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Impact of ENSO on the thermal condition over the Tibetan Plateau

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Abstract

The proposed study aims to examine the relation between the Tibetan Plateau (TP) thermal condition and El Niño and Southern Oscillation (ENSO). There were significantly positive correlations between the snow water equivalent (SWE) over the TP from November to next April and sea surface temperature (SST) in the Eastern Equatorial Pacific (EEP) in November from 1987 to 2005. SST in EEP in November is most significantly correlated with the TP-SWE in next April, which suggests an accumulative effect of the ENSO on the TP snow cover. Although El Niño conditions could bring anomalous snowfall over the TP by generating a wave train entering the North African-Asian jet, it is questionable if this impact could change the thermal condition over the TP. There was almost no significant negative correlation between the SWE and TP surface temperature (representing the TP thermal condition) in winter. This suggests that the TP thermal condition hardly varies with the anomalous snowfall caused by this ENSO impact, despite some cooling effect of snowfall during the El Niño phase. On the contrary, preceding El Niño conditions tended to be associated with increasing TP surface temperature in May and there were significant positive correlations between SWE in April and TP surface temperature in May and June. ENSO might play a part in affecting TP thermal condition in a way that is quite different from the previous research. A plausible mechanism based on the relation of ENSO-TP thermal condition has been proposed. The mechanism explained the direct and indirect effects of ENSO on the TP thermal condition and role that the seasonal progress can play in this relation. The issues about snow cover aging and the impact
of global warming, among others, were also included in the mechanism.

Key words: ENSO, Tibetan Plateau, Snow depth

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1. Introduction

Many studies have pointed out that the Tibetan Plateau (TP) could play a strong role in affecting the ambient and downstream weather conditions (Manabe and Terpstra 1974, Murakami 1981, Hahn and Manabe 1975 etc.). The thermal effect of TP is especially important for the change of the downstream airflow, which could affect East Asian monsoon in early summer (Wang et al. 2011, Liu et al. 2007). Unlike the mechanical effect of the TP, the thermal effect has large interannual variation that could make different impacts in different years. Finding what can cause the thermal changes in the TP is crucial for the evaluation of its effect. Given an atmospheric stationary wave teleconnection mechanism, Shaman and Tziperman (2005, hereafter referred to as ST05) proposed an explanation about how the El Niño event in the wintertime could affect the TP snow depth, which may result in a change in south Asian monsoons from winter to summer. They argued that an El Niño might generate a barotropic wave train that first travels in the Northeastern hemisphere, is turned by a North American jet reflection, and the wave finally enters the North African-Asian jet. The wave propagation with the westerly jet resulted in anomalous increase of the vorticity and snow depth over TP in winter. According to their speculation, the TP snow depth may persist until summer, which might largely reduce the TP thermal effect, so that the ENSO could affect Asian summer monsoon as well. The teleconnection mechanism of the ST05 was convincing because it agreed with common alternative methods used to approach this phenomenon (i.e. wave tracing
and correlation analyses). In addition, their work has successfully linked the ENSO events to the discussions about causation of the Asian monsoon changes. However, their speculation about the persistence of the TP snowpack from winter to summer seems to remain questionable. This is because the historical snow depth data used in that study was too short, only ten years, to explain such a complex phenomenon. Note that the snow data has improved over the years by the same provider. On the other hand, according to the results of Cohen and Rind (1991), the large snow cover does not always play an essential role in decreasing surface temperature. Thus, the TP thermal effect would remain the same even if the ENSO brings anomalous snow cover to the TP, which would result in an opposite inference to the speculation of ST05. Since understanding the delayed impacts of ENSO on Asian summer monsoon’s variation through the TP thermal effect is of great importance, there is no doubt that a reexamination of this issue is necessary. The purposed study aims to reexamine the relation between ENSO and TP thermal condition initially proposed by ST05. We will finally propose a plausible mechanism about the ENSO impact on the TP thermal condition.

2. Data

2.1. Snow water equivalent (SWE) data

This study uses SWE data rather than snow depth, since it represents snow depth and many studies have pointed out that the snow volume or depth is better than snow cover at expressing the capacity affecting the overlying airflow (Barnett et al. 1989, Kripalani and Kulkarni 1999, Ye and Bao 2001). The global SWE data is derived
from Scanning Multichannel Microwave Radiometer and selected Special Sensor Microwave/Imagers (SSM/I) obtained from the National snow and ice data center. The entire period of the data available was from 1978 to 2007 (Takala et al. 2011). However, NSIDC reported a sensor break from July to August 1987, which has a clear difference between the two months, so we chose to use the longest and most improved SWE monthly data from August 1987 to May 2007. The horizontal resolution is 25 x 25 km.

2.2. Sea surface temperature (SST) data

The SST data averaged over the Niño-3 region (5°N–5°S, 150°–90°W) was the index of ENSO (SST3) used for this study (Kaplan et al. 1998). The National Oceanic and Atmospheric Administration Extended Reconstructed monthly SST V3b on a 2° latitude/longitude grid from 1987 to 2006 was used.

2.3. NCEP/NCAR reanalysis data

The National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) global atmospheric reanalysis dataset is the primary dataset used in this study (Kalnay et al. 1996). Specifically, the monthly 500-hPa geopotential heights (hgt500, 1988-2006)) and 200-hPa relative vorticity (1963-2013) on a 2.5° latitude/longitude grid were used here.

2.4. Outgoing longwave radiation (OLR)

National Oceanic and Atmospheric Administration’s monthly OLR on a 1° latitude/longitude grid from 1988 to 2006 were used here (Li 2014). The original data source can be found at the following URL:
2.5. **TP surface temperature (TP-Ts)**

Monthly surface air temperature for 75 stations located in the eastern TP for the years 1987–2006 were used (Fig. 1), which was provided by Atmospheric-Scientific Information Department of Chinese Academy of Meteorological Sciences. Since higher SWE values were mainly distributed in the eastern part of the TP, comparing the stations’ temperature data to snow depth is adequate for this analysis. The thermal condition over the TP generally means how much the quantity of heat over the TP can be retained. The surface air temperature on the TP would be a useful index that can roughly measure the TP thermal condition in an easy way. Note that the higher SWE values also existed in the western and southern edges of the TP, which may exist due to the effect of the raised mountains in situ where dominating southwesterly winds with rich water vapor. Interestingly, there was less SWE in central TP (i.e., the highest area as shown in Fig. 1b). This study only focuses on studying the regional TP-SWE and TP-Ts.

3. **A case in 1998**

A specific case is studied to understand how the elements over the TP evolve with an El Niño phenomenon. The El Niño event in 1997 is one of the strongest on record, and its mature period began from September 1998 as pointed out by Wang et al. (2001). The positive SWE anomalies strongly reached the top in January 1998, and then sharply dropped below zero in May 1998 forming the parabolic shape, as shown in Fig. 2. The SWE during this winter is the largest in the history on record. On the
other hand, the TP-Ts generally kept lower values from November, 1997 to March 1998, except for a temporal increase in February 1998 when either snowfall or rainfall may occur with a storm system. The cooling effect of SWE appeared obvious. Note that the SWE did not drop as fast as the temperature increased in the spring of 1998, which implies that melting might not be the only cause of the increase in TP temperature. The OLR values can generally detect the height of the cloud top. Thus, negative OLR anomalies mean that the cloudy or wet weather in situ and vice versa. Although, quite low OLR value on the surface of the TP can also be seen from winter to spring in the case of 1979 (Yanai et at. 1992). Lower OLR appeared in TP in January and March, whereas the opposite signs were found in situ in other months (Fig. 3). The months with positive OLR anomalies over the TP coincide with those of positive geopotential height anomalies over the TP (Fig. 4), which suggest that the situation of the high pressure covering the TP results in sunshine weather conditions in situ. Note that the large SWE in February was associated with a warmer TP, as shown in Fig. 2. This phenomenon implies that the snowpack that was melting does not always play a role in cooling the overlying air, which coincides with the study by Cohen and Rind (1991).

4. Correlation analysis

Figure 5 displays the correlation between SST in November and SWE averaged over the area of 27.5°–37.5° N, 90°–104° E from November to next June in 1987–2006. To estimate a delayed impact of ENSO on the TP weather, we regard November as the month when the ENSO events tends to mature, which followed the definition adopted
by Wang and Lupo (2009). Thus, an ENSO-like distribution would mean a significant correlation area distributed in Eastern Equatorial Pacific (EEP), as shown in Figs. 5a–5f. The significantly positive correlation areas in situ imply that an El Niño (La Niña) event is closely associated with an increase (decrease) of the TP snowpack from winter to middle spring. The detailed calculation shows that the lag correlation between SST3 in November and TP-SWE in next April reached a high R of 0.66. However, there was no such a relation after April, which does not support the speculation of ST05 who suggested that the effect of El Niño on the TP snow depth might persist until summer. Table 1 shows the monthly lag autocorrelations of TP-SWE. Interestingly, all the significantly positive autocorrelations with 99% confidence level stop at April. The longest positive autocorrelation staying significant was from November to next April. This phenomenon implies that snow depth accumulated over the TP during autumn and winter could sustain itself only until April. After this month, the autocorrelation decreases rapidly since the TP snow cover tends to melt with the advent of the warmer season. This correlation result did not coincide with that of ST05 as well (see Table 1 of ST05). Note that, although the best correlation between SST3 in November and SWE happened in April, it does not mean that the previous ENSO condition could result in an anomalous snowfall in April. This is because the impact of the ENSO on the storm track or the westerly jet that passes through the TP, which was mentioned by ST05, tends to occur only during the mature time of the ENSO. We have produced the relative vorticity composite maps similar to ST05’s Fig. 5, except on a monthly timescale (Fig. 6). The figure shows that the
positive vorticity belt that represents the storm track across the TP is significantly stronger from September to next February and stopped in March, which coincided with the figures demonstrated by ST05. Note that the significant positive vorticity reappeared in quite smaller areas around the TP in June. Since SWE is a measurement for the deposit of the snowfall, the best correlation in April would be a reflection of the accumulative effect of the ENSO. However, since the vorticity over the TP tended to be neutral or even negative in April to May, the different circulation from before dominating over the TP might be considered as an indirectly delayed ENSO effect.

Figure 7 shows the correlation between SST in the Pacific Ocean in November and the TP-Ts from November to next June in 1987–2005, which could display if a change of the thermal condition over the TP can be caused by the anomalous snowfall ENSO brought. However, the distributions of the correlations were different from those in Fig. 5. Note that the variable (TP-Ts) introduced in this study compensates for the lack of direct measurement of the TP thermal condition in ST05. If the snowpack could affect the TP thermal condition, there should be significant negative correlation areas in EEP during the wintertime. We found only small areas of the significantly negative correlation in EEP in December (Fig. 7b). This situation is reconfirmed in Table 2, in which all of the correlations did not appear negatively significant although some negative values existed from autumn to winter, e.g., the maximum negative one between SST3 in November and Ts in November (−0.28). This implies that even if the effect exists, the impact of the snowpack on the TP thermal condition is quite weak. A largely increasing trend was found in TP-Ts historical records, especially in winter,
which is known as the effect of global warming (Wang et al. 2011). After a detrending process was applied to the TP-Ts used in Fig. 7, the images of the correlation remained the same in comparison with those in Fig. 7, except for the expansion of the significant negative correlation area in EEP regarding December’s calculation (figure omitted). This implies that the effect of global warming on the TP thermal condition might play a role in reducing the cooling effect from El Niño, especially in December, although we do not intend to estimate the global warming effect by using the less accurate calculation method here. This can also explain why the cooling or warming effect of ENSO on the TP air as mentioned by ST05 appeared weak. On the other hand, the ENSO-like distribution of the positive correlations appeared in April and more significantly in May, which coincided with the values in Table 2. The SST3 in November appeared well positively correlated with the TP surface air temperature in April and May (Table 2 and Fig. 8). In particular, the positive correlation coefficient between SST3 in November and TP-Ts in May reached 0.48 that was beyond the 95% confidence level (Table 2). Although there was no significant correlation between SST3 in November and TP-SWE in next May and June, we found significant positive correlations between the TP-SWE in April and TP-Ts in May and June (Table 3). Since the TP-SWE in April was well correlated with the preceding SST3 in November too, it is more difficult to exclude the possibility that there may be some causality between the preceding ENSO event and thermal condition over the TP in May and June.

5. Composite analysis
Figure 9 (or 10) shows the composite of the Ts anomalies in all of TP stations from January to June for the years when the anomaly of the SST3 in preceding November was beyond 0.8 K (or under −0.8 K), which was associated with the mature phase of the El Niño (or La Niña). As expected, the cold Ts circles tended to occur in TP from January to March in Figs. 9a–c while the opposite sign for the same months tended to appear in Figs. 10a–c. This suggested that the mature phase of El Niño (La Niña) tends to be associated with cold (warm) TP from January to March, which coincides with the results of the case in 1998. However, there were also some warm (cold) circles in Figs. 9a-c (Figs. 10a–c), which could explain why the negative correlations in Table 2 were not significant. This is further discussed in Section 6. On the other hand, the warm Ts circles dominated from April to June in Figs. 9d–f, whereas the warm and cold Ts circles mixed for the same months in Figs. 10d–f. In addition, there were quite a number of filled warm Ts circles in May and June in Figs. 9e–f. Although there were strong correlations between SST3 in November and Ts in May to June as shown in Table 2, the unbalanced images between the two sets of the composites exist. This suggests that warmer air over the TP from late spring to early summer tends to be associated with a preceding mature phase of the El Niño, whereas the opposite situation is difficult to appear during a decayed La Niña stage. These correlations suggest that the previous El Niño might play a delayed role in increasing the TP’s thermal condition during that period. Note that we did not take into account the potential effect of Indian Ocean warming on Asian monsoon as mentioned by Lau et al. (2005) and Park et al. (2010) due to the less significant effect than that of ENSO.
To explore why the thermal condition from spring to early summer tended to increase with previous high SST3, we produced Fig. 11 that shows the respective composite of OLR and hgt500 anomalies from April to June when the anomaly of the SST3 in preceding November is beyond 0.8 K. Positive OLR anomalies covered most parts of the TP in May and June, while nearly neutral ones occurred over the TP in April. The hgt500 anomalies that occupied the TP during the three months appeared neutral or weakly positive, which indicates that neutral to positive hgt500 anomalies accompany few clouds of weather over the TP. This situation roughly coincides with the case study in 1998 in section 3, which indicated that the sunshine weather with high hgt500 resulted in an increase of TP-Ts in spring to early summer. On the other hand, an inconspicuous wave train-like pattern with southwest-northeast direction across the TP appeared in June (Fig. 11e), which was passing the area of significant positive vorticity in June (Fig. 6j). This is consistent with the research of Wang et al. (2011) who found that anomalous warm TP in June tended to generate northeastward Rossby wave propagation with a similar wave-train structure, as seen in Fig. 11e. Incidentally, the climatic position of the westerly jet has largely shifted northward in June. This phenomenon needs to be further studied in the future.

6. Summary and discussion

The results are summarized as follows:

(1) Using the new and longer period of snow data, we find that there are significant positive correlations between the TP-SWE from November to next April and the SST in EEP in November. This confirms that the ENSO event could affect the TP snow
depth through the wave propagation, as pointed out by ST05. The significant positive vorticity belt across TP, which represents ENSO generating Rossby wave propagation, was changed into neutral or negative ones around March (Fig. 6). This should have an indirect effect of ENSO on the TP weather.

(2) The lag autocorrelations of the TP-SWE indicated that the snow depth could only persist from November to next April. The persistence period was much shorter than the previous calculations in ST05.

(3) There was no significant negative correlation between the ENSO signal and TP-Ts from winter to March (Fig. 7, Table 2), although the composite maps did not deny the possibility of their linkage (Figs. 9 and 10). On the other hand, high SST3 during the mature period of El Niño appeared to be more closely associated with high TP-Ts in the next late spring, even extending to June, not vice versa.

Here we discuss the issue about the complex mechanism of the relation of ENSO-TP thermal condition in detail as follows:

We have confirmed that the El Niño is closely associated with an increase of the TP snow depth in winter as pointed out by ST05. However, the persistent time of the SWE was much shorter than that calculated by ST05, as shown in Table 1. This implies that if there were large snowfalls in winter, the large snow depth created by the snowfall would be gone or aged after April. The cooling effect by the snow depth in winter, as mentioned by ST05, cannot keep until next summer. In fact, we did not find significant negative correlation between TP-SWE and TP-Ts in winter and spring (table omitted). Although Table 2 showed less correlation between SST3 and TP-Ts
from November to March, the composites in Figs. 9 and 10 indicate that the high (low) SST3 tended to be associated with a cold (warm) TP-Ts. This suggests that some strong ENSO condition, e.g., case in 1997–1998, may result in cooling or heating of the TP air through the barotropic wave-train propagations that bring more or less snow depth as mentioned by ST05. However, the delayed cooling or warming effect of ENSO may not be as strong as what ST05 pointed out. The rapid decrease of TP-Ts in winter of 1997–98 was majorly due to the fast increase in SWE that was generated by the super-strong El Niño. Note that only this single case could account for quite a proportion in the composite maps (Figs. 9a and 9c), whereas more samples with opposite signs to this case accounted for smaller proportions in the maps, which was the result of a comprehensive examination. This could be the reason why the inconsistency between correlation and composite analysis exist in winter to early spring. Nevertheless, although the situation in 1998 does not occur frequently, we cannot deny the cooling effect of a strong El Niño. The mechanism of the ENSO affecting the TP thermal condition and Asian summer monsoon, as suggested by ST05, would need to be reconstructed.

There were significantly positive correlations between SST3 in November and TP-Ts in next May (Table 2). This table together with the unbalanced images in Figs 9 and 10 suggest that a maturing El Niño event might tend to accompany a warm TP in the following late spring, which is the opposite result of what ST05 has estimated. In addition, there was significant positive correlation between SWE in April and TP-Ts in May and June (Table 3), which seems to display some connection between snow
depth and thermal condition over the TP. Referring back to Table 1, we can find that almost none of the significant autocorrelations of the TP-SWE could keep beyond April, which indicates that the snow depth tends to melt easily with seasonal temperature increases after April. Thus, if the snow cover in TP exists in April, it should be easily aging and barely keep. Such a snow cover cannot play any role in cooling air temperature over the TP effectively no matter how thick it is, as pointed out by Cohen and Rind (1991). The case in 1997–98 is a good example for this explanation. Although the SWE anomalies in TP were at high levels of 14.78 mm in April, the TP-Ts anomalies increased to 1.79 K, as shown in Fig. 2. The lower TP-Ts during the colder period from November 1997 to March 1998 appeared to be a cooling result of the high SWE over the TP. Thus, the relatively lower ambient temperature of the TP might be the key point in enhancing the cooling effect. Note that the large SWE in the colder months should be considered as a response to the wave-train propagation generated by the ENSO event as explained by ST05. In fact, the negative hgt500 anomalies over the TP in January and March in 1998 indicate a weather situation that tends to produce more snowfall in situ (Fig. 4), which suggests that the storm track through the TP was enhanced by the propagation of the wave train in the ENSO phase. This situation could cause negative OLR anomalies in the TP, as shown in Fig. 3, which accompanied anomalous precipitation (i.e., snowfall) in situ (figure omitted). Thus, the direct impact of the ENSO on the TP thermal condition in 1997–98 would be as follows: (1) wave train generated by ENSO enhanced the storm track extending over the TP area, (2) this created the situation that the low
pressure system dominated in the TP, (3) cloudy and snowfall weather conditions occurred frequently, and (4) the much deeper snow depth could play a role in cooling the TP air effectively during winter. Note that if the snow depth was not deep enough, the cooling effect in winter may not appear. This is because the simultaneously negative correlation between TP-SWE and TP-Ts were less significant in winter and spring.

On the other hand, since TP-Ts in May and June were significantly correlated with SWE in April, as shown in Table 3, there is an indirect impact of the ENSO on the thermal condition. This implies that the increasing snow depth over the TP in April tends to be associated with warmer conditions in the next two months, which was not in agreement with result of ST05. A good example is the case in 1997–98, which showed a corresponding evolution for TP-Ts and TP-SWE. Although the SWE anomaly in April was the highest (about 14.78 mm) in the history, the TP-Ts anomalies largely increased above 1.5 K in April and remained at the high level in May and June, as shown in Fig. 2. The high SWE in April obviously played little role in cooling the TP air as the curve of SWE dramatically decreased from 29.14 mm to 14.78 mm, as seen in Fig. 2. This quick decrease in the SWE is evidence that the TP snow cover in April was greatly aged when the air temperature began to raise largely in the middle latitude regions of the Northern Hemisphere. Although further confirmation is necessary, the abundance of snow water in the plateau soils in April might more easily release the retaining heat to the TP air when warmer seasons approach, which may be one of the reasons why the TP temperatures will be higher
than normal in May to June in this case. On the other hand, in 1998, positive OLR anomalies covered the TP from April to June (Fig. 2). Meanwhile, the positive hgt500 anomalies almost dominated over the TP during these months. Above evidence suggests that the cloudless days, which the higher hgt500 brought during the period from April to May, would mainly be responsible for the higher air temperature over TP. Note that the negative hgt500 anomaly is representative of the active westerly jet dominating around the TP in January and March. Thus, the positive hgt500 anomalies from April to June 1998 (Fig. 4) would show an inactive one. The composite maps in Fig. 6 show a similar trend, in which the positive vorticity belt across the TP tend to be neutral or even negative from March to May. This implies that after persistence of the active phase of the westerly jet during a long period, the opposite or neutral phases of that occur. This phenomenon is also in line with the objective laws of nature. In particular, the timescale of variation in the atmosphere is much shorter than that in ocean. Thus, the ENSO generating anomalous state of circulation over the TP could only keep until February or March. Other calculations (Tables 2 and 3, Figs. 9, 10, and 11) support this view as well. Note that this phenomenon was accompanied by a slightly northward shift of westerly jet position with the seasonal progress. In this sense, some increased TP thermal condition from spring to early summer might result from the indirect impact of the previous El Niño event. In spite there being less correlation between SWE and TP-Ts, the cooling effect to the TP air may be possible and could even continue to March as long as the deposit of fresh snowfall increases large enough. The TP-Ts would increase when the TP weather improves from April to
June since the storm track over the TP has not been active without the presence of the direct impact of El Niño. Opposite processes may occur in case of a La Niña event. It is not exactly opposite, however, because the unbalanced images existed (Figs. 9 and 10). This mechanism needs to be further studies in the future.

Acknowledgments

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References


Table and figure captions:

Table 1 Monthly lag autocorrelations of SWE averaged over the area of 27.5–37.5°N, 75–104°E. Bold digits (bold asterisks) were statistically significant at the 95% (99%) confidence level.

Table 2 The correlation between SST3 in November and TP-Ts from November to next August. Italic (bold) digits were statistically significant at the 90% (95%) confidence level.

Table 3 The correlation coefficients between SWE averaged over the area of 27.5–37.5°N, 90–104°E in April and TP-Ts from April to August. Bold (bold asterisks) digits were statistically significant at the 95% (99%) confidence level.

Fig. 1 The locations of the TP station (circles) and the altitude (shaded areas, left a), the climatological SWE value (shaded areas, unit: mm, right b). The opened circles are the ones west of the 90°E. We only used TP-Ts data in the 75 stations to the east of the 90°E.

Fig. 2 Evolution of the anomalies of the SWE (90–104°E, 27.5–37.5°N) and surface temperature in the TP from November in 1997 to the next August. The left (right) y-coordinate indicates scale K for the surface temperature (scale mm for SWE).

Fig. 3 The OLR anomalies from January to June 1998 (Wm⁻²). Bold/dashed line indicates the topography height above 3000 meters in TP.

Fig. 4 500-hPa geopotential height anomalies from January to June in 1998 (gpm).
The correlations between SWE (90–104°E, 27.5–37.5°N) from November to next June and the SST in the November (1987–2005). Shaded areas indicate the confidence level over 95%. The contour interval is 0.2.

200-hPa relative vorticity composite maps based on El Niño minus La Niña event years from September to next August. Shaded areas indicate the regions beyond the 95% confidence level.

The correlation between SST in previous November and TP surface temperature from November to next June.

The evolutions of TP-Ts (left y-coordinate) in April and SST3 in preceding November (right y-coordinate). The unit is °C.

The composite for Ts anomaly circles when the anomaly of the SST3 anomaly in preceding November was beyond 0.8K.

The composite for Ts anomaly circles when the anomaly of the SST3 anomaly in preceding November was below −0.8K.

The composite for 500-hPa geopotential height anomalies (gpm) and OLR (Wm$^{-2}$) in April (a, b), May (c, d), and June (e, f) when the anomaly of the SST3 in preceding November was beyond 0.8K.
Table 1 Monthly lag autocorrelations of SWE averaged over the area of 27.5–37.5°N, 75–104°E. Bold digits (bold asterisks) were statistically significant at the 95% (99%) confidence level.

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</tbody>
</table>

Table 2 The correlation between SST3 in November and TP-Ts from November to next August. Italic (bold) digits were statistically significant at the 90% (95%) confidence level.
Table 3 The correlation coefficients between SWE averaged over the area of 27.5–37.5°N, 90–104°E in April and TP-Ts from April to August. Bold (bold asterisks) digits were statistically significant at the 95% (99%) confidence level.

<table>
<thead>
<tr>
<th>SST3-Nov</th>
<th>Ts-Dec</th>
<th>Ts-Jan</th>
<th>Ts-Feb</th>
<th>Ts-Mar</th>
<th>Ts-Apr</th>
<th>Ts-May</th>
<th>Ts-Jun</th>
<th>Ts-Jul</th>
<th>Ts-Aug</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.28</td>
<td>-0.21</td>
<td>-0.15</td>
<td>-0.09</td>
<td>-0.13</td>
<td>0.43</td>
<td>0.48</td>
<td>0.37</td>
<td>-0.40</td>
<td>-0.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ts-Apr</th>
<th>Ts-May</th>
<th>Ts-Jun</th>
<th>Ts-Jul</th>
<th>Ts-Aug</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP-SWE</td>
<td>0.27</td>
<td>0.71*</td>
<td>0.48</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Fig. 1 The locations of the TP station (circles) and the altitude (shaded areas, left a), the climatological SWE value (shaded areas, unit: mm, right b). The opened circles are the ones west of the 90°E. We only used TP-Ts data in the 75 stations to the east of the 90°E.
Fig. 2 Evolution of the anomalies of the SWE (90–104°E, 27.5–37.5°N) and surface temperature in the TP from November in 1997 to the next August. The left (right) y-coordinate indicates scale K for the surface temperature (scale mm for SWE).
Fig. 3 The OLR anomalies from January to June 1998 (Wm$^{-2}$). Bold/dashed line indicates the topography height above 3000 meters in TP.
Fig. 4 500-hPa geopotential height anomalies from January to June in 1998 (gpm).
Fig. 5 The correlations between SWE (90°–104°E, 27.5°–37.5°N) from November to next June and the SST in the November (1987–2005). Shaded areas indicate the confidence level over 95%. The contour interval is 0.2.
Fig. 6 200-hPa relative vorticity composite maps based on El Niño minus La Niña event years from September to next August. Shaded areas indicate the regions beyond the 95% confidence level.
Fig. 7 The correlation between SST in previous November and TP surface temperature from November to next June.
Fig. 8 The evolutions of TP-Ts (left y-coordinate) in April and SST3 in preceding November (right y-coordinate). The unit is °C.
Fig. 9 The composite for Ts anomaly circles when the anomaly of the SST3 anomaly in preceding November was beyond 0.8K.
Fig. 10 The composite for Ts anomaly circles when the anomaly of the SST3 anomaly in preceding November was below −0.8K.
Fig. 11 The composite for 500-hPa geopotential height anomalies (gpm) and OLR (Wm$^{-2}$) in April (a, b), May (c, d), and June (e, f) when the anomaly of the SST3 in preceding November was beyond 0.8K.