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The Variation of Warm Pool in the Equatorial Western Pacific and Its Impacts on Climate①

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ABSTRACT

The variation of warm pool ocean temperature in the equatorial western Pacific and its impacts on climatic change are studied in the present paper. The SSTs in the warm pool region not only have seasonal variation but also have interannual variation more clearly; The influence of anomalies of SST in the warm pool region on the East Asian monsoon is studied with data analysis; And the impact of SSTA in the warm pool region on the teleconnection (wave–train) in the atmospheric circulation is still investigated. The influence of ocean temperature anomalies in the warm pool subsurface on the occurrence of ENSO is also discussed by using data analysis and modelling with CGCM. All above–mentioned studies show that the situation of ocean temperature in the warm pool region in the equatorial western Pacific plays an important role in the global climatic variation.

Key words: Warm Pool, Sub–surface ocean temperature (SOT), Monsoon, ENSO (El Nino / Southern Oscillation)

1. Introduction

Since the El Nino event was regarded as a result of the air–sea interaction (Bjerknes, 1969; Rasmusson and Wallace, 1983; Philander, 1990), the tropical Pacific has been paid much attention by meteorologists in the climatic studies. Particularly, there is the highest ocean temperature in the equatorial western Pacific, the "warm pool", and the strongest convection and atmospheric heating are over the equatorial western Pacific, so that the equatorial western Pacific is very important to the climatic variation in the globe. The numerical simulation with a simple ocean model showed that the sea level subsiding in the equatorial western Pacific began in the last winter prior to the rises of SST and the sea level in the equatorial eastern Pacific (O'Brien, 1983); and the observational data analysis showed that the precedence sign of El Nino event is in the equatorial western Pacific and closely related to the anomaly of winter monsoon in East Asia (Li, 1989; 1990). Thus, the importance of the equatorial western Pacific region (especially, the warm pool) in the climatic variations drew forth the coupled ocean–atmosphere response experiment (TOGA–COARE) in 1992–1993 (Webster and Lukas, 1992), and to a certain extent demonstrated the predictability of seasonal–interannual climatic variability by using data analysis and modelling.

Moreover, some studies showed that there is an atmospheric wave–train (PJ or EPA) in East Asia / the northwestern Pacific region, and it is related to the cumulus convection over

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the equatorial western Pacific (Nitta, 1987; Huang and Li, 1999). This means that the equatorial western Pacific is also important to the atmospheric circulation in the globe. So, it is very necessary to study further the influences of thermal regime in the western Pacific warm pool on the atmospheric circulation and the summer monsoon in East Asia.

The purpose of this paper is to study the influences of thermal anomalies of the western Pacific warm pool on the occurrence of ENSO, monsoon activity in East Asia and the atmospheric wave–train by using the data analysis and numerical simulation with a CGCM. The data used in this paper are mainly the COADS and the JEDAC (Joint Environmental Data Analysis Center) data. At the same time, the numerical simulations are completed by using a coupled atmosphere–ocean general circulation model (CGCM) developed in the Institute of Atmospheric Physics, Chinese Academy of Sciences.

2. Temporal variation of ocean temperature in the warm pool region

As the warmest ocean area, the ocean temperature of the warm pool has obvious temporal variations. The normals for 1950–1992 showed that the annual variation of SST in the warm pool region (10°S–10°N, 140°E–180°) is evident with the maximum in November and May and the minimum in February and August (Fig. 1), and it is different from the annual variation of SST in the equatorial eastern Pacific, which shows an unimodal distribution with the maximum in spring and the minimum in autumn.

The interannual variation of SST in the warm pool region is also evident. In Fig. 2, the power spectrum of the SST and SOT (subsurface ocean temperature) in the warm pool (6°S–6°N, 140°E–180°) and the SST in the equatorial eastern Pacific (6°S–6°N, 150°–90°W) are shown, respectively. It is very clear that the interannual variation of SST in the equatorial eastern Pacific is similar to the interannual variation of SOT in the warm pool region, the ENSO mode (3–4 years) and QBO mode are their major components. But differing from the interannual variations of SST in the equatorial eastern Pacific and SOT in the warm pool region, the interannual variation of SST in the warm pool region has a major spectrum peak at about 3.1–year period. Therefore, the variation of SOT in the warm pool region is closely related to SST in the equatorial eastern Pacific but not to the SST in the warm pool. The temporal variations of the anomalies of SST and SOT in the warm pool showed that they are sometimes in phase but sometimes out–of–phase (figures not given).

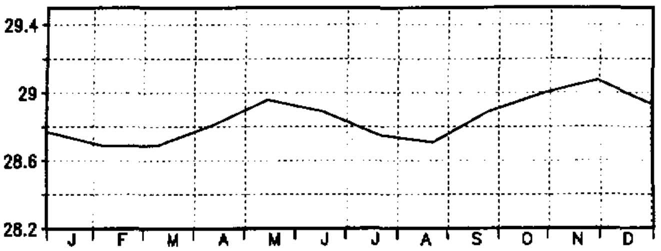

Fig. 1. The annual variation of SST (°C) in the warm pool region (10°S–10°N, 140°E–180°) averaged for 1950–1992.

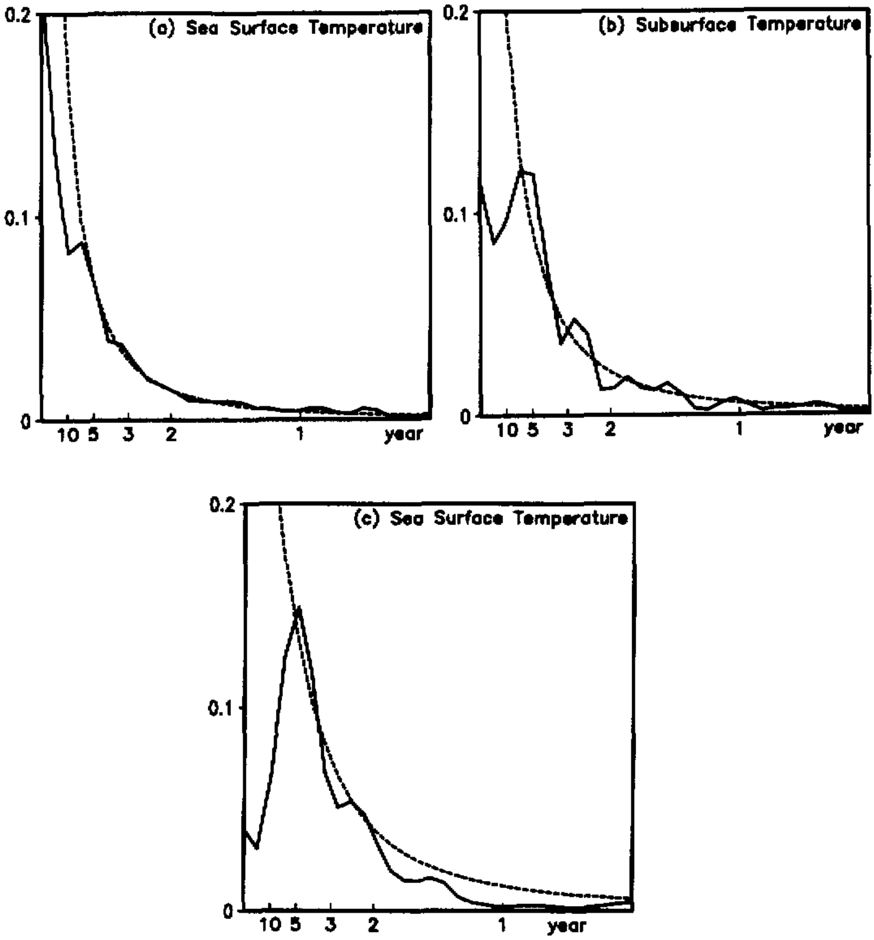

Fig. 2. The power spectra of the SST (a) and SOT (b) in the warm pool region (6°S–6°N, 140°E–180°) and the SST (c) in the equatorial eastern Pacific (6°S–6°N, 150°–90°W).

3. East asian monsoon activity and the thermal regime of warm pool

It has been known that East Asian summer monsoon is different from the South Asian (Indian) summer monsoon, the monsoon index (I_u) advanced by Webster and Yang (1992) is unsuitable to represent the summer monsoon in East Asia, including in the South China Sea region. Therefore, a new monsoon index (I_d) is advanced, which is defined by using the divergence difference between the upper troposphere (at 200 hPa) and the lower troposphere (at 850 hPa) and very suitable to represent the activities of the summer monsoon in East Asia (Li

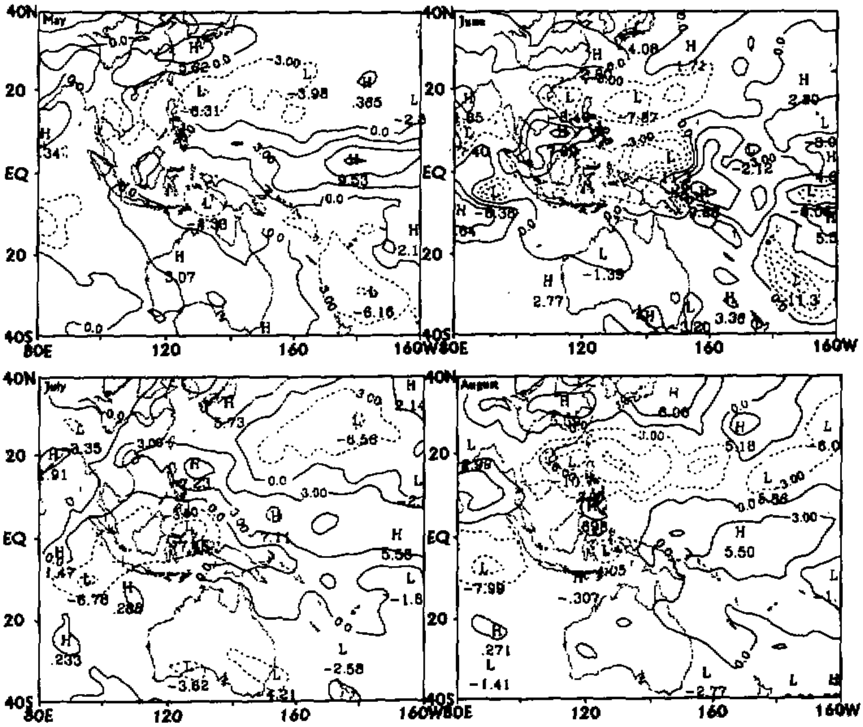

Fig. 3. The distributions of TBB anomalies in May, June, July and August for the strong East Asian summer monsoon case (composite for 1984, 1985 and 1986).

and Zhang, 1999①). The computed monsoon index I_d in the South China Sea region by using the ECMWF data (1980—1989) shows that there are stronger summer monsoons in East Asia in 1984, 1985 and 1986; but weaker summer monsoons in 1980, 1983 and 1987. Thus, the composite results in 1984, 1985 and 1986 can be regarded as an example of the strong East Asian summer monsoons and the composite results in 1980, 1983 and 1987 can be regarded as an example of the weak East Asian summer monsoons.

For the strong summer monsoon, the distributions of anomalies of the black body temperature (TBB) observed in GMS during May, June, July and August are shown in Fig. 3, respectively. It is clear that there are always positive anomalies in the eastern China to Japan region and mainly negative anomalies in the South China Sea region, which means that the summer rainfall is less than normal in the Yangtze River basin to Japan in the strong summer monsoon case. Contrary, in the weak summer monsoon case, the distributions of TBB anomalies (Fig. 4) show that there are positive anomalies in the South China Sea region and negative anomalies in the Yangtze River basin to Japan region, this means that the summer

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①Li, C., and L. Zhang, The future of summer monsoon in the South China Sea and its index, will be published in "Progress in Natural Science", 1999.

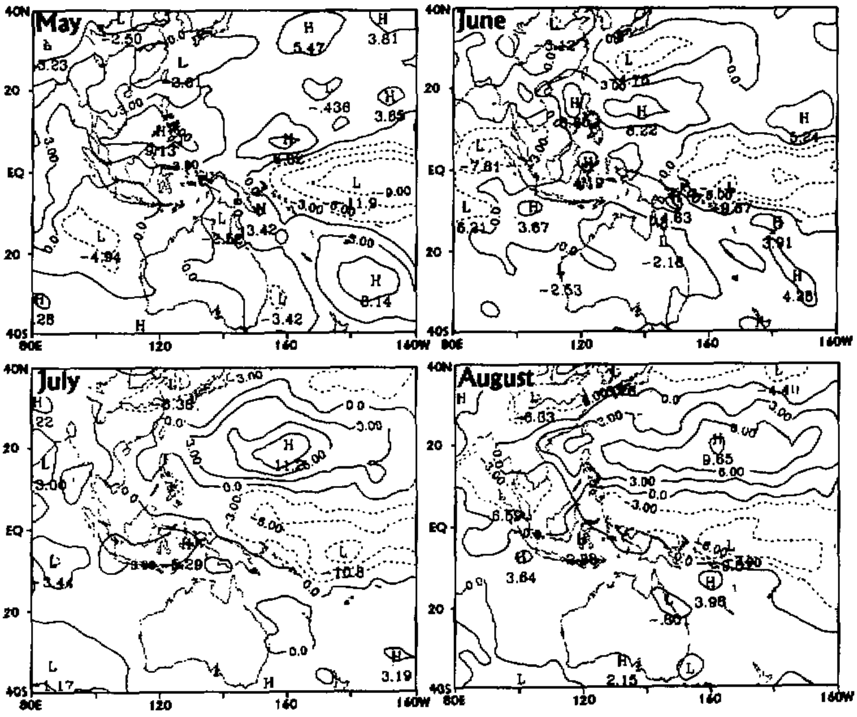

Fig. 4. Same as Fig. 3, but for the weak East Asian summer monsoon case (composite for 1980, 1983 and 1987).

rainfall is more than normal in this area. These results are consistent with the previous studies in relation to summer monsoon rainfall in the eastern China (Xu and Tao, 1996).

It is very interesting that the TBB anomalies over the warm pool region in the strong East Asian monsoon case (positive) are different from ones in the weak East Asian monsoon case (negative). In other words, the convection activity over the warm pool region is closely related to the convection activity in East Asia or the activity of summer monsoon in East Asia. In order to investigate the relation of the convection activity to the SSTA in the warm pool region, the SSTA distributions in the tropical western Pacific are given in Fig. 5 and Fig. 6 by using the NCAR data respectively, for the strong SCS summer monsoon case and the weak SCS summer monsoon case. It can be seen that there are positive SSTA in the warm pool region for the strong SCS summer monsoon case but mostly negative SSTA for the weak SCS summer monsoon case. Comparing Fig. 3 to Fig. 5 and Fig. 4 to Fig. 6, it can be shown that there is stronger convection in the west of the warm pool region, in which the positive SSTA exists for the strong SCS summer monsoon case; but for the weak SCS summer monsoon case, there is not stronger convection in the west of the warm pool region, in which the negative SSTA exists. In other words, the thermal regime of the warm pool is closely related to the monsoon activity in East Asia through the convection activities over the equatorial western Pacific and the South China Sea.

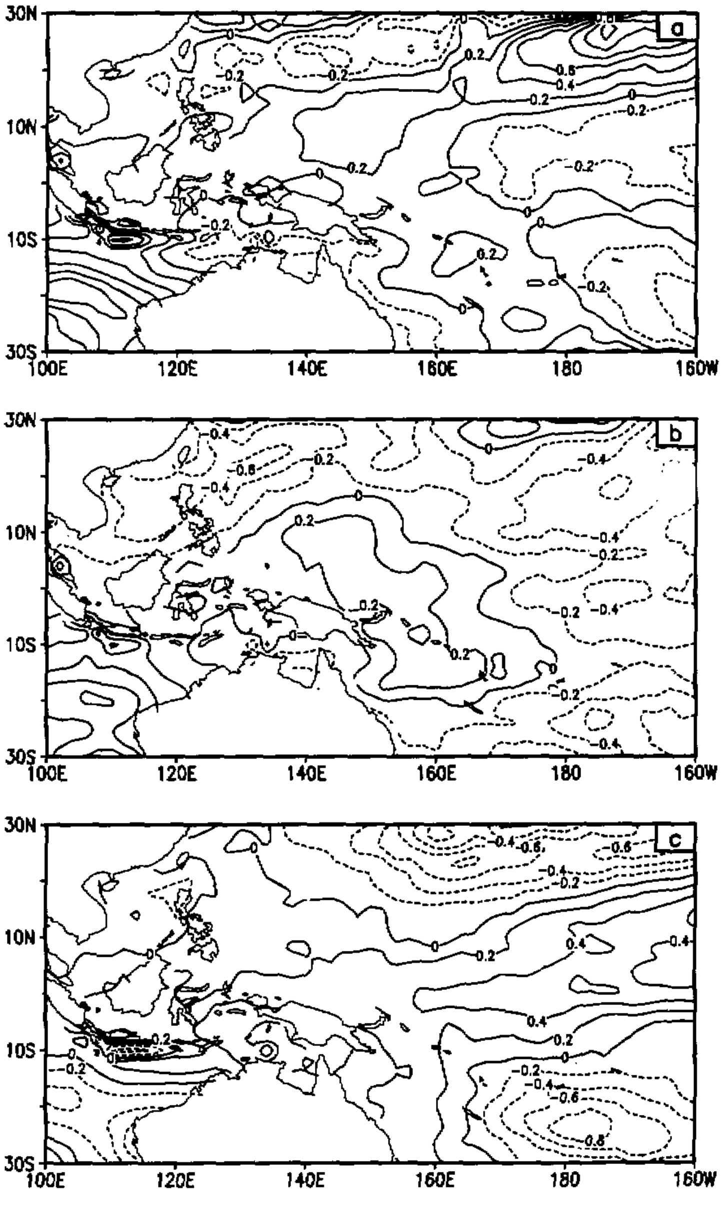

Fig. 5. The distributions of SSTA in the tropical western Pacific for the strong East Asian summer monsoon case, respectively for June (a), July (b) and August (c).

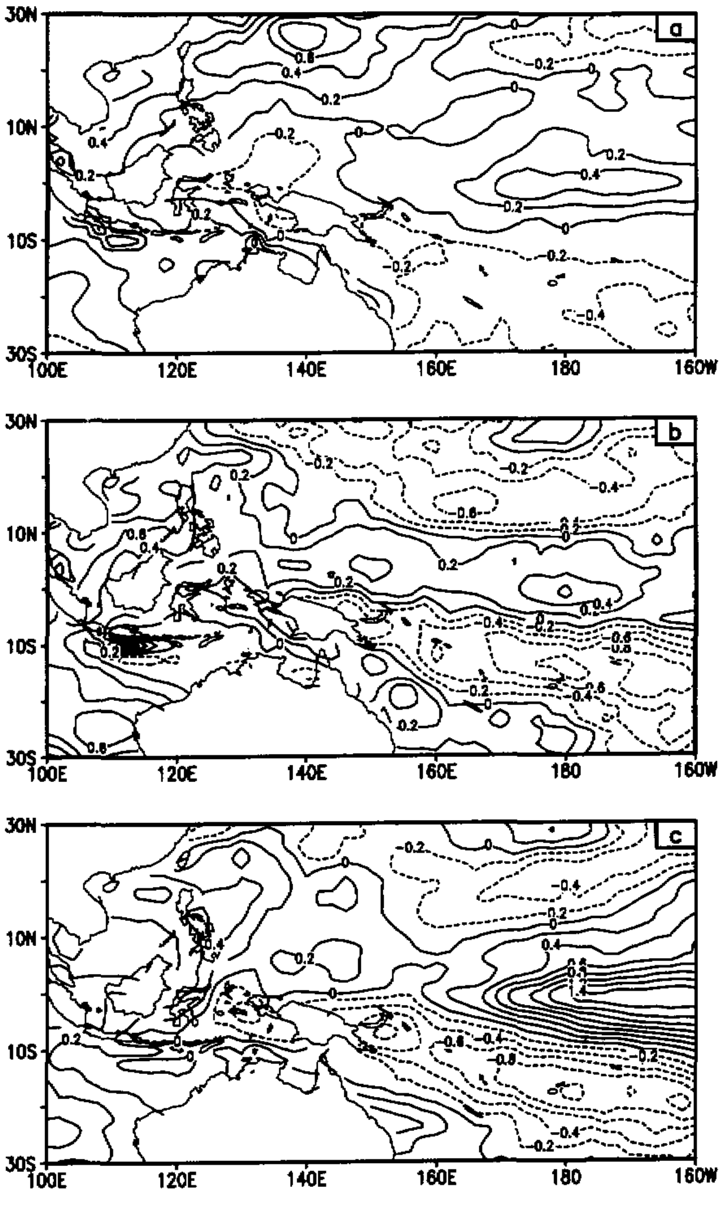

Fig. 6. Same as Fig. 6, but for the weak East Asian summer monsoon case.

4. Atmospheric wave–train in East Asia/ Northwestern Pacific and the thermal regime of the warm pool

In the last section, we showed that the summer monsoon activity in East Asia is closely related to the thermal regime of the warm pool. In summer, there is another important atmospheric circulation pattern in East Asia / Northwestern Pacific, which was named the PJ teleconnection pattern (wavetrain). But recently, some analyses show that it is better to be named the EPA wave–train, because this pattern can stretch right to North America from East Asia through the northern Pacific. The relationship of the EPA wave–train with the summer monsoon activity in East Asia was investigated (Huang and Sun, 1992; Li and Zhang, 1999), the impact of the thermal regime of the warm pool on the EPA wave–train will be discussed in this section.

It was shown in the last section that the positive SSTA in the warm pool is associated with the stronger SCS (East Asian) summer monsoon, but the negative SSTA in the warm

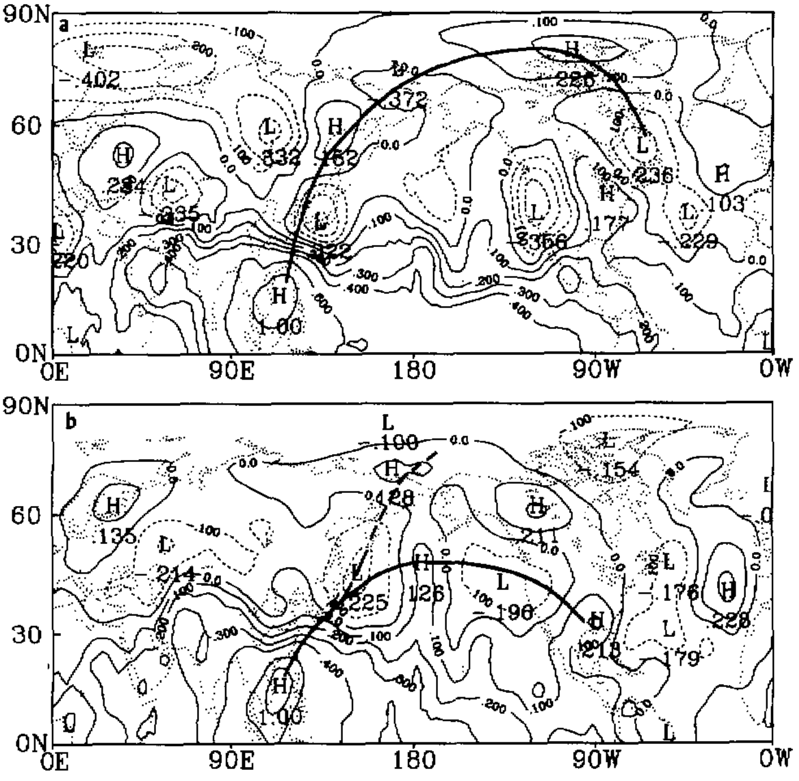

Fig. 7. The distributions of correlation coefficient of geopotential height at 500 hPa for the strong SCS summer monsoon case (a) and for the weak summer monsoon case (b).

pool is associated with the weaker SCS summer monsoon. The data analyses showed very clearly that the EPA wave–train has the different pattern in the strong SCS summer monsoon case, in comparison to that in the weak SCS summer monsoon. The point–to–point correlation coefficients of the geopotential height at 500 hPa (by using ECMWF data and the reference point at 15°N, 112.5°E) are shown in Fig. 7a for the strong SCS summer monsoon (1984, 1985 and 1986) and Fig. 7b for the weak SCS summer monsoon (1980, 1983 and 1987). It is evident that the EPA wavetrain, represented with the thick black line, stretches northwards to higher latitudes in the strong summer monsoon year, but to lower latitudes in the weak summer monsoon year.

The numerical simulations with the IAP–AGCM (Zeng et al., 1990) also showed the similar results to the observation data analyses. For the strong SCS summer monsoon case associated with the positive SSTA in the warm pool, the EPA wavetrain stretches northwards to higher latitudes than that in the weak SCS summer monsoon case associated with the negative SSTA in the warm pool (figure omitted).

5. The occurrence of ENSO and the subsurface ocean temperature anomalies in the warm pool

The close relationship between ENSO occurrence and the sub–surface ocean temperature (SOT) anomalies in the Pacific warm pool region is also studied through data analysis and numerical simulation with a CGCM. It is shown that there are continual positive (negative) anomalies of SOT in the warm pool region prior to the El Nino (La Nina), and the outbreak of El Nino (La Nina) is directly associated with the eastward propagation and expanding of positive (negative) SOT anomalies.

5.1 1997 *El Nino event*

A very strong El Nino event occurred in 1997, the observed SST anomalies are greater than +6 °C in the eastern Pacific for several months. This El Nino event caused serious climate disasters obviously in great scopes in the globe, such as the droughts in Indonesia and Australia, the floods in South America, some climate disasters also occurred in China.

The 1997 El Nino began in May, because there are positive anomalies of SST in the equatorial eastern Pacific in May, with anomalies greater than +4 °C observed, but till May, the systematic positive anomalies of SST were not formed in the equatorial eastern Pacific. It is very clear that the sub–surface ocean temperature anomalies of the warm pool in the equatorial western Pacific seem to be an important omen to the occurrence of El Nino.

The analyses of the equatorial depth–longitude sections of the ocean temperature anomalies for the different month showed that there were positive anomalies of the SOT (100–200 m) in the western Pacific warm pool, but negative anomalies of the SOT (50–100 m) in the equatorial eastern Pacific during August–November 1996. In December 1996, the positive anomalies of the SOT in the warm pool were enhanced and expanded eastwards. In January 1997, the positive anomalies of the SOT were very strong (>5 °C) and expanded to the east of 160°W. The negative anomalies of the SOT in the equatorial eastern Pacific were replaced by the positive anomalies along with the continued eastward expanding of the anomalous SOT; In March 1997, there was not only a strong positive anomaly centre in the western Pacific warm pool, but also a positive center in the equatorial eastern Pacific. Then, the positive anomalies area of the SOT gradually moved into the equatorial eastern Pacific. In May 1997, the anomalous SOTs were over +6 °C in the equatorial eastern Pacific, but there were the negative anomalies of the SOT in the equatorial western Pacific; At the same time, positive anomalies of the SOT gradually propagated up to the sea surface and the positive anomalies of SST occurred in the equatorial eastern Pacific. Thus, the El Nino event was excited, and the thermal regime of the equatorial Pacific Ocean was shown that there were positive anomalies (SST and SOT) in the equatorial eastern Pacific but the negative anomalies in the equatorial western Pacific after the occurrence of El Nino.

The above analysis showed that the occurrence of El Nino event in 1997 is closely related to the anomalies of SOT in the warm pool in the equatorial western Pacific. The positive anomaly of SOT in the warm pool and its eastward propagation play an important role in the occurrence of the El Nino event.

5.2 *The analyses with the previous data*

In order to investigate the relationship between the anomalies of SOT in the warm pool and the occurrence of El Nino events, the temporal variations of the anomalous SOT in the warm pool (10°S–10°N, 140°E–180°) and the anomalous SST in Nino 3 (5°S–5°N, 150°–90°W) region are shown in Fig. 8 by using the JEDAC and COADS data. It is very clear that the positive anomalies of the SOT in the warm pool region always exist prior to the occurrence of El Nino event, but after the outbreak of El Nino, the SOT anomalies in the warm pool region are out–of–phase to the SST anomalies in Nino 3 region. It is also shown in Fig. 8 that the sub–surface warming in the warm pool region leads to the outbreak of El Nino event for six months to two years.

The sub–surface warming in the warm pool is closely related to the occurrence of the El Nino event, but the eastward propagation of positive anomalies of the SOT is more important. It seems to be an important reason for the occurrence of the El Nino event that the eastward propagation of positive anomalies of the SOT along with the gradual rise of thermocline in the equatorial eastern Pacific leads to the occurrence of positive anomalies of

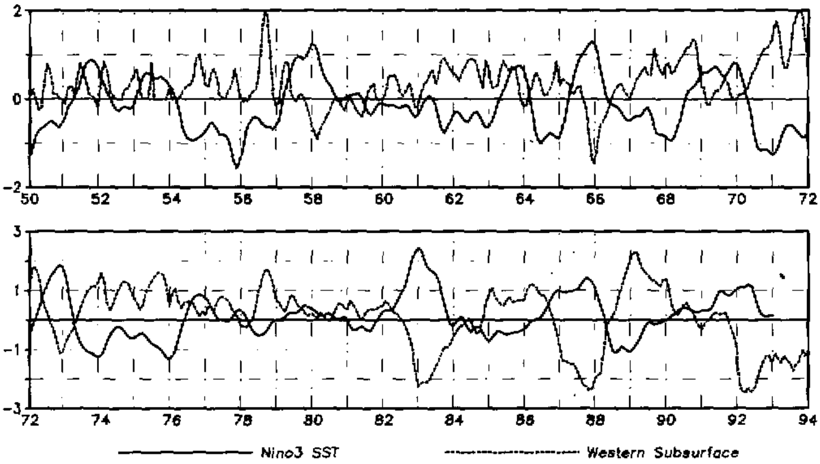

Fig. 8. Temporal variations of the SST anomalies in Nino3 region (solid line) and the SOT anomalies in the warm pool region (dashed line).

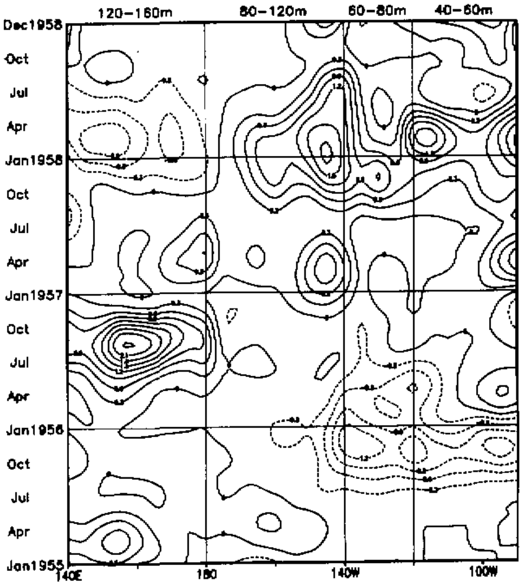

Fig. 9. Time–longitude section of the SOT anomalies (°C) in the equatorial Pacific along the maximum variation layer of ocean temperature for the 1957 El Nino case.

SST in the equatorial eastern Pacific. Sometimes the eastward propagation of positive anomalies of SOT is in time after the warming in the warm pool region, but sometimes the eastward propagation is delayed, so that there is six months to two years span of the time difference between the warming in the warm pool and the outbreak of the El Nino event.

The relationship between the occurrence of El Nino and the positive anomalies of SOT in the warm pool region and its eastward propagation can be obviously shown by using the time–longitude section of SOT anomalies in the equatorial Pacific. Because the thermocline is deeper and thicker in the western Pacific than that in the equatorial eastern Pacific, the depths of the maximum SOT anomaly are also different. In order to represent the section of SOT anomalies, the data should be respectively adopted for the different depths, such as 160–120 m in the equatorial western Pacific, 120–60 m in the equatorial central Pacific and 60–40 m in the equatorial eastern Pacific.

The data analysis showed the similar results, as examples, the results for only two cases are given here. The time–longitude sections of SOT anomalies in the equatorial Pacific are shown in Fig. 9 for the 1957 El Nino and Fig. 10 for the 1972 El Nino, respectively. For the 1957 El Nino case (Fig. 9), the obvious warming of the warm pool began in April–May 1956 even though the positive anomalies of SOT were weaker in the equatorial western Pacific, the maximum anomaly of SOT was about +2.5 °C in the autumn of 1956 and the positive anomalies of SOT propagated into the equatorial central–eastern Pacific in the winter of 1956 and the spring of 1957, thus, the El Nino occurred in April 1957; It was about one year from the obvious warming in the warm pool to the outbreak of El Nino. For the 1972 El Nino case (Fig. 10), the obvious warming of the warm pool began in May 1970 and the strong warming

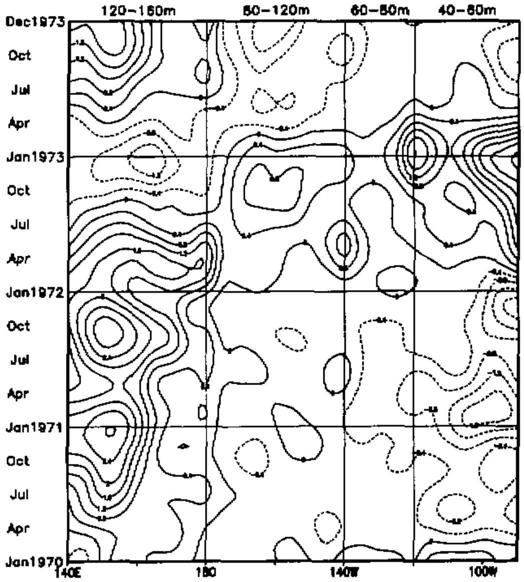

Fig. 10. Same as Fig. 9, but for the 1972 El Nino case.

was in August–October 1971 (>3 °C), but until the spring of 1972, the positive anomalies of SOT just expanded into the equatorial central–eastern Pacific, and then, the El Nino occurred in May 1972; The time from the obvious warming in the warm pool to the outbreak of El Nino was about 2 years.

5.3 *Numerical simulation results with CGCM*

In order to explore the important role of SOT anomalies in the warm pool region in exciting ENSO, the numerical simulation results with a CGCM are analyzed. The model used in this study is a coupled atmospheric–oceanic general circulation model, developed in the Institute of Atmospheric Physics / Chinese Academy of Sciences. The atmospheric component is a two–level global atmospheric general circulation model formulated in the σ–coordinate with the resolution of 4° in latitude and 5° in longitude (Zeng, et al., 1989), which has been shown to have quite good simulating abilities for climate variations in the AMIP project. The oceanic component is a free surface tropical Pacific general circulation model with the resolution of 1° in latitude and 2° in longitude and 14 unequal layers in the vertical direction with flat–bottom (4000 m), of which the domain is 121°E–69°W and 30°S–30°N. The more details about the OGCM are described by Zhang and Endoh (1992). The coupled model has successfully simulated the ENSO like variation (Zhang and Levitus, 1997). In order to control the " climate drift" in the coupled system, the linear statistical correlation is used in the model integration. The outputs are analyzed for the last forty years of the total 100–year integration, it shows that the model has reached the equilibrium for the 50 years.

The time–longitude section of the simulated sea surface temperature anomalies (SSTA)

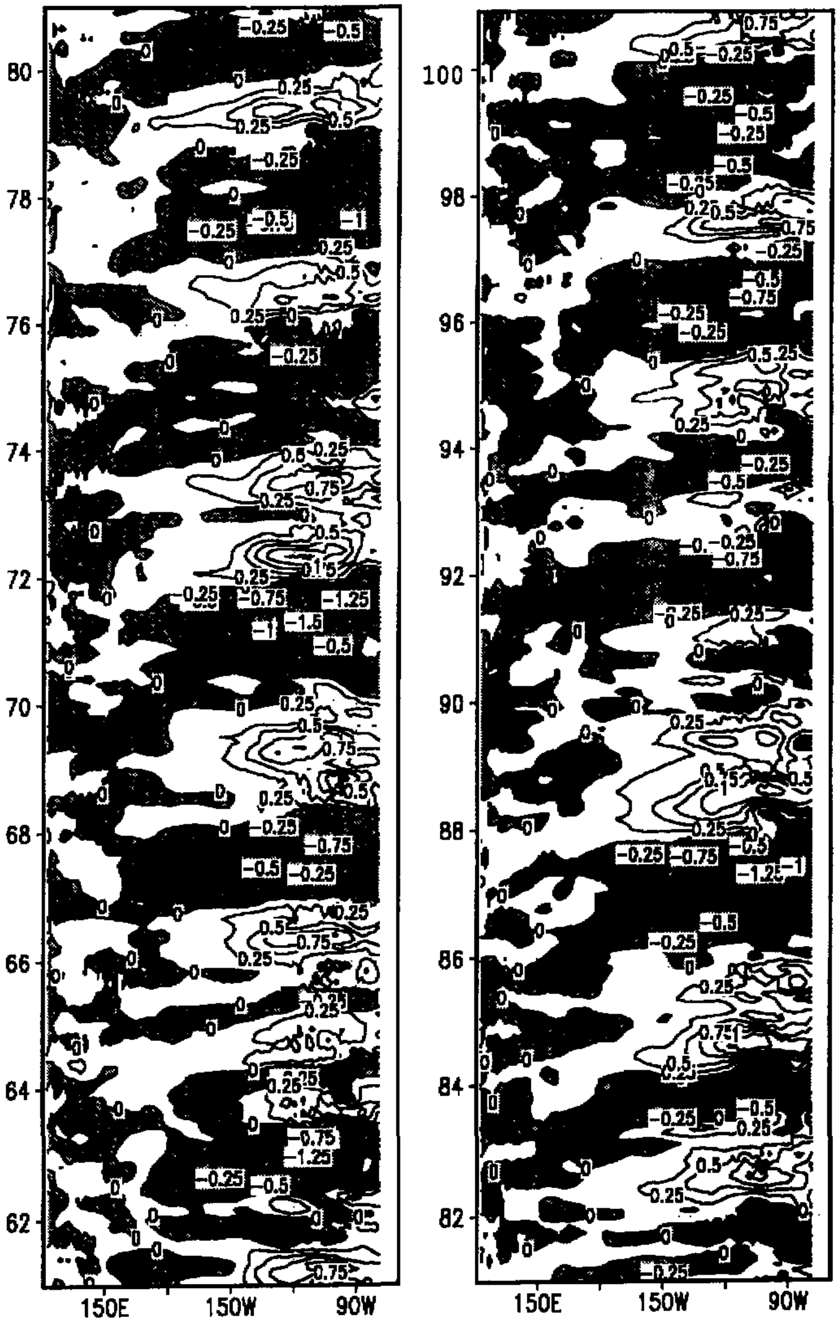

Fig. 11. The time–longitude section of simulated sea surface temperature anomalies (SSTA) in the equatorial Pacific (2.5°S–2.5°N).

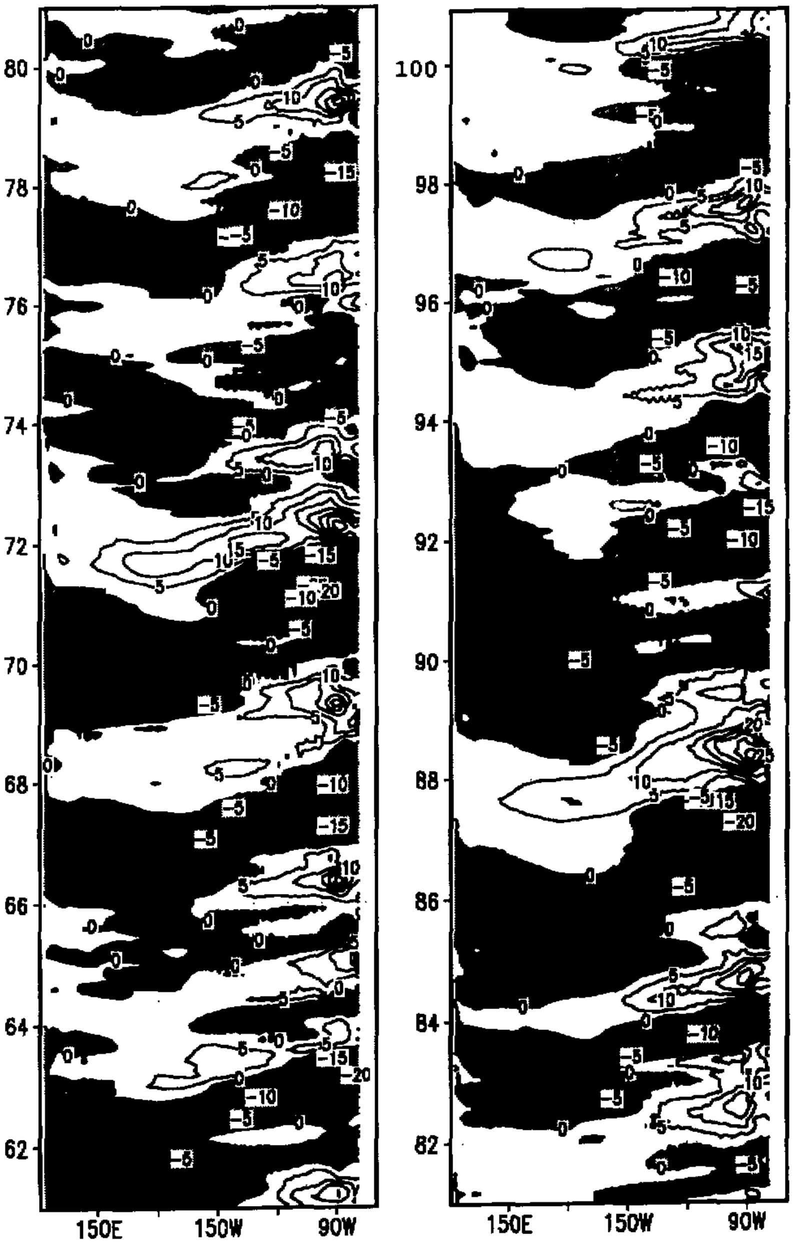

Fig. 12. The time–longitude section of simulated anomalies of the 20 °C isotherm depth (m) along the equator (2.5°S–2.5°N).

in the equatorial Pacific (2.5°S–2.5°N) is shown in Fig. 11. Even though the intensity of SSTA is weaker than the observation, its interannual variations are very clear and the most of them propagate eastwards. If we define an event that the SSTA is higher than 0.5 °C as a warm event and an event that the SSTA is lower than –0.5 °C as a cold event, there are 13 warm events and 12 cold events in the 61–100–year integration in total. It is very interesting that there are always positive (negative) anomalies of the sub–surface ocean temperature (SOT) in the equatorial western Pacific prior to the warm (cold) events and these anomalies propagate eastwards. In Fig. 12, the time–longitude section of the simulated anomalies of the 20 $_{o}$C isotherm depth along the equator (2.5°S–2.5°N) is shown. It is very clear that the simulated anomalies of the 20 °C isotherm depth showed not only the obvious interannual variation and the eastward propagation but also the close relationship with ENSO.

In order to further explore the relationship between the SSTA in the equatorial eastern Pacific (ENSO) and SOT anomalies in the equatorial western Pacific, the temporal variations of the simulated SSTA in Nino 3 region and the SOT anomalies in the equatorial western Pacific (140°E–180°, 6°S–6°N) are shown in Fig. 13. It can be seen that there are obvious positive anomalies of SOT (SSTA) prior to the most of warm events and the SOTA becomes negative after the appearances of warm events. On the contrary, the cold events always correspond to negative SOTA in the equatorial western Pacific in the earlier stage.

The composite analyses of the SOT in the equatorial Pacific for the simulated El Nino and La Nina have the advantage to explore the importance of the SOTA in the warm pool to

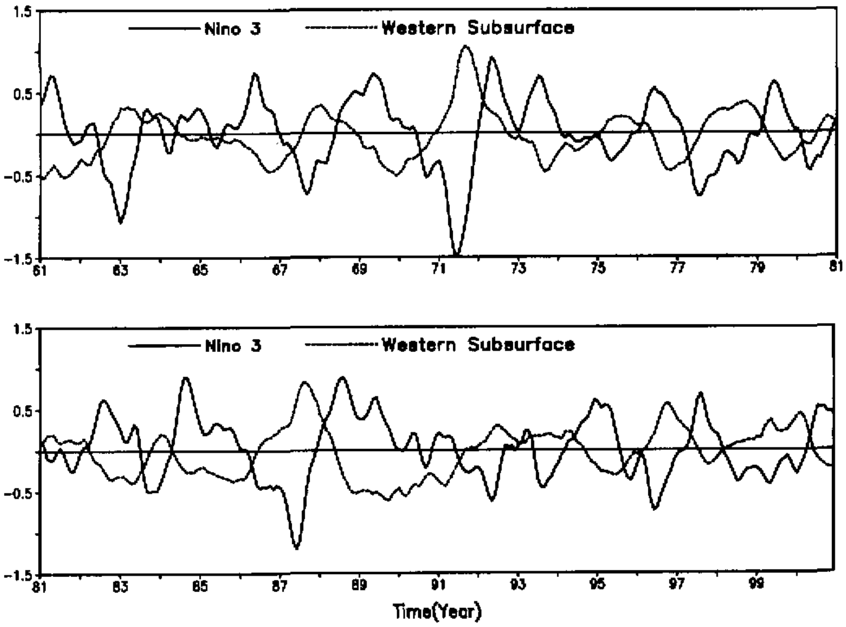

Fig. 13. Temporal variations of the simulated SSTA (solid line) in Nino 3 region and simulated SOT (100–200 m depth) anomalies (dashed line) in the equatorial western Pacific (140°E–180°, 6°S–6°N).

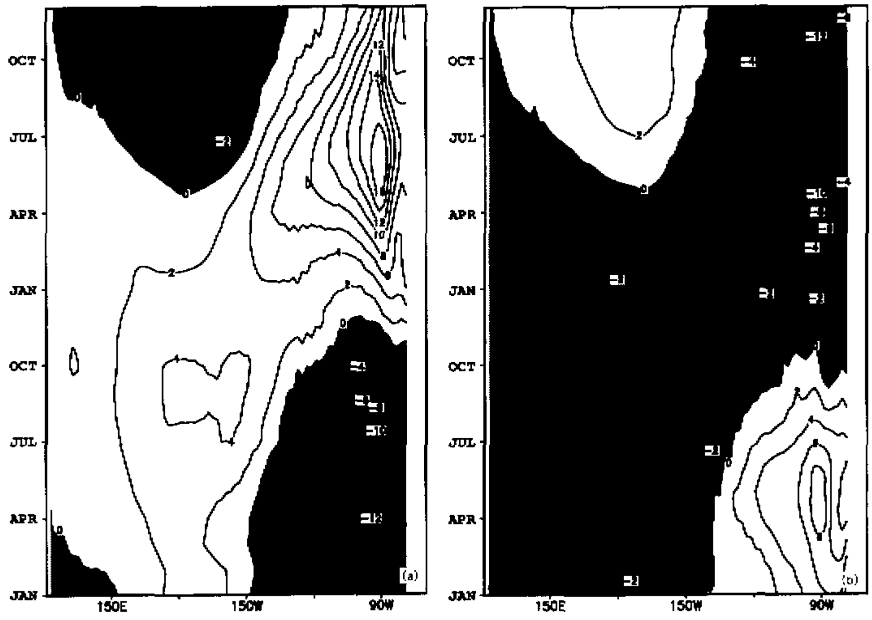

Fig. 14. The composite time–longitude sections of the simulated depth anomalies (m) of 20°C isotherm in the equatorial Pacific for El Nino cases (a) and La Nina (b), respectively.

excite the ENSO. In Fig. 14, the composite time–longitude sections of the simulated anomalies of the 20 °C isotherm depth along the equator (2.5°S–2.5°N) during the two–year period are shown for the warm and cold cases, respectively. In the warm case, there is the positive SOTA in the warm pool region in the previous autumn and winter, and then because of the eastward propagating and enhancing of the positive SOTA, the positive SSTA gradually appears in the equatorial eastern Pacific. Contrary to the warm case, the negative SSTA gradually rises in the equatorial eastern Pacific as a result of the eastward propagation and enhancement of the negative SOTA which exists in the warm pool in the previous autumn and winter.

6. Conclusions

The observational and numerical simulation analyses in this paper clearly showed the following main results:

1) The interannual variation of SOT in the warm pool region is different from SST in the same region but closely related to SST in the equatorial eastern Pacific.

2) The thermal regime of the warm pool has evident effects on the summer monsoon in East Asia, the positive SSTA in the warm pool region is related to the stronger summer monsoon but the negative SSTA in the warm pool region is associated with the weaker summer monsoon.

3) The thermal regime of the warm pool is closely related to the EPA wave–train, for the positive (negative) SSTA in the warm pool, the EPA wave–train stretches northwards to

higher (lower) latitudes.

4) The occurrence of ENSO is closely related to the anomalies of SOT in the warm pool region, and there are the continual positive (negative) anomalies of SOT in the warm pool prior to El Nino (La Nina).

5) The outbreak of the El Nino (La Nina) event is directly associated with the eastward propagation of anomalous SOT. The eastward propagating of anomalous SOT into the equatorial eastern Pacific and expanding to the sea surface will lead to the anomalies of SST in the equatorial eastern Pacific and the occurrence of ENSO.

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