Article ID: 1006-8775(2000) 01-0086-08

THE CLIMATE FEATURES OF THE SOUTH CHINA SEA WARM POOL

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ABSTRACT: There exists a warm pool in the South China Sea (SCS). The temporal and spatial distribution and evolution of SCS warm pool is investigated using water temperatures at a depth of 20 m in the sea. The formation of the warm pool is discussed by combining water temperatures with geostrophic currents and simulated oceanic circulation. It is found that there are significant seasonal and interannual changes in the warm pool and in association with the general circulation of the atmosphere. The development of SCS warm pool is also closely related to the gyre activities in the sea and imported warm water from Indian Ocean (Java Sea) besides radiative warming.

Key words: South China Sea warm pool; seasonal and interannual variability; gyre activity; warm water transport

CLC number: P732.7 **Document code:** A

1 INTRODUCTION

The South China Sea, the largest and deepest marginal sea in the tropical pacific, is located at the link of the Indian Ocean and the Pacific Ocean and the bridge between the Asian monsoon and the Australian one. It will play an important role on the East Asian monsoon due to its high water temperature and large heat content in the upper ocean. When we worked on the subject that the interannual variability of the heat content in the upper ocean of SCS effects on the rainfall in the South China academician HUANG Rong-hui and we pointed out that there exists a warm pool in SCS based on the fact that a low temperature region with 23℃ in the vertically averaged temperature（TAV）over the upper 100m of the ocean is observed in the southern SCS in Mar. ~ Apr., and it rises rapidly up to 27℃ in May ~ Jun. In the same period the 25℃ isotherm moves rapidly to the northwest and the vicinity of Bashi strait, and moves northwards continually in Jul.~ Aug.(He, Guan and Gan, 1992; Guan and He, 1996; He and Guan, 1996; He and Guan, 1997). The knowledge of basic features and formation of SCS warm pool is very important in order to understand air-sea interactions and its effect on summer monsoon over SCS.

Data used in this study are mainly time sequence of temperature - depth (T–Z) profiles in SCS for the period from 1959 to 1988 with a grid 20m in the vertical, 2 (latitude) by 2 (longitude) on horizon, and bimonthly in time, which come from temporal and spatial interpolation of about 60,000 observed T-Z profiles in the ocean (0^0 ~ 23^0N, 100^0E ~ 123^0E) during that period using the optimum technique after data quality control (Alaka and Elvander, 1972; White, 1975; He, Guan and Gan, 1997). SST data is from COADS. A warm pool in SCS is observed by the water temperatures at a depth of 20 m in the ocean, which is adopted to describe its temporal and spatial dis-

Received date: 1999-06-15; **revised date:** 2000-03-15

Foundation item: National Natural Science Foundation of China (No.49875015); State Key Project for basic Research ”The South China Sea Monsoon Experiment”

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tribution and variation. The formation of SCS warm pool is also discussed by combining water temperatures with geostrophic currents and simulated oceanic circulation.

2 SEASONAL FEATURES OF SCS WARM POOL

The 28℃ isotherm of annual mean of sea surface temperature (SST) over the tropical Indian-Pacific Ocean region (30°S ~ 30°N, 40°E ~ 140°W) for the period 1946 ~ 1992 (Figure omitted) goes across SCS from the Western Pacific warm pool to the northeastern Indian ocean which is the warm water area, the maximum oceanic heat storage in the world (He and Guan, 1999). Annual monthly mean of SST for the same period shows that in winter SST in SCS is quite low with temperature below 20℃ observed in the vicinity of the northern coast, except some waters near the southern coast with SST about 28℃. In spring SST rises rapidly and the warming occurs over the entire SCS, with SST above 28℃ observed south to 19^0N. In summer (Jun., Jul. and Aug.) SST reaches its maximum and distributes evenly, with SST about 29℃ observed over most of SCS, except in the Taiwan strait with SST below 28℃. In autumn SST descends evidently, especially in the waters near the northern coast with SST below 25℃, while SST above 28℃ is observed south to 14^0N. Therefore SST in SCS has a large seasonal variation, but it is difficult to describe adequately characteristic of the warm pool and also limited in application of it to climate prediction only using SST because it distributes quite evenly in summer and is influenced greatly by the short-term weather conditions. The influence of oceanic circulation on water temperatures is stronger with increase in water depth, therefore water temperature below surface is a better index of oceanic heat storage, and the signal of interannual variability of water temperatures becomes stronger with increase in depth from surface to subsurface in the sea as we can see in the next section. Therefor, the water temperature at a depth of 20m in the sea is adopted to describe the development and variation of SCS warm pool according to the identification of the Western Pacific warm pool and SCS conditions.

Maps of the bimonthly long-term mean of water temperatures at a depth of 20 m in SCS for the period 1959 -1988 are displayed in Fig.1. It can be seen that in Jan. ~ Feb. two warm areas

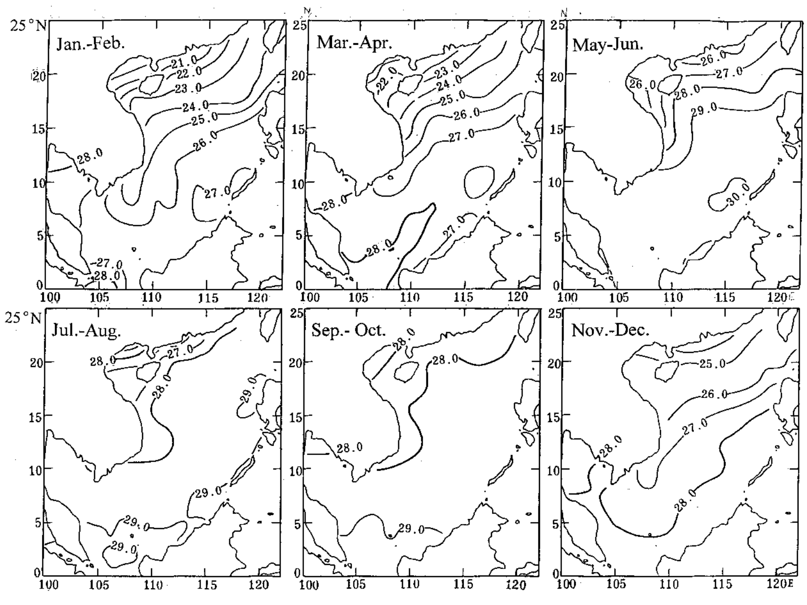

Fig.1 Annual bimonthly mean of water temperatures at a depth of 20 m in SCS for the period 1959 ~ 1988. The contour interval is 1.0°C, which is twice greater than the interpolated error.

semi-enclosed by 28.0℃ isotherm (dark contour) are observed in the southwest-most waters, the Gulf of Thailand and near the equator respectively, the cool water with temperature below 21.0℃ is observed in the waters near the northern coast, temperature gradient is large in the north and small in the south. In Mar.~ Apr. the two warm areas extend northeastwards to the vicinity of Nanwei and Beikang shoals, and to the southeastern Gulf of Thailand respectively, which is consistent with the result of TAV over 100m depth of the sea (He, Guan and Gan, 1992). In May ~ Jun. the two warm areas expand rapidly, conjoin together and extend northwards to the waters between the southeast of Hainan Island and the middle of Bashi strait owing to warming over the entire SCS, with temperature above 29.0℃observed in the middle and southern SCS, the warmest area enclosed by 30.0℃ isotherm is observed over the Nansha (Palawan) trough. In Jul. ~ Aug. the 28.0℃ isotherm becomes south-northwards owing to warming continually in the northern SCS and cooling near Vietnamese coast from north of 12^0N to the mouth of Gulf of Beibu (Tonkin), where the cooling is induced by upwelling. During this period, however, somewhat descent of water temperatures from above 29.0℃ in May ~ Jun. is observed in the middle and southern SCS, which is associated with decrease in solar radiation. In Sept.~ Oct. the 28.0℃ isotherm retreats southwards in the northeastern shelf region owing to effecting by the northeast monsoon, while the isotherm near the middle Viet Nam coast shifts somewhat westwards owing to weakening of the upwelling. In Nov.-Dec. the 28.0℃isotherm retreats southwards farther, from 4 - 5^0N in the southwest to the west of Luzon Island via the middle of Nansha Islands, a little southward than its annual mean location (Figure omitted). Therefore seasonal evolution of SCS warm pool is more clear on temperature fields on the 20 m depth layer than on the surface.

3 INTERANNUAL VARIABILITY OF SCS WARM POOL

The map of interannual rms differences about the mean annual cycle of water temperatures in the upper ocean (0 ~ 400 m) along 112^0E section for the period 1959 ~ 1988 is displayed in Fig.2. It is seen that the signal of interannual anomaly of water temperatures is stronger in the middle of the basin (9^0N ~ 18^0N), and becomes stronger with increased depth from surface to subsurface, which is similar to that in the Western Pacific warm pool (White, He and Pazan, 1989) and indicates that the water temperature field below surface is more useful in climate prediction.

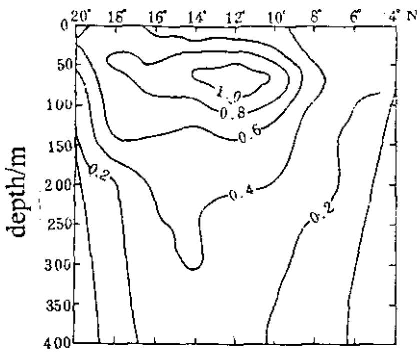

Fig.2 RMS of water temperature in the upper ocean (0 ~ 400 m) along 112°E section from 1959 to 1983.

The interannual variability of water temperature in the Western Pacific warm pool is closely associated with ENSO event, with experiencing descent, lower, ascent during the onset, peak and mature phases of ENSO event, and then higher after ENSO. Variation of water temperatures in the equatorial Pacific during 1982 ~ 1986 is a typical sample, as showed in Fig.3. The descent (negative anomaly), lower (large negative anomaly), and ascent (from negative to positive anomaly) of water temperatures in the western tropical Pacific occurred in May ~ Jun. of 1982, the beginning of 1983 and Aug. ~ Sept. of 1983, corresponding to the onset, peak and end of 1982-83 El Niño respectively. Water temperatures in the tropical western Pacific rose continually in 1984 and had lasted until the occurring of

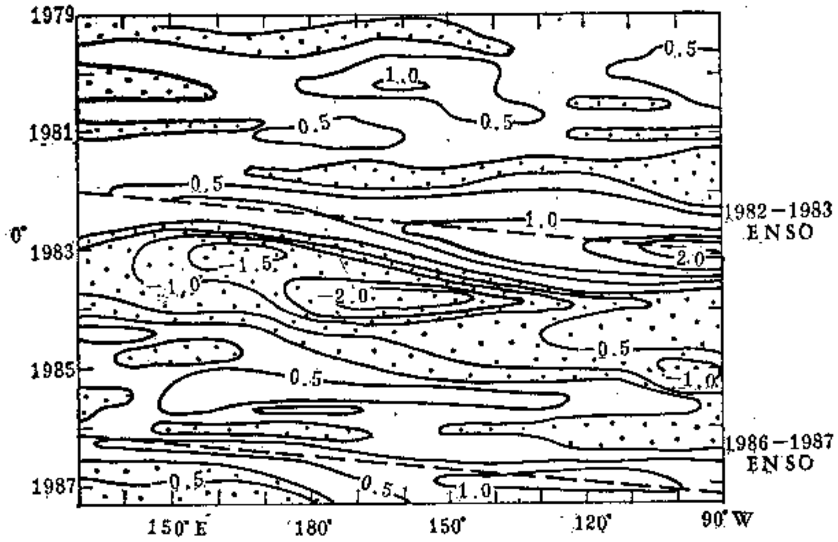

Fig.3 Longitude-time matrices of anomalous vertical averaged temperature (0 ~ 400 m) at the equator in the Pacific from 1979 to 1987 (Negative anomalies are shaded)

the next El Niño event in 1986. There is also a significant interannual variability of water temperatures over the upper 400 m of SCS, associated with the ENSO event, however, out of phase with that in the western tropical Pacific. Maps of the bimonthly anomalous temperatures at a depth of 20m in SCS in early spring (Mar. ~ Apr.) and summer (Jul. ~ Aug.) for 1983 and 1984 are displayed in Fig.4. From this figure it can be seen that the 28.0℃ isotherm in Mar. ~ Apr. of 1983 expanded to 14^0N, with northward 7-8^0 latitudes more than normal (Fig.1), and in Jul.-Aug. of 1983 temperatures above 29.0℃ were observed in most SCS, about 1.0℃ higher than normal, SCS warm pool expanded to farther north and west. In Mar ~ Apr. of 1984, however, SCS warm pool was smaller than normal and the 28.0℃ isotherm was observed only in waters northwest to the Borneo Island, with southward 2^0 ~ 3^0 latitudes more than normal. In Jul. ~ Aug. of 1984, the area of the warm pool was also smaller than normal, and a remarkable retraction eastward induced by stronger upwelling was observed near the coast of Vietnam between 10^0N and 15^0N, with water temperatures below 29.0℃ observed in most of SCS, 1.0℃ lower than normal. In fact positive anomalous water temperatures in the upper ocean of SCS occurred in the winter of 1982 and reached its maximum in the beginning of 1983, and then decreased, and the anomalies became negative in 1984. Therefor there is a significant interannual variability in the thermodynamic structure in SCS warm pool, out of phase with that in the western equatorial Pacific, and in phase with that in the eastern equatorial Pacific, with a lag by about 4 months. This is consistent with the early studies (Guan, 1983; He and White, 1987).

Geopotential height fields at 500 hPa for Jan. ~ Feb. of 1983 and 1984 are displayed in Fig.5. It can be seen that the western Pacific (or SCS) subtropical high is much stronger and dominates over SCS in 1983, in contrast to 1984. This pattern lasted to the late spring. We had shown that the Asian winter monsoon is weaker than normal when the western Pacific subtropical high is strong and extends westwards (He, Guan and Gan, 1992). The water temperatures in the upper ocean of SCS rises remarkably owing to gaining more heat and losing less heat when the strong western Pacific subtropical high and/or the weak winter monsoon dominate over the sea (He and Guan, 1982). While during the ENSO year the water temperatures in the upper ocean of the western

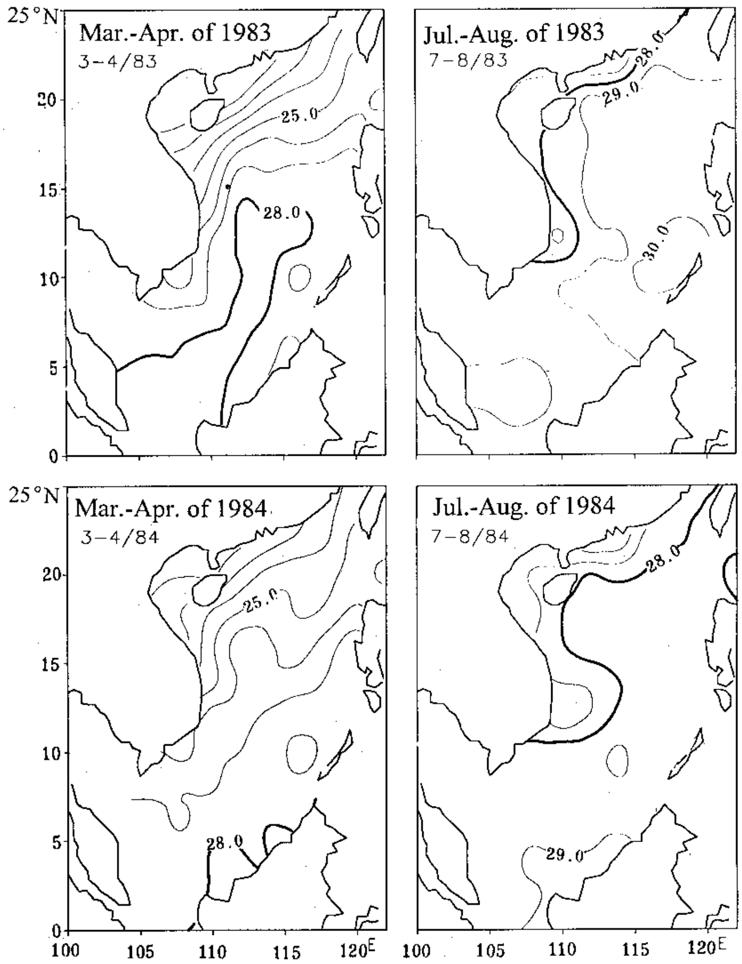

Fig.4 Bimonthly mean of water temperature at a depth of 20 m in SCS for Mar.- Apr. And Jul.- Aug. of 1983 and 1984. The contour interval is 1.0°C, which is twice the interpolated error

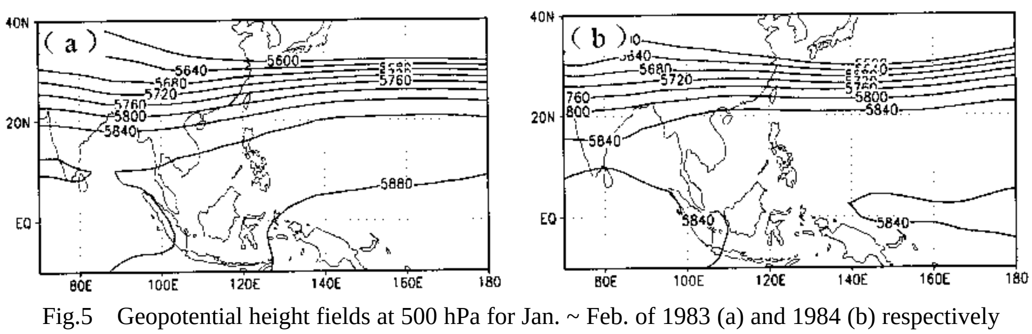

Fig.5 Geopotential height fields at 500 hPa for Jan. ~ Feb. of 1983 (a) and 1984 (b) respectively

equatorial Pacific descend owing to the transportation of the warm water from there to the eastern equatorial Pacific to make the mixed layer thinner and the main thermocline ascent in the western equatorial Pacific, which is induced by the Kelvin waves when the anomalous strong westerly winds occurred.

4 DEVELOPMENT OF WARM POOL AND THE OCEANIC CIRCULATION

Water temperature in SCS rises rapidly in spring and the warm pool expands quickly into the basin from the southwest, reaches its maximum in size in summer. On the one hand this is closely related to increase in solar radiation reached to sea surface with large angle of incidence and subtropical high over the sea, and to the oceanic circulation on the other during the period. The dynamic heights relative to 400 m of the ocean and the corresponding geostrophic currents for the region south of 15^0N in SCS from winter to summer are displayed in Fig.6. They are calculated from annual bimonthly mean of T-Z and salinity-depth data for the period 1959 ~ 1988 using dynamic method. This depth chosen is due to more than 90% of data confined to it owing to large shelf and spread of shoal and islands in the southern SCS. Thus it may have somewhat errors for those in the sea waters deeper than 400 m owing to neglect of water movement under this depth. The characteristic of large scale circulation in the upper SCS displayed in Fig.6 is consistent with the numerical result in the subsurface layer in the sea using the OGCM model (He and Yamagata, 1994). It can be seen that in Mar. ~ Apr. there are two anti-cyclonic circulation occurring in central SCS and in the mouth of the Gulf of Thailand respectively. The anti-cyclonic circulation can inhibit the upwelling and favor the warming of the upper ocean and transport warm water into SCS basin from the Gulf and the equator region. From spring to summer the anti-cyclonic circulation moves to the waters of Nansha islands from the southwestern region, and its strength intensifies to form an anti-cyclonic gyre (called the southern anti-cyclonic gyre) and to promote transport of warm water

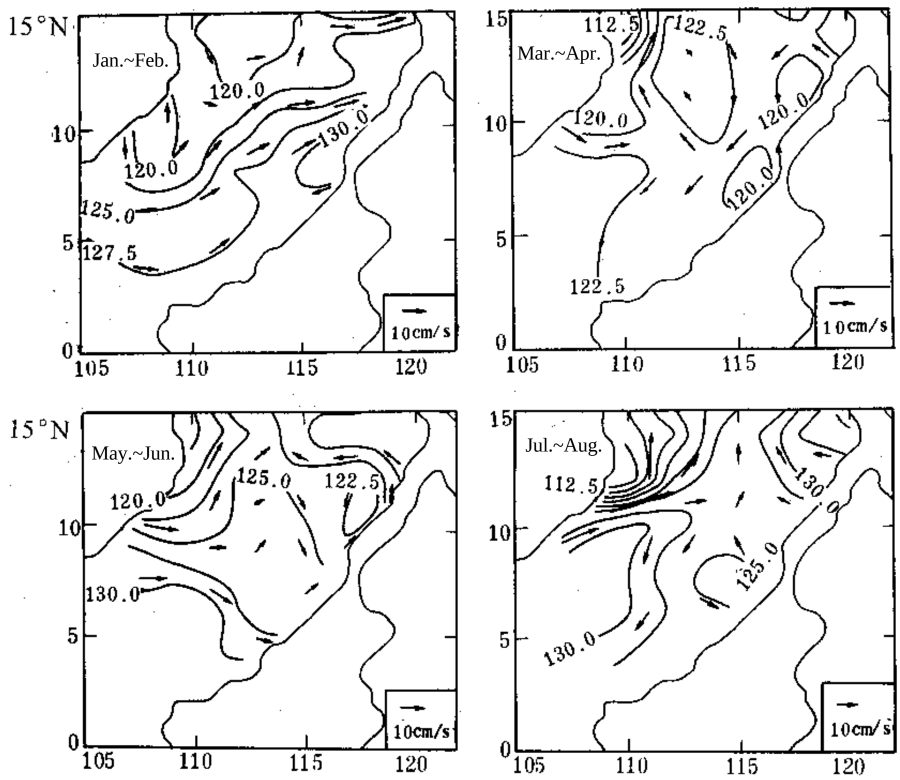

Fig.6 Bimonthly distribution of dynamic height (0/400 m) and geostrophic current vectors from winter to summer (The contour interval is $2.5\times10^{-2}m^2s^{-2}$)

to the basin from southwestern and southern waters, resulting in rapidly increase in heat content in the upper ocean of the basin and quick expanding of the warm pool (Fig.2). From late spring /early summer to full summer there is a cyclonic gyre developing near the Vietnamese coast which intensifies the eastward and northeastward currents between the cyclonic and anti-cyclonic gyres. The pattern of the oceanic currents is favorable to transport warm water from the south to the north, thus the warm pool extends with maintaining higher temperature. A part of warm waters probably comes from the Java Sea from May to August. This can be seen from the numerical simulation result. The oceanic current distribution at a depth of 5 m in May-Jun. from a numerical simulation result of oceanic circulation using OGCM is displayed in Fig.7. The domain of the simulation covers the Pacific and Indian oceans from 30^0S - 30^0N, including SCS with Taiwan , Bashi and Kalimata Straits opening for free water exchange between SCS and East China Sea, Philippine Sea and Java Seas (Masumoto and Yamagata, 1993). From this figure it is obviously seen that there is warm water transporting into SCS from Indian ocean (the Java Sea) during the southwest monsoon season.

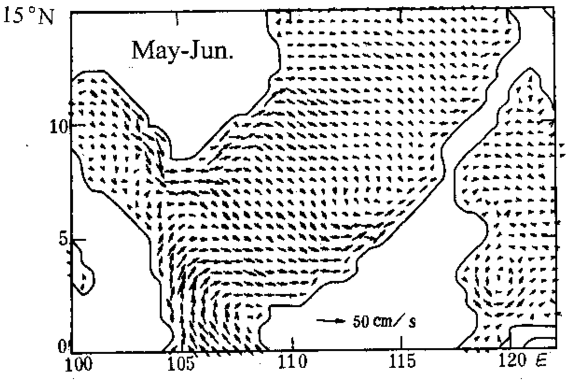

Fig.7 Bimonthly simulated oceanic current at a depth of 5 m in May ~ Jun.

5 CONCLUDING REMARKS

A warm pool in SCS is observed based on the water temperatures at a depth of 20 m in the sea. There is a remarkable seasonal change in SCS warm pool — it shrinks to the minimum in size with lower water temperature in winter; it rises rapidly in water temperatures and expands quickly northeastwards into the basin in late spring and early summer; it has the highest temperature and reaching its maximum size in summer; it cools in temperature and retracts southwards of the warm pool in autumn. There is also a significant interannual variability in the warm pool, associated with the ENSO event. During the El Niño years the SCS warm pool is bigger than normal with higher water temperature, which is out of phase with that in the western equatorial Pacific, and in phase with that in the eastern equatorial Pacific, with a lag by about 4 months. The western Pacific (or SCS) subtropical high and monsoon play an important role in the interannual variability of water temperature in the upper SCS. The warm water in SCS is independent of the western Pacific warm pool and is called the SCS warm pool. The development of SCS warm pool is also closely related to gyre activities in the sea, imported warm water from Indian ocean (the Java Sea) to SCS which is induced by southwest monsoon, besides solar radiation.

Acknowledgements: It is particularly the authors' intent to thank academician Huang Ronghui, who has supported this research and made valuable suggestions. The authors appreciate his kindness.

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