RELATIONSHIP BETWEEN THE 30 TO 60 DAY OSCILLATION OF ATMOSPHERIC HEAT SOURCE AND THE DROUGHT AND FLOOD EVENTS IN JUNE IN THE SOUTH OF CHINA

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Abstract: Based on the NCEP/NCAR reanalysis data and the observed precipitation data in the south of China from 1958 to 2000, the impact of 30 to 60 day oscillation of atmospheric heat sources on the drought and flood events in June in the south of China is discussed. During the flood (drought) events, there exists an anomalous low-frequency anticyclone (cyclone) at the low level of the troposphere over the South China Sea and the northwestern Pacific, accompanied with anomalous low-frequency heat sinks (heat sources), while there exists an anomalous low-frequency cyclone (anticyclone) with anomalous heat sources (sinks) over the area from the south of China to the south of Japan. On average, the phase evolution of the low-frequency in drought events is 7 to 11 days ahead of that in flood events in May to June in the south of China. In flood events, low-frequency heat sources and cyclones are propagated northward from the southern South China Sea, northwestward from the warm pool of the western Pacific and westward from the northwestern Pacific around 140°E, which have very important impact on the abundant rainfall in June in the south of China. In drought events, the northward propagations of the low-frequency heat sources and cyclones from the South China Sea and its vicinity are rather late compared with those in flood events, and there is no obvious westward propagation of the heat sources from the northwestern Pacific. The timing of the low-frequency heat source propagation has remarkable impact on the June rainfall in the south of China.

Key words: climatology; statistical feature; atmospheric heat source; 30-60 day oscillation; flood and drought; the south of China

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1 INTRODUCTION

The rainfall in the south of China occurs mainly from April to September (a rainy season), and the associated rainfall amount is the key factor to drought/flood conditions in the south of China. According to the difference in dominant precipitation systems, the rainy season is divided into the first rainy season (April to June) and the second rainy season (July to September). Persistent heavy rainfall and the resulting extensive flooding disaster are often observed during the first rainy season in the south of China. Therefore, study on influence factors and forecasting of rainfall in the annually first rainy season has been one of the most significant research areas in meteorology[1-3]. Relationships between the entire rainfall in the rainy season of the south of China and the other factors were examined in many previous studies. However, correlation coefficients between rainfall in April and rainfall in May and that between rainfall in May and rainfall in June over the south of China during 1958–2000 are both insignificant at a 0.05 significance level, indicating that the south of China rainfall anomalies in April, May, and June are not in phase with each other. Hence it is highly necessary to investigate the month-by-month rainfall variability in the south of China. On multi-year average, the heaviest rainfall occurs in June, and persistent heavy rainfalls as well as flood events are frequently observed in June in the south of China. Zheng et al.[4] found that two different types of rainfall, frontal rainfall and summer monsoon (SM) rainfall, occur during the first rainy season in the south of China. They also determined the beginning
date of SM rainfall in the south of China as 24 May, under the climatological mean condition, by using a criterion that 100-hPa zonal wind shifts from westerly to easterly and easterly persists for over five days. It indicates that June rainfall in the south of China is primarily affected by the South China Sea summer monsoon (SCSSM).

Lots of studies showed that 30 to 60 day low-frequency oscillation has significant impact on the onset of SCSSM and the rainstorm process in southern China. Chen and Chen[5] examined intraseasonal oscillation (ISO) of the 1979 SCSSM activity and found that SCSSM was modulated by the northward-migrating 30 to 60 day monsoon troughs/ridges, the monsoon onset occurred when the 30 to 60 day monsoon trough and the 10 to 20 day low center arrived concurrently at the northern South China Sea (SCS) in the middle of May, while the breaks occurred when the 30 to 60 day monsoon ridge lines and the 10 to 20 day high center met in the northern SCS. Lin[6] used multi-year outgoing longwave radiation (OLR) data to investigate the characteristics of interseasonal variation of ISO in SCS and its relation to the establishment and activity of SCSSM. Results showed that the intensity of ISO is higher during the SM period than that during the winter monsoon period, and the establishment of summer monsoon is in the negative phase (i.e., wet phase) of the first strong oscillation. Mao and Chan[7] explored the interannual variability of ISO during the SCSSM period and found that the 30 to 60 day and 10 to 20 day oscillations are the two major intraseasonal modes that control the SCSSM activities for most of the years. Recently, Wang et al.[8] provided a review on the multi-scale variations of SCSSM which addressed the intraseasonal variability and interannual variability and related mechanisms. For the northwestern Pacific SM, the climatological ISO is mainly composed of 30 to 60 day and 10 to 20 day oscillations while the 30 to 60 day oscillation is significant (Wang et al.[9]). The extreme flood event over the middle and lower reaches of the Yangtze River in the summer of 1998 was associated with the convergence of northward-propagating SCS low-frequency cyclones and southward-propagating mid-high latitude low-frequency cyclones (Chen et al.[10]; Chen et al.[11]). Ju et al.[12] found that flooding (drought) in the middle and lower reaches of the Yangtze River is associated with the strong (weak) East Asia SM surges, and the 30 to 60 day oscillation is most remarkable in the years with strong SM surge over the SCS. Both of the successive heavy rain events over the south of China during June–July of 1994 and that in June of 2005 were closely related to northward-propagating SCS 30 to 60 day oscillations (Shi and Ding[13]; Lin and Liang[14]).

The atmospheric heat source (i.e., diabatic heating) plays an important role in driving atmospheric circulation. The vertical motion with convective condensation heating would be one order of magnitude larger than that without convective condensation heating over the tropical regions (Holton[15]). Therefore, an abnormal atmospheric heat source can induce abnormal atmospheric circulation, and then results in abnormal precipitation. Jiang and Luo[16] found that there exists 30 to 60 day oscillations of atmospheric heat sources over the Asian monsoon area using the 1980–1983 data taken from the European Centre for Medium-Range Weather Forecasts (ECMWF). However, the time period of the data was short. Until now, studies on the impacts of low-frequency oscillations of atmospheric heat sources on June rainfall in the south of China are very limited. Therefore, this study will examine the relationship between the flood/drought events in June in the south of China and 30 to 60 day oscillations of atmospheric heat sources.

2 DATA AND CALCULATION OF ATMOSPHERIC HEAT SOURCE

Daily wind, temperature and vertical motion fields at 12 standard pressure levels (1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150 and 100 hPa) on the 2.5° × 2.5° latitude-longitude grids are taken from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR, USA) reanalysis dataset (Kalnay et al.[17]). We also use the monthly precipitation data of 160 stations in the mainland of China compiled by China National Climate Center. All these data cover 43 years from 1958 to 2000.

The inverse calculation of the apparent heat source $Q_1$ (Yanai et al.[18]; Luo and Yanai[19]) is used. $Q_1$ is computed with

\[ Q_1 = \int \frac{\partial T}{\partial t} dt + \nabla \cdot \mathbf{V} T + \left( \frac{\partial}{\partial P_0} \right) \frac{\kappa}{\omega} \frac{\partial T}{\partial P} \]  

where $T$ is the temperature, $\mathbf{V}$ the horizontal wind, $\kappa$ the potential temperature, $\omega$ the vertical p-velocity, $\kappa = \mathcal{R} c_p$, $\mathcal{R}$ and $c_p$ are the gas constant and the specific heat at constant pressure of dry air, respectively. $P_0$ is 1000 hPa.

The vertical integration of $Q_1$ is denoted as

\[ \langle Q_1 \rangle = \frac{1}{g} \int P S Q_1 dp \approx LP + S + \langle Q_R \rangle , \]  

where $L$ is the latent heat of condensation, $P$ the precipitation, $S$ the surface sensible heat flux, $\langle Q_R \rangle$ the vertically integrated radiation heating, $P_S$ and $P_T$ are the pressure at ground surface and the pressure at the top of the atmosphere (usually 100 hPa, where the eddy motion vanishes), respectively. The vertical integration of the atmospheric heat source $\langle Q_1 \rangle$.
(hereafter atmospheric heat source) is adopted in this study. The 30 to 60 day components of the atmospheric heat source and wind field are obtained by applying Butterworth band-pass filter to original time series.

3 RESULTS

3.1 Determination of drought/flood years for June in the south of China

Following the method used by Wu et al. [20], we first calculate the standard deviations of June rainfall for the 160 stations in mainland China, treat the station with maximum standard deviation in the south of China as the base station, and then get the spatial one-point correlation between the June rainfall of the 160 stations and that of the base station. Therefore the rainfalls have relatively consistent variation in significantly correlated areas. Figure 1a indicates the standard deviations of June rainfall for the 160 stations in China during the period 1958–2000. Relatively higher variation in June rainfall occurs in southern China, high-variation areas are located in the south of China and south of the Yangtze River, and June rainfall of Heyuan, Guangdong shows the maximum variation (242 mm/month). Hence Heyuan is selected as the base station to calculate the one-point correlation. Figure 1b shows the one-point correlation. Significant positive correlations are shown in the shaded area. It indicates that June rainfall in the south of China has consistent interannual variation characteristics. Thus averaged June rainfall of 18 stations in the shaded area, including Fuzhou, Yongan, Guangchang, Ganzhou, Hengyang, Meixian, Shantou, Qujiang, Heyuan, Guangzhou, Guilin, Liuzhou, Wuzhou, Nanning, Beihai and Baise, is considered as the rainfall of June for the south of China.

![Figure 1](image1.png)

Figure 1. (a) Standard deviations of June rainfall for 160 stations in mainland China. (Values in shaded area are over 80 mm/month) (b) One-point correlation map of June rainfall when Heyuan is the base station (Shaded areas indicate the 95% significance level).

Figure 2 shows standardized time series of June rainfall anomalies in the south of China during the period 1958–2000. It indicates that June rainfall in the south of China is dominated by interannual variation. The amplitude of interannual variation was quite evident before the 1970s, and then started to decrease, finally began to increase again after the 1990s. In addition, with respect to interdecadal variation, the anomalies showed a positive phase before the late 1970s, a negative phase in the 1980s, and a positive phase again after the 1990s. As we set the thresholds of standardized anomalies for flood and drought years as 0.8 and −0.8, respectively, there are 9 flood years (1959, 1962, 1964, 1966, 1968, 1977, 1993, 1994, and 1998) and 8 drought years (1960, 1967, 1980, 1985, 1987, 1988, 1989, and 1999).

![Figure 2](image2.png)

Figure 2. The standardized time series of June rainfall anomalies in the south of China during the period 1958–2000.

3.2 Relationship between drought/flood events in June in the south of China and 30 to 60 day oscillations of atmospheric heat source and wind field

To examine the relationship between the drought/flood events in June in the south of China and 30 to 60 day oscillations (hereafter ISO1) of the
atmospheric heat source and wind field, composite analysis is employed on monthly mean ISO1 atmospheric heat source (Figure 3) and 850 hPa wind field (Figure 4) in the drought and flood years, respectively.

During flood years (Figures 3a and 4a), in the lower troposphere, an anomalous low-frequency anti-cyclone occurs over the western North Pacific (WNP) from Indochina Peninsula and the SCS to the southeast of Japan, where convective activity is weaker than normal, corresponding to anomalous low-frequency heat sinks (negative anomalies); and an anomalous low-frequency cyclone occurs from the south of China to southern Japan accompanied with anomalous low-frequency heat sources (positive anomalies), low-frequency northerly winds over the northern part, and low-frequency southerly winds over the southern part, of the south of China, result in low-level anomalous convergence, corresponding to the rainy condition in the south of China.

The conditions during drought years (Figures 3b and 4b) are opposite to those during the flood years. In the lower troposphere, an anomalous low-frequency cyclone occurs over WNP from Indochina Peninsula and the SCS to the southeast of Japan, corresponding to anomalous low-frequency heat sources, and low-frequency heat sinks occur in the south of China. Low-frequency northerly winds appear both in the northern and southern part of the south of China, while low-frequency northerly winds in the southern part are much stronger, resulting in low-level anomalous divergent over the south of China.

3.3 Spatial structure and propagation features of ISO1 in drought/flood years for June in the south of China

To clearly identify propagation features of ISO1 in severe drought/flood years, ISO1 components of the atmospheric heat source and 850 hPa wind field are composed phase by phase taking reference to the method in Zhu et al.\cite{21}. Temporal evolution of the ISO1 filtered area-averaged atmospheric heat source in the south of China (105 to 120°E, 22.5 to 25°N) is similar to sine function. Generally speaking, one ISO1 cycle is composed of positive and negative anomalies (active and inactive periods), and the peak (trough) amplitude of positive (negative) anomalies is larger than standard deviation. There is always a full cycle from May to June, and the peak occurs in June. One cycle is divided to 9 phases for composition, as shown in Figure 5. The mean dates of all the 9 phases for the 9 flood years and 7 drought years (1999 is excluded because no peak occurred in that year) are indicated in Table 1. It shows that the phases in the flood years occurred 7 to 11 days prior to the same phases in the drought years.
Figure 5. Sketch map of phase division for atmospheric heat source.

Table 1. Mean dates of all phases for atmospheric heat source in drought/flood years (month/day).

<table>
<thead>
<tr>
<th>Phase</th>
<th>1</th>
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3.3.1 Spatial structure and propagation of ISO1 in flood years for June in the south of China

Figure 6 shows the composite map of the atmospheric heat source and 850 hPa wind field in the flood years for June in the south of China. In Phase 1 (Figure 6a), a weak low-frequency heat source (LHS) occurs in southern SCS; in the lower troposphere, intense LHS and an obvious low-frequency cyclone occur over the Warm Pool in tropical western Pacific, and extend northward in Phase 2 (Figure 6b). LHS over the SCS enhances and moves northward, a zonal belt of LHS is located from Indochina Peninsula to northern Warm Pool. In Phase 3 (Figure 6c), LHS over the SCS intensifies further and LHS over the Warm Pool shrinks northward and westward, then strong LHS over the Warm Pool connects with that over the SCS, resulting in a tilted northeast-southwest belt with strong LHS. In Phase 4 (Figure 6d), LHS around 140°E over WNP expands westward and LHS east of the Philippines moves northward to the nearby island of Taiwan; LHS over the SCS intensifies and moves further northward, and at the same time a low-frequency anticyclone occurs in the south of the Philippines. In Phase 5 (Figure 6e), the LHS belt from Indochina Peninsula to WNP breaks off, LHS over Indochina Peninsula moves southwest to east of Bay of Bengal, and LHS over WNP tends to move westward; LHS around the SCS and the Philippines moves northward and its center lies around Taiwan Island, and this strong LHS extreme belt continues to move northward and arrives in the south of China with intensified LHS in Phase 6 (Figure 6f). The low-frequency cyclone extends from the south of China to southern Japan. In Phase 7 (Figure 6g), the low-frequency heat source and cyclone are most intense, while the locations of low-frequency heat source, heat sink, cyclone and anti-cyclone are almost opposite to those in Phase 3. A low-frequency heat source and cyclone over the south of China start to weaken and move northward in Phase 8 (Figure 6h).

The above results indicate that the northward propagation of LHS from the southern SCS, the northwestward propagation of LHS from the Warm Pool, and the westward propagation of LHS around 140°E are quite evident during June in the flooding years in the south of China, and they have significant impact on the June rainfall in the region.

Phase-latitude maps of heat sources averaged along 110 to 120°E and longitude-phase maps of heat sources averaged along 22.5 to 25°N (Figure 7) are used to clearly identify longitudinal and zonal propagation and corresponding propagation speed. Figure 7, together with the mean dates of all the 9 phases (Table 1), indicates that northward propagation of LHS since Phase 1 (May 16th, one month before Phase 7) from the southern SCS and westward propagation of LHS since Phase 3 (May 25th, 20 days before Phase 7) from the mid-latitude WNP around 140°E are quite evident during June in the flooding years in the south of China, and they have significant impact on the June rainfall in the region.

Phase-latitude maps of heat sources averaged along 110 to 120°E and longitude-phase maps of heat sources averaged along 22.5 to 25°N (Figure 7) are used to clearly identify longitudinal and zonal propagation and corresponding propagation speed. Figure 7, together with the mean dates of all the 9 phases (Table 1), indicates that northward propagation of LHS since Phase 1 (May 16th, one month before Phase 7) from the southern SCS and westward propagation of LHS since Phase 3 (May 25th, 20 days before Phase 7) from the mid-latitude WNP around 140°E are highly visible. LHS intensifies significantly when it arrives near 130°E in Phase 4 (May 31st) and then continues to intensify and reaches the maximum in the south of China in Phase 7 (June 25th). The westward propagation speed and northward propagation speed are estimated to be 1.4 and 0.6 m s⁻¹, respectively, based on Figures 7a and 7b.
Figure 6. Phase composite map of $<Q1>$ (shaded area, unit: W m$^{-2}$) and 850 hPa wind field (vector, unit: m s$^{-1}$) in flood years for June in the south of China. (a)–(h) denote Phase 1 to 8, respectively. The shaded area indicates positive $<Q1>$ anomalies, in which there are low-frequency heat sources, and low-frequency heat sinks occur elsewhere.
3.3.2 Spatial structure and propagation of ISO1 in drought years for June in the south of China

Figure 8 shows the composite map of the atmospheric heat source and 850 hPa wind field in the drought years for June in the south of China. From Phase 1 to Phase 3 (Figures 8a to 8c) LHS around the SCS intensifies continuously and results in a belt with high LHS, which does not move northward until Phase 5 (Figure 8e, June 15th, 7 days before Phase 7). In Phase 4 and Phase 5 (Figure 8d and 8e), a LHS belt occurs south of the Yangtze River and area to its east, and this belt enhances in Phase 6 and merges with a LHS belt in the southern part of southern China in Phase 7 (June 22nd), so that LHS in the south of China reaches the maximum. Westward extension of LHS over WNP is not evident, and there is no northwestward propagation of LHS from the Warm Pool to the south of China. Phase-latitude maps and longitude-phase maps of heat sources in the drought years (Figure 9) clearly indicate the convergence of atmospheric heat sources in the southern and northern parts of the south of China. However, the propagation of heat sources is not as evident as that in the flood years (Figure 7). It is also shown that LHS in the drought years is weaker than that in the flood years (Figure 6).
4 CONCLUSIONS

This study investigates 30 to 60 day oscillations of the atmospheric heat source and 850 hPa wind field in East Asia and western Pacific region in the drought/flood years for June in the south of China, with the primary findings shown as follows.

(1) In the flood (drought) years, in the lower troposphere, an anomalous low-frequency anti-cyclone (cyclone) occurs over WNP from the SCS to the southeast of Japan, corresponding to anomalous low-frequency heat sinks (sources). An anomalous low-frequency cyclone (anti-cyclone) occurs from the south of China to southern Japan, corresponding to anomalous low-frequency heat sources (sinks). Low-level anomalous convergence (divergence) occurs over the south of China.

(2) On average, phase evolution of 30 to 60 day oscillations during May and June over the south of China in the drought years is 7 to 11 days later than that in the flood years.

(3) In the flood years, the northward propagation from southern SCS, the northwestward propagation from the Warm Pool in WNP and the westward propagation from the mid-latitude WNP around 140°E of low-frequency heat sources during May and June are quite evident, and they play an important role in heavy rain in the south of China. Westward propagation speed is about 1.4 m s⁻¹, and northward propagation is about 0.6 m s⁻¹. In the drought years, westward propagation of low-frequency heat sources from WNP is not obvious, and low-frequency heat sources over the south of China begin to propagate till mid-June, merging with the southward-propagating low-frequency heat sources from the south of the Yangtze River. Low-frequency heat sources over the
south of China in the drought years are weaker than in the flood year, resulting in less rainfall in June. Therefore the timing of the northward propagation of low-frequency heat sources from the SCS and westward propagation of low-frequency heat sources from the tropical WNP have significant impact on the June rainfall in the south of China.

REFERENCES:
