Interannual and Interdecadal Variations in Heat Content of the Upper Ocean of the South China Sea

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ABSTRACT

The vertically averaged temperature (TAV) from surface to 100 m depth of the South China Sea for the period 1959–1988 is analyzed. The results indicate that there is a significant long–term variability from interannual to interdecadal scales in the heat content in the upper ocean. The heat content of the upper ocean of the South China Sea increases evidently in the El Nino year. TAV anomaly in the ocean was negative from the end of 1950's to early 1970's, and then changed to positive. The changes of TAV of the ocean are closely related to ENSO events, the Asian winter monsoon and the tropical atmospheric circulation anomalies.

Key words: Heat content, Interannual variability, Interdecadal variability

Recently the global climate changes have called more and more public attention. Among them the global warming issue has been become a research spotlight on climate today. Since the impact of climate changes on our society is mainly determined by regional response, we need particularly to have clear images of regional processes as well as their interaction with the global climate changes.

The South China Sea (SCS) is one of the most important marginal seas for the world climate research community because it is located at the link of ocean–atmosphere circulation over the Indian Ocean and the Pacific Ocean, and of Asian monsoon and Australia monsoon. SCS region is one of the major heat sources for the global troposphere. Therefore knowledge of variations of heat content in the upper ocean of SCS will be very helpful to understand the general circulation, especially SCS monsoon and climate anomaly in South China.

I. DATA PROCESSING

Data used in this study are temperature–depth (T–Z) profiles in SCS (0–23°N, 100–123°E) from 1959 to 1988. The total number of observations is about 62,000. Variations of the total number of T–Z profiles for each year and bimonth are showed in Fig. 1. The profiles are interpolated on a 2 (latitude) by 2 (longitude) grid in space and bimonthly in time using the optimal technique. The vertically averaged temperature (TAV) from surface to 100 m depth of the ocean is taken to be an assessment of the upper ocean heat content because many T–Z profiles and the depth of mixing layer in the region of interest are all confined to this layer owing to spread of islands and shoal.

II. CHARACTERISTIC OF INTERANNUAL VARIABILITY OF TAV

The empirical orthogonal function (EOF) method is chosen in TAV analysis. The anomaly of TAV was standardized first and then the EOF was computed. The result shows that the first four EOFs of anomalous TAV together account for 51% of total interannual variance for 30 years. The first EOF of TAV explains 29% of total variance and is the most important one.

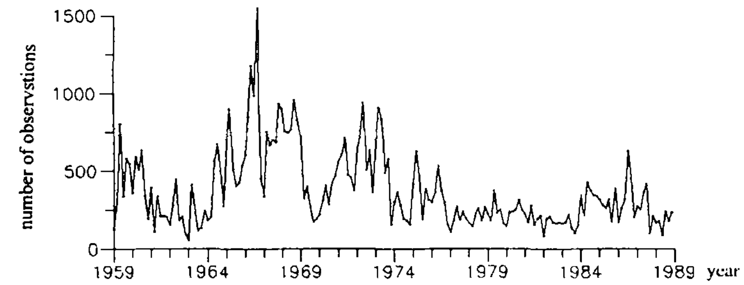

Fig. 1. Time sequence of bimonthly number of temperature / depth observations in the South China Sea from 1959 to 1988.

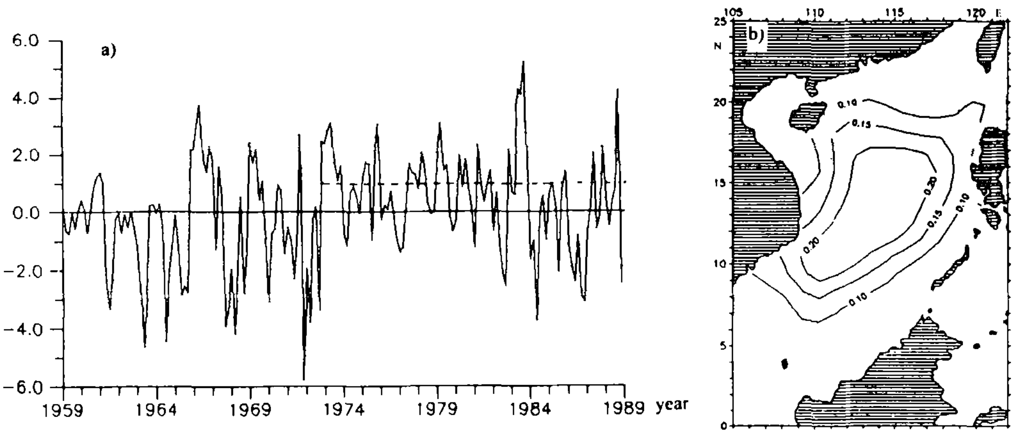

Fig. 2. First empirical orthogonal function of anomalous TAV with time function (a) and spatial patterns (b) displayed.

Fig. 2a shows time function of the first EOF of TAV. It has major peaks occurring in winter of 1965–winter of 1966, 1969, winter of 1972–winter of 1973, summer of 1977–summer of 1978, winter of 1982–winter of 1983 and autumn of 1987–autumn of 1988. Comparing Fig. 2a with Fig. 1, it cannot be seen that there is relationship between peaks in Fig. 2a and the number of observations in Fig. 1. Those major peaks in Fig. 2 are associated with strong signal of interannual climatic anomaly in the tropical zone, mainly corresponding to the ENSO events. The interannual changes of TAV in the upper ocean of SCS have the same tendency as those of sea surface temperature (SST) in the equatorial eastern Pacific, and with a lag by 4 to 12 months. This is consistent with the early results (Guan, 1983; He and White, 1987; He et al., 1992). In Fig. 2a it also can seen that minor peaks between major peaks occurred such as in autumn of 1960–spring of 1961, 1975, 1979 and 1985 et al. This indicates that there also exists an oscillation period shorter than ENSO cycle in TAV in SCS. The spatial pattern (Fig. 2b) associated with the first EOF of anomaly of TAV is positive, with a maximum in the central basin between 10 and 18°N, where is the area of largest interannual variability of TAV and maybe the most sensitive area to air–sea interactions. Moreover, the time function of the first EOF has a significant long–term trend with persistent warming, and increase in TAV in the upper ocean of SCS (about 0.2°C increase in TAV in central basin on an

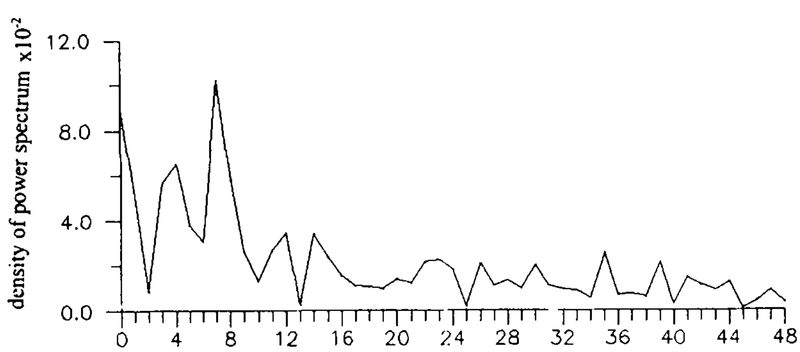

Fig. 3. The spectrum of anomalous TAV averaged for the whole basin for the period 1959–1988 with a maximum lag by 48 bimonths

average, broken straight lines in Fig. 2a) since mid–1970′s, which is correspondent to land air temperature rising in the Northern Hemisphere.

The spectrum of anomaly of TAV time series with a lag by 48 bimonths is displayed-in Fig. 3. In Fig. 3 it can be seen that there exist at least two peaks, one maximum component with a period of 14 bimonths (about 2 years), another with a period of 4–5 years. The former is consistent with the early study on SST (Gan et al., 1991). In the spectrum there is another significant component with frequency 0, which indicates that there exists a lower frquency component in TAV. This is consistent with the time function of the first EOF of TAV anomaly.

III. CHARACTERISTIC OF INTERDECADAL VARIABILITY OF TAV

Fig. 4 shows time variations of yearly mean of TAV anomalies (solid lines) and its 5–year running means (dashed line) in SCS. In 5–year running means TAV anomalies are negative from the beginning of 1960′s to the beginning of 1970′s, a cold decade. And then it has entered the warm decade in SCS, with increase in heat content and persistent positive TAV anomalies, especially during the strong 1972–73 and 1982–83 ENSO events the increase in TAV was more evident with values about +0.25°C, and +0.4°C respectively. Therefore, the warming trend of water temperature in the upper ocean of SCS is associated with ENSO events. Analysis of low frequency oscillation of rainfall during pre–summer rainfall in South China indicates that rainfall has decreased gradually since 1973, and then entered a less rainfall decade (He and Guan, 1996). It is consistent with the beginning time when warming trend of water temperature in the upper ocean of SCS appeared. Nitta et al. 1989 mentioned that the rising of SST in the Indian Ocean and the tropical eastern Pacific appeared in late 1970′s. However, the rising of water temperature in the upper ocean of SCS seems to be in advance of that warming, which is associated with a high sensitivity of water temperature in SCS to the strong 1972–1973 ENSO event, and regional climate anomaly.

IV. RELATIONSHIP BETWEEN VARIATION OF TAV IN UPPER OCEAN OF SCS AND THE GENERAL CIRCULATION

Ocean and atmosphere are two most important components making the ‘big heat machine’ controlling variation of the global climate. They influence on and dominate each other, one responds and adjusts itself to the other′s changes.

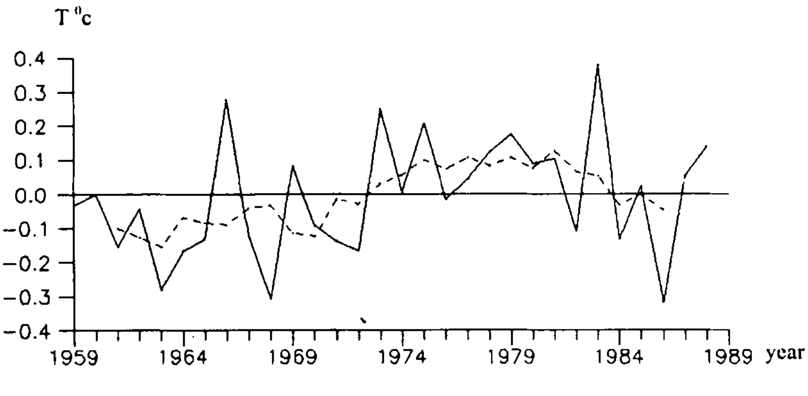

Fig. 4. Time sequence of yearly mean of anomalous TAV (solid line) from 1959 to 1988 and the 5-year running means (dashed lines) of it.

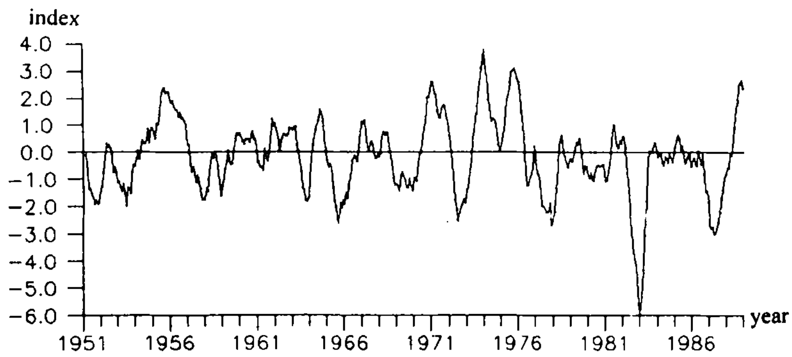

Fig. 5. 5-month running means of the Southern Oscillation Index from 1951–1988.

The Southern Oscillation Index (SOI) is one of the important interannual variations in the ocean-atmosphere system. Time sequence of SOI's five month running means for 1951–1988 is displayed in Fig. 5. TAV in the upper ocean of SCS increases evidently about half a year after SOI enters its negative phase, therefore SOI means prediction of variation of water temperatures in SCS. It is worth noting that there were a long-term low trend with negative SOI after 1976, and a warming trend with higher TAV in SCS after mid-1970's. Therefore there exists an opposite relationship between SOI and TAV in SCS, i.e the lower SOI, the higher TAV (such as 1982–1983). These imply that development of anomaly in ocean is often in concordance with atmosphere.

Fig. 6 shows time sequence of bimonthly difference between the westernmost longitude of the western Pacific subtropical high ridge at 500 hPa and longitude 125°E during the period 1959–1988. The difference with negative value indicates that the subtropical high only exists in the region east to 125°E and doesn't affect on SCS. The difference with value more than 20 indicates that SCS is dominated by the subtropical high. In Fig. 6 it can be seen that SCS is basically dominated by the subtropical high during ENSO events. It is also interesting that the subtropical high was persistently stronger than anomaly after mid-1970's, when it is correspondent to the decade of increase in TAV in SCS.

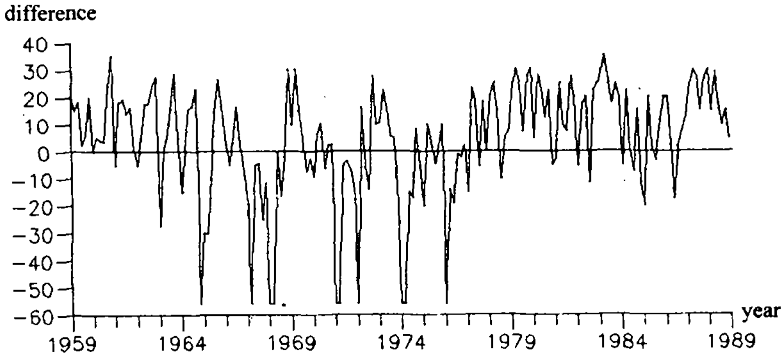

Fig. 6. Time sequence of difference between the westernmost longitude of the western Pacific subtropical high ridge and longitude 125°E from 1959 to 1988.

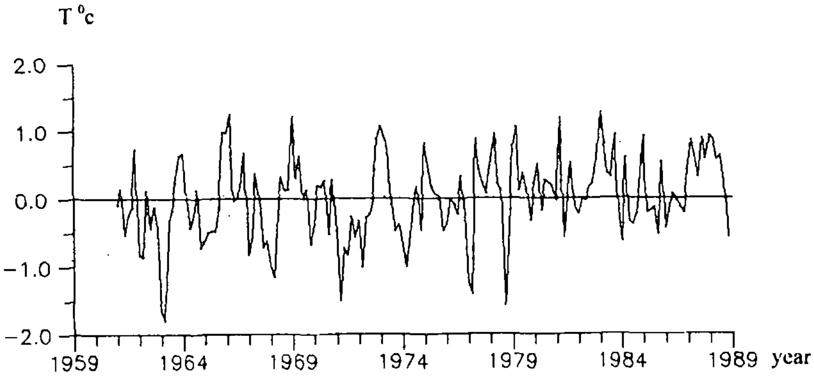

Fig. 7. Time sequence of bimonthly anomalous air temperature at meteorological Station Xisha for the period 1961–1988.

Fig. 7 shows time sequence of bimonthly air temperature anomalies at meteorological Station Xisha (16.5°N, 112.2°E) during the period 1961–1988. The variation of air temperature at the station during winter and spring can indicate the strength of winter monsoon in East Asia affected on SCS. Positive air temperature anomaly is more evident during winter and spring in El Nino years (such as from November–December 1965 to March–April 1966 and so on) and the positive air temperature anomalies are persistent after mid–1970's, which implies that winter monsoon in East Asia is weaker than normal. TAV in SCS increases owing to less heat transporting to the atmosphere from sea surface under weak winter monsoon, which is a probable oceanic response to the general circulation changes.

It is well known that El Nino event often occurs as SOI is in its negative phase (low SOI). The strength of the western Pacific subtropical high is closely related to change of tropical ocean–atmospheric system. The early study shows that interannual change of the strength of the western Pacific subtropical high has the same tendency as those of SST in the equatorial eastern Pacific, and with a lag by 4–6 months. After El Nino occurring the western Pacific subtropical high strengthens, stretches to the west and controls over SCS, over SCS it is mainly downward air current, fine weather with weak wind, gaining in heat on sea surface and rising SST (He and Guan, 1982); vice versa rising of SST favours strengthening of the subtropical high (He and Guan, 1996); at the same time, weat winter monsoon favours rising of temperature in SCS during winter and spring in El Nino year. Therefore TAV in the upper ocean of SCS increases evidently and persists for a longer time. It must be pointed out that even if it is not an ENSO year, weak winter monsoon invading SCS also causes TAV increasing evidently (such as 1975, 1978 and so on). This is a regional characteristic of interannual change of TAV in SCS.

V. RESULTS

Main results are as follows from above analysis.

(1) There exists a significant interdecadal variability of TAV in the upper ocean of SCS, with increase in TAV after mid–1970's, corresponding to the global warming. Rising of water temperature in the upper ocean of SCS seems to be leading in that warming in the Indian Ocean and the tropical eastern Pacific. This is associated with SCS lying in East Asian monsoon region.

(2) There exists an interannual variability of TAV in SCS, with periods of quasi–2 years and 4–5 years respectively, associated with strong interannual climatic anomaly in the tropical zone. TAV increases significantly in El Nino year, i. e., the stronger El Nino, the higher TAV. The interannual change of TAV in SCS has the same tendency as those in the eastern tropical Pacific, and with a lag by about six months. On spatial distribution the increase of TAV is more evident in the central basin between 10° and 18°N.

(3) Interannual and interdecadal variabilities of TAV in SCS are associated with the general circulation, corresponding to low SOI, the strong western Pacific subtropical high and weak winter monsoon in East Asia. SOI is one of the probable important predictors for TAV in SCS.

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