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Multitime scale variations of sea surface temperature in the China seas based on the HadISST dataset

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Abstract

The variability of the sea surface temperature (SST) in the China seas has been studied in seasonal, interannual and interdecadal scales based on the monthly data of HadISST spanning from 1870 to 2007. The main results obtained are SST in the China offshore changes most actively at the seasonal scale with the intensity diminishing from north to south, as the temperature differences between summer and winter reaching 17 and 4°C in the northern and southern areas, respectively. Moreover, seasonal variation near the coastal regions seems relatively stronger than that far from the coastline; significant interannual variations are detected, with the largest positive anomaly occurring in 1998 in the overall area. But as far as different domains are concerned, there exists great diversity, and the difference is also found between winter and summer. Differed from the seasonal variations, where the strongest interannual variability takes place, resides to the south of that of the seasonal ones in the northern section, nevertheless in the South China Sea, the most significant interannual variability is found in the deep basin; interdecadal changes of summer, winter and annual mean SST in different domains likewise present various features. In addition, a common dominant warming in recent 20 a are found in the overall China offshore with the strongest center located in the vicinity of the Changjiang Estuary in the East China Sea, which intensifies as high as 1.3°C during the past 130 a.

Key words: China seas, sea surface temperature, multitime scale variations

1 Introduction

As one of the fundamental variables to describe the coupled ocean-atmosphere system, sea surface temperature (SST) is, on one hand, a surface indicator or manifestation of many geophysical and biological processes in the ocean, such as ocean currents, planetary waves, ocean primary productivity, and marine fisheries, and on the other hand, it constitutes the bottom boundary condition of the atmosphere and plays a key role in the air-sea exchanges of mass, momentum, and energy (Chen and Li, 2008). Many significant progresses have been made during the past 30 a or so in characterizing low-frequency variations of SST in the Pacific, Indian and Atlantic Oceans, especially in identifying its principal modes at intraseasonal-to-multidecadal periods (Lau and Weng, 1999; Yeh and Kirtman, 2004; Solomon and Jin, 2005; Mochizuki and Kida, 2006; Frankignoul and Sennechael, 2007; Chen and Li, 2008). China has complicated features in its near-coastal continental shelf distribution, and the SST of the offshore exhibits its own variation characteristic influenced by many factors, such as the continent climate, the coastal shape, and the nearshore current oscillation. (Cai et al., 2006), and moreover, on the background of the global warming, SST in the China seas presents warming tendancy in the last 100 a and the warmest occurring from the 1990s till now (Zhang et al., 2005), so it has practical significance to investigate the variabilities of the SST in offshore sea of China. The study by Huang et al. (2007) confirmed that the correlation between the East Asia coastal regions SST and the East Asian summer monsoon is strengthened after the mid-1970s through numerical

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*Corresponding author, E-mail: jinqh@cams.cma.gov.cn simulations. Therefore, further understanding the characteristics and dynamics of SST variability at seasonal-to-decadal time scales in coastal area is favorable for better knowledge of the physics of China's climate change.

Some related researches have demonstrated the seasonal and interannual variations in the Bohai Sea (BHS), the Huanghai Sea (HS), the East China Sea (ECS) and the South China Sea (SCS) to a certain degree during the past decades. Li (1986) investigated the climate change in the ECS by using the air temperature observations, indicating that the cold and warm period occurred alternately in the past decades. Then Yan and Li (1997) pointed out the air temperature in the ECS presented a similar tendency with the SST variations during the period of 1900–1987 by use of the COAS data and offshore observations, and the warmest period occurring in the 1950s and the coldest in the 1910–1920s, SST in the ECS existing the 5–7 a and quasi-biennial oscillation, while the study by Yu and Xu (2003) showed a 41-month variation cycle of the SST in the ECS by use of AVHRR satellite data. Bao et al. (2002) further analyzed the characteristics of the SST seasonal variations in the BHS, the HS and the ECS through AVHRR data, indicating that SST monthly variations are not obvious in winter and summer in these areas, as in contrast to that in spring and autumn. The study by Feng and Lin (2009) discussed the long-term trend of SST variations in East China offshore during 1945–2006 based on the HadISST1 data, showing that the SST tends to get warmer with a rate of 0.015℃/a and the most obvious change occurring in the ECS. SST variations in the SCS also attract many researchers. Wang et al. (1997) discussed the seasonal cycle of the SCS SST variation, while Yu et al. (1994) and Wang et al. (2000) revealed quasibiannual oscillation existing in the SCS SST variations from COADS data. Fang et al. (2006) thought sea surface warming rate in the SCS presenting significantly higher than the corresponding global rates. Studies by Fang et al. (2002) and Wu et al. (2005) also showed an increase of SST in the BHS during the past decades.

In these China offshore-related studies, it is noted that due to the lack of long-range observations, the previous researches are mostly concentrated to a limited area or focused on the seasonal and interannual time scales, while discussions on interdecadal changes and long-term variations in overall China offshore keep not adequate. Therefore, based on the long-time high spatial resolution data, this study will systematically reveal the interdecadal, interannual and seasonal variations of SST in detail in China offshore area.

The paper is organized as follows. In Section 1, we firstly present the motivation for this study as well as the related research, and then data and methodology used in this study are introduced briefly in Section 2. In Section 3, we present the detail analysis and discussions, and the conclusions are in Section 4.

2 Dataset and method

The study area is located between 5℃S–45℃N and 95°–140℃E, and SST data utilized are from Met Office HadISST version 1.1, which replaces the Global Sea Ice and Sea Surface Temperature version 2.3b (GISST2.3b) dataset ended in February 2003. The data are monthly averaged, available for the whole globe with a spatial resolution of $1^\circ\times1^\circ$ from January 1870 to December 2007. The SST climatology in this paper is given as the mean of 1971–2000 monthly data. Standardization of the time series is carried out prior to discussing the interannual SST variations, as well as the empirical orthogonal function (EOF) is utilized to find out how China's near-coastal SST interannual variability performs. Finally, the moving t-test technique (MTT) is implemented for quantitatively detecting the decadal abrupt changes in the summer, winter and annual mean time series.

3 The multitime scale variations of SST in offshore seas of China

3.1 *Seasonal variability*

Greatly affected by the Eastern Asian monsoon, the SST of China eastern coastal area displays remarkable seasonal variations (Fig.1). SST in winter presents in a southeast-northwest direction in the ECS, the HS and the BHS with the consequence of the Kuroshio (Fig.1a). The most striking and compelling feature in winter is the SST weakens gradually northwesternward from the Kuroshio region, and in the BHS it is below 8℃, in the HS about 8–12℃, while in the ECS it varies southward from 12 to above 20℃ and reaches greater than 22℃ in the north SCS with a continuous increase to 24–28℃ in the south SCS. In summer (Fig.1b), SST distribution differs from the winter strip-like pattern, when in the BHS and the north HS it augments to 22–24℃, and in the south HS and the north-mid ECS to 24–28℃, as well in the south ECS

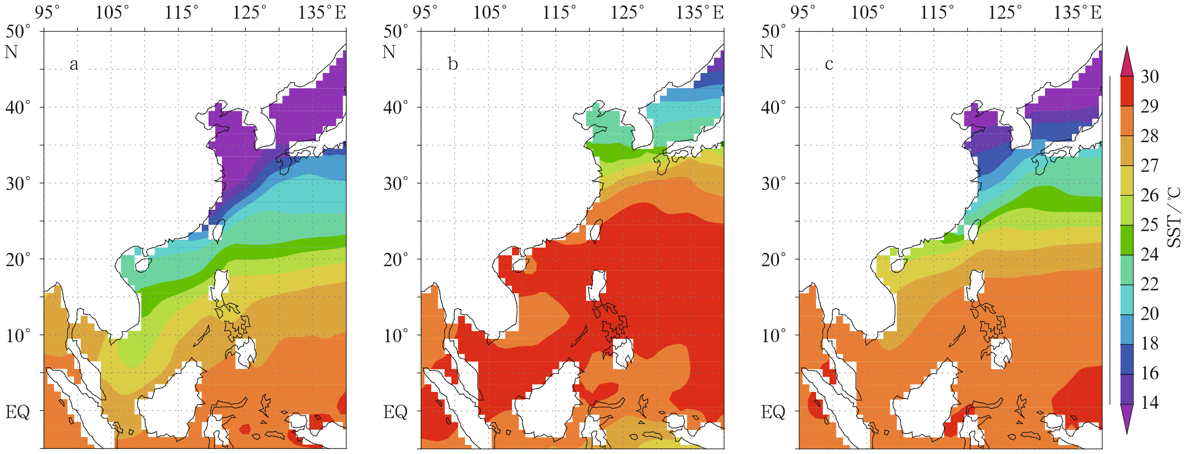

Fig.1. The climatological SST distribution based on 1971–2000. a. January, b. July, and c. annual mean.

and the SCS warmer than 30℃. The annual mean SST field resembles the winter situation (Fig.1c), with temperature increases northeasternward from 12℃ in the BHS to near 30℃ in the SCS.

The seasonal standard deviation (STD) of SST based on the 12 climatological monthly means presents regional characteristics of the seasonal variations, as is shown in Fig. 2. The distribution of STD is much similar to the climatological SST annual pattern. Two features are identified. First, it is noteworthy that the SST mean square variance in the north is much stronger than that in the south. It reaches a maximum greater than 7 in the BHS and decreases gradually southward to 1.0 in the southern part of the SCS, which denotes the SST seasonal variation in tropics is comparatively weaker than that in the subtropics, as is ascribed mainly to the geographic location. The dominant seasonal variation occurs to the north of 23°N. Second, as far as one latitude belt is concerned, the SST mean square variance in the coastline zone presents relatively large, for example, the intensity exceeding 6.0 centered in the Changjiang Estuary and diminishing gradually eastward to about 4.0 in Kuroshio region, showing that the seasonal variations in nearshore are much more evident.

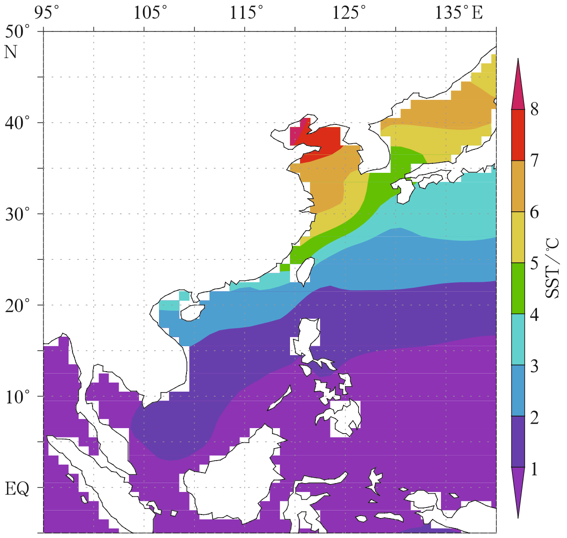

Fig.2. Seasonal standard deviation of SST constructed from the 12 climatological SST monthly means.

3.2 *Interannual variability*

The superior mode of the SST interannual variability in the China offshore is performed by EOF analysis. Here, the seasonal variability and the long term trend of the SST at each grid have been removed before applying EOF. The first three modes contribute 34.3%, 20.3% and 6.5% to the total variance, which spatial distribution and related time coefficient are depicted in Fig. 3. The first mode demonstrates that the most evident interannual variability center is located in the north of HS with a gradual southward decrease. As compared with Fig. 2, obvious difference in the location of the interannual and seasonal variation can be detected. In the northern part of China's marginal seas, the evident center of the interannual variability resides to the south of that of the seasonal variation. Moreover, the interannual variations do not present evident banded pattern, as is very different from the zonal distribution from northwest to southeast of the seasonal one. In addition, the difference in the SCS is also identified obviously, where the seasonal variation intensity weakens from north to south, nevertheless the most significant interannual variability occurs in the deep basin, in accordance with the results by

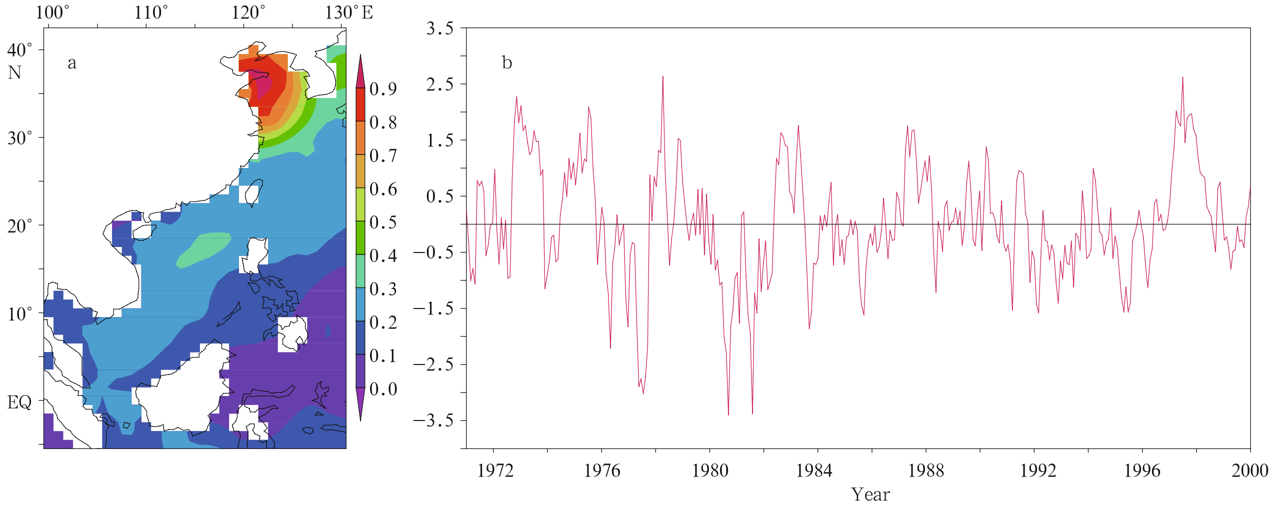

Fig.3. The first eigenvector field of monthly SST (℃) anomalies in China offshore (a) and the associated PC time series (b) based upon 1971–2000.

Wang et al. (2000). In this mode the effects of the ENSO events on China's near-coastal SST may also be revealed, which is very clear when SST rise distinctly (Fig. 3b) in 1983, 1988 and 1998, when strong El Niño events took place. Another EOF analysis of the synchronous NCEP monthly wind vector anomaly at 850 hPa level is also calculated (Figure omitted). The correlation coefficient between the time series of EOF first modes from these two fields is 0.21, above significance level of 0.01, which can confirm the close relationship between China's near-coastal SST evolution and monsoon change.

The above analysis presents the spatial distribution and temporal variation of the SST interannual variability in China offshore. What is the fluctuation characteristic of the various region is as follows. In this paper, the January SST and July one are selected as the representative of winter and summer respectively. The normalized yearly January SST in the BHS, the HS, the ECS and the SCS is plotted in Fig. 4, respectively. In 1870–1900, dominant interannual variability of the BHS and the HS is warmer, where most SST anomalies are positive, especially in 1882, 1898 and 1899, but the ECS and the SCS are in opposition, where negative anomalies dominate, such as 1880, 1885 and 1891. In the first half of the 20th century, consistent cooling prevails in the northern part of China's marginal seas, with extreme negative anomalies occurring in 1933, 1936, 1943 and 1944 in the BHS, the HS and the ECS. While in the SCS, the cold and warm events appear alternately, implying no remarkable cooling in the SCS during this period. In the 1950s–1980s, more positive anomalies come into being in the BHS and the HS with dominant warm occurrence in 1954, 1960 and 1979, but that is not obvious in the ECS and the SCS. After the 1980s, all these marginal seas are getting warmer, and the most significant warming is found in the overall seas with exceeding 1 standard deviation in many years, such as in 1992, 1995 and 1998.

Figure 5 is normalized yearly anomalies of July SST. In contrast to the most of positive anomaly of winter SST in the BHS and the HS during 1870–1900, the summer counterpart presents more cold occurrence during this period, especially in 1877 and 1884. Whereas positive dominates in 1910–1970, especially in 1930–1960, SST is singularly high, then it becomes cold comparatively in 1970- the mid 1990s, but in the late 1990s it increases again with extreme positive anomalies such as in 1994, 1998, and 2001. About the ECS SST, continuous negative anomalies emerge before the 1930s, and from the 1930s to the mid 1970s the interannual variability is much evident with positive with negative situation occurrence alternately in few years, then warming maintains after the end of the 1970s with a maximum occurrence in 2001 during the last 100 a or so. SST in the SCS presents a similar characteristic with ECS, but the warming becomes dominant after the 1980s.

As far as the annual mean SST is concerned (Fig.6), the BHS and the HS are relatively cool before the mid 1940s, with a warm phase from the end of the 1940s to the 1960s, cooling again in the 1970s, then keep significantly warm since the 1980s.

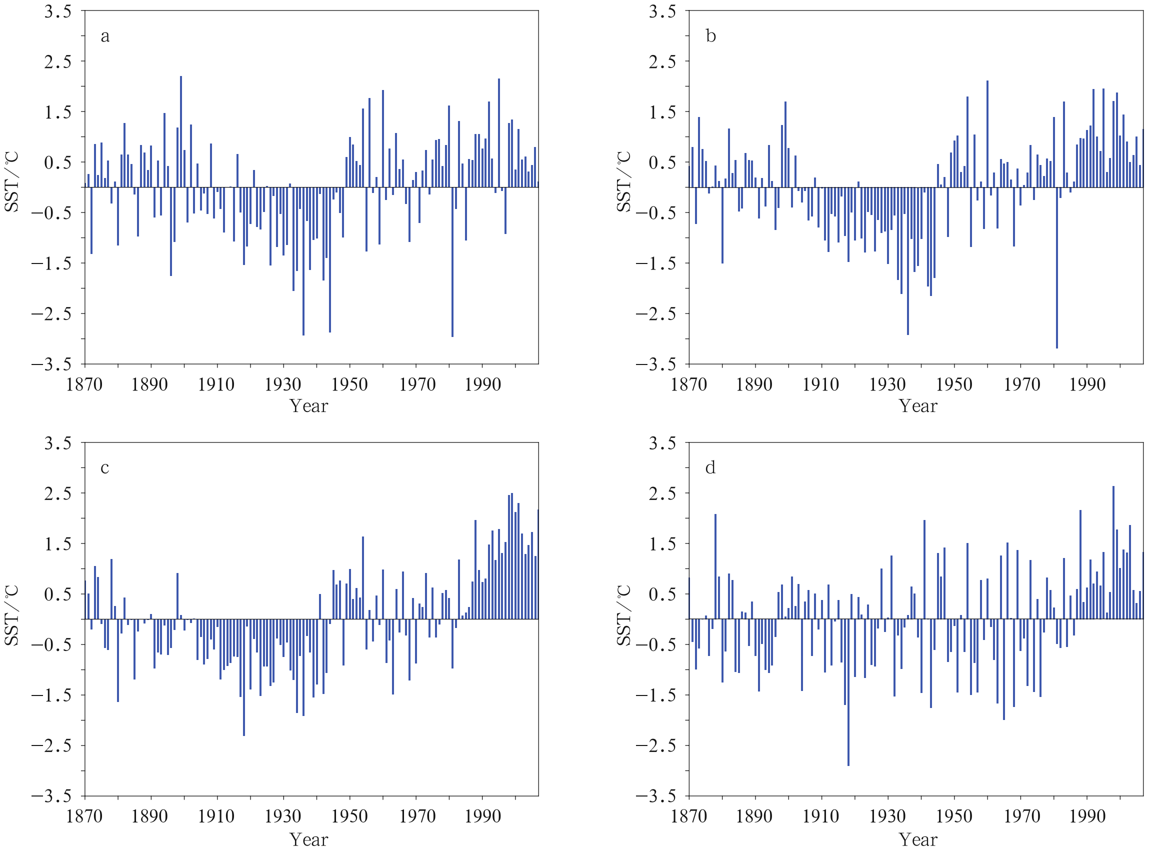

Fig.4. Normalized yearly anomalies of January SST for the period of 1870–2007. a. the BHS, b. the HS, c. the ECS, and d. the SCS.

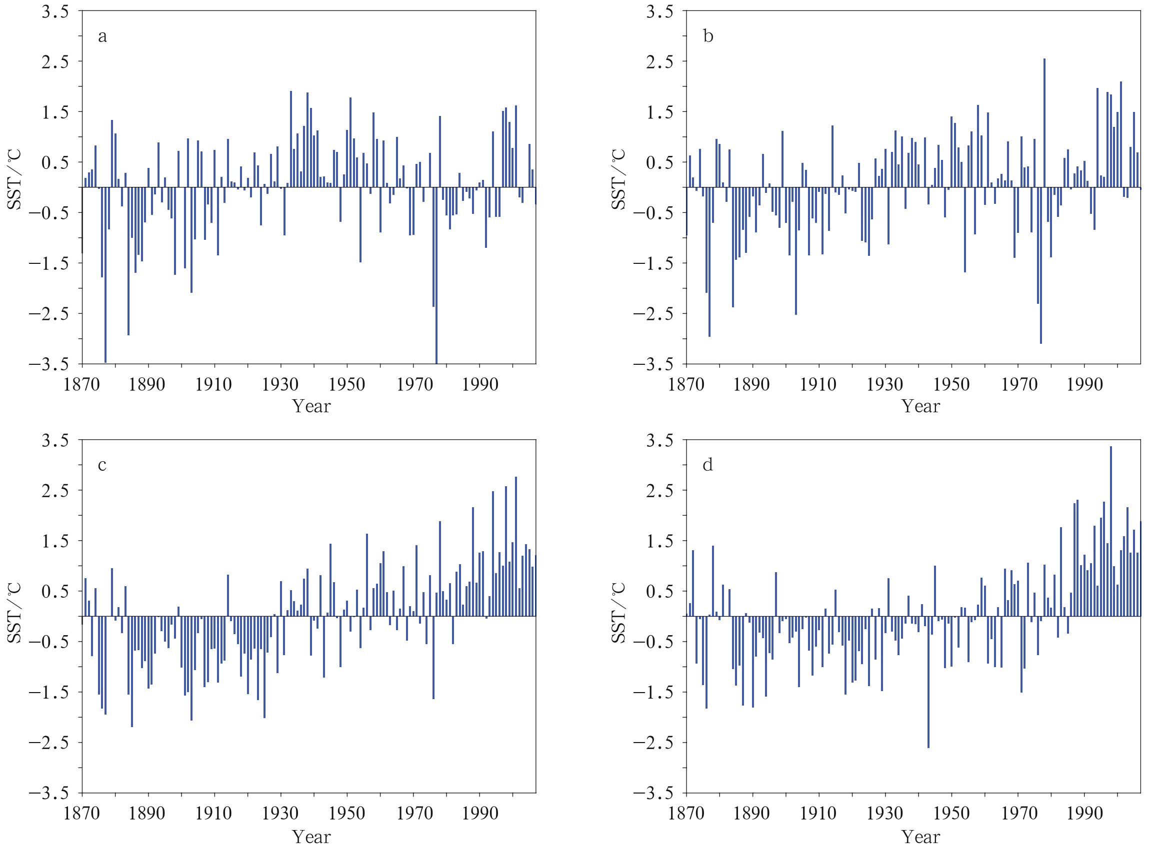

Fig.5. Same as Fig. 4, but for the July SST. a. the BHS, b. the HS, c. the ECS, and d. the SCS.

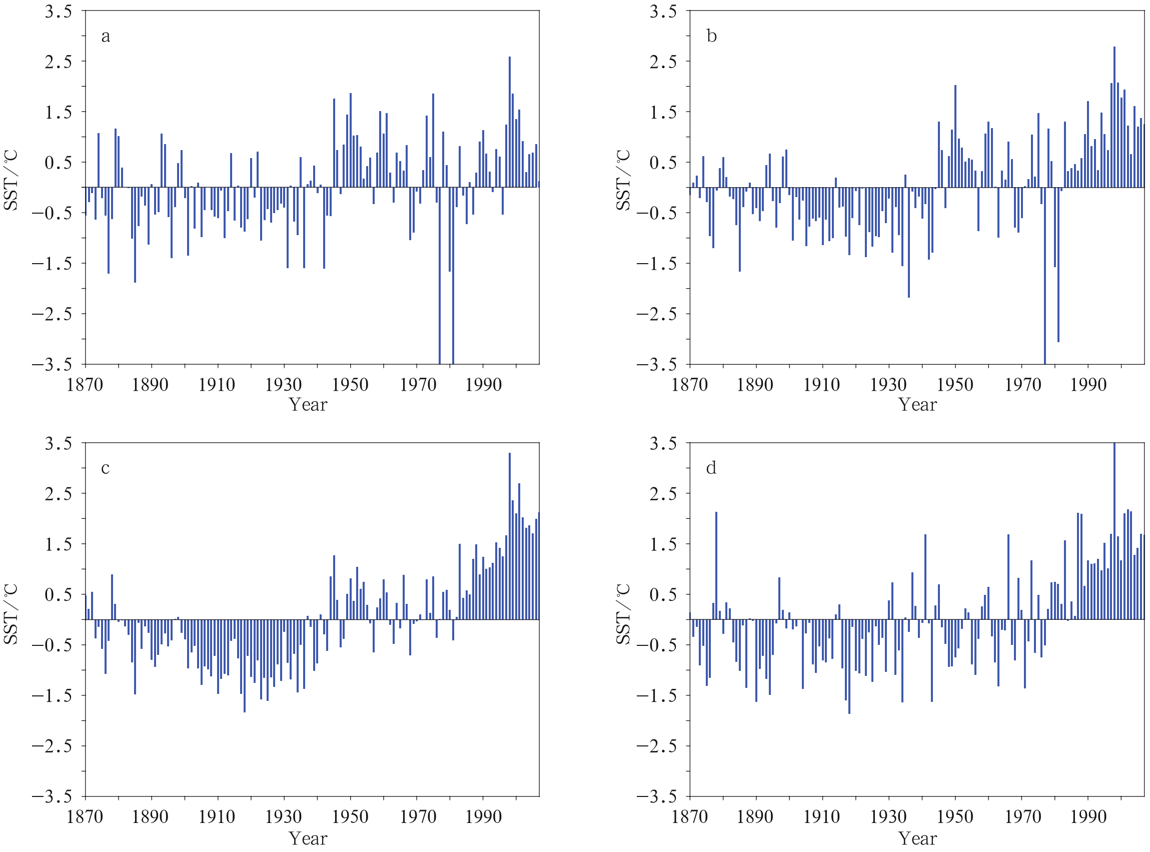

Fig.6. Same as Fig. 4, but for the annual mean SST. a. the BHS, b. the HS, c. the ECS, and d. the SCS.

Similar variation trend is discovered in the ECS, but the cooling observed in the 1970s is not evident. The SCS lasts cold before the end of the 1970s, then warm persistently till now, especially in 1998.

3.3 *Interdecadal variability*

Decadal variability as background of the long-time scale variations on one hand has great impact on the interannual changes, and on the other hand is an important fluctuation in the century climate change. Interdecadal variabilities are explored in the following section. Figure 7 presents the spatial distribution of the decadal variations, from which one of the most striking characteristic is the warming in the overall area. The most significant event occurs in the vicinity of the the Changjiang Estuary in the ECS with an increase by more than 0.1℃ per decade, intensified as high as 1.3℃ during the past 130 a. The warming in the HS is weaker in comparison with that in the ECS with a warming rate of about 0.06℃/10 a, and the SST is increased by 0.8℃ from 1870 to 2000. SST in the BHS is magnified at the speed of about 0.04℃/10 a with the intensity greater than 0.02° per decade in the SCS.

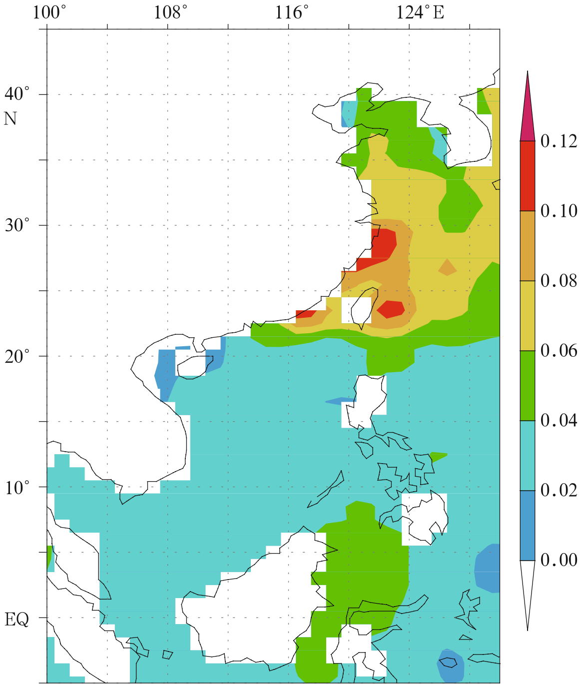

Fig.7. Distribution of the SST per decade (°C/10 a) variation.

The above analysis shows the decadal warming rate of SST in overall area, but the interdecadal SST variations in each domain also receive much concern. Moving t-test technique is applied to quantitatively detect the decadal abrupt changes of winter, summer and annual mean SST based on each region, and the winter one is shown in Fig. 8, in which the green red thick solid straightline is episode average between abrupt points at significant level of 0.05. The left Y coordinate axis is t, and the right is temperature. For the winter SST, at 5% significance level, decadal scale abrupt changes in the BHS take place in 1909, 1930 and 1945. In 1909, the BHS faces an abrupt cooling with average temperature decrease about 0.71℃, which goes on till 1930, when another decadal dashed curve denotes the series of statistic quantity t_0, with the blue dotted and dashed straightline denoting the significant level of 5% and 1% respectively, and the cooling observed with a concomitance of 0.74℃ dropping in average temperature, then, on the contrary, in 1945 a dominant abrupt warming may be discovered exceeding the 99% significance test with an increase in average temperature as high as 1.6℃. Similar changes could also be seen in the HS, but the intensity of the abrupt cooling in 1909 is much more evident which exceeds the 99% significance test with temperature decreasing of 0.9℃. In addition, an abrupt warming in the HS from 1987 could be detected at 5% significance level with the rising temperature greater than 0.9℃. Concurrently in 1987, SST in the ECS and the SCS also increases notably exceeding 1℃ and 0.5℃ in averaged temperature respectively, and moreover SST in the ECS likewise experiences an abrupt cooling in 1909 and warming in 1945. But the SCS differs significantly with the above two seas in the winter SST variability, where besides the abrupt warming in 1987 mentioned above, another significant warming emerges in 1897 at 5% significance level.

The summer SST of China's marginal seas changes in a different way from the winter counterpart (Fig. 9). In the BHS, interdecadal scale abrupt changes occurred in 1933, 1942 and 1994. Besides in 1942, the warming occurring in 1933 and 1991 is conspicuous, especially the averaged temperature during

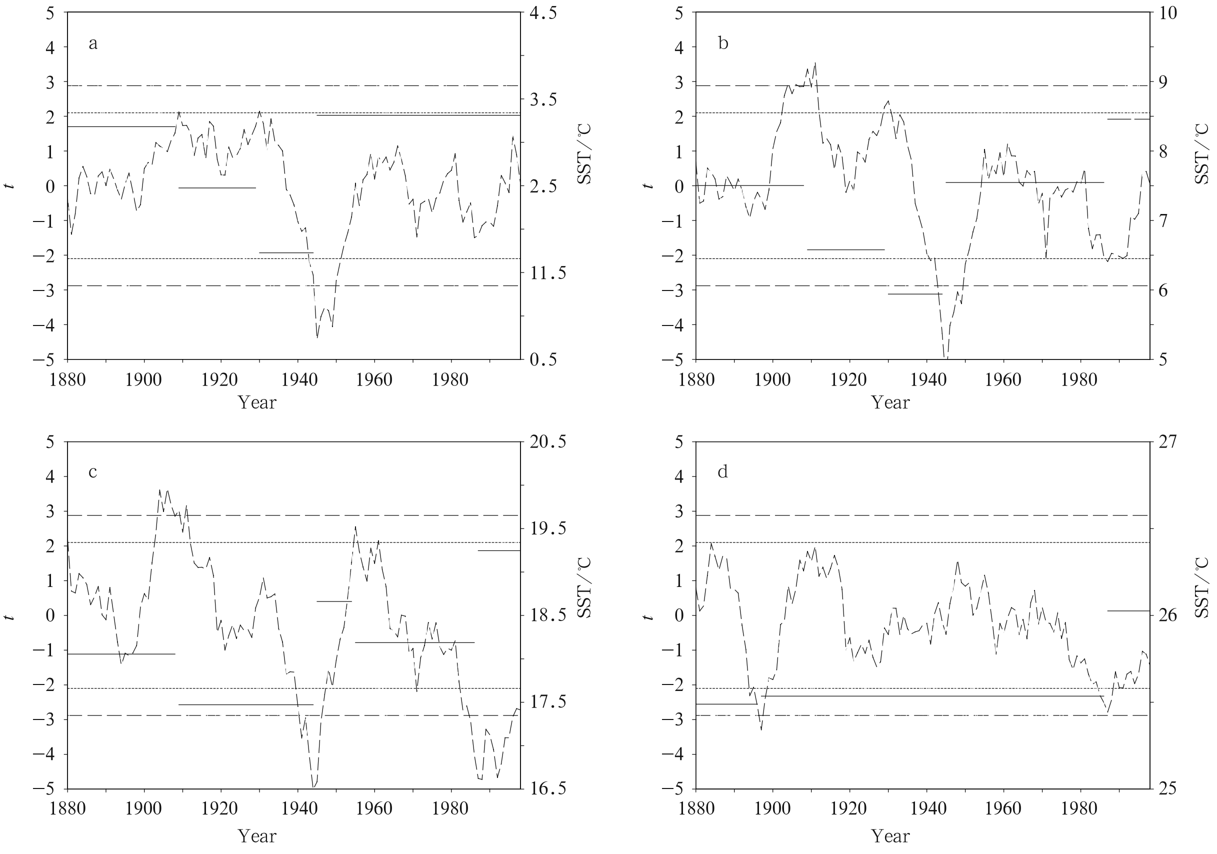

Fig.8. The winter SST moving t-test line. The green dashed curve denotes the series of statistic quantity t_0; the blue dotted and dashed straightline is the threshold at significance level of 0.01 and 0.05 respectively, while the red thick solid straightline is the episode average between abrupt points at significance level of 0.05. The left of the coordinate axis in Y direction is t, the right is temperature. a. the BHS, b. the HS, c. the ECS, and d. the SCS.

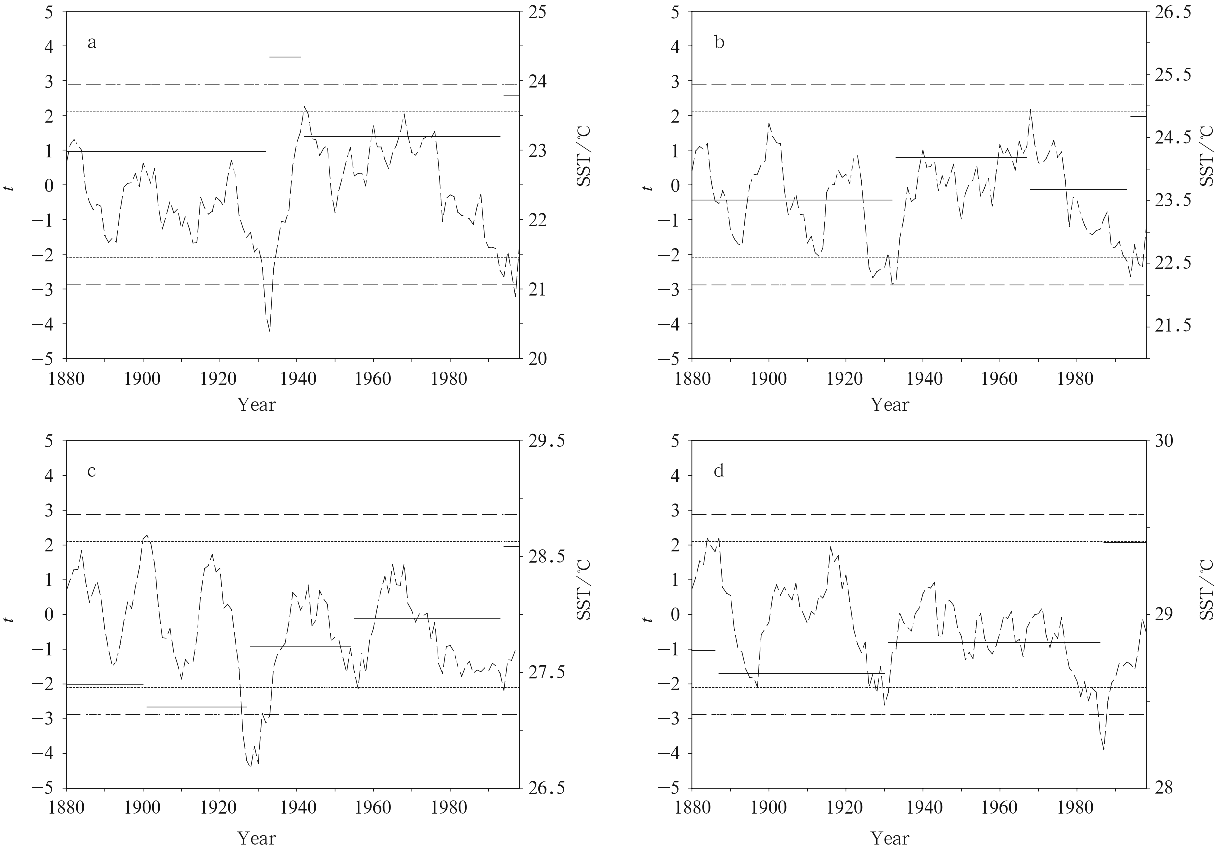

Fig.9. Same as Fig. 8, but for the summer SST. a. the BHS, b. the HS, c. the ECS, and d. the SCS.

1932–1941 is 1.36°C higher as compared with that during 1870–1932. But in 1942, a decadal cooling at 5% significance level is observed, the averaged temperature over 1942–1993 lower by 1.14°C than that in the previous warmer phase. From 1994, sustained elevating temperature is identified in summer with an increase by 0.59°C. Analogous variations in 1933 and 1994 also emerge in the HS, but the evident decadal cooling in the HS occurs in 1968 rather than in 1942. The mean SST in 1933–1967 is 24.2°C, which is greater by 0.67°C than that in 1870–1932, followed by a comparatively cold phase with the averaged temperature being 23.7°C, from 1994, the summer mean SST in the HS increasing by 1.16°C. As far as the ECS concerned, except that the abrupt cooling was detected in 1901, three continual rising temperature mutations occurred in 1928, 1955 and 1994. Compared with that in the 1870s, the temperature in the 1990s is higher by 1.19°C. Same as the northern part of the China seas, the SST in the SCS showed temperature increase in the early 1930s as well. Furthermore, just as the winter SST, its summer SST values also amplified in 1987 interdecadally by 0.58°C compared with the former episode.

For the annual mean SST (Fig.10), dominant temperature rising since 1987 was found in China's marginal seas from north to south with a further enhancement from 1994. In the BHS, a decadal warming was found in 1945 in concomitance with SST increase by 0.66°C and a cooling counterpart emergence in 1962 accompanying with averaged SST dropping by 0.59°C in comparison with the former episode. But followed by the warming abrupt change occurring in 1987 and 1994, SST was intensified dominantly up to 0.62°C. The HS presented similar changes as the BHS in 1945, 1962, 1987 and 1994, and moreover additionally another significant cooling at 1% significance level could be found in 1903. For the ECS, first cooling in decadal scale was found in 1884, followed by a further pronounced cooling in 1903 exceeding 99% significance test, then SST was raised evidently in 1945 and continuous warming in 1994 as the HS and the BHS to its north, but no abrupt change in 1962. In the SCS, besides the consistent apparent warming in the recent 20 a, the warming in 1945 and the cooling in 1903 were likewise detected, but the intensity of the decadal

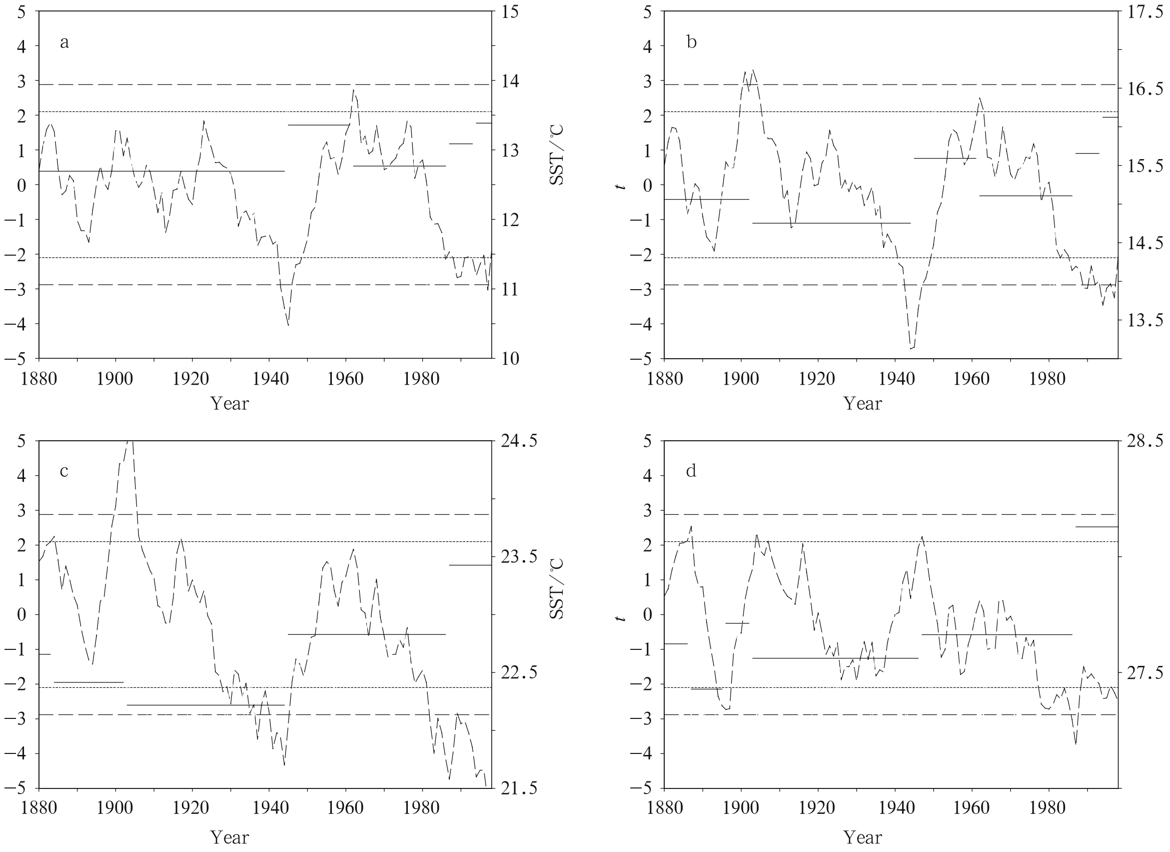

Fig.10. Same as Fig. 8, but for the annual mean SST. a. the BHS, b. the HS, c. the ECS, and d. the SCS.

cooling in 1903 was much weaker than the simultaneous progress in the HS and the ECS.

4 Summary and discussion

This study presents the analysis of the HadISST dataset in depicting the seasonal, interannual and interdecadal variabilities in the offshore sea of China in detail. The major findings are summarized as follows.

For the seasonal cycle, which generally exhibits zonal distribution with a gradual decrease from southeast to northwest, and the intensity change in the tropics is comparatively weaker than that in the subtropics, especially the difference between summer and winter in the BHS gets higher than 16℃, and as far as one latitude belt is concerned, the SST in the nearshore zone presents much more evident seasonal variation than the offshore area. The interannual variations location differs from the seasonal one, in the northern part of China offshore, the evident center of the interannual variability resides to the south of that of the seasonal variation. And moreover, the interannual variations do not present evident banded pattern, in which the variation in the SCS is worthy to be pointed out where the seasonal variation intensity weakens from north to south, nevertheless the most significant interannual variability occurs in the deep basin.

Interdecadal changes present various features in different domains, but a common dominant warming in recent 20 a is found in the overall China offshore with the strongest center located in the vicinity of the Changjiang Estuary in the ECS, which is intensified as high as 1.3℃ during the past 130 a.

In summary, SST in China offshore seas is characterized by the complex multitime scale variations, and moreover the feature of changes in each domain exists dominant diversity, as will absolutely has great impacts on the climate of the adjacent continent. The past research has indicated the close relationship between the SST variations and ocean processes, and the potential connection with the wind changes is somewhat mentioned in the above analysis, but the mechanism of SST variations will be revealed further in later studies.

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