Article ID: 1006-8775(2006) 01-0034-07

CHARACTERISTICS OF FREQUENCY SPECTRUM VARIATION OF INTRASEASONAL OSCILLATION OF CONVECTION DURING SOUTH CHINA SEA SUMMER MONSOON

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ABSTRACT: Datasets of equivalent temperature of black body (TBB) and sea surface temperature (SST) ranging from 1980 to 1997 are used to diagnose and analyze the characteristics of frequency spectrum and strength of intraseasonal variation of convection. The relationship between the strength of intraseasonal oscillation of convection, strength of convection itself and SST in the South China Sea (SCS) is studied. It is shown that, there are distinguishable annual, interannual and interdecadal variations in both strength and frequency spectrum of intraseasonal variation of convection in SCS. There are connections between strength of convection, strength of ISO1 in the summer half (s.h.) year and SST in ensuing winter half (w.h.) year in SCS. The strong (weak) convection and strong (weak) ISO1 are associated with negative (positive) bias of SST in ensuing w.h. year in SCS.

Key words: convection in South China Sea; intraseasonal oscillation; characteristics of frequency spectrum; SST in South China Sea

CLC number: P425 **Document code:** A

1 INTRODUCTION

Situated in the region of East Asian Monsoon (EAM), weather and climate in China are deeply influenced by the activities of EAM. Especially in flood seasons, distribution of precipitation, movement of rain-bands and occurrence of droughts and floods from May to September for the eastern part of China are controlled by the EAM to a great extent. In history, almost all disastrous droughts and floods in China have close connections with activities of monsoon. For example, the extraordinarily severe floods in Changjiang (formerly known as Yangtze) -Huaihe River valleys in 1991, the extraordinarily severe floods in South China in the summer of 1994 and the extraordinarily severe floods in Changjiang River valley in 1998 all had close relations with activity anomalies of summer monsoon. EAM bursts out firstly in SCS and then moves northward and southward. The time of onset and strength of South China Sea Summer Monsoon (SCSSM) and its activity have important influences on the weather and climate in South China or even the whole country[1-7]. Since the research of SCSSM is valuable in both theory and application, it has drawn much attention in recent years. Some past studies showed that many physical elements in the monsoon area take on visible characteristics of intraseasonal variation (also named low frequency oscillation (LFO)). Krishhnamuti, et al. [8] discovered that low frequency waves can affect the establishment, break and active phases of South Asian Monsoon directly. Through analyses of outgoing long wave radiation (OLR) dataset, Murakami, et al. [9] showed that 90°E equatorial Indian Ocean and 130°E～150 °E equatorial west Pacific Ocean are two activity centres of LFO; Song and Xie et al. [10] pointed out that LFO of OLR in the s.h. year accounts for a considerable part of the total variance of its original series in SCS and LFO strengthens after the break of SCSSM; The results from Mu and Li[11] and Xu and Zhu[12] all suggest that the outset of SCSSM has

Received date: 2005-04-01; **revised date:** 2006-02-23

Foundation item: "Research on the monitoring and service of South China Sea monsoons", a public welfare project from the Ministry of Science and Technology (2002RKT01); "Response of interdecadal changes of South China Sea summer monsoon to global change", a project from the Natural Science Foundation of China (902110110)

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very close connections with atmospheric intraseasonal oscillation (ISO) in SCS and peripheral areas; Zhu and Xu's study[13] showed that the northward propagation of low frequency SCSSM gives important contribution to the precipitation in the Changjiang River valley. These studies mentioned above all suggest that it's necessary to continue research on ISO of SCSSM. Despite all that, current studies on ISO are mainly confined to the segments of period ranging from 30 to 60 days[8-14] and the past researches did not pay attention to the fact if there exist any interannual variation in the principal period or feature of frequency spectrum and its strength of intraseasonal variation of SCSSM. In fact, past researches have shown that the period length of ISO has close association with regional draughts and floods[15-17]. So, it is of value to study on this. In the work, datasets of equivalent temperature of black body (TBB) and sea surface temperature (SST) ranging from 1980 to 1997 will be used to diagnose and analyze the characteristics of frequency spectrum and strength of intraseasoanl variation of convection and the relationship between strength of ISO of convection, strength of convection itself and SST in SCS will be studied.

2 DATASETS AND METHODS

TBB dataset, six times daily from 1980 to 1997, covering an area from 59.5 °S to 59.5 °N and from 80.5 °E to 160.5 °W, with a resolution of 1 °×1 ° from Japan meteorology agency, is employed. The data is averaged over six time intervals to get daily mean and the area of 5°N – 20 °N，105 °E –120 °E is taken to represent the SCS region. Dataset of monthly mean global SST is from the Hadley Centre for Climate Prediction and Research of U.K. Met. Office[18] and data fraction of temporal coverage corresponding to that of TBB is selected.

The method of wavelet analysis[19] is used here and the Morlet wavelet, i.e.,

$$y_0(h) = \pi^{-\frac{1}{4}} e^{i w_0 h} e^{-\frac{h^2}{2}} \qquad (1)$$

is taken as transform function.

The continuous wavelet transform of discreet sequence x_n (n=0, 1, ……, N-1. N is the length of temporal sequence）is

$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} y^* \frac{(n'-n)}{s} dt \qquad (2)$$

Here, the superscript "*" denotes complex conjugate. Nondimensional frequency ω_0=6 and scale parameter S_j is a function of power of 2, i.e. $S_j = S_0 2^{j\delta j}$, j=0, 1, ……，J, S_0=2, δ_j=0.25. The Fourier period is $1.03S_j$.

The strength of oscillation for a given waveband (S_{j1}～S_{j2}) can be computed by the following formula:

$$\overline{W}_n^2 = \frac{d\,jdt}{C_d} \sum_{j=j_1}^{j_2} \frac{|W_n(s_j)|^2}{s_j} \qquad (3)$$

｜$W_n(s)$｜^{2} is the power spectrum of wavelet transform at time n. The total wavelet power spectrum is

$$\overline{W}^2(s) = \frac{1}{N} \sum_{n=0}^{N-1} |W_n(s)|^2 \qquad (4)$$

The total energy of wavelet transform is conservative and the variance of temporal sequence is

$$s^2 = \frac{d\,jdt}{C_d N} \sum_{n=0}^{N-1} \sum_{j=0}^{J} \frac{|W_n(s_j)|^2}{s_j} \qquad (5)$$

Here, $C_d = \frac{d\,jdt^{1/2}}{y_0(0)} \sum_{j=0}^{J} \frac{\Re\{W_d(s_j)\}}{s_j^{1/2}}$. For the waveband ($S_{j1}$～$S_{j2}$), the reconstructed sequence is

$$x_n' = \frac{d\,jdt^{1/2}}{C_d y_0(0)} \sum_{j=j_1}^{j_2} \frac{\Re\{W_n(s_j)\}}{s_j^{1/2}} \qquad (6)$$

Through reconstruction of temporal sequence for a waveband, the effect of filtering can be achieved. This is one of the methods employed here for data processing. The detailed realization is, subtracting the reconstructed sequence for 132 days and more (i.e. S_j⩾128) from the sequence of 18 years' daily mean and then obtaining the anomaly sequence of intraseasonal variation. It can be seen from the results of calculation that, the variance of TBB of intraseasonal variation (≤94 days) consists of 44.5% of the total variance and the variance of 10 – 94days variation, which is the main waveband for analysis in this article, consists of 32.7% of the total variance.

3 ANNUAL VARIATION

The annual variation of averaged wavelet power spectrum for daily mean TBB from 1980 to 1997 in SCS and corresponding averaged wavelet power spectrum for the whole year and for the s.h. year is given in Fig.1. The vertical coordinates in Fig.1 are the length of oscillation period (days). The horizontal coordinate in Fig.1a is days (i.e. the sequential ranking of the 365 days in one year) and the isolines are values of power spectrum. The horizontal coordinates in Fig.1b and Fig.1c are values of power spectrum. It can be seen from the power spectrum for the whole year (Fig.1b) that the main significant oscillation periods are those around 14 – 35days and those around 50 – 70 days whereas the periods around 35 – 70 days are insignificant. It is shown from the annual variation of power spectrum (Fig.1a) that the intraseasonal variation of TBB is stronger in the s.h. year than that in the w.h. year and the oscillations with periods around 14 – 35 days are mainly in early summer whereas the oscillations with periods around 50 – 70 days are mainly in midsummer. The averaged wavelet power spectrum for the s.h. year (Fig.1c) is similar to the average for the whole year. They are all characterized by a distribution of double peaks, but the feature for the s.h. year is more significant. Since the intraseasonal variation of TBB is stronger during summer monsoon, the following analysis will be mainly for the s.h. year (May to October). It is also shown from Fig.1 that, in SCS, the single waveband of 30 – 60 days cannot represent the main oscillation pattern of intraseasonal variation.

4 INTERANNUAL AND INTERDECADAL VARIATION

The oscillation strength of intraseasonal variation (10 – 90 days) and two wavebands (one is 50 – 70 days, denoted by ISO1; another is 14 – 35 days, denoted by ISO2) within it for the s.h. year(from May to October) is calculated. It is shown that there exist significant signals of interannual variation in all the three cases (Fig.2). Of which, oscillation strength of ISO1 is stronger (weaker) in 1980, 1981, 1984, 1988, 1996 (1986, 1989, 1991, 1992, 1993, 1995) and oscillation strength of ISO2 is stronger (weaker) in 1984, 1986, 1987, 1992, 1997 (1981, 1982, 1985, 1988, 1991). It is also shown in Fig.2 that the interannual variation of TBB has close connections with the oscillation strength of ISO1. When oscillation strength of ISO1 is stronger (weaker), TBB is lower (higher) and convection is stronger (weaker). The relationship is contrary to the case of South Asian monsoom. As suggested by Lawrence and Webster[17], there's a negative correlation between the strength of ISO (25 – 80 days) and the strength of Indian monsoon (as denoted by precipitation or convection). So, the South China Sea monsoon is of peculiar characteristics. It can also be seen from Fig.2 that there are interdecadal variations for the strength of convection and ISO in SCS. Compared to the 1980's,

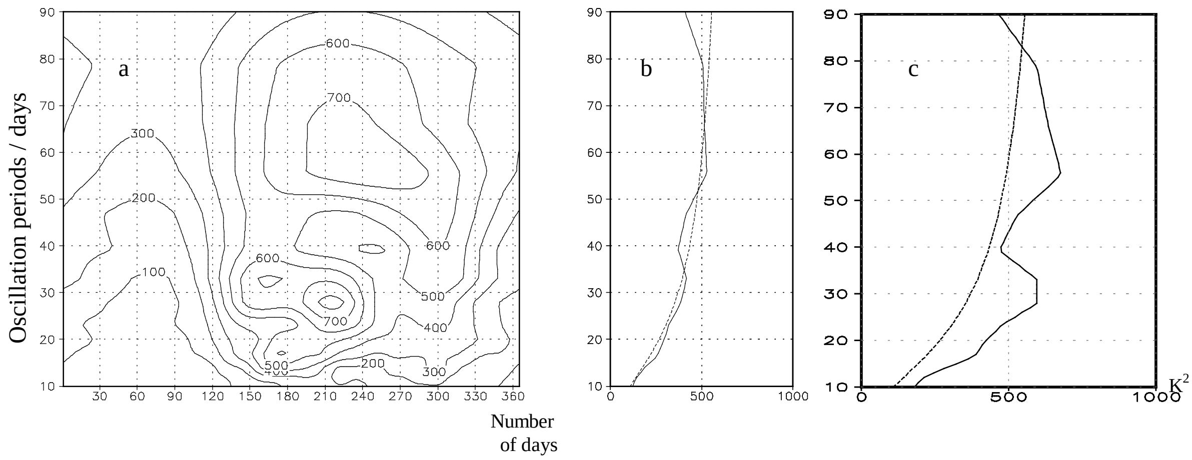

Fig.1 Distribution of isolines of averaged wavelet power spectrum for daily mean TBB from 1980 to 1997 in SCS (a, unit: K^2) and curves of averaged wavelet power spectrum for the whole year (b) and for the s.h. year (c). In (b) and (c), the dotted lines are curves of confidence test with α =0.05 and the unit of vertical coordinates are identical to that in (a).

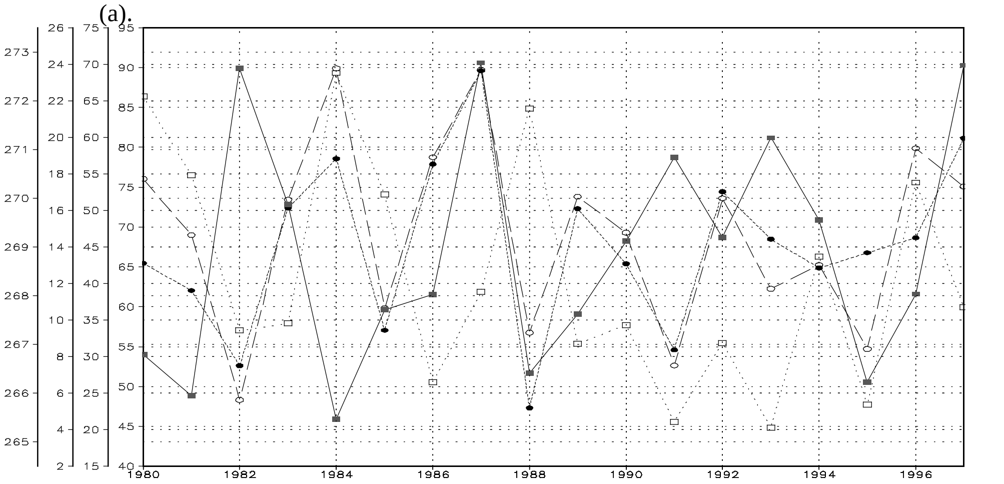

Fig.2 Variation of TBB (real line, unit: K) and oscillation strength (unit: K^2) of ISO (10-90 days, long broken line), ISO1 (50-70 days, dotted line) and ISO2 (14-35 days, short broken line) from 1980 to 1997 in SCS.

the strength of convection and ISO weaken in the 1990's. Of them, the weakening of strength of ISO1 is more significant.

Through comparing the cases of strong and weak ISO1, it is clear that there are apparent differences between the features of frequency spectrum in strong, weak or normal years of oscillation. The features of wavelet power spectrum for strong, weak and normal years of ISO1 are given in Fig.3. Of them, Fig.3a – c are the wavelet power spectrums for strong, weak and normal years and Fig.3d are the averaged wavelet power spectrums for strong (the solid line), weak (the long broken line) and normal (the short broken line) years of ISO1. The dotted lines are the curves of confidence test with α=0.05. It is shown from the figure that, in most years of strong ISO1, the strength of wavelet spectrum for 10 – 70 days reach the significance level of confidence test and peaks arise in periods around 45 – 70 days. The patterns of those distributions are mainly wide spectrum with single peaks. These features can be seen more clearly from the variation of averaged power spectrum (the solid line in Fig.3d). In years of weak ISO1, on the other hand, the strength of power spectrum for 40 – 90 days are very weak and cannot reach the significance level of confidence test. But the strength of wavelet power spectrum for wavebands of 14 – 30 days is stronger than that in years of strong ISO1 (Fig.3b). On average, the curve of wavelet power spectrum in years of weak ISO1 is of single peak (the long broken line in Fig.3d) whereas its spectrum is narrow. In years of normal ISO1, the strength of wavelet power spectrum in wavebands of 40 – 80 days lies between those of strong and weak ISO1 years. In other wavebands, all three cases of IOS1 share similar features of strength of wavelet power spectrum. The curves of wavelet power spectrum in years of normal ISO1 have double peaks (See the short broken lines in Fig.3c and Fig.3d). Similar to those for ISO1, there are also significant differences among frequency spectrum features in strong, weak and normal ISO2 years (Fig.4). The curves of wavelet power spectrum present wide spectra with single peaks, narrow spectra with single peaks and double peaks in years of strong, weak and normal ISO2 strength respectively.

From the results of the above analysis, it is shown that there are significant interannual variation for features of frequency spectra of ISO of convection in SCS and it can be categorized into 5 types of (1) wide spectra with single peaks dominated by ISO1 (corresponding to strong ISO1), (2) wide spectra with

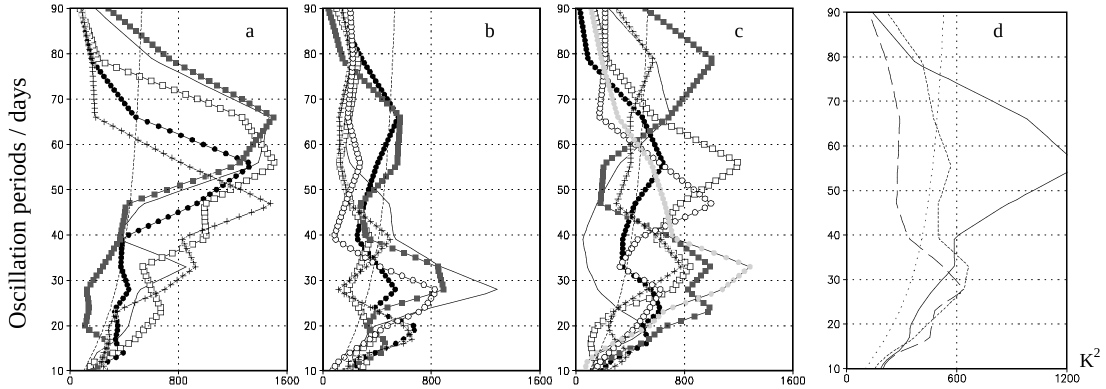

Fig.3 Wavelet power spectra for years of strong (a), weak(b) and normal(c) ISO1 and averaged wavelet power spectra for years of strong(real line), weak(long broken line) and normal(short broken line) ISO1(d). The thin dotted line is the curve of confidence test with α =0.05.

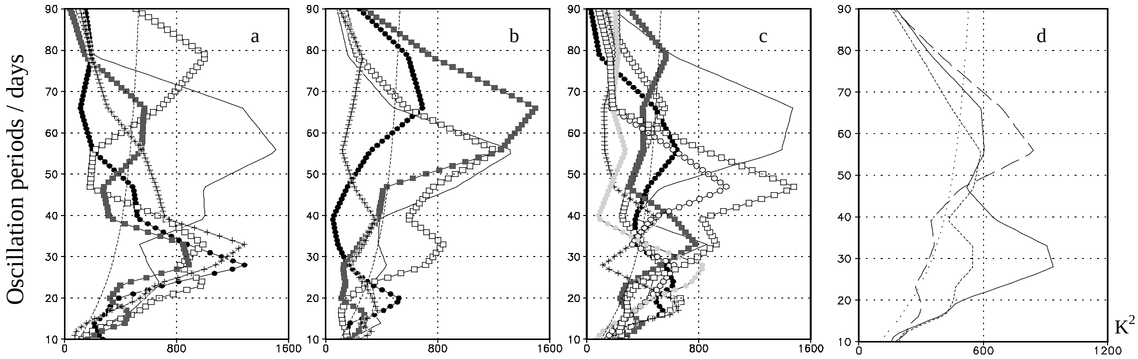

Fig.4 Wavelet power spectrum for years of strong (a), weak (b) and normal (c) ISO2 and averaged wavelet power spectrum for years of strong (real line), weak (long broken line) and normal (dotted line) ISO2 (d). The thin dotted line is the curve of confidence test with α =0.05.

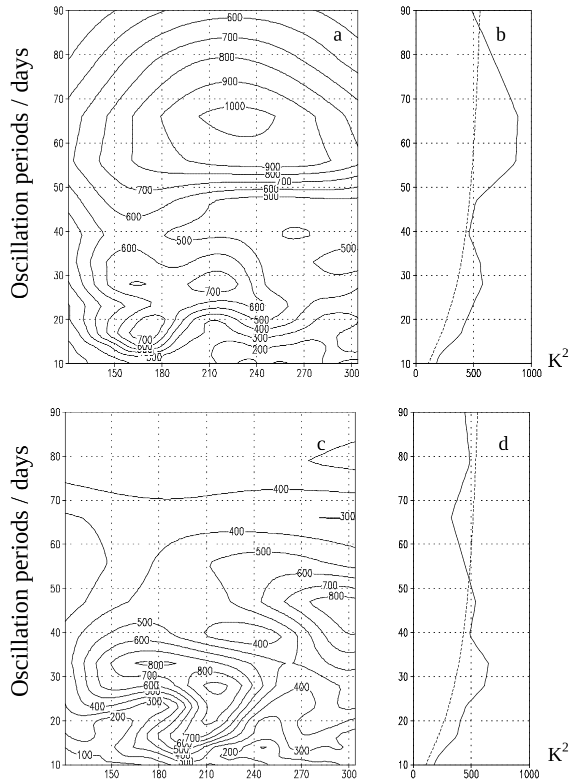

Fig.5 Distribution of wavelet power spectra (a, c) and the global wavelet power spectra (b, d) (a) and (b) are for the average from 1980 to 1989, c and d are for the average from 1990 to 1997. The dotted lines in b and d are the curves of confidence test with α =0.05.

single peaks dominated by ISO2 (corresponding to strong ISO2), (3) narrow spectra with single peaks dominated by ISO1 (corresponding to weak ISO2), (4) narrow spectra with single peaks dominated by ISO2 (corresponding to weak ISO1) and (5) double peaks dominated by ISO1 and ISO2. Only in exceptional years (1996), there exists a type of single peaks in the 30–60-day waveband. In addition, it can be seen that, the situation is rare when both ISO1 and ISO2 are strong. The exception is 1984, when convection is the strongest in all the 18 years studied.

There exists interdecadal variation for features of frequency spectrum of ISO of convection in SCS. The averaged wavelet power spectrum for the periods 1980 – 1989 and 1990 – 1997 is given in Fig.5. It can be seen from the figure that the differences between Fig.5a, 5b and Fig.5c, 5d are very obvious. The high center of 50-80-day oscillation from June to October in the 1980's (see Fig.5a) disappeared in the 1990's. That is to say, the strength of ISO1 has weakened greatly and the strength of ISO2 has strengthened in the 1990's. From the variation curves of the global wavelet power spectrum, it is clear that, different from the type of double peaks dominant in the 1980's (Fig.5b), the type of single peaks of ISO2 is dominant in the 1990's (Fig.5d) and the period of ISO of convection is shorter.

5 PRELIMINARY DISCUSSION ON THE ASSOCIATIONS BETWEEN FREQUENCY SPECTRA AND CONVECTION STRENGTH AND SST

Results from the analysis of observation and numerical simulation by general circulation model (GCM) all show that[20-21], during El Niño, the atmospheric oscillation of 30 – 60 days has weakened significantly in tropical regions (especially in the western Pacific Ocean and Indian Ocean), suggesting that El Niño has important influences on 30–60-day oscillation in the tropical atmosphere. Recent studies suggest that[22] interannual variation of TBB has connections with El Niño. During El Niño (La Niño), higher (lower) TBB is associated with weaker (stronger) convection. But it is still unclear if there is any connection between SST in SCS and convection / strength of ISO. Here, preliminary analysis and discussion on this topic will be given. From the results of data analysis, it is shown that, there is no connection between convection / strength of ISO in s.h. year and antecedent (spring) or current SST in SCS. The 18 years variation of averaged TBB in s.h. year (real line), strength of ISO1(long broken line) and SST in winter in SCS (short broken line) is given in Fig.6. It can be seen that, under normal conditions, stronger ISO1 in s.h. year and lower TBB (i.e. convection is stronger) are associated with lower SST in ensuing winter in SCS and weaker ISO1 in s.h. year and higher TBB (i.e. convection is weaker) are associated with higher SST in ensuing winter. The lagged response of SST in SCS suggests that, in the local sea-air interaction in SCS, the atmosphere may play a dominant role initially. On the interdecadal scale, similar relationship also holds. Compared to the 1980's, the strength of ISO1 weakens, TBB increases(i.e. convection weakens) and SST has a positive anomaly. But the mechanism behind them remains unknown.

6 CONCLUSIONS

(1) There are two main wavebands, one is 50 – 70 days (ISO1), another is 14 – 35 days (ISO2), for the intraseasonal variation of convection in SCS. ISO2 is stronger in early summer and ISO1 is stronger in midsummer.

(2) Along with the interannual variation of oscillation strength of ISO1 and ISO2, features of frequency spectrum of intraseasonal variation of convection in SCS have changed obviously. Interannual

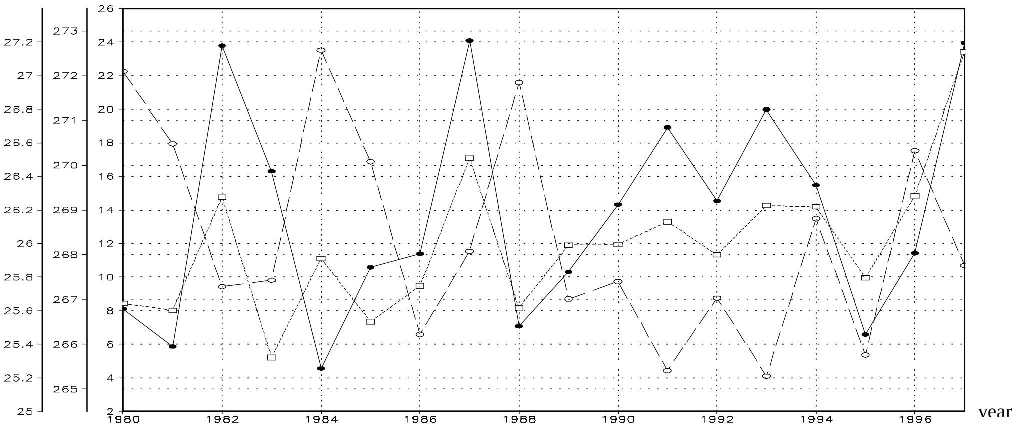

Fig.6 Variation of averaged TBB(real line, unit: K), strength of IOS1(long broken line, unit: K^2) for the s.h. year and SST(short broken line, unit: ℃) in winter over 1980 – 1997 in SCS.

variation of TBB has close connections with that of oscillation strength of ISO1. When oscillation of ISO1 is strong (weak), convection is strong (weak). The relationship between intraseasonal variation and convection in SCS is contrary to the case of South Asia monsoon.

(3) The features of frequency spectrum of intraseasonal variation of convection in SCS can be categorized into 5 types of (1) wide spectra with single peaks dominated by ISO1, (2) wide spectra with single peaks dominated by ISO2, (3) narrow spectra with single peaks dominated by ISO1, (4) narrow spectra with single peaks dominated by ISO2 and (5) double peaks dominated by ISO1 and ISO2. Besides, there exists a type of single peaks with 30–60-day waveband in exceptional years (1996).

(4) There exists interdecadal variation for features of frequency spectrum of intraseasonal variation of convection in SCS. In the 1980’s, the type of double peaks is dominant. In the 1990’s, the type of single peak of ISO2 is dominant and the period of ISO of convection is shorter.

(5) It is shown from our preliminary analysis that there are connections between the strength of convection, strength of ISO1 in s.h. year and SST in ensuing w.h. year in SCS. The strong (weak) convection and strong (weak) ISO1 is associated with negative (positive) bias of SST in ensuing w.h. year in SCS. But the mechanism behind it is still unknown.

Acknowledgement: The SST dataset used here is by courtesy of Prof. Zhang Ren-he from the Chinese Academy of Meteorology. The TBB dataset is by courtesy of Prof. Chen Long-xun from the Chinese Academy of Meteorology.

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