THERMAL FIELD OVER TIBETAN PLATEAU AND INDIAN SUMMER MONSOON RAINFALL

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ABSTRACT

The interannual variability of the temperature anomalies over the Tibetan Plateau (25–45°N, 75–105°E) is examined in relation to the Indian summer monsoon rainfall (ISMR: June to September total rainfall). For this purpose, the temperature anomaly data of the central-eastern Tibetan Plateau is divided into three regions using principal component analysis and the ISMR data for the period 1957–89 have been used. It is found that the January temperature anomaly of Region 2 has a significant negative relationship (r = −0.67) with the ISMR of the subsequent season. This region is located over the northeastern part of the Tibetan Plateau, mostly in Qinghai province, including the Bayan Harr Mountain range and the Qaidam Basin. This relationship is consistent and robust during the period of analysis and can be used to predict the strength of the Indian summer monsoon in the subsequent season. It was found that the January temperature anomaly in this region was associated with a persistent winter circulation pattern over the Eurasian continent during January through to March. Finally, the variation patterns of the temperature anomalies in all three regions over the central-eastern Tibetan Plateau during extreme years of the ISMR are examined. It is concluded that the January temperature anomaly over the northeastern Tibetan Plateau can be useful in forecasting the drought and flood conditions over India, especially in predicting the monsoon rainfall over the areas lying along the monsoon trough. Copyright © 2003 Royal Meteorological Society.

KEY WORDS: Indian summer monsoon rainfall; temperature anomaly; Tibetan Plateau

1. INTRODUCTION

The Asian summer monsoon circulation, a component of the atmospheric general circulation, is mainly forced by the asymmetric pattern of atmospheric heating and cooling over major land masses and oceans. The northernmost orographic barriers over the Indian subcontinent, i.e. the Himalayas and the Tibetan Plateau (TP), also have a profound influence on the general circulation pattern, especially on the Asian monsoons. It is now believed that the Asian monsoon circulation basically results from the differential heating between the Eurasian land mass and adjacent oceans and is influenced by the thermal and dynamic effects of the TP. The TP also serves as a natural dividing screen between the tropical and polar air masses. The impact of the TP on the monsoon circulation has been recognized since the 1950s. For example, Flohn (1957, 1968) proposed that the TP acts as an elevated heat source during the northern summer season. According to Fu and Fletcher (1985), the TP is a heat source for the atmosphere during the northern summer, contributing to the thermal forcing of large-scale quasizonal atmospheric circulation. They have also shown that the thermal contrast between the TP and the equatorial cold tongue is significantly related to the Indian summer monsoon rainfall (ISMR: June to September total rainfall). The relationship between the atmospheric conditions over the TP

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and that in its surrounding areas has also been demonstrated by Chang (1981), who found that there is an inverse relationship between central ISMR and central Tibet precipitation in July and August.

Many modelling studies have been conducted to examine the dynamical effects of orographic forcing over the northernmost Indian region on the general circulation. Upon removing the influence of orographic barriers over the northernmost Indian region, Hahn and Manabe (1975) found that the Tibetan anticyclone and the corresponding low in the lower troposphere would have shifted by several degrees of latitude. A number of studies (Gao et al., 1981; Nitta, 1983; Luo and Yanai, 1984; He et al., 1987; Shi and Smith, 1992; Yanai et al., 1992; Liu et al., 1994, 1995) have also revealed the thermal effects of TP on the planetary-scale summer monsoon circulation. A study by Liu and Luo (1990) showed that the snow cover on the northern Eurasian continent and the TP has a profound association with the temperature and rainfall over China in the following summer; yet another study, by Kripalani et al. (2003), has suggested that the spring snow melt in the western Himalayas may be related to rainfall over India in the following summer.

Owing to the sparse nature of the data available prior to the 1980s, studies relating the ISMR and any meteorological field over the TP are scarce. The availability of good-quality data over the TP during the more recent period provides the opportunity to many international scientists to explore various aspects of the effects of the TP and its relationship with the Asian summer monsoon circulation. Recent studies have shown that the heating and cooling over the TP have significant effects on the South and East Asian monsoons (Li and Yanai, 1996; Ueda and Yasunai, 1998). Ringler and Cook (1999) found that during the summer a large amount of latent heating occurs over the TP and the plateau is relatively dry, with low-level diabatic heating rates in the order of 3 K day$^{-1}$, whereas during winter the near-surface cooling is of the order of 1–2 K day$^{-1}$. Also, they have indicated that the thermal forcing will modify the horizontal flow and it has the potential to modify the mechanical forcing indirectly. Liu and Chen (2000) suggest that the TP has experienced statistically significant warming since the mid-1950s during winter. The warming trend tended to increase with the elevation over the TP and in its surrounding areas.

From the above, it is clear that the thermal condition over the TP plays a very important role in influencing circulation and atmospheric conditions in South and East Asia. Most studies before 1990, however, treated the entire TP as a single entity due to the limitations of the data available. Hence, in the present study, we will analyse the spatial pattern of the thermal field over the TP to investigate in detail its relationship with the subsequent monsoon rainfall over India.

2. DATA AND METHODS

Using principal component analysis (PCA) on monthly temperature data for 44 stations with relatively long records, the central-eastern part of the TP (Figure 1) was divided into three regions (Yin et al., 2000). Region 1 is located in the south-central TP, including the areas of northern slope of the Himalayas and the Yarlung Zangbo valley. Region 2 represents the northeastern part of the plateau, mostly located in Qinghai Province, including the area north of the Bayan Har Mountains and the Qaidam Basin. Region 3 is located in the eastern part of the plateau, mostly in western Sichuan Province. The boundary of the core area for each subregion was determined using the interpolated loadings of the stations in the PCA. Monthly temperature data for those stations located at the core areas of the three regions (21, 15, and 12 stations in Regions 1, 2, and 3 respectively) were used to construct time series of the temperature record for each region and the normalized temperature anomalies for each month for the period 1951–93. On account of some missing data, a common period with data available for all three regions (i.e. 1957 to 1989, 33 years) has been used in this study.

The all-India monthly and seasonal rainfall and the rainfall for each of the meteorological subdivisions of India were obtained from Parthasarathy et al. (1995) for the period 1957–89. The ISMR is calculated as the sum of June to September rainfall.

The El Niño years (1965, 1969, 1972, 1976, 1982, 1987) and the La Niña years (1964, 1966, 1970, 1973, 1975, 1978, 1983) were determined based on Rasmussen and Carpenter (1983) and van Loon and Shea (1985) respectively, and then were updated by the Climate Diagnostic Bulletins published by the Climate Analysis Center (CAC) of the NOAA. We also used the southern oscillation index (SOI) obtained from the

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Figure 1. Stations in the central-eastern TP used in PCA and calculation of the regional mean monthly temperature time series

Climate Prediction Center (CPC) Website (http://www.cpc.noaa.gov/). The monthly 2.5° latitude–longitude grid point data for the 500 hPa geopotential height were extracted from the National Centers for Environmental Prediction (NCEP) reanalysis, for the period 1957 to 1989 (Kalnay et al., 1996).

In order to study the relationship between the thermal field over the TP and the ISMR, the following approaches have been used: simple linear correlation analysis, composites of temperature anomalies during extreme years of the ISMR, composites of 500 hPa geopotential heights, and correlation analysis for a running window of different widths to test the consistency of the relationship.

For each month of January through to December, the time series of temperature anomalies of the three regions over the TP was correlated against the ISMR. The consistency of the relationship between the temperature anomalies and the ISMR has been evaluated by calculating correlation coefficients over running windows of different widths (21 and 31 years) during the period of analysis. This is also useful in understanding the medium- and low-frequency changes in the strength of the relationship. To explore the links between temperature anomalies and the ISMR, correlation field analysis was conducted between temperature anomalies and 500 hPa geopotential heights. Additionally, composites of 500 hPa geopotential heights were constructed for extreme warm ($T > 1.0SD$) and cold ($T < 1.0SD$) conditions, where $T$ is the mean temperature and SD is the standard deviation of temperature.

To extract meaningful signals during extreme years of the ISMR, individual monthly (January to December) composites of temperature anomalies for all three regions over the TP were calculated and compared for drought ($< R - 1.0SD$) and flood ($> R + 1.0SD$) years, where $R$ is the long-term mean of the ISMR and SD here is the standard deviation of the ISMR.
4. RESULTS AND DISCUSSION

4.1. The relationship between regional temperature anomalies and ISMR

It is worthwhile examining the annual cycles of temperature variation over the three regions over the TP. The monthly (January–December) variation of mean temperature for all three regions over TP is shown in Figure 2. Although the annual cycles of all three regions are quite similar, the mean temperature in Region 2 is substantially colder in winter than the temperature in Regions 1 and 3. Also, it is noted that the warming from January to July is more intense over Region 2 than in Regions 1 and 3. To examine the interdependence between temperature anomalies in all three regions, we calculated the correlation coefficients among them. The correlations between the temperature anomalies in Region 1 with those in Regions 2 and 3 are 0.16 and 0.32 respectively, whereas the correlation between temperature anomalies in Regions 2 and 3 is 0.45 (significant at the 0.01 level with \( N = 384 \)). The strong correlation between temperature anomalies in Regions 2 and 3 might be due to the fact that these regions are both located over the eastern part of the TP. It should be noted that most of the stations in Region 1 are located in river valleys or plateau surface, although this region includes many mountain ranges of high elevations.

The annual cycles of correlation coefficients between the ISMR and monthly temperature anomalies (January to December) for the three regions are presented in Figure 3. For Region 1 (Figure 3(a)) the correlation coefficients are negative and insignificant statistically for all months, except a barely significant positive correlation coefficient for October. For Region 2 there is a strong negative significant correlation \((r = -0.67)\) found in January, but thereafter the correlation reduces sharply and remains statistically insignificant through to December. Winter temperature anomalies in Region 2 were also correlated with the subsequent ISMR with a correlation coefficient of \(-0.38\). Although statistically significant, it is not as strong as the relationship between January temperature anomaly and ISMR. In the case of Region 3, significant positive correlations are found in September and October. To examine the overall influence of the TP as a whole on the ISMR, we also calculated the correlation between the ISMR and the average temperature anomalies for all three regions for the months January to December. The only statistically significant relationship is found to be in January, with \(r = -0.37\).

![Figure 2. Annual march of the mean temperature in three regions over the TP](image-url)
Figure 3. Correlations between the monthly temperature anomalies and ISMR for individual months from January to December: (a) Region 1; (b) Region 2; (c) Region 3

Since the January temperature anomalies of Region 2 display the strongest relationship with the subsequent ISMR, it has the potential to be used as a predictor for the strength of the South Asian summer monsoon. The strong negative correlation between temperature anomalies over Region 2 and the ISMR suggests that the above- (below-)normal activity of the monsoon rainfall over the Indian region is related to greater (less) cooling of the northeastern part of the TP during winter. The interannual variability of the all-India monsoon rainfall along with the interannual variability of the January temperature anomaly of Region 2 is presented in Figure 4, which clearly demonstrates the inverse relationship.

The physical cause of such a relationship can be quite complex, since the impact of the TP is twofold. First, it acts as a major mechanical blocking barrier that influences both the zonal and the meridional flows. During the wintertime, the TP is located on the path of the westerlies, which will split into two branches that will meet again east of the plateau. The northern branch has an anticyclonic flow pattern while the southern branch has a cyclonic pattern. Second, the TP has a thermal impact on the monsoon circulation, since it is a weak heat sink during winter and a heat source during summer (Yanai et al., 1992). The below-normal temperatures during January over the TP indicate strong cooling and the effect of TP as a heat sink is enhanced and lasts for a longer time. Such a long-lasting heat sink seems to restrict the eastward shifting of the Tibetan anticyclone at the 200 hPa level during the summer monsoon season, which indirectly strengthens the monsoon circulation and hence causes above-normal rainfall over the Indian subcontinent.

To understand and establish a physical linkage between the temperature anomaly for region 2 during January and the ISMR, we undertake correlation analysis between temperature anomalies of Region 2 and 500 hPa geopotential heights. The result indicates similar patterns in the January–March correlation fields (Figure 5(a)–(c)), with strongly negative $r$ values over the northern Eurasian continent and generally positive $r$ values to the south. Therefore, below-normal January temperatures in Region 2 are associated with an anomalous ridge over Siberia and a reduced north–south gradient over the mid-latitude region over Eurasia ($30^\circ$–$60^\circ$ N). This pattern would weaken the westerly flows over the TP and bring less snowfall, especially to the western part of the TP. Both modelling and observational studies have pointed to the relationship between snow depth, winter circulation patterns over Eurasia, and the strength of the subsequent Indian monsoon (Douville and Royer, 1996; Kripalani and Kulkarni, 1999; Kripalani et al., 2003). In general, less snow cover would result in quick springtime melting and heating of the land mass. This would enhance...
the thermal lows over northern India at the onset of the monsoon season and generate strong southwesterly
flows in the South Asian monsoon region. It is interesting to note that such a circulation pattern is persistent
from January to March, but beginning in April a new pattern emerges in the correlation fields. There is a
large area, stretching from Mongolia down to southern India, dominated by persistently positive correlation
coefficients between the temperature anomaly of Region 2 and the 500 hPa geopotential heights throughout
the onset and then the entire monsoon season (Figure 5(d)–(h)). Starting in May, various regions in India have
relatively high \( r \) values \( (r > 0.4) \), indicating potential locations of the enhanced thermal lows corresponding
to below-normal January temperature in Region 2. When there is an above-normal temperature in Region 2,
the above-mentioned patterns would be inverted.

Composites of the 500 hPa geopotential heights confirm the above relationships. For below-normal January
temperature in Region 2 (Figure 6(a)), an anomalous ridge is found over Siberia, as well as a deepened
trough over East Asia during January through March. This clearly leads to a meridional flow pattern at the
500 hPa level. In April and May, the anomalous ridge disappears and the East Asia trough becomes much
shallower, and slightly below-normal 500 hPa heights appear over South Asia. During the monsoon season
(June–September), there is a belt of below-normal heights over South Asia for the year with below-normal
January temperature in Region 2, indicating the enhanced monsoon trough. Again, for above-normal January
temperature in Region 2, the above pattern is reversed (Figure 6(b)).

4.2. Stability of the relationship between ISMR and temperature anomalies

The relationship between the temperature anomalies and the ISMR should be tested for its stability before
using it in prediction of the ISMR, since a recent study by Prasad et al. (2000) has found that some predictors
of the ISMR lose the power of prediction of ISMR during the recent decade.

Since the temperature anomaly data available for Region 2 is from 1955 to 1989, we calculated the
correlation coefficient with ISMR again using the entire 35 year period. The relationship is only weakened
marginally \( (r = -0.58) \), and it is still statistically significant at the 0.01 level. Figure 7 shows the variation of
the correlation coefficients between the ISMR and the temperature anomalies of Region 2 during the period
1955–89 for the running windows of 21 and 31 years, with the \( r \) values being plotted against the middle
years of the running windows. For both the 21 and 31 year running windows the correlation coefficients are

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Figure 5. Correlation fields between January temperature anomaly of Region 2 and 500 hPa geopotential heights, January to September:
(a) January; (b) February; (c) March; (d) April; (e) May; (f) June; (g) July; (h) August; (i) September
Figure 5. (Continued)
Figure 6. Composites of 500 hPa geopotential heights corresponding to (a) below-normal and (b) above-normal January temperature in Region 2 for January–March, April–May and June–September
Figure 6. (Continued)
Figure 7. Correlation coefficients between the ISMR and the January temperature anomalies of Region 2 calculated for the (a) 21 year and (b) 31 year running windows. The $r$ values are plotted against the centre years of the running windows. Horizontal line shows correlation coefficient at the 5% level.

found to be consistently negative and statistically significant throughout the period of analysis. Therefore, the relationship of the ISMR with the January temperature anomaly of Region 2 appears to be robust and should be a valid predictor for ISMR. Hereafter, the January temperature anomaly of Region 2 is termed the thermal index (TI) and the results using TI are based on 35 years of data (1955 to 1989).

4.3. Temperature anomaly over the TP during ISMR extreme years

The composites of the temperature anomalies of the three regions over the TP during extreme (i.e. drought and flood) ISMR years were constructed. For Region 1 (Figure 8(a)), its temperature anomalies tend to be mostly positive during flood years, with two peaks: one in June and another in October. For drought years, the temperature is mostly near normal, but with an obvious trough in October. For Region 2 (Figure 8(b)), its temperature is mostly below normal for the first half of the year during flood years, then it becomes close to normal for the remaining months. This supports the notion of the enhanced and longer lasting effect of the TP as a heat sink after an exceptionally cold January, which leads to an intensified summer monsoon season. For drought years, the temperature anomaly has a positive peak in January and then it varies along the mean condition afterward. For Region 3 (Figure 8(c)), the temperature anomaly has a similar pattern to that of Region 1, with two peaks during flood years: one in June and another in October. However, during drought years, it has a minor peak in May and a trough in September.

The composite analysis again suggested that the TI seems to be the strongest predictor of ISMR among all the regional temperature anomalies over the TP. To support this notion, we classified the 35-year record into cold, normal, and warm based on the TI, and constructed the contingency table corresponding to the occurrence of drought, normal and flood years (Table I). For warm years (i.e. $TI > 1.0SD$), four out of the nine years are classified as drought years, whereas none is a flood year. For cold years (i.e. $TI < -1.0SD$), on the other hand, four out of the six years are normal and there is one drought year and one flood year. For normal years ($-1.0SD \leq TI \leq 1.0SD$), there are 15 normal years for ISMR and six flood years. It seems that the degree of uncertainty in the prediction of ISMR is less during warm years of the TI. In other words, the TI...
is more effective in predicting the occurrence of droughts than floods. An alternative is to use the consistent negative monthly temperature anomalies in Region 2 from January to May (Figure 8(b)) as an indicator of flood years. Also, $\chi^2$ computed from the contingency table is found to be significant at the 5% level.

5. SPATIAL AND TEMPORAL PATTERNS IN THE RELATIONSHIP BETWEEN TI AND ISMR

Monsoon precipitation in India has significant spatial variation. Therefore, although the TI seems to be a good predictor of ISMR, it is interesting to examine its effectiveness spatially. For this purpose, the TI is

Table I. Contingency table of frequency of occurrence of drought, flood, and normal rainfall over India during the monsoon season (June to September) corresponding to cold, normal, and warm temperatures in Region 2 during January (TI)$^a$

<table>
<thead>
<tr>
<th></th>
<th>Drought</th>
<th>Normal</th>
<th>Flood</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>1.0</td>
<td>4.0</td>
<td>1.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Normal</td>
<td>0.0</td>
<td>14.0</td>
<td>6.0</td>
<td>21.0</td>
</tr>
<tr>
<td>Warm</td>
<td>4.0</td>
<td>5.0</td>
<td>0.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Total</td>
<td>5.0</td>
<td>24.0</td>
<td>7.0</td>
<td>35.0</td>
</tr>
</tbody>
</table>

$^a$ $\chi^2 = 11.68$ (significant at 5% level).
correlated with the summer monsoon rainfall of each of the meteorological subdivisions of contiguous India. The spatial structure of the correlation coefficients is presented in Figure 9. The TI is negatively correlated with the monsoon rainfall in most subdivisions in contiguous India, except for subdivisions 2 and 3. The strongest correlation’s are found for subdivisions along the monsoon trough region, where the relationship also shows a high spatial coherence.

To examine the temporal pattern of the relationship between the TI and the monsoon rainfall, the TI is further correlated to the all-India rainfall for each of the monsoon months (Table II). The relationship is found to be consistently significant (negative) for each of the individual months of the summer monsoon season. Also, during the first half of the monsoon season (June and July), the association is found to be slightly stronger than in the second half of the monsoon season (August and September). The stronger relationship during the first half of the monsoon season might be due to the impact of the TP as a heating source on the monsoon circulation during the initial and peak monsoon months. Afterwards, the heating due to the release of latent heat by the monsoon precipitation and the general warming of the entire region during the summer plays a more important role in maintaining the monsoon circulation further toward the end of the monsoon season.

Table II. Correlation coefficients (R) between all-India rainfall (monthly and seasonal) and the TI for individual months (an absolute r value of 0.35 would indicate the statistical significance level of 0.05)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>June + July</th>
<th>August + September</th>
<th>Seasonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>−0.43</td>
<td>−0.42</td>
<td>−0.37</td>
<td>−0.42</td>
<td>−0.55</td>
<td>−0.45</td>
<td>−0.58</td>
</tr>
</tbody>
</table>
6. RELATIONSHIP BETWEEN TI AND ISMR DURING THE EL NIÑO–SOUTHERN OSCILLATION EVENTS

Many studies (e.g. Rasmusson and Carpenter, 1983; Angell, 1990; Ju and Slingo, 1995) have pointed out that the interannual variability of the Asian summer monsoon rainfall is influenced by the El Niño–southern oscillation (ENSO) events. On the interannual and longer time scales, the variability of the Asian monsoon is linked with ENSO events. The occurrence of El Niño (EN) events is generally associated with weak monsoon seasons, and the La Niña (LN) events are associated with strong monsoon seasons (e.g. Webster and Yang 1992). Also, a number of studies have attempted to assess the relationship between the SOI and the ISMR to predict the summer monsoon rainfall over India in advance (Sikka, 1980; Pant and Parthasarathy, 1981; Mooley and Parthasarathy, 1983; Shakla and Paolino, 1983; Bhalme and Jadhav, 1984; Mooley et al., 1985; Parthasarathy and Pant, 1985; Kripalani and Kulkarni, 1997). However, recently, Krishna Kumar et al. (1999) found that the relationship between the ENSO events and monsoon rainfall over India has been weakening during the recent period.

Hence, we examined whether ENSO events have any effect on the relationship between the TI and ISMR. The correlations between the TI and ISMR were recalculated after excluding the year of the ENSO events (both EN and LN years). The results show that the relationship between the TI and ISMR remains essentially the same with or without the ENSO events ($r = -0.53$ without the ENSO years compared with $r = -0.58$ with the ENSO years). Thus, it can be argued that the impact of the TP on the ISMR is independent of the occurrence of ENSO events. The recent studies show that the eastern sea-surface temperature condition lags behind the Asian monsoon variation (Ye, 2001). Hence, we also calculated the correlations between the concurrent and lag monthly SOI and temperature anomalies of all three regions over the TP (Table III). There are only weak associations between the SOI and the temperature anomalies for the months of January to December for all three regions, except for a significant positive correlation during April and September for Region 3. We also examined lag correlations between SOI and temperature anomalies for all three region (Table IV). We found that only the January temperature anomaly in Region 2 was correlated with SOI in the previous year, May to October. If there is any influence of ENSO events on the effect of the TP on the ISMR, it should therefore be minor or minimal.

7. CONCLUSIONS

The impact of the TP on Asian monsoon circulations has long been recognized. Results from this study conform with many other studies on the relationship between winter temperature and/or snow pack over the

<table>
<thead>
<tr>
<th>Region</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1</td>
<td>0.11</td>
<td>0.26</td>
<td>-0.11</td>
<td>0.30</td>
<td>-0.01</td>
<td>-0.03</td>
<td>-0.26</td>
<td>-0.09</td>
<td>-0.03</td>
<td>0.29</td>
<td>-0.02</td>
<td>-0.14</td>
</tr>
<tr>
<td>Region 2</td>
<td>-0.06</td>
<td>-0.05</td>
<td>0.12</td>
<td>0.22</td>
<td>0.12</td>
<td>0.04</td>
<td>-0.06</td>
<td>0.24</td>
<td>0.14</td>
<td>-0.09</td>
<td>-0.02</td>
<td>-0.19</td>
</tr>
<tr>
<td>Region 3</td>
<td>0.02</td>
<td>0.24</td>
<td>0.23</td>
<td>0.47*</td>
<td>-0.13</td>
<td>0.11</td>
<td>0.03</td>
<td>0.21</td>
<td>0.41*</td>
<td>0.30</td>
<td>0.23</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level as indicated by an absolute $r$ value of 0.35.

<table>
<thead>
<tr>
<th>Region/SOI</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 2 (Jan)</td>
<td>-0.05</td>
<td>0.04</td>
<td>-0.06</td>
<td>-0.30</td>
<td>-0.36*</td>
<td>-0.38*</td>
<td>-0.35*</td>
<td>-0.39*</td>
<td>-0.34</td>
<td>-0.38*</td>
<td>-0.21</td>
<td>-0.24</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level as indicated by an absolute $r$ value of 0.35.
TP and the strength of the South Asian monsoon in the following summer. However, this study is focused on the subregional variation of the thermal conditions of the TP and the strength of the South Asian monsoon. The relationship between the monthly temperature anomalies in three regions over the TP and the ISMR was analysed for the period 1957–89. The January temperature anomaly of Region 2, located in the northeastern part of the TP, is found to be negatively correlated to the subsequent ISMR with strong statistical significance. This relationship is also found to be consistent during the study period and can be used to predict the ISMR. Therefore, the January temperature anomaly time series is considered as an index (TI) that represents the thermal character of the TP in winter. The analysis on the spatial pattern of the relationship indicated that the TI has the strongest relationship with summer monsoon rainfall in the areas along the monsoon trough. Although the Indian summer monsoon is influenced by ENSO events, our analysis suggests that the relationship between the TI and the ISMR is not affected by the occurrence of ENSO events. Therefore, it can be argued that the impact of the TP on the South Asian monsoon may be independent of ENSO events.

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