Teleconnection Patterns along the Asian Jet Associated with Different Combinations of Convection Oscillations over the Indian Continent and Western North Pacific during Summer

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Abstract A zonal teleconnection has been found along the Asian jet over the Eurasian continent during summer. In this study, the authors investigated circulation anomalies in the extratropics, in particular for the zonal teleconnection, under different combinations of subtropical convection anomalies over the northern Indian continent (IND) and the western North Pacific (WNP). The out-of-phase configuration (i.e., stronger (weaker) IND convection and weaker (stronger) WNP convection) was found to be more common than the in-phase configuration (i.e., stronger (weaker) IND convection and stronger (weaker) WNP convection), which is consistent with previous results. Composite results indicated that circulation anomalies for out-of-phase configurations of 30–60-day convection oscillations are much stronger in the middle latitudes than those for in-phase configurations. In addition, zonal teleconnection patterns are predominant for the out-of-phase configurations, particularly for the configuration of strong IND convection and weak WNP convection; however, they are either weak or obscure for the in-phase configurations. These results suggest that the zonal teleconnection pattern along the Asian jet is dependent on different combinations of the IND and WNP subtropical convection anomalies.

Keywords: subtropical convection, mid-latitude teleconnection, western North Pacific, Indian continent

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1 Introduction

There is a teleconnection along the subtropical upper-tropospheric westerly jet over the Eurasian continent. This teleconnection propagates eastwards and affects the weather and climate in East Asia during summer months (Krishnan and Sugi, 2001; Lu et al., 2002; Enomoto et al., 2003; Enomoto, 2004; Ding and Wang, 2005; Liao et al., 2006; Sato and Takahashi, 2006; Yang and Zhang, 2008). This zonal teleconnection along the upper-tropospheric westerly jet (or the Asian jet) can be a reason for the climatic linkage between India and North China (Guo and Wang, 1988; Kripalani and Singh, 1993), as well as between India and Japan (Krishnan and Sugi, 2001). Ding and Wang (2005) have suggested that the strong convection over northern India, which is triggered by a wave train extending from the northeastern Atlantic to East Asia, could excite a Rossby wave and, in turn, reinforce the wave train.

On the other hand, the atmospheric convection anomalies over the western North Pacific (WNP) are closely associated with anomalous circulation over East Asia during summer. This has been confirmed by many studies that have focused on the tropical-extratropical interaction over the WNP and East Asia (e.g., Kawamura and Murakami, 1995; Lu et al., 2007) and on the East Asian climate (e.g., Nitta, 1987; Huang and Sun, 1992; Lu, 2004; Mao et al., 2010).

These two teleconnection patterns (i.e., the zonal teleconnection along the Asian jet and the meridional teleconnection over the WNP and East Asia) can result in a combined effect on summer weather and climate in East Asia. Ogasawara and Kawamura (2007) have found that a combination of the zonal and meridional teleconnections establishes a zonally-elongated anticyclonic (or cyclonic) anomaly over northern Japan, resulting in anomalously high (or low) surface temperatures at this location. They have indicated that the combination of teleconnection patterns can lead to a larger temperature anomaly compared to a single teleconnection pattern alone. Bueh et al. (2008) have also suggested that the circulation anomalies over the WNP and East Asia may be induced by the interaction between the zonal teleconnection in the upper troposphere and the meridional teleconnection in the lower troposphere.

However, the mechanism for the relationship between the zonal and meridional teleconnections remains unknown. Although both teleconnections may be maintained by the energy transfer from the mean flow (Kosaka and Nakamura, 2006; Sato and Takahashi, 2006), many studies have indicated the existence of tropical or subtropical atmospheric heating anomalies over the WNP and Indian continent that are associated with these teleconnections (e.g., Nitta, 1987; Krishnan and Sugi, 2001; Lu et al., 2002; Ding and Wang, 2005; Kosaka and Nakamura, 2006). Therefore, in this study we examined circulation anomalies in the extratropics for different combinations of tropical/subtropical convection anomalies associated with

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the zonal and meridional teleconnection patterns. We focused on the convection anomalies over two regions, including the northern part of the Indian continent and the WNP, which will be specified in the following section.

2 Data and methods

In this study, we used National Oceanic and Atmospheric Administration (NOAA) satellite-observed outgoing longwave radiation (OLR) data (Gruber and Krueger, 1984) and horizontal winds from the National Centers for Environmental Prediction-Department of Energy (NCEP-DOE) reanalysis dataset (Kanamitsu et al., 2002). These datasets are comprised of daily data, which are recorded over 30 years from 1979 to 2008.

We examined the 30–60-day oscillation, which is one of the dominant timescales for tropical/subtropical convection activities. We applied a band-pass filter to the annual cycle-removed daily anomalies to obtain the 30–60-day components for each year. The annual cycle for a particular year was defined as the sum of the annual mean and the first three harmonics at each grid point. We focused on the summer season, which was specified as the period from 1 June to 31 August in this study.

We chose two regions and averaged the 30–60-day component of the OLR over these regions to obtain the time series of convection oscillations over the Indian continent (IND) and WNP, respectively. For the IND, the specified region was (22.5–27.5°N, 50–100°E), and the WNP region was (22.5–27.5°N, 110–160°E). These latitude scopes were determined according to the theory that stationary Rossby waves cannot propagate through the critical lines, at which the zonal winds are zero (Hoskins and Karoly, 1981). In summer, the zero line of zonal flows is located around 25°N latitude at the middle and upper troposphere over the southern Eurasian continent. We examined the results based on different averaging regions and found that they are similar to those shown in this paper. Our results indicated that, although the amplitudes of responding circulation anomalies are clearly dependent on the latitudes of convection oscillations, the patterns of circulation teleconnections are not (not shown). In agreement with the theory, the circulation anomalies become stronger (weaker) when the convection regions shift northwards (southwards) (results not shown).

Composite analyses were performed based on the reference time series of 30–60-day oscillations for IND and WNP convections. In any particular year, the days during which the reference time series are below (above) one standard deviation are called S-days (W-days). Thus, S-days (W-days) were represented by stronger (weaker) convection. Composite analyses were performed based on these days.

3 Results

Figure 1 shows the composite differences in 200-hPa horizontal winds between S-days and W-days for the IND and WNP, respectively. There are two anticyclonic anomalies that corresponded to stronger convection over the IND (505 days in total): one appears northwest of the Indian continent, and the other is centered over the Korean peninsula. There is a cyclonic anomaly in between these two anticyclonic anomalies, and another cyclonic anomaly east of Japan. These anticyclonic and cyclonic anomalies seem to happen in a wave-like pattern along the subtropical westerly jet over the southern Eurasian continent. This westerly jet becomes much weaker over the North Pacific. The correspondence between stronger convection over the IND and the anticyclonic anomalies northwest of the Indian continent and over East Asia, as shown in Fig. 1a, is consistent with previous studies (e.g., Krishnan and Sugi, 2001; Lu et al., 2002; Guan and Yamagata, 2003; Ding and Wang, 2005; Ogasawara and Kawamura, 2007).

On the other hand, there was a clear wave-train-like pattern along the WNP coast and the North Pacific that corresponded to stronger convection over the WNP (471 days in total; Fig. 1b). In particular, there is a cyclonic anomaly over East Asia. This cyclonic anomaly appears over roughly the same region with the anticyclonic anomaly associated with stronger IND convection.

A close comparison between the circulation anomalies associated with IND and WNP convection (Fig. 1) reveals a possible link between the zonal and meridional upper-tropospheric teleconnections. There is a westerly anomaly over the South China Sea and Philippine Sea that corresponded to stronger IND convection (Fig. 1a), where

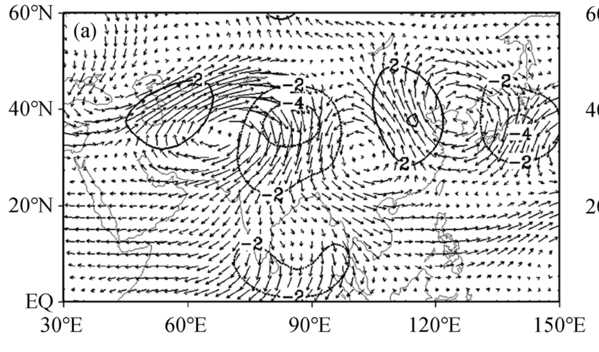

Figure 1 Composite differences in 200-hPa horizontal winds between strong and weak convections over (a) the northern Indian continent (IND) and (b) the WNP. Meridional wind differences are also shown as contours to facilitate comparison with Fig. 4. Units: m s^{-1}.

an easterly anomaly appears in association with stronger WNP convection (Fig. 1b). In addition, there is a weak but noticeable anticyclonic anomaly over the Loess Plateau in China that corresponded to stronger WNP convection (Fig. 1b), which is in contrast with the cyclonic anomaly over the roughly same region associated with stronger IND convection (Fig. 1a). In fact, among 505 IND S-days, there are 65 WNP S-days and 125 WNP W-days, implying a reverse relationship between convection oscillations over these two regions. This finding is consistent with some previous results suggesting that there is a seesaw pattern of 30–60-day convection oscillations between the Indian Ocean/Indian continent and the WNP (Zhu and Wang, 1993; Annamalai and Sperber, 2005; Lu and Ren, 2005). Therefore, in the following, we investigate the extratropical circulation anomalies associated with different configurations of IND and WNP convection oscillations.

Four configurations are made according to different combinations of IND and WNP convection oscillations. These configurations are named SS, SW, WW, and WS, respectively. For instance, the SW configuration represents that the IND convection oscillation is in an enhanced phase and exceeds one standard deviation (or, the IND OLR oscillation is in a negative phase and is lower than minus one standard deviation), and concomitantly, the WNP convection oscillation is in a suppressed phase and is lower than minus one standard deviation. Figure 2 illustrates how these configurations are determined by showing the different combinations of reference time series in two particular summers: 1991 and 2005. An in-phase pattern between the IND and WNP tends to be dominant for the case of 1991 (Fig. 2a), while a seesaw pattern is notable for the case of 2005 (Fig. 2b). Therefore, the former case provides the SS and WW configurations, and the latter provides the SW and WS configurations. Based on these criteria, we obtained 65, 53, 125, and 84 days for SS, WW, SW, and WS, respectively. Thus, the days for out-of-phase configurations (209 days, SW or WS) are much more than those for in-phase configurations (118 days, SS or WW), which is consistent with previous results (Zhu and Wang, 1993; Annamalai and Sperber, 2005; Lu and Ren, 2005).

Figure 3 shows the composite OLR anomalies for these four configurations. As expected, different combinations of convection anomalies appear over the IND and WNP in the subtropics. Although the specified regions for IND and WNP convection reference time series are separated by only ten degrees in longitudinal scope (for IND the region is (22.5–27.5°N, 50–100°E), and for WNP the region is (22.5–27.5°N, 110–160°E)), actual convection anomalies are well separated. In the subtropics, convection anomalies are centered over the northwestern Indian continent and east of Taiwan Island, respectively. In comparison with WNP convection anomalies, IND anomalies extend southwards for the WW, SW, and WS configurations. For the out-of-phase configurations (SW or WS), composite convection anomalies tend to be stronger than those for the in-phase configurations (SS or WW), and the IND convection anomaly stretches to the tropical WNP. In the tropics, there are also convection anomalies for the four configurations. However, these tropical anomalies are clearly concentrated in the regions of upper-tropospheric easterly flows. Thus, they are not expected to be significantly or directly linked to extratropical circulation, although they may influence subtropical convection.

Figure 4 shows the composite meridional wind anomalies at 200 hPa for these four configurations, respectively. Here, only meridional wind anomalies, rather than horizontal wind anomalies, are shown for the clarity. Comparing these meridional wind anomalies with the horizontal wind anomalies (not shown), we found that anticyclonic or cyclonic anomalies can be inferred from the meridional wind anomalies. Figure 4 clearly shows that the composite circulation anomalies for the out-of-phase configurations (SW or WS, Figs. 4b and 4d) are two or three times stronger in the middle latitudes than those for the in-phase configurations (SS or WW, Figs. 4a and 4c). In addition, the meridional wind anomalies exhibit the waves along the subtropical upper-tropospheric westerly jet over the Eurasian continent and North Pacific for the

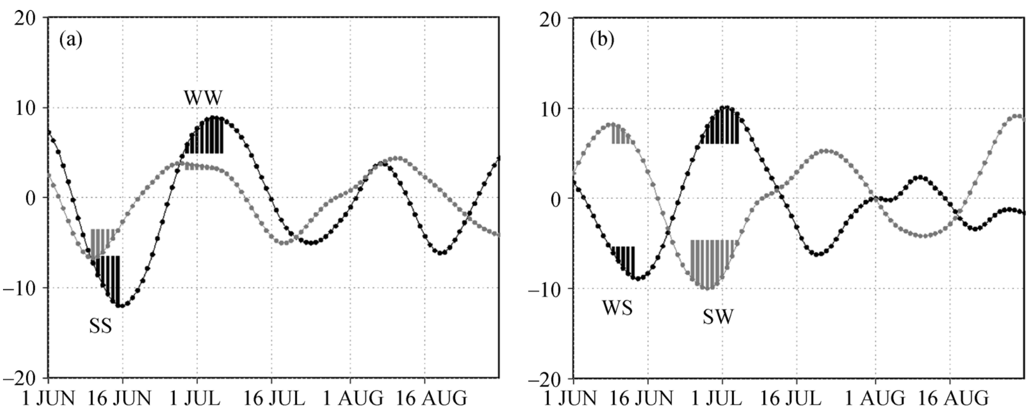

Figure 2 Time series of 30–60-day OLR oscillations averaged over the IND (22.5–27.5°N, 50–100°E) (grey line) and over the WNP (22.5–27.5°N, 110–160°E) (black line). (a) Summer of 1991; (b) summer of 2005. Units: W m^{-2}. Four configurations, named SS, SW, WW, and WS, respectively, are generated according to the time series. For instance, the SW configuration shows that the IND convection is stronger (or, the IND OLR oscillation is lower than minus one standard deviation) and the WNP convection is weaker simultaneously.

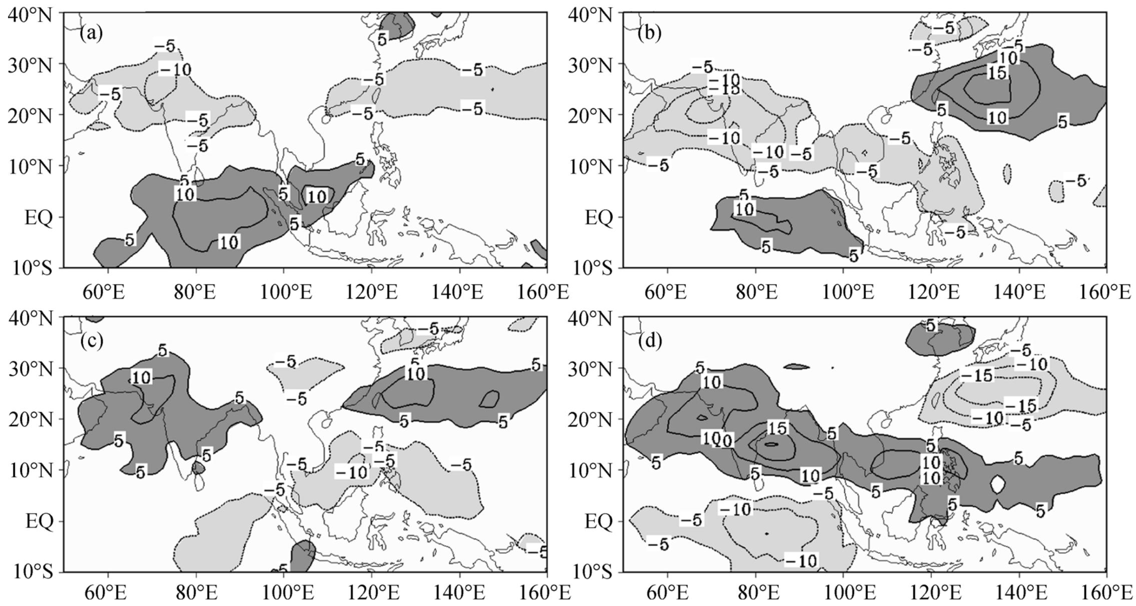

Figure 3 Composite 30–60-day OLR anomalies for different configurations. (a) Strong IND convection and strong WNP convection; (b) strong IND convection and weak WNP convection; (c) weak IND convection and weak WNP convection; (d) weak IND convection and strong WNP convection. Units: W m^{-2}.

out-of-phase configurations (Figs. 4b and 4d), particularly for the SW configuration (Fig. 4b), whereas the waves are weak or obscure for the in-phase configurations. The difference in strength of circulation anomalies is consistent with, but much greater than, that of convection (Fig. 3). This suggests that the zonal teleconnection pattern along the Asian jet is dependent on the different combinations of the subtropical convection anomalies. Corresponding to stronger (weaker) IND convection, there tends to be an anticyclonic (cyclonic) anomaly northwest of the Indian continent, without regard to whether convection over the WNP is enhanced or suppressed concurrently. Similarly, corresponding to stronger (weaker) WNP convection, there is a cyclonic (anticyclonic) anomaly centered over the Korean peninsula, and there is a wave-train-like pattern along the coast of the WNP and North Pacific (not shown), regardless of whether convection over the IND is enhanced or suppressed concurrently.

The composite convection anomalies for the four configurations (Fig. 3) are roughly equivalent to one standard deviation of 30–60-day oscillation (not shown). The

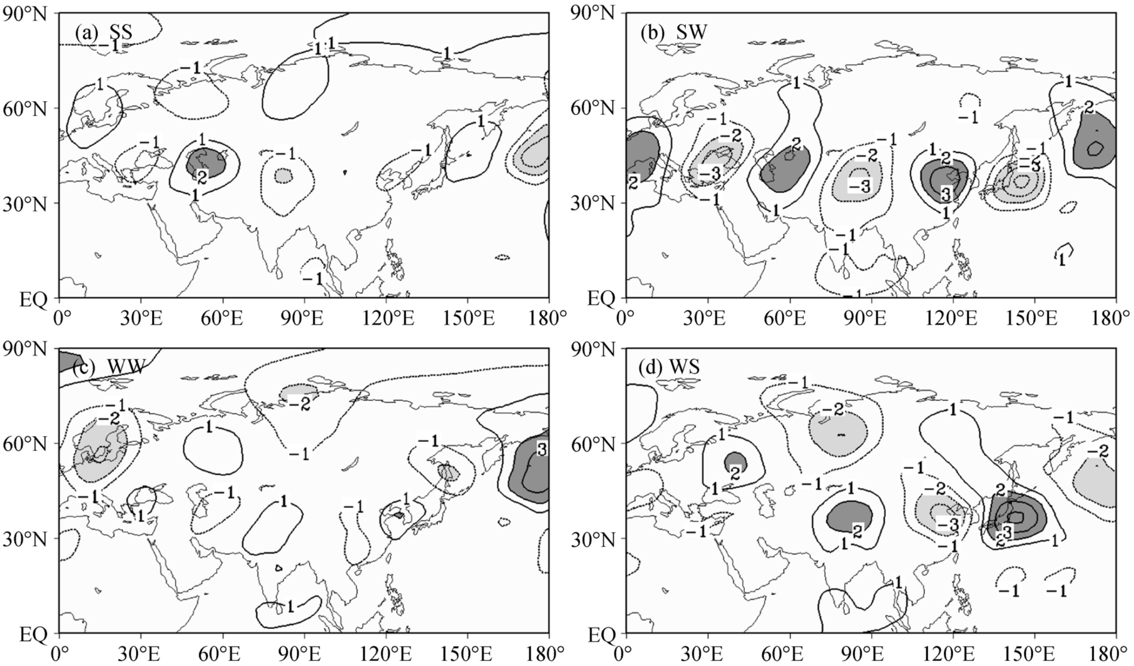

Figure 4 Same as Fig. 3, but for 200-hPa meridional wind anomalies. Units: m s^{-1}.

meridional wind anomalies associated with the waves along the jet (Fig. 4) are also equivalent to one standard deviation (not shown) for the out-of-phase configurations, but they are much weaker than one standard deviation for the in-phase configurations. This finding suggests that the waves along the subtropical jet are reliable for the out-of-phase configurations.

4 Summary

In this study, we investigated circulation anomalies in the extratropics for different combinations of subtropical convection anomalies over the IND and WNP. Previous studies have shown that these convection anomalies are associated with the zonal teleconnection along the Asian jet and the meridional teleconnection over the WNP, respectively. We focus on 30–60-day convection oscillations and the associated circulation anomalies.

Based on different combinations of 30–60-day convection oscillations over the IND and WNP, four configurations are made, in which two are in-phase and the other two are out-of-phase. Composite analyses are performed on these configurations. The days for out-of-phase configurations (strong IND convection and weak WNP convection, or weak IND convection and strong WNP convection) are much more than those for in-phase configurations, being consistent with previous studies which indicated that 30–60-day convection oscillations tend to be out-of-phase between the IND and WNP.

Composite results reveal that circulation anomalies for the out-of-phase configurations are much stronger in the middle latitudes than those for the in-phase configurations. There are teleconnection patterns along the Asian jet for the out-of-phase configurations, particularly for the configuration of strong IND convection and weak WNP convection. However, the zonal teleconnection patterns are either weak or obscure for the in-phase configurations. These differences in teleconnection suggest that the zonal teleconnection along the Asian jet is dependent on different combinations of IND and WNP subtropical convection anomalies.

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