng [9]; Li and Wang[10]; Kao and Yu[11]) and climatic impact (Taschetto et al.[12]; Kug et al.[13]; Ratnam et al.[14]). Several studies show that, in the subsequent summer of different types of El Niño events, the precipitation in South China such as the Yangtze River basin or the Huaihe River basin is different, and the difference in the Western North Pacific anticyclone (WNPAC) between the two types of El Niño events is the key contributing factor to the difference in climate in the summer over South China (Feng et al.[15]; Yuan et al.[16]; Xia et al.[17]; Wang et al.[18]). Currently, most of the studies are focused on the low-latitudes area; it is rare to study the influence of different types of El Niño events on the climate of Northeast China. Because Northeast China is located in mid-latitudes, the circulation factors that influence the precipitation in this region are more complex than the area in low-latitudes, including the tropical and subtropical circulation system such as summer monsoon and subtropical high, as well as the circulation system in the high-latitudes such as the westerly jet and Northeast Asia blocking high (Sun et al.[19]). Research has also shown that the anomalies of these circulation systems are not only associated with tropical Pacific warm pool but also closely related to the sea surface temperature (SST) over the Kuroshio region and its extension (Feng et al.[20]). He suggested that the SST anomalies off the shore of China can affect the precipitation in Northeast China by influencing the activity of the Northeast Cold Vortex [21]. Wang noted that the SSTA in Kuroshio and its extension in early summer can affect the precipitation in Northeast China through the Okhotsk blocking high[22]. Gao and Qi found that the summer precipitation in Northeast China will increase when the SST is lower over the Kuroshio or higher over its extension in early winter, and in recent decades, the predictive capability of SST over the Kuroshio and its extension area on the summer precipitation in Northeast China gradually increased [23, 24]. Recently, Tan suggested that there is a negative correlation between central El Niño and SST over Kuroshio and its extension, which further shows that it is necessary to discuss the influence of SSTA at Kuroshio and its extension on the summer precipitation in Northeast China under the background of different types of El Niño[25].

## 2 DATASETS AND METHODS

### 2.1 *Datasets*

The primary datasets used in this paper include the monthly precipitation in 160 stations within mainland China from January 1970 to December 2010, reanalysis data provided by the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) with a horizontal resolution of 2.5°×2.5° (Kalnay et al.[26]). Extended reconstruction sea surface temperature (ERSST) data provided by the National Oceanic and Atmospheric Administration (NOAA) with a horizontal resolution of 2°× 2° (Smith et al.[27]). Considering that the flooding occurred in July and August, in this paper, the term “summer” refers to this July and August timeframe.

### 2.2 *AGCM and experimental design*

The sensitivity experiment is performed by using the atmospheric model AM2.1 developed by NOAA. More details can be obtained from the GMAT (Anderson et al. [28]). We performed three sets of ensembles with three members each, covering 60 years each. The experiments are designed as follows:

Experiment one, referred to as the control ensemble (CTL), used the climatological (1950—1998) monthly SST to drive the model.

In experiment two, the sensitivity experiment, the climatological monthly mean SST in the Kuroshio area (20 °N to 35 °N, 125 °E to 150 °E) and its extension (35 °N to 45 °N, 140 °E to 170 °E) was replaced by observations from September 1997 to August 1998, with other areas unchanged. This experiment is referred to as “E98”.

Experiment three was similar to experiment two. The climatological monthly mean SST in Kuroshio area (20 °N to 35 °N, 125 °E to 150 °E) and its extension (35 °N to 45 °N, 140 °E to 170 °E) were replaced by observations from September 2009 to August 2010, with other areas unchanged. This experiment is referred to as “E10”.

Experiments four and five are similar to E98 and E10, respectively, but the observational SST in July and August of each year is replaced with the SST from June, which means the SST in June lasts through August. These experiments are referred to as “E98_JunP” and “E10_JunP”.

The influence of SST in Kuroshio and its extensions can be recognized by comparing the results of experiments two and three to the control experiment. Considering the fact that the observed SST in July and August contains information about the air-sea interaction in the corresponding period, we designed experiments four and five, which will help to make the influence of SST at Kuroshio and its extension in the early stage even clearer.

## 3 COMPARISON OF THE ANOMALOUS LARGE-SCALE CIRCULATION

### 3.1 *Precipitation anomalies and water vapor transportation*

In the summer of 2010, the positive center of precipitation anomalies was located to the northeast of central China. Meanwhile, the negative center was located in the northwest, giving the appearance of a dipole pattern (Fig.1a). In 1998, precipitation anomalies in most areas of Northeast China were positive, and the center was located in the middle of Northeast China, which tended to be a single-pole pattern (Fig.1b).

Water vapor is one of the necessary conditions for rain, and a rainstorm of any significant duration requires sufficient water vapor supply and water vapor convergence. Fig.1c and 1d, and Table 1 illustrate that in 2010 the water vapor flowed into Northeast China from the western, southern, and northern boundaries of the region, mainly from the southern boundary. The water vapor converged in the south of Northeast China, with its center located in the Korean Peninsula. The water vapor diverged in the western region, which is consistent with the precipitation distribution (Fig.1) of more rainfall in the southwestern region and less rainfall in the northwestern region. In 1998, water vapor flowed from the western and southern boundaries and converged mostly in the region of Northeast China (except part of Heilongjiang)[1]. The convergence center was located in the northeastern region, which is consistent with the pattern of more rainfall over the whole region and the location of the precipitation center shown in Fig. 1b. From the analysis made above, we can conclude that the water vapor flowed more in 2010 than in 1998. The convergence was centered in the Korean Peninsula, which shifted southeastward compared to 1998; thus, the precipitation pattern in 2010 was significantly different from 1998.

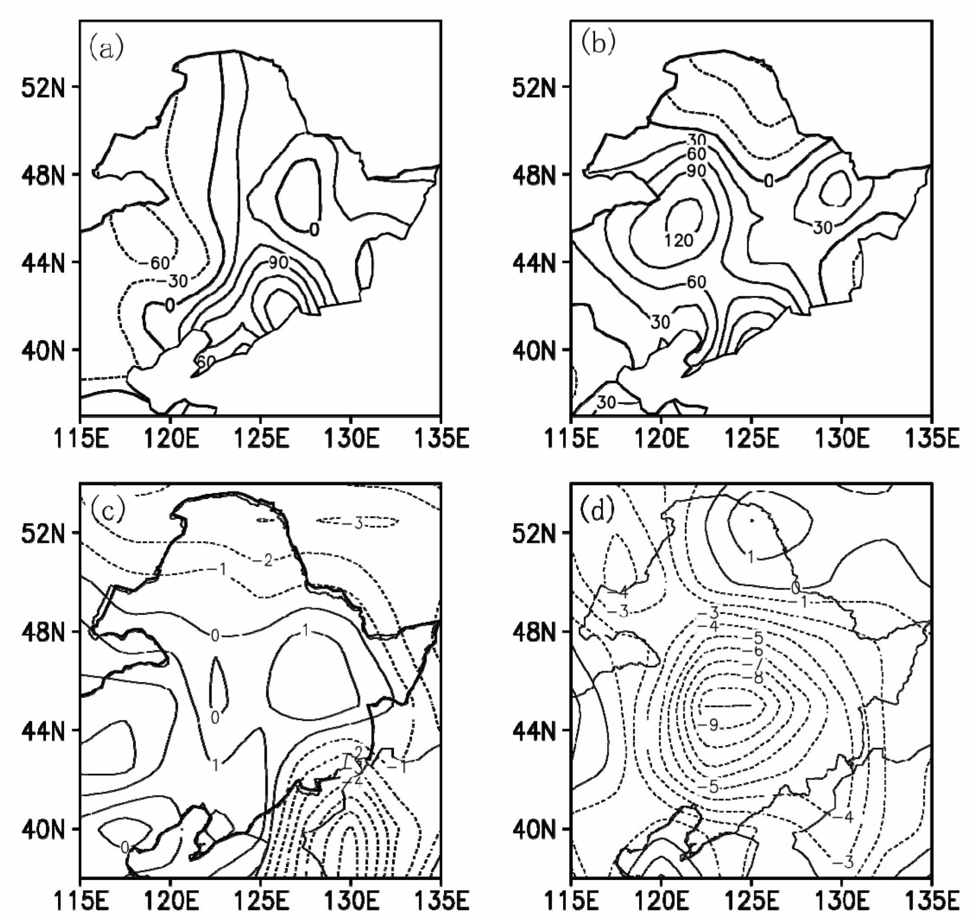


**Figure 1.** Distribution of summer mean precipitation anomalies (a-b, unit: mm/month) and water vapor flux divergence (c-d, unit: $10^{-4}$ kg/ (m$^2$·s)). a & c: 2010; b & d: 1998.

**Table 1**. Integrated water vapor flux from the eastern, western, northern, and southern boundaries of Northeast China (37.5°N to 52.5°N, 115°E to 135°E) in 2010 and 1998 (unit: ×$10^7$ kg/s).

| Year | South Boundary (>0, input) | West Boundary (>0, input) | North Boundary (<0, input) | East Boundary (<0, input) | Regional water vapor budget |
|---|---|---|---|---|---|
| 2010 | 22 | 12 | –1.6 | 33 | 2.6 |
| 1998 | 9.3 | 9.1 | 3.8 | 3.8 | 8.4 |

3.2 *Differences of large-scale atmospheric circulations*

Water vapor transport cannot be separated from the corresponding atmospheric circulation, so the differences in water vapor must be related to that differences in this circulation between the two years studied. As shown in Fig.2, except for the existence of the WNPAC in the summer of the two years, and the fact that in 2010 the WNPAC extended westward and northward (Wang et al. [18]), the eastern region of Northeast China and the region east of the Okhotsk Sea were influenced by anomalous cyclones and anticyclones, respectively. Therefore, from south to north on the east coast, these two anomalous circulations together with the WNPAC constitute the pattern of "anticyclone-cyclone-anticyclone" (Fig.2a). Under the influence of this pattern, the anomalous southwesterly winds prevailed from the South China Sea to Japan; the East Asian summer monsoon strengthened and stretched northward and eastward, which can be used to explain the increasing water vapor transportation in Northeast China, the Korean Peninsula, and the Sea of Japan (Fig.1c). At the same time, western Northeast China was influenced by anomalous northerly wind, so the precipitation was less than normal. Under the influence of the southern part of this pattern, the anomalous southerly and northerly flows meet in southern Northeast China and the Korean Peninsula, which produces an anomalous upward movement of intensive convergence and increases precipitation in the region.

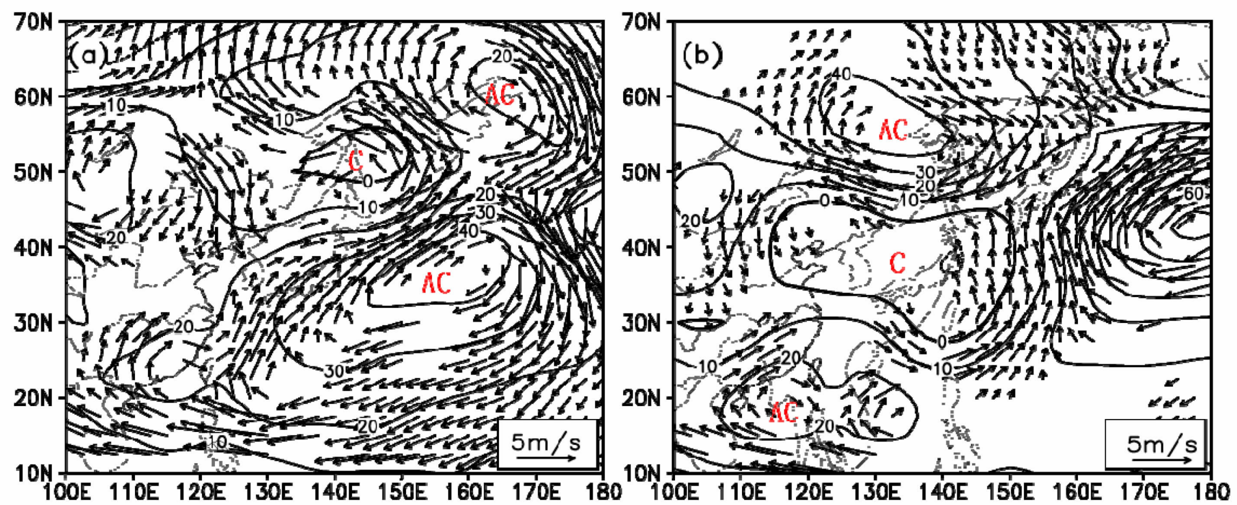


**Figure 2.** Anomalous wind field of 850 hPa in the summer of 2010 (a) and 1998 (b) (vector, unit: m/s, the wind speed less than 2 m/s is not shown in this figure, "AC" indicates the anticyclone, and "C" indicates cyclone).

In the summer of 1998, a similar anomalous anticyclone-cyclone-anticyclone pattern appeared along the east coast (Fig.2b), but the pattern as a whole was shifted southward with three centers located in the South China Sea, the Sea of Japan, and the land west of the Okhotsk Sea. This spatial distribution was similar to the East Asia/Pacific (EAP) teleconnection pattern of negative phase excited by negative SSTA in the Western Pacific Warm Pool (Huang [29]). The moisture came from the tropics, the Yellow Sea, the Bohai Sea, and Japanese waters and converged in Northeast China. It was affected by the anomalous cyclonic circulation over Northeast China, which enhanced the uplift movement of convergence, causing more rainfall in that region (Fig.1d).

Li suggested that the anomalous blocking high in Northeast China is one of the key circulation patterns for the formation of significant rainstorms in the Songhuajiang-Nenjiang river basin in 1998 [30]. In fact, the difference between the blocking highs in 2010 and 1998 is also the key to the spatial distribution of precipitation in Northeast China. From April to May of 2010 (Fig.3a), strong positive geopotential height anomalies appeared near 40 °E and 160 °E and lasted until August (indicated in the figure by the red arrow). In contrast, positive geopotential height anomalies appeared later in 1998. At the beginning of July, the Asian continent was controlled by the double blocking high pattern, but in the west this blocking high weakened later over time, and in August, the geopotential height anomalies turned negative in the west while remaining positive in the east. It is worth noting that in northeast Asia, the center of the positive geopotential height anomalies was located at 160 °E in 2010, but in 1998, it was located at 120 °E to 150 °E, which means that the northeast Asian blocking high moved eastward in 2010, leading to the eastward tacks of the low trough or the northeast cold vortex at the west side of the blocking high. Correspondingly, the region from the northeast of Northeast China to the Okhotsk Sea was controlled by negative geopotential height anomalies in 2010, and these negative anomalies were located in Northeast China in 1998 (Fig.2).

The East Asian subtropical westerly jet stream is also one of the systems affecting the summer precipitation in Northeast China (Liao et al. [31]). The field of zonal wind and geopotential height anomalies at 200 hPa shown in Fig.4 illustrate that the position of the

East Asian subtropical westerly jet in 2010 was significantly different from that in 1998. The intensity of the jet was stronger in 2010; the jet axis was southwest to northeast and stretched eastward to 150 °E, which was farther north than the climatological mean. There were two centers along the jet axis, located, respectively, at Xinjiang and in northeast Japan. The jet stream in 1998 was weaker than that in 2010, and the location was farther south than the climatological mean, only stretching eastward to the Korean Peninsula. The center of the jet was located south of 40 °N. Fig.2 illustrates that the jet axis appeared directly over Northeast China in 2010, so the region from the east of Northeast China to the south of Japan at the low level was controlled by the anomalous anti-cyclone. Meanwhile, the north of Northeast China was controlled by the anomalous cyclone. In 1998, Northeast China was left of the exit of the jet stream and the corresponding anomalous low level cyclone was located in Northeast China. As defined by Yang, the difference in zonal wind speed at 200 hPa between (35 °N to 40 °N) and (40 °N to 45 °N) was used to represent the location change of the East Asian subtropical westerly jet stream. A positive value indicates that the jet was farther south than normal, and vice versa[32]. The results shown in Fig. 4c illustrate that the East Asian subtropical westerly jet stream was indeed farther south than normal in 1998 and farther north in 2010.

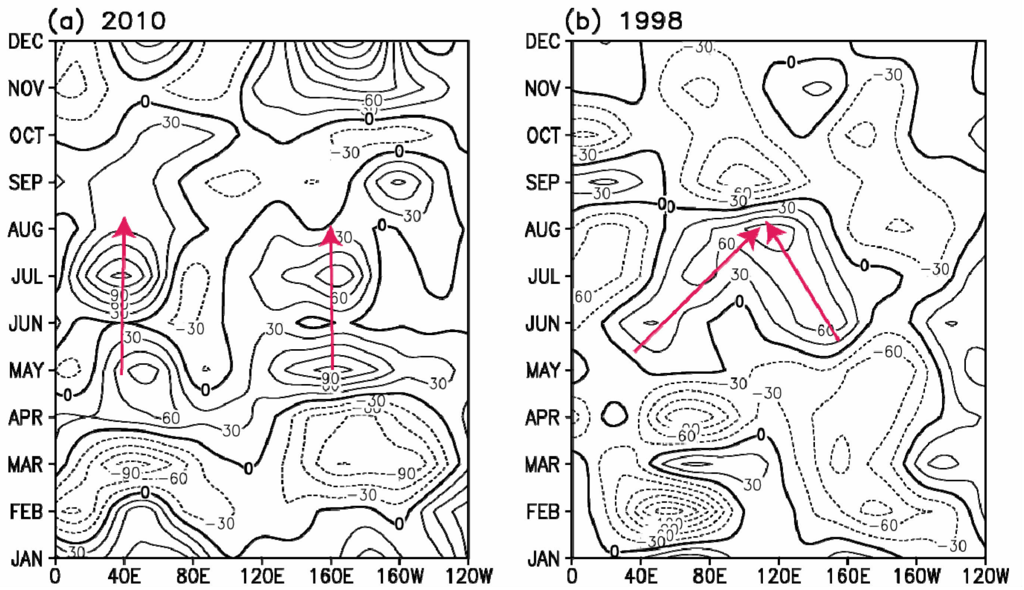


**Figure 3.** Monthly evolution of geopotential height anomalies over 500 hPa averaged from 57.5 °N to 65 °N in the summer of 2010 (a) and 1998 (b).

Based on this analysis, the key systems responsible for the difference in summer precipitation in Northeast China between 2010 and 1998 include the meridional pattern of anticyclone-cyclone-anticyclone (hereinafter referred to as "EAP like" anomalous circulations) along the East Asian coast in 2010 and the fact that this pattern was more eastward and northward than in 1998, which led to the northward and eastward shifts of the western Pacific subtropical high trough at mid-latitudes and the northeast Asia blocking high. In addition, the subtropical westerly jet stream in 2010 was stronger than that in 1998 and stretched farther northward and eastward.

## 4 INFLUENCE OF SST

### 4.1 *Comparison of observed SST*

Due to the large amount of heat in the waters of the Kuroshio area and the fact that there is an east-west ocean front in its extension region, Kuroshio and its extension are crucial to ocean-atmosphere interactions in the high latitudes of the north Pacific. In addition to the significant difference that in the event of 2009/2010, the strongest warming was in the central Pacific and in the event of 1997/1998, the strongest warming was in the eastern Pacific (Wang et al. [18]), there is significant difference in the spatiotemporal distributions in Kuroshio and its extension (Fig.5).

From the strongest period of central El Niño in 2009/2010 to April of the following year (Fig.5a), the SST over Kuroshio and its extension appeared as positive anomalies. In May and June, SST anomalies over Kuroshio became negative; the positive SST anomalies over the extension area lasted until August. Although the SST over Kuroshio and its extension also showed a strong sustainability during 1997/1998, the spatial distribution of SST is largely different from that in 2009/2010. From the strongest period to decaying in summer, positive SST anomalies were mainly located in the Kuroshio area, and the SST anomalies over the extension area were negative (Fig.5b).

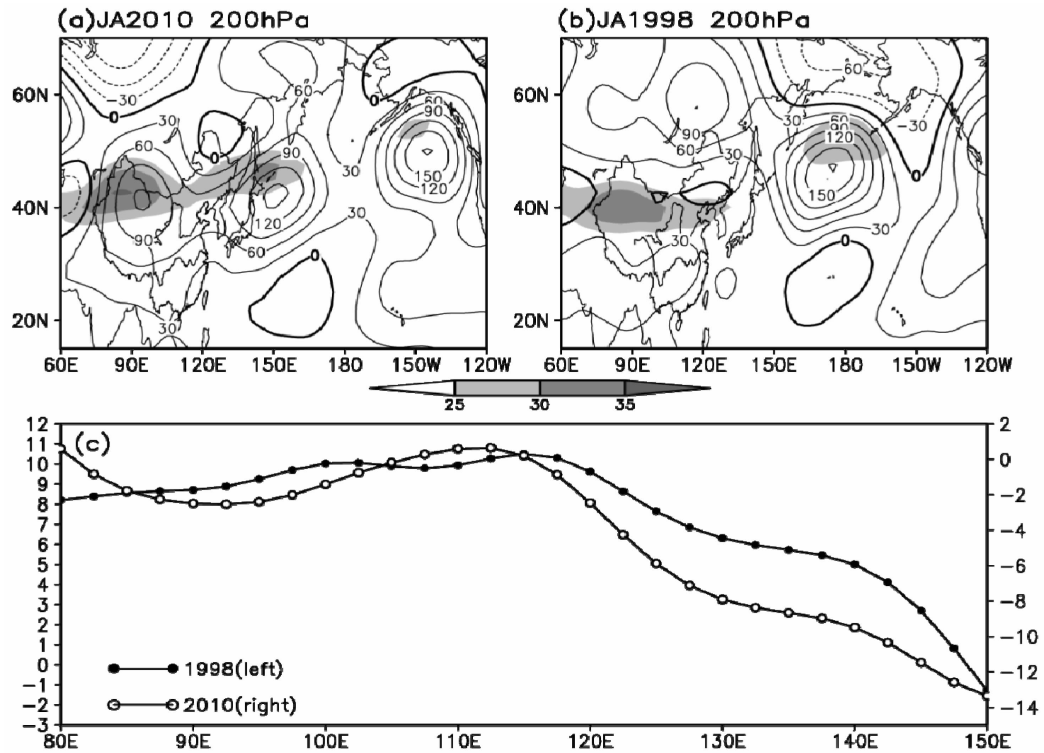


**Figure 4.** Geopotential height anomalies at 200 hPa during the summers of 2010 (a) and 1998 (b) (contour, unit: gpm), zonal wind with speeds more than 25 m/s (shaded), index of East Asia subtropical westerly jet (c). Positive values indicate that the jet was shifted northward compared to the climatological mean.

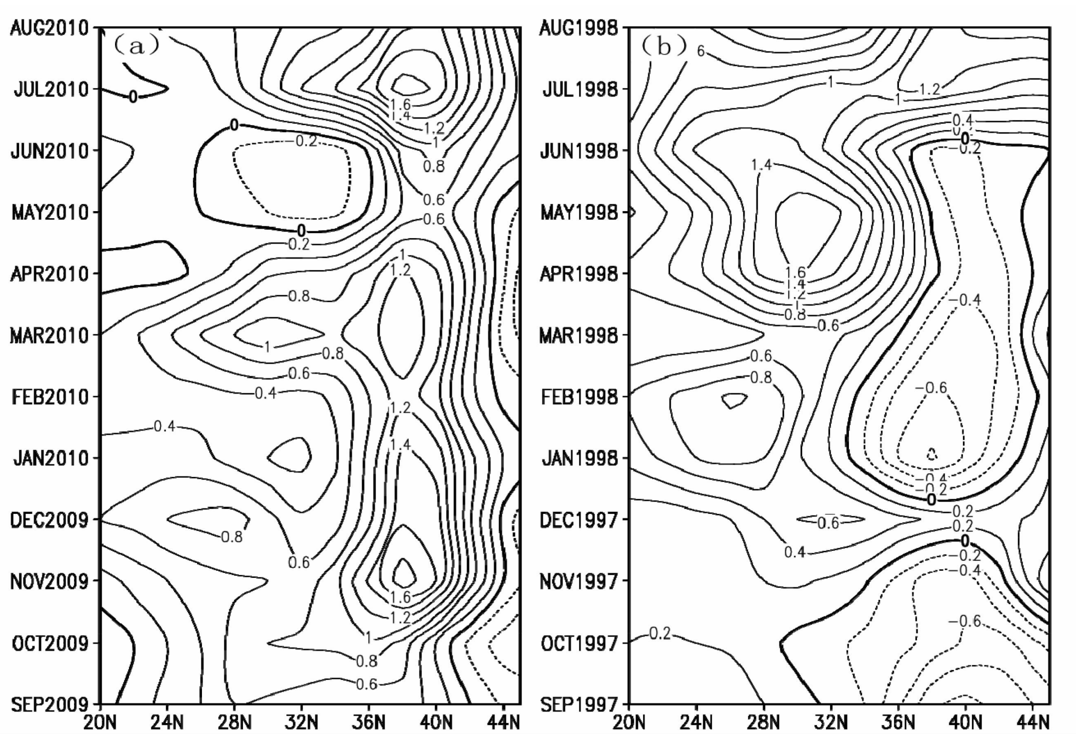


**Figure 5.** Time-latitude section of the SST anomalies of the 140 °E to 160 °E zone for the period of (a) 2009/10 and (b) 1997/98 (unit: ℃).

Combining the spatial distribution of SST anomalies over Kuroshio and its extension Fig.6 shows that in 2010, bounded by the extension area, the north-south SST gradient of the north side increased, whereas it decreased on the south side, which is contrary to the situation in 1998. This resulted in the location of the ocean front (max SST gradient (Ma and Xu [33])) shifting northward during 2009/2010 compared to 1997/1998. In the research of Tan and Cao regarding the influence of the El Niño Modoki on the Chinese offshore SST anomaly and adjacent waters [25], the traditional El Niño resulted in a warm SST in the southern Kuroshio area of Japan and, in the year of Modoki, a cold SST in southern Kuroshio, Japan, and a warm SST in the Kuroshio extension area; the spatial distribution pattern is similar to that presented in this article. This indicates that the sea temperature anomalies in the black tides and their extended areas in 2009/2010 and 1997/1998 are related to two different types of El Niño events.

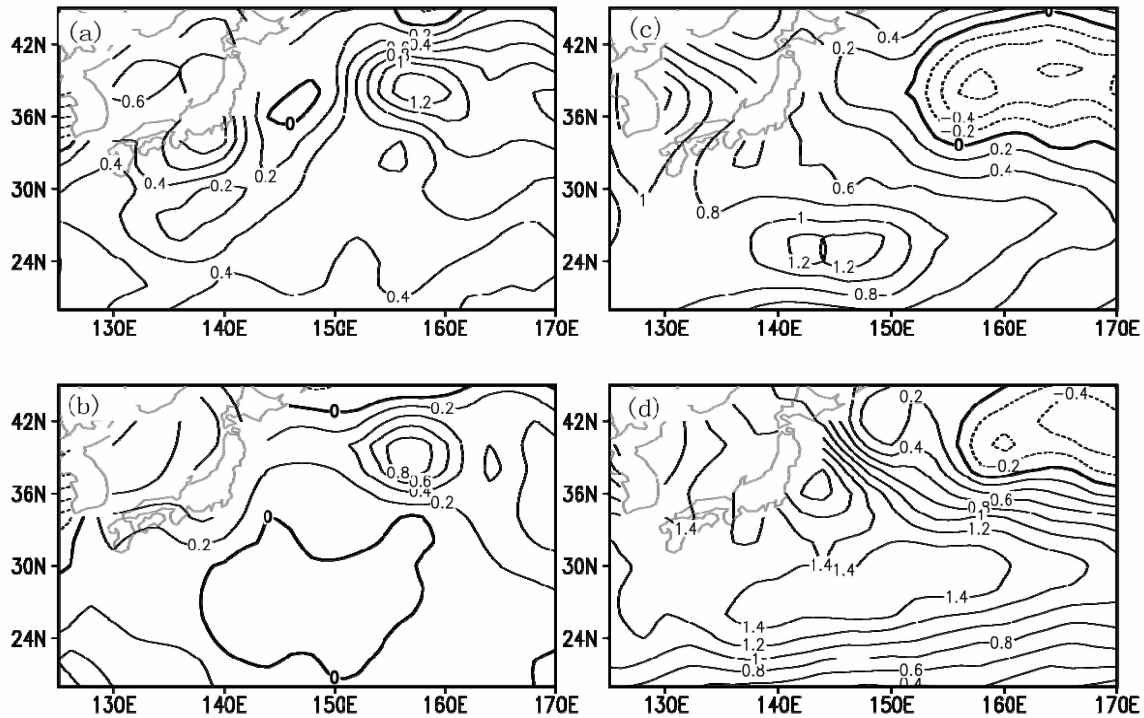


**Figure 6.** January-March mean (a-b) and April-June mean (c-d) SST anomalies at Kuroshio and its extension (unit: ℃); a and c for 2009/2010, and b and d for 1997/1998.

4.2 *Possible mechanism of anomalous SST over Kuroshio and its extension*

Previous analysis has shown that in the summer of 2010, the anomalous EAP-like circulation along the East Asian coast was distinct from that in 1998. The western Pacific subtropical high, westerly trough and northeast Asian blocking high in the low levels, and the East Asia westerly jet in the upper level were also different between the two years. The following question thus arises: are these distinct anomalous circulations caused by the difference in SST background? For the anomalous warm SST over the warm pool, there are downward heat flux anomalies over this area in both summer of 2010 and 1998 (figure omitted), which suggests that the EAP-like anomalous circulation is not the recognized East Asia Pacific teleconnection, so it cannot be explained using only the difference in the warm SSTA center along equatorial Pacific and meridional circulation.

The distribution of latent heat flux anomalies in the winter of the two El Niño events (Fig.7a & 7b) shows that the latent heat flux anomalies in both 2009/2010 and 1997/1998 are negative, which means the SST in this period is mainly driven by the atmosphere. However, compared to 1997/1998, the negative latent heat flux anomalies and the anomalous warm SST shifted northward in 2009/2010. This is because the anomalous warm SST over the equatorial Pacific shifted westward in 2009/2010. The anomalous updraft also moved westward, which further led to the northward movement of the downdraft over the northwest Pacific, so the anomalous warm SST moved northward through the sinking air. It has been demonstrated that the difference in the SSTA in Kuroshio and its extension in the strongest period of the two El Niño events is caused by the difference of surface heat flux through an "atmospheric bridge".

Because of air-sea interaction, the warm SSTA at Kuroshio and its extension lasted until the following summer of the two El Niño events separately, and the latent heat flux anomalies changed from negative in the early stage to the positive (Fig.7c & 7d), which indicate that the air was heated by the ocean during the decaying period. According to the study of Ma and Xu, location changes of the oceanic front at Kuroshio's extension in the spring can affect the westerly jet in the later summer by affecting the activity of Rossby waves [33]. Vertical sections of wave activity flux along 140 to 150 °E (Fig.8) show that there is apparent upward wave activity flux near 35 °N in 2010, and the northward wave activity flux increased as the height increased. By contrast, the northward wave activity flux only appeared at approximately 30 °N in the summer of 1998. For the climatological mean, the East Asian upper westerly jet in summer moves northward to 37.5 °N in early July. It can be concluded from Figs. 4 and 5 that in the summer following the central El Niño 2009/2010, the anomalous warm SST center was located at the Kuroshio extension region. Therefore, there is an upward and northward wave activity flux due to the significant heating in the lower troposphere, which leads to the northward and eastward movement of westerly jet to 150 °E. Meanwhile, the strong northward wave activity flux in the upper level strengthened the westerly jet near Japan. In the summer following the eastern El Niño 1997/1998, the anomalous warm SST center was located at the Kuroshio region, and an anomalous cold SST was located in the Kuroshio extension region, which led to the weakening of Rossby wave activity near 37.5 °N. The south East Asia westerly jet thus moved southward and weakened. Because the air rises at the left side of the westerly jet's exit region, and sinks at the right side, when the jet moves northward, the updraft and downdraft at each side will also move northward and eastward. Therefore, in the summer of the central El Niño 2009/10, the subtropical high, low trough and northeast Asia blocking high moved northward overall.

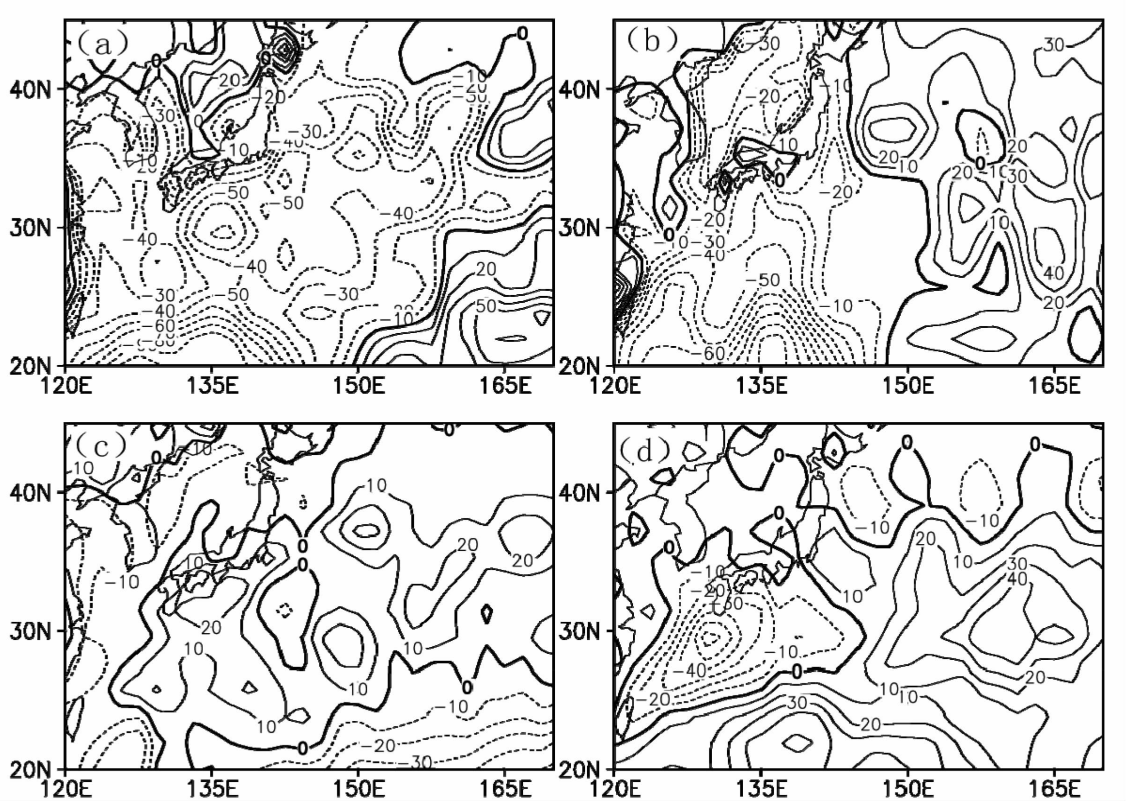

**Figure 7.** Spatial distribution of latent heat flux anomalies in the winter and the following summer of El Niño. a and c: 2009/2010; b and d: 1997/1998.

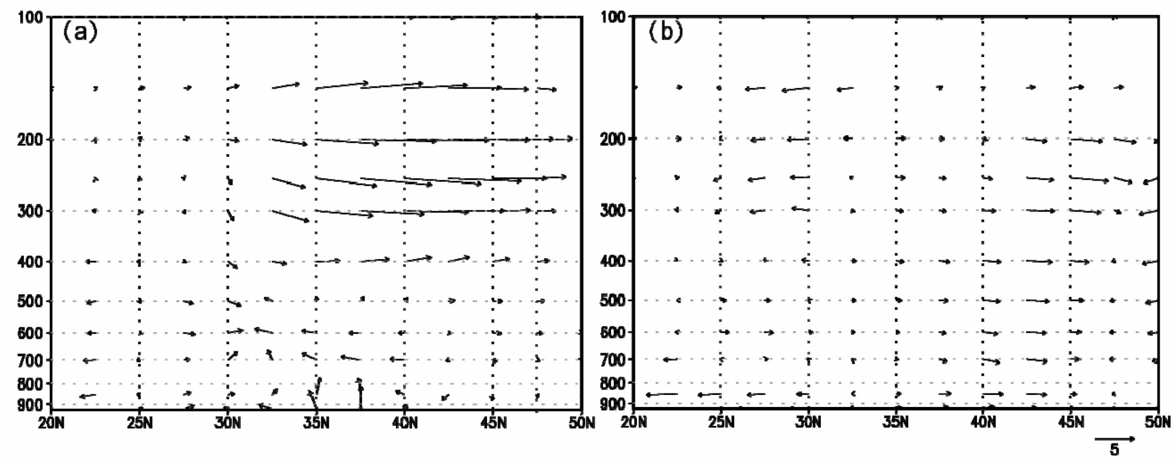

**Figure 8.** Latitude-height section of Rossby wave activity flux along 140° to 150 °E in the summer of 2009 (a) and 1998 (vector, unit: $10^8$ $m^2 \cdot s^{-2}$).

According to the definition by Kwon, and considering the observed SSTA, numerical sensitivity experiments were designed by choosing the Kuroshio region as 20 °N to 35 °N, 125 to 150 °E, and the Kuroshio extension region as 35 °N to 45 °N, 140 to 170 °E; the results are shown in Figs.9 and 10[34].

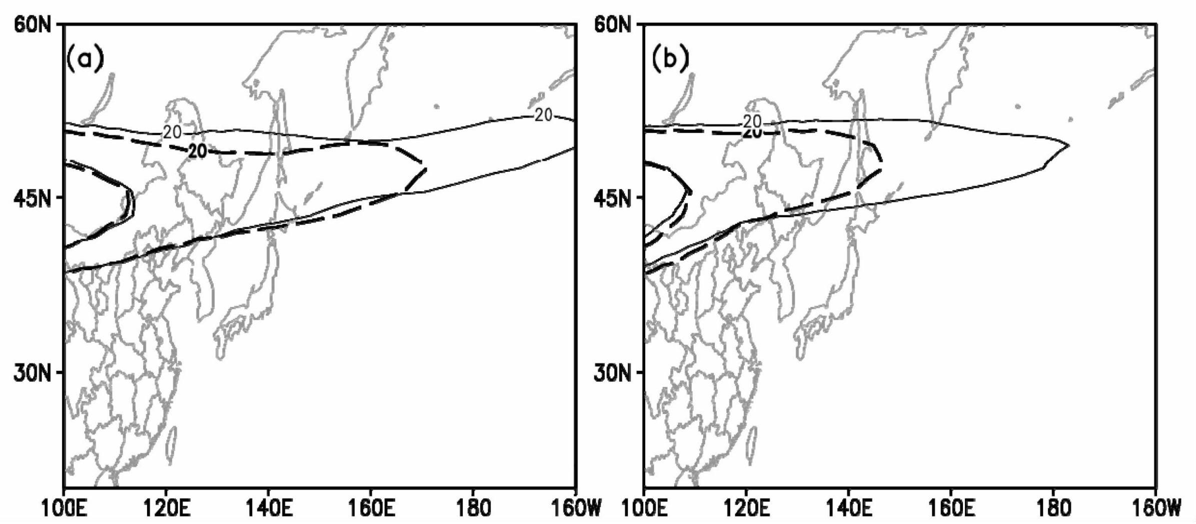


**Figure 9.** Simulated zonal wind with speed more than 20 m/s for the summer of 2010 (a) and 1998 (b). Dashed line denotes E10_JunP and E98_JunP respectively and solid line denotes E10 and E98 respectively.

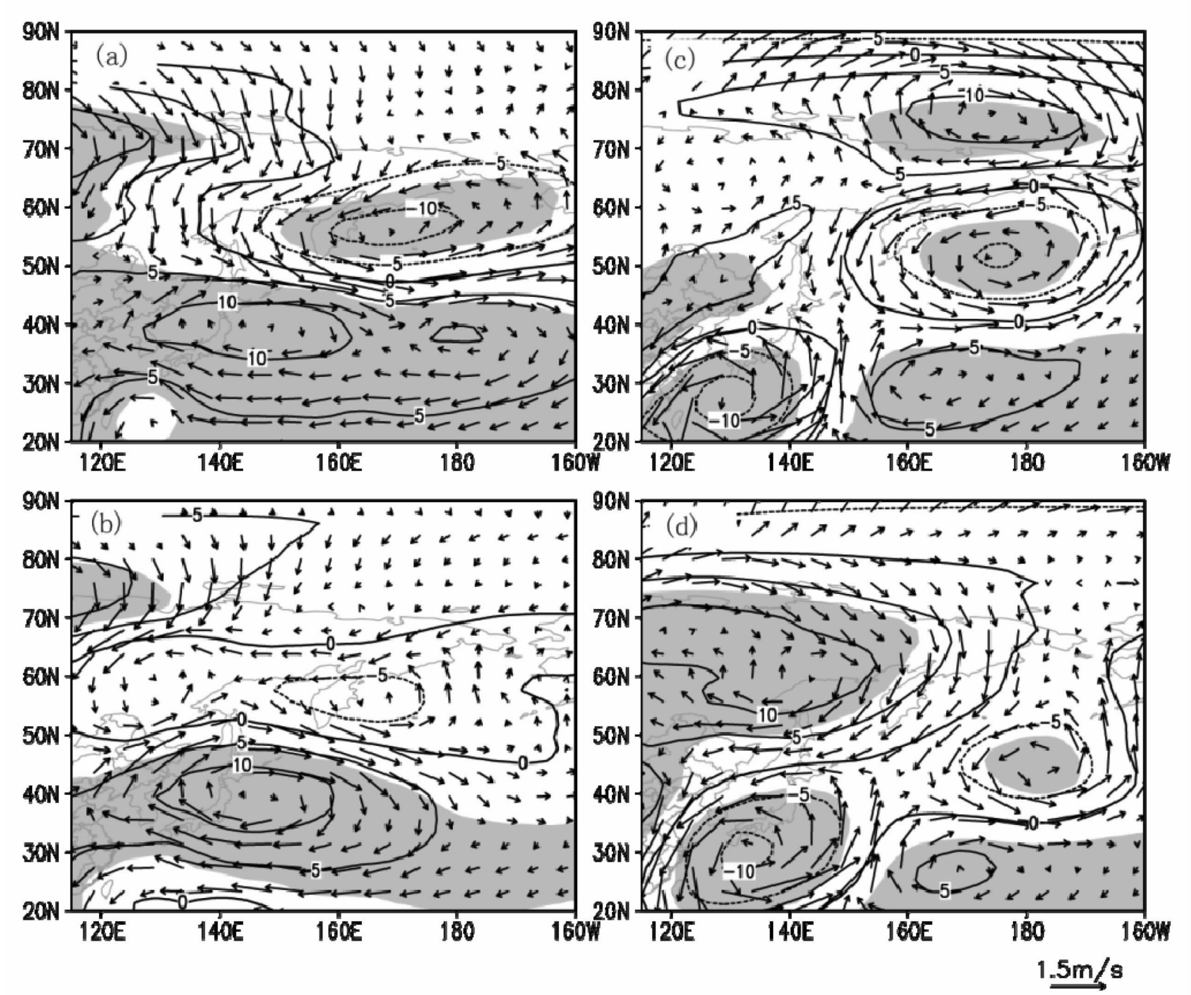


**Figure 10.** Simulated 850-hPa anomalous geopotential height (unit: gpm) and wind fields (unit: m s$^{-1}$) for the summer 2010 and 1998. a: E10; b: E98; c: E10_JunP; d: E98_JunP; values significant at the 90% level are shaded.

Because the climatologically averaged westerly jet in the model is weaker than in the observation, the wind speed of more than 20 m/s is chosen to represent the westerly jet, as shown in Fig.9; thus, the result of the simulated westerly jet shows that under the influence of SST anomalies at Kuroshio and its extension in 2009/2010, the East Asia subtropical westerly jet significantly strengthened and stretched eastward in the summer of 2010 relative to 1998, which is consistent with the observations illustrated by Fig.4. Simulated anomalous atmospheric circulations at 850 hPa shown in Fig.10a illustrate that the region from the Sea of Japan to the Sea of Okhotsk were controlled by the anomalous anticyclone and cyclone in the summer of 2010, which means that the western Pacific subtropical high strengthened and extended northward. At the same time, the negative center of geopotential height anomalies at Okhotsk suggests that the blocking high in this region was weakened. In 1998 (Fig.10), the area f rom Kuroshio to the Okhotsk sea was controlled by an anomalous cyclone and anticyclone, which indicates that the western Pacific subtropical high moved southward, and the Okhotsk blocking high strengthened. The experiment using persistent SST shown in Fig.10b and 10d demonstrate that the observational anomalous atmospheric circulations can be forced by previous SSTA without overlaying the SSTA at Kuroshio and its extension in July and August, which indicates that the previous SSTA played a major role in the formation of anomalous circulations at middle and high latitudes in the following summer of the two types of El Niño events.

Comparing Fig.2 with Figs.9 and 10, although the location of the simulated anomalous circulation centers at middle and high latitudes were different, the simulated anomalous circulations from the Sea of Japan to the Okhotsk Sea and the East Asian subtropical upper westerly jet region of abnormal circulation were in agreement with observations. This suggests that the SSTA at Kuroshio and its extension has an important contribution to the formation of the anomalous circulations at middle and high latitudes in the two years.

## 5 SUMMARY AND DISCUSSION

For the two cases of precipitation anomalies in Northeast China in the summer of 2010 and 1998, the influence of SSTA at Kuroshio and its extension under the background of two types of El Niño are discussed, and the main conclusions are as follows:

(1) Under the background of central El Niño 2009/2010, there was strong water vapor convergence centered at the northern Korean peninsula in the summer of 2010; hence, there was more rainfall in the south and less in the north region of Northeast China. Under the background of eastern El Niño 1997/1998, the strong water vapor convergence center appeared at the central area of Northeast China, and the rainfall increased regionally.

(2) The key reason for the difference in precipitation in Northeast China is the shift of the EAP-like circulation along the East Asian coast in the two years. Compared with 1998, the EAP-like circulation shifted northeastward in 2010. Correspondingly, the western Pacific subtropical high, westerly trough at mid-latitude and northeast Asia blocking high also moved northeastward, and the upper westerly jet also shifted northward.

(3) In the two types of El Niño events, the difference in SSTA at Kuroshio and its extension is the main reason for the shift of the anomalous circulations along the East Asian coast: (1) in the strongest period of central El Niño 2009/2010, the convective updraft in the equatorial region moved westward; thus, the corresponding downdraft at the northwest Pacific moved northward, which leads to the anomalous warm SST located at the Kuroshio extension area in the former event, and Kuroshio in the later event; (2) because of the air-sea interaction, the SSTA at Kuroshio and its extension can persist until the decaying period, so the anomalous warm SST at Kuroshio and its extension in 2009/2010 shifted more northward than that in 1997/1998, which further leads to the northward movement of the East Asia upper westerly jet in the spring, and finally the western Pacific subtropical high, mid-latitude westerly trough and East Asia blocking high along the East Asia coast shifted northward in the summer. The results of sensitivity experiments show that in the central El Niño event, the anomalous warm SST can force the upper westerly jet to move further northward than the eastern one.

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