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# **Analysis for the Effect of Sea Surface Temperature (SST) on the Coastal Environments of Jiangsu Province, China**

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Additional information is available at the end of the chapter

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## **Abstract**

In this chapter, we present the analysis for the effect of summertime SST on the coastal environments of Jiangsu province, China. We analyze the relationship between the SST and the Jiangsu precipitation in summer based on GPCP's precipitation data and NOAA's SST data from 1979 to 2011, using approaches that include correlation analysis, regression analysis, and lead-lag analysis. The results show that certain strong oceanic signals affect summer Jiangsu precipitation, showing that SST of some oceanic areas significantly affect the precipitation of Jiangsu in summer. By the lead-lag analysis, it is found that the spring SST plays an important role in the summer precipitation in the coastal areas of Jiangsu, China.

**Keywords:** Jiangsu province, precipitation, sea surface temperature, Pacific Ocean, summer

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## **1. Introduction**

As one of the world's most densely populated regions, Jiangsu province, is dominated by the well-known East Asian monsoon. The economy and society are quite vulnerable to the variability in the summer precipitation [1]. Being located in the downstream of the Yangtze River, droughts and floods occur in Jiangsu province in summer.

According to the previous studies, many events occurring in the ocean could affect the precipitation of Jiangsu, such as ENSO and IOD.

The first studies about ENSO influence on precipitation events worldwide are dating back to the early 1920s [2]. More recent works are from the 1980s [3, 4].

Influenced by the continental and oceanic processes, Southeast China is affected by the precipitation related large-scale atmospheric circulation patterns. Over the Southeast China, some patterns have been demonstrated to be influential for the interannual variability of precipitation, such as East Asian Winter Monsoon, ENSO, the strength and position of the East Asian trough, Siberian High, and sea surface temperature (SST) of South China Sea [5–7].

The relationship between the SST anomalies over tropical Pacific and the climate of South China has changed after the late 1970s [8, 9], which is partially associated with the tropical SST patterns shifting from “conventional” ENSO SST to ENSO Modoki-like conditions in recent three decades [10, 11].

Previous work has shown that positive IOD events induce a stronger South Asian High, with an eastward-extending position and a strengthened Western Pacific subtropical high and with a westward-extending position [12], which leads to precipitation anomalies in East China and causes extremely hot and dry summers in South China by generating a Rossby wave train [13].

Tibetan Plateau underwent interdecadal warming around 2002, which led to the interdecadal shift northward of the West Pacific Subtropical High, and consequently, the interdecadal increase of summer precipitation over the Huaihe River valley during 2002–2010 in comparison to 1979–2001 [14].

Li and Leung found that there has been a tendency for enhanced summer precipitation over the Yangtze River valley and South China, but drought over North and northeastern China after the end of the 1970s [15]. It is claimed that the transformation is related to the Arctic spring warming. And some research found that compared with the above factors, the SST has played the greatest extent role on the decadal variability of precipitation in China [16]. Yang and Lau demonstrated that the upward trend of spring precipitation over southeastern China and downward trend of summer precipitation over northern China are attributable to the warming trend of the ENSO-like mode [17].

By reviewing the previous studies, although much research has examined the correlation between SST and precipitation, only a few have considered SSTs' influence on the precipitation of Jiangsu province. This study analyzes the relationship between the SST and the summer precipitation of Jiangsu province and discusses the lead-lag relationship between them.

## 2. Data and methods

### 2.1. Data

#### 2.1.1. NOAA data

National Oceanic and Atmospheric Administration (NOAA) monthly mean SST data from 1979 to 2011, with a horizontal resolution of  $2.5^\circ \times 2.5^\circ$  and  $180 \times 89$  grid points.

2.1.2. GPCP version 2.3 combined precipitation data set

Monthly precipitation dataset are provided by Global Precipitation Climatology Project (GPCP) from 1979 to 2011 combines observations and satellite precipitation data into 2.5° × 2.5° global grids.

2.2. Methods

2.2.1. Calculation of standardization index

Z-SCORE standard method is used to measure the relationship between a value and the mean in a group of values [18]:

$$K_i = \frac{X_i - \bar{X}}{S} \quad i = 1, 2, 3, \dots, n \tag{1}$$

where  $X_i$  is the sample value,  $\bar{X}$  represents the mean of the sample, and  $S$  is the standard deviation of the sample.

A positive value indicating the score is above the mean and a negative score indicating it is below the mean. If the absolute value of  $K_i$  is greater than 1, we take it as abnormal.

2.2.2. Correlation analysis

In this chapter, to measure whether there is a linear relationship between the selected variables, we perform Pearson correlation test on the data. The formula is [19]:

$$r = \frac{1}{n-1} \sum_{i=1}^n \left( \frac{X_i - \bar{X}}{s_X} \right) \left( \frac{Y_i - \bar{Y}}{s_Y} \right) \tag{2}$$

where  $n$  is the sample size,  $r$  lies between  $-1$  and  $1$ . When the value is above  $0$ , it indicates that the two variables are positively correlated. When it is less than  $0$ , the two variables are negatively correlated, and a T-test should be carried out to judge the relevant level.

2.2.3. Mann-Kendall test

Mann-Kendall trend test is a nonparametric test used to identify a trend in a series, even if there is a seasonal component in the series. We assume that the observations are independent before our computations [20, 21].

The formula is expressed as [20, 21]:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}}, & S < 0 \end{cases} \tag{3}$$

The test statistic  $Z_c$  is used as a measure of the significance of a trend.

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^n \text{sgn}(x_k - x_i) \tag{4}$$

where  $x_k$  and  $x_i$  are the annual values in years  $k$  and  $i$  and  $k > i$ , respectively.

$$\text{var}[S] = \left[ n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) \right] / 18 \quad (5)$$

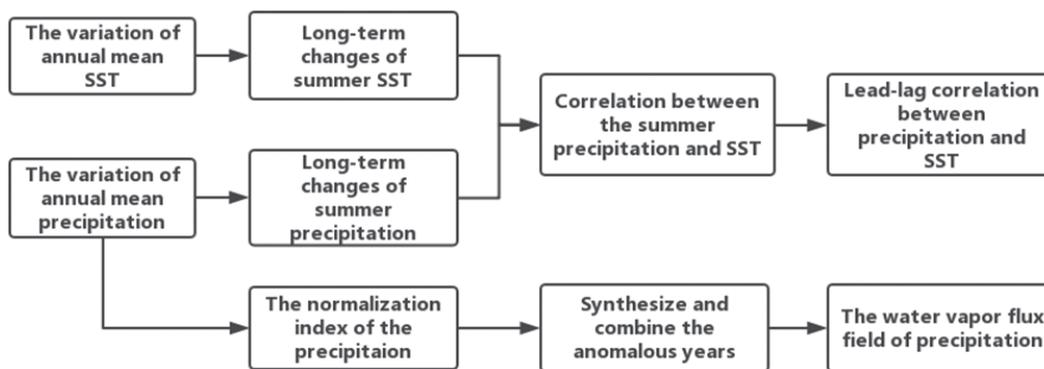
where  $t$  is the observations' number.

$$\beta = \text{Median} \left( \frac{x_i - x_j}{i - j} \right), \forall j < i \quad (6)$$

$1 < j < i < n$ ,  $\beta$  represents the slope; the positive value rises, and negative value declines.

### 2.3. Technology flowchart

See **Figure 1**.



**Figure 1.** Flowchart of the study.

## 3. Results and discussion

### 3.1. Long-term variation of SST

The variations of SST in summer are studied first, as well as annual average from 1979 to 2011. During this period, according to the result, SSTs have fluctuated along an upward trend. Both trends for two SSTs pass the M-K test of 99% confidence with values of 5.3146 and 5.0667—thus the upward trend is significant. Specifically, the annual average SST has increased from 13.8 to 14°C, and the summer SST has increased from 13.9 to 14.2°C. Our results are consistent with those in [22, 23].

### 3.2. Long-term variation of the precipitation of Jiangsu province

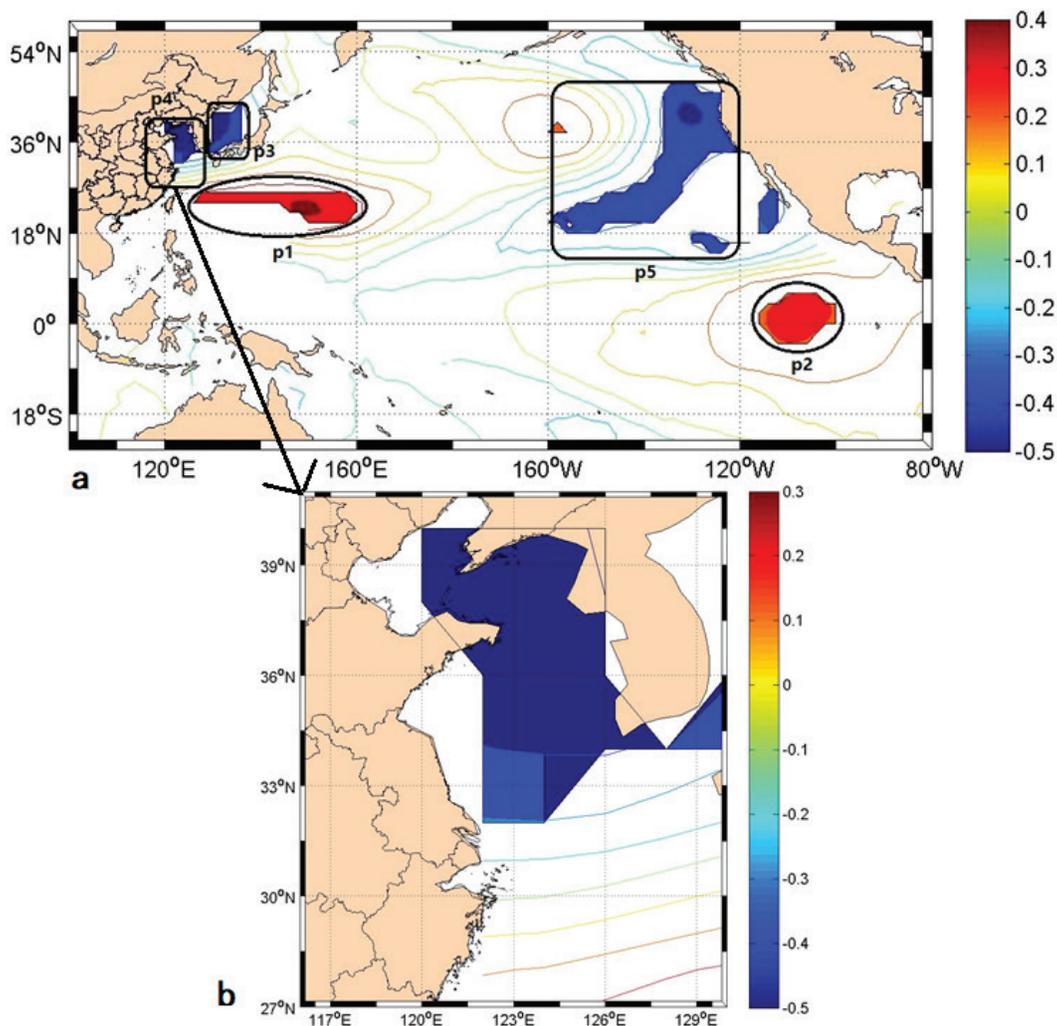
Using the Global Precipitation Climatology Project (GPCP) monthly precipitation dataset, the precipitation of Jiangsu province is calculated. We selected the area of 116°–121.5°E and 30.5°–35.5°S as Jiangsu province. The results show an overall upward trend of summer-time precipitation, in which the values of 2002–2006 slightly drop but then rise later, much as described in [24]. And this trend passes the M-K test, with a value of 1.6269 and is significant.

Using Eq. 1, the normalization index of the precipitation during the period from 1979 to 2011 in Jiangsu province is calculated and analyzed.

Certain inter-annual variations of the precipitation are obvious. Taking  $K_1 = 1$  as the threshold, the high (low) value of the precipitation is immediately apparent. According to the result, abnormally high years were 1980, 1991, 1993, 2008, and 2011 and abnormally low years were 1981, 1985, 1988, 1992, 1994, 2002, and 2004.

### 3.3. SST signals affecting the precipitation of Jiangsu province

**Figure 2** shows the correlation coefficient distribution of the precipitation in Jiangsu province for summer and contemporary SSTs during the period 1979–2011. Colored areas represent high correlation between SST field and precipitation, with correlation coefficients passing the t-test, with a confidence level of 95%. **Table 1** gives the correlation coefficient for each mainly correlated area (**Figure 2a**).



**Figure 2.** (a) Correlation between the summer precipitation and SST for the period of 1979–2011 and (b) the area p4 in **Figure 2a** (the areas passing 95% significance test are colored); before the correlation analysis on the SSTs time series, the data were detrended.

Area	p1	p2	p3	p4	p5
Coefficient	0.36	0.3	-0.4	-0.33	-0.33

Note: All color areas passed 95% significance testing. The p1, p2, p3, p4, and p5 are the areas of correlation marked in **Figure 2a**.

**Table 1.** The correlation coefficient of each color area.

As presented in **Figure 2a**, for the Pacific Ocean, two positive and three negative correlation areas are shown in **Figure 2**. The positive areas are situated in the West Pacific Ocean (125°–155°E and 25°N, marked as area p1) and the Equatorial Eastern Pacific Ocean (centered at about 110°W and 0°, marked as area p2). The Bohai Sea and Yellow Sea (marked as p4), Northeast Pacific Ocean (160°–130°W and 20°–45°S, marked as area p5), and Sea of Japan (marked as area p3) are three negative correlation areas.

Further, focusing on the area of p4 (**Figure 2b**), we could find that the SSTs of the Bohai Sea and Yellow Sea are highly correlated with the precipitation of Jiangsu province. And they present a negative correlation, that means when the SST is abnormally low (high), the precipitation of Jiangsu will be high (low). So, we could forecast the precipitation of Jiangsu by monitoring the SST of the Bohai Sea and Yellow Sea.

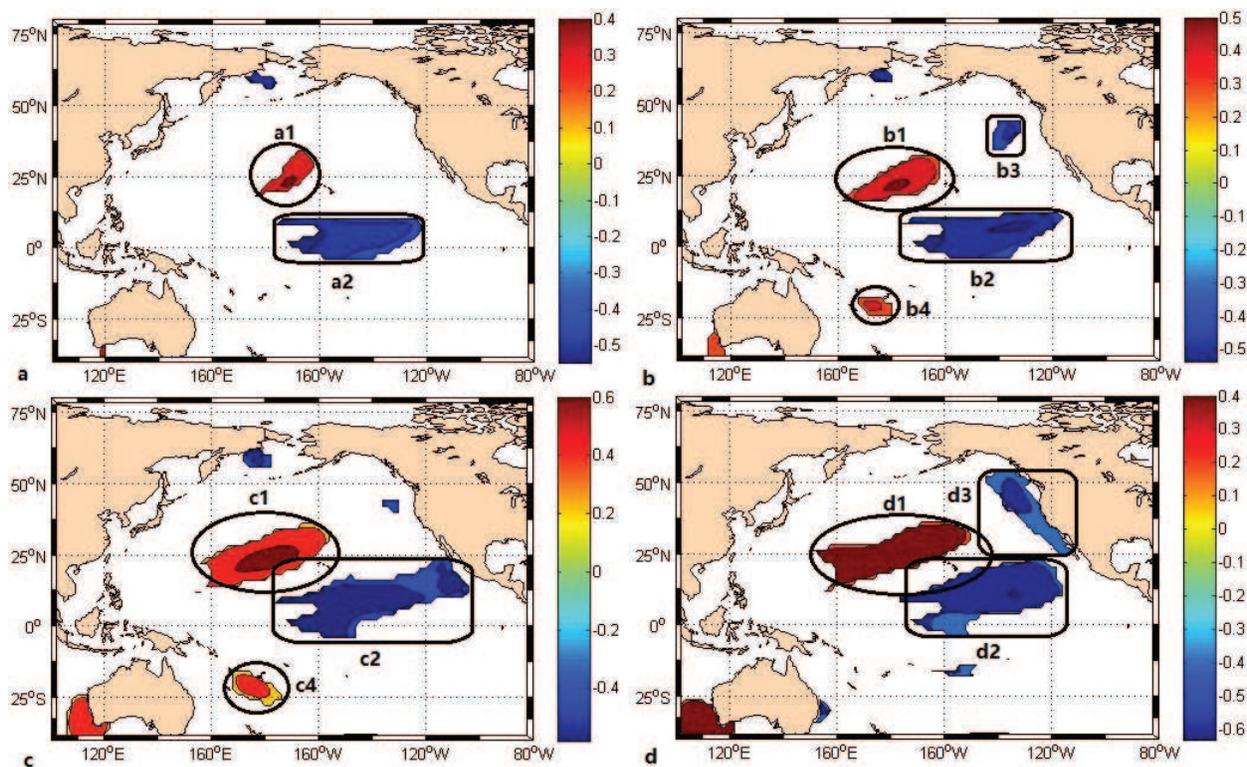
Moreover, the regression of summer time SST into the precipitation of Jiangsu province also shows statistically significant correlations between SST and precipitation. And the results in **Figure 2a** are similar to the area of correlation seen in regression analysis, which further illustrates the summer SSTs' effect on the precipitation of Jiangsu province.

To further analyze the effects of SST on the persistence of the precipitation over different periods, the precipitation in June, July, and August are selected to calculate the correlation coefficient with previous SST. Accordingly, it is found that the correlation field is more significant in June.

**Figure 3** displays the distribution of the correlation coefficient between the precipitation of June and the previous SSTs of February, March, April, and May, respectively. The areas passed 95% significance test are colored. Focusing on the Pacific Ocean, we find that correlation areas are varying from time to time. **Table 2** is the correlation coefficient of each correlated month and area. **Table 3** gives the proportion of them (unit: %).

Here, we focus on the Pacific Ocean, and the areas of correlation vary from month to month. The North Pacific Ocean are positive (centered at about 180°W and 20°N, marked as area 1) correlation areas, and it becomes larger month by month. For the Equatorial Pacific Ocean, the average of negative correlation area (centered at about 150°W and 0°, marked as area 2) increases gradually. A positive correlation area is lying in the southwest of the Pacific Ocean (centered at about 180°W and 20°S, marked as area 4). Besides, a negative correlation region, presented in **Figure 3b–d**, lies in the West Coast of the United States (marked as area 3), becomes larger in May.

The years of anomalous precipitation have been selected above. When these anomalous precipitation years are synthesized and combined, all layers of the water vapor flux field are



**Figure 3.** Correlation between precipitation in June and the SST in previous months ((a) February, (b) March, (c) April, and (d) May from 1979 to 2011) (the areas passing 95% significance test are colored).

Area	1	2	3	4
February (a)	0.38	-0.43		
March (b)	0.43	-0.44	-0.37	0.38
April (c)	0.46	-0.43		0.39
May (d)	0.5	-0.45	-0.38	

Note: All areas passed 95% significance testing. 1, 2, 3, and 4 are the areas of correlation marked in Figure 3.

**Table 2.** The correlation coefficient of each color area.

Area	1	2	3	4
February (a)	2.87	10.5		
March (b)	6.18	11.6	2.1	1.4
April (c)	8.86	16.3		2.8
May (d)	8.18	16.9	5.9	

Note: All areas passed 95% significance testing. 1, 2, 3, and 4 are the areas of correlation marked in Figure 3.

**Table 3.** The proportion of each correlated area (unit: %).

obtained. And we get the water vapor flux field of precipitation anomaly years. By analyzing it, we can see that water vapor is transported northeast over the Equatorial Northeastern Pacific Ocean. For the South East Pacific Ocean, it moves northeastward, which may enhance the convection and precipitation anomalies. Besides, for the Yellow Sea and the East China Sea, the water vapor propagates northward.

#### **4. Conclusions**

In this chapter, GPCP precipitation data and SST data from the NOAA have been used to analyze the strong signals of SSTs. We have discussed the relationship between summer SST and precipitation in Jiangsu province. The chapter shows that the precipitation of Jiangsu province in summer presents an upward trend during the period of 1979–2011. By analyzing the correlation coefficient distribution of the precipitation in Jiangsu province for summer and contemporary SSTs, finding that there are several high correlation areas in the Pacific Ocean that have significant effect on the precipitation in Jiangsu province. The results show that the precipitation in June is highly correlated to SSTs from the previous 1–4 months. This suggests that SSTs in February, March, April, and May might exert a significant influence on the precipitation of Jiangsu province, and their correlated areas and degrees are varying monthly. In the Pacific Ocean, the correlation is significant, with the area of correlation is bigger in May than other months.

According to the whole layer of water vapor flux field of precipitation anomaly years, it is transported northeast over the Equatorial Northeastern Pacific Ocean. And it moves northeastward in the South East Pacific Ocean, which may enhance the convection and precipitation anomalies. Besides, for the Yellow Sea and the East China Sea, the water vapor propagates northward.

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#### **Conflicts of interest**

The authors declare no conflict of interest.

#### **Author contributions**

Chenxu Ji and Yuanzhi Zhang conceived and designed the experiments, performed the experiments, analyzed the data, and wrote the chapter; Kapo Wong, Yu Li, and Xia Lu

improved the data analysis; Tingchen Jiang and X. San Liang contributed reagents/materials/analysis tools.

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