The role of synoptic-scale waves in the onset of the South China Sea summer monsoon

Jingliang Huangfu1 | Wen Chen1,2 | Xu Wang3,4 | Ronghui Huang1,2

1Center for Monsoon System Research, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
2College of Earth Sciences, University of Chinese Academy of Sciences, Beijing, China
3Ministry of Education Key Laboratory for Earth System Modeling, Department for Earth System Science, Tsinghua University, Beijing, China
4Joint Center for Global Change Studies, Beijing, China

Correspondence
Jingliang Huangfu, Center for Monsoon System Research, Institute of Atmospheric Physics, Chinese Academy of Sciences, P. O. Box 2718, Beijing 100190, China.
Email: hfjl@mail.iap.ac.cn

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The role of premonsoon synoptic-scale waves (2- to 10-day oscillation) in the onset of the South China Sea summer monsoon (SCSSM) is investigated in this study. The results indicated that the onset date of the SCSSM from 1979–2016 was related to the intensity of premonsoon synoptic-scale waves. The more active the premonsoon synoptic-scale waves, the earlier the SCSSM tended to be established. This study focused on the accumulative effects of premonsoon synoptic-scale waves on the SCSSM onset because active years often included more than one process. According to the regression analysis results, three premonsoon synoptic-scale waves influenced the onset of the SCSSM. First, waves over the southern Bay of Bengal (BOB) were related to Kelvin waves, which accelerated the intrusion of southwesterly winds over the BOB into the South China Sea (SCS). Second, waves over the eastern SCS were related to tropical depression (TD)-type waves. Westerly anomalies south of this type of synoptic-scale wave were favorable for the onset of the SCSSM. Third, waves originating from the north were hypothesized to be related to the mid-latitude fronts. The mid-latitude vortex moved northeast of the SCS and induced the intrusion of southwesterlies over the SCS. All three waves continuously enabled the westerly anomalies and affected the SCSSM. In addition, the combined effects of these synoptic-scale waves were investigated. The results showed that active waves led to significant anomalous westerlies along the boreal tropical region and cyclonic circulation over the Philippine Sea. Anomalous convection was enhanced over the BOB and SCS, and the western Pacific subtropical high was suppressed. The combined intensities of these premonsoon synoptic-scale waves indicated their potential for use as a new predictor of the onset of the SCSSM.

KEYWORDS
onset process, South China Sea summer monsoon, synoptic-scale waves

1 | INTRODUCTION

The East Asian summer monsoon (EASM) consists of tropical and subtropical monsoon types, and the South China Sea summer monsoon (SCSSM) belongs to its tropical type (Zhu et al., 1986). The onset of the SCSSM marks the beginning of the EASM, whereas the rainy season occurs over South China due to a southwest warm-wet airflow (Tao and Chen, 1987; Ding and Chan, 2005; Zhu and Li, 2017). The onset date of the SCSSM is commonly used to indicate droughts and floods during the first rainy season over South China as well as anomalous precipitation over other regions (Huang et al., 2006; Yuan et al., 2010; He and Zhu, 2015; Gu et al., 2018). Recently, the onset date of the SCSSM has been

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shown to be related to the tropical cyclone (TC) genesis over the western North Pacific in May (Huangfu et al., 2017a, 2017b, 2017c; Huangfu et al., 2018a, 2018b). Hence, the onset date of the SCSSM has been intensely studied.

Significant interannual variations are observed in the onset date of the SCSSM (Xie et al., 1998). According to the definition by Wang et al. (2004), the SCSSM was established on pentad 25–32 and the onset pentad varies annually. Previous studies have discussed the mechanisms underlying the SCSSM onset (Chang and Chen, 1995; Chan et al., 2002; Zhou and Chan, 2005; Straub et al., 2006; Mao and Wu, 2008; Tong et al., 2009; Kueh and Lin, 2010; Huangfu et al., 2015; Chen and Wang, 2017; Wang et al., 2018). On an intraseasonal timescale, two important components of the intraseasonal oscillations (ISO) that influence the onset of the SCSSM are observed. One is the Madden–Julian Oscillation (MJO; 30- to 60-day oscillations) (Madden and Julian, 1994; Chan et al., 2002), which is thought to play a major role in generating the SCSSM onset. When the MJO propagates northeastward during the premonsoon period before the SCSSM, an anomalous convective band can stretch from the tropical Indian Ocean to the Bay of Bengal (BOB). This 30- to 60-day oscillation provides a favorable environment for the onset of the SCSSM. The other component is the quasi-biweekly oscillation (QBWO; 10- to 20-day oscillations) (Keshavamury, 1972; Zhou and Chan, 2005; Wang et al., 2016). When the QBWO propagates northwestward, it weakens the western Pacific subtropical high (WPSH). This process interacts with the MJO and modifies the convective activities and thus the onset of the SCSSM. In addition, on a synoptic timescale, the contribution of synoptic-scale anomalies to the total westerly wind anomaly is comparable with that of intraseasonal wind anomalies, especially in the normal onset cases (Wang et al., 2018). Several types of synoptic-scale disturbances that influence the onset of the SCSSM have been identified. The first consists of Kelvin waves, which constitute an integral component that is often combined with the MJO. Straub et al. (2006) suggested that MJO-related Kelvin waves can emanate over the Pacific and generate westerly surface winds, which accelerate or trigger the monsoon onset process. The second disturbance consists of mid-latitude fronts (Chang and Chen, 1995; Kueh and Lin, 2010). According to Tong et al. (2009), the convergence of a mid-latitude front and a northward-moving South China Sea (SCS) monsoon trough enables the onset of the SCSSM. The third disturbance consists of the TCs. Mao and Wu (2008) found that the first TC of 2006 triggered the onset of the SCSSM. Huangfu et al. (2017c) performed a statistical analysis and found additional TC examples that influenced the onset of the SCSSM. Westerly winds south of TCs also accelerate or trigger the onset of monsoons.

The above information indicates that previous studies have focused on the roles of individual synoptic-scale events in the onset of the SCSSM, such as the aforementioned mid-latitude fronts or TC processes. However, this study attempts to answer whether or not premonsoon synoptic-scale waves have cumulative effects on the SCSSM onset, which may improve our current understanding of the mechanisms underlying the onset of the SCSSM from a synoptic-scale and statistical perspective.

2 DATA AND METHODOLOGY

Daily horizontal wind data at 850 hPa and geopotential data at 500 hPa at a 2.5° × 2.5° resolution from 1979 to 2016 were extracted from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim Reanalysis dataset (Simmons et al., 2007). In addition, the daily mean outgoing longwave radiation (OLR) data at a 2.5° × 2.5° resolution from 1979 to 2013 were obtained from the National Oceanic and Atmospheric Administration (NOAA) archives (Liebmann, 1996). Uninterpolated daily OLR data from 2014 to 2016 were also obtained from the NOAA archives. These data were then interpolated and added to the 1979–2016 OLR dataset.

The present study used the first day of the onset pentad as the first day of the SCSSM onset, with onset pentad defined based on the work of Wang et al. (2004). Using a bandpass filter, the OLR and 850-hPa horizontal wind fields were filtered to extract a 2- to 10-day cutoff period to isolate synoptic-scale waves (excluding the ISOs). The premonsoon period of the SCSSM was defined as the 30-day period before the onset date. The intensity of the synoptic-scale waves was calculated with the SDs of the 2- to 10-day filtering OLR during the premonsoon periods. Based on the time series of the 2- to 10-day filtering OLR at different reference points, the filtered OLR data and horizontal wind data at 850 hPa were regressed. The daily sequence of the horizontal structures of synoptic-scale waves can reflect the transitions of the corresponding waves. The leading/lag analyses were performed by referencing the onset date of the SCSSM. In addition, based on the combined intensity of the synoptic-scale waves, the original OLR field and horizontal wind field at 850 hPa were regressed. The regressions were based on data collected 10 days before the SCSSM onset. The results can reflect the cumulative effects of the premonsoon synoptic-scale waves on monsoon circulation during the SCSSM onset period.

3 ROLES OF SYNOPTIC-SCALE WAVES IN THE ONSET OF THE SCSSM

3.1 Relationship between the premonsoon synoptic-scale waves and the onset date of the SCSSM

The relationship between the intensity of the premonsoon synoptic-scale waves (2- to 10-day oscillation) and the onset
date of the SCSSM is analyzed via a correlation analysis. The onset date of the SCSSM is defined according to that of Wang et al. (2004), which is determined by the occurrence of the intrusion of westerly winds into the SCS. The 2- to 10-day oscillation can differentiate the activity of synoptic-scale waves from that of ISOs (most of which are filtered by the 10- to 60-day band). As shown in Figure 1a, negative correlation coefficients between the interannual intensity of the synoptic-scale waves and the onset date of the SCSSM are observed over the southern BOB, the eastern SCS and the Philippine Sea. These preliminary results indicate that the premonsoon synoptic-scale waves play a role in the onset of the SCSSM. Considering that the intensity of these waves was achieved using data collected over 1 month, the intensity should be treated as a cumulative effect. According to the aforementioned previous studies, we infer that negatively correlated regions over the southern BOB (represented by point A) are related to Kelvin waves while those over the eastern SCS (represented by point B) are related to the TD-type waves. Since the negative regions near (2.5°N, 125°E) are highly related to point B, they are not selected separated. Additionally, the signals over the Philippine Sea (represented by point C) are related to synoptic-scale waves originating from the north, which are related to mid-latitude fronts.

As noted above, the premonsoon synoptic-scale waves over these three regions play important roles in the onset of the SCSSM. To investigate the interannual relationship between the SCSSM onset date and the intensity of synoptic-scale waves over different key regions, we compare their normalized time series and calculate their correlation coefficients (Figure 1b). The normalization process is conducted by dividing the interannual anomalies by each of their SDs. The comparisons indicate that the onset date of the SCSSM is generally out of phase with the intensities of all premonsoon synoptic-scale waves, although their correlation coefficients are almost equal (A: −0.39; B: −0.33; and C: −0.34) and statistically significant. Stronger premonsoon synoptic-scale wave activities can predict the advanced onset of the SCSSM. In addition, considering that synoptic-scale waves over these three key regions are not absolutely independent of each other, we define a combined index, which is referred to as point D and defined as the arithmetic mean of the aforementioned selected points (A, B and C). In addition, the correlation coefficient between the onset date of the SCSSM and the combined intensity of the three synoptic-scale waves is greater than that for each single selected point. This result indicates that the synoptic-scale waves interact with each other in many cases, thus leading to stronger westerly anomalies and an earlier onset of the SCSSM.

3.2 Transitions of the premonsoon synoptic-scale waves

As mentioned above, these three related regions correspond to different synoptic-scale waves. To validate this inference, we first plotted a daily sequence (daily lags between −2 and +3) of the horizontal structures of synoptic-scale waves (Figure 2). The daily lags are determined by referencing the onset date of the SCSSM. These results are derived from a regression analysis of both the 2- to 10-day filtered OLR field and the 850-hPa wind field based on a time series of the filtered OLR at point A (5°N, 88°E). On lag day −1, a strong OLR center was observed between 80°E and 100°E, and it was coupled with a significant vortex circulation. On day 0, this OLR center became stronger and presented stronger westerly winds and weaker easterly winds to the east. On day +1, the westerly anomalies shifted eastward and were observed over the western SCS. The wave periods, eastward-propagating wavenumbers and phase speeds met the Kelvin waves, which is consistent with the analysis of Straub et al. (2006). The 2- to 10-day filtering reflects the synoptic-scale portion of Kelvin waves, which transports westerly anomalies to the east. This process accelerates the intrusion of southwesterly winds over the BOB into the SCS.

We also plotted another daily sequence of horizontal structures for the synoptic-scale waves based on the time series of the filtered OLR results at point B (10°N, 121°E) (Figure 3). On lag day −2, a clockwise circulation disturbance was observed near (8°N, 130°E). The center of the
vortex circulation was located over a positive OLR center, and this pattern resembled the transformation of a TD-type wave from an equatorial mixed Rossby-gravity (MRG) wave. On lag day $-1$, this coupled vortex strengthened and approached the SCS. At day 0, this TD-wave related synoptic-scale wave reached its maximum and transported westerly anomalies over the SCS. Then, the wave decayed and moved northwestward, and the westerlies to the south persisted and continued to affect the SCS (Figure 3d,f). Typically, the onset of the SCSSM requires persistent and steady westerlies. Therefore, the TD-type wave train is critical for the onset of the SCSSM.

In addition, we plotted a daily sequence of the horizontal structures of synoptic-scale waves based on the time series of the filtered OLR at point C ($20^\circ$N, $135^\circ$E) (Figure 4). On lag day $-1$, a wave train with a northwest–southeast orientation was observed as shown in Figure 4b. The upstream vortex, which was led by the downstream vortex, moved southwestward gradually from day $-1$ to day +1 (Figure 4b,e). On day +2, the mid-latitude vortex moved northeast of the SCS and the westerly anomalies to the south merged with the southwesterlies from the SCS. These anomalous westerlies were favorable for the onset of the SCSSM. The transition of the synoptic-scale waves from the north might be related to mid-latitude fronts, which is consistent with the findings of Tong et al. (2009).

Over all, these three related regions represent three different types of synoptic-scale waves, and the moving paths of these waves influence to the onset of the SCSSM. These wave trains transport westerly anomalies, which are continuously absorbed by the mean stream. More than one synoptic-scale wave contributes to the onset of the SCSSM, which explains how the accumulative effects of premonsoon synoptic-scale waves occur.

## 3.3 Combined contribution of synoptic-scale waves to the onset of the SCSSM

We compared the correlation coefficients between the onset date of the SCSSM and the intensity of each pair of synoptic-scale waves (AB: $-0.43$; BC: $-0.44$; and AC: $-0.38$). The combination of two types of synoptic-scale waves showed clearly higher correlation levels than that for a single wave. Then, we calculated the combined contribution of all three synoptic-scale waves by considering points A, B and C, which achieved an even better result (ABC: $-0.45$). In other words, the combined intensity of the premonsoon synoptic-scale waves showed greater potential as a predictor of the onset of the SCSSM.
Hence, to investigate the combined contributions of synoptic-scale waves to the onset of the SCSSM, an analysis was performed of low-level (850 hPa) horizontal winds and OLR anomalies regressed onto the interannual wave intensity of point D. Both the winds and OLR field were calculated using the original data 10 days before the onset of the SCSSM. This analysis was performed to show the low-level circulation anomalies induced by the premonsoon synoptic-scale waves. As shown in Figure 5, strong synoptic-scale waves led to significant anomalous westerlies along the boreal tropical region and a cyclonic circulation over the Philippine Sea. Enhanced anomalous convection was observed over the BOB and the SCS. We also examined the changes in the 500-hPa geopotential height and observed negative anomalies over the SCS, meaning that the southwestern portion of the WPSH was weakened (figure not shown). Based on the premonsoon anomalous circulation, convection and weakening of the WPSH, the SCSSM is expected to occur earlier.

4 | SUMMARY AND DISCUSSION

This study investigated the accumulative effects of the premonsoon synoptic-scale waves (2- to 10-day oscillation) on the onset of the SCSSM. It showed that the onset date was negatively correlated with the intensity of the premonsoon synoptic-scale waves over three key regions: the southern BOB, the eastern SCS and the Philippine Sea. Based on the regression analysis, the premonsoon synoptic-scale waves over the southern BOB were related to Kelvin waves. Consistent with Straub et al. (2006), the 2- to 10-day filtering can reflect the synoptic-scale portion of Kelvin waves, which can transport westerly anomalies eastward. However, instead of analyzing a complex system that contains both ISO and synoptic-scale waves, our analysis focused on the latter and its accumulative effects. These premonsoon synoptic-scale waves accelerate the intrusion of westerly winds over the BOB into the SCS. Moreover, the premonsoon synoptic-scale waves over the eastern SCS were related to the TD-type waves, which were transformed from equatorial MRG waves that propagated northwestward. The westerly anomalies south of this type of synoptic-scale wave were favorable for the onset of the SCSSM. In addition, the premonsoon synoptic-scale waves over the Philippine Sea were related to the synoptic-scale waves from the north, and these northerly waves were likely related to mid-latitude fronts, which is consistent with the results from Tong et al. (2009). The mid-latitude vortex moved northeast of the SCS.
and the westerly anomalies to the south merged with southwesterly anomalies from the SCS. To reiterate, these premonsoon synoptic-scale waves utilized 1 month of data, which indicates that the intense wave activity was caused by more than one process. The waves provided a continuous source of westerly anomalies and affected the SCSSM.

The accumulative effects of these synoptic-scale waves can influence related premonsoon convection and circulation. Because the combined intensity of all three synoptic-scale waves is most strongly correlated with the onset date of the SCSSM, a regression analysis of low-level horizontal winds and OLR anomalies 10 days before the onset of the SCSSM was conducted using the time series of the combined intensity. The results showed that stronger synoptic-scale waves led to significant anomalous westerlies along the boreal tropical region and cyclonic circulation over the Philippine Sea because convection was enhanced over the BOB and the SCS. The premonsoon WPSH was suppressed. Hence, this study proved that accumulative effects of the premonsoon synoptic-scale waves do occur and the SCSSM is expected to be established earlier when the combined intensity of the waves was strengthened.

This work conducted a comprehensive analysis of the influence of premonsoon synoptic-scale waves on the onset of the SCSSM. The results added new mechanisms to previous hypotheses and findings. However, the driving forces influencing the intensity of synoptic-scale waves are not included in this study. Zhu and Li (2017) summarized that three preceding factors can predict the early onset of the SCSSM: (a) a
warming tendency in the middle and lower troposphere over central Siberia, (b) a La Niña-like pattern and (c) a meridional dipole sea level pressure pattern. Considering the high reforecast skill of these factors, they might be important driving forces for the synoptic-scale waves. These driving forces will be a focus of our future work. In addition, more integral studies should be carried out, including comparisons between the effects of ISOs and synoptic-scale waves on the onset of the SCSSM, the dynamic processes of wave–mean flow interactions, related numerical experiments and other meaningful analyses.

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ORCID

Jingliang Huangfu http://orcid.org/0000-0003-4805-9629

REFERENCES

Chan, J.C.L., Ai, W.X. and Xu, J.J. (2002) Mechanisms responsible for the maintenance of the 1998 South China Sea summer monsoon. Journal of the Meteorological Society of Japan, 80, 1103–1113.

Chang, C.-P. and Chen, G.T.-J. (1995) Tropical circulations associated with southwest monsoon onset and westerly surges over the South China Sea. Monthly Weather Review, 123, 3254–3267.

Chen, G. and Wang, X. (2017) Effect of the westward-propagating zonal wind anomaly on the initial development of quasi-biweekly oscillation over the South China Sea during early summer. Atmospheric and Oceanic Science Letters, 10, 89–95.

Ding, Y.H. and Chan, J.C.L. (2005) The East Asian summer monsoon: an overview. Meteorology and Atmospheric Physics, 89, 117–142.

Gu, W., Wang, L., Hu, Z.-Z., Hu, K. and Li, Y. (2018) Interannual variations of the first rainy season precipitation over South China. Journal of Climate, 31, 623–640.

He, J. and Zhu, Z. (2015) The relation of South China Sea monsoon onset with the subsequent rainfall over the subtropical East Asia. International Journal of Climatology, 35, 4547–4556.

Huang, R., Gu, L., Zhou, L. and Wu, S. (2006) Impact of the thermal state of the tropical western pacific on onset date and process of the South China Sea summer monsoon. Advances in Atmospheric Sciences, 23, 909–924.

Huangfu, J., Huang, R. and Chen, W. (2015) Influence of tropical western pacific warm pool thermal state on the interdecadal change of the onset of the South China Sea summer monsoon in the late-1990s. Atmospheric and Oceanic Science Letters, 8, 95–99.

Huangfu, J., Huang, R. and Chen, W. (2017a) Interdecadal increase of tropical cyclone genesis frequency over the western north pacific in May. International Journal of Climatology, 37, 1127–1130.

Huangfu, J., Huang, R. and Chen, W. (2017b) Relationship between the South China Sea summer monsoon onset and tropical cyclone genesis over the western north pacific. International Journal of Climatology, 37, 5206–5210.

Huangfu, J., Huang, R. and Chen, W. (2017c) Statistical analysis and a case study of tropical cyclones that trigger the onset of the South China Sea summer monsoon. Scientific Reports, 7, 12732. https://doi.org/10.1038/s41598-017-13128-2.

Huangfu, J., Chen, W., Ma, T. and Huang, R. (2018a) Influences of sea surface temperature in the tropical Pacific and Indian Oceans on tropical cyclone genesis over the western north pacific in May. Climate Dynamics, 51, 1915–1926. https://doi.org/10.1007/s00382-017-3989-y.

Huangfu, J., Chen, W., Jian, M. and Huang, R. (2018b) Impact of the cross-tropopause wind shear on tropical cyclone genesis over the western north pacific in May. Climate Dynamics. https://doi.org/10.1007/s00382-018-4363-4.

Keshavamurthy, R.N. (1972) On the vertical tilt of monsoon disturbances. Journal of the Atmospheric Sciences, 29, 993–995.

Kueh, M.-T. and Lin, S.-C. (2010) A climatological study on the role of the South China Sea monsoon onset in the development of the East Asian summer monsoon. Theoretical and Applied Climatology, 99, 163–186.

Liebmann, B. (1996) Description of a complete (interpolated) outgoing longwave radiation dataset. Bulletin of the American Meteorological Society, 77, 1275–1277.

Madden, R.A. and Julian, P.R. (1994) Observations of the 40–50-day tropical oscillation—a review. Monthly Weather Review, 122, 814–837.

Mao, J. and Wu, G. (2008) Influences of typhoon chanchu on the 2006 South China Sea summer monsoon onset. Geophysical Research Letters, 35, L12809. https://doi.org/10.1029/2008GL033810.

Simmons, A., Uppala, S., Dee, D. and Kobayashi, S. (2007) Era-interim: new ecwmf reanalysis products from 1989 onwards. ECMWF Newsletter, 110, 25–35.

Straub, K.H., Kiladis, G.N. and Ciesielski, P.E. (2006) The role of equatorial waves in the onset of the South China Sea summer monsoon and the demise of El Nino during 1998. Dynamics of Atmospheres and Oceans, 42, 216–238.

Tao, S. and Chen, L. (1987) Review of recent research on the East Asian summer monsoon in China. In: Chang, C.-P. and Krishnamuritis, T.N. (Eds.) Monsoon Meteorology. Oxford University Press, Oxford, pp. 60–92.

Tong, H.W., Chan, J.C.L. and Zhou, W. (2009) The role of mjo and mid-latitude fronts in the South China Sea summer monsoon onset. Climate Dynamics, 33, 827–841.

Wang, B., Linho, Zhang, Y.S. and Lu, M.M. (2004) Definition of South China Sea monsoon onset and commencement of the East Asia summer monsoon. Journal of Climate, 17, 699–710.

Wang, X., Chen, G. and Huang, R. (2016) Different characteristics of the quasi-biweekly oscillation over the South China Sea in two boreal summer stages. Theoretical and Applied Climatology, 126, 1–13.

Wang, H., Liu, F., Wang, B. and Li, T. (2018) Effects of intraseasonal oscillation on South China Sea summer monsoon onset. Climate Dynamics, 51, 2543–2558. https://doi.org/10.1007/s00382-017-4027-9.

Xie, A., Chung, Y.-S., Liu, X. and Ye, Q. (1998) The interannual variations of the summer monsoon onset over the South China Sea. Theoretical and Applied Climatology, 59, 201–213.

Yuan, F., Wei, K., Chen, W., Kun, F.S. and Cheng, L.K. (2010) Temporal variations of the frontal and monsoon storm rainfall during the first rainy season in South China. Atmospheric and Oceanic Science Letters, 3, 243–247.

Zhou, W. and Chan, J.C.L. (2005) Intraseasonal oscillations and the South China Sea summer monsoon onset. International Journal of Climatology, 25, 1585–1609.

Zhu, Q., He, J. and Wang, P. (1986) A study of circulation differences between East-Asian and Indian summer monsoons with their interaction. Advances in Atmospheric Sciences, 3, 466–477.

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