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# Summertime Atmospheric Teleconnection Pattern Associated with a Warming over the Eastern Tibetan Plateau

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**ABSTRACT**

By using a surface air temperature index (SATI) averaged over the eastern Tibetan Plateau (TP), investigation is conducted on the short-term climate variation associated with the interannual air warming (or cooling) over the TP in each summer month. Evidence suggests that the SATI is associated with a consistent teleconnection pattern extending from the TP to central-western Asia and southeastern Europe. Associated rainfall changes include, for a warming case, a drought in northern India in May and June, and a stronger mei-yu front in June. The latter is due to an intensified upper-level northeasterly in eastern China and a wetter and warmer condition over the eastern TP. In the East Asian regions, the time-space distributions of the correlation patterns between SATI and rainfall are more complex and exhibit large differences from month to month. Some studies have revealed a close relationship between the anomalous heating over the TP and the rainfall anomaly along the Yangtze River valley appearing in the summer on a seasonal mean time-scale, whereas in the present study, this relationship only appears in June and the signal's significance becomes weaker after the long-term trend in the data was excluded. Close correlations between SATI and the convection activity and SST also occur in the western Pacific in July and August: A zonally-elongated warm tone in the SST in the northwestern Pacific seems to be a passive response of the associated circulation related to a warm SATI. The SATI-associated teleconnection pattern provides a scenario consistently linking the broad summer rainfall anomalies in Europe, central-western Asia, India, and East Asia.

**Key words**: teleconnection pattern, short-term climate variation, Tibetan Plateau, surface air temperature

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## 1. Introduction

As an elevated heating source, the Tibetan Plateau (TP) has been considered to exert profound thermal and dynamical impacts on the weather and climate in Asia. During the summer monsoon onset, the seasonal warming over the TP accounts for a reversal of the meridional temperature gradient south of the TP and contributes to the establishment of the Asian summer monsoon (Flohn, 1958; Ye and Gao, 1979; Yeh, 1981; Luo and Yanai, 1984; He et al., 1987; Yanai et al., 1992; Li and Yanai, 1996; Wu and Zhang, 1998; Liu et al., 2007; Wu et al., 2007). Recently, Lau et al. (2006) suggested that an interaction between aerosol absorbing and the physical processes over the TP may create a positive temperature anomaly over the TP in the mid-to-upper troposphere and favors the onset of the South Asian summer monsoon. On an interannual time-scale, the heating anomaly over the TP, associated with the anomalous snow cover in the winter-spring time, is found to affect the summer monsoon rainfall anomalies in Asia (Blanford, 1884; Walker, 1910; Hahn and Shukla, 1976; Bamzai and Shukla, 1999; Wu and Qian, 2003; Zhang et al., 2004; among others).

More evidence also indicates that the Asian sum-

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mer monsoon heating, including the thermal heating over the TP, is closely related to the atmospheric teleconnection patterns in Eurasian, and can bring about climate anomalies in regions far away from the Asian monsoon region. Rodwell and Hoskins (1996) demonstrated that the summertime descent over the eastern Mediterranean and Sahara could be induced by the Asian monsoon heating due to the motivation of westward-propagating Rossby waves in response to the heating. Very recent studies (Ding and Wang, 2005; Duan and Wu, 2005) revealed a close relationship between the South Asian monsoon/Tibetan Plateau heating and the climate anomalies in western Asia and Europe. However, some important aspects of the teleconnection pattern, especially a focusing on the subseasonal heating anomalies over the TP, are not clarified.

The Asian summer monsoon rainfall has a complex temporal-spatial structure in the summer. For the East Asian monsoon, the rainfall exhibits a staged progression of a zonally oriented rainbelt with a different location in the different summer months (Tao and Chen, 1987; Ding, 1992). The South Asian monsoon rainfall is also characterized by a northward march of convection from south of the Arabian Sea and the southeastern Bay of Bengal toward the northern Indian subcontinent (Wang and LinHo, 2002). This implies that the spatial distribution of rainfall anomalies associated with the thermal anomalous heating over the TP may differ from month to month in the summer.

The major objective of this work is to examine the dominant features of the teleconnection pattern related to the interannual variation of the surface air temperatures over the TP in each summer month by using a surface air temperature index averaged from the long-term stational observations over the eastern TP, and to explore the associated rainfall and SST anomalies on a so-called interannual-subseasonal time scale.

## 2. Data

The surface maximum and minimum temperatures at 54 stations over the eastern TP are used in this study, with the missing rate for May–August less than 5% during 1965–2002. Figure 1a shows their geographic locations. In this study, a surface air temperature index (SATI) is derived by averaging these stations.

The following datasets are also used: (1) Monthly precipitation over the land area derived by the Climatic Research Unit (Mitchell and Jones, 2005); (2) SST data from the Met Office Hadley Centre (Rayner et al., 2002); (3) Monthly wind and air temperature from the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year re-analysis (ERA-40) project; and (4) The Climate Prediction Center (CPC)

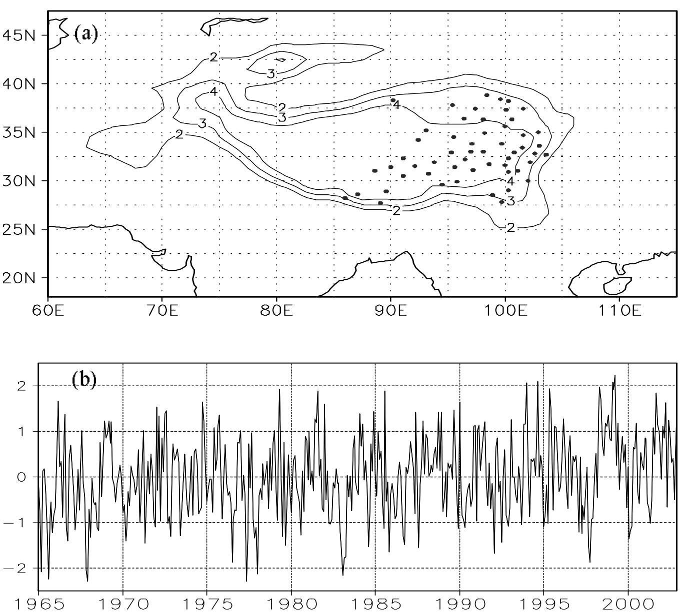


**Fig. 1.** (a) Map of observing stations for surface air temperatures. Contours indicate the height (km) of the Tibetan Plateau. (b) Normalized (divided by the standard deviations at each month) surface air temperature index (SATI) over the TP with long-term trends longer than 6 years eliminated.

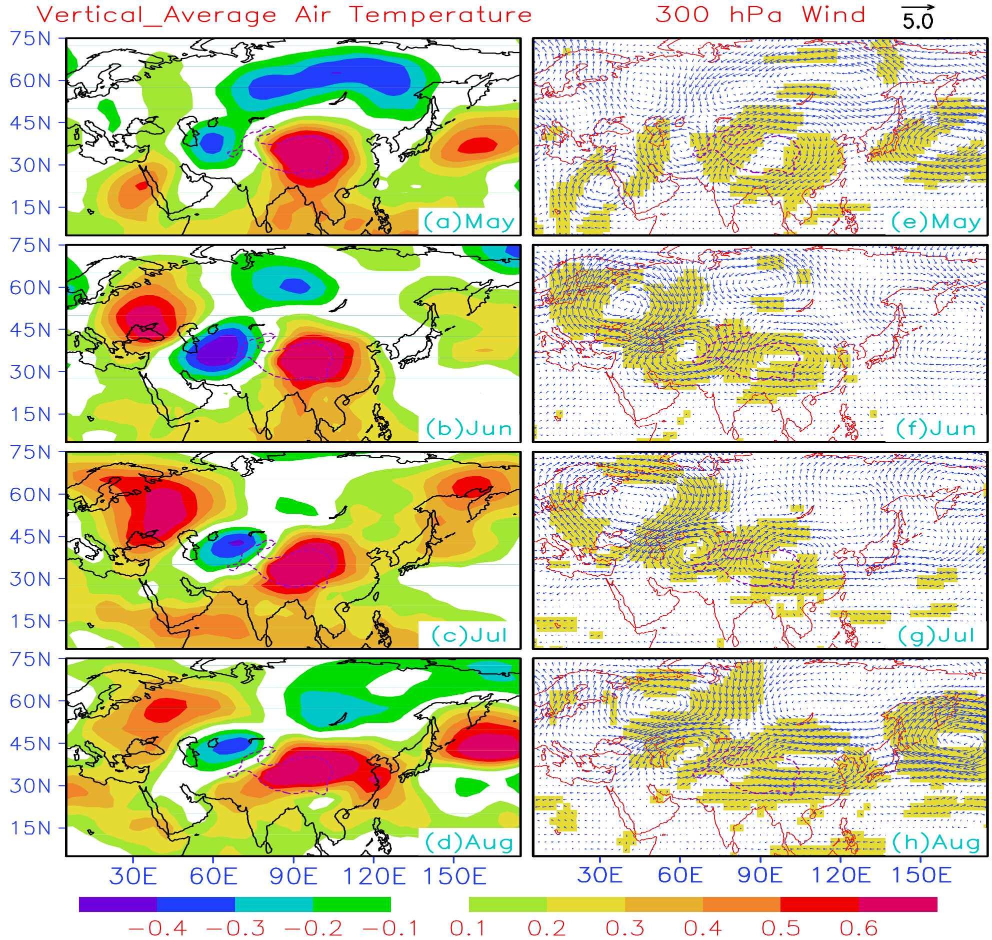


**Fig. 2.** Distributions of monthly simultaneous correlation coefficients between SATI and the vertical mean air temperature from 300 to 600 hPa (left panels), and anomalous wind vectors simultaneously regressed with SATI at 300 hPa (right panels) for 1965–2002. The thick dashed line indicates the elevation of the Tibetan plateau at 2.5 km. The threshold values for exceeding the 95% confidence level are ±0.33. The shading in the right panels denotes the area where the wind exceeds the 95% confidence level.

merged analysis of precipitation (CMAP). Since some studies show that air temperature over the TP and summer rainfall in eastern Asia have experienced obvious interdecadal changes (Liu and Chen, 2000; Zhang et al., 2004), a high-frequency-passed filter was used to eliminate the long-term trends longer than 6 years in all of the above datasets.

## 3. Results

The normalized SATI with the long-term trend eliminated is shown in Fig. 1b. To estimate the signal persistence of the SATI anomaly, we calculated its self-lagged correlation coefficients (CC). Those CC values of May–June, June–July, and July–August appear at 0.38, 0.28, 0.34, while May–July and June–August appear as −0.06 and −0.02, respectively[a]. This demonstrates that persistence of the surface air temperature anomaly over the TP is less than two months during the summer, convincing that, compared to that based on the seasonal mean data, a study on the sub-seasonal ones between the SATI and the climate anomalies is meaningful.

### 3.1 *Characteristics of the atmospheric teleconnection pattern associated with a warming over the eastern TP*

Figures 2a–d show the distribution of simultaneous CCs between SATI and the vertical mean air temperature from 300 hPa to 600 hPa during 1965–2002. They present a consistent teleconnection pattern that appears from June to August in the Eurasian conti-

[a]The threshold values for the 95% confidence level are ±0.33 for the 38-year samples.

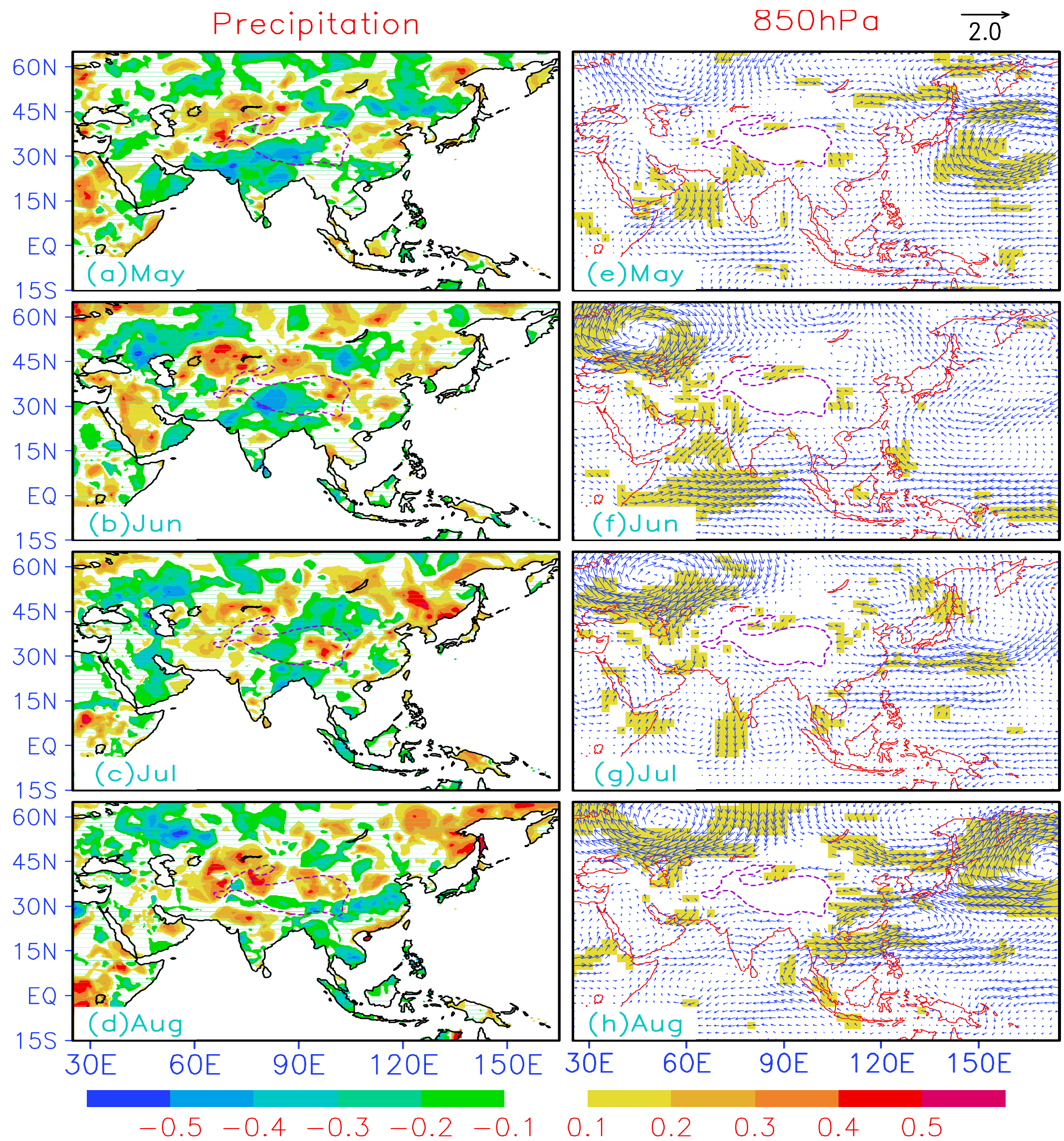


**Fig. 3.** Same as Fig. 2, but for the correlation between SATI and precipitation (left panels) and the regressed wind at 850 hPa (right panels).

nent. It consists of a warm cell over the TP and its neighboring region and another one in southeastern Europe, and a cold cell in central-western Asia. The teleconnection reaches its greatest intensity in June and July, coincident with the seasonal change of the heat source intensity (Gao et al., 1981)

Figures 2e–h show the anomalous wind vectors at 300 hPa simultaneously regressed with the normalized SATI. It is seen that the circulation changes are consistent with the temperature changes: a warming cell over the TP is associated with an upper-level anomalous anti-cyclone, similar to the one in southeastern Europe, and meanwhile an anomalous cyclone appears in central-western Asia in relation to a cold cell. The wave-train pattern has a northward movement trend from May to August while the center of the anti-cyclonic circulation over the TP moves from its southern to northeastern part, following the northward seasonal migration of the mid-latitude westerly jet.

Associated with the circulation changes, large-scale wet and dry weather conditions also appear, though they are not as significant as the correlation of the air temperature. In Figs. 3a–d, a warming over the TP is accompanying a drought in southeastern Europe during June–August, and a wet condition in central Asia. In South Asia, a drought in northern India in May and June is related to a warming over the TP. Also, the warming of the TP tends to be concurrent with a drought along the coast of the northern Bay of Bengal in all the summer months. The above spatial distribution of rainfall anomalies also seems to exhibit a wave-

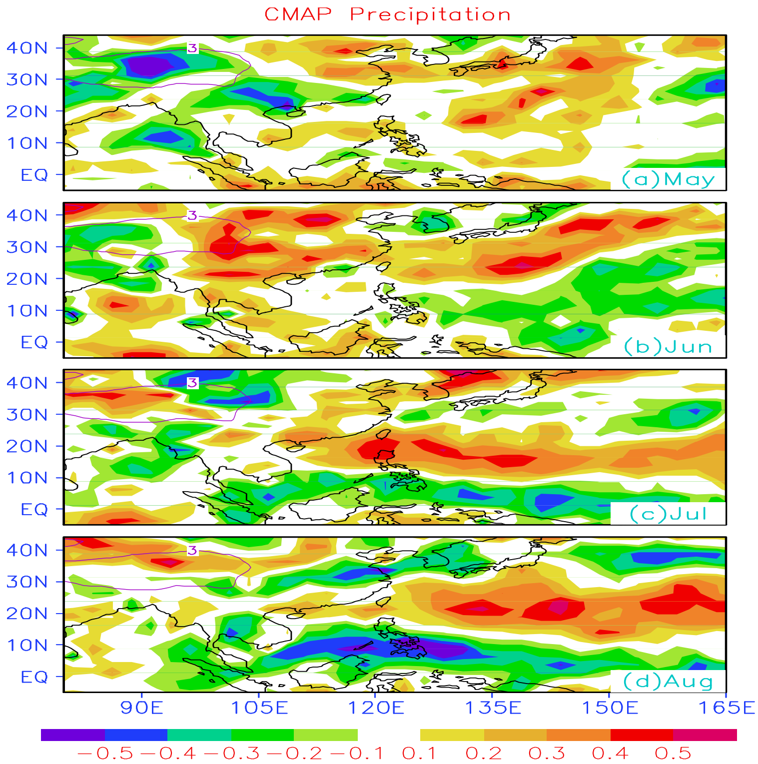


**Fig. 4.** Simultaneous correlation coefficients between the SATI and CMAP rainfall for 1979–2002. The threshold values for exceeding the 95% confidence level are ±0.41.

train pattern extending from northern India- northern coastal region of Bay of Bengal to central Asia and southeastern Europe, consistent with the changes of the circulation.

### 3.2 *The Asian summer rainfall anomaly associated with warming over the eastern Tibetan Plateau*

Figure 2 and Figs. 3a–d show a dominant atmospheric teleconnection covering extensive regions across Eurasia. Therefore, it could contribute to largescale fluctuations of the summer rainfall anomalies in Asia. In South Asia, the most significant signals are found over northern India in May and June, and the coastal region of the Bay of Bengal in June and July. They are concurrent with the lower-level anomalous northerlies over the northern Indian subcontinent and the Arabian Sea shown in Figs. 3e–g, implying weakened northward vapor transportation from the ocean to these regions. A descending motion, forced by the strong ascending over the TP, may also suppress the convection activities to its south, over the coastal region of the northern part of the Bay of Bengal, creating a drought.

Air warming over the TP could induce strong local ascending motion and force a lower-level convergence (Figs. 3f–g) and therefore, *in situ* precipitation in the eastern TP in June and July appears to be positively correlated to SATI (Figs. 3b and 3c). In the East Asian regions, the time-space distribution of the correlation patterns between SATI and rainfall shown in Figs. 3a–d are more complex and exhibit large differences from month to month. Noting that, climatologically in East Asia, the location of the heavy convection rainfall belt moves northward from the southern coast of China to northern China from May to August, we therefore argue that, to a great extent, the interaction between the seasonal rainfall belt (and prevailing flow) and the warming over the TP is responsible for these changes in each month. Some studies have revealed a close relationship between the anomalous heating over the TP and the rainfall anomaly along the Yangtze River valley appearing in the summer on a seasonal mean time-scale (Hsu and Liu, 2003; Wu and Qian, 2003; Zhang et al., 2004). In our study, this relationship only appears in June (Fig. 3b) and the signal's significance becomes weaker after the long-term trend in the data was excluded. A stronger signal is obtained though when we used the CMAP data for 1979–2002 shown in Fig. 4b. With adding the data over the ocean in the CMAP data, we can see that a warming over the eastern TP is related to a heavier rainfall belt extending from the eastern TP, Yangtze River valley, and the Yellow Sea (Fig. 4b), implying a stronger mei-

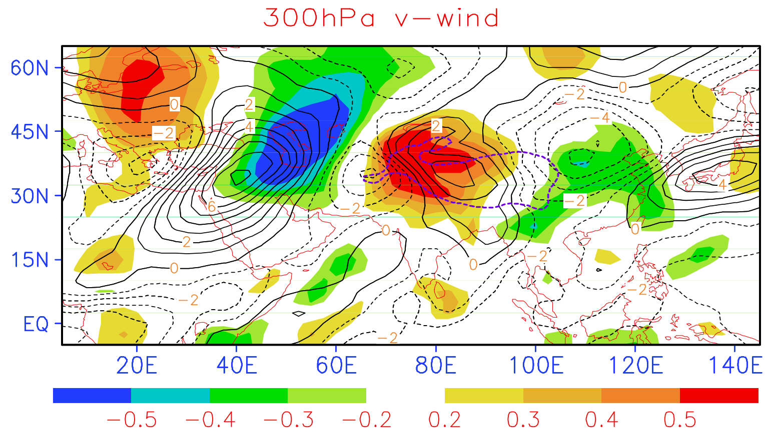


**Fig. 5.** Monthly simultaneous correlation coefficients between the SATI and the 300 hPa meridional wind (shading) in June and the climatological 300 hPa meridional wind in June for 1965–2002 (contour). The threshold values for exceeding the 95% confidence level are ±0.33.

yu front[b]. Figure 5 shows on the one hand, how the climatological meridional winds couple with the winds deduced by a warming over the eastern TP. A negative CC center between the SATI and the meridional winds at 300 hPa over the region between 20°–40°N, 100°–120°E is coincident with the prevailing northerly flow (Fig. 5), indicating that a warming over the TP tends to intensify the upper-level prevailing northerly flow over this region in June, so that it will increase the vertical wind shear for creating a more unstable condition for the mei-yu front. On the other hand, more mei-yu rainfall may also contribute to the anomalous northerly maxima due to the Sverdrup balance (Liu et al., 2001, 2004). This leads to a slight eastward shiftof the northerly maxima. Additionally, a wetter and warmer condition over the eastern TP will provide more energy for the development of the eastward-migrating low-level vortex over the eastern flank of the Tibetan Plateau[c], therefore, favoring a wetter summer in the vicinity of the Yangtze River valley (Fig. 4b).

A warming over the TP in July and August is concurrent with intensified convection activities over the western subtropical Pacific Ocean along 20°N and suppressed ones to their south (Figs. 4c and 4d). Associated circulation anomalies are seen with the development of an anomalous cyclone along the southeastern coast of China and the East Sea. Related to that, strong anomalous northeasterly flow prevails over central China and results in a southwest-to-northeast-tilted deficient rainfall belt in this region (Figs. 4c and 4d).

### 3.3 *The variation of the SST associated with warming over the eastern Tibetan Plateau*

To estimate the relationship between SST anomalies and the warming over the eastern Tibetan Plateau, we calculated the simultaneous CCs between the SATI and SST. The results are shown in Figs. 6a–d in the region west of the date line because there are not any notable signals in the central and eastern Pacific Ocean. The SATI is seen to be positively correlated to the SST in the western Pacific Ocean appearing as a warm tone extending from the eastern coast of China to the date line, with a northeast-titled trend. The anomalous SSTs move northward from the northwest Philippine Sea in May (Fig. 6a) to the southern Japan Sea in August (Fig. 6d). In June, the warming SST anomalies in southern Japan coincide with an increase of the rainfall in the region (Fig. 6b), implying the warm SST may provide a warm boundary layer for the development a stronger mei-yu front. During July and August, however, the warming SST anomalies (Figs. 6c and 6d) are concurrent with a deficient rainfall and anomalous easterly zone (Figs. 4c–d and Figs. 3g–h) over the East Sea in June and the Bohai Sea-to-southern Japan Seas in July, respectively. In these regions, a wind-evaporation feedback involving the ocean and anomalous easterlies and a reduction of the rainfall, which indicates a stronger short-wave radiation heating to the ocean, may account for a SST warming in July (Fig. 6c) and August (Fig. 6d) in the northwestern Pacific Ocean. In the Indian Ocean, the signal between the SATI and SST in the equatorial-

[b]In East Asia, the rain belt arrives at the Yangtze River valley and southern Japan after mid-June, which is referred to as mei-yu in China and Baiu in Japan.

[c]During the mei-yu period, the low-level vortices frequently develop on the eastern flank of the Tibetan Plateau producing heavy rain along the mei-yu front, and the energy for the vortex generation mostly comes from the release of latent heat. A detailed discussion on this issue can be seen in the literature of Zhang et al. (2004).

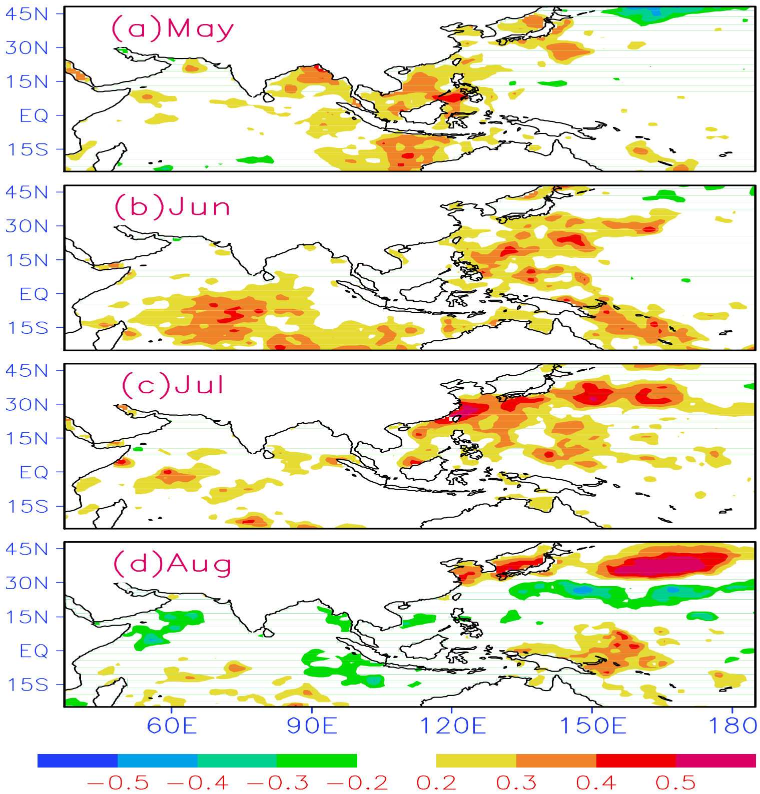


**Fig. 6.** Monthly simultaneous correlation coefficients between the SATI and SST for 1965–2002. The threshold values for exceeding the 95% confidence level are $\pm0.33$.

central Indian Ocean is only found in June (Fig. 6b), coinciding with the anomalous westerly in the region, partly due to a strong wind-evaporation feedback. The above evidence suggests that the teleconnection tends to play a more active role in the modulation of the SST.

## 4. Discussion

In this study, the teleconnection pattern associated with the SATI variation provides a scenario linking the broad rainfall anomalies in Europe, central-western Asia, India, and East Asia. The structures in wind and air temperature exhibit a robust barotropical feature related to a deep heating source forcing. An important question raised is what original sources are responsible for initiating this teleconnection. Though a deep exploration needs help from numerical simulations, we will give a discussion in the following based on the evidence revealed in this study.

In Fig. 7, we present the 300 hPa climatological zonal winds (contour) and the CCs between the 300 hPa zonal winds and SATI (shading). The locations of the CC maximum or minimum centers consistently show that the teleconnection seems to be a Rossby wave train along the mid-latitude westerly jet, noting that the heating over the TP is notably one of the important sources to initiate a stationary upper-level anticyclone in the summer. Therefore, the perturbation of the heating over the TP should be very important for setting-up such a teleconnection pattern. This conclusion is supported by some studies (Rodwell and Hoskins, 1996; Ding and Wang, 2005), which demonstrate that the heating related to the South Asian summer monsoon could active a westward-propagating Rossby wave.

Specifically, we think two sources could produce such perturbations: One is the snow cover anomaly over the TP that mainly appears in the early summer (May and June), and another one may come from the remote forcing of the heating anomaly in the western Pacific Ocean. The former is supported by the study of Zhang et al. (2004), which presents a similar teleconnection pattern that appears in June in relation to the local anomalous snow cover, an important modulator of the sensible heating anomaly over the TP. For the latter one, significant correlations between the SATI and the 300 hPa zonal winds are seen in the equatorial maritime continent (Figs. 7c and 7d), and convection activities in the tropical western Pacific Ocean (Figs. 4c and d). This implies that the convection activities in the northwestern Pacific Ocean seem to be another

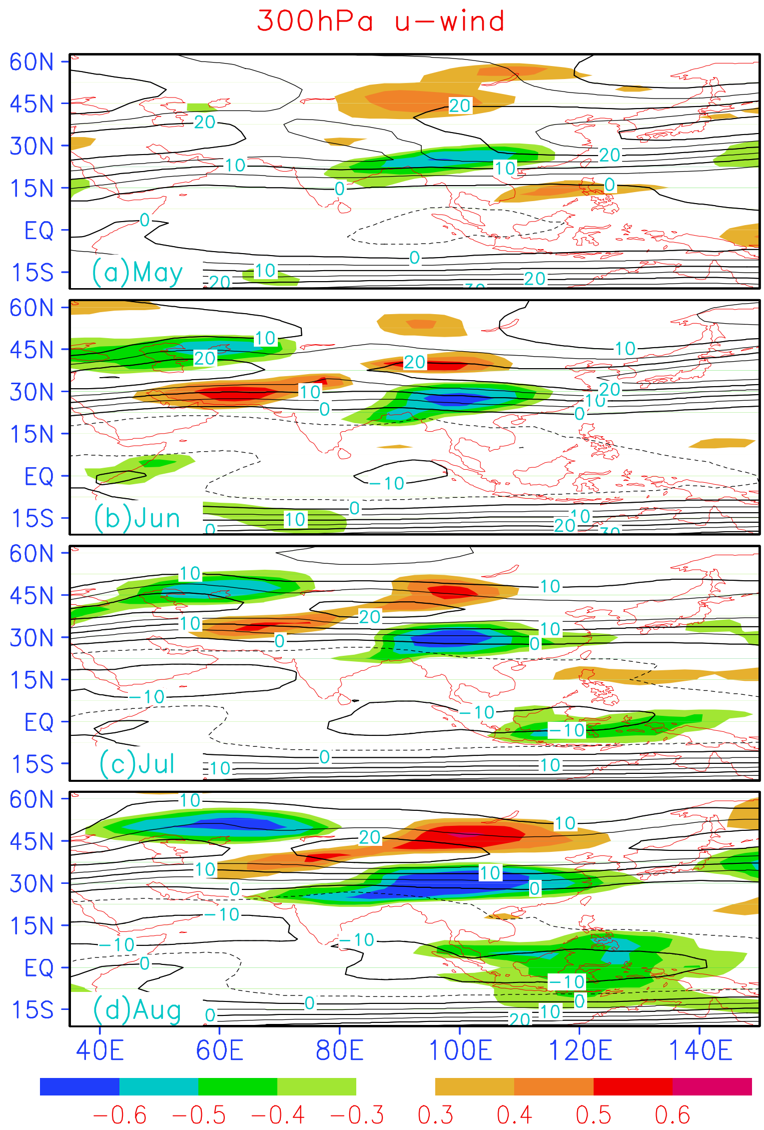


**Fig. 7.** Monthly simultaneous correlation coefficients between the SATI and the 300 hPa zonal wind (shading) and the climatological 300 hPa zonal wind for 1965–2002 (contour). The threshold values for exceeding the 95% confidence level are ±0.33.

remote heating source for the modulation of the air temperature over the TP through the changes of the Hadley circulation in the region.

## 5. Summary

Using the monthly observational surface air temperatures, we investigated the summer atmospheric teleconnection pattern associated with the interannual-subseasonal atmospheric warming over the TP for 1965–2002. The results show that the interannual warming (cooling) over the eastern TP is not only locally related to an anomalous upper-level anti-cyclone (cyclone) over the eastern TP, but is also related to an anomalous cyclone (anti-cyclone) cell in central-western Asia and an anti-cyclone (cyclone) in southeastern Europe, with its strongest intensity appearing in June and July. Correlation maps also show that the circulation associated with this teleconnection pattern strongly interacts with the tropical-subtropical circulation and accounts for the rainfall anomalies in India and eastern Asia and their large month to month differences. For a SATI warming event, an associated anomalous northerly over the Arabian Sea is responsible for a drought in northern India in May and June. Meanwhile, the mei-yu front becomes stronger in June modulated by the upper-level anomalous northwesterly and a wet and warming condition over the eastern TP, which may motivate more low-level vortexes, which migrate eastward and produce more rainfall along the mei-yu front. A zonally-elongated warm tone in the SST in the northwestern Pacific also seems to be a passive response of the associated circulation related to a warm SATI.

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