Intraseasonal variation of the East Asian summer monsoon in La Niña years

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ABSTRACT
Based on the composite result of six major La Niña events during 1979–2012, the authors reveal the intraseasonal variation of the East Asian summer monsoon (EASM) and summer rainfall in East Asia in La Niña years. Due to a higher SST over the western Pacific warm pool in the proceeding winter and spring, warm pool convection in summer is enhanced, leading to a cyclonic anomaly in the subtropical western Pacific. As a result, the western Pacific subtropical high is located more northeastward, and the seasonal march in East Asia is thus accelerated. This anomalous pattern tends to change with the seasonal march, with a maximum anomaly in July. Besides, there is less Mei-yu rainfall in the Yangtze River basin, with an earlier start and termination. The rainfall distribution in East Asia during La Niña years is characterized by a zonal pattern of less rainfall in eastern China and more rainfall over the oceanic region of the western Pacific. By comparison, a meridional pattern is found during El Niño years, with less rainfall in the tropics and more rainfall in the subtropics and midlatitudes. Therefore, the influence of La Niña on the EASM cannot be simply attributed to an anti-symmetric influence of El Niño.

1. Introduction

ENSO consists of two basic modes: El Niño and La Niña. Although the SST anomaly in the tropical Pacific in El Niño years is almost opposite to that in La Niña years, the influence of the former on the East Asian summer monsoon (EASM) is much stronger than that of the latter. During the decaying summer after the peak of an El Niño event, the western Pacific subtropical high (WPSH) tends to extend westward with stronger intensity, resulting in more rainfall in the Yangtze River basin and less rainfall in southern and northern China (Fu and Teng 1988). In comparison with the extensive number of studies on the influence of El Niño, less attention has been paid to the influence of La Niña due to a relatively weak response of the EASM and influences of some other factors (Chen, Zhang, and Xu 2001; Xue 2008). The influence of La Niña on the EASM is usually ascribed to an anti-symmetric aspect of El Niño (Tao and Zhang 1998).

It is worth noting that the EASM exhibits a distinct intraseasonal variation. Specifically, the EASM circulation shows a totally different state between early and late summer. After late July, the WPSH retreats eastward to the south of Japan, leading to a termination of the Mei-yu season in the Yangtze River basin and Japan (Su and Xue 2010). The intraseasonal variation can further influence the response of the EASM to the ENSO cycle. For instance, Kawatani, Ninomiya, and Tokioka (2008) found that the interannual variability of the WPSH is smallest in June and largest in August. Xue and Liu (2008) also noted that the influence of El Niño on the EASM tends to change with the seasonal march, with the weakest influence in June and strongest influence in August. While the influence of El Niño on the intraseasonal variation of the EASM is generally clear, the influence of La Niña is not yet well understood. For this reason, we conduct a composite analysis to reveal the
intraseasonal features of the EASM and summer rainfall in East Asia in La Niña years based on pentad mean data, in order to further promote the forecast skill of the EASM.

2. Data and methods

Several datasets are used in this study. The geopotential height and wind data, with a resolution of 2.5° × 2.5°, are from the second version of the daily NCEP–NCAR reanalysis (Kanamitsu et al. 2002). The daily OLR, with the same resolution is derived from NOAA satellite observations (Liebmann and Smith 1996). The daily data are pretreated to the pentad mean to facilitate the analysis. The pentad mean precipitation data, with a resolution of 2.5° × 2.5°, are from the combined datasets of the GPCP (Huffman et al. 1997). The monthly SST data are taken from the Hadley Climate Center, with a resolution of 1.0° × 1.0° (Rayner et al. 2003). For convenience, all datasets are taken from 1979 to 2012.

First, El Niño and La Niña events are identified based on the three-month running mean Niño3.4 index, which refers to the regional averaged SST anomalies over (5°S–5°N, 170°–120°W) (Trenberth 1997). Considering the weak influence of a weak event, we only take the major events with a peak Niño3.4 index value over one standard deviation (i.e., 1 °C) for composite analysis. As shown in Figure 1, there are six major La Niña events during 1979–2012: 1984–85, 1988–89, 1998–99, 1999–2000, 2007–08, and 2010–11. Besides, there are eight major El Niño events: 1982–83, 1986–88, 1991–92, 1994–95, 1997–98, 2002–03, 2006–07 and 2009–10. Because the phase evolution of the El Niño event during 1986–88 is different from the other events, this event is excluded. The composite results based on the other seven El Niño events are used to compare with those during La Niña years. The composite results in the second year for the selected events are used to analyze the intraseasonal features of the EASM during La Niña years, with a focus on the WPSH and rainfall. The Student’s t-test is used to test the significance of the results.

The WPSH at 500 hPa is used to describe the EASM circulation during La Niña years. This high can be well represented by the following indices, as proposed by Zhao (1999): (1) the ridge-line index, which is used to represent the meridional movement, and is the latitude of the ridge-line averaged over 110°–150°E; (2) the west-point index, which is used to represent the zonal movement, and is the westernmost longitude along the 5,880-gpm contour between 90°E and 180°E; and (3) the area index, which is used to represent intensity, and is the area within the 5,880-gpm contour over the region (5°–45°N, 90°–180°E).

Figure 1. The normalized three-month running mean Niño3.4 index during 1979–2012, in which the grey region indicates the major El Niño and La Niña events.

Figure 2. Pentad mean western Pacific subtropical high indices during summer: (a) ridge-line index (units: degrees latitude); (b) west-point index (units: degrees longitude); (c) area index (dimensionless). The solid and dashed lines represent the La Niña years and climatological mean, respectively.
3. Results

Figure 2 shows the pentad mean WPSH indices during summer. Compared with the climatology, the ridge-line in La Niña years is located more northward by about 2° of latitude (Figure 2(a)). By the beginning of August, the difference reaches a maximum of 7° of latitude, and it tends to decrease afterwards. The west-point retreats eastward with a pronounced east–west oscillation in La Niña summer, especially in July (Figure 2(b)). Corresponding to the start and termination of the Mei-yu season, the first westward extension and major eastward retreat occurs on 5 June and 10 July, respectively, which is much earlier than the climatology (Su and Xue 2010). This indicates that the seasonal march in East Asia is accelerated in La Niña summer. As for the area index, it is near to the climatology at the beginning of June, and decreases rapidly after 20 June (Figure 2(c)). The area in July is only half of the climatology. After mid-August, the WPSH tends to intensify again. In summary, the WPSH tends to be located more northeastward, with weaker intensity, in La Niña summer. The influence of La Niña is closely related to the seasonal march, with the largest difference in July and less difference in June and August. Compared with the largest influence in August in El Niño years, the influence of La Niña on the

Figure 3. (a) Pentad mean rainfall in summer averaged over 110°–150°E, in which the contours and shading represent the climatological mean and La Niña years, respectively. (b) Rainfall anomalies in La Niña years, in which the regions with black and white dots indicate the rainfall anomalies over the 90% and 95% confidence level, respectively (units: mm d⁻¹).

Figure 4. Rainfall anomaly in La Niña years (units: mm d⁻¹) and the 500-hPa western Pacific subtropical high (WPSH) (units: gpm): (a) June; (b) July; (c) August; (d) June–July–August mean. Regions over the 95% confidence level are shaded, and the black and red contours represent the WPSH in La Niña years and the climatological mean, respectively.
WPSh tends to lead by one month (Xue and Liu 2008; Zhao et al. 2016).

Figure 3(a) shows the latitude–time cross section of summer rainfall averaged over 110°–150°E. There are two major rain belts in the tropics and subtropics. Both belts are located more northward due to a northward position of the WPSh in La Niña years (Figure 2(a)). The tropical belt tends to migrate northward from 8°N to 25°N, with significant oscillation. After 20 July, rainfall increases dramatically, especially in La Niña years. The subtropical belt moves northward from 20°N to 40°N. Compared with the climatology, the subtropical rainfall in La Niña years tends to decrease, and regions with rainfall of 6 mm d⁻¹ are confined to 27°–32°N. Besides, rainfall of 6 mm d⁻¹ disappears after 10 July. Corresponding to the earlier extension and retreat of the WPSh in Figure 2(b), the Mei-yu season tends to start and terminate earlier in La Niña years.

The influence of La Niña can be seen more clearly in Figure 3(b). Except in mid-August, there is more rainfall in the tropics during La Niña summer. In southern China, rainfall tends to decrease in June but increase afterwards, due to the northward movement of the tropical rain belt. On the other hand, there is more rainfall in June and less rainfall in July and August over the Yangtze River basin. Therefore, the rainfall anomaly exhibits a regional characteristic and is closely related to the summer seasonal process.

Figure 4 shows the monthly and seasonal mean rainfall anomalies in La Niña years, together with the corresponding WPSh. In June (Figure 4(a)), the WPSh is located northeastward slightly. There is more rainfall from the Yangtze River basin to Japan, signaling an earlier start of Mei-yu. Besides, more rainfall near the Philippines indicates enhanced convective activity in the warm pool region. In July (Figure 4(b)), the WPSh retreats eastward to the east of 150°E and reaches a maximum difference from the climatology with sharply reduced intensity. There is more rainfall over the oceanic regions east of Taiwan and parts of northeastern Asia and less rainfall in eastern China and Japan. In August (Figure 4(c)), the WPSh maintains a northeastward position with less difference compared with July. There is more rainfall in southern China and less rainfall in northern China. In general, the anomalous pattern of the WPSh and summer rainfall in East Asia is related with the preceding SST anomaly in La Niña years (Lu 2002; Nitta 1987). As shown in Figure 5(a), the SST in the tropical western Pacific is enhanced, while the SST in the tropical eastern Pacific and Indian Ocean is reduced, during La Niña winter and spring. Forced by the local SST anomaly, the warm pool convection in summer is clearly enhanced (Figure 5(d)). The enhanced convection further intensifies the tropical–extratropical relationship over the tropical western Pacific and East Asia by exciting a Rossby wave-train propagating northeastward (Lu, Hong, and Li 2016). There appears to be a clear Pacific–Japan pattern along the East Asian coast, with a cyclonic anomaly to the northwest of the warm pool.
and an anticyclonic anomaly near Japan. As a result, the WPSH tends to move northeastward. In particular, the northerly anomaly in eastern China is unfavorable for tropical moisture transportation, resulting in less rainfall there (Figures 4(d) and 5(d)).

By comparison, the SST anomaly in El Niño years is almost opposite to that in La Niña years, with a higher SST in the tropical eastern Pacific and Indian Ocean and a lower SST to the east of Philippines (Figure 6(a)). The SST anomaly, especially the higher SST in the Indian Ocean, can act as a capacitor, prolonging the effect of El Niño on the EASM (Xie et al. 2009; Yang et al. 2007). By exciting a baroclinic Kelvin wave in the Indian Ocean, warm pool convection is largely suppressed with the eastward propagation of the Kelvin wave, resulting in an anomalous anticyclone in the subtropical western Pacific (Figure 6(b)). The WPSH tends to be enhanced and extends westward. In this case, the moisture transportation from the tropics to the high latitudes is also intensified, leading to more rainfall to the north of the WPSH and less rainfall in the tropical western Pacific (Figure 6(c)).

Summarizing the above results, we can conclude that some anti-symmetric aspects exist between La Niña and El Niño, such as warm pool convection and the associated WPSH. On the other hand, there are some significant differences. Although the SST anomaly in La Niña years is almost opposite to that in El Niño years, warm pool convection in La Niña years is driven by the local SST anomaly, whereas it is remotely forced by the SST anomaly in the Indian Ocean in El Niño years. Besides, the intraseasonal variation of the WPSH evolves in a different way, with the largest discrepancy in July of La Niña years but in August of El Niño years (Xue and Liu 2008; Zhao et al. 2016). Note also that the rainfall anomaly over East Asia in La Niña years exhibits a zonal pattern of more rainfall over the oceanic region of the western Pacific and less rainfall in eastern China (Figure 4(d)). In El Niño years, however, a meridional rainfall pattern is found, with more rainfall in the subtropics and midlatitudes and less rainfall in the tropics (Figure 6(c)). Therefore, the EASM anomaly in La Niña years is not a simple mirror image of El Niño years, as previously thought.

4. Summary

Based on composite results of six major La Niña events during 1979–2012, the present study reveals the intraseasonal features of the EASM and summer rainfall over East Asia in La Niña years. It is shown that the influence of La Niña on the WPSH is related to the seasonal march, with the strongest influence in July, leading to an accelerated seasonal march in East Asia. The WPSH tends to be located more northeastward, and this anomalous pattern is unfavorable for moisture transportation from the tropics to high latitudes. As a result, there is less rainfall in eastern China and more rainfall in the oceanic regions of the western Pacific.

Comparison shows that there are some anti-symmetric aspects between La Niña and El Niño. In La Niña (El Niño) years, for instance, warm pool convection is enhanced (suppressed), resulting in a weaker (stronger) WPSH and less (more) rainfall in eastern China. Yet, some asymmetric features are evident. Instead of the strongest influence on the EASM being in August, as it is with El Niño (Xue and Liu 2008), the strongest response to a La Niña signal is found in July. The rainfall anomaly over East Asia in La Niña years exhibits a zonal pattern, whereas a more meridional distribution is found in El Niño years. Hence, the influence of La Niña on the EASM is not simply anti-symmetric to that of El Niño.
It should be emphasized that a La Niña signal is useful in Mei-yu prediction. In La Niña summer, the seasonal march in East Asia is accelerated, with a more rapid eastern retreat of the WPSH. In this case, there is less Mei-yu rainfall in the Yangtze River basin, with an earlier start and termination. The influence of La Niña on Mei-yu is also different from that of El Niño. As indicated by Xue and Liu (2008), a moderate El Niño signal is of little use in Mei-yu prediction, as the strongest response to El Niño appears in August over East Asia. In this respect, the influence of La Niña is not anti-symmetric to that of El Niño.

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References

Chen, G. Y., P. Q. Zhang, and L. Xu. 2001. “Preliminary Studies on the Cause of Southern Flood and Northern Drought during the Summer of 1999 in China.” Climatic and Environmental Research (in Chinese) 6: 312–320.

Chu, J.-E., and S. N. Hameed, and K.-J. Ha, 2012. “Nonlinear, Intraseasonal Phases of the East Asian Summer Monsoon: Extraction and Analysis Using Self-Organizing Maps.” Journal of Climate 25: 6975–6988.

Fu, C. B., and X. L. Teng, 1988. “Relationship between Summer Climate in China and El Niño/Southern Oscillation Phenomenon.” Chinese Journal of Atmospheric Sciences (in Chinese) 12 (Special Issue): 133–141.

Huffman, G. J., R. F. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A. McNab, B. Rudolf, and U. Schneider. 1997. “The Global Precipitation Climatology Project (GPCP) Combined Precipitation Dataset.” Bulletin of the American Meteorological Society 78: 5–20.

Kanamitsu, M., W. Ebisuzaki, J. Woollen, S.-K. Yang, J. J. Hnilo, M. Fiorino, and G. L. Potter. 2002. “NCEP-DOE AMIP-II Reanalysis (R-2).” Bulletin of the American Meteorological Society 83: 1631–1643.

Kawatani, Y., K. Ninomiya, and T. Tokioka. 2008. “The North Pacific Subtropical High Characterized Separately for June, July, and August: Zonal Displacement Associated with Submonthly Variability.” Journal of the Meteorological Society of Japan 86: 505–530.

Liebmann, B., and C. A. Smith. 1996. “Description of a Complete (Interpolated) Outgoing Longwave Radiation Dataset.” Bulletin of the American Meteorological Society 77: 1275–1277.

Lu, R. Y. 2002. “Precursory SST Anomalies Associated with the Convection over the Western Pacific Warm Pool.” Chinese Science Bulletin 47: 696–699.

Lu, R. Y., X. W. Hong, and X. Y. Li. 2016. “Asymmetric Association of Rainfall and Atmospheric Circulation over East Asia with Anomalous Rainfall in the Tropical Western North Pacific in Summer.” Atmospheric and Oceanic Science Letters 9: 185–190.

Nitta, T. 1987. “Convective Activities in the Tropical Western Pacific and Their Impact on the Northern Hemisphere Summer Circulation.” Journal of the Meteorological Society of Japan 65: 373–390.

Oh, H., and K.-J. Ha. 2015. “Thermodynamic Characteristics and Responses to ENSO of Dominant Intraseasonal Modes in the East Asian Summer Monsoon.” Climate Dynamics 44: 1751–1766.

Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan. 2003. “Global Analyses of Sea Surface Temperature, Sea Ice, and Night Marine Air Temperature since the Late Nineteenth Century.” Journal of Geophysical Research 108: 4407. doi:10.1029/2002JD002670.

Su, T. H., and F. Xue. 2010. “The Intraseasonal Variation of Summer Monsoon Circulation and Rainfall in East Asia.” Chinese Journal of Atmospheric Sciences (in Chinese) 34: 611–628.

Tao, S. Y., and Q. Y. Zhang. 1998. “Response of the Asian Winter and Summer Monsoon to ENSO Events.” Chinese Journal of Atmospheric Sciences (in Chinese) 22: 399–407.

Trenberth, K. E. 1997. “The Definition of El Niño.” Bulletin of the American Meteorological Society 78: 2771–2777.

Xie, F., and C. Z. Liu. 2008. “The Influence of Moderate ENSO on Summer Rainfall in Eastern China and Its Comparison with Strong ENSO.” Chinese Science Bulletin 53: 791–800.

Yang, J., Q. Liu, S.-P. Xie, Z. Liu, and L. Wu. 2007. “Impact of the Indian Ocean SST Basin Mode on the Asian Summer Monsoon.” Geophysical Research Letters 34: L02708. doi:10.1029/2006GL028571.

Zhao, Z. G. 1999: Droughts and Floods in China during Summer and Their Environmental Fields. Beijing: China Meteorological Press, 297 pp. (in Chinese).

Zhao, J. J., F. Xue, W. T. Lin, and A. M. Duan. 2016. “The Influence of El Niño on the Intraseasonal Variation of East Asian Summer Monsoon and Summer Rainfall.” Climatic and Environmental Research (in Chinese) 21: doi:10.3878/j.issn.1006-9585.2016.15244.