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DIAGNOSTIC ANALYSIS AND VERIFICATION OF PREDICTION OF THE TROPICAL PACIFIC SEA SURFACE TEMPERATURE ANOMALIES DURING 1997 ~ 1998

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ABSTRACT: By comparing with ENSO events that ever happened in the history, the basic features and probable causes of the anomalous sea surface temperature of the tropical Pacific Ocean during 1997 and 1998 have been analyzed diagnostically. It is found that the 1997/1998 El Nino had significant abnormalities and peculiarities. It differs from the previous El Niño events falling into the simple "eastern pattern" or "western pattern". The predictions of 1997/1998 El Niño event have also been tested with an intermediate ocean-atmosphere coupled dynamic model. The results show that the skills of the 0～24 lead month forecasts for the warm event are all above 0.5. The predictions of the mature phase and the later stages of the warm event are better than those of the beginning phase.

Key words: ENSO; diagnostic analysis; numerical forecast; verification of prediction

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1 INTRODUCTION

In the summer of 1998, it was rainy widely in most areas of South and North China. Many parts of the nation suffered from flooding disasters in varying extents due to the sustained, heavy rainfalls. For instance, the unusual floods occurring in the basins of Yangtze River, Nenjiang River, Songhua River, Minjiang River and part of Zhujiang River have caught worldwide attentions. However, one of the main climatological backgrounds for the 1998's flood in China is the 1997/1998 El Nino event. In recent years, more and more data analyses and numerical simulations have already indicated that ENSO (El Niño and La Niña) event is an important factor that influences the variation of weather and climate in China. For example, the statistical analysis results based on the precipitation and temperature data of 160 stations in China from 1951 to 1990 show that the precipitation will be less than normal and temperature will be lower than normal in most areas of China in the year that ENSO event happens, but in the next year, the precipitation will be more than normal and temperature will be higher than normal in most areas of China[1]. The precipitation condition of China in the summer of 1998 is similar to the mean result stated above, but in the summer of 1997, it was continuously hot and drought in the North China, with rain belts located in the south side and less rainfall in the regions of Yangtze River and Huaihe River Basins. During the wintertime of 1998, precipitation was generally less than normal and temperatures were generally higher than normal in most areas of China. It not only indicates that the 1997/1998 El Nino event relates to the flood in China in the summer of 1998, but also reflect that the relationships between El Nino/La Nina event and the climate of China is

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complicated. It is obvious that the 1997/1998 ENSO event has not only the typical characteristics of usual ENSO events but also its unique features. Therefore, detailed studies on the occurrence and development processes as well as the physical causes of this event will be very helpful to the advancement of understanding and knowledge on ENSO as well as the improvement of ENSO forecast model and the increase of relevant forecast skills.

2 DIAGNOSTIC ANALYSES ON THE ANOMALOUSLY STRONG EL NIÑO EVENT DURING 1997-1998

Since the 1950s, the intensities of the warm events in the eastern and central tropical Pacific Ocean have tended to increase (See Fig.1). During 1997-1998, the strongest El Niño event in the 20th century occurred. This event is similar to the 1982/1983 El Niño event in some aspects, but it preponderates over the 1982/1983's strong process in others. In addition, the 1997/1998 warm event has some unique features. In the present paper, on the basis of the sea surface temperature, sub-surface temperature and wind stress data and through comparison with 1982/1983 El Niño event, a detailed analysis on the process of the 1997/1998 El Niño event has been conducted.

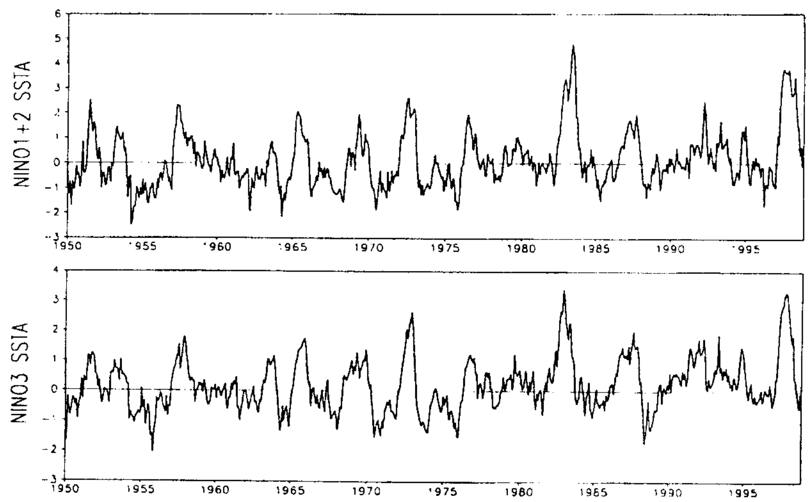

Fig.1 Nino1+2 (top) and Nino3 (bottom) index of observational sea surface temperature anomalies from 1961 to 1998

The occurrence of the 1982/1983 El Niño event necessitates the modification of the classical pattern of ENSO. Its strong intensity and the feature of phase propagation are distinctly different from those of the classical El Niño event. In the process of this event, the warm sea temperature first appeared in the central and western equatorial Pacific rather than the eastern equatorial Pacific where it is usually thought to be. In May 1982, the convergence zone associated with the development of El Niño event began to move eastwards continuously and slowly from the western equatorial Pacific. Simultaneously, outgoing long-wave radiation (OLR) anomalies (Figure not shown here), western wind anomalies (WWA) (See Fig.2b) and sea surface temperature (SST) anomalies (See Fig.3b) expanded eastwards. By the end of 1982, the warm phase of the sea temperature has propagated eastwards to the coast of South America. At the same time, the western wind anomaly over the equator prevailed in most areas of the central and western Pacific. In January 1983, the warm event reached its peak. The 1982/1983 warm episode implies that the order in which an El Niño event develops could be reversed, i.e. sea surface temperature anomalies might propagate either westwards or eastwards.

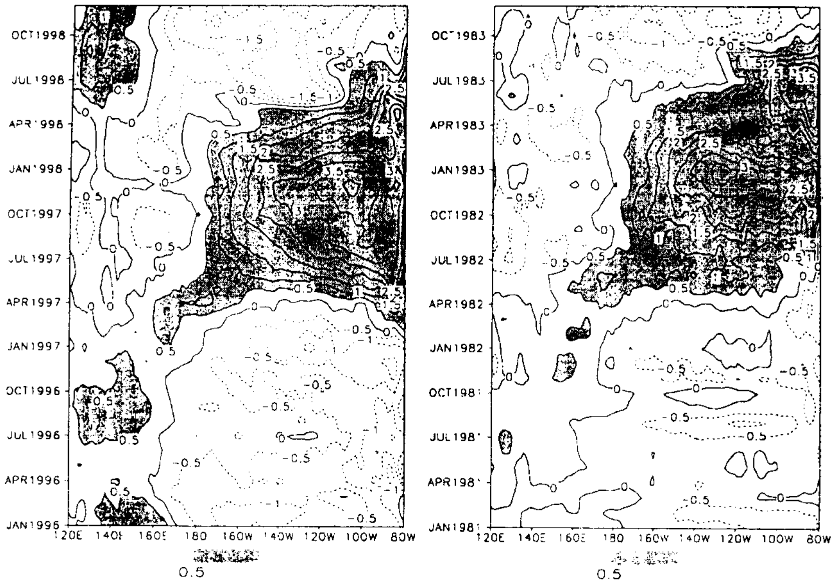

Fig.2 Time-longitude section of anomalous zonal pseudo stress along 5°N ~ 5°S for the period 1996 ~ 1998 (left) and 1981 ~ 1983 (right).

A notable characteristic of the 1997/1998 El Niño event is its rapid onset and development and its strong intensity. In the spring of 1997, the Nino3 index turned positive. It entered the peak period six months later. In December 1997, the index was 3.3°C and hereafter it decreased rapidly. Only six months later, the Nino3 index resumed close to zero. Then it gradually evolved into a La Niña event (See Fig.1). As shown in Fig.3, in the early 1997, 0.5°C positive anomalies appeared first in the western equatorial Pacific, which is similar to the situation in the corresponding time period of 1982. However, in the spring of 1997, there were positive anomalies in Nino1+2 area, which enhanced rapidly and reached 1.5°C, while in the spring of 1982, there were negative anomalies valued -1.0°C in the same area. The reason why the 1997/1998 El Niño could develop so fast is that two positive anomalous areas appeared in the

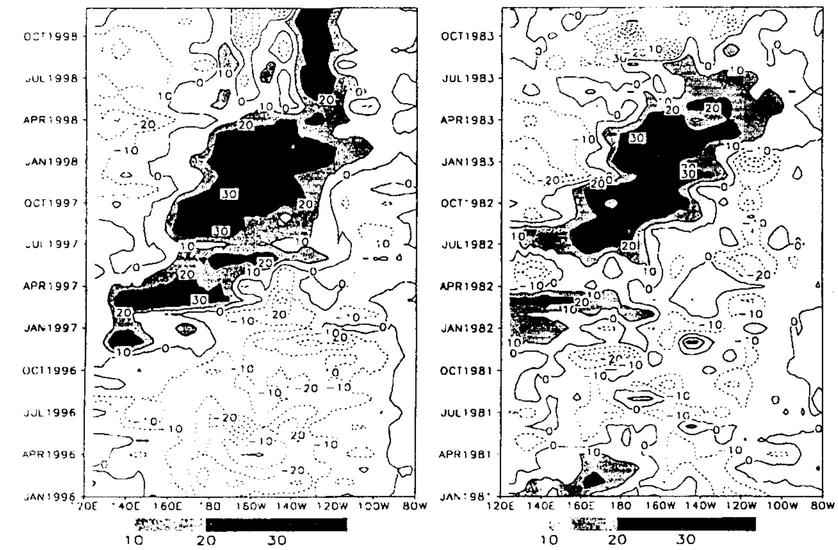

Fig.3 Same as Fig.2 but for anomalous sea surface temperature.

eastern Pacific and the western Pacific contemporarily before expanding westwards and eastwards respectively. It soon entered the mature phase in the autumn of 1997 and reached its peak in December 1997, with the maximum positive anomaly being 4°C. The central position of maximum positive anomaly in the 1997/1998 El Niño episode is approximately 20 longitudinal degrees east to that in the 1982/1983 El Niño event. In contrast to the 1982/1983 event, the 1997/1998 El Niño event declined rapidly after it peaked. In the autumn of 1998, negative SST anomalies of -2°C appeared in the central and eastern equatorial Pacific Ocean. A new cold water process has formed in the central and eastern equatorial Pacific Ocean.

As shown in Fig.2, from the end of 1996 to the early 1997, there was anomalous western wind in the western equatorial. In the spring of 1997, the western wind anomaly over the western Pacific Ocean extended eastwards and got across the dateline. Hereafter, as the El Niño event happened and the western wind anomaly continued the movement eastwards. By early 1998, it had connected with the week western wind anomaly over the eastern Pacific. In contrast, the western wind anomaly over the western equatorial Pacific obviously declined in the spring of 1982. It was after June 1982 that it began to enhance and extend eastwards. But both the range and the intensity of the western wind anomaly in 1982 are not comparable to those in 1997. This is also a cause that makes the 1997 warm event occur and develop rapidly. After the El Niño event declined, the western wind anomalies over the central and eastern equatorial Pacific disappear rapidly in 1983, but in 1998, there still remained stronger western wind anomalies over the eastern equatorial Pacific, which strengthened the divergence over the eastern equatorial Pacific and were favorable for SSTA to become negative from positive rapidly.

In order to analyze conveniently the characteristics of the variation of sub-sea-surface temperature in the current paper, the sea temperatures of the levels on which the mean square deviations of the sub-sea-surface temperatures are above 0.5°C were averaged vertically. The vertical mean values were applied to represent the anomalous sub-surface temperatures. The used data are the sea temperature data on the 11 upper levels （0,20,40,60,80,120,200,240,300,400 m） of the ocean, which are provided by the Joint Environment Data Analysis Center (JEDAC) of the United States. Each level, on which the vertical mean sub-surface temperature is computed, is selected according to the mean square deviation of the sea temperature that is above 0.5°C. The individual levels differ from each other because their ocean-geographical locations are different. Generally speaking, the sub-surface of the sea tilts upwards from the western Pacific to the eastern Pacific along the equator with the thermocline (20°C isotherm) approximately as axes. For instance, the mean levels approximately lie between 50 m and 300 m in 140°E, but they approximately lie between 0 m and 150 m at 100°W. Fig.4a shows the distribution of the computed sub-surface temperature anomalies averaged between 5°N and 5°S from 1996 to 1998. It can be seen that the distribution of the equatorial Pacific sub-surface temperature mainly appears to be positive anomaly in the west and negative anomaly in the east in 1996. Besides, anomalously warmer water accumulated in the western equatorial Pacific with positive anomaly above 1°C. As comparison, the pileup of anomalously warmer water in the sub-surface of the western equatorial Pacific in 1981 is much weaker than that in 1996. In 1981, the maximum positive anomaly was only about 0.5°C (See Fig.4b). In the early 1997, the negative sea temperature anomaly in the central and eastern equatorial Pacific gradually vanished while the positive anomaly in the western equatorial Pacific enhanced. In the spring of 1997, as the anomalous western wind over the equatorial Pacific enhanced and extended eastwards (See Fig.2a), positive anomaly began to propagate eastwards from the western Pacific. The sea temperatures of the whole central and eastern equatorial Pacific almost simultaneously increased violently so that the sea surface temperature went up rapidly. An anomalously strong El Niño event occurred. Subsequently, the positive sea temperature anomalies in the central and eastern equatorial Pacific continually increased, but the sea temperatures in the warm pool area notably

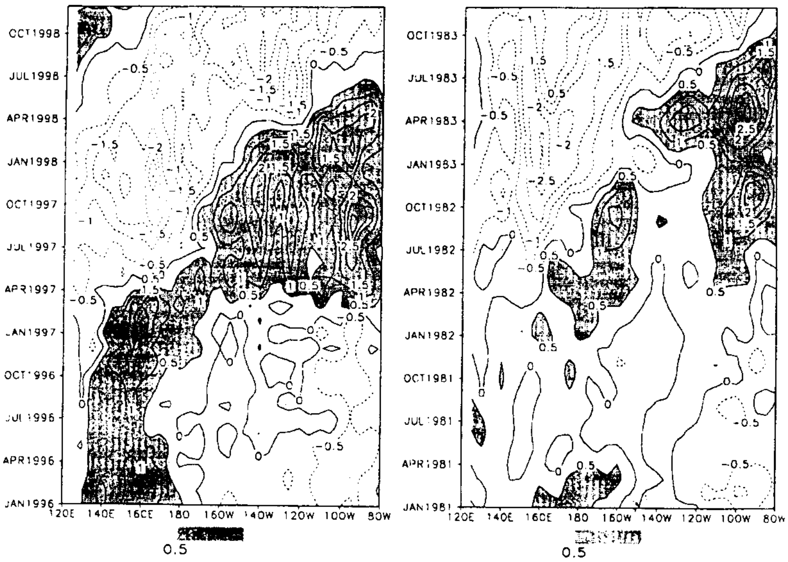

Fig.4 Same as Fig.2 but for anomalous sub-sea-surface temperature.

dropped with negative anomalies appearing in the western and central Pacific. However, as shown in Fig.4b, in 1982, the positive sub-surface temperature anomalies in the central and eastern equatorial Pacific had two maximum value centers. The overall intensity with which sea temperature increased anomalously in 1982 was much weaker than that in 1997. In the spring of 1998, over the central equatorial Pacific, western wind anomaly decreased so significantly that eastern wind anomaly appeared (See Fig.2a). The accumulated cold water in the warm pool area expanded eastwards, the temperature of the warm water in the central and eastern equatorial Pacific descended sharply, and the range of the positive sea surface temperature anomaly reduced promptly and its intensity weakened rapidly. The El Niño event entered its ending phase. Hereafter, the central and eastern tropical Pacific Ocean gradually went into the phase of cold water and a new La Niña event developed.

3 PREDICTIONS FOR THE TROPICAL PACIFIC SSTA USING AN INTERMEDIATE OCEAN-ATMOSPHERE COUPLED MODEL DURING 1997-1998

The model used in this paper is a tropical Pacific ocean–atmosphere coupled model, named as NCC mode [3]. It is a dynamical model and developed under the support of the sub-project II-“Development of Prediction Model for Interannual Variability of ENSO” of the National Key Project –“Studies on Short-term Climate Prediction System in China ”. The oceanic component of the coupled model has 2.5 levels in the vertical direction, with the lowest layer motionless and the two upper layers movable. The ocean model is described by linear reduced gravity equations on the equatorial β-plane. The atmosphere component is a Gill type model whose horizontal range can extend to the global tropics. Since early 1997, the coupled model has been applied to perform experimental predictions. The predictions of the tropical Pacific SSTA have been reported at national consultation meetings on weather forecasts for flooding season, supplemental predictions, and yearly predictions[4, 5].

Fig.5a shows the predictions of the tropical Pacific SSTA for 1997 by using the NCC model and six consecutive initial fields from August 1996 to January 1997, which was performed in March 1997. The prediction result indicated that there would be a new El Niño process in 1997 and 1998. After March 1997, the supplemental predictions performed by using the initial fields of April, May, June and July 1997 further made it clear that the positive Nino3 SSTA would continually develop and that a strong warm event would begin in the spring of 1997 and enter its peak period in the winter of 1997, with its peak value around 3°C ~ 4°C (See Fig.5b).

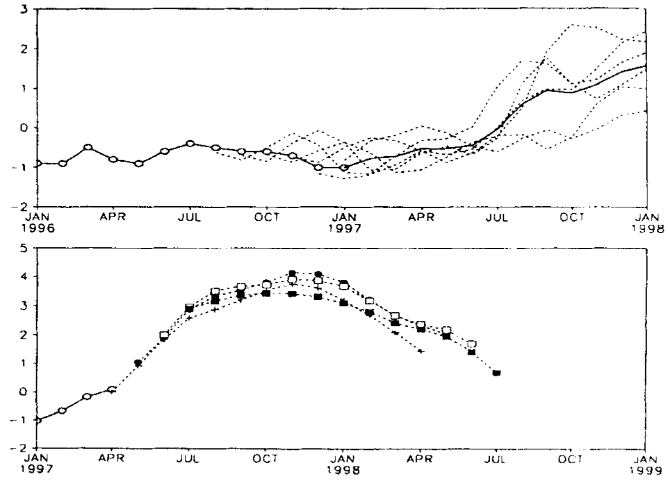

Fig.5 Observed (solid curves with "o" signs) and predicted sea surface temperature anomalies for Nino3 region. In Fig.5a (top), forecasts were made from six consecutive monthly initial conditions from July 1996 to January 1997 (dashed lines). The ensemble mean of all six forecasts is shown by the thick solid curve. In Fig.5b (bottom), the "+", "●", "■" and "□" signs connected by dashed lines indicate the forecasts started from April, May, June, July 1997, respectively.

Fig.6 shows the predictions for the evolution tendency of NINO3 SSTA during 1998 by using the NCC model and six consecutive initial fields from August 1997 to January 1998, which was performed in March 1998. It can be seen that the warm event began to weaken after it reached its peak in December 1997. It was predicted that the warm event would maintain till June 1998, and the positive SSTA over the central and eastern equatorial Pacific Ocean would disappear and become zero or even negative in June and July 1998. From the ensemble forecasts of the tropical Pacific SSTA for April, July, and October 1998 at 3, 6, and 9 lead months (Fig.7), it can also be seen that the positive SSTA, which had lasted for one year, was dissipating and reversing to normal state gradually. Since April 1997, the positive SSTA of the central and eastern equatorial Pacific Ocean has weakened distinctly, the central value of which decreased from above 2°C in April 1997 to below –0.5°C in July 1998 (See Fig. 7a and 7b). Hereafter, SST kept on going down. By October 1998, most areas of the central and eastern equatorial Pacific Ocean have been controlled by negative SSTA with the minimum value below –1°C (Fig.7c), and NINO3 SST index has already been below –0.5°C (See Fig.6). Compared with observations (Fig.1 and Fig.3a), it is clear that not only the evolution and ending of 1997/1998 El Niño but also the beginning of 1998/1999 La Niña have been predicted successfully by using this model.

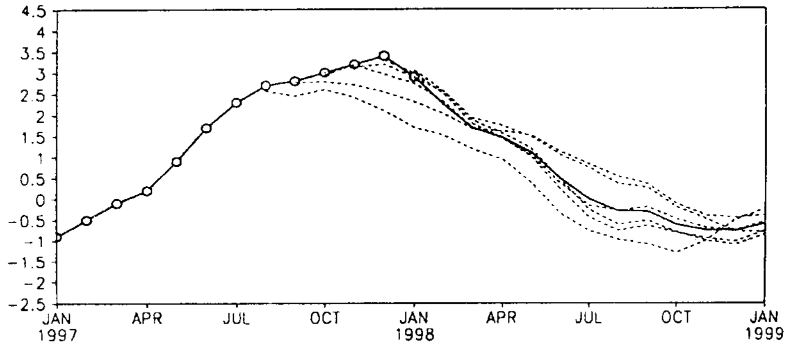

Fig.6 Predictions of Nino3 SSTA for 1998. The solid curve with "o" signs indicate observed SSTA . The dashed lines indicate the six consecutive forecasts started from August, September, October, November, December 1997 and January 1998. The ensemble mean of the six forecasts is shown by the thick solid curve.

4 VERIFICATION AND EVALUATION OF PREDICTION

One characteristic of NCC model is that its predictive skill is high in the 1990s[2]. Fig.8 shows the anomaly correlation coefficients (ACC) and root mean square errors (RMSE) between observations and the 3 and 6 lead months' predictions of NCC model for the 1997/1998 El Niño event (from April 1997 to June 1998). It can be seen that the skills of NCC model when predicting this warm event are all above 0.5 at 0 ~ 24 lead months. Moreover, as shown in Tab.1, compared with several contemporaneous and congeneric foreign models, such as BMRC, OXFORD1, OXFORD2, LDEO1, and LDEO2, RMSE in the NCC model is the smallest and its ACC the largest. So the forecast skill of NCC model is notably higher than that of other intermediate models when predicting the 1997/1998 El Nino event at 3 and 6 lead months.

Tab.1 Verification of predictions of tropical Pacific SSTA during the 1997/1998 warm episode by using intermediate ocean-atmospheric coupled models

Model	NCC	BMRC	OXFORD1	OXFORD2	LDEO1	LDEO2
ACC	0.77	0.70	0.26	0.50	-0.38	-0.48
RMSE	1.25	1.81	1.81	1.88	2.61	2.82

Note: Anomaly Correlation Coefficients (ACC) and Root Mean Square Errors (RMSE) of BMRC, OXFORD1, OXFORD2, LDEO1, LDEO2 model were calculated by using the 3.5 and 6.5 lead months' predictions of each model during Jun1996～Sept1998, respectively (See Bamston,A.G. and He,Y. 1998). ACC and RMSE of NCC model were calculated by using the 3 and 6 lead months' predictions of each model during June 1996～September 1998, respectively.

Tab.2 Test of 6-month lead forecast of NINO3 SSTA for 1997 and 1998

	El Niño			La Niña	
Model	Onset month	Peak month	Amplitude of peak	Ending month	Onset month
NCC	Aug. 1997	Dec. 1997	+3.8°C	June 1998	Oct. 1998
Observation	May 1997	Dec. 1997	+3.3°C	June 1998	Oct. 1998

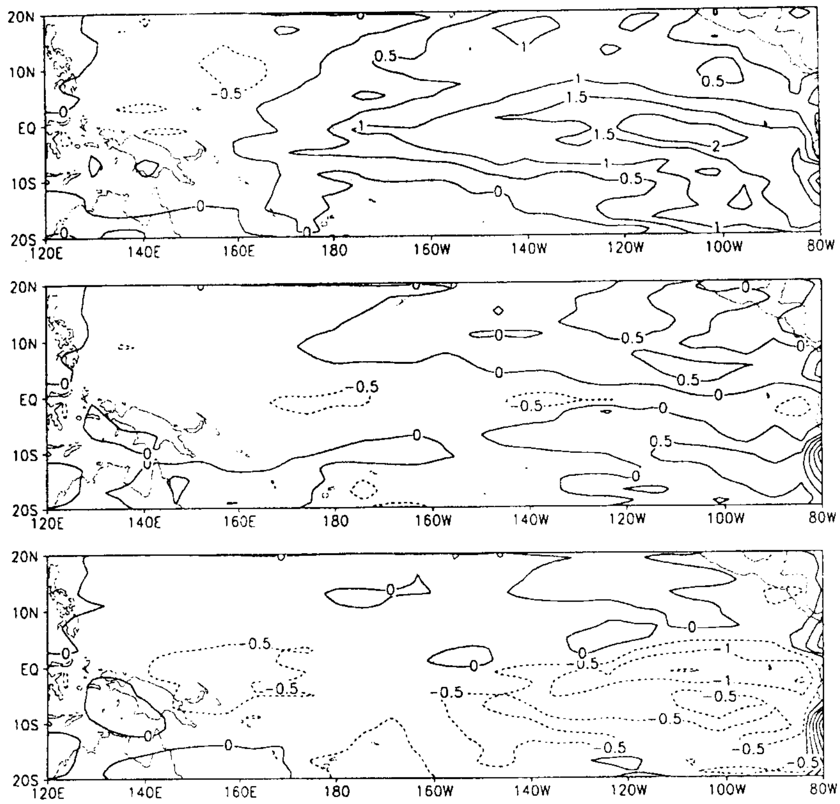

Fig.7 Forecasts of the tropical Pacific SSTA for 1998 at 3 month (top), 6 month (middle), 9 month (bottom) lead. Solid (dashed) contours indicate positive (negative) anomalies.

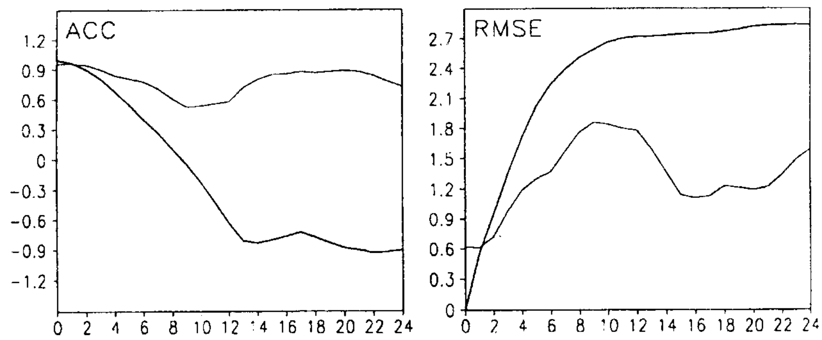

Fig.8 Anomaly correlation coefficients (ACC, left) and root mean square errors (RMSE, right) between model predictions and observations of NINO3 SSTA (thin solid curve) and those between persistence predictions and observations of NINO3 SSTA (thick solid curve) during the 1997～1998 warm episode.

However, as shown by the forecasting results in the third part, there are some departures between the predictions of NCC model and observations. For instance, according to the 6-month lead prediction for the NINO3 SSTA of the eastern equatorial Pacific Ocean (See Tab.2), the beginning time of the 1997-1998 warm event predicted by model (in August 1997) is 3 months later than observation (in May 1997), and the predicted peak value of the warm event is about 0.5°C higher than the observed one. So it is necessary to improve and refine the model continually in the future prediction practice.

5 CONCLUSIONS

a. The 1997/1998 El Niño event had distinct abnormality and particularity. It occurred, developed and ended rapidly and had great intensity. The increase of sea temperature appeared first on the coast of the South America and the equator near the dateline and then expanded towards the central part of the central equatorial Pacific, which differs from the simple "eastern pattern" or "western pattern" El Niño event that happened previously. In the mature phase of this warm episode, the center of the maximum positive SSTA was located in the eastern equatorial Pacific. The weakening of the western wind anomaly over the central equatorial Pacific, the eastward expanding of cold water that accumulated in the warm pool area, as well as the intensive development of negative SSTA in the central and eastern equatorial Pacific resulted in rapid decline of this warm episode.

b. By using an intermediate ocean-atmosphere coupled model over the tropical Pacific Ocean, the occurrence, evolution, and ending of the 1997/1998 El Niño event have been predicted reasonably. However, the prediction for the beginning phase of the El Niño event is not as good as the prediction for the mature phase. The verification of the model predictions and the comparisons with the contemporaneous and congeneric foreign models indicate that the model used here has the capability of predicting the variation tendency of El Niño and La Niña. The skills of this model in predicting the 1997/1998 warm event are all above 0.5 at 0 ~ 24 lead months.

However, there are some departures between the predictions of NCC model and observations. For example, the beginning time of the 1997-1998 warm event predicted by model is later than observation, and the predicted anomalies have deflections from observations. Moreover, the prediction for the western tropical Pacific SSTA is not as good as that for the central and eastern Pacific SSTA. Those issues, are related to the significant abnormality and particularity of the 1997/1998 warm episode on the one hand, and reflect the problems of the prediction model itself, on the other. Due to the highly parameterized and simplified physics in the intermediate ocean-atmosphere coupled model, the predictive skill and the forecast accuracy of this model are limited by not only its simplified physical process but also its initialization scheme and initial data. Some other issues, for instance, internal dynamics, initial and boundary condition, and forecast technique, etc., need to be taken into account for further improvement of the NCC model, so that the interannual variability of the tropical Pacific sea surface temperature can be predicted much better.

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