OBSERVATIONAL STUDY OF AIR-SEA FLUXES DURING THE SCS SUMMER MONSOON IN 2000——FEATURES OF THERMAL BUDGET AT THE SEA SURFACE*

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Received April 22, 2003; revised November 12, 2003

ABSTRACT

This paper is devoted to the features of sea-surface heat budget during the active/break phases of the 2000 summer monsoon in the South-China Sea (SCS) by means of the observed air-sea heat fluxes and data from Xisha Weather Station and NCEP/NCAR in the same period. Results suggest that the primary factors affecting sea-surface thermal budget are solar shortwave penetrating radiation and latent heat flux. Regardless of their changes, however, the thermal gain is reduced or becomes net loss at the active stage and the thermal gain gets gradually increased in the weakening and lull periods; during the first emergence of southwest monsoon the net loss happens thanks to the dramatic diminution of penetrating radiation resulting from increased cloudiness and intense precipitation; while at the re-emergence of the wind, reduced net sea-surface thermal gain is attributed to the sharp increase in latent heat flux resulting from intense evaporation; owing to great thermal inertia of water the SST change lags behind that of heat budget over the sea surface, and the lagging is responsible for regulating the budget by affecting latent heat fluxes, which, in turn, has effect upon the change of the SST, thereby forming short-term oscillations that are in association with the active/break phases of the monsoons. Part of the conclusions have been borne out by the observational study based on 1998 and 2002 data.

Key words: SCS summer monsoon, South-China Sea (SCS), active/lull monsoon phase, air-sea flux, sea-surface thermal budget, SST

I. INTRODUCTION

Flux exchange at the sea-air interface acts as an essential link for their interactions. This is because, on the one hand, the sea influences the atmospheric boundary layer via the flux exchange at the interface and further affects atmospheric circulations and, on the other hand, the force driving the motion of sea water comes mostly from the flux exchange at the interface. As a result, sensible/latent heat and radiation fluxes serve as the

* This work is sponsored jointly by the NSFC (National Natural Science Foundation of China) key program (No. 40136010) and the NSFC programs (No. 40075003 and No. 90211010).

important factors for the change in the mixed layer and seasonal thermocline, and momentum fluxes are the source of the force driving oceanic currents and waves. The flux exchange at the interface is accomplished first by affecting the motions in upper-level sea water and structure of temperature and salinity and further motions in the water at depth with the aid of intra-ocean thermal/dynamic adjustments. Consequently, with the advances in sea and climate numerical prediction models, observational studies of air-sea fluxes are receiving more and more attention in the meteorological communities at home and abroad. Globally, air-sea flux observation is the main undertaking of such atmosphere-ocean scientific experiments as Barbados Oceanographic and Meteorological Experiment (BOMEX), Tropical Oceans and Global Atmosphere Project (TOGA), Climate Variability and Predictability Project (CLIVAR), Asian-Australian Monsoon Experiment Program (AAMP) and Bengal Bay Air-Sea Interaction Experiment (JASMINE). In the 1998 South-China China Monsoon Experiment (SCSMEX) the National Climate Center of China set up a flux-observing tower over the waters of Xisha Islands (Yan et al., 1999), a first scientific experiment for fixed-point and continuous observation over the extensive sea by Chinese researchers, thus filling the gap of meteorological data. Such observational activity was performed again at the same zone by the same Climate Center and the Meteorological College of PLA Science/Technology University from early April to late June, 2000, achieving high-quality and temporal high-resolution radiation, dry- and wet-bulb temperatures, water temperatures, windspeed and turbulent fluctuation data. The lack of short-term sea data resulted in little research on the short-range variation relations between SCS summer monsoon development and sea. Based on the temporal high-resolution air-sea flux measurements and the synchronous Xisha and NCAR/NCEP data, study is performed of air-sea interface flux variations and the relationships between thermal budget and summer monsoon in the 2000 SCS monsoon period, arriving at several noteworthy conclusions.

II. OBSERVATION, DATA AND METHOD

The field observation tower was located in Xisha's Yongxing Island (16°50′N, 112°20′E) in the northern central SCS and at the fringe of a reef about 300 m to the southwest of Yongxing Island and a little more 20 m from the wavebreak with the tower built on a concrete "pedestal" of the size of 1.5 m×1.5 m×1.5 m with its top surface beneath water in most cases. The tower was 18 m high, consisting of 3 layers and fixed by 9 cable wires, with its top 0.9 m below averaged water level. With the mean level as a benchmark, radiometers were installed on a N-S horizontal bar fixed to the tower's body by shorter iron bars, 2 m long and 3 m above the sea and devices for gradient measurements, e.g., anemograph and wet- and dry-bulb thermometers, were mounted on E-W horizontal bars 2, 4, 8, 12.5 and 17.8 m above sea (refer to Fig. 1). The thermometers for top water layer temperatures were at 0.05 and 0.5 m levels below the surface at anchor-tied buoys. Observation lasted form May 7 to June 17 during which were experienced the monsoon onset, a break and an active stage wherein were recorded two events of cold air intrusion southward and effect of the southern part of the monsoon depression.

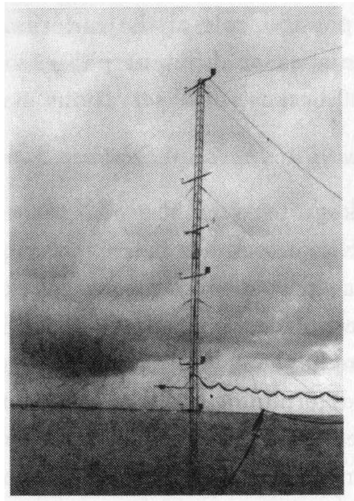

Fig. 1. The photo of the observing tower with measuring instruments thereupon.

Sampling was done at a 1-min interval. Because such samples contained too many micro-scale high-frequency variations, it was necessary to make data averaging over 30 min and error correction. Note that only the mean data were used in study, unless otherwise stated. Besides, in view of the temporal difference in device installment the timeseries of radiation and dry- and wet-bulb temperatures were relatively complete from May 8 to June 16 (Jiang et al. 2002b) and wind data covered May 10 to June 16. Apart from these observations we made use of the data from Xisha Weather Station and NCAR/NCEP in May to June of the year (taken from the Atmospheric Data Service of Nanjing Institute of Meteorology) to investigate the weather background during the observation.

In the study of the thermal budget no calculation was conducted of the kinds of instrument-observed radiation, and sensible/latent heat fluxes were found by use of dry/wet-bulb and sea surface temperatures, and wind measurements. The calculations of latent/sensible fluxes are generally based on two methods. One is the eddy correlation method, similar to direct observation, the value determination of which is, however, dependent on high-precision fast-changing pulsating winds, temperature and vapor. Something was wrong with the used infra-red hygrograph in the 2000 experiment, leading to the incompleteness of data so that we dropped the technique; the other is the gradient-profile scheme for which a range of calculation techniques are available. And in the present study we employed the method and procedure , as given in Launiainen and Vihma (1990), Xu and Xu (1994) and Sun et al. (1999). For the details of the scheme and principles, the reader is referred to Xu and Xu (1994). The method used has its greatest merit in obtaining momentum, latent/sensible heat fluxes through numerical iteration from conventional sea-surface measurements, with comparable accuracy to that of directly observed fluxes (Sun et al. 1999).

III. FEATURES OF THE OBSERVED SCS SUMMER MONSOON IN 2000

One of the primary objectives of the "South-China Sea Air-Sea Flux Observational Experiment" is to investigate the variations in heat budget over the waters during summer monsoon and to explore the possible role of the variations in the monsoon evolution. To investigate the flux characteristics at different phases of the monsoon we examine the evolution in May—June. 2000 because of observations made during the months.

1. *Weather/Climate Background of the* 2000 *Summer Monsoon*

Thanks to the close linkage between the SCS monsoon and the weather/climate of China the research of the SCS monsoon has been receiving great attention from the part of Chinese meteorologists and oceanographers, the typical example being the China-organized SCSMEX intensive observation project carried out in 1998. Many contributions have been reported, including, for example, Ding et al. (1999), Chen and Zu (1999) and Li and Wu (1999). And techniques for determining the date of the monsoon onset are many (Li and Wu 1999; He et al. 1999; He et al. 2001). This paper defined the onset, break and active intervals of the wind dominantly by means of the variations in wind fields and cloudiness for later use, which is among the usual methods in the research of the problem.

Figure 2 portrays the variations in regional mean sea-surface wind field (a) and cloudiness (b) over 5—25°N, 110—120°E for May—June, 2000 based upon NCAR data. It is evidenced therefrom that in terms of the regional means the onset occurs around May 8. And its related first process of southwest monsoon is accompanied by increased cloudiness and prolonged precipitation (figure not shown), lasting from early to late May (about May 28), during which two periods of remarkable weakening took place, one weakening is associated with two events of southward march of cold air, and the other with the beginning of the break stage covering about a week. The SW gale re-occurs about June 7, showing much stronger winds compared to the initial event as seen on the 850 hPa

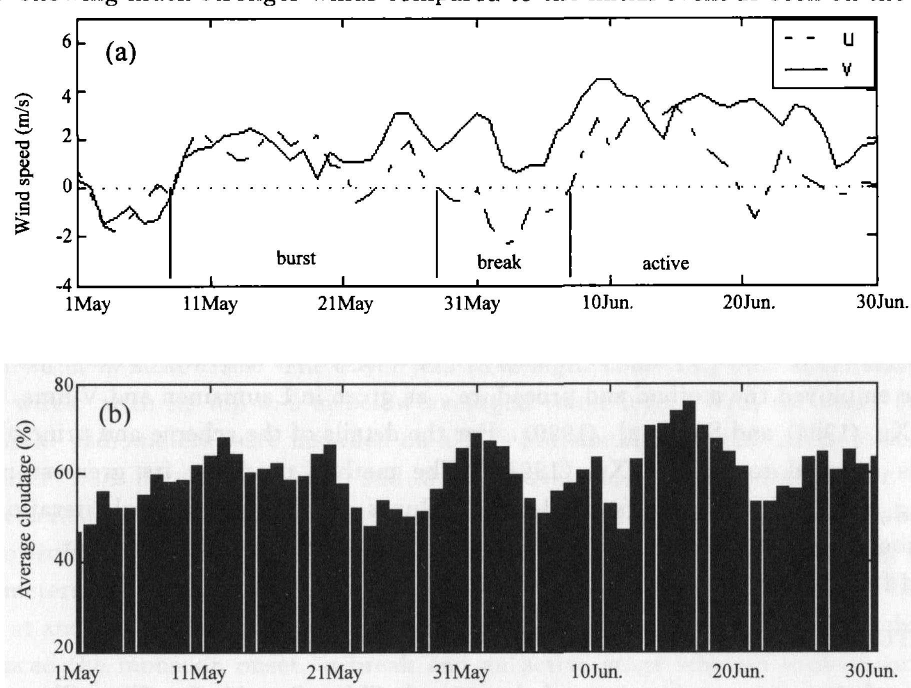

Fig. 2. Variations in SCS sea-surface winds (a) and cloudage (b) averaged over 5—25°N, 110—120°E for May-June, 2000.

map (figure not shown), with the incipient active stage marked by gales but with no rainfall, and increased cloudiness and precipitation concentrated mainly in its mid-late phases.

2. Weather Background in May—June Recorded at the Xisha (Yongxing) Observing Site

Xisha portion where our observation was made is in the northern central SCS. The SCS is so extensive that the summer monsoon evolution differs, to some degree, in features from part to part of the sea. Thanks to the close relationship between observation and calculation, on one side, and atmospheric and oceanic conditions of the target area, on the other, it is necessary to give the synoptic background with which to divide the background process for later discussion.

Figure 3 depicts the variations in zonal and meridional winds in May—June and Fig. 4 presents the curves of cloudiness (a) and precipitation (b) for the same period at Xisha Station, respectively. It is apparent from Fig. 3 that the SW monsoon begins about May 10, somewhat later compared to regional mean, with weaker intensity of the wind in the onset but with conspicuously intense precipitation (reaching >300 mm on some days, refer to Fig. 4) and markedly increased cloudiness (covering the whole sky, see Fig. 4b). Located in the northern SCS, Xisha is under greater effect of cold air, leading to the occurrence of the monsoon's break, which differs from the regional-mean weakening. With the cold air effect over, the SW gale re-occurs immediately due to the fact that the sea portion remains under the influence of the southern part of the monsoon depression. Afterwards, in accordance with the regional average over the sea, the monsoon falls into a lull interval and an SW gale breaks out again around June 7, causing a rough sea, a condition quite different from the May 10 event. Data plotted on Fig. 3a are taken from the island station where observed winds are smaller than at sea where they are much bigger

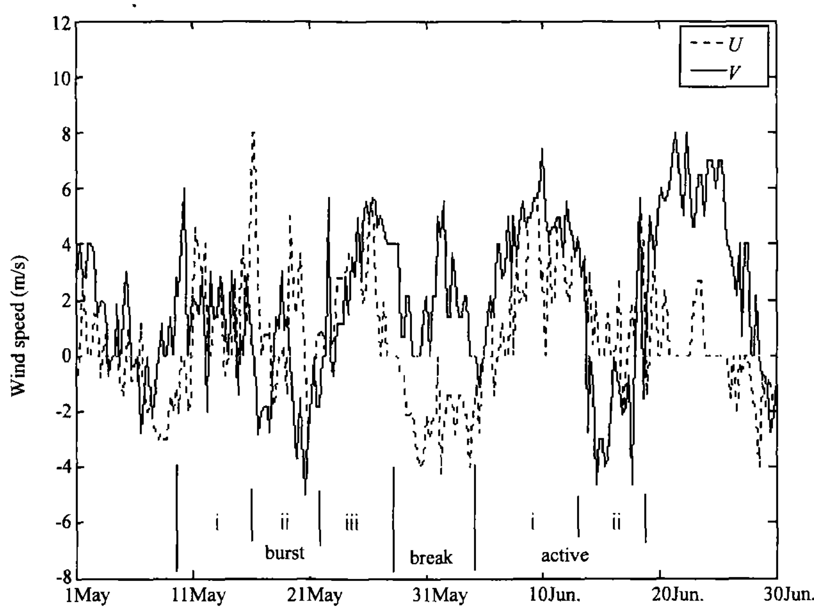

Fig. 3. Curves of zonal and meridional winds in May—June, 2000 at Xisha Station.

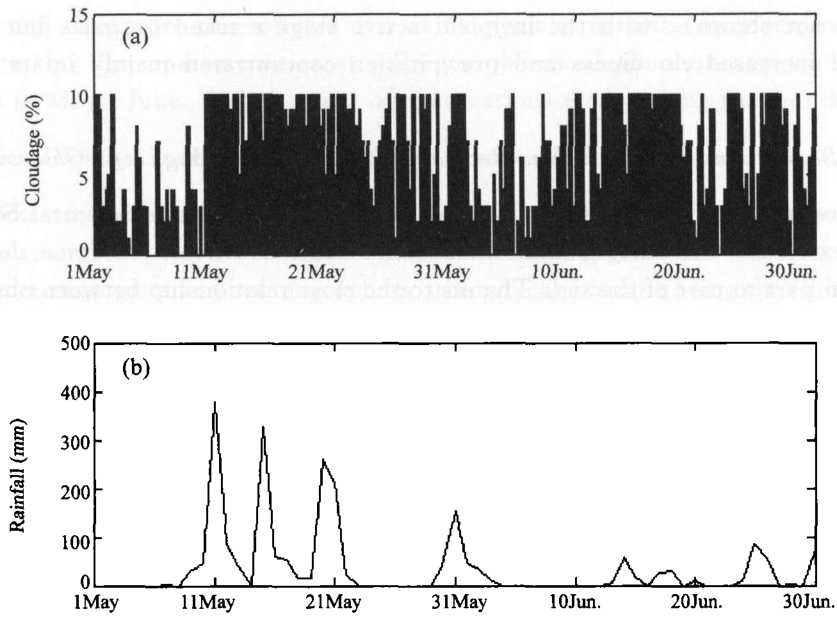

Fig. 4. As in Fig. 3 but for cloudage (a, %) and precipitation (b, mm).

(figure omitted). A spell of high waves caused by strong SW winds did some damage to observations, leading to futility of some wet-bulb records due to no water added to the device on the strength of huge waves, and besides, the sea temperature instrument was moved shoreward off the anchor cable, resulting in no observation for some period of time.

Based on the analysis of the weather background and actual records we separate the evolution of the monsoon in May—June, 2000 into a few stages (refer to the marks of Fig. 3) for the sake of future investigation. The stages are (1) the onset of the monsoon on May 10, with the first span of SW gales covering 10—28 of May, which, in turn, is divided, following different synoptic processes, into such periods as (a) the first appearance of SW winds marked in Fig. 3 by the interval I for May 10—15; (b) cold air intrusion marked by the interval II in the onset covering May 16—21; and (c) effects of the southern part of the monsoon depression by III in the onset lasting between 22 to 28 of May; (2) the lull interval for May 29 to June 6; and (3) the re-occurrence of SW gales persisting approximately for June 7—25. Since observation is ended on June 17, we have given in the second process of SW gales (see the interval I of the active stage in Fig. 3) on June 7—13 and the second cold air intrusion (see the interval II) on June 14—19.

IV. FEATURES OF THE VARIATION OF SEA-LEVEL HEAT BUDGET

It is well-known that the major factors controlling thermal budget at the air-sea interface include penetrating radiation (sea surface-striking solar total minus reflective radiation), effective longwave radiation (LWR), or sea-surface available back-coming radiation (sea-surface LWR minus atmospheric LWR), latent and sensible heat flux exchange. The first two of the four are radiation-related and device-measured but the rest are given through calculation of gradient data. In this observation the continuous available wind data are slightly short, covering May 10 to June 16, leading to only 38 days of gradient-based latent/sensible fluxes, whose period includes the first SW gales (the intervals Ⅰ, Ⅱ and Ⅲ of the onset stage), break, and the second span of the winds of their second occurrence (the interval Ⅰ of the active phase) and part of the second intrusion of cold air. We shall address the variations in both the fluxes at different stages during observation in what follows.

1. *Latent and Sensible Heat Fluxes*

(1) *Latent heat fluxes*

Figure 5a presents the daily variation in latent fluxes for May 10 to June 16, showing a remarkable change over the range of roughly 50 to 200 W/m^2, averaging 90.96 W/m^2. It can, therefore, be inferred that of the components contributing to sea-surface thermal budget, latent heat flux is found to be of greater importance. Figure 5a shows the mean fluxes at different stages (refer to the marks of Fig. 3 and Table 1 for their values). One can see that throughout the first appearance of SW gales and cold air intrusion, the fluxes are a bit smaller than the mean, reaching the minimum under the effect of the southern part of the monsoon depression; the latent flux begins to be augmented during the lull of the wind and maximizes when the second event of gales comes. The variation in the fluxes may bear a relation to windspeed and SST. We shall continue to discuss the problem with the aid of sea-surface thermal budget.

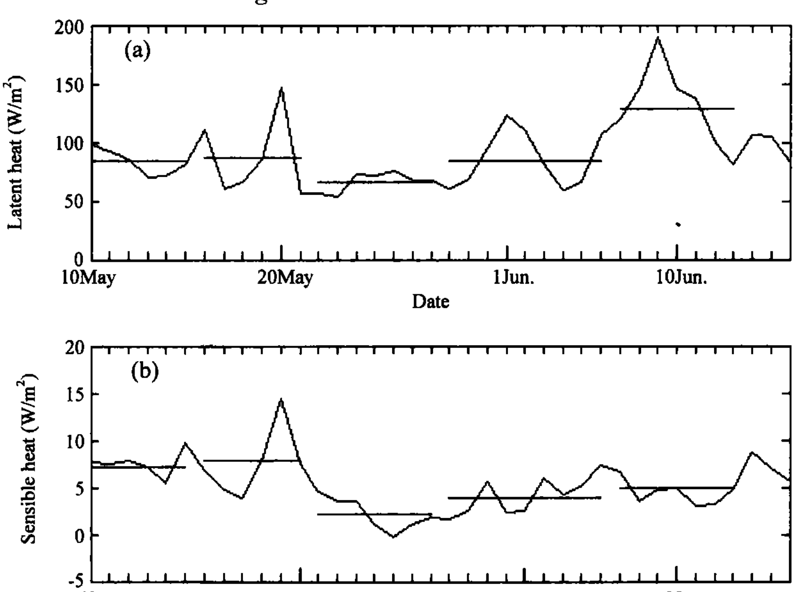

Fig. 5. Daily variations in latent heat fluxes (a) and sensible heat fluxes (b) for May 8—June 16, 2000 at Xisha (Yongxing) observing site where short horizontal lines indicate the means of their fluxes at different stages (intervals Ⅰ, Ⅱ and Ⅲ of the onset and the lull period and the interval Ⅰ of the active phase).

(2) *Sensible heat fluxes*

Figure 5b is a plot of the daily change in sensible heat fluxes from May 10 to June 16, indicating that looking at the trend, the sensible fluxes are broadly similar in change to latent fluxes but in terms of magnitude the former shows a smaller range over 0 — 15 W/m^2, averaging 5.24 W/m^2. It follows that over the low-latitude sea, sensible heat flux has no big effect on the thermal budget in comparison to the latent counterpart. Things are, however, different on land, for instance, at the Qinghai-Tibetan Plateau where sensible heat fluxes may be in excess of 100 W/m^2, even greater than the latent counterpart (Ding et al. 1999). Furthermore, the trend of variation in the averages of sensible heat fluxes at different stages marked on Fig. 4b (see Table 1 for the values) is analogous to that of the latent fluxes, as shown, for example, by the fact that both factors experience a history of high to low value and again increase during the first to second SW gale periods except that maximum sensible heat flux occurs in the first rather than the second gale interval, which may bear a close relationship of sensible flux to the difference in temperature between air and sea water.

2. *Penetrating Radiation and Net Radiation*

Net radiation has its budget dependent on penetrating (or shortwave) radiation and longwave (or sea-surface effective) radiations, the former being the difference between sea surface-striking solar total and surface-reflected radiation and the latter denoting the difference between the sea- and air-emitted longwave radiations. The global radiation, reflected shortwave radiation, oceanic and atmospheric longwave radiations have their measurements form radiometers. We have presented in our paper (Jiang et al. 2002b) the variations of these factors during observation. We shall present below the variations of net and penetrating radiation at different stages.

Figure 6 gives the daily variations in penetrating (a) and net radiations (b), meaning the difference between penetrating and effective longwave radiations. One can see on Fig. 6b that during the observational period, net radiation displays big difference, ranging from 50 to nearly 250 W/m^2, differing almost fivefold. Comparing to Fig. 6a, we notice a broadly similar trend of the change in both the factors except that net radiation is roughly 50 W/m^2 smaller than the penetrating radiation, the difference arising due to the fact that sea-surface effective longwave radiation remains positive throughout the observation. And its difference (maximum minus minimum) is of mere 22 W/m^2 (Jiang et al. 2002a; Jiang et al. 2002b). As a result, the component of shortwave penetrating radiation plays a greater role in net radiation. From the separated monsoon stages and mean net radiation over the different phases in the May—June observation, we see that minimum net radiation interval is related to the first SW monsoon process, covering May 10—15 during which time weak winds are blowing but strong rainfall occurs quite often, with heavy clouds (see Fig. 4) that is responsible for sharp decrease of penetrating radiation (Fig. 6a), thereby resulting in smaller values of net radiation, whose relative smallness also happens when cold air exerts effect in May 16—21 and again in June 14—16 (the averages are not shown because of lack of data for June 17—19). Referring to the distribution of cloudiness and rainfall of

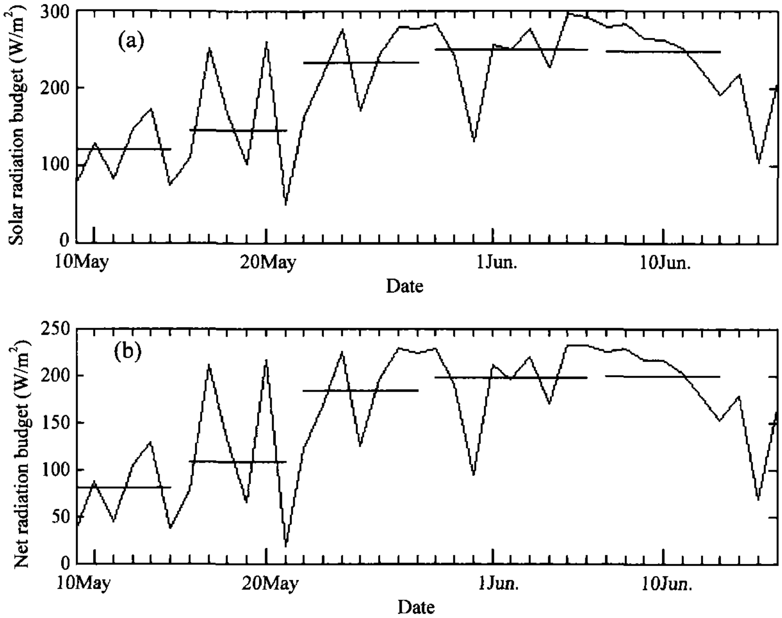

Fig. 6. Daily variations in penetrating radiation (a) and net radiation (b) for May 8—June 16, 2000 at Xisha (Yongxing) observing site where short horizontal lines indicate the means of their fluxes at different stages (intervals I, II and III of the onset and the lull period and the interval I of the active phase).

Fig. 4, we notice the occurrence of heavy cloudiness and precipitation in the two time intervals, caused by the mergence of cold air southward with warm, wet air over the sea. The higher-value net radiation is seen dominantly in the lull interval of monsoon and when the south part of the depression covers the target portion. From the rainfall and cloudiness shown in Figs. 4a and 4b, the two time intervals have little precipitation and particularly low cloudiness. In a word, the immediate factors affecting net radiation are cloudiness and precipitation.

3. *Variations of Sea-Surface Thermal Budget and SST*

Now let us examine the variation in the budget of sea-surface heat (Q), which is calculated by

$$Q = R_n - Q_e - Q_h, \tag{1}$$

with

$$R_n = S_L - S_a + L_a - L_w, \tag{2}$$

where Q stands for the thermal budget; Q_e and Q_h for latent and sensible heat fluxes, respectively, R_n for net radiation; S_L, S_a, L_a and L_w for solar total radiation, sea-surface reflected radiation, atmospheric counter radiation (atmospheric longwave radiation) and sea surface emitted longwave radiation, in order. Figure 7a delineates Eq. (1)-calculated daily variations of Q for May 10 to June 16, with the mean heat budget given for different intervals. It is easy for us to see that Q depends on the aforementioned components for its change so that its variation differs from that of each of the components. To facilitate quantified analysis and comparison we present a table showing the means of Q and each of its components at the different intervals of the May—June monsoon process in the target region (Table 1). It is seen therefrom that after the onset of the monsoon, Q displays its

Table 1. The Means of Each of the Components of Sea Surface Thermal Budget at the Onset and Lull Phases of the 2000 Summer Monsoon over the SCS. Units: W/m^2

Interval*	Net radiation (R_n)	Latent flux (Q_e)	Sensible flux (Q_h)	Sea-surface heat budget (Q)
May 10—May 15	80.26	83.48	7.13	−10.35
May 16—May 21	107.88	86.65	7.85	13.37
May 22—May 28	184.20	66.52	2.21	115.48
May 29—June 6	197.29	83.81	3.86	112.28
June 7—June 13	199.54	128.27	4.93	66.38

* These intervals denote the different phases of the monsoon (see the end of Ⅲ—2).

features of variation as follows. During the first span of SW gales the sea surface is in a state of net heat loss; as the gales begin to weaken on account of cold air intrusion southward, its net thermal gain gets increased little by little, but it exhibits sharp drop when the second event of the gales sets in. These seem to indicate that during the active stage of monsoon the sea receives a reduced amount of energy or even loses it (as in the first occurrence of SW winds); the sea gains energy bit by bit in the weakening and break periods. Each of the Q-affecting components shows the features of its own. During the first occurrence of SW gales, sea surface net thermal loss is attributed mainly to decreased net radiation largely from plentiful rainfall and heavy cloudiness (refer to Table 1), causing local thermal convection; at the second occurrence of the gales the reduced net sea-surface heat gain is consequent chiefly upon dramatic increase in latent heat from vigorous evaporation and it can be inferred that by means of large-scale strong SW winds, vapor can reach a region far away from the source, serving as one of the causes of rainfall there. The mechanisms of the two processes seem quite different but they produce similar results. Therefore, if we inspect the development of the monsoon in terms of sea-surface thermal budget, its active (weakening or break) phase is found to give rise to the decrease (increase) of sea-acquired energy.

As we know, the change in sea-surface thermal budget is definitely responsible for the corresponding change of SST. Now we make analysis of the SST variations during observation before examining their possible role in the change of the thermal budget and the monsoon development. Referring to Fig. 7b and comparing it to Fig. 7a, we find that, in terms of day-to-day variation, the sea surface temperature does not seem to change, as we think, in such a way that as net thermal gain begins to increase gradually, so does the temperature. Instead, the water lowers its temperature at first before increasing it. In their study on the 1998 flux observations of the southern SCS, Bai et al. (1999) discovered that SST increases significantly (drops bit by bit) before (after) the monsoon's onset, a conclusion that is in agreement with ours (although covering only two days before the monsoon onset, our data show the SST to be higher). We hold that the out-of-phase change between SST and thermal gain is caused by thermal inertia of sea water, which is liable for the SST lagging in variation by 15 days or so behind thermal budget. Since SST bears a greater relation to latent and sensible heat fluxes, its lagging is bound to exert

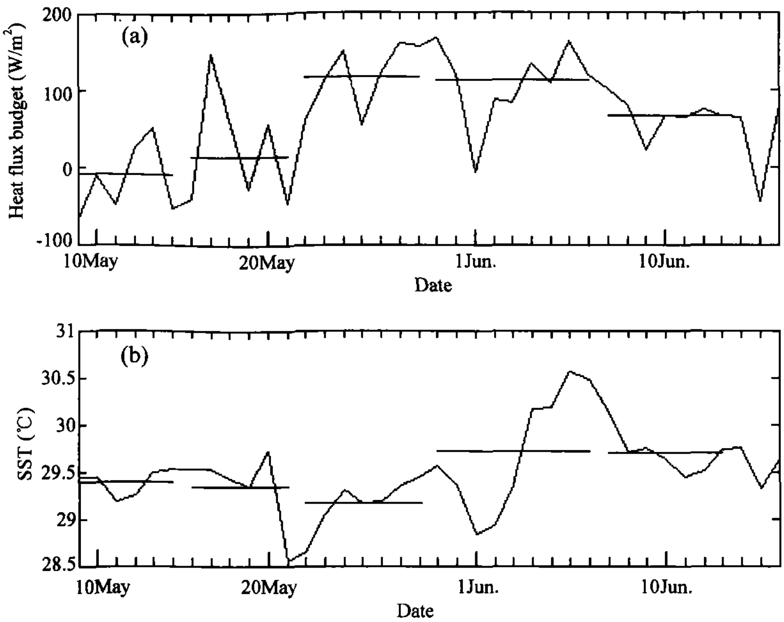

Fig. 7. Daily variations in sea-surface thermal budget (a) and SST (b) for May 10—June 9 during the 2000 Xisha observation, with horizontal bars denoting the means of thermal budget and SST at the intervals Ⅰ, Ⅱ and Ⅲ for the onset stage, break and the interval Ⅰ of the active span of the monsoon.

some effect on both forms of fluxes. By inspecting Figs. 5 and 7 we notice that after the onset SST drops little by little, thus making the two forms of fluxes diminish correspondingly; meanwhile, net radiation gets increased gradually, which leads to the progressive growth of net heat gain at sea surface. Obviously, the growth, in turn, suppresses the trend of SST dropping, and eventually causes it to rise; the fact that the magnitude of penetrating radiation has its upper limit for a particular season makes net radiation growth have an upper limit, during which time SST is gradually increasing, thereby allowing latent/sensible heat fluxes to be augmented. And the augmentation reaches its maximum before the monsoon enters another active phase, which reduces the thermal gain at sea level, thereby keeping SST from rise. The independent processes are responsible for short-term oscillations of SST at an interval of 30 days or so. These oscillations are related to a cycle of active to break periods of the monsoon. However, based upon the foregoing analysis we remain unaware whether SST plays a key role (e.g., triggering) in the monsoon's cycle or it responds just passively. Thus, further research remains to be done.

V. COMPARISON OF OUR FINDINGS TO THOSE OF OTHER STUDIES

A large-scale field observation campaign was begun in May—August, 1998 by the "South-China Sea Monsoon Experiment" as an A-class scaling project under the State Science and Technology Ministry of China. And the observation concerning sea-surface thermal budget before and after the monsoon's onset was undertaken at two sites, one on a tower at Yongxing Island in Xisha waters (Yan et al. 1999) and the other (6°15′N, 110°E) in the southern SCS (Sun et al. 1999; Bai et al. 1999) for ship measurements. There are many findings from observations of the two sites (Yan et al. 1999; Sun et al. 1999; Bai et al. 1999), and especially the observation and analysis of southern SCS sea-surface thermal budget before and after the monsoon's onset (Bai et al. 1999;) can be used in comparison with ours. Drawing on the 1998 intensive observations in study, Bai et al. (1999) discovered that prior to the onset sea surface has net thermal gain for SST rise, averaging 98.32 W/m^2; subsequent to onset there occurs net heat loss, averaging -36.78 W/m^2; before onset SST experiences remarkable rise and after onset SST shows persistent drop. Part of their conclusions agree with ours, i.e., the persistent drop of SST during onset is attributed to the reduced heat gain or net loss at sea surface. Our 2000 field observations are fairly continuous, making it possible to perform detailed analysis of the conditions at different stages of the monsoon, including the onset, break and active phases. But analysis of the pre-onset stage is not involved because of data.

Under the joint support of the Foundation Committee of China and PLA General Staff Meteorological Bureau, China National Climate Center and the Meteorological College of PLA Science and Technology University implemented a second field observation mission at Yongxing Island of Xisha in April—June, 2002. The tower's position was moved 10 m seaward compared to the 2000 case (Jiang et al. 2002a; 2002b). To guarantee the acquisition of pre-onset data, the observation began on April 24 and ended on June 21 (total of 59 days). The monsoon broke out on May 14 for the given year. The observation covers the following intervals: (1) pre-onset (April 24—May 13), (2) onset (May 14—June 12), and (3) lull stage (June 13—June 21), of which the onset period can be divided into an early interval (May 14—22), cold air intrusion (May 23—28) and a late onset (May 29—June 12). It should be noted that, despite our longer observation time, the 2002 monsoon differs from the 2000 counterpart in that its onset stage is persistent over 30 days so that the observational intervals consist only of the stages, pre-onset, onset, and break. The averages of sea-surface thermal budget and its components over different stages of the 2002 monsoon are tabulated in the following.

Table 2. The Means of Each of the Components of Sea Surface Thermal Budget at the Onset and Lull Phases of the 2002 Summer Monsoon over the SCS. Units: W/m^2

Intervals*	Net radiation (R_n)	Latent flux (Q_e)	Sensible flux (Q_h)	Sea-surface heat budget (Q)
April 24—May13	222.40	84.95	3.94	133.51
May 14—May 22	166.42	97.71	0.89	67.82
May 23—May 28	140.10	82.76	8.89	38.45
May 29—June 12	181.02	97.63	4.00	79.39
June 13—June 21	204.45	108.71	4.32	91.42

* The time intervals are related to the different stages of the monsoon's lifecycle and for the corresponding phases refer to the text above the table.

It is seen therefrom that before onset the sea surface receives amounts of heat, averaging 133.51 W/m^2. But in terms of the components, winds prior to onset are weak, latent heat flux small and net radiation strong such that the large amount of heat gain is associated with high net radiation. During the 2002 monsoon's onset the sea-acquired thermal heat reduces, a result that is in agreement with the 2000 condition except that the thermal gain remains net income with no net loss of heat, as it occurs in 1998 and 2000. Inspecting the components, we notice that in comparison to the 2000 values (see Table 1), the difference arises due to the intensity of net radiation. At the early stage of the 2000 monsoon's onset, net radiation is weakened fast while it diminishes slowly in 2002; at the break period the thermal gain begins to increase again, a result in concord with the 2000 analysis. Form the foregoing investigation of the 2002 monsoon the heat gain is high (low) during the pre-onset and break (onset) stages, implying that sea accumulates (releases) its energy in the former (latter) case, findings that agree with the analysis of the 2000 monsoon.

VI. CONCLUSIONS AND DISCUSSION

Based on the observations of the 2000 summer monsoon, we make analysis of sea-surface thermal budget and its related components (net radiation, sensible and latent heat fluxes) for their variations, with SST and its relations to thermal budget and possible linkage to the monsoon explored and comparison to the 1998 and 2002 investigations made, arriving at the following.

(1) During the 2000 monsoon, sea-surface penetrating radiation and latent heat flux serve as the main factors affecting sea-surface thermal budget. Regardless of their change, the heat gain is diminished and even becomes net loss at the active phase while the net heat gain increases when the monsoon is at its pre-onset and lull stages.

(2) In the first emergence of SW gales the sea-surface net heat loss is attributed to rich rainfall and high cloudiness responsible for the sharp reduction of penetrating radiation, which is a situation of local convection; in the second span of the gales the reduction of net heat gain is consequent largely upon the dramatic growth of latent heat flux from intense evaporation.

(3) During the monsoon development, the change in SST (which displays the role of sea) is out-of-phase with the thermal budget and lags behind it because of its great inertia. The lagging regulates the budget by affecting latent and sensible heat fluxes, thereby forming short-term interdependent oscillations, corresponding to the active and break stages in the monsoon's cycle.

It is worth noting that the foregoing conclusions are preliminary because of the short-interval observation. Some problems need to be explored. For example, what role does the SST play in the monsoon's onset? Is the steady increase of sea-surface net heat gain in the lull interval related to the re-active period of the wind? They remain to be studied in the future.

Acknowledgements: We are deeply grateful to Mr. LI Jianglong, TANG Zhiyi and LÜ Zhanjun of CMA National Climate Center, and Profs. LI Xunxiang and XIAO Yiguo of Meteorological College, PLA Science/Technology University for their contribution to acquiring 2000 and 2002 field observation, to Profs. DING Yihui, LUO Yong and ZHANG Xiuzhi of CMA National Climate Center and Prof. SHA Wenyu of the Meteorological College for their direction and help in the establishment of the observational site for the sake of performance, and also to Nanjing Atmospheric Service and Xisha Meteorological Station of CMA for their provision of NCAR/NCEP data and station measurements of the same period of

time.

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