

# Indices of the Summertime Western North Pacific Subtropical High

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## ABSTRACT

By averaging June–July–August (JJA) mean geopotential height anomalies at 850 hPa over the specified areas, the author proposes two innovative and succinct parameters to objectively define the zonal and meridional displacements of the western North Pacific subtropical high (WNPSH) in summer, respectively. Thus, these two indices and the present results may provide a basis for validating atmospheric general circulation models simulating the WNPSH. For the zonal index, the specified area is the west edge (110°–150°E, 10°–30°N) of the WNPSH. For the meridional index, the specified area is the northwest edge (120°–150°E, 30°–40°N) of the WNPSH. The interannual variations of these two indices are found to be independent. The results from a composite analysis based on the meridional index are in good agreement with previous studies based on case analyses.

The two indices are compared with the existing indices announced by the National Climate Center (NCC) in China, on the interannual timescale. Despite slight differences, the interannual variations of the presented indices are basically similar to those of the NCC indices, and thus the circulation and precipitation associated with the present indices exhibit similar features to those associated with the NCC indices. Furthermore, an analysis of the differences between the associations of the present indices and the NCC indices shows that the presented indices are better than the NCC indices. An important result is that the zonal index is related to a more outstanding anomaly of precipitation, especially in East Asia and the Philippine Sea, both based on the presented indices and the NCC indices.

The two indices can also be used to describe the seasonal march of the WNPSH during summer, namely, the poleward and eastward shifts. It is found that climatologically, the WNPSH shifts poleward and eastward rapidly in middle July, but the amplitudes of the poleward and eastward shifts are more remarkable in the summers when the WNPSH is located poleward and eastward in average.

**Key words:** WNPSH indices, interannual variability, seasonal evolution

## 1. Introduction

The western North Pacific subtropical high (hereafter WNPSH) greatly influences the climate in East Asia. The low-level jet at the northwestern edge of the WNPSH transports a large amount of water vapour into East Asia. Therefore, the position, shape and strength of the WNPSH dominate the large-scale quasi-stationary frontal zones in East Asia (Tao and Chen 1987; Ding 1994).

There have been many studies on the WNPSH (e.g., Huang and Li 1987; Kurihara 1989; Huang and Sun 1992; Wu et al. 1999; Liu et al. 1999 a,b; Zhang and Tao 1999; and many others). Recently, Liu and Wu (2000) gave a review on the studies of the WNPSH. However, the WNPSH was only qualitatively investigated in many of the previous studies. Quantitative

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and objective definitions are necessary to further investigate the variations of the WNPSH and the relationship of the WNPSH to other factors, and in particular, to facilitate the validation of variations of the WNPSH simulated by atmospheric general circulation models (GCMs).

The 500-hPa geopotential heights have been widely used to define the WNPSH (e.g., Tao and Zhu 1964; Zhang and Yu 1998; Sun and Ying 1999; Chen et al. 2001; Mu et al. 2001; Xu et al. 2001). In fact, the National Climate Center in China (NCC) announced the monthly indices of westward extension and north edge and intensity of the WNPSH, according to monthly mean 500-hPa geopotential heights. However, the WNPSH appears more intensified and stable at lower levels. On the other hand, the low-level jet, which is associated with the WNPSH, transports a large amount of water vapour into East Asia and plays a dominant role in influencing the East Asian summer monsoon. Therefore, geopotential heights at 850 hPa, rather than 500 hPa, are used to define the WNPSH in this study. The following section gives additional reasons for the choice of 850 hPa.

In general, the WNPSH shifts poleward and eastward over the western North Pacific during summer. The interannual variability of the WNPSH also appears to be a zonal or meridional displacement. These shifts and displacements dominate the distribution of rainfall anomalies in East Asia. On the other hand, the eastern extent of the North Pacific subtropical high does not significantly influence the East Asian summer monsoon. Therefore, in this study, we define two indices to describe the zonal and meridional displacements and shifts of the WNPSH.

Since the WNPSH is a crucial component of the East Asian summer monsoon system and significantly influences rainfall anomalies in East Asia, reproducing well the variability of the WNPSH is essential for GCMs to properly capture the variability of the summer rainfall in East Asia. Presently, simulating well the variability of the WNPSH and rainfall in East Asia remains a tough task. Therefore, an objective and simple definition of the WNPSH is necessary to give a basic validation of the variability of the WNPSH simulated by GCMs.

In section 2, we define two indices (namely zonal and meridional) to describe the zonal and meridional displacements of the WNPSH, respectively. The associations with the WNPSH indices are examined by a composite study in section 3. Section 4 is devoted to a comparison of our WNPSH indices with the NCC indices. In section 5, the indices are adjusted and used to depict the seasonal evolution of the WNPSH during summer. A summary is given in section 6.

## 2. Definition of zonal and meridional WNPSH indices

In this study, the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR) reanalysis data are used (Kalnay et al. 1996). Also used are estimates of precipitation data based on gauge observations and satellite-estimates (Xie and Arkin 1997). The monthly data are used to calculate the summer (June–July–August, JJA) data. To study seasonal evolution, we also use pentad-mean data. All these data are given on a  $2.5^\circ$  longitude–latitude grid mesh.

Although the NCEP / NCAR reanalysis data cover a much longer period, a period from 1979 to 1998 is utilized in this study for the purpose of matching outgoing longwave radiation (OLR) data and avoiding interdecadal variability. According to Tanaka (1997) and Kawamura et al. (1998), there would be interdecadal variations in the western North Pacific monsoon, East Asian monsoon and tropical Pacific SSTs, and in the relationships among

them. Accordingly, one should be cautious in extending the present conclusions to a longer period.

On the interannual timescale, 500 hPa may not be the best level to describe the variations of the WNPSH, although the 500-hPa geopotential heights have been widely used in China to describe the WNPSH (e.g., Tao and Zhu 1964; Zhang and Yu 1998; Sun and Ying 1999; Chen et al. 2001; Mu et al. 2001; Xu et al. 2001), and they can depict well the effects of midlatitude disturbances on the WNPSH on the synoptic timescale. Figure 1 shows the year-to-year standard deviation of JJA mean heights at 850, 500, and 300 hPa, respectively. In the low latitudes, the standard deviation is generally small at all levels. At 850 hPa, however, the standard deviation is relatively large over the subtropical western North Pacific, in comparison with other places with similar latitudes. This indicates that the North Pacific subtropical high at 850 hPa exhibits a greater interannual variability in its western extent. The situation at 500 hPa is basically similar, but with much weaker contrast between the subtropical western North Pacific and other places with similar latitudes. This contrast, however, disappears at 300 hPa.

The North Pacific subtropical high is much more dominant at lower levels than at middle and upper levels (Fig. 2). There is clearly a subtropical high with a southwest–northeast oriented ridge at 925 and 850 hPa. The subtropical high exhibits a considerably similar shape at these two lower levels. At 500 hPa, although a subtropical high appears over the western and central North Pacific, it is rather weak, being indicated by only one close contour line. One may argue that the contour interval is larger at 500 hPa. However, the contour intervals are not important when one focuses on the shape of a high and pays no attention to the strength of winds. At 200 hPa, the North Pacific subtropical high disappears, and the high over the East China Sea is the east extent of another high, i.e., the upper-level Tibetan high. The 850-hPa heights are more familiar and do not exhibit much difference in the features of the North Pacific subtropical high as those at 925 hPa, and thus are used to describe the WNPSH in this study.

The WNPSH shows a seasonal tendency of poleward shift and eastward retreat at 850 hPa, like at 500 hPa. The poleward shift and eastward retreat can be indicated by location of a contour line of 1480 and 1500 gpm, respectively (Fig. 3). In June, the 1480 line is located over the southern coastline of Japan, and shifts poleward to the southern coastline of Korea in July and further to North Korea in August. On the other hand, the 1500 line is located over the Philippines in June, and retreats eastward to the western Pacific in July and further eastward in August.

Therefore, geopotential heights at 850 hPa are used to depict the WNPSH in this study. We use the JJA–mean 850-hPa geopotential height anomalies averaged over a specified region at the west edge of the WNPSH as an index for describing the year-to-year zonal displacement of the WNPSH. Concerning the subtropical area with large standard deviation of 850-hPa geopotential heights in Fig. 1, and concerning the possible influence of the WNPSH on the East Asian summer monsoon, we choose the specified region as (110°–150°E, 10°–30°N). Similarly, we use the JJA–mean anomalies of geopotential heights at 850 hPa averaged over a specified region (120°–150°E, 30°–40°N) at the north edge of the WNPSH as an index for describing the year-to-year meridional displacement. Actually, we have examined several slightly different average areas, relative vorticity rather than geopotential height, and the disturbances after removing the zonal means, and found very similar results. Among these examined definitions, the present ones are most straightforward and best delineate the zonal and meridional shifts of the WNPSH.

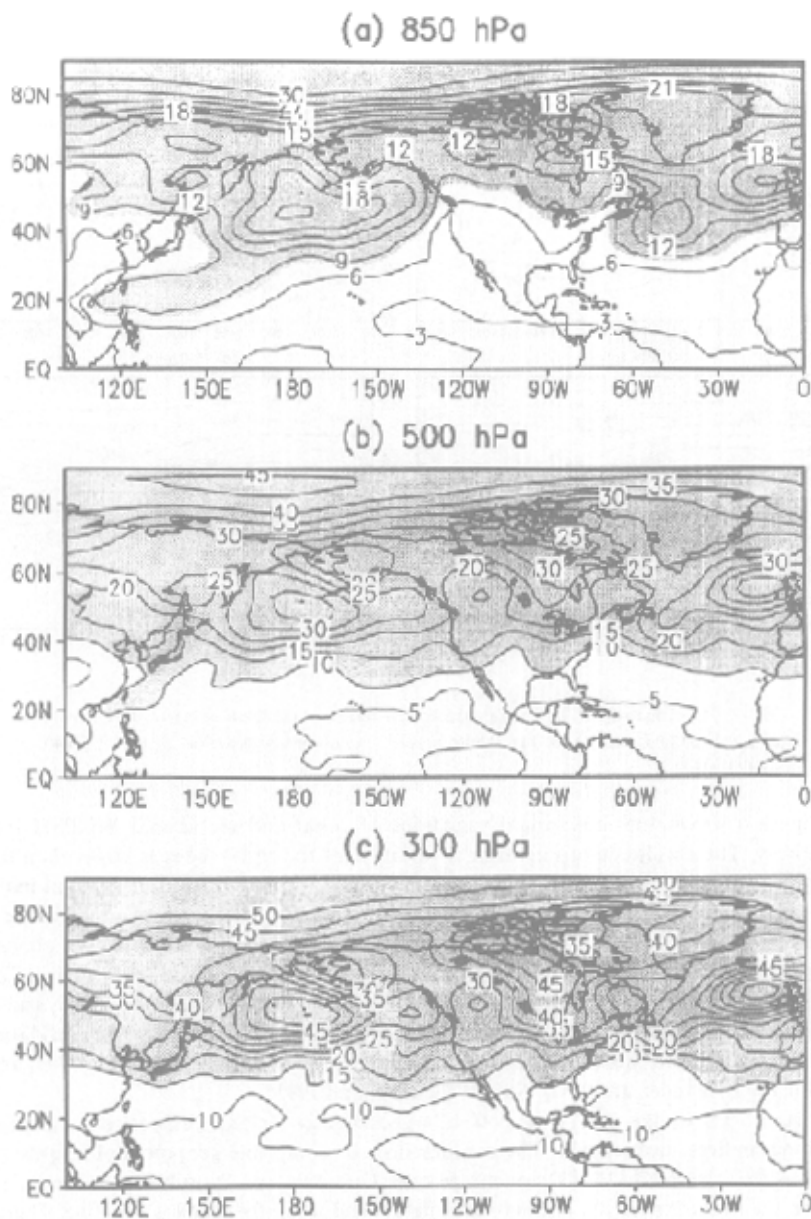


Fig. 1. The year-to-year standard deviation of JJA mean geopotential heights at (a) 850 hPa, (b), 500 hPa, and (c) 300 hPa, respectively. Units in gpm. Contour intervals are (a) 3, (b) 5, and (c) 5. The shading indicates the values greater than (a) 8, (b) 10, and (c) 15.

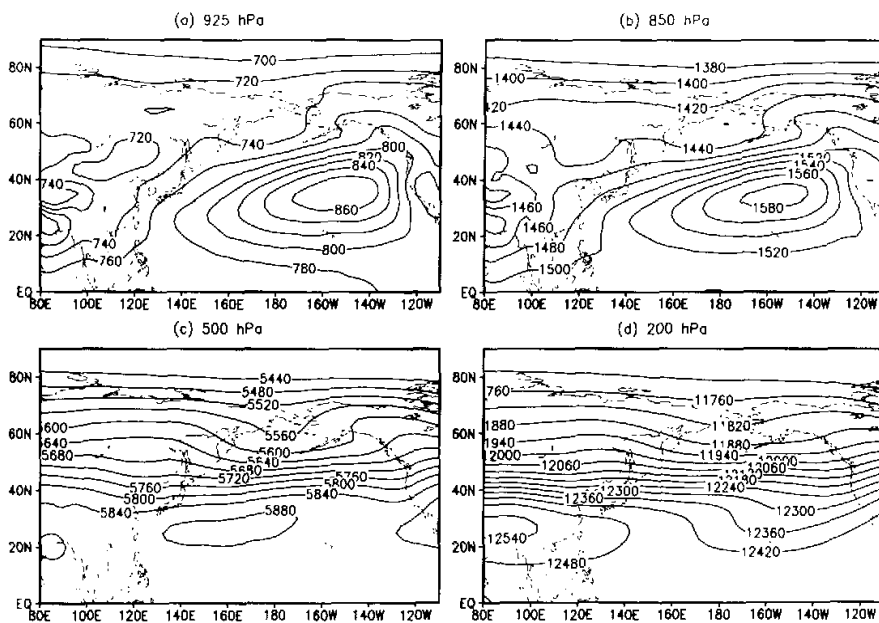


Fig. 2. The climatological JJA mean geopotential heights at the levels of (a) 925 hPa, (b) 850 hPa, (c) 500 hPa, and (d) 300 hPa. Units in gpm. Contour intervals are (a) 20, (b) 20, (c) 40, and (d) 60.

Figure 4 shows the interannual variations of zonal and meridional WNPSH indices, respectively. The amplitude of interannual variation of the zonal index is larger than that of the meridional index. The correlation coefficient between the zonal and meridional indices is only  $-0.03$  during the 20 years from 1979 to 1998, indicating that these two indices are independent on the interannual timescale. In order to perform a composite study, we choose ten extreme years among these twenty years, five for positive index and five for negative. For the zonal index, the years that are chosen for positive index are 1980, 1983, 1987, 1995, and 1998, and the years for negative index are 1981, 1984, 1985, 1986, and 1990. For the meridional index, the years that are chosen for positive index are 1979, 1985, 1989, 1994, and 1995, and the years for negative index are 1982, 1983, 1988, 1991, and 1993.

Figure 5 shows the composite 850-hPa geopotential heights for positive and negative meridional indices, respectively. The contour lines of composite geopotential heights at 850 hPa show that the WNPSH shifts poleward over East Asia and the subtropical western Pacific when the index is positive, and moves equatorward when the index is negative. Therefore, the meridional index defined in this study describes the meridional displacement of the WNPSH. The WNPSH also exhibits differences in the zonal direction. However, no further discussion will be given, since the zonal index is specially used to describe the zonal displacement of the WNPSH. Readers should refer to Lu (2001) and Lu and Dong (2001) for the composite 850-hPa geopotential heights for positive and negative zonal indices.

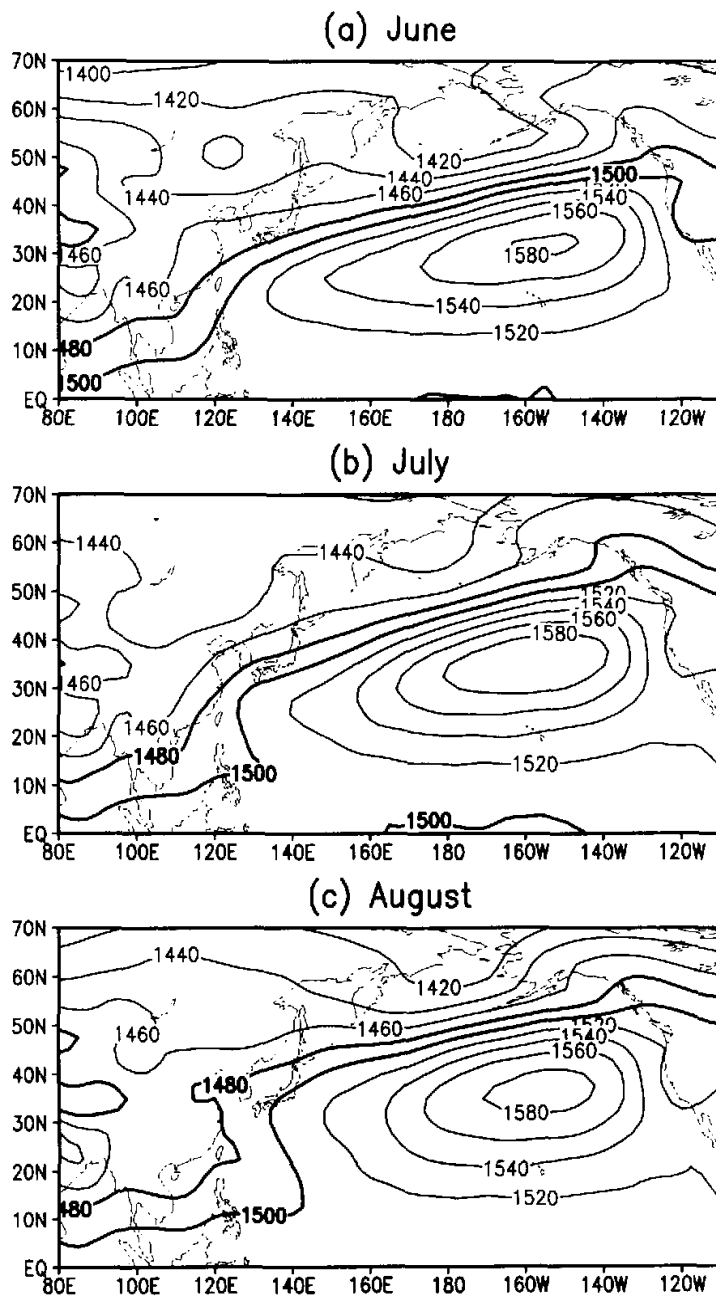


Fig. 3. The climatological monthly mean geopotential heights at 850 hPa. (a) June, (b) July, and (c) August. Units in gpm. Contour intervals are 20, and the contour lines of 1480 and 1500 are thicker.

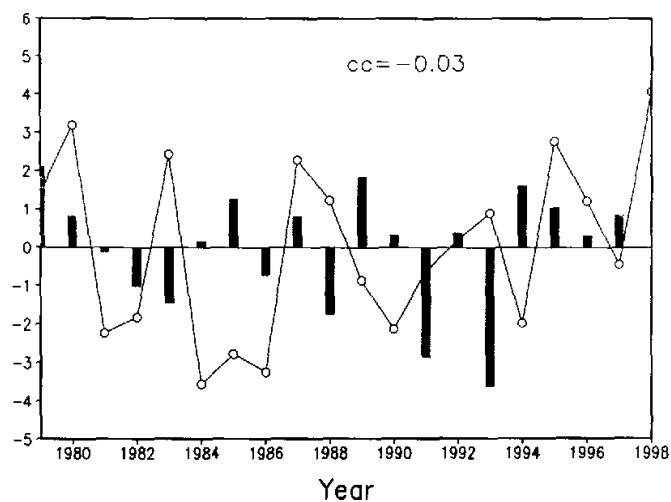


Fig. 4. The interannual variation of the western North Pacific subtropical high (WNPSH) indices (m) from 1979 to 1998. The curve with blank circles represents the zonal index and the bars indicate the meridional index. The correlation coefficient between two indices is also given.

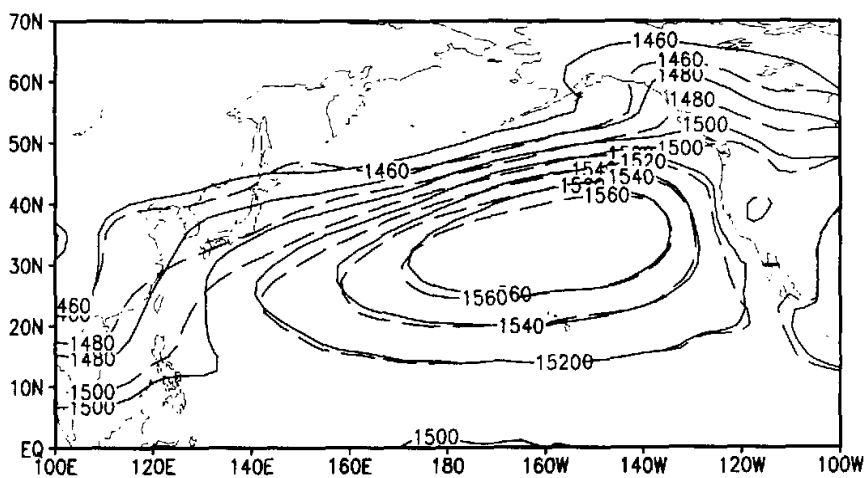


Fig. 5. Composite JJA-mean 850-hPa geopotential heights over North Pacific for positive (solid lines) and negative (dashed lines) meridional indices, respectively. Only the contour lines of 1460, 1480, 1500, 1520, 1540, and 1560 gpm are shown for the sake of clarity.

### 3. Composite study based on the interannual variations of WNPSH indices

Figure 6 shows the composite differences in geopotential heights between positive and negative meridional indices. At 850 hPa, significant positive anomalies occur over South Korea and southern Japan, and extend northeastward to the Aleutian Islands. This indicates that the poleward displacement of the WNPSH appears not only over East Asia but also over North Pacific (see also Fig. 5). Over northeastern Asia, there are significant negative anomalies.

The distribution of differences at 500 and 300 hPa is similar to that at 850 hPa. However, a careful comparison indicates that the positive anomalies over East Asia and North Pacific exhibit a slight poleward tilt with heights. The significant negative anomalies over northeastern Asia at 500 and 300 hPa suggests that there would be lower frequency of blocking occurrence, which is consistent with previous results. It has been widely believed that the meridional displacement of the WNPSH is related to the occurrence of blocking highs over northeastern Asia. When a blocking high occurs over northeastern Asia, the WNPSH usually exhibits a southward displacement (e.g., Chen 1957; Tang 1957; Ye and Huang 1996).

Figure 7 shows the composite differences in upper-level zonal velocity between positive and negative meridional indices. There are significant negative anomalies over the East Asian summer monsoon region (Fig. 7a). South and north of this region, i.e., over the tropical western Pacific and over northeastern Asia, there are positive anomalies. Corresponding to the positive meridional index, the upper-level westerly jet is weaker and shifted poleward (Fig. 7b).

These two indices are both related to the summer rainfall anomalies in East Asia and the western North Pacific. There is significantly more precipitation along the Meiyu front and significantly less precipitation in the tropical western Pacific in the summers of positive zonal index (Fig. 8a). This indicates that when the WNPSH extends westwards, rainfall is above normal along the Meiyu front and below normal in the tropical western Pacific. This result is consistent with those of Lu (2001) and Lu and Dong (2001). The meridional index is also related to the rainfall anomalies in East Asia and the western Pacific. The distribution of precipitation difference associated with the meridional index (Fig. 8b) is basically similar to that associated with the zonal index (Fig. 8a), but with opposite signs and lower statistical significance. The poleward displacement of the WNPSH corresponds to less rainfall along the Meiyu front and more rainfall in the tropical western North Pacific, which is in agreement with previous results.

### 4. Comparison of present WNPSH indices to the NCC indices

#### 4.1 Interannual variations of the NCC indices

The WNPSH indices announced by the National Climate Center in China (NCC) have been widely used in previous studies (e.g., Mu et al. 2001; Chen et al. 2001). The NCC defined five indices to describe the location and intensity of the WNPSH, namely, the WNPSH intensity index, north edge index, westward extension index, mean ridge index, and area index, according to monthly mean 500-hPa geopotential heights in the weather charts published by the China Meteorological Administration (Chen 1999).



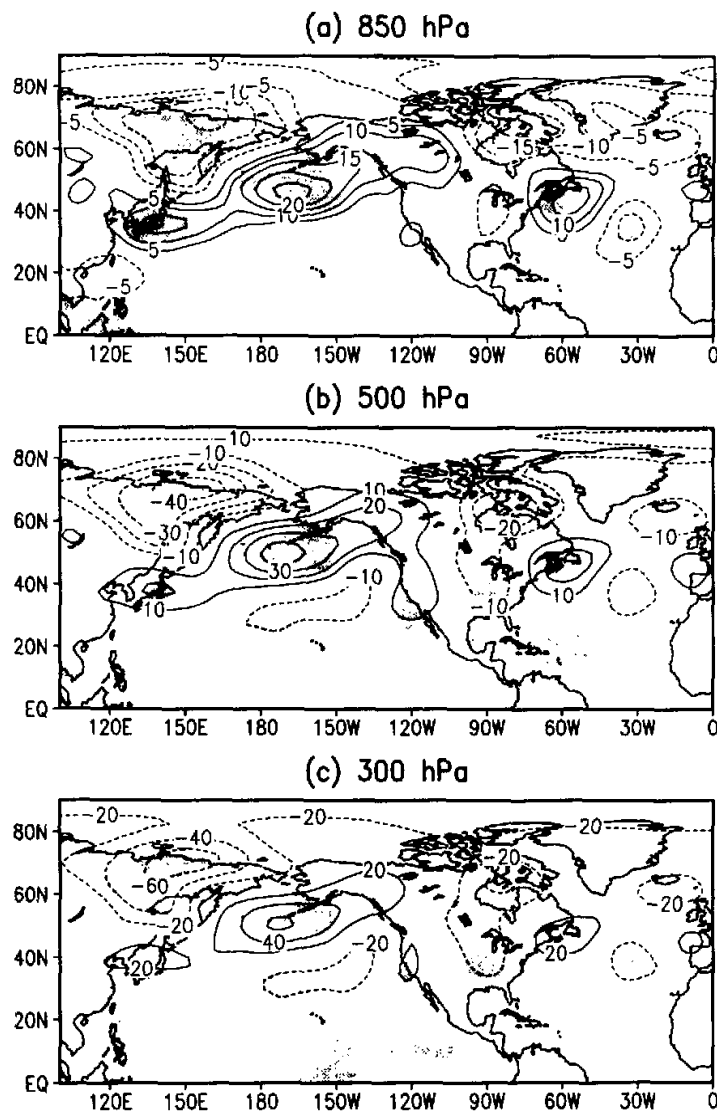


Fig. 6. Composite difference (positive minus negative meridional indices) in JJA-mean geopotential heights at (a) 850 hPa, (b) 500 hPa, and (c) 300 hPa. The positive index years are: 1979, 1985, 1989, 1994, and 1995, and negative index years are: 1982, 1983, 1988, 1991, and 1993. Units in gpm. Contour intervals are (a) 5, (b) 10 and (c) 10. Zero contours are not shown for the sake of clarity. The shading illustrates the significance of the differences at the 95% level determined from the two-sided Student's *t*-test.

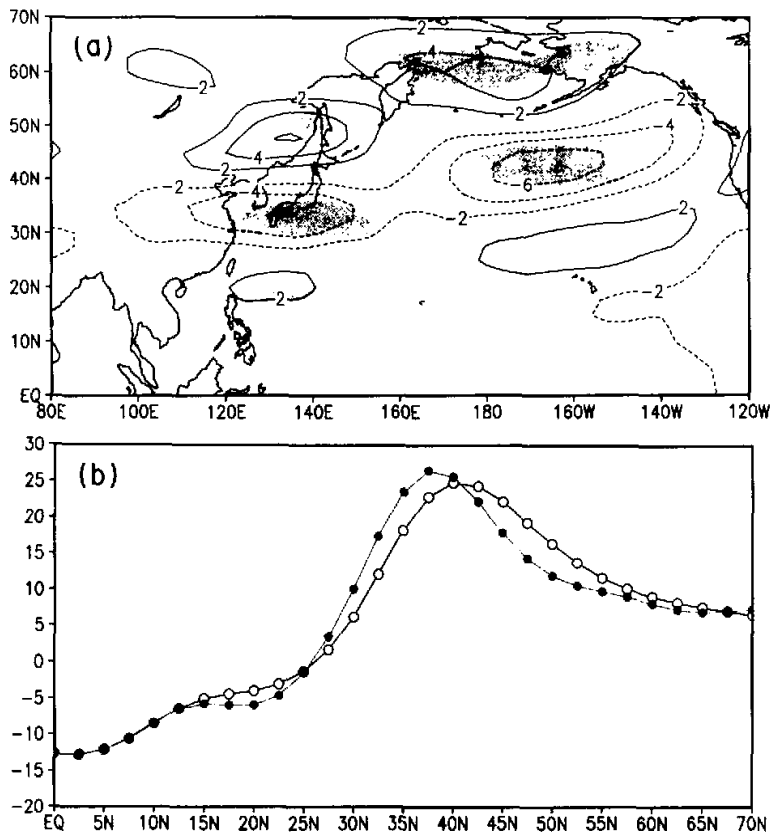


Fig. 7. Panel (a) shows the composite difference (positive minus negative meridional indices) in JJA-mean 200-hPa zonal wind. Units in  $\text{m s}^{-1}$ . Contour interval is 2, and zero contours are not shown for the sake of clarity. The shading illustrates the significance of the differences at the 95% level. Panel (b) is the composite 200-hPa zonal velocity ( $\text{m s}^{-1}$ ) averaged over 120°–150°E for positive and negative meridional indices, indicated by blank and black circles, respectively. The positive index years are: 1979, 1985, 1989, 1994, and 1995, and negative index years are: 1982, 1983, 1988, 1991, and 1993.

Among these five indices by the NCC, the westward extension index and north edge index are comparative to the presented zonal and meridional indices of this study, respectively. The westward extension index is defined as the value of the longitude where the 5880-gpm contour line reaches most westward in the scope of 90°E–180°, and the north edge index is defined as the averaged value of the latitudes of the northern 5880-gpm contour line over the nine longitudinal grids with an interval of five degrees between 110°–150°E. If for a weak subtropical high, the 5880-gpm contour line is only over a few grids among these nine longitudinal grids, then only the grids (but there must be more than one) are used to calculate the north edge index.

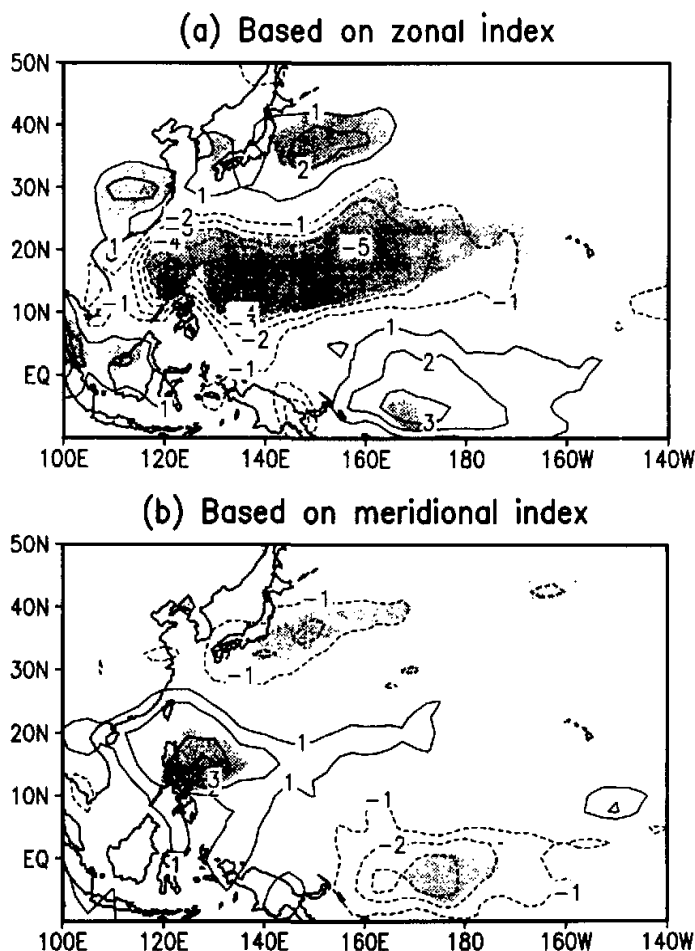


Fig. 8. Composite difference (positive minus negative indices) in JJA-mean precipitation, (a) for zonal index, and (b) for meridional index. Units in  $\text{mm d}^{-1}$ . Zero contours are not shown and the contour interval is 1. The shading illustrates the significance of the differences at the 95% level. For the zonal index, the positive index years are: 1980, 1983, 1987, 1995, and 1998, and the negative index years are: 1981, 1984, 1985, 1986, and 1990. For the meridional index, the positive index years are: 1979, 1985, 1989, 1994, and 1995, and negative index years are: 1982, 1983, 1988, 1991, and 1993.

There are many differences in definitions between the presented indices and the NCC indices. The NCC's definition is based on the geopotential heights at 500 hPa. However, as mentioned in the introduction, the WNPSH exhibits a much more intensified and stable feature at lower levels, and the shapes and locations of the WNPSH at lower levels are closely related to the lower-level jet, which transports a large amount of water vapour into East Asia and plays a dominant role in influencing the East Asian summer monsoon. Therefore, in this study, we

define the WNPSH indices by using the 850 hPa geopotential height anomalies.

Due to the differences in definitions between the presented indices and the NCC indices, a comparison of the presented indices to the NCC indices is necessary and useful in judging the reliability of the presented indices. Figure 9 shows the interannual variations of the NCC indices. It is natural to compare the zonal index of the present study to the westward extension index announced by the NCC, and to compare the meridional index of present study to the north edge index announced by the NCC. The correlation coefficient between the zonal index and westward extension index is  $-0.89$  at the 99.9% statistical significance level, and  $0.39$  between the meridional index and north edge index at the 90% significance level. Thus, there is a correlation between the presented indices and the NCC indices, and in particular, the correlation is considerably high between the zonal index and westward extension index. Figure 9 shows that the westward extension index and north edge index are also basically independent, with a small correlation coefficient of  $0.08$ .

#### 4.2 Circulation and precipitation anomalies associated with the NCC indices

In the following, we examine the circulation and precipitation anomalies associated with the NCC indices, and compare them with those associated with the presented indices. For this purpose, cases are selected according to the interannual variations of the NCC indices (Fig. 9), and a composite study is performed based on these cases. The years with an index greater or less than a half standard deviation are chosen. The years of westward extension (lower values of westward extension index) are 1980, 1983, 1987, 1993–1996, and 1998 (8 years), while those of eastward retreat (greater values of westward extension index) are 1982, 1984–1986, and 1989–1991 (7 years). On the other hand, the years of poleward displacement (greater

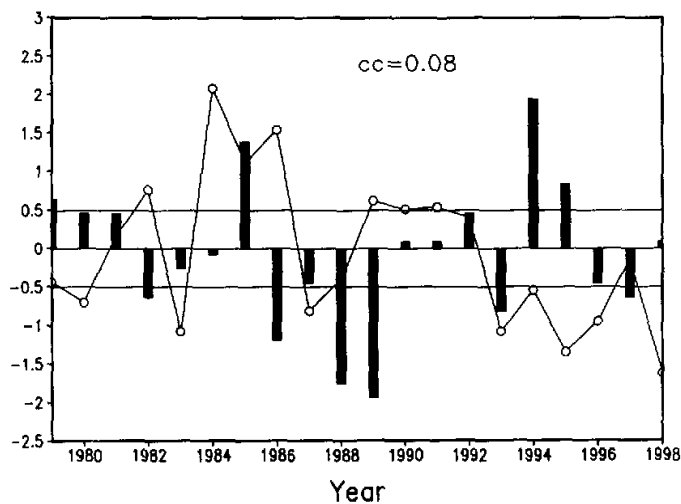


Fig. 9. The standardized interannual variation of the National Climate Center in China (NCC) WNPSH indices from 1979 to 1998. The curve with blank circles represents the westward extension index, and the bars indicate the north edge index. The correlation coefficient between the two indices is also given.

values of north edge index) are 1979, 1985, 1994, and 1995 (4 years), while those of southward displacement (lower values of north edge index) are 1982, 1986, 1988, 1989, 1993, and 1997 (6 years).

These chosen years also exhibit a similarity with those based on the zonal and meridional indices. For instance, all five years of greater zonal index are included in the years of westward extension, and all four years of poleward displacement are included in the years of greater meridional index. A major difference between our indices and the NCC indices appears in 1989, the year of greater meridional index by our definition but of southward displacement by the NCC definition.

The composite differences in geopotential heights based on the north edge index (Fig. 10) are extremely similar to those based on our meridional index (Fig. 6). This similarity exists not only over East Asia and the North Pacific, but also over the North Atlantic. At all levels, there are significant positive anomalies over South Korea and southern Japan and over the Aleutian Islands, and there are significant negative anomalies over northeastern Asia. In Fig. 10, however, the negative anomalies over northeastern Asia appear relatively southwards, in comparison with those in Fig. 6.

The composite differences in upper-level zonal velocity based on the north edge index (Fig. 11) are also similar to those based on our meridional index (Fig. 7). However, the positive anomaly over northeastern Asia is more significant and stronger in Fig. 11 than in Fig. 7. Accordingly, the upper-level westerly jet over East Asia is slightly stronger and shifted poleward in the years of northward displacement of the WNPSH (Fig. 11b).

There is more precipitation along the Meiyu front and significantly less precipitation in the Philippine Sea in the summers of westward extension of the WNPSH (Fig. 12a), while there is no significant precipitation anomaly related to the north edge index, except a small region in the South China Sea. This indicates that precipitation differences related to the NCC indices are less significant than those related to our WNPSH indices (Fig. 8). On the other hand, the precipitation differences related to the westward extension index are more significant than those related to the north edge index, in agreement with the results based on our zonal and meridional indices.

#### *4.3 Differences between the associations of the present indices and NCC indices*

In subsection 4.1, it was shown that the present indices and the NCC indices have a similar interannual variability. Thus, the years chosen for composite analysis based on the presented indices and the NCC indices are often identical, which results in the similar associations shown in subsection 4.2. However, it has been also found in subsection 4.2 that there are some differences in circulation and precipitation associated with the presented indices and with the NCC indices, especially in precipitation. In this subsection, these differences are examined according to the different years chosen for composite analysis based on the presented indices and the NCC indices.

The years that appear only as the NCC westward extension cases, but not as the positive present zonal index cases, are 1993, 1994, and 1996. The years that appear only as the NCC eastward retreat cases, but not as the negative present zonal index cases, are 1982, 1989, and 1991. There is only one year (year of 1981) chosen as the negative present zonal index case but not as the NCC eastward retreat case. Therefore, the differences between the NCC westward extension index cases and present zonal index cases can be represented by the difference between the composite of 1981, 1993, 1994, and 1996 and that of 1982, 1989, and 1991.

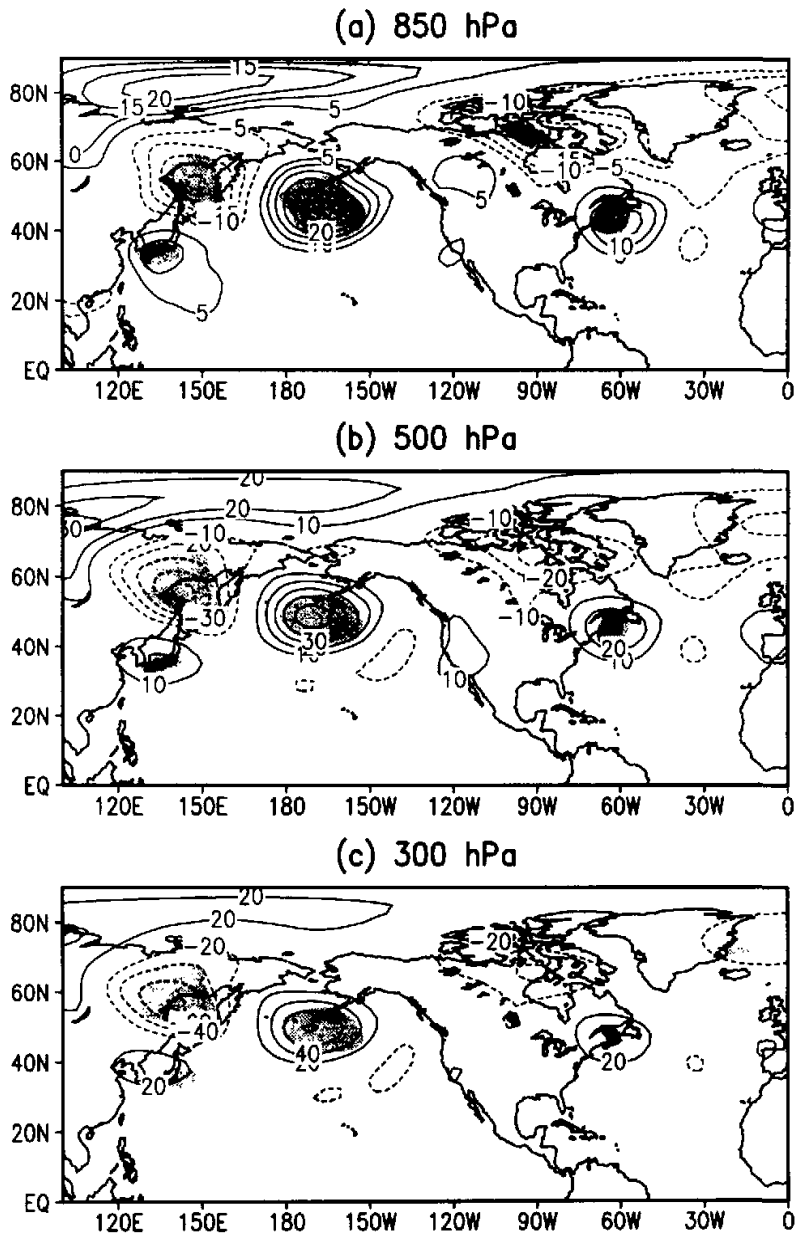


Fig. 10. Same as Fig. 6, but based on the NCC north edge index. Thus, the positive index years are: 1979, 1985, 1994, and 1995, and the negative index years are: 1982, 1986, 1988, 1989, 1993, and 1997.

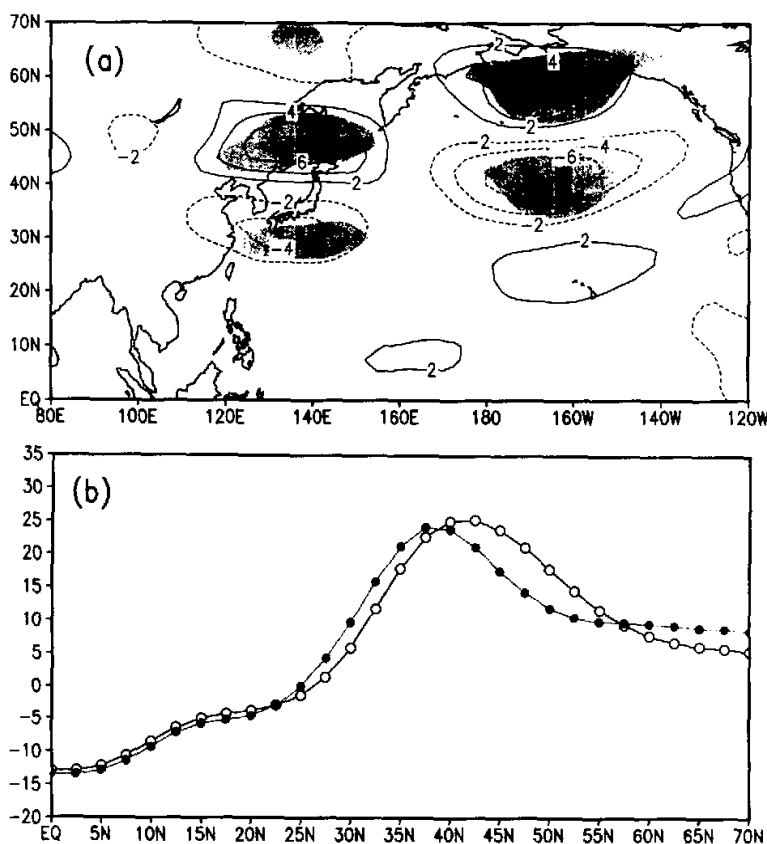


Fig. 11. Same as Fig. 7, but based on the NCC north edge index. Thus, the positive index years are: 1979, 1985, 1994, and 1995, and the negative index years are: 1982, 1986, 1988, 1989, 1993, and 1997.

Similarly, the differences between the NCC north edge index cases and the presented meridional index cases can be represented by the differences between the composite of 1983 and 1991 and that of 1986, 1989, and 1997.

The differences in circulation and precipitation caused by the different years between the NCC index cases and the presented index cases can be examined by a composite analysis according to the above-mentioned years. If these circulation and precipitation differences exhibit a distribution and intensity similar to the composite differences based on the presented indices or based on the NCC indices, these different years also contribute to the results shown in last subsection and in section 3. Under those circumstances, the NCC indices would be better than the presented indices in describing the associations of circulation and precipitation, which indicates that suitable years are not missed by the NCC indices while some unsuitable years are chosen by the present indices. Otherwise, the presented indices would be better than the NCC indices in describing the associations of circulation and precipitation.

Figure 13 shows the composite differences in geopotential heights between the NCC north edge index cases and the presented meridional index cases, i.e., the differences between the composite of 1983 and 1991 and that of 1986, 1989, and 1997. The composite differences exhibit a barotropic vertical structure. A comparison of this figure to Figs. 6 and 10 shows that there is not an agreement with respect to distribution. Over East Asia, northeastern Asia and the western North Pacific, the centers of anomalies in Fig. 13 are generally located on the zero contour lines in Figs. 6 and 10.

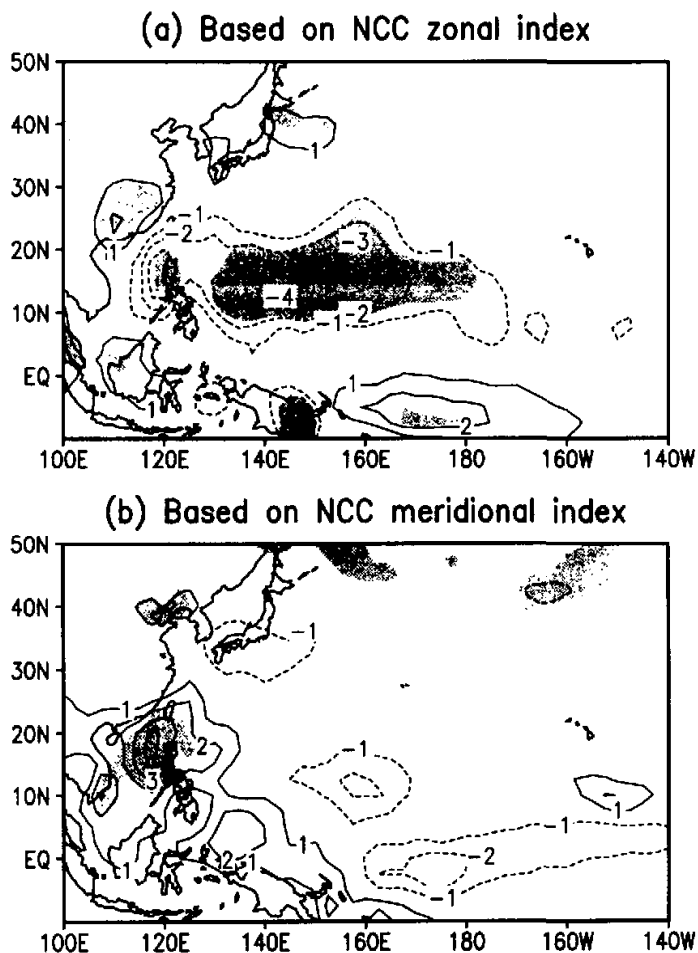


Fig. 12. Same as Fig. 8, but based on the NCC indices. (a) the differences between the westward extension years and eastward retreat years, and (b) the differences between the positive and negative north edge index years. The westward extension years are: 1980, 1983, 1987, 1993–1996, and 1998, and the eastward retreat years are: 1982, 1984–1986, and 1989–1991. The positive north edge index years are: 1979, 1985, 1994, and 1995, and the negative north edge index years are: 1982, 1986, 1988, 1989, 1993, and 1997.





Such an inconsistent distribution also exists in the composite differences of 200-hPa zonal velocity. The centers of anomalies in Fig. 14a are located on the zero contour lines in Figs. 7 and 11. The composite upper-level westerly jet over East Asia does not exhibit a noticeable difference in meridional location (Fig. 14b), which is a feature quite different with that in Figs. 7b and 11b.

Figure 15 shows the composite differences in JJA-mean precipitation between the NCC index cases and present index cases. It does not exhibit a distribution similar to that in Figs. 8 and 12. Along the Meiyu front, in particular, the precipitation differences exhibit a negative and positive anomaly based on zonal and meridional indices, respectively. This distribution is opposite to that in Figs. 8 and 12, and is in disagreement with the previous results.

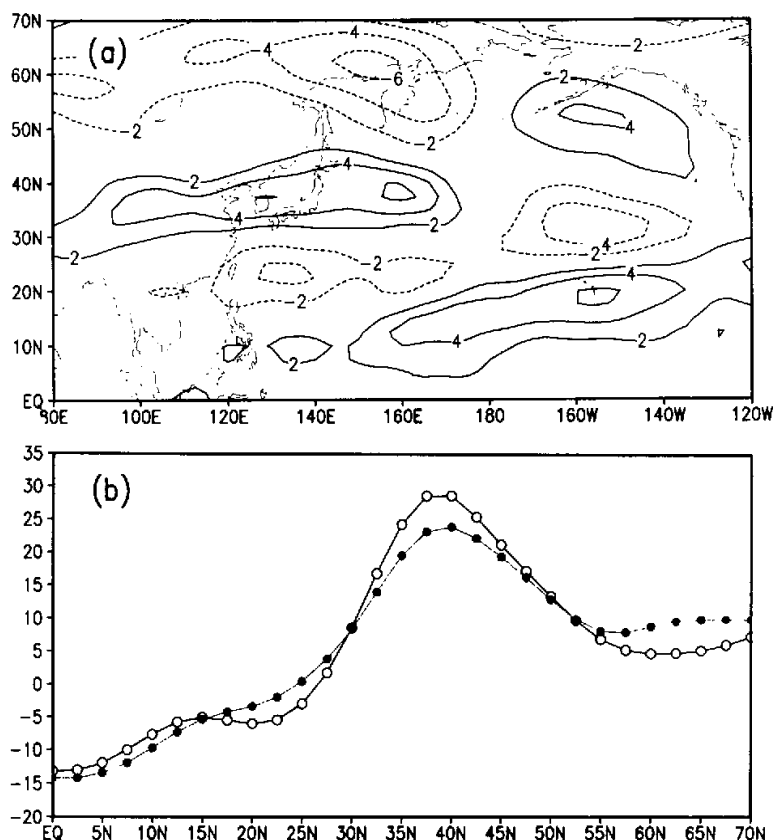


Fig. 14. Panel (a) gives the differences in JJA-mean 200-hPa zonal velocity between the composite of 1983 and 1991 and that of 1986, 1989, and 1997. Unit in  $\text{m s}^{-1}$ . Contour interval is 2, and zero contour are not shown. Panel (b) is the composite 200-hPa zonal wind ( $\text{m s}^{-1}$ ) averaged over 120°–150°E for the years of 1983 and 1991 and for the years of 1986, 1989, and 1997, indicated by blank and black circles, respectively. This figure shows the differences between the NCC north edge index cases and the presented meridional index cases.

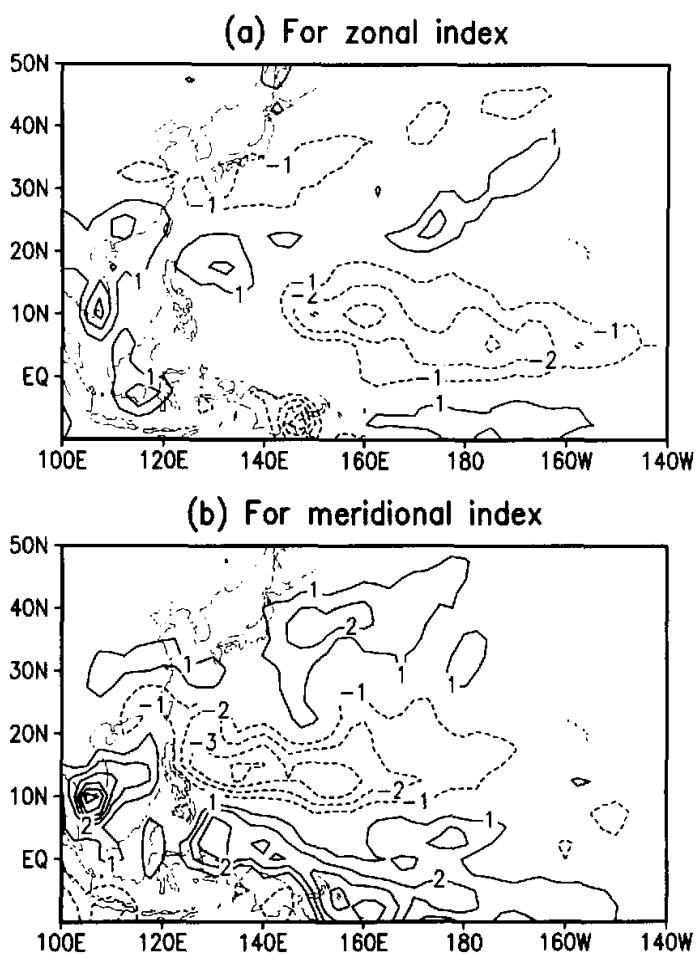


Fig. 15. The composite differences in JJA-mean precipitation (a) for zonal index, and (b) for meridional index. Units in  $\text{mm d}^{-1}$ . Zero contours are not shown and the contour interval is 1. For the zonal index, the differences are between the composite of 1981, 1993, 1994, and 1996 and that of 1982, 1989, and 1991. For meridional index, the differences are between the composite of 1983 and 1991 and that of 1986, 1989, and 1997. This figure shows the differences between the NCC index cases and the presented index cases.

Therefore, the differences in circulation and precipitation caused by the different years between the NCC and the presented index cases exhibit a distribution unlike the composite differences based on the present indices or based on the NCC indices. In particular, precipitation differences show opposite signs along the Meiyu front. Based on these results, we conclude that the present indices are better than the NCC indices in describing the associations of circulation and precipitation.

### 5. Composite study on seasonal evolution

In this section, we examine the seasonal evolution of the WNPSH by using zonal and meridional indices. We define the zonal and meridional indices by averaging pentad-mean geopotential heights at 850 hPa, rather than JJA-mean anomalies, over the specified regions. The specified average regions are identical to those in section 3, namely, (110°–150°E, 10°–30°N) for the zonal index and (120°–150°E, 30°–40°N) for the meridional index.

Figure 16 shows the climatological seasonal evolution of the zonal and meridional indices, respectively. The zonal index does not change much during the first half of the summer, but decreases swiftly in middle July and increases at the end of summer. This variation of zonal index indicates that climatologically, the WNPSH retreats eastwards swiftly in middle July, and extends westwards at the end of summer.

The meridional index exhibits a greater subseasonal oscillation than the zonal index. Roughly the meridional index increases during the whole summer, and does so remarkably in middle July. This variation of meridional index is consistent with the fact that the WNPSH advances polewards during summer. The remarkable poleward shift of the WNPSH in middle July corresponds to the withdrawal of the Meiyu.

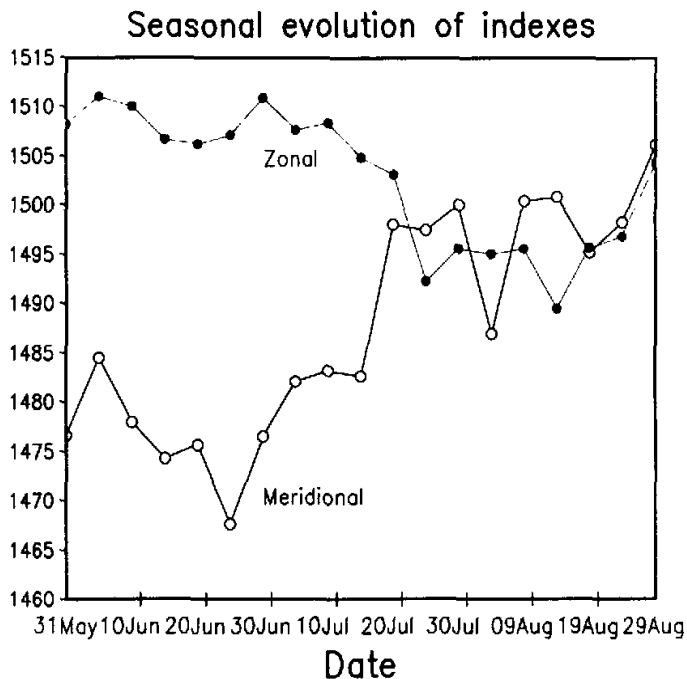


Fig. 16. Climatological seasonal evolution of zonal (black circles) and meridional indices (blank circles) in summer. Each circle indicates the climatological mean value of index at a particular pentad. Units in gpm.

The above-mentioned features of the seasonal evolution of the indices or the WNPSH are considerably different between the summers of positive and negative indices. The years of positive and negative indices are identical to those mentioned in section 3. Figure 17 shows the composite seasonal evolution of the zonal index for the summers of positive and negative zonal indices, respectively. During the summers of positive index, the zonal index does not exhibit a great variation. However, during the summers of negative index, the zonal index shows a remarkable subseasonal oscillation and a significant decrease around July 20. This result is in good agreement with the seasonal evolution of the WNPSH shown by Lu (2001).

There is also a clear difference in the seasonal evolution of the meridional index between the summers of positive and negative meridional indices (Fig. 18), although the difference is not as remarkable as that in Fig. 17. Basically, the meridional index increases during summer and is generally larger during the summers of positive index than the summers of negative index. In addition, the meridional index exhibits a more remarkable increase in middle July during the summers of positive index.

## 6. Summary

In this study, we define two simple yet objective indices that describe the year-to-year zonal and meridional displacements of the WNPSH by averaging JJA-mean 850-hPa

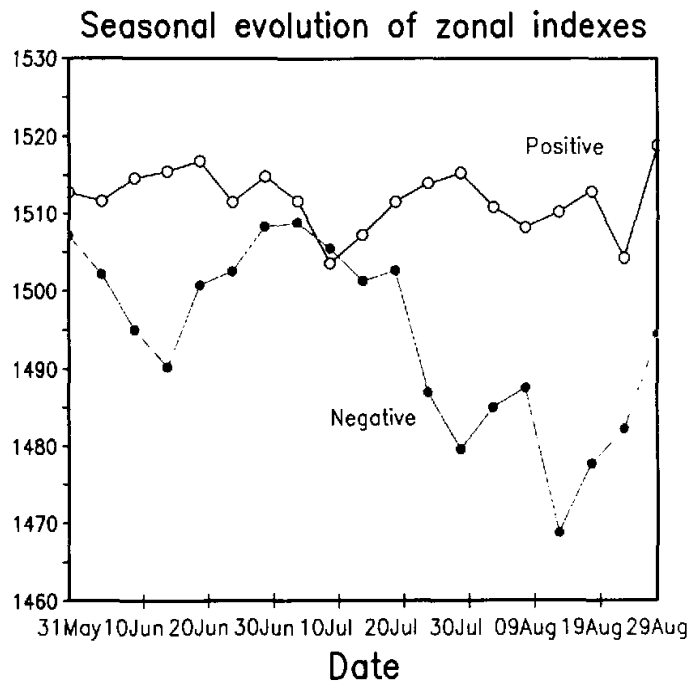


Fig. 17. Composite seasonal evolution of the zonal index for the five greatest positive (blank circles) and negative (black circles) zonal indices. Each circle indicates the composite mean value of the index at a particular pentad. Units in gpm.

### Seasonal evolution of meridional indexes

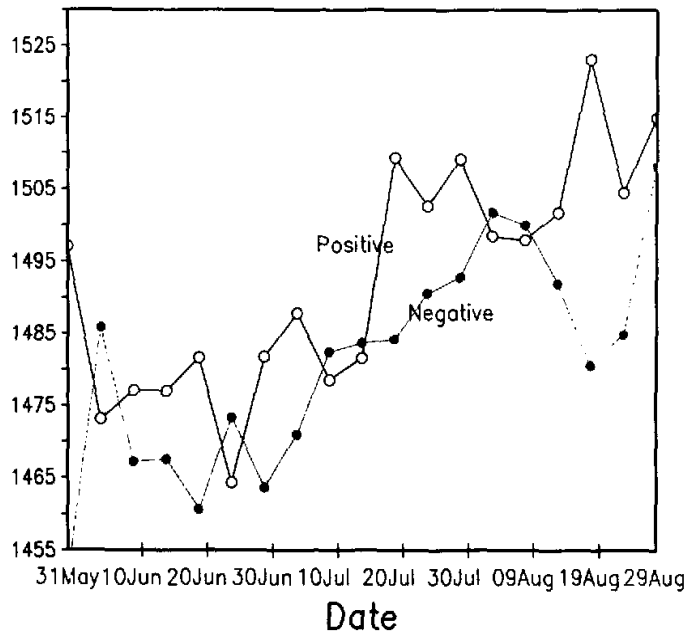


Fig. 18. Composite seasonal evolution of the meridional index for the five greatest positive (blank circles) and negative (black circles) meridional indices. Each circle indicates the composite mean value of the index at a particular pentad. Units in gpm.

geopotential height anomalies over specified regions. For the WNPSH zonal index, the specified region is ( $110^{\circ}$ – $150^{\circ}$ E,  $10^{\circ}$ – $30^{\circ}$ N), the west edge of the WNPSH. For the meridional index, the specified region is ( $120^{\circ}$ – $150^{\circ}$ E,  $30^{\circ}$ – $40^{\circ}$ N), the northwest edge of the WNPSH. The interannual variations of zonal and meridional indices are independent according to correlation analysis.

A composite study based on the interannual variations of the meridional index is performed. It is found that the analysis based on the meridional index can reproduce well the features of circulation and precipitation related to the meridional displacement of the WNPSH. These features were pointed out by previous case studies (e.g., Ye and Huang 1996) and experiences, which showed that the poleward (equatorward) displacement of the WNPSH is associated with the poleward (equatorward) displacement of the upper-level westerly jet over East Asia, less frequency of blocking occurrence over northeastern Asia, and less rainfall along the Meiyu front. A composite study based on the interannual variations of the zonal index is also performed. It is found that the westward extension (eastward retreat) of the WNPSH is associated with significantly heavier (lighter) rainfall along the Meiyu front and less (more) precipitation in the tropical western North Pacific.

In order to deepen the understanding of our WNPSH indices, we perform a comparison to the existing WNPSH indices announced by the National Climate Center (NCC) in China, which have been widely and conventionally used in China. Despite slight differences, the interannual variations of the presented indices bear a similarity to those of the NCC indices.

In addition, the circulation and precipitation associated with the presented indices exhibit similar overall features to those associated with the NCC indices. However, an analysis on the differences between the associations of the presented indices and the NCC indices shows that the present indices are better than the NCC indices. Furthermore, the results based on both our indices and the NCC indices all show that the precipitation differences related to the zonal index (or westward extension index) are more significant than those related to the meridional index (or the north edge index).

The zonal and meridional indices can also be used to depict the seasonal evolution of the WNPSH in summer. Under the circumstances, pentad-mean geopotential heights, rather than JJA-mean height anomalies, are averaged. The indices can depict well the eastward and poleward shifts of the WNPSH during summer. Analysis of the indices indicates that climatologically, the WNPSH swiftly advances poleward and retreats eastward in middle July. However, the zonal index does not show a great seasonal change during the summers of positive zonal index, indicating that the WNPSH does not exhibit a great seasonal evolution in the zonal direction during the summers when the WNPSH extends westwards in average. In addition, analysis of the meridional index shows that the WNPSH shows a more remarkable poleward shift in middle July for the summers when the WNPSH exhibits a poleward displacement in average.

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## 夏季西北太平洋副热带高压指数

陆日宇

摘 要

利用在特定区域上平均的夏季(6、7、8月)平均850 hPa位势高度异常,我们定义了两种指数,分别用来描述夏季北太平洋副热带高压在东西方向和南北方向上的偏移。对于东西向指数,平均的区域为副高的西侧(110°–150°E, 10°–30°N);对于南北向指数,平均的区域为副高的西北侧(120°–150°E, 30°–40°N)。发现这两种指数是相互独立的。基于南北向指数的合成分析结果与以往的研究结果吻合得相当好。



在年际时间尺度上,将这两种指数与国家气候中心公布的副高指数进行了比较,发现尽管有一些微弱的差别,本文定义的指数与国家气候中心的副高指数大致具有相似的年际变化,因而本文的指数与国家气候中心的指数也对应着相似的环流和降水型。进而,对本文的指数与国家气候中心的指数对应的环流(降水)型之间的不同进行了分析,表明本文的指数比国家气候中心的指数能够更好地描述对应的环流和降水型。一个重要的结果是,不论根据本文指数,还是根据国家气候中心指数,东西向指数(或西伸指数)都比南北向指数(或北界指数)对应着更显著的降水异常,特别是在东亚地区和菲律宾海。

这两种指数还可以用来描述副高在夏季里的季节推进,即,北移和东退。副高在7月中旬迅速北移和东退,发现在副高平均处于偏北或偏东的夏季里,北移或东退的幅度明显偏强。这两种指数和本文的结果可用于对大气环流模式的评估。

**关键词:** 副高指数, 年际变化, 季节演变