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Decadal Variation of the Precipitation Relationship between June and August over South China and Its Mechanism

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Declarations

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Availability of data and material: The daily precipitation data set were downloaded from the National Meteorological Information Center, China Meteorological Administration (http://data.cma.cn/data/cdcindex/cid/6d1b5efbdbc19a58.html). The reanalysis data in this paper were downloaded from the Version2 Global Precipitation Climatology Project (https://psl.noaa.gov/data/gridded/data.gpcp.html) and the National Centers for Environment Prediction–Department of Energy (NCEP–DOE) Atmospheric Model Intercomparison Project-II reanalysis dataset (NCEP2) (https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html), and OAFlux dataset were downloaded from WHOI OAFlux Project (https://oaflux.whoi.edu/data-access/).
And the Ocean data were downloaded from the NCEP Global Ocean Data Assimilation System (https://psl.noaa.gov/data/gridded/data.godas.html), and the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) dataset (https://www.metoffice.gov.uk/hadobs/hadisst/data/download.html), and the Extended Reconstructed SST (ERSST) version 4 (https://psl.noaa.gov/data/gridded/data.noaa.ersst.html).

**Code availability:** NCAR Command Language (NCL)

**Authors' contributions:** Guolin Feng, Zhiqiang Gong and Jie Yang designed research; Shuai Li performed research; Shuai Li and Zhiqiang Gong analyzed data; Shuai Li and Zhiqiang Gong wrote the paper. Shui Li, Zhiqiang Gong, Guolin Feng, Jie Yang, Shixuan Zhang and Shaobo Qiao contributed to reviewing the manuscript. All authors have read and approved the final manuscript.
Abstract

This paper investigates the characteristics and causes for the interdecadal change in the relationships between early and late summer rainfall over South China (SC). This study finds that the correlations of the precipitation over SC between June and August shift from weakly positive in 1979 – 1995 to obviously negative in 1996-2019. Further analysis demonstrates that the interdecadal variations of monthly SST anomaly (SSTA) and associated air-sea interactions in June and August account for the decadal variations of the precipitation relationships. During the prior period 1979-1995, the tropical West Indian Ocean (WIO) shows a significant positive SSTA in June, which triggers Kevin waves and an anticyclone circulation over the tropical Northwest Pacific (NWP). The warm and wet air transported by the southwest airflow at the north of the anticyclone provides favorable environmental condition to produce more precipitation over SC region in June. In contrast, the SST dipole pattern with the negative SSTAs in the maritime continent (MC) and positive SSTAs in the tropical Central Pacific (CP) is dominant in August. The SST dipole pattern is inconducive to the formation of anticyclone over SC, causing a weak positive precipitation correlation between June and August. During the latter period 1996-2019, the precipitation over SC in June is the same as that in the prior period as there is no significant decadal change in tropical WIO SST and East Asian circulation. However, an opposite phase of the SST dipole anomaly pattern in MC and the tropical CP is dominant in August during the latter period. Accordingly, the positive feedback mechanism of air-sea interaction leads to the enhancement of local convection activities in MC and the meridional Hadley circulations and the NWP subtropical high, leading to a decrease of precipitation over SC in August. Overall, the decadal variation of the SST dipole anomaly pattern in MC and the tropical CP is the key factor affecting the adjustment of the correlations between June and August precipitation in the two periods.

Key words: South China, Precipitation in June and August, significant negative correlation, SST dipole
1. Introduction

South China (SC) is in the East Asian (EA) monsoon region with significant intraseasonal and interdecadal variations of summer precipitation (Su et al. 2014; Ha et al. 2016; Ding et al. 2016; Ha et al. 2019; Wu et al. 2010b). The burst of the SC summer monsoon around mid-May marks the beginning of the EA summer monsoon. SC is located to the northwest side of the Northwest Pacific subtropical high (NWPSH), with significant southwest water vapor transportation, precipitation increasing and reaching the maximum precipitation in June (Ding Y H 1992; Ding et al. 2005; Karori et al. 2013). In mid-June, convection in the SC Sea intensifies, the NWPSH jumps north to control SC, which indicates the end of the rainy season in SC and the start of the Meiyu season over Yangtze-Huaihe River (Su and Xue 2010; Su et al. 2017; Feng et al. 2016). Due to the significant changes of the meridional position of the NWPSH before and after June, the circulations related to the SC precipitation during May-June and July-August are significantly different (Su et al. 2014). Yuan et al. (2019) and Su et al. (2014) found that the local cyclone and the Northwest Pacific (NWP) anticyclone are associated with the SC precipitation during May-June. And the local more significant cyclone circulation is related to the July-August precipitation, but there is no significant circulation anomaly over the NWP.

In the early 1990s and early 21st century, the summer precipitation in SC shows significant increasing and decreasing trend respectively (Ding et al. 2008; Wang et al. 2009; Wu et al. 2010b; Ha et al. 2016, 2019), and these two interdecadal variations of summer precipitation are related to the SST anomalies in the tropical Pacific and Indian Ocean. The former change is related to the Walker circulation and Hadley circulation anomalies caused by the continuous warming of the tropical Indian Ocean and Pacific Ocean in summer, which leads to the increase of snow cover in winter and spring over the Tibetan Plateau and the strengthening of the East Asian monsoon trough (Wu et al. 2010a; Zhu et al. 2014). The latter change is related to the strengthening of the circulation sinking branch in SC caused by the tropical Pacific SSTAs (Ha et al. 2016). The NWPSH also experienced the first and second mode shift of EOF decomposition in the late 1990s, which is related to the variation of SST mode in the Pacific from canonical ENSO to “Modoki” central ENSO (Huang et al., 2018; Funk et al. 2015; Li et al. 2015).
In summary, previous studies have shown that the precipitation feature of May-June is different from the July-August and the interdecadal variations of summer precipitation over SC. Under different interdecadal backgrounds, the summer precipitation in SC, the NWPSH related to precipitation and the SST anomalies all have significant interdecadal variations around 1990 (Li et al. 2015; Gong et al. 2016; Ha et al. 2016, 2019). It is necessary to further discuss if the precipitation relationships have changed between different months in summer around 1990s, and whether there are interdecadal changes in the circulation field and key areas of SST related to variable precipitation correlation. Comprehending these scientific issues will promote understanding of intraseasonal variations in precipitation and improve short-term climate prediction.

The rest of the article is organized as follows. Section 2 briefly describes the data and methods. Section 3 presents the circulations and SST related to the inverse relationship of precipitation between June and August under different interdecadal backgrounds. Sections 4 investigates the influence mechanism of SST in the tropical WIO, MC and CP on the inverse change of precipitation relationship. Sections 5 studies the Physical mechanism of gradual enhancement of SST dipole. Section 6 gives a summary and discussion.

2. Data and methods

a. Datasets

The precipitation data of 295 stations in SC from June to August in 1979-2019 are selected, which from the national daily precipitation data set published by the National Meteorological Information Center, China Meteorological Administration (CMA). Monthly mean precipitation data are from the Version2 Global Precipitation Climatology Project (GPCP) for the period 1979-2019 (Adler et al., 2003). The National Centers for Environment Prediction–Department of Energy (NCEP–DOE) Atmospheric Model Intercomparison Project-II reanalysis dataset (NCEP2), including monthly mean geopotential heigh, horizontal and vertical wind components and relative humidity are employed to analyze atmospheric circulation anomalies (Kanamitsu et al.2002). These variables are accepted from 1979-2019 with a horizontal resolution of 2.5° ×2.5 °. And other NCEP2’ surface variables, including monthly mean 10-m wind, 2-m specific humidity, skin temperature, latent heat net flux, sensible heat net flux, downward shortwave radiation flux, downward longwave
radiation flux, upward solar radiation flux and upward longwave radiation flux, which are on a T62 Gaussian grid. In addition, the downward net heat flux, downward shortwave and upward longwave radiative flux, upward latent and sensible heat fluxes and near-surface wind speed, temperature, humidity information of the sea surface/near-surface air provided by the OAFlux dataset are also adopted in the calculation (1.0° ×1.0° resolution; Yu and Weller 2007). The monthly mean subsurface temperature, oceanic current and vertical velocity from 1980 to 2019 are obtained from the NCEP Global Ocean Data Assimilation System (GODAS, 1.0° ×0.33°, with 40 vertical levels, Saha et al. 2006). The ocean data are from the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) dataset (Rayner et al. 2003), and the Extended Reconstructed SST (ERSST) version 4 (ERSST.v4, Huang et al. 2015; Liu et al. 2015). The results from the GPCP, OAFlux and HadISST are consistent with CMA, NCEP2 and ERSST.v4, we only show the results of the latter.

b. Methods

The selected SC region in this paper is 21°N-29°N;110°E-121°E (Fig. 1, Yim et al. 2014), 295 stations with continuous precipitation observation data from June to August in 1979-2019 are chosen. We define an inverse variation index of precipitation relationship between June and August in SC, Index = Pre6 − Pre8, Pre6 and Pre8 are the normalized precipitation values. The SST indices for three key regions (the rectangular boxes in Fig. 5) are defined in this paper, Tropical West Indian Ocean SST Index (WIDI, average SST in the 18°S-14°N;40°E-70°E), the maritime continent SST Index (MCI, average SST in the 10°S-18°N;120°E-144°E), the tropical Central Pacific SST Index (CPI, average SST in the 8°S-18°N;170°E-134°W) and the index of SST dipole (MCCP, MCCP = MCI − CPI). In order to specifically and quantitatively explain the physical mechanism of the SST dipole gradual enhancement from June to August, the downward net heat fluxes and latent heat fluxes in the MC and CP are decomposed. According to the articles of Wang et al. (2019) and Cheng et al. (2019), the downward net heat fluxes (Qnet↓) are the sum of the downward shortwave (SWF↓) and upward longwave (LWF↑) radiative fluxes and the upward latent (LHF↑) and sensible (SHF↑) heat fluxes.

\[ Q_{\text{net} \downarrow} = \text{SWF} \downarrow - \text{LWF} \uparrow - \text{LHF} \uparrow - \text{SHF} \uparrow \quad (1) \]

Yu and Weller (2007) and Yu et al. (2008) pointed out that the radiative fluxes are based on satellite observations while the surface latent heat fluxes are calculated using
the bulk algorithm:

$$LHF \uparrow = \rho L_e C_e U \Delta q$$  \hspace{1cm} (2)

\(\rho\) is the density of the air, \(L_e\) is the latent heat of evaporation. The turbulent exchange coefficient for latent heat fluxes is denoted by \(C_e\). \(U\) is the wind speed near the sea surface; \(\Delta q\) is the specific humidity differences between the sea surface and near-surface air. The term \(U\Delta q\) in the latent heat fluxes is determined by atmospheric and oceanic states simultaneously and the influence of these factors need to be isolated. For the latent heat flux, we have

$$LHF \uparrow = \overline{LHF} \uparrow + LHF' \uparrow$$  \hspace{1cm} (3)

and \(U\Delta q\) can be decomposed into

$$U\Delta q = (\bar{U} + U')(\Delta \bar{q} + \Delta q') = \bar{U}\Delta \bar{q} + U\Delta q' + U'\Delta \bar{q} + U'\Delta q'$$  \hspace{1cm} (4)

$$LHF' \uparrow = LHF \uparrow - \overline{LHF} \uparrow = \rho L_e C_e (U\Delta q - \overline{U\Delta q})$$

$$= \rho L_e C_e [(\bar{U} + U')(\Delta \bar{q} + \Delta q') - (\bar{U} + U')(\Delta \bar{q} + \Delta q')]$$

$$= \rho L_e C_e [\bar{U}\Delta \bar{q} + \bar{U}\Delta q' + U'\Delta \bar{q} + U'\Delta q' - \overline{U\Delta q} - \overline{U'\Delta q}]$$

$$= \rho L_e C_e [U\Delta q' + U'\Delta \bar{q} + U'\Delta q' - \overline{U\Delta q} - \overline{U'\Delta q}]$$

$$= \rho L_e C_e [U\Delta q' + U'\Delta \bar{q} + (U'\Delta q')]$$  \hspace{1cm} (5)

The latent heat is decomposed in formula (5), where the first, second and third terms are affected by the difference of specific humidity in the air-sea interaction interface, the atmospheric near-surface wind anomalies and the nonlinear interaction term (small term, can be ignored), respectively. All the linear trends and climatic mean values are removed before calculation.

3. **Circulation and SST associated with reverse index**
A 21-year moving correlation is carried out for any two months of precipitation with a moving step of 1 year. As shown in Figure 2a, there is a weak positive correlation between June and July, and a strong positive correlation between July and August, but the correlation becomes weak in recent years. Precipitation correlation between June and August is 0.25 in 1979-1995 and -0.45 (passing the 95% significance test) in 1996-2019, revealing a clear change of sign in the two different climatological periods. Figures 2b,c show the interannual and interdecadal variations and the linear trend of precipitation over SC in June and August. After 1996, these two months show obviously opposite interannual variation characteristics, the precipitation interdecadal variations are very weak and there is no obvious increasing or decreasing trend. In this paper, the raw data of precipitation (the trend and the climatic average are not removed) are also calculated and the conclusions are the same as above results (Zhu et al.2011; Leung et al. 2020).
Figure 2. (a) 21-year sliding correlation between June and July (black solid line), June and August (red solid line), July and August (green solid line). The dashed blue lines are the threshold of 90% significance test (±0.369). The interannual and interdecadal variations and trends of precipitation in June (b) and August (c) (interdecadal changes multiplied by three times).

To understand the reasons for the reverse change of precipitation relationship between June and August. The water vapor fluxes (WVF) and their convergence/divergence in Southeast Asia are regressed onto the precipitation reverse change index. During the prior period, the significant southwest water vapor transport over SC is shown in June (Fig. 3a), providing the favorite condition for the formation of precipitation. In contrast, there is no significant water vapor transport, and local water vapor divergence is weak in August (Fig. 3b). During the latter period, the strong local water vapor convergence and an increase of the southwest water vapor transport over SC are valid in June, while the local water vapor divergence associated with the anticyclone circulation over the SC is dominant in August (Fig. 3d). As a result, the precipitation in August is significantly less than those in the prior period, and a significant negative correlation between the June and August precipitation is observed.
Figure 3. The water vapor flux regressed by inverse index (vectors, $10e^{-2} kg/m \cdot s$, blue vectors indicate passing 90% significance test) and its convergence/divergence (shadings, $10e^{-5} kg/m^2 \cdot s$, passing 90% significance test) at 1000-300hPa in June (a) and August (b) during 1979-1995. (c) and (d) is as (a) and (b), but for 1996-2019.

Because the anticyclone in the NWP region is closely related to the change of the NWPSH (Lu et al. 2002; Yang et al. 2003), the 500hPa geopotential height in June and August during the two periods are also regressed onto the precipitation reverse change index. During the prior period, the significant negative potential height anomalies are in the subtropical region in June (Fig. 4a), which correspond to the cyclone in Figure 3a, and SC is located to the south of the cyclone. In August, there is no significant geopotential height anomaly in East Asia (Fig. 4b), which corresponds to the absence...
of significant anomaly of WVF in Figure 3b. During the latter period, the positive potential height anomalies are located in the south of 20°N and the significant negative potential height anomalies in East China in June (Fig. 4c) (corresponding to Fig. 3c, cyclone and anticyclone in the north and south of SC), Which are beneficial to precipitation in SC (Leung et al. 2020). The positive geopotential height anomalies gradually move northward from June to August. In August, as shown in Figure 4d, the maximum potential height anomalies are located in SC, so there are significant anticyclone and water vapor divergence in SC (Fig. 3d). In the later period positive anomaly years, the 5880 potential meter contour (588 line) is westward in June and August, indicating that the NWPSH is strong. In June, SC is located on the north side of 588 line accompanied with southwest airflow (Fig. 3c), which is conducive to precipitation. In August, the 588 line and SC are located at the same latitude, so the precipitation in SC is suppressed, which is conducive to the formation of a reverse change relationship. In the later period negative anomaly years, the 588 line is eastward in June and August, indicating that the NWPSH is weak. Therefore, the water vapor transport of NWPSH to SC in June weakens and the inhibitory effect on August precipitation also weakens, which are also beneficial to the formation of the inverse relationship between June and August precipitation (Figs. 4c,d). However, during the prior period, there are no such change regularity of the 588 line in positive and negative abnormal years (Figs. 4a,b).
Figure 4. The 500hPa geopotential height regressed by the inverse index (shadings, $m$, passing 90% significance test) and 588 lines (purple, black, blue are the average value of 588 line in positive, negative and all years respectively) in June (a) and August (b) in 1979-1995. (c) and (d) is as (a) and (b), but for 1996-2019.

4. Physical mechanism of precipitation reverse change

Figure 5. The SST regressed by the inverse change index in June (a) and August (b) during 1979-1995 (K, dotted areas pass 90% significance test). (c) and (d) is as (a) and (b), but for 1996-2019 (rectangular boxes indicate the location of key marine areas).

In order to further clarify the reasons why the evolution process of the local circulation in SC and NWPSH from June to August change significantly around 1996, the SST in Indian and pacific are regressed against the inverse change index during
two periods. During the prior period, the regressed SST shows the positive SSTA over
the tropical CP and the tropical WIO in June (Fig. 5a), and the dipole SST anomaly
over MC (negative SSTA) and tropical CP (positive SSTA) in August (Fig. 5b). During
the latter period, there are also positive SSTA over the tropical WIO in June, but the
tropical CP is a significant negative SSTA (Fig. 5c). In August, the anomalous SST
dipole, with positive SSTA over MC and negative SSTA over tropical CP, is opposite
to the prior period (Fig. 5d). In other words, the significant change of precipitation
relationship between June and August during the two periods may be related to the
phase shift of dipole SST.

Previous studies pointed out that the IO warming excites a Matsuno–Gill-type
response in tropospheric temperature, with the Kelvin wave wedges penetrating the
equatorial western Pacific, resulting in the enhancement of NWP anticyclone and
NWPSH (Terao et al. 2005; Xie et al. 2008; Wu et al. 2009). Especially in June, the
warm tropical Indian Ocean can only affect the precipitation in the south of the
Yangtze River (Yuan et al. 2019; Zheng et al. 2021). The dipole of the MC and the
tropical CP also have independent and coordinated effects on the NWPSH (Gill, 1980;
Lu et al. 2006; Sui et al. 2007; Wu et al. 2010a; Chung et al. 2011; Wang et al. 2013;
Xiang et al. 2013), which have been verified by numerical simulation (Wu et al. 1992;
Chung et al. 2011; Wang et al. 2013; Yuan et al. 2019). During the prior period, the
pattern of the water vapor transports and tropospheric temperature regressed against
the tropical WIO SST in June verify the previous research results. SC is located in the
northwest of the anticyclone, and the southwest direction of water vapor transport is
conducive to the increase of precipitation (Fig. 6a). At this time, there is no significant
abnormality of the circulation over SC and the meridional Hadley regressed onto the
SST dipole index (Figs. 6c, 7a). In August, although the intensity of SST dipole is
strengthened (Fig. 5b), it has little influence on the circulation over SC and the
meridional Hadley (Figs. 6d, 7b). During the latter period, the results of the June
tropical WIO SST regression are consistent with those of the prior period (Fig. 6b). At
this time, the SST dipole can cause convergence ascending motion in SC (Figs. 6e, 7c),
further enhancing the precipitation in June. The influence of SST dipole on SC in
August is far greater than that in the prior period, SC is accompanied with remarkable
anticyclone, positive potential height, divergence of wind and sinking movement
(Figs. 6f, 7d). From June to August, the intensity of the SST dipole is gradual
increasing (Figs. 5c, d), which leads to the convective activity increasing, the
meridional Hadley circulation ascending and descending branches strengthening (Figs. 7c,d) and finally enhancing the NWPSH (Figs. 6e,f). However, the phase of SST dipole during the prior period is opposite to the later period (Figs. 5b,d), which weakens the intensity of NWPSH. Finally, the precipitation relationship between June and August over SC changes from the weak positive correlation to the significant negative correlation.

**Figure 6.** The average air temperature at 850hPa-250hPa (shadings, °C, passing 90 %
significance test) and 850hPa wind (vectors, $m/s^{-1}$, blue vectors indicate passing 90% significance test) in June during the prior (a) and latter (b) period regressed onto the tropical WIO. The 850hPa wind (vectors, $m/s^{-1}$, blue vectors indicate passing 90% significance test) and its convergence/divergence (shading, $s^{-1}$, purple counters indicate passing 90% significance test) and 500hPa geopotential height (red counters, $m$, passing 90% significance test) in June (c) and August (d) during 1979-1995 regressed onto the SST dipole. (e) and (f) is as (c) and (d), but for 1996-2019.

Figure 7. The average vertical velocity (shadings, $10^{-2}$ Pascal $* s^{-1}$, purple counters indicate passing 90% significance test) and meridional-vertical velocity
The physical mechanism of gradual enhancement of SST dipole

The physical mechanism of the interdecadal variation of precipitation relationship between June and August over SC has been studied above. The Pacific SST dipole gradually increases from June to August, which plays a crucial role. So why does the SST dipole grow from June to August? The role of local air-sea interactions in the interseason variation of the SST dipole are discussed in the following studies. First of all, it is stated that the positive feedback of air-sea interaction during the two periods are consistent, but the phase of SST dipole in the prior and latte period is opposite (Figs. 5b,d), which leads to completely opposite results. This article only shows the latter period results. Figure 8 presents the evolution of the latitude-vertical velocity anomalies regressed against SST dipole index. The SST dipole forms a closed circulation circle, with the significant easterly and westerly winds in the low and high level and the significant upward and downward movements in the MC and the tropical CP, respectively, which lead to the intensification of convective activities in the MC and the enhancement of the meridional Hadley circulation (Figs. 7c,d).

Figure 8. The average vertical velocity (shadings, $10^{-2}$ Pascal $\cdot$ s$^{-1}$, purple counters indicate passing 90% significance test) and latitude-vertical velocity (vectors, m $\cdot$ s$^{-1}$, black vectors indicate passing 90% significance test) in 5°S -5°N in June (a) and August (b) during 1995-2019 regressed onto the SST dipole.
The results of SST dipole regression of 10 m wind show that the MC and tropical CP are abnormal northeast and easterly winds in June, which are superimposed on the climatic wind fields and make the local wind speed decrease and increase respectively (Fig. 9a). August and June are similar, but the abnormal degree is further strengthened in August (Fig. 9b). The significantly abnormal easterly winds cause the warmer ocean currents flowing westward from the tropical CP to the MC, and the colder deep ocean currents flowing eastward from the MC to the tropical CP (Figs. 9c,d). Thereby forms a closed ocean current and further strengthens the intensity of the SST dipole (Xie et al. 1999; Kug et al. 2006; Ham et al. 2007).

Figure 9. The 10 m climatic wind (shadings and vectors are wind velocity and wind direction, m/s) regressed onto the SST dipole in June (a) and August (b) during 1996-2019. The latitude-vertical subsurface current (vectors, m/s, passing 90% significance test, latitude and vertical velocity multiplied by 10 and 10^5) and subsurface sea temperature (shading, K, passing 90% significance test) in June (c) and August (d) during 1996-2019 regressed onto the SST dipole.

Equatorial easterly wind anomalies triggered by SST dipoles can not only cause changes of ocean currents, but also cause significant changes of the net radiation flux,
latent heat flux and the first, second and third items of latent heat flux (Fig. 10). The regression results show that the significant increase of the net radiation fluxes over the MC in June and August are mainly due to the contribution of the decrease of latent heat release (Fig. 10a). The second term of the latent heat flux related to the sea surface wind speed plays an absolute role in the significant decrease of the latent heat flux release (Fig. 10b). This is related to that the climatic winds of the MC are southwest and southeast winds, but the SST dipole will cause easterly and northeasterly wind anomalies (Figs. 8a,b; Figs. 9a, b). The net radiant fluxes and latent heat flux only pass the 90% significance test in August over tropical CP (Fig. 10c), which may be due to the cooling of the tropical CP mainly comes from the upturn of the cold water (Figs. 9c,d). The latent heat flux and the second term of latent heat flux related to wind speed are also the main reasons for the decrease of net radiation flux over CP (Figs. 10c,d).

In summary, the anomalous SST dipole will enhance the equatorial easterly winds, promote the warmer ocean currents westward to the MC and reduce the latent heat release, resulting in the warming of SST. However, it will increase the release of latent heat over the CP and the upturn of the colder water, resulting in the cooling of SST. Finally, the strength of the SST dipole is further strengthened, forming a positive feedback mechanism.

**Figure 10.** (a) The downward net heat (red), upward latent (orange) and sensible heat (blue), downward shortwave radiative (green), upward longwave radiative (yellow) fluxes during 1996-2019 regressed onto the MC SST index. (b) The upward latent (orange), latent heat flux first term (gray), latent heat flux second term (light blue) and latent heat flux third term (black) during 1996-2019 regressed onto the MC SST index. (c) and (d) is as (a) and (b), but for the CP SST index. (The tropical CP is negative}
SST A, so it is reversed before the regression. The rectangle symbols indicate passing the 90% significance test.

6. Summary and discussion

This paper is based on China's daily precipitation data and reanalysis data from June to August during 1979-2019, using 21-year sliding correlation, regression analysis, and sea surface heat flux decomposition methods. We reveal the interdecadal variation of precipitation relationship between June and August over SC around 1996 and further study its physical mechanism. The relationship between June and August precipitation over SC changes from a weak positive correlation (0.25) in 1979-1995 to a significant negative correlation (-0.45, passing 95% significance test) in 1996-2019. During the prior period, the tropical WIO is a significant positive SST A in June, which excites the Kelvin wave and forms an anticyclone circulation over the tropical NWP. At the north side of the anticyclone, the warm and wet water vapor transported by the southwest airflow combined with the local convergences lead to more precipitation in June over SC. The SST dipole anomaly is negative SST A over MC and positive SST A over tropical CP in August, which is not conducive to the formation of anticyclone over SC, resulting in weak positive correlation between June and August precipitation. During the latter period, the tropical WIO SST and East Asian circulation are the same as the prior period in June, but the phase of SST dipole is opposite to the prior period. The SST dipole produce the significant easterly wind anomalies at the equator, which cause the decrease of latent heat fluxes release and the inflow of warmer currents in MC, and the increase of latent heat fluxes release and the upturn of the colder water in tropical CP. The SST dipole reaches its peak in August through the positive feedback mechanism of air-sea interaction, which leads to the enhancement of local convection activities in MC and the meridional Hadley circulations and the NWP subtropical high, and the decrease of precipitation over SC. Therefore, the variation of the SST dipole anomaly pattern in the MC and the tropical CP plays a crucial role in leading to the significant negative correlation between June and August precipitation in the latter period.

Compared with previous studies that they only study the interdecadal variation of summer precipitation over SC (Ding et al. 2008; Wang et al. 2009; Wu et al. 2010b; Ha et al. 2016, 2019), or the physical mechanism of precipitation in early and late rainy seasons (Yuan et al. 2019). This paper further studies the interdecadal variation of the
inverse precipitation relationship between June and August over SC, which has important practical significance to forecast precipitation in rainy seasons.

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