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NUMERICAL SIMULATION EXPERIMENTS OF THE IMPACTS OF LOCAL LAND-SEA THERMODYNAMIC CONTRASTS ON THE SCS SUMMER MONSOON ONSET

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ABSTRACT: The important effects of local land-sea thermodynamic contrast between the South China Sea (SCS) and Indochina Peninsula on SCS summer monsoon onset are preliminarily studied by using two sets of SSTA tests and two ideal tests in $p-s$ regional climate model. The result shows that warm SST in the SCS in winter and spring is favorable for the formation of monsoon circulation throughout all levels of the atmosphere over the sea, which hastens the onset of SCS summer monsoon. The effects of cold SST are generally the opposite. The local land-sea contrast in the SCS is one of the possible reasons for SCS summer monsoon onset. Superposed upon large-scale land-sea thermodynamic differences, it facilitates the formation of out-breaking onset characteristics of SCS summer monsoon in the SCS area.

Key words: local land-sea thermodynamic contrast; SCS summer monsoon; p-σ regional climate model

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1 INTRODUCTION

Among driving factors for the East Asian monsoon are planetary-scale land-sea thermodynamic contrast (e.g. between the Eurasian continent and the Pacific Ocean) and sub-planetary-scale one (e.g. between the Indochina and the South China Sea). It is over the South China Sea (SCS) and adjoining areas that the East Asian summer monsoon first breaks out. It then advances to the regions of East Asia and South Asia. It is therefore natural to find local geographic and topographic effects of the SCS region evidently shown on the onset of the SCS summer monsoon. Specifically, the effect of the anomalous SST in the SCS and adjacent waters on the monsoon onset and evolution has been a subject of wide interest in Chinese meteorologists[1-2]. He et al[1]. have found a warm SST center in March – April in their study of monthly mean SST in the subsurface layer of 0 m – 100 m in the SCS; the central value is about 23°C but rapidly rises to 27°C in May – June, possibly increasing the possibility of monsoon onset. One month before the Southwest Monsoon onset, the SST rapidly increases in the subsurface of the sea, making it ready for the onset in terms of thermal and moisture condition[2]. As also shown in numerical studies[6-8], the anomalous SST in the SCS can affect the seasonal changes in the rain bands and monsoon in the SCS. While most of the above numerical experiments focus on the effect of the summer or spring/summer anomalies on the summer monsoon in East Asia, little is addressed of the effect of winter or winter/spring anomalies and local land-sea contrast on it.

With a p-σ regional climate model, the current work uses numerical experiments involving four sets of SST anomalies to study the effect of winter/spring SCS SST anomalies on the onset of the summer monsoon over the sea; it then discusses the important role of land-sea contrast

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between the SCS and Indochina Peninsula, with two idealized experiments.

2 BRIEF MODEL ACCOUNT, EXPERIMENT SCHEMES AND RESULT ANALYSIS

2.1 *Brief model account & design of numerical experiment of SST anomalies*

The regional model used in the work was first designed by Qian et al[9]. With the development and perfection over the dozens of years ever since, the model has become what it is today. For details see References [9-12]. Fig.1 gives the model domain and topographic distribution. It covers an area bounded by 75°E –145°E, 5°S – 45°N, which encompasses the bulk of the Qinghai-Tibet Plateau, the Bay of Bengal, adjoining waters off China and part of the waters in the western Pacific. Employing real topography, the model depicts the plateau with a maximum altitude of more than 5000 m. It is spaced into 1°×1° intervals in the horizontal direction and its time integration is accomplished by alternative execution of the 1-hr Euler backward scheme and 5-hr central scheme, at time steps of 3 min. For the initial field and lateral boundary forcing, the source is the monthly mean fields averaged over 17 years from 1979 to 1995 based on the reanalysis data of NCEP. For the month-to-month surface-layer SST, it is provided with data sets averaged over the years. The model integration begins at 20:00 (L.T.) on January 15 and ends on July 31. The simulation is called a control experiment (CON).

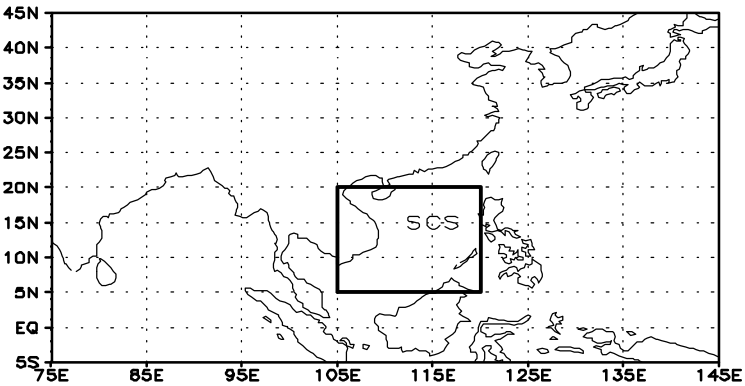

Fig.1 The region of SST increase and decrease in the SCS (indicated by the box).

Two experiments were designed for the SST anomalies, S+ (with the surface-layer warming by 2°C in the SCS waters but unchanged in others) and S– (with the surface-layer cooling by 2°C in the SCS waters but unchanged in others). The region in which the SST is increased or decreased is located within the box in the figure that is bounded by 105°E – 120°E, 5°N – 20°N. One must be reminded of the fact that in the SCS the SST anomalies usually distribute in an approximately elliptical pattern centered over the central and northern parts of the sea and the intensity reduces outwards. Fig.1 is actually an idealized and simplified model, in order to increase the amplitude of anomalous states simulated so as to contribute to the analysis and discussions of issues concerned. The model integration lasts from January 15 to the end of July while the increase or decrease of SST covers the period from January 15 to the end of May, with the remaining dates having normal distribution in place of anomalies, for the SST.

2.2 *Effects of winter/sprig SST anomalies on Southwest Monsoon*

The numerical experiment in which normal SST is used in the simulation is called the control experiment (CON) and two other sensitivity experiments for SST anomalies are called S+ and S–

respectively, having the same meaning as above. Fig.2 gives the time-latitude cross-section (averaged over 105°E – 120°E) for the *u* component in the lower levels of the SCS region (Layer Five in the model) as simulated by individual sensitivity experiments, with the abscissa in the unit of five-day (pentad) periods. For more illustrative comparison, the results of the CON are placed in the left panel and fine, blackened solid line outlines the contour of u = 0 (Fig.3 is similar to Fig.2 but for the difference between the CON and corresponding sensitivity experiments). In the figure, fine, blackened solid lines are used to describe the contour of u = 0. The middle and right panels of Fig.2 depict the contour with bold, blackened solid lines. The contour of u = 0 reflects the time when easterlies shift to westerlies with the change in latitude, which can be viewed as the marking line for the onset of low-level westerlies.

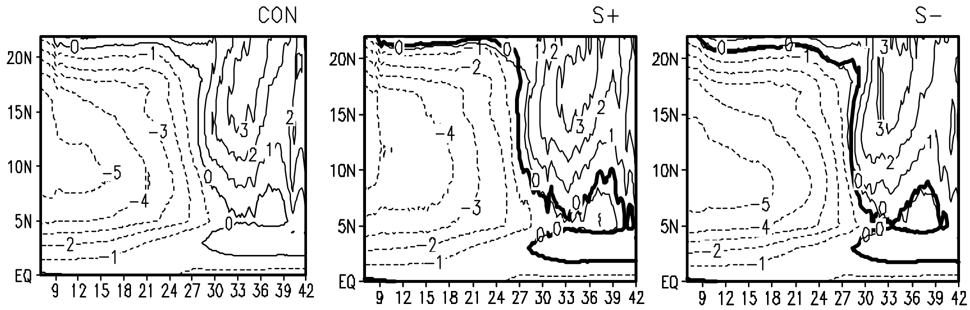

Fig.2 Time-latitude cross-sections of the low-level *u* component simulated (unit: m/s).

From Figs.2 & 3, we know that S+ decreases the intensity of easterlies prior to the SCS summer monsoon onset while S– increases it, though not as much as S+ does. It is clear from the u = 0 contour in Fig.2 that S+ shifts the westerlies onset in advance by about 1 pentad for waters from 7°N to 17°N in the SCS while S– does not have significant effect on the onset time of westerlies in central SCS, only that it postpones that in the northern part of the sea. From Fig.3, we also see that the S+ increases the westerlies while S– decreases it in northern SCS several weeks after the summer monsoon onset.

Fig.4 gives a time-latitude cross-section (averaged over 105°E – 120°E) for the difference between low-level southwest winds ($u > 0$, $v > 0$) and the CON over Pentads 7 – 42. It shows that S+ strengthens the low-level southwest winds over the sea but slightly decreases southern China in the subtropical zone while S– does the opposite. On the whole, there is no definitive conclusion on the effect of preceding variations of SST in the sea on the intensity of Southwest Monsoon in June – July.

On the upper-level profile, the SCS summer monsoon is shown as abrupt shifts from westerly to easterly, which the winter/spring SST anomalies affect to some extent. Generally, the upper-lever *u* component of wind speed changes less than the lower-level one in all sensitivity experiments. It is, however, found from a difference map (omitted) that S+ slightly increases the middle-latitude westerlies and low-latitude easterlies in upper levels for Pentads 13 – 30 (March – May), suggesting intensified anti-cyclonic vorticity at the upper levels. The upper-level easterlies in the SCS region (0° – 20°N) strengthen a little over Pentads 24 – 30 (the 6th pentad in April – 6th pentad in May), which is around the onset of the SCS summer monsoon. For S–, the results are basically the opposite. From Pentad 30 on, the wind speed increases or decreases following no regular patterns, which is resulted from the withdrawal of SST anomalies from simulation experiments.

It is known from the analysis above that the warming of surface-layer SST in winter/spring decreases low-level easterlies in the SCS waters to bring forward the onset of westerlies in the central part of the sea, being favorable for the onset of SCS summer monsoon; the cooling, on the

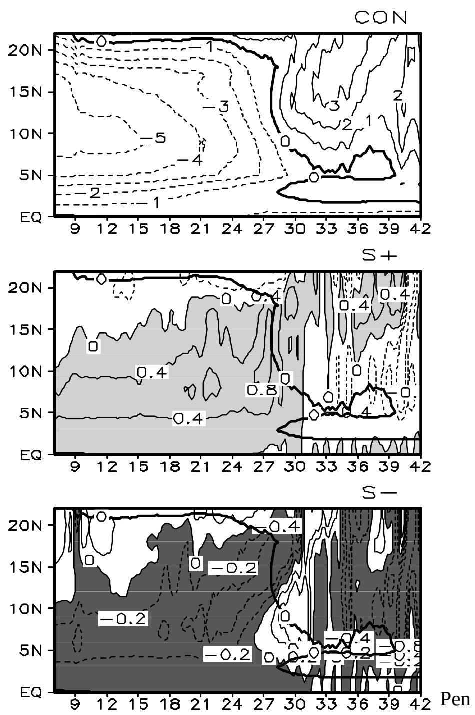

Fig.3 Same as Fig.2, but for the differences with CON. The abscissa is for the pentad. Same in Fig.4.

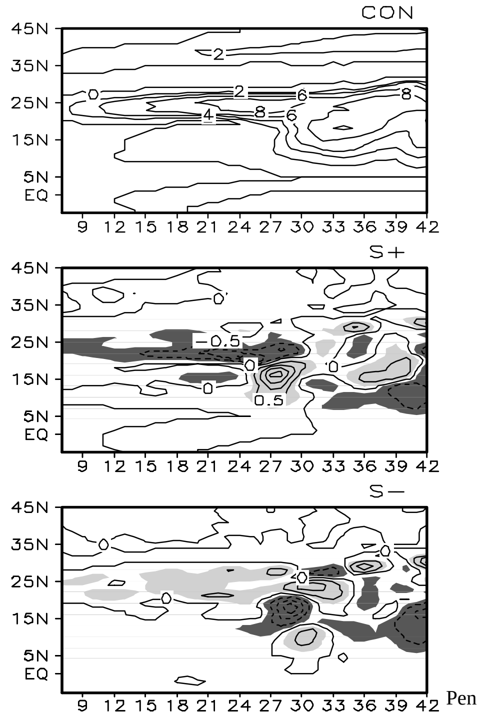

Fig.4 Same as Fig.3, but for the differences between the low-level southwest wind (u>0, v>0) and CON.

other hand, decreases the low-level southwesterlies in the SCS region around the onset of the monsoon, being unfavorable for the onset, though with more moderate effect as compared to the warming of surface-layer SST in the sea, i.e. not strong enough to affect the timing of summer monsoon onset in the central part of the sea. In the meantime, the variation of surface-layer SST affects the low-level wind field more than the upper-level one. Such systematic departure mainly occurs in the period of sustained SST anomalies. When the SST anomalies are removed, it also disappears, suggesting more sensitive response of monsoon circulation to simultaneous SST anomalies than to preceding ones.

2.3 *Effect of winter/spring SST anomalies on general circulation patterns during the onset of summer monsoon*

Fig.5 gives the difference between the 100-hPa wind field, which is averaged over May 10 – 25 in individual sensitivity experiments, and the CON. It shows that the upper level for S+ is an anti-cyclonic difference circulation field with the center generally in northern Indochina Peninsula and northern SCS. As shown in relevant studies, the South Asia high is near 20°N right over the Indochina Peninsula over the period. It is seen that S+ strengthens the South Asia high, which then helps it establish securely in early summer and jump northward later on; S– has the opposite effect.

Before the onset of the SCS summer monsoon, the low-level atmosphere is within the governing subtropical high in the SCS region so that the southeast wind prevails. With the set-up of the summer monsoon, the subtropical high withdraws eastward and a monsoon trough forms in the low-level atmosphere over the SCS[13]. As clearly shown in the difference between sea surface pressure field, which is averaged over May 10 – 25 in all results of sensitivity experiments, and the CON (figure omitted), S+ lowers the sea surface pressure field for the onset period of SCS summer monsoon so that it favors the formation of monsoon trough over the SCS region while S– has just the opposite effect, though with weaker intensity.

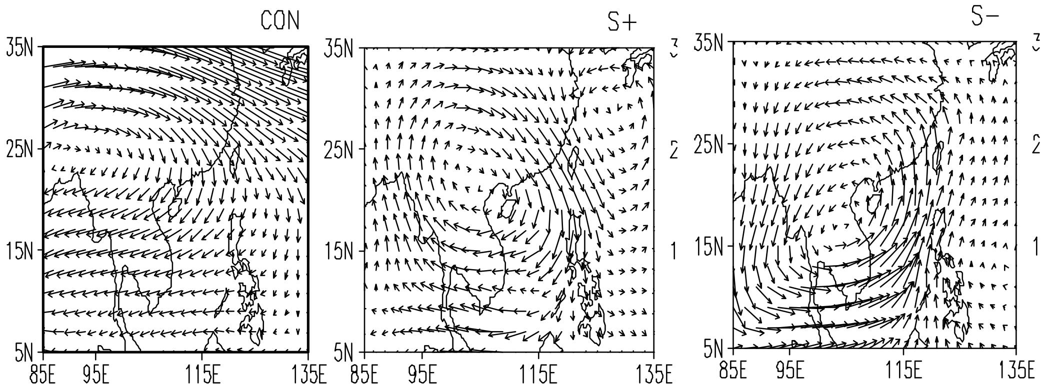

Fig.5 Differences between the simulated 100 hPa wind fields and CON (averaged over May 10 – 25)

In summary, the warming of SST in the SCS during the winter/spring season causes the monsoon circulation and SCS summer monsoon to appear more easily; the cooling, on the other hand, has just the opposite effect. In comparison, an increase of 2°C in the SST has larger effect than a decrease of 2°C, for the winter/spring season. It may attribute to cooler SST in the winter/spring season than in the summer/autumn season and thus more dramatic effect with the warming than with the cooling, of SST. It is noted that conclusions drawn in the work are different from observations, which is not hard to understand, as the numerical simulation experiments here only consider the effect of SST in the SCS on monsoon. None of the conclusions drawn from such simulations so far, it seems, has been final[6-8, 15].

2.4 *Effect of local land-sea contrast on summer monsoon*

From the above sensitivity experiments and previous statistical and simulating work, we know that the South China Sea is indeed a key area that affects the summer monsoon. Being a tropical sea adjacent to the continent of China, it may have more direct influence on the weather and climate in the SCS and south of China than the eastern and western Pacific do. Together with the adjoining Indochina Peninsula, the SCS constitutes a local land-sea contrast environment. The thermal difference between them is an additional difference superposed upon large-scale land-sea thermal contrast, which facilitates the onset of the SCS monsoon. For more discussions of its importance for the monsoon, two idealized sensitivity experiments are conducted.

In the first experiment, called S-L experiment, the SCS as indicated by a bold frame in Fig.6a is changed to “land”, which is of the tropical rain forest. The SCS is in effect only a narrow strip of waters in the east. In the second experiment, called I-S experiment, the Indochina Peninsula as indicated by a fine frame in Fig.6b is changed to “ocean”, whose SST is replaced by a mean value of the central SCS over the same period. It is seen that the S-L experiment weakens the role of oceans in the local land-sea environment of the SCS region while the I-S experiment causes the local land-sea contrast to disappear in the SCS region. The model and covering areas are the same as in the preceding part and integration also lasts from January 15 to July 31 with all of the above assumptions present over the period. The initial field and boundary layer condition follow what has been used up to this point. It is therefore for the boundary settings to include the effect of part of the Indochina Peninsula topography. For the I-S experiment, however, much alteration has been done to the underlying surface.

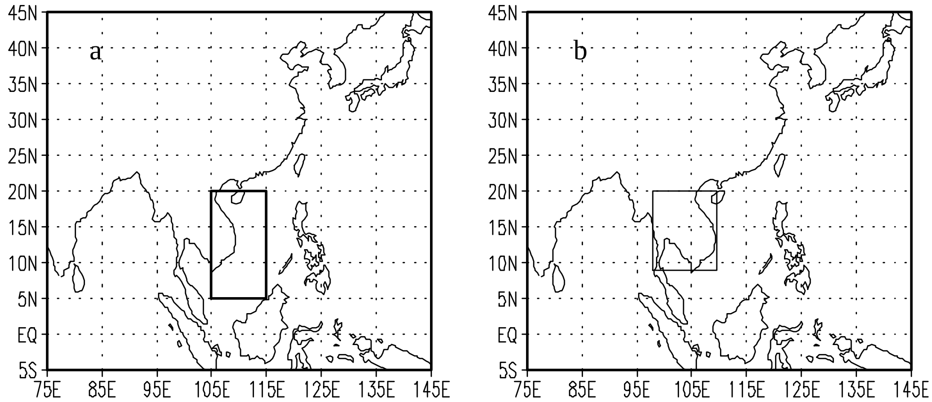

Fig.6 The domains for the two ideal experiments.

In Fig.7 (a & b), time-latitude cross-sections are respectively given for low-level *u* component at the fifth model layer in the S-L and I-S experiments (averaged over 105°E – 120°E). From the $u = 0$ contour in Fig.7a (in which the fine black line is for the CON and the bold black line for sensitivity experiments), one knows that S-L postpones the onset of westerlies in northern SCS and coastal areas of southern China but brings that forward in areas at 5°N. Fig.7b clearly shows that I-S causes the westerlies to progress southward in the SCS without any signs that accompany the westerlies onset. Fig.7c and 7d are similar to Fig.7a and 7b only for the difference between S-L, I-S and the CON. In Fig.7c, positive difference is shown for the months February through July in central and southern SCS, i.e. the easterlies decrease before the westerlies onset but the westerlies increase after it. The difference is negative in northern SCS and coastal southern China, i.e. the easterlies increase before the westerlies onset but the westerlies decrease after it. Fig.7d shows that the difference is negative in Pentads 21 – 42 (from the 3rd pentad in April to 6th pentad in July) in central and southern SCS, or, the westerlies substantially reduce over the waters.

Fig.8 gives time-latitude cross-sections for low-level southwest wind ($u>0$, $v>0$) at the fifth model layer in the S-L and I-S experiments for February through July (averaged over 105°E – 120°E). It shows that the southwest wind bursts out at low levels in a way similar to the CON, though with a lower high value, especially from Pentad 27 to Pentad 42, for S-L; I-S causes the southwest wind to appear in a slowly evolving way from north to south over the SCS, instead of abrupt onset around Pentad 27.

It is now clear that when part of the SCS changes to “land” in the experiment, local land-sea thermal contrast still exists to affect the onset of summer monsoon, with the abruptness of onset unchanged; when the Indochina Peninsula becomes “ocean”, the contrast disappears so that there is no more out-bursting of low-level southwest wind and instead it slowly progresses northwards with time. The study shows that the land-sea thermal contrast in local waters of the SCS is one of the causes for the onset of the summer monsoon in the region; the superposition of the local contrast on the large-scale contrast helps to form explosive onset of the SCS summer monsoon.

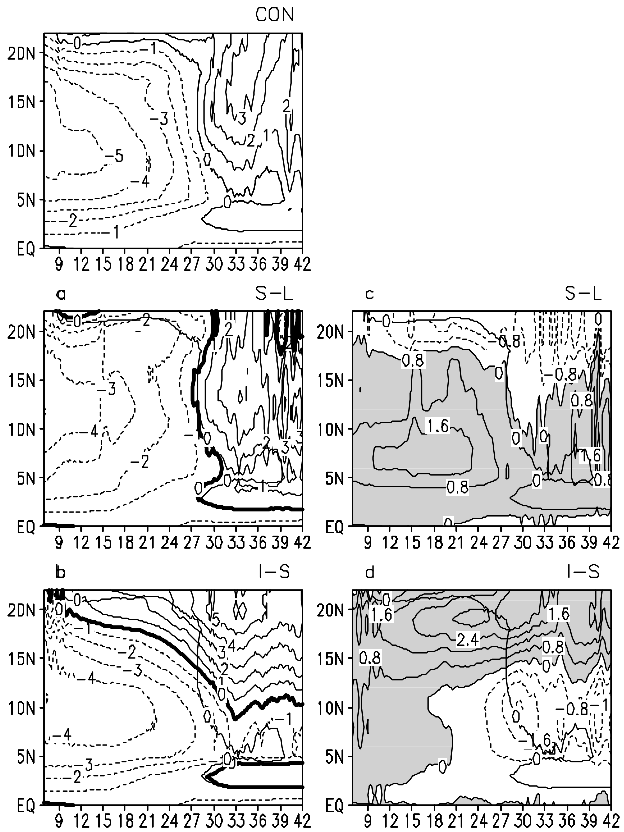

Fig.7 Same as Fig.2, but a,b for the two ideal tests; the same as a. b but c, d for the differences with CON.

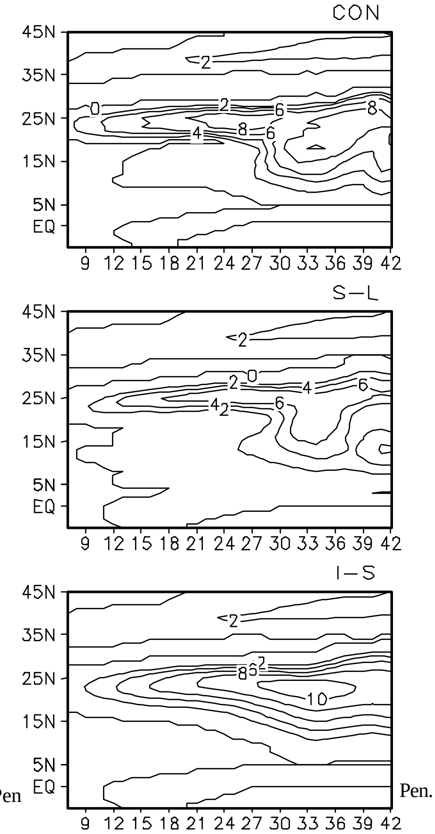

Fig.8 Time-latitude sections of the simulated low-level southwest wind (u>0, v>0,105°E～120 °E mean).

3 CONCLUDING REMARKS

With a $p-\sigma$ regional climate model, the work uses two sets of numerical experiments with SST anomalies assumption to study the effect of winter/spring SST anomalies in the SCS on the regional summer monsoon; it uses two idealized experiments to make an preliminary study of the important role of local land-sea contrast between the SCS and Indochina Peninsula in the summer monsoon onset. The main conclusions are as follows:

a. The warming of surface-layer SST in the winter/spring season over the SCS decreases the simultaneous easterlies and brings the westerly onset forward for low-level atmosphere in the central part of the sea, being favorable for the onset of SCS monsoon; the cooling, however, decreases the low-level southwest wind around the onset of summer monsoon, being unfavorable for the onset of SCS monsoon. Furthermore, the role is mainly shown at the time around the onset.

b. The warming of winter/spring SST over the SCS provides situations favorable for the formation of monsoon circulation at both high and low levels, accelerating the onset of the SCS summer monsoon. The role of the SST cooling is generally the opposite.

c. In the S-L experiment, part of the SCS is changed to "land", for which the local land-sea thermal contrast still exists and has some effect in the onset of the summer monsoon, with much of out-break characteristics unchanged; when the Indochina Peninsula becomes "ocean", the contrast disappears, making the explosive onset of low-level southwest wind and characteristics associated with it non-existent. Instead, the southwest wind progresses southward slowly with time.

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