CORRESPONDENCE

Comments on “Interdecadal Change of the South China Sea Summer Monsoon Onset”

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ABSTRACT

In a recent paper, Kajikawa and Wang detected the interdecadal shift of the South China Sea summer monsoon (SCSSM) onset with a late SCSSM onset in an earlier epoch (1979–93) and an early SCSSM onset in a later epoch (1994–2008) and attributed this change to enhanced tropical cyclone (TC) activity and intraseasonal variability (ISV) related to 30–80-day and 10–25-day anomalies in the second epoch. This comment assesses the individual impact of TCs and ISV on the interdecadal change of the SCSSM onset by means of the removal of anomalies associated with TCs and ISV. Results herein show that TCs have no significant impact on the SCSSM onset in all years, except 2006 in which a strong and long-lived TC occurred over the South China Sea. After removing the 30–80-day anomaly, the difference in the mean SCSSM onset date in the two epochs decreases to some extent, implying that the 30–80-day anomaly can, in part, play a role in the interdecadal shift of the SCSSM onset. In contrast, the 10–25-day anomaly has an insignificant contribution to the interdecadal shift of the SCSSM onset. The discrepancy of ISV contribution results from the SCSSM background state, the magnitude and spatiotemporal scale of ISV, and the phase relationship between ISV and SCSSM transition from easterly to westerly.

1. Introduction

It is well known that the South China Sea summer monsoon (SCSSM), as an important ingredient of the Asian summer monsoon, is characterized by an abrupt onset over the South China Sea (SCS) around mid-May. Increasing evidence reveals that the East Asia summer monsoon exhibited a climate shift in the mid-1990s (e.g., Kwon et al. 2005, 2007; Yim et al. 2008). In a recent paper, using a simple yet effective definition of SCSSM circulation index (the 850-hPa zonal winds averaged over the central SCS) proposed by Wang et al. (2004), Kajikawa and Wang (2012, hereafter KW12) also pointed out a significant change in the SCSSM onset date around 1993/94, with a late onset in the first epoch (1979–93) and an early onset in the second epoch (1994–2008). They calculated mean standard deviations of the 10–25-day and 30–80-day filtered outgoing longwave radiation (OLR) from 15 April to 15 May and compared the epochal differences of mean standard deviations between 1979–93 and 1994–2008 (see Fig. 8 in KW12). They attributed the interdecadal change of the SCSSM onset date to the enhancement of intraseasonal variability (ISV) prior to the SCSSM onset in the second epoch. In addition, the increased frequency of tropical cyclones (TCs) passing through the SCS and Philippine Sea in the second epoch is also documented (see Fig. 9 in KW12). Consequently, KW12 concluded that “the enhancements of the ISV activity and tropical cyclone genesis after 1994 are major triggers for the advanced SCSSM onset” (see their section 6).

However, an intriguing question is raised: Is it true that the enhancement in the ISV and TC activities are major triggers for the advanced SCSSM onset across 1993/94? Based on the definition of SCSSM onset in KW12, this comment aims to examine whether the enhancement of ISV and TC activity in the second epoch can exert direct influences on the interdecadal shift of the SCSSM onset in the mid-1990s. The relative importance of ISV and TC on the interdecadal change of

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the SCSSM onset is measured by removing the anomalies related to TC and ISV in wind fields.

2. Data and methodology

In this study, the Japanese 55-Year Reanalysis (JRA-55) data are used to define the SCSSM circulation index and onset date. This dataset is a third-generation reanalysis with distinct improvements such as adopting a four-dimensional variational data assimilation system and updated dynamical and physical processes (Ebita et al. 2011). The reanalysis data have a 1.25° horizontal resolution at a 6-hourly interval. Instead of the data from National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) used in KW12, the JRA-55 data are employed based on the following considerations. On one hand, the new data are intended to validate the consistency in the SCSSM onset from the different dataset resources. On the other hand, the TC-removal method used in this study is more effective when applied to high-resolution fields as opposed to coarse-resolution fields. In addition, the period is extended from 2008 to 2012, to check the persistence of early SCSSM onset after 1993.

Following the definitions in Wang et al. (2004) and KW12, the SCSSM circulation index is defined as 850-hPa zonal wind averaging over the region 5°–15°N, 110°–120°E. Although there are a great variety of indices with objective or subjective criteria to define the SCSSM onset, this index can depict well the sudden establishment of the lower-level southwesterly monsoon and the rainfall bursts in the central-northern SCS (Wang et al. 2004). The SCSSM onset date can be defined as the first day after 25 April according to the following criteria: 1) on the onset day and during the subsequent 5 days, the SCSSM circulation index must be positive (westerly wind); 2) the number of days of positive SCSSM circulation index during the subsequent 20 days reaches at least 15; and 3) the 20-day mean SCSSM circulation index must be larger than 1 m s$^{-1}$.

To quantify the impacts of TCs and ISV activity on the SCSSM onset, the zonal winds, after removing the anomalies associated with TCs and ISV, are used to reconstruct the SCSSM circulation index and onset date, and then compared with those derived from the raw zonal winds. A vortex removal algorithm (Kurihara et al. 1993, 1995) is applied to remove TC-related circulation with respect to 6-hourly TC positions obtained from the Joint Typhoon Warning Center (JTWC). This TC removal method can effectively filter TC circulation and retain background field (e.g., Hsu et al. 2008; Chen 2013). The Lanczos bandpass filter (Duchon 1979) is employed to isolate the 30–80-day and 10–25-day intraseasonal anomalies, which are subtracted from the original zonal winds. Prior to the filtering, the climatological annual cycles are removed from the raw data. To examine the impact of the possible spurious signal produced by the bandpass filter on the definition of SCSSM onset date, the Fourier technique is also conducted to extract the harmonics corresponding to 30–80-day and 10–25-day wave band. The results indicate that, except for the noticeable modification in the SCSSM onset date in individual years, the interdecadal shift of SCSSM onset is consistent with the counterpart in this study (not shown). Therefore, from the interdecadal viewpoint, the conclusions are less sensitive to the selection of filter.

3. Results

First, the SCSSM onset dates from the JRA-55 data are evaluated to compare with those from the NCEP–NCAR data used in the study of KW12. The interannual variability of the SCSSM onset date corresponds well, with a correlation coefficient of 0.86 from 1979 to 2008 (cf. Figs. 1a and 3 in KW12). Similarly, the statistically significant shift between the two epochs of 1979–93 and 1994–2012 can be identified, with a late SCSSM onset in the first epoch and an early SCSSM onset in the second epoch, even though the period extends to 2012. This suggests that the interdecadal change of the SCSSM onset is robust and coherent, and the JRA-55 data can reproduce the interdecadal shift between the two epochs.

a. The impact of TCs on SCSSM onset

Figure 1a shows the time series of the SCSSM onset date from 1979 to 2012, which is derived from the original and TC-removal fields (referred to as SMO_ORI and SMO_NOTC, respectively). It is clearly demonstrated that two time series are almost coincident except for the year 2006. In 2006, the SCSSM onset date shifts from 12 May in SMO_ORI to 1 June in SMO_NOTC, indicating that TC circulation around mid-May can influence the large-scale flow to the extent that the SCSSM onset is delayed (based on criteria defined in section 2).

To clarify the impact of TCs, Fig. 2 depicts the 850-hPa wind field averaged from 8 to 18 May and the time evolution of the SCSSM circulation index in the original and filtered data. In contrast to strong westerly winds in the southern SCS in SMO_ORI (Fig. 2a), the cyclonic circulation is evidently weakened in SMO_NOTC with prevalent easterly winds in the northern SCS through the east of the Philippines and decreased westerly winds in the southern SCS (Fig. 2b). The difference can be attributed to Typhoon Chanchu, which was first identified as a tropical depression at 8.8°N, 137.6°E and then
migrated northwestward and entered into the SCS around 13 May. In the following days, Typhoon Chan-chu continued to intensify and achieved a minimum sea level pressure of 916 hPa at 14.1°N, 115.3°E on 15 May. Subsequently, it moved northward and landed on the coast of southern China on 18 May. The comparison of the SCSSM circulation index in the two datasets reveals that, due to the absence of TC circulation, the intensity of SCSSM circulation index is significantly reduced in mid-May; moreover, the time of reversal from easterly to westerly wind is delayed (Fig. 2c). As a result, the cumulative strength and duration of westerly wind cannot satisfy the criteria of the SCSSM onset in May. Only in the period of late May to 1 June do the westerly winds build up steadily for nearly 10 days such that the SCSSM onset is defined to occur on 1 June in SMO_NOTC. Therefore, Typhoon Chanchu acted as an immediate trigger for the SCSSM onset and establishment in 2006, which is also consistent with the findings by Mao and Wu (2008).

It should be noted that although TC occurrence over the SCS has an increasing tendency in the second epoch as shown in KW12, there is no evidence verifying that the enhanced TC activity can significantly modify the SCSSM onset date in all years except 2006. In other years, TC circulation contributes little to modulating the SCSSM onset date owing to the life span, intensity, and position of the TCs. Hence, more active TCs over the SCS in the second epoch may be the consequence, instead of the cause, of the long-term change of SCSSM circulation. To sum up, TC activity hardly influences the interdecadal change of the SCSSM onset date according to the SCSSM onset definition in this study.

b. The impact of ISV on SCSSM onset

Many studies have found that the power spectrum of SCSSM variability has two peaks on the time scales of Madden–Julian oscillation (30–80-day) and quasi-biweekly oscillation (10–25 day) (e.g., Chen et al. 2000; Mao and Chan 2005; Kajikawa and Yasunari 2005). To examine the relative importance of the intraseasonal oscillations in the interdecadal change of SCSSM onset, the wind anomalies related to 30–80-day and 10–25-day ISV are filtered in the two scenarios (referred to as SMO_NO38 and SMO_NO12, respectively). Because of potential feedback between ISVs and embedded higher-frequency disturbances, an 80-day low-pass filter is also applied to extract the low-frequency background state signal (SMO_NO80).

Figure 1b exhibits the time series of the SCSSM onset date in the SMO_ORI and SMO_NO38 scenarios. The salient feature in SMO_NO38 is that, among 19 years in
the second epoch, the SCSSM onset is postponed in 12 years and advanced in only one year, which causes the mean SCSSM onset date in the second epoch to shift from 11 to 16 May. In contrast, a moderate advance in the SCSSM onset in the first epoch can be observed. As a result, the discrepancy in the mean SCSSM onset dates between the two epochs in SMO_NO38 is reduced in comparison with that in SMO_ORI. The statistical significance in the different onset dates between the two epochs in SMO_NO38 is decreased to a 90% confidence level by a Student’s t test. Examination of the SCSSM onset dates in SMO_ORI and SMO_NO12 reveals that the decadal mean SCSSM onset dates remain nearly unchanged, especially in the second epoch (Fig. 1c). It suggests that the 10–25-day anomaly has little influence on the interdecadal shift of the SCSSM onset.

In Figs. 1b and 1c, the mean SCSSM onset date is advanced in the first epoch and delayed in the second epoch in SMO_NO38, whereas no substantial change is detected in SMO_NO12. The distinctive features may be attributed not only to the different mean SCSSM circulation where the ISV resides, but also to the phase relationship between the SCSSM transition and ISV. Figure 3 depicts the composite SCSSM circulation index and filtered anomaly relative to the SCSSM onset date of SMO_ORI. The composites for the two epochs in different scenarios show that, in SMO_ORI, the westerly wind after the SCSSM onset (positive days) has a larger magnitude in the first epoch than in the second epoch (black solid curves in Figs. 3a,b), indicating a weakening of the westerly wind after the SCSSM onset in the second epoch. Consequently, the 30–80-day anomaly can exert a relatively important influence on the SCSSM onset. After removing the 30–80-day anomaly, the SCSSM circulation index becomes smaller in the second epoch than in the first epoch (black dashed curves in Figs. 3a,b). It implies that the criteria of the SCSSM onset in the second epoch in SMO_NO38 cannot be satisfied easily, leading to the delay of SCSSM onset in agreement with the result in Fig. 1b. In addition, the composite SCSSM onset date is located in the node of the 30–80-day filtered wave in the first epoch (Fig. 3a) and in the positive developing phase in the second epoch (Fig. 3b). This phase difference between ISV and the SCSSM onset date suggests that the evolution of 30–80-day anomaly in the second epoch could help accelerate the negative-to-positive transition of zonal wind over the SCS, leading to an early SCSSM onset in the second epoch.

In contrast, the removal of 30–80-day anomaly can lead to an early mean SCSSM onset date in the first epoch (dashed line in Fig. 1b). It is primarily attributed to a larger negative amplitude of the 30–80-day anomaly in the first epoch prior to the SCSSM onset (negative days in Figs. 3a,b) such that, in SMO_NO38, the easterly wind is more suppressed in the first epoch than that in the second epoch due to the subtraction of ISV-related easterly anomaly from the original easterly. It may be responsible for the early mean SCSSM onset in the first epoch after removing the 30–80-day anomaly via the advance of negative-to-positive transition of SCSSM circulation index.

To further demonstrate the different contributions of the 30–80-day anomaly to the SCSSM onset date in the two epochs, the time series of the SCSSM circulation index in 1985 and 2008 are depicted in Fig. 4. In 1985, the SCSSM onset in SMO_ORI occurs on 27 May, which is in the negative phase of 30–80-day anomaly. After removing the ISV anomaly, the SCSSM circulation index before 27 May is enhanced, leading to the early SCSSM onset on 19 May (Fig. 4a). In 2008, the SCSSM onset date is originally defined on 1 May, concurrent with a positive developing phase of 30–80-day anomaly. After filtering the 30–80-day anomaly, the SCSSM onset date is postponed until 8 May (Fig. 4b). It is also noted that for the years with less robust easterly–westerly
transition around the SCSSM onset date the recognition of SCSSM onset date is likely to be sensitive to the ISV anomalies.

The mean magnitude of 10–25-day anomaly is about half of that of 30–80-day anomaly (orange line in Fig. 3), and the composite SCSSM onset date occurs near the node of 10–25-day filtered wave. Moreover, the 10–25-day anomaly has a time scale not long enough to modulate persistently the SCSSM circulation index (Figs. 3c,d). Consequently, the difference in the SCSSM circulation index between SMO_ORI and SMO_NO12 scenarios is subtle, in agreement with the result in Fig. 1c. Overall, the 10–25-day anomaly has a tiny contribution to the interdecadal change of the SCSSM onset.

Many previous studies have revealed a two-way interaction between the ISVs and higher-frequency disturbances. The high-frequency disturbances can be modulated during the different ISV phases (e.g., Maloney and Dickinson 2003); in turn, the synoptic-scale perturbations can also strongly feed back to the ISV through nonlinear rectification of surface latent

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**Fig. 3.** Composite evolution of SCSSM circulation index relative to the SCSSM onset date of SMO_ORI for (a) SMO_ORI and SMO_NO38 during 1979–93, (b) SMO_ORI and SMO_NO38 during 1994–2012, (c) SMO_ORI and SMO_NO12 during 1979–93, and (d) SMO_ORI and SMO_NO12 during 1994–2012. The black solid and dashed curves stand for the index evolution in SMO_ORI and SMO_NO38, respectively. The orange curve represents the composite filtered anomaly. The abscissa indicates the lagged day relative to the SCSSM onset date in SMO_ORI.
heat flux, diabatic heating, and eddy momentum transport (e.g., Zhou and Li 2010; Hsu and Li 2011). To eliminate the possible effect due to their interactive feedback, the less-than-80-day anomaly is removed in SMO_NO80 (Fig. 1d). The interdecadal shift of the SCSSM onset date is qualitatively similar to that in SMO_NO38 (cf. Figs. 1b and 1d), indicating that the 30–80-day anomaly plays a dominant role in the contribution of ISVs and high-frequency disturbances to the interdecadal shift of the SCSSM onset date.

4. Conclusions and discussion

Recently, KW12 revealed that there exists an interdecadal shift of the SCSSM onset date around 1993/94 with a late onset in 1979–93 and an early onset in 1994–2008. The enhanced TC activity and ISV were thought to be responsible for the significant advance in the SCSSM onset date in the second epoch. This study attempts to qualify to what extent the synoptic TC circulation and multiscale intraseasonal oscillations modulate the SCSSM onset date and thus determine its interdecadal change, using the JRA-55 data for the period of 1979–2012. The original wind field and processed wind fields with the removal of circulation anomalies related to TC and ISV are applied to reconstruct the SCSSM circulation index to define the SCSSM onset date.

The comparison shows that TCs have little effect on the SCSSM onset date during 1979–2012, with the exception of 2006 in which a strong typhoon occurring over the SCS induced a persistent westerly anomaly in mid-May. If the TC-related circulation is removed, the onset date would be postponed for nearly 20 days. The ISV direct influence primarily comes from the 30–80-day anomaly. Because of the weakening of mean westerly flow in the region of interest after the SCSSM onset in the second epoch, the influence of the 30–80-day anomaly stands out. In view of the magnitude and phase of the 30–80-day anomaly around the SCSSM onset, the removal of 30–80-day anomaly causes an advanced SCSSM onset in the first epoch and a delayed SCSSM onset in the second epoch. In contrast, after removing the 10–25-day anomaly, the mean SCSSM onset dates in the two epochs vary insignificantly, which can be ascribed to the small magnitude and short time scale of the 10–25-day anomaly.

In addition, the following factors need to be considered concurrently when investigating the interdecadal shift of the SCSSM onset. 1) The SCSSM circulation background state should be taken into account in the interdecadal change of the SCSSM onset. For example, Xiang and Wang (2013) also revealed that the advanced Asian summer monsoon onset represents a robust decadal shift in the mid-to-late 1990s, and attributed it to mean state change in the Pacific basin characterized by a grand La Niña–like pattern. Besides, the weakened SCSSM background circulation along with strong ISV could augment the impact of ISV on SCSSM onset. 2) The magnitude and spatiotemporal scale of ISV can also play a crucial role in SCSSM onset. Strong ISV with a spatially broad scale and a temporally long scale is favorable for modulating persistently SCSSM circulation. 3) The phase relationship between ISV and SCSSM transition could have a pronounced influence. When a reversal of easterly wind to westerly wind occurs in a positive developing phase of ISV, the strength and duration of monsoonal westerly wind are more likely to reach the thresholds defined by the SCSSM onset.

It should be cautioned that this comment discusses the direct influence of TC and ISV activity on the SCSSM onset based on linear filtering, whereas the possibility of indirect influence cannot be ruled out. Because of non-linear interaction, it is possible that multiple TCs and multiscale ISVs could exert an upscale feedback to rectify the mean state of large-scale circulation, which was also neglected in KW12. So far, to what extent the indirect impact of enhanced TC and ISV activity

![Fig. 4. The time series of SCSSM circulation index in (a) 1985 and (b) 2008. The black solid and dashed curves stand for the index evolution in SMO_Ori and SMO_NO38, respectively. The orange curve represents the 30–80-day anomaly. Red and blue dots indicate the SCSSM onset date in SMO_Ori and SMO_NO38, respectively.](image-url)
modulates the interdecadal change of SCSSM onset is still elusive. Last but not least, it is emphasized that the causality between enhanced TC and ISV activities and interdecadal shift of the SCSSM onset cannot be subjectively derived from statistical analysis of concurrence in KW12. Even if the SCSSM circulation index and onset date showed large differences with and without signals of ISV and TCs, their dynamic relationships still cannot be directly inferred.

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