The wavelet analysis of satellite sea surface temperature in the South China Sea and the Pacific Ocean

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Abstract Using wavelet transform, the sea surface temperature (SST) during the period of 1982—1999 of the South China Sea and the equatorial Pacific, from datasets of NOAA/AVHRR, was analyzed. It is shown that there are 4- and 8-year interannual oscillations in the eastern equatorial Pacific and 8-year interannual oscillation in the western equatorial Pacific. In terms of attractive time-frequency localization and multi-scale properties of wavelet transform, as shown by the Morlet wavelet, it is found that an in-phase coupling oscillation occurs between the SCS and the equatorial Pacific. The SST changes of SCS will have echoed every event of El Niño (abnormally warm) and La Niña (abnormally cold) in the equatorial Pacific. There is a positive correlation between the SCS and the western equatorial Pacific in the 8-year time-scale. Evidence is presented that the SST anomalies of the equatorial Pacific influence the SST of the SCS.

Keywords: SST, the South China Sea, the Pacific, El Niño, wavelet transform, remote sensing.

The interannual variability is a strong signal in the climatic system. Because the relationship between the interannual variability and the anomalies of the global climate, scientists pay more and more attention to it. El Niño and La Niña are important features which influence the interannual variability in global climate. Abnormally warm sea surface temperature (SST) in the equatorial Pacific is the essential character of El Niño. SST and sea surface temperature anomaly (SSTA) are thought to be important symbols of the ocean thermodynamic parameters, so researching SST and SSTA is a very important aspect in global and local area climate change. The South China Sea (SCS) is a tropical sea located between the Asian land mass to the north and the west, the Philippine Islands to the east, Borneo to the southeast, and Indonesia to the south. It includes the shallow Gulf of Thailand and connections to the East China Sea (through the Taiwan Strait), the Pacific Ocean (through the Luzon Strait), the Sulu Sea (through the Mindoro Strait), the Java Sea (through the Gapser and Karimata Straits) and to the Indian Ocean (through the Strait of Malacca). All of these straits are shallow except the Luzon Strait where the maximum depth is 1 800 m. So, how the Pacific influences the SCS and what interrelationship is between them have been attracting increasing interest. Zhou[1,2] has shown that the low-frequency oscillation in the SCS is one of components of the variety of the tropic Pacific by using the power spectral analysis and digital filter. Niu[3] researched the month-average datasets of SST by power spectral analysis and found that there is common interannual variability of 3.3-year cycle in both coasts of Peru and the SCS. Xie[4] also shows the in-phase low-frequency coupling oscillation about 16.6-year cycle between the Nansha in the SCS and the Warm Pool in the west Pacific through power spectral analysis. The Fourier transform (FT), including spectral analysis, has been a major tool for investigation of temperature structure of the SCS and the Pacific, it maps signal from time to frequency domain, providing a time-mean power spectrum. As such it fails to reveal possible changes of the oscillation characteristics with time. However, in wavelet analysis the coefficients are displayed in time-frequency frames for the entire time domain on several different time-scales, separating the large-scale behavior from the small-scale behavior. The temporal localization of wavelet coefficients displayed in these time-frequency frames is an additional advantage of wavelet transform over FT. Since some of the meteorological phenomena, such as intra-annual oscillations, are localized in time, the WT method is highly suitable to studying these phenomena. The temperature structure itself and the processes interacting with it are multiscale, so the traditional analysis technique cannot reveal the interrelation between the SCS and the Pacific from only the time-scale. And, the routine observation data are difficult to use to show the global character of the whole SCS or the Pacific. In the present study, we use the continuous WT to analyze the time series data of weekly SST of the SCS and the Pacific averaged from a grid dataset for the period of January 1982—February 1999 derived from National Oceanic and Atmospheric Administration (NOAA)-Advanced Very High Resolution Radiometer (AVHRR). We present the information about the interrelation between the SCS and the Pacific in different scales. This is helpful to researching the air-sea interaction, and the large-cale circumfluence in SCS and the Pacific.

1 The time series of SSTA in the SCS and the Pacific

The ocean remote sensing satellites provide us a great amount of data with high quality, large scope, long periods and high resoluion. The SST data used here were derived from the NOAA/AVHRR for the period of January 1982—January 1999, which are 1° × 1° grid, weekly mean. We selected three rectangular areas, each covering an area of (105°E—125°S, 5°S—25°N), (105°W—90°W, 15°S—15°N), (130°E—180°E, 15°S—15°N), which represent the SCS, the eastern equatorial Pacific Ocean and the western equaorial Pacific Ocean, respectively. The mean temperature of every area was derived from the area average. Figs. 1(a), 2(a), 3(a) show the time series used in our analysis, namely,

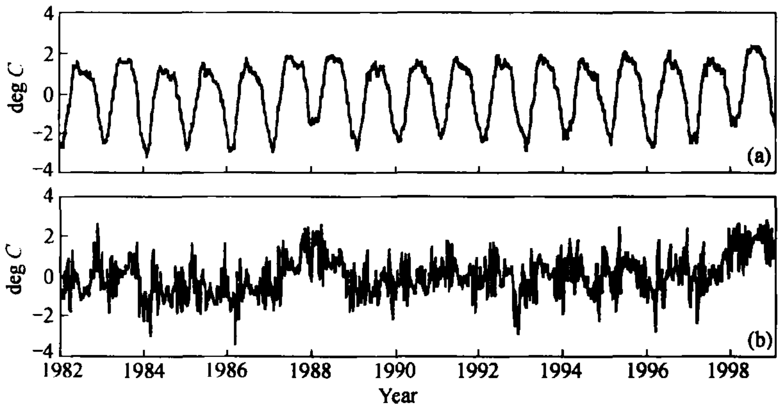

Fig. 1. (a) The anomaly time series of SST in the SCS; (b) that in the SCS with the annual means removed.

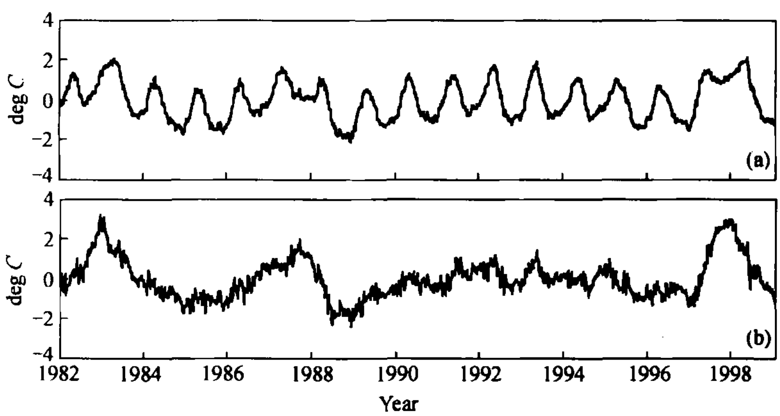

Fig. 2. (a) The anomaly time series of SST in the eastern equatorial Pacific Ocean; (b) that in the eastern equatorial Pacific Ocean with the annual means removed.

(1a) weekly mean SST anomalies in the SCS and (2a) the eastern equatorial Pacific and (3a) the western equatorial Pacific. The annual cycle is obvious, which is one of the strongest signals of climate change. It is caused by the seasonal solar radiation. So what we care about here is the anomaly time series with the annual means for the entire record removed. These anomaly time series (SSTA) of the SCS, the eastern equatorial Pacific Ocean and the western equatorial Pacific Ocean are shown in figs. 1(b), 2(b), 3(b), respectively.

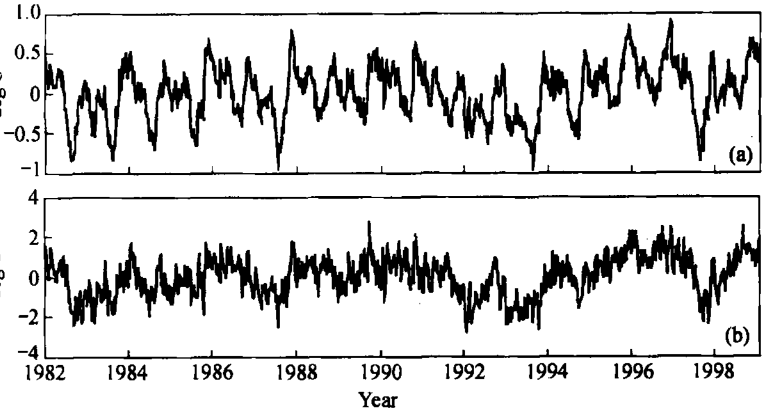

Fig. 3. (a) The anomaly time series of SST in the western equatorial Pacific Ocean; (b) that in the western equatorial Pacific Ocean with the annual means removed.

2 Wavelet analysis

Wavelet analysis has been widely applied to meteorological analyses of various fields[5—7], according to the definition of wavelet analysis[8], the wavelet basis of Morlet is adopted in researching the SSTA. First, the wavelet frequency spectra[9] of SSTA in the SCS, the eastern equatorial Pacific and the western equatorial Pacific are shown in fig. 4.

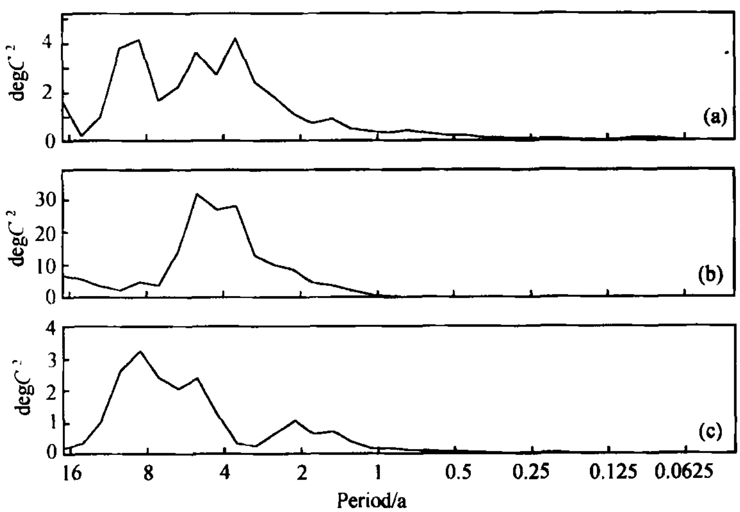

Fig. 4. (a) The wavelet frequency spectra of SSTA in the SCS; (b) that in the eastern equatorial Pacific; (c) that in the western equatorial Pacific.

As shown in fig. 4, after the annual means have been removed, there are two primary cycles of 3—5 years and 8.5 years around of SSTA in the SCS, the dominating cycle of SSTA in the eastern equatorial Pacific 3—5 years. An 8-year around cycle of SSTA is more prominent than the 3—5-year cycle in the western equatorial Pacific. It is interesting that major enhanced 3—5-year cycles of SSTA occurred in both the SCS and the eastern equatorial Pacific, 8.5-year cycle of SSTA in both SCS and the western equatorial Pacific. It is difficult for the traditional methods to reveal the temporal structure of an energy spectrum. However the real part of wavelet transform (WFT) may reveal the spatiotemporal structure of the signal[8,10], this particularly valuable characteristic of WFT provides a continuous view of variance as a function of time and frequency. The time-frequency structure of the SSTA which is derived from the WFT is shown in fig. 5. The horizontal axis is time, vertical axis is the frequency scale. The colors (light and shade) in the figure stand for the structure of SSTA variety. Light color stands for warm anomalies and darker color cold anomalies.

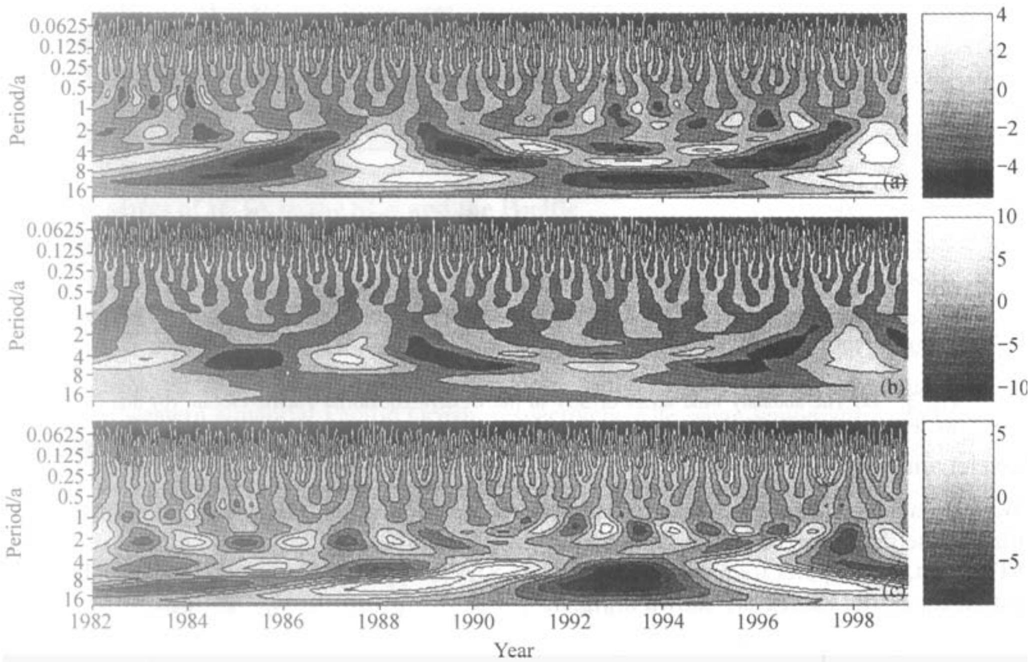

Fig. 5. (a) The time-frequency structure of SSTA in the SCS; (b) that in the eastern equatorial Pacific; (c) that in the western equatorial Pacific.

The same characteristics of the wavelet spectrum as in fig. 4 can be found in fig. 5. The SSTA in the eastern equatorial Pacific is used as a measure of the amplitude of the El Niño[3]. As shown in fig. 5(b), the alternation of warm and cold episodes in the scale of 4 years around is obvious. There are four warm episodes in that scale from 1982 to 1999: 82/83, 87/88, 93, 97/98, which correspond to four El Niño episodes. There are also three cold episodes in that 4-year scale: 85, 89/90, 95/96, which correspond to three La Niña episodes. It is interesting that warm episodes occurred in the SCS (fig. 5(a)) after every warm anomaly in the eastern equatorial Pacific, but there is a lag of half a year around. In the western equatorial Pacific (fig. 5(c)), the alternation of warm and cold episodes is out of phase according to the eastern equatorial Pacific (fig. 5(b)), also with a lag of half a year, but it is almost in phase with that of the SCS. In order to show this more clearly, the varieties in 4—5-year scale are picked up from fig. 5, as shown in fig. 6.

As shown in fig. 6(a), (b), namely the characteristic of temperature abnormity in 4—5-year scale in the SCS and the eastern equatorial Pacific, there are four warm anomalies (El Niño episodes) from 1982 to 1999, they are December 1982, June 1987, May 1992, December 1997 in the eastern equatorial Pacific, and they are May 1983, November 1987, February 1993, June 1998 in the SCS. The SSTA oscillation of this scale in SCS is correlated with the SSTA oscillation in the eastern equatorial Pacific. There are lags, which are 5 months, 6 months, 8 months, 7 months, respectively. There are three cold anomalies (La Niña episodes) from 1982 to 1999, they are March 1985, September 1989, August 1995. The SCS responded to those cold anomalies in August 1985, February 1990, March 1996, the lags are 6 months, 6 months and 8 months. The SSTA oscillations in the western equatorial Pacific are almost opposite in phase to those in the eastern equatorial Pacific, as shown in fig. 6(c).

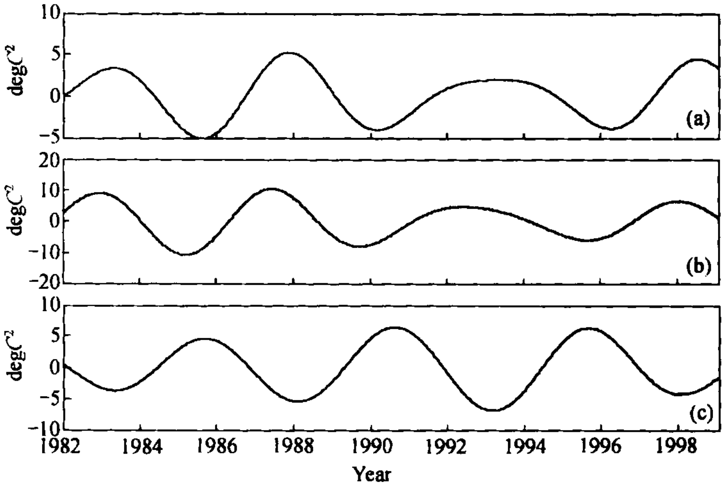

Fig. 6. (a) The average variety in 4—5-years scale in the SCS; (b) that in the eastern equatorial Pacific; (c) that in the western equatorial Pacific.

It is clearly shown that there is an indication of concentration of energy on a 8—10-year timescale in both the SCS and the western equatorial Pacific (fig. 4(a), (c)). The variety of SSTA on an 8—10-year scale was abstracted, as shown in fig. 7. The variety of SSTA in the SCS and the western equatorial Pacific are shown in fig. 7(a), (c) respectively. They bear great similarity, which is in-phase coupling oscillation. Same as in fig. 6, the SSTA oscillations in the western equatorial Pacific opposite in phase to those in the eastern equatorial Pacific, and its amplitude is larger.

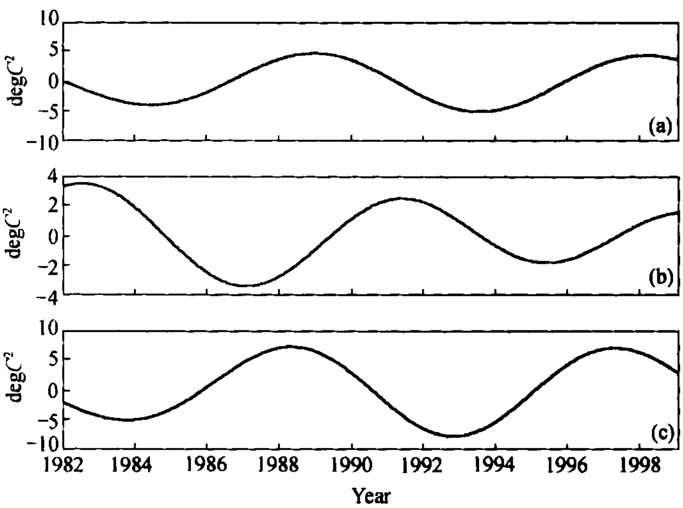

Fig. 7. (a) The average variety in 8—10-year scale in the SCS; (b) that in the eastern equatorial Pacific; (c) that in the western equatorial Pacific.

3 Conclusion

From the above discussion, there is a very close interrelationship between the SST of the SCS and the equatorial Pacific on different scales. The episodes of El Niño and La Niña which happened in the eastern equatorial Pacific have had a strong effect on the SST of the SCS. This effect is very obvious in the interannual variety of SST. In the 4-year cycle scale, in-phase oscillations of SSTA occur between the SCS and the eastern equatorial Pacific, in the 8-year cycle scale, the in-phase oscillations of SSTA occur between the SCS and the western equatorial Pacific. The out-of-phase oscillation of SSTA occurs between the eastern equatorial Pacific and the western equatorial Pacific in the two scales. At the 4-year scales, the variety of SST in the eastern equatorial Pacific has more effect on the SST in the SCS, but in the 8-year scales, the variety of SST in the western equatorial Pacific has more effect on the SST in the SCS. The change in the Pacific will act on the SCS, and the SCS will respond to the change in the Pacific with a 5—8 months lag. The in-phase oscillation of SST between the SCS and the equatorial Pacific in different interannual scales suggests that this oscillation is universal. Further studies are necessary to determine the possible causes of these interannual oscillations.

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