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Change in early-summer meridional teleconnection over the western North Pacific and East Asia around the late 1970s

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ABSTRACT: Previous studies have shown that during summer there is a meridional teleconnection over the western North Pacific and East Asia (WNP-EA) on the interannual time scales. This meridional teleconnection is characterized by the zonally elongated circulation anomalies with alternate signs in the meridional direction over this region. The present study indicates that there is a significant change in the early-summer meridional teleconnection around the late 1970s, by using ERA-40 reanalysis data during 1958–2001. Although this meridional teleconnection appears as a dominant mode during the whole analysis period, a close inspection revealed that the teleconnection becomes obscure considerably after the late 1970s. Before the late 1970s, the meridional displacement of the East Asian upper-tropospheric jet stream (EAJS), which is the most dominant mode of EAJS interannual variability, has a statistically significant relationship with both the zonal shift of the WNP subtropical high and rainfall anomaly in the tropical WNP. After the late 1970s, however, this tropical–extratropical interaction over the WNP-EA is disrupted. We hypothesize that this change in meridional teleconnection is due to the weakening of vertical easterly shear over the tropical WNP in June after the late 1970s. Before the late 1970s, the easterly vertical shear permits the coupling of external mode and internal mode excited by the tropical WNP precipitation anomaly and results in a significant barotropic response, which is necessary for the meridional teleconnection over the WNP-EA. After the late 1970s, the near-zero vertical shear is unfavourable for the coupling and thus weakens the meridional teleconnection. Copyright © 2009 Royal Meteorological Society

KEY WORDS interdecadal change; meridional teleconnection; western North Pacific subtropical high; East Asian jet stream

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1. Introduction

The variability of East Asian summer climate is significantly affected by a meridional teleconnection of circulation over the western North Pacific and East Asia (WNP-EA). The meridional teleconnection was previously referred to as the Pacific-Japan (PJ) pattern (Nitta, 1987; Kosaka and Nakamura, 2006) or East Asia-Pacific pattern (Huang and Sun, 1992). Associated with the meridional teleconnection, rainfall anomalies exhibit a seesaw pattern over the WNP-EA, i.e. precipitation is enhanced (suppressed) along the climatological East Asian rainy belt when it is suppressed (enhanced) over the Philippine Sea.

The WNP subtropical high (WNPSH) in the lower troposphere and the East Asian jet stream (EAJS) in the upper troposphere are two dominant components of East Asian summer monsoon circulation system (Tao and Chen, 1987; Huang *et al*., 2003; Lu, 2004; Tao and Wei, 2006). Their interannual variations are closely related to the anomalous convective activity over the tropical WNP (Lu, 2001, 2004; Lu and Dong, 2001; Wang *et al*., 2001). On one hand, anomalous convection (or precipitation) over the Philippine Sea induces an anomalous anticyclone/cyclone in the lower troposphere to the northwest, which corresponds to the westward extension/eastward retreat of the WNPSH (Lu, 2001; Lu and Dong, 2001). On the other hand, anomalous convection over the Philippine Sea is also significantly associated with meridional displacement of the EAJS (Wang *et al*., 2001; Lu, 2004). Thus, the zonal shift of the WNPSH and the meridional displacement of the EAJS can be viewed as two components of the meridional teleconnection over the WNP-EA (Lau *et al*., 2000; Wang *et al*., 2001; Lu and Lin, 2009).

Numerous previous studies showed that the East Asian summer monsoon experiences an obvious change around the late 1970s. Wang (2001) showed that in the end of 1970s there is an anomalous lower-tropospheric northerly, which is opposite to the climatological summertime southerly over east China, indicating the weakening of East Asian summer monsoon. Yu and Zhou (2007) have shown that after the late 1970s the EAJS

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exhibits a trend of southward shift in July–August and northward shift in June. He and Gong (2002) proposed that since the late 1970s, the WNPSH extended southwestward. Corresponding to these circulation changes, summer rainfall is enhanced over the Yangtze River valley in China (Gong and Ho, 2002) but suppressed in North China (Huang *et al.*, 1999).

These previous studies, however, have not investigated the possible change in relationships between these monsoonal components around the late 1970s. Moreover, previous studies on the meridional teleconnection over the WNP-EA also ignored the possible change in this teleconnection around the late 1970s. On one hand, some previous studies (e.g. Lu, 2001, 2004; Kawatani *et al.*, 2008) analysed the meridional teleconnection over the WNP-EA by using data after the late 1970s, when satellite-observed outgoing longwave radiation (OLR) data and precipitation estimates are available, and therefore it was impossible for these studies to find any change that happened around the late 1970s. On the other hand, other previous studies (e.g. Wang *et al.*, 2001; Lu and Lin, 2009) used the data covering both before and after the late 1970s, but they did not attempt to compare the features of the meridional teleconnection between these two periods.

Kwon *et al.* (2005) found that the relationship between the East Asian and WNP summer rainfall, which can be considered as a manifestation of the meridional teleconnection, exhibits decadal fluctuation around the mid-1990s. The relationship is much stronger in the recent decade (1994–2004) than that in the epoch before 1994 (1979–1993). Yim *et al.* (2008a) showed that the relationship between the East Asian and WNP summer rainfall is mainly associated with sea surface temperature (SST) anomaly in the NINO3 region during the period 1979–1993, whereas it is associated with the SST anomaly in the NINO4 region during the period 1994–2006. Furthermore, Yim *et al.* (2008b) suggested that the suppressed El Niño-Southern Oscillation (ENSO) may induce greater WNP summer rainfall variability and stronger relationship between the East Asian and WNP rainfall. Most recently, Kim *et al.* (2009) suggested that the SST anomalies in the Indian ocean may also play a role in modifying the relationship between the East Asian and WNP rainfall. These results suggest that the meridional teleconnection may not be stationary. However, focusing on the decadal change in the teleconnection around the mid-1990s, all these studies used observational data after the late 1970s.

Wu and Wang (2002) compared the impacts of the WNP summer monsoon on precipitation in East Asia during 1962–1977 and 1978–1993. They revealed that associated with the strong WNP summer monsoon, precipitation in eastern North China is significantly suppressed before the late 1970s in contrast to that after the late 1970s. Their results are based on the June–July–August mean. However, the meridional teleconnection exhibits distinct characteristics between early summer and late summer. Lu (2004) found that the meridional teleconnection over the WNP-EA is weak in June but strong in July and August, by using the data during 1979–1998. Corresponding to the suppressed convection over the Philippine Sea, an anomalous anticyclone appears over the subtropical WNP in each month of summer, and the EAJS shifts significantly southward in July and August but not in June (Lu, 2004). Moreover, Lin and Lu (2005) identified that, during 1979–2002, the southward displacement of the EAJS is associated with significant westward extension of the WNPSH in July and August but not in June. Does the meridional teleconnection change coherently in early and late summer after the late 1970s?

A recent study, by using a much longer period (1958–2002) of data, revealed that in June the zonal shift of the WNPSH is also significantly related to meridional displacement of the EAJS (Lin and Lu, 2009). This difference from the previous studies cannot be explained by the differences in the analysis methods, and so it may suggest a weakening of the June meridional teleconnection after the late 1970s. Note that the results of both Lu (2004) and Lin and Lu (2005) are obtained by using data during the period after the late 1970s. Actually, as shown in Table I, the correlation coefficients between the zonal shift of the WNPSH and the meridional displacement of the EAJS in June change from 0.72 during 1958–1979 to 0.23 during 1980–2001. Similar to that in June, the meridional teleconnection patterns in July and August are also examined, but they do not show any significant changes around the late 1970s. Thus, in this study, we concentrate on the interdecadal change in meridional teleconnection of June, leaving a brief discussion on the July and August situations in the Section 5.2.

The arrangement of the text is as follows. After a brief description of the data and indices used in this study in Section 2, we depict some basic features of meridional teleconnection in June during 1958–2001 in Section 3. In Section 4, an abrupt weakening of the meridional teleconnection around the late 1970s is identified. In Section 5, we propose a possible mechanism for this interdecadal change: that is, the effect of change in vertical shear of basic flow over the tropical WNP. We also show that in July and August the vertical shears do not exhibit any significant changes and the meridional teleconnection patterns persist before and after the late 1970s, which is in contrast to that in June. Finally, the conclusions are presented in Section 6.

Table I. Correlation between the EAJSI, the WNPSHI, and the NPPI in June.

Correlation	EAJSI, WNPSHI	EAJSI, NPPI	WNPSHI, NPPI
1958–1979	0.72[a]	−0.56[a]	−0.71[a]
1980–2001	0.23	−0.33	−0.73[a]
1958–2001	0.45[a]	−0.43[a]	−0.72[a]

See the details for definitions of these three indices in Section 2.
[a] Significance at the confidence level of 99%.

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2. Data and indices

We used the 40-year European Center for Medium-Range Weather Forecast reanalysis data (ERA-40, Uppala *et al.*, 2005). The variables include monthly zonal and meridional winds and geopotential heights at a resolution of $2.5^\circ \times 2.5^\circ$, and the period spans from 1958 to 2001. We also used the monthly land precipitation data from Climatic Research Unit (CRU), University of Anglia, UK, during 1958–2001 (Mitchell and Jones, 2005) and the precipitation data derived by the Global Precipitation Climatology Project (GPCP) from 1979 to 2001 (Huffman *et al.*, 1997; Adler *et al.*, 2003).

To depict the early-summer meridional teleconnection over the WNP-EA, the EAJS index (EAJSI) and the WNPSH index (WNPSHI) are used. The EAJSI is defined as the time series of principal component of the leading empirical orthogonal function (EOF) mode of interannual variation of zonal winds at 200 hPa (U200) over the region 20°–60°N, 120°–150°E in June. In the years with the positive values of the EAJSI, the EAJS shifts southward, while in the years with the negative values it shifts northward. The WNPSHI is depicted by the difference of U850 anomalies in June averaged over the regions between 20°–30°N, 110°–140°E and 5°–15°N, 110°–140°E, similar to that in Lin and Lu (2009). When the WNPSHI is positive, the WNPSH extends westward, and vice versa.

We also used a north Philippine precipitation index (NPPI), which is defined as the CRU land precipitation anomalies averaged in 13°–18°N, 115°–123°E in June, as a proxy of convective activities over the tropical WNP, due to the shortage of precipitation data over the ocean before 1979.

To isolate the interannual circulation anomalies associated with the meridional teleconnection over the WNP-EA, the interdecadal components with periods exceeding 8 years have been removed through the harmonics analysis method, except for the basic state depicted in Figures 1(a) and 10. All the three indices are calculated by using the interannual components.

3. Meridional teleconnection associated with meridional displacement of the EAJS

Figure 1 shows the climatology and interannual standard deviation of U200 in June during 1958–2001. A strong westerly dominates over East Asia in the upper troposphere with maximum velocity exceeding 30 m s^{-1} (Figure 1(a)). The axis of westerly jet stream is situated at about 37.5°N extending from northern China, across southern Korea, eastward to southern-central Japan. The interannual variation of upper-tropospheric zonal wind (Figure 1(b)) mostly appears in mid latitudes between 20° and 60°N, and two maxima reside to the south and north sides of the EAJS's axis, respectively. Between the longitudes of 120°E and 150°E, the maximum of standard deviation is larger than 4 m s^{-1} to the south of the EAJS's axis and 5 m s^{-1} to the north.

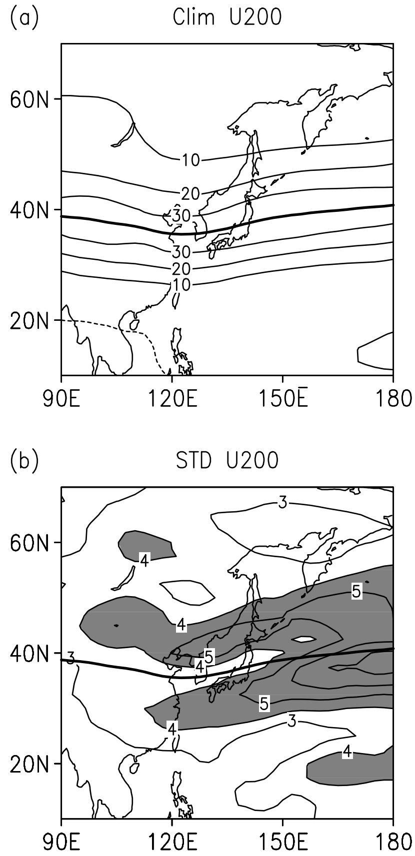

Figure 1. (a) Climatology and (b) standard deviation of zonal wind speed (m s^{-1}) at 200 hPa (U200) in June during 1958–2001. The thick solid line denotes the axis of averaged westerly jet stream during 1958–2001, and standard deviation exceeding 4 m s^{-1} is shaded in (b).

In order to identify the main mode of interannual variation for the June EAJS, we perform an EOF analysis on the U200 over the region 20°–60°N, 120°–150°E. The first mode explains 40% of total variance during 1958–2001, and is significantly separated from the other modes as the second mode only explains 19% of total variance (North *et al.*, 1982). The leading mode is characterized by a meridional dipole structure, with a westerly anomaly to the south of the EAJS's axis and an easterly anomaly to the north (Figure 2(a)). Thus, it depicts the meridional displacement of the EAJS in June, similar to the results of Lin and Lu (2005) by using the National Centers for Environmental Prediction-Department of the Energy (NCEP-DOE) reanalysis data during 1979–2002. We also apply the EOF analysis on the EAJS during 1958–1979 and slightly expand or shrink the region, and find that the spatial distribution of zonal wind anomalies for the first mode is similar to that shown in Figure 2(a). The corresponding principal component (PC1), which is defined as the EAJSI, is shown in Figure 2(b). In years with the positive values of the EAJSI, the EAJS shifts southward, while in years with the negative values it shifts northward.

The meridional displacement of the EAJS is related to remarkable upper- and lower-tropospheric circulation anomalies over the WNP-EA (Figure 3). When the EAJS

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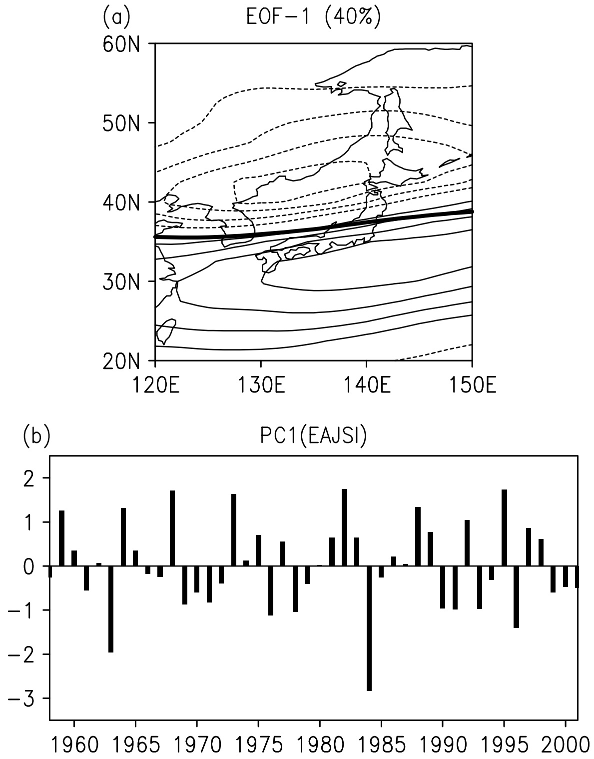

Figure 2. (a) The first EOF leading mode (EOF-1) of June U200 over the region 20°–60°N, 120°–150 °E and (b) the corresponding principal component (PC1), which is defined as the East Asian jet stream index (EAJSI). The thick solid line denotes the EAJS's axis, the contour interval is 1 m s^{-1} and zero contour is omitted in (a).

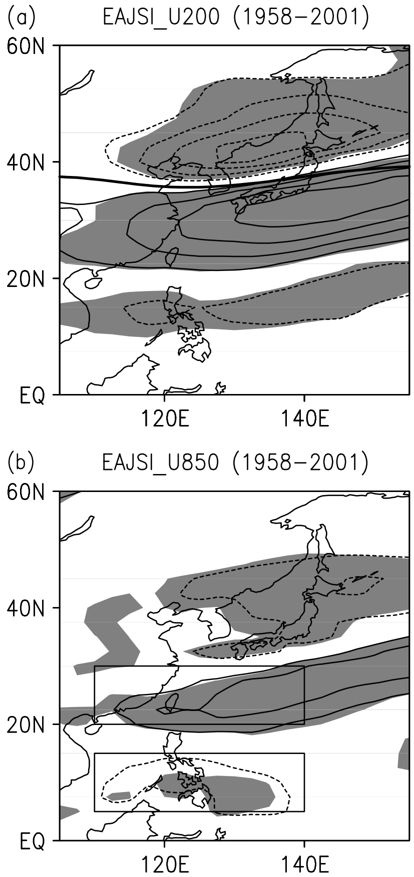

Figure 3. June U200 (a) and 850-hPa zonal wind (U850) (b) regressed upon the EAJSI during 1958–2001. The thick solid line depicts the axis of averaged westerly jet stream during 1958–2001 in (a). Shading denotes significance at the confidence level of 95%, contour intervals are 1 m s^{-1} in (a) and 0.5 m s^{-1} in (b), and zero contours are omitted.

shifts southwards, in the upper troposphere a significant easterly anomaly appears over the tropical WNP and the westerly anomaly to the south of the EAJS's axis and the easterly anomaly to the north (Figure 3(a)). In the lower troposphere, the spatial distribution of zonal wind anomalies resembles that in the upper troposphere, but the anomalies shift slightly southwards. The easterly anomaly centred at 10°N and the westerly anomaly around 25°N form an anticyclonic anomaly over the WNP.

We depict this WNP anticyclonic anomaly by the difference of U850 anomalies averaged over the regions between 20°–30°N, 110°–140 °E and 5°–15°N, 110°–140 °E, similar to that in Lin and Lu (2009) and Wang *et al*. (2001).This index is shown in Figure 4. In the years with the positive index, the WNPSH remarkably extends westwards, and it retreats eastwards when the index is negative (figure is not shown). In the meridional direction, the WNPSH does not show a significant change. Therefore, the index depicts the zonal shift of the WNPSH in June (Lu, 2001; Lu and Dong, 2001) and it is thus named as the WNPSHI. We compared the WNPSHI in this paper with that of Lu (2001), which is defined as averaged 850-hPa geopotential height over the region 10°–30°N, 110°–140 °E. The correlation coefficient between them is 0.68 during 1958–2001, significant at the confidence level of 99%. Therefore, the WNPSHI well represents the zonal extension of the WNPSH.

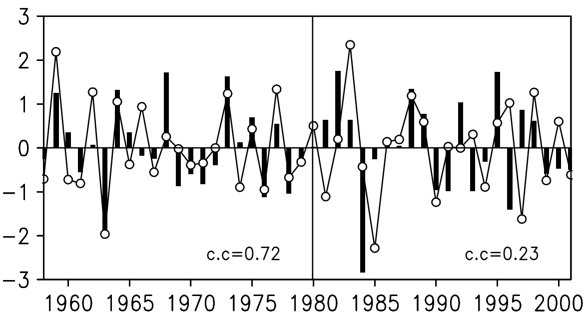

Figure 4. Time series of the EAJSI (black bar) and the WNPSHI (solid line with blank circles) during 1958–2001. The WNPSHI is defined as the difference of U850 anomalies averaged over the two boxes in Figure 3 between 20°–30°N, 110°–140 °E and 5°–15°N, 110°–140 °E. According to the weakened in-phase relationship, i.e. the correlation coefficient (c.c.) from 0.72 to 0.23 between the EAJSI and the WNPSHI since 1980, the whole period is divided into two stages: 1958–1979 before the late 1970s and 1980–2001 after the late 1970s.

The correlation coefficient between the EAJSI and the WNPSHI is 0.45 during 1958–2001, significant at the confidence level of 99%. That is, the meridional displacement of the EAJS is closely associated with the zonal shift of the WNPSH in June during this period.

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When the EAJS shifts southwards (northwards), the WNPSH extends westwards (eastwards).

The meridional displacement of the EAJS and the zonal shift of the WNPSH are both significantly associated with the precipitation anomaly in the tropical WNP (Wang *et al*., 2001; Lu, 2004; Lu and Lin, 2009). Following Lu (2004), we choose the region 10°–20°N, 110°–160 °E to represent the tropical WNP. However, due to the lack of credible precipitation data over the ocean in the tropical WNP before the late 1970s, the NPPI, which is defined as the averaged CRU precipitation in the land region in 13°–18°N, 118°–123 °E, is used as a proxy of the precipitation in the tropical WNP in this study (Figure 7). The correlation coefficient is −0.43 between the EAJSI and the NPPI and −0.72 between the WNPSHI and the NPPI during 1958–2001, both significant at the confidence level of 99% (Table I).

4. Interdecadal change in meridional teleconnection around the late 1970s

The correlation between the EAJSI and the WNPSHI is weakened considerably after the late 1970s (Figure 4), although it is significant during the entire analysis period. The correlation coefficient between the EAJSI and WNPSHI is 0.72 during 1958–1979 (Table I), significant at the confidence level of 99%, but is only 0.23 during 1980–2001 (Table I), not reaching the confidence level of 90%. Thus, in this study we divide the whole period of 1958–2001 into two stages: 1958–1979 before the late 1970s and 1980–2001 after the late 1970s, each stage including 22 years. We also analysed the results for alternative choices of stages, such as 1958–1976 and 1977–2001, and found similar results, suggesting that the interdecadal change is robust as long as the two stages are separated by a certain year in the late 1970s. For brevity, only the results for two stages of 1958–1979 and 1980–2001 are presented in this paper.

Figure 5(a) and (b) show the horizontal wind anomalies (vector) and zonal wind anomalies (thin contour) at 850 hPa related to the southward displacement of the EAJS before and after the late 1970s, respectively. The thick dashed contours depict the WNPSH averaged for the stage before the late 1970s (Figure 5(a)) and the stage after the late 1970s (Figure 5(b)), with the unfiltered geopotential height data at 850 hPa. Before the late 1970s, the southward displacement of the EAJS is related to an anticyclonic anomaly over the WNP (Figure 5(a)) situated to the west of the WNPSH, corresponding to westward extension of the WNPSH (Lu, 2001). The spatial distribution of the anticyclonic anomaly over the WNP and a cyclonic anomaly east of Japan (Figure 5(a)) resembles a PJ pattern (Nitta, 1987; Kosaka and Nakamura, 2006). After the late 1970s (Figure 5(b)), associated with the southward displacement of the EAJS, a cyclonic anomaly is located over south of Japan to the northwest of the WNPSH. However, there is no significant anomaly over the tropical WNP, suggesting a weakened tropical–extratropical teleconnection over the WNP-EA after the late 1970s.

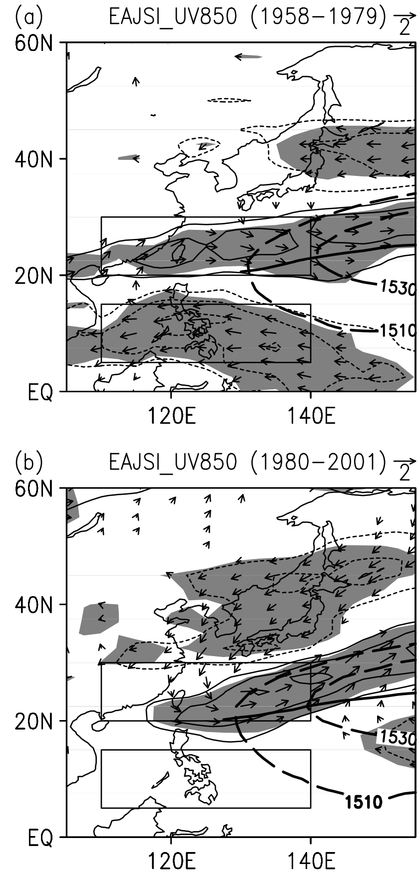

Figure 5. June horizontal winds (vector) and zonal wind (thin contour) at 850 hPa regressed upon the EAJSI during 1958–1979 (a) and 1980–2001 (b). Shading denotes significance for U850 at the confidence level of 95%, contour interval is 0.5 m s^{-1} and zero contours are omitted. The thick dashed lines depict the 850-hPa WNPSH averaged for 1958–1979 in (a) and 1980–2001 in (b), and the thick solid lines denote their ridges.

The weakening of meridional teleconnection over the WNP-EA can be further illustrated by precipitation anomalies (Figure 6). Before the late 1970s, when the meridional teleconnection is strong, precipitation enhances in south China, while it decreases in north Philippines, South Korea and west Japan (Figure 6(a)), associated with the southward displacement of the EAJS. After the late 1970s, however, the precipitation anomalies associated with the meridional displacement of the EAJS are confined to the subtropics and mid latitude north of 25°N. Although there is also negative precipitation anomaly in north Philippines, this anomaly is not statistically significant.

The meridional teleconnection pattern over the WNP-EA has been considered as northward propagation of a Rossby wave triggered by the anomalous convective activities over the tropical WNP (e.g. Kurihara and Tsuyuki, 1987; Nitta, 1987; Huang and Sun, 1992). Here, to depict the precipitation in the tropical WNP, the NPPI defined in Section 2 is used. This index can well delineate the precipitation in the tropical WNP (Figure 7).

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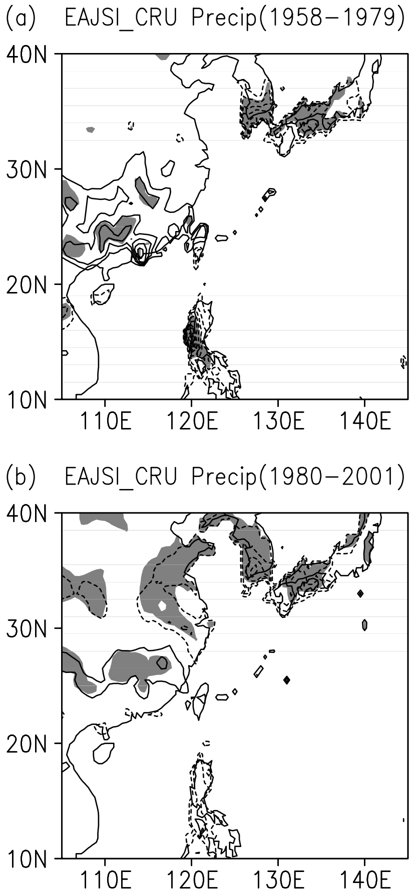

Figure 6. June precipitation regressed upon the EAJSI during 1958–1979 (a) and 1980–2001 (b). Shading denotes significance at the confidence level of 95%, contour interval is 20 mm per month and zero contours are omitted.

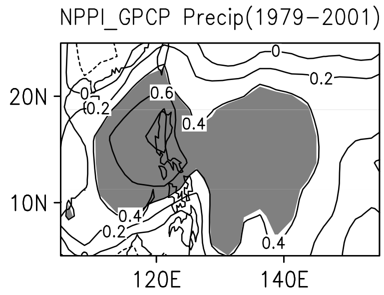

Figure 7. Spatial distribution of correlation coefficients of June GPCP precipitation with the NPPI during 1979–2001. Shading denotes significance at the confidence level of 95%, and contour interval is 0.2.

Corresponding to the increased precipitation in north Philippines, the precipitation increases remarkably in the tropical WNP, from South China Sea eastwards to the Philippine Sea west of 140 °E. The correlation coefficient between the NPPI and the averaged GPCP precipitation in the tropical WNP (10°–20°N, 110°–160 °E) is 0.68 during 1979–2001, significant at the confidence level of 99%.

Figure 8 shows the June U200 anomalies associated with the NPPI before and after the late 1970s. Before the late 1970s, associated with the enhanced precipitation in

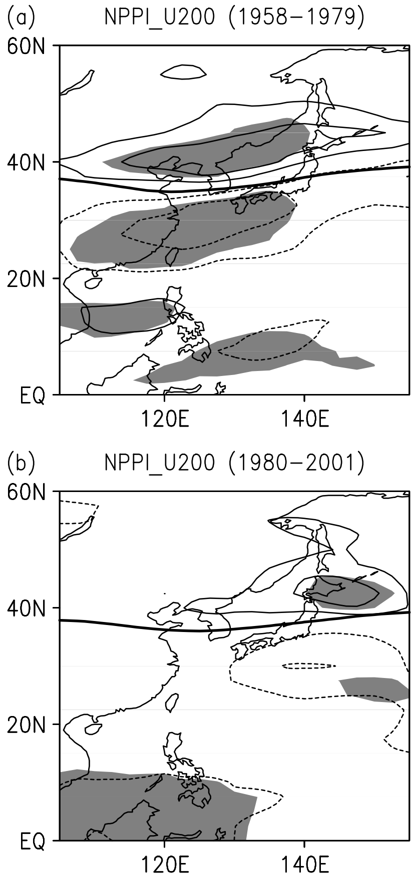

Figure 8. June U200 regressed upon the NPPI during 1958–1979 (a) and 1980–2001 (b). Shading denotes significance at the confidence level of 95%, contour interval is 1 m s^{-1} and zero contours are omitted.

north Philippines, a significant meridional teleconnection appears in the upper troposphere (Figure 8(a)). In the extratropics, a westerly anomaly is situated to the north of the EAJS's axis and an easterly anomaly to the south, indicating a northward displacement of the EAJS. During 1958–1979, the correlation coefficient between the NPPI and the EAJSI is −0.56 (Table I), significant at the confidence level of 99%. In the tropics, a westerly anomaly over the South China Sea and an easterly anomaly south of Philippine Sea form an anticyclonic anomaly as a direct thermal response to the local heating source around north Philippines. After the late 1970s, the zonal wind anomalies related to the precipitation in north Philippines are weak and mostly confined to east of 140 °E (Figure 8(b)). The correlation coefficient between the NPPI and the EAJSI is only −0.33 during 1980–2001 (Table I), below the confidence level of 90%. This weak meridional teleconnection in June after the late 1970s is consistent with that revealed by Lu (2004) using the outgoing longwave radiation (OLR) data during 1979–1998.

In the lower troposphere, before the late 1970s, related to the enhanced precipitation in north Philippines, a significant cyclonic anomaly appears to the northwest over northern South China Sea (Figure 9(a)). In East Asia, a weak anticyclonic anomaly appears over Japan.

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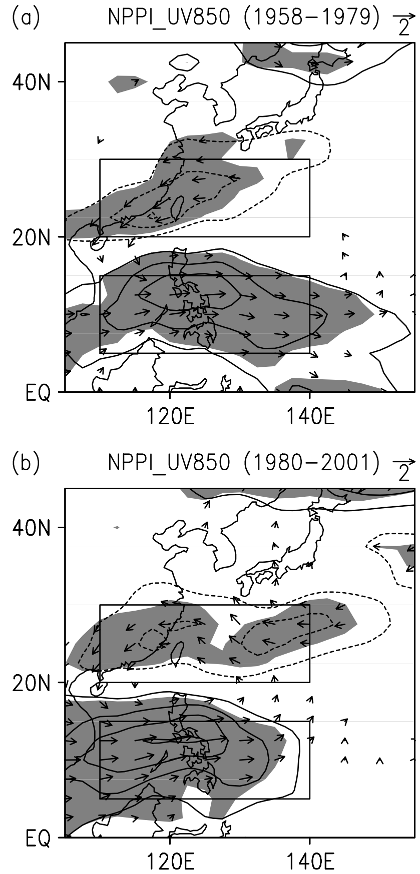

Figure 9. Same as Figure 5, but regressed upon the NPPI.

The cyclonic anomaly over the WNP and the anticyclonic anomaly over East Asia are similar to those associated with the meridional displacement of the EAJS (Figure 5(a)), but with the opposite signs due to the negative correlation between the EAJSI and the NPPI (Table I). That is, before the late 1970s, the meridional teleconnection between the lower-tropospheric anticyclonic/cyclonic anomaly over the WNP and the meridional displacement of the EAJS in the upper troposphere may be attributed to the teleconnection pattern excited by the tropical WNP precipitation anomaly. After the late 1970s, the associated zonal wind anomalies (Figure 9(b)) exhibit a similar tropical pattern over the WNP to that before the late 1970s (Figure 9(a)). The correlation coefficients between the NPPI and the WNPSHI are −0.71 during 1958–1979 and −0.73 during 1980–2001 (Table I), both significant at the confidence level of 99%.

In summary, the meridional teleconnection in early summer is significantly weakened after the late 1970s, which is illustrated by the decreased correlations of the meridional displacement of the EAJS with the tropical WNP precipitation anomaly (Table I and Figure 8) and zonal variation of the WNPSH (Table I and Figure 5). In the lower troposphere, the significant cyclonic anomaly over the WNP before and after the late 1970s (Figure 9) is a Gill-type response to the tropical WNP precipitation anomaly (Gill, 1980). Why are the meridional teleconnection different between before and after the late 1970s? Next section is devoted to the discussion on the possible mechanism responsible for this difference.

5. Effect of change in vertical shear of tropical WNP basic flow

5.1. Change of vertical shear in June

Kasahara and Silva Dias (1986) have found the solutions to a prescribed tropospheric equatorial heating distribution with and without the vertical shear of zonal winds. Their numerical experiments showed that without the vertical shear the tropical heating excites the relatively small barotropic external mode, while the vertical shear of zonal wind permits the coupling of external mode and internal mode and results in a significant barotropic response. The barotropic response emanates from the tropics into the extratropics enabling the tropical–extratropical teleconnection (Kato and Matsuda, 1992; Wang and Xie, 1996). By using reanalysis data from 1979 to 1998, Lu (2004) found that the EAJS exhibits only a weak southward shift in June when the convective activity over the tropical WNP is suppressed. He proposed that this weak association is due to the averaged near-zero vertical shear of zonal wind over the tropical WNP during 1979–1998, close to the stage of 1980–2001 after the late 1970s in this study. Does the change in meridional teleconnection relate to change in the vertical shear of zonal wind over the tropical WNP?

The vertical shear of zonal wind over the tropical WNP does exhibit a considerable change around the late 1970s. Figure 10(a) shows the averaged vertical shear of zonal wind during 1980–2001 (thin contours) and its difference (thick contours) from that during 1958–1979. After the late 1970s, the zero contour line of vertical shear is across the tropical WNP and the average of vertical shear of zonal wind over the tropical WNP is near zero (see also Figure 10(b)). Compared with that after the late 1970s, the vertical shear of zonal wind before the late 1970s has become more negative over the tropical WNP between 10°N and 20°N as depicted by the thick contours. Following Lu (2004), we choose the region 10°–20°N, 110°–160°E to represent the tropical WNP. The vertical distribution of unfiltered zonal wind averaged for 1958–1979 and 1980–2001 over this region is given in Figure 10(b). The vertical distribution of zonal wind is roughly neutral after the late 1970s, similar to that in Lu (2004, in his Figure 11(d)), while it exhibits an easterly shear before the late 1970s. The easterly shear before the late 1970s permits the coupling of external mode and internal mode excited by the tropical WNP precipitation anomaly, and then facilitates the tropical–extratropical teleconnection over the WNP-EA. However, the near-zero vertical shear of basic flow after the late 1970s prevents the coupling of external mode and internal mode, and weakens the meridional teleconnection.

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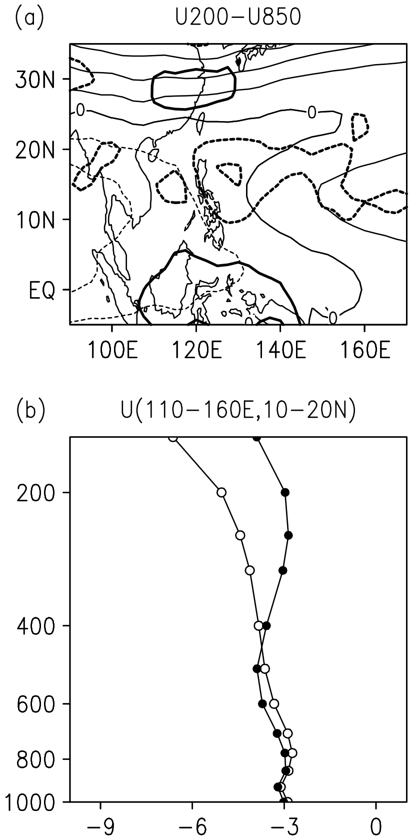

Figure 10. (a) The vertical shear (200 hPa minus 850 hPa) of basic zonal wind in June averaged during 1980–2001 (thin lines) and its difference (thick lines) with that during 1958–1979 (1958–1979 minus 1980–2001). (b) The vertical distribution of basic zonal wind averaged over the tropical WNP (10°–20°N, 110°–160°E) during 1958–1979 (blank circles) and 1980–2001 (filled circles). Contour intervals are 10 m s^{-1} for the thin lines and 2 m s^{-1} for the thick lines in (a).

5.2. July and August situations

The present study revealed an abrupt weakening of meridional teleconnection over the WNP-EA in June since the late 1970s. Unlike the June situations, the meridional teleconnection patterns in July and August do not show any significant changes around the late 1970s. Figure 11 shows the horizontal wind anomalies regressed upon the EAJSIs in July and August (Lin and Lu, 2005), which are defined as the time series of the principal component corresponding to the first EOF dominant mode of U200 over the region 20°–60°N, 120°–150°E in July and August, respectively.

Before the late 1970s, in years with a positive July EAJSI, the EAJS shifts southwards and an anomalous anticyclone is located over the subtropical WNP, with an anomalous westerly appearing over the subtropical WNP and an anomalous easterly over the tropical WNP in July (Figure 11(a)). After the late 1970s, the circulation anomaly associated with the July EAJSI (Figure 11(b)) does not show any significant change, compared with that before the late 1970s. The correlation coefficients between the July EAJSI and July WNPSHI, defined as the difference of U850 averaged over the two boxes shown in Figure 11(a) and (b) between 25°–35°N, 130°–160°E and 10°–20°N, 130°–160°E, are 0.55 during 1958–1979 and 0.65 during 1980–2001 (Table II), both significant at the confidence level of 99%.

The lower-tropospheric circulation anomalies associated with the August EAJSI is similar to that in July (Figure 11(d) and (e)), but with a northwestward movement as the seasonal march of the WNPSH from July to August. The correlation coefficients between the August EAJSI and the August WNPSHI, defined as the difference of U850 averaged over the two boxes in Figures 11(d) and (e) between 30°–40°N, 110°–140°E and 15°–25°N, 110°–140°E, are 0.72 during 1958–1979 and 0.60 during 1980–2001. The selection of the boxes in Figure 11 is consistent with the seasonal evolution of interannual variability of convective activity over the WNP (see Figure 1 in Lu, 2004). The results indicate that in July and August the meridional teleconnection patterns associated with the meridional displacement of the EAJS do not show any significant changes around the late 1970s.

We attribute the abrupt weakening of June meridional teleconnection since the late 1970s to the change in vertical easterly shear in the tropical WNP. We propose that the June meridional teleconnection before the late 1970s is due to the vertical easterly shear in the tropical WNP, and the disruption of this meridional teleconnection after the late 1970s to the near-zero vertical shear over the tropical WNP. In July and August, however, the vertical easterly shear persists before and after the late 1970s, although it exhibits some disturbances (Figure 11(c) and (f)). This persistent vertical easterly shear thus favours the meridional teleconnection over the WNP-EA in July and August before and after the late 1970s (Figure 11(a), (b), (d) and (e)).

6. Conclusions

In this study, we identify a significant change around the late 1970s in early-summer meridional teleconnection over the WNP-EA by using ERA-40 reanalysis data from 1958 to 2001. Although this meridional teleconnection appears as a dominant mode during the whole analysis period, a close inspection reveals that the teleconnection becomes obscure considerably after the late 1970s. Before the late 1970s, the meridional displacement of the EAJS, which is the dominant mode of the EAJS interannual variability, is closely related to both zonal shift of the WNPSH and precipitation anomaly in the tropical WNP. However, the tropical–extratropical teleconnection over the WNP-EA is disrupted since the late 1970s. The correlation coefficients change from 0.72 (−0.56) during 1958–1979 to 0.23 (−0.33) during 1980–2001 between the zonal extension of the WNPSH (the precipitation anomaly in the tropical WNP) and the meridional displacement of the EAJS in June.

We attribute this change in early-summer meridional teleconnection to the weakening of vertical easterly shear

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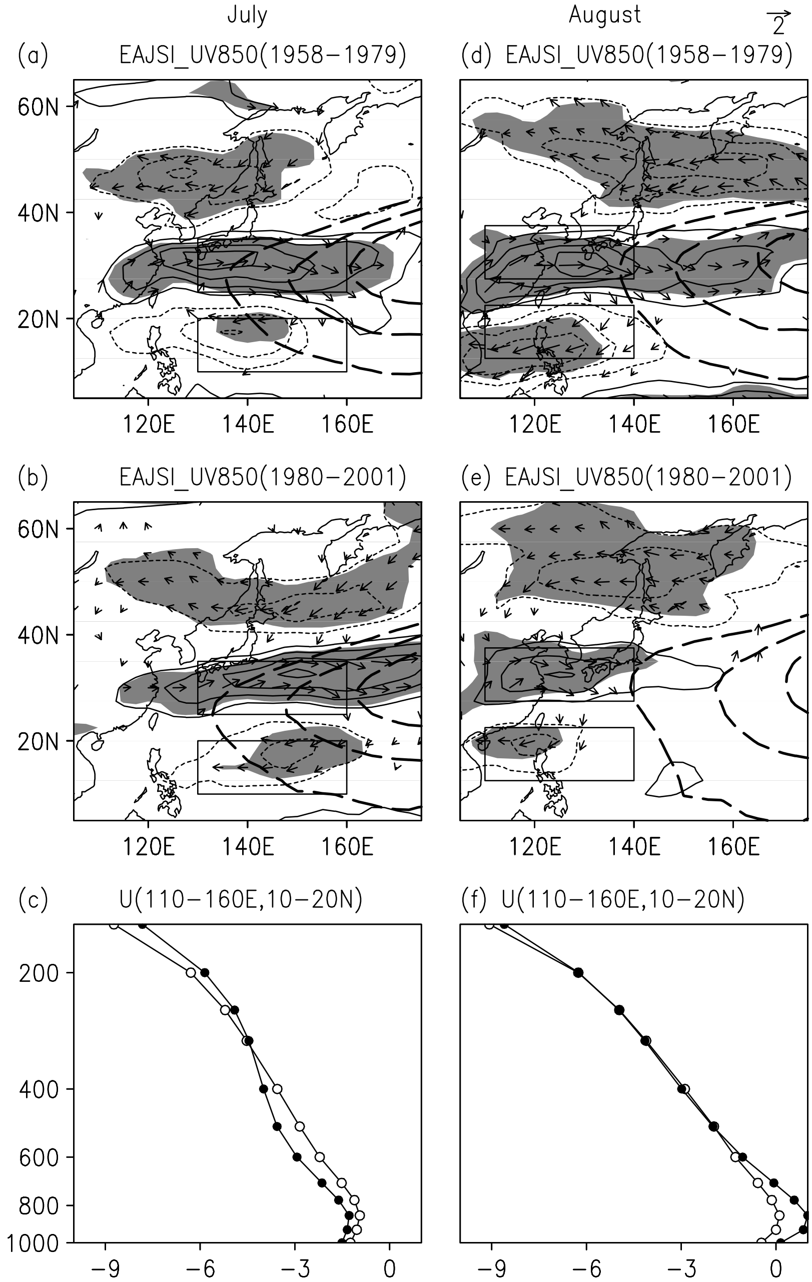

Figure 11. Same as Figure 5, but in July [(a), (b)] and August [(d), (e)]. (c) and (f) depict the vertical distribution of basic zonal wind averaged over the tropical WNP (10°–20°N, 110°–160°E) during 1958–1979 (blank circles) and 1980–2001 (filled circles) in July (c) and August (f).

Table II. Correlation (CORR) between the EAJSI and the WNPSHI in July and that in August.

CORR(EAJSI, WNPSHI)	July	August
1958–1979	0.55[a]	0.72[a]
1980–2001	0.65[a]	0.60[a]

See the details for definitions of the two indices in Section 5.2.
[a] Significance at the confidence level of 99%.

of basic flow over the tropical WNP after the late 1970s. Before the late 1970s, the vertical easterly shear permits the coupling of external mode and internal mode excited by the precipitation anomaly in the tropical WNP and results in a significant barotropic response, which is necessary for the meridional teleconnection over the WNP-EA. After the late 1970s, the near-zero vertical shear inhibits the coupling and thus weakens the meridional teleconnection over the WNP-EA. However, the reason for this weakening of vertical easterly shear over the tropical WNP after the late 1970s is not clear.

We also discuss the meridional teleconnection patterns over the WNP-EA in July and August. They do not show any significant changes around the late 1970s, compared with that in June. This result is consistent with the persistent vertical easterly shear of basic flow over the tropical WNP in July and August before and after the late 1970s.

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