Article ID: 1006-8775(2006) 01-0067-09

THE IMPACT OF INITIAL FORCED WIND ON THE PREDICTABILITY OF THE ZEBIAK-CANE COUPLED OCEAN-ATMOSPHERE MODEL

YUE Cai-jun (岳彩军), **LU Wei-song** (陆维松), **LI Qing-quan** (李清泉)

(1. Shanghai Typhoon Institute, Shanghai 200030, China; 2. Department of Atmospheric Sciences, Nanjing University of Information Science and Technology, Nanjing 210044 China; 3. National Climate Center, Beijing 100081 China)

ABSTRACT: With simultaneous observed sea surface temperature anomaly (SSTA), the difference between NCEP/NCAR 925hPa reanalysis wind stress anomaly (NCEPWSA) and FSU wind stress anomaly (FSUWSA) is analyzed, and the prediction abilities of Zebiak-Cane coupled ocean-atmosphere model (ZC coupled model) with NCEPWSA and FSUWSA serving respectively as initialization wind are compared. The results are as follows. The distribution feature of NCEPWSA matches better with that of the observed SSTA than counterpart of FSUWSA both in 1980s and in 1990s; The ZC ocean model has a better skill under the forcing of NCEPWSA than that of FSUWSA, especially in 1990s. Meanwhile, the forecast abilities of the ZC coupled model in 1990s as well as in 1980s have been improved employing NCEPWSA as initialization wind instead of FSUWSA. Particularly, it succeeded in predicting 1997/1998 El Niño 6 to 8 months ahead; further analysis shows that on the antecedent and onset stages of the 1997/1998 El Niño event, the horizontal cold and warm distribution characteristics of the simulated SSTA from ZC ocean model, with NCEPWSA forcing compared to FSUWSA forcing, match better with counterparts of the corresponding observed SSTA, whereby providing better predication initialization conditions for ZC coupled model, which, in turn, is favorable to improve the forecast ability of the coupled model.

Key words: Zebiak-Cane coupled ocean-atmosphere model; initialization impact wind; prediction ability; effect

CLC number: P435 **Document code:** A

1 INTRODUCTION

In the past 20 years, the coupled ocean-atmosphere models with respect to ENSO events forecast have already made very great progress, among them, a moderate complicated model, such as the Zebiak-cane (ZC hereafter) coupled model[1], is widely used for the forecast of ENSO events and predictability study[2-9]. It is pointed out that the predictive skill of the ZC coupled model, whose initial forced wind was provided by the FSU wind stress anomaly (FSUWSA) data, obviously decreased after 1992, and it failed to forecast the strongest 1997/98 El Niño event in particular[10]. Chen et al.[7] pointed out that when the FSU wind stress was substituted by the NSCAT wind data in the process of initialization, the forecast performance of the ZC coupled model with respect to the 1997/98 El Niño event was greatly improved, mainly because the resolution of the NSCAT wind is higher than that of FSU wind over the southeast Pacific Ocean. As the time during which there are the NSCAT data is too short, however, this hinders the evaluation of its impact on the forecast skill of ZC coupled model during long time. The NCEP/ NCAR reanalysis data have the longer time record and are the model output on the base of assimilation[11]. Recently, Kug et al.[12] used a moderately complicated coupled model[13], which combines a ocean model and a statistic atmosphere model, to compare the two forecast skill of the coupled model for tropical Pacific SSTA with the initial forced wind supplied by the NCEP wind stress anomaly (NCEPWSA) and FSUWSA, respectively. The results

Received date: 2004-12-18; **revised date:** 2006-03-29

Foundation item: Natural Science Foundation of China (40275016); Science and Technology Development Project for the Shanghai Meteorological Bureau (0301)

Biography: YUE Cai-jun (1972-), male, native from Anhui Province, assistant researcher, Ph.D., mainly undertaking the forecasting and mechanism study on ENSO, heavy rain with the Mei-yu front and precipitation with landfall typhoons.

E-mail: yuecaijun2000@163.com

show that during 1980-1999 using NCEPESA as the initial forced wind, the forecast skill of the coupled model is greatly improved, particularly during 1992-1999. Owing to the above-mentioned reason, this paper will focus on the forecast performance of the ZC coupled model in the period of 1982-1999 and compare the difference of prediction ability of the ZC coupled model using the wind stress anomalies of NCEP and FSU as the initial forced wind field, with particular attention to the 1997/98 El Niño event, in order to find out what the impact of the initial forced wind is on the prediction ability of the ZC coupled model.

2 MODEL AND DATA

In the paper a simple coupled dynamical model developed by the Lamont- Doherty Earth observatory (LDEO) of Columbia University in USA, i.e. ZC coupled model, is used, which is mainly composed of the ZC ocean model and the ZC atmosphere model. In the ZC oceanic (atmospheric) component the horizontal area is 124°E-80°W and 29°S-29°N (from 101.25°E to 73.125°W and from 29°S to 29°N) with horizontal grid resolution of 2.0° long. by 0.5 ° lat. (5.625° long. by 2.0° lat.). The basic idea for model coupling to work is that the ocean is driven by anomalous wind stress and the atmosphere is forced by latent heat release. The latent heat release is a function of the wind convergence and SSTA and the two forces are nonlinear. The model integral time step is 10 days. The wind response, resulting from the atmosphere heated by SST, reaches the balance within 10 days and about a month is needed to reduce the feedback effect of the water vapor convergence. Since the coupled model is introduced in detail in the literature [14], here we would not give any description. The wind field data used in the paper include the NCEP/ NCAR reanalysis wind at 925 hPa and FSU wind.

The NCEP/ NCAR reanalysis mean monthly wind field data are provided by the atmospheric data service center of Nanjing University of Information Science and Technology from January 1948 to December 2000, its horizontal resolution is 2.5° long. by 2.5° lat. The FSU wind data from January 1961 to February 2002 are obtained from the LDEO climate database with the horizontal resolution 2° long. by 2° lat. The computational schemes of NCEP and FSU wind stress follow reference [12] and [14], respectively and the calculation of NCEPWSA and FSUWSA refer to literature [14]. The mean monthly sea surface temperature (SST) data from January 1970 to February 2002 are acquired from the database of LDEO with the horizontal resolution also 2° long. by 2° lat. and the area 124°E-70°W and 29°S-29°N. Since the SST data have always been used by LDEO, they are regarded as the observational SST. In addition, we consider the time span from January 1982 to December 1999 as a climate period in the study and regard the time interval from January 1982 to December 1989 as the 1980's and that from January 1990 to December 1999 as the 1990's. Moreover it is noted that we do not carry on any spatial and/or temporal smoothing for the above wind or SST data.

3 COMPARISON BETWEEN NCEPWSA AND FSUWSA

We first compare NCEPWSA and FSUWSA with the corresponding observational sea surface temperature anomaly (SSTA).

From the Figs.1a and 1b we know that as a whole the NCEP zonal wind stress anomaly is similar to that of FSU with regard to the distribution of time evolution along the equator, with obvious differences though. Compared with the time cross-section (Fig.2) of corresponding observational SSTA along the equator, we clearly see that the NCEPWSA is closer to the measurement of SSTA while the FSUWSA is worse and cannot be in equilibrium with the observational SSTA forcing during some time. For example, during the La Niña events in 1984/1985, 1988/1989 and 1998/1999, significant FSU west wind stress anomaly appear over the central and eastern Pacific Ocean, when the SSTA forcing is favorable for the creation of the east wind anomaly.

4 COMPARISON BETWEEN THE IMPACTS OF NCEPWSA AND FSUWSA ON THE INITIALIZATION OF ZC OCEAN MODEL

To find out the difference between the impacts of NCEPWSA and FSUWSA on the initialization of ZC ocean model, on the basis of the Niño3 index (the area is 120-80 °W, 5 °S-5 °N) measured from January 1982 to December 1999, i.e. Niño3O, we compare the Niño3N and Niño3F index, where the Niño3N (Niño3F) is a Niño3 index to describe the effect of NCEPWSA (FSUWSA) on the initialization of ZC ocean model, in order to pick up specific differences between the impacts of both on the initialization.

From Fig.3 we can know that the Niño3N can better represent the Niño3O than the Niño3F, for instance, from January 1988 to December 1988 and from January 1998 to December 1998, the Niño3N is very close to the Niño3O, while the Niño3F differs from Niño3O. Further we compute the correlation coefficient between the Niño3N and Niño3O and between the Niño3F and Niño3O, respectively, and find from January 1982 to December 1999, from January 1982 to December 1989 and from January

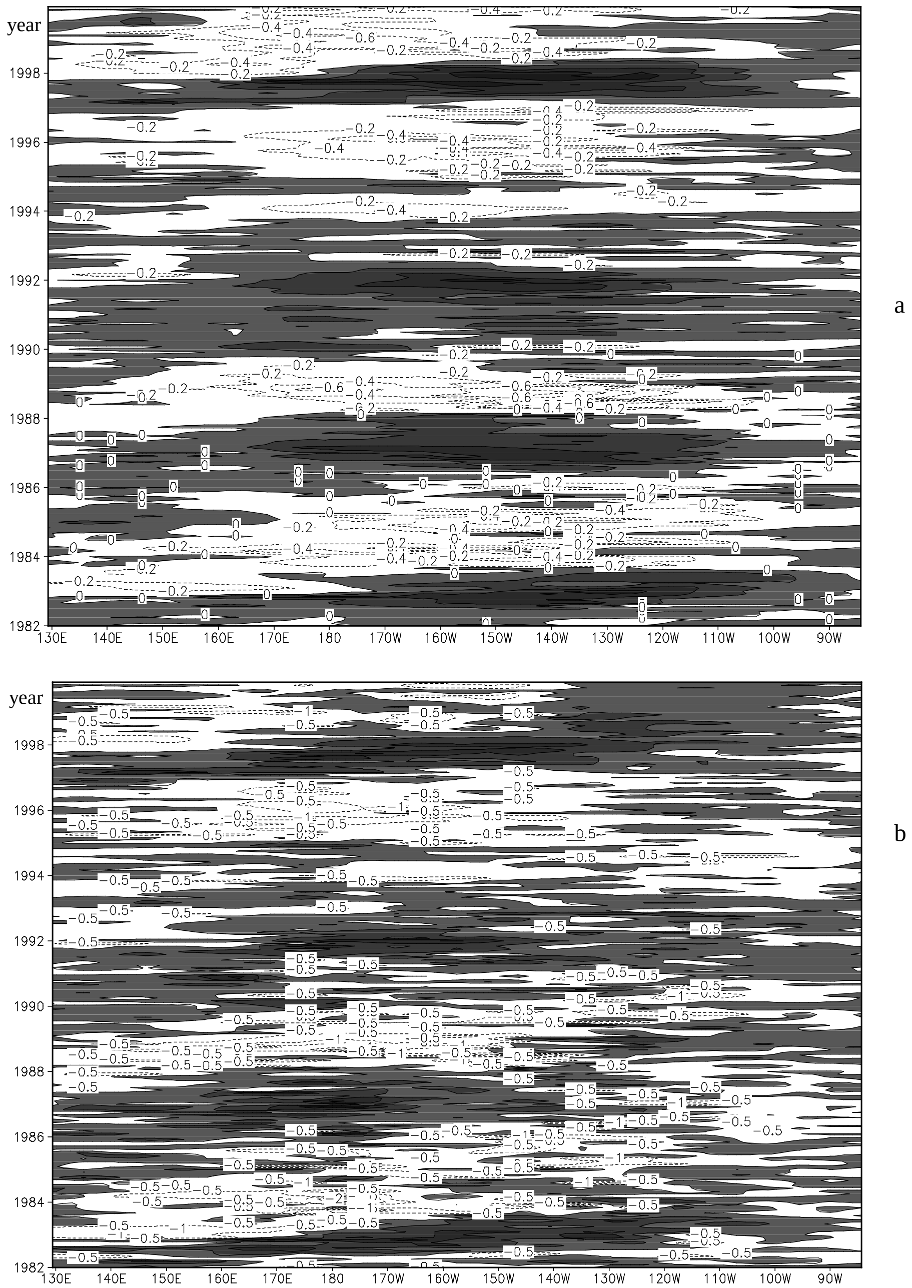

Fig.1 Time cross-section of zonal wind stress anomaly for NCEP (a) and FSU (b) along the equator from 1982 to 1999, the contour interval in (a) and (b) is 0.25 dyne/cm^2 and 0.5 dyne/cm^2, respectively, the shaded area between the solid lines indicates west wind stress anomaly, and the dashed line indicates east wind stress anomaly.

1990 to December 1999 the correlation coefficient between the Niño3N and Niño3O reaches 0.88, 0.85 and 0.90, respectively, while the correlation coefficient between the Niño3F and Niño3O arrives to 0.63, 0.73 and 0.53, respectively. The quantificational results show from January 1982 to December 1999 the impact of NCEPWSA on the initialization of ZC ocean model is obviously better than that of FSUWSA, in particular more obviously for the 1990's.

5 COMPARISON BETWEEN IMPACTS OF NCEPWSA AND FSUWSA ON THE ZC COUPLED MODEL

In section 3 and section 4 the obtained results show that the NCEPWSA is closer to the corresponding observed SSTA than the FSUWSA, and the former results in a better initialization of ZC ocean model than

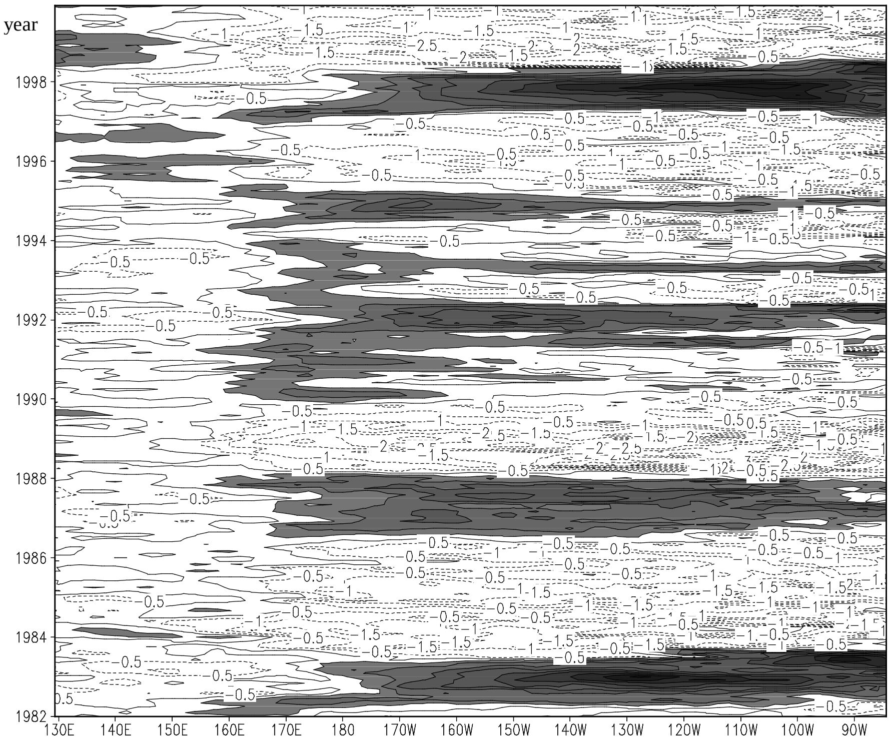

Fig.2 Time cross-section of the observed SSTA along the equator from 1982 to 1999, the solid (dashed) line indicates positive (negative) SSTA, the contour interval is 0.5℃, the shaded area shows that SSTA is not less than 0.5℃

the latter, particularly for the 1990's. Then, when the NCEPWSA and FSUWSA are used as initial forced wind of the ZC coupled model to forecast ENSO event, respectively, what is the difference? Next we will discuss it in detail.

5.1 Comparison between 1980's and 1990's

For the sake of the descriptive convenience, with the NCEPWSA (FSUWSA) used as the initial forced wind to forecast for 24 hours beginning from every month, the correlation coefficient and root mean square error between Niño3N (Niño3F) and the corresponding observed one is depicted as R1 (R2) and JFG1 (JFG2), respectively.

On the whole, whether from January 1982 to December 1989 or from January 1990 to December 1999, 0-16 months in advance, the R1 is obviously larger than the corresponding R2(Figs.4a1 & 4b1), while the JFG1 is remarkably smaller than JFG2 (Figs.4a2 & 4b2). This suggests that the forecast skill of the ZC coupled model with NCEPWSA instead of FSUWSA used as the initial forced wind is better. That is to say, in the 1980's as well as in the 1990's, as NCEPWSA instead of FSUWSA is used as the initial forced wind of ZC coupled model, the forecast skill of the model for ENSO events becomes obviously better.

5.2 Comparison with the 1997/1998 El Niño event

It is known to all that with the FSUWSA used as the initial forced wind of the ZC coupled model we fail to forecast the strongest and warmest event in last century, namely 1997/1998 El Niño event. Then when NCEPWSA is used as the initial forced wind, can the forecast skill for the event be improved? Next we will analyze it specifically.

According to the literature [15] we divide 1997/1998 El Niño event into 6 stages, namely, antecedent from August 1996 to October 1996, onset from November 1996 to January 1997, development from March 1997 to May 1997, transition from July 1997 to September 1997, mature from November 1997 to January 1998 and decay from February 1998 to April 1998. At the antecedent stage (Fig.5a), the forecast skill of the ZC coupled model with the NCEPWSA used as the initial forced wind for 1997/1998 El Niño event is much better than that with FSUWSA used as initial forced wind, the ensemble forecast of Niño3 by the former is very close to that of Niño3O, while Niño3F of the latter could not present the distributive state and amplitude of the Niño3O. Therefore, at the antecedent stage, if the NCEPWSA instead of FSUWSA is used as the initial forced wind of ZC coupled model, the forecast skill of the model for the 1997/1998 El Niño event can be greatly improved, and it can make the coupled model predict this warmer

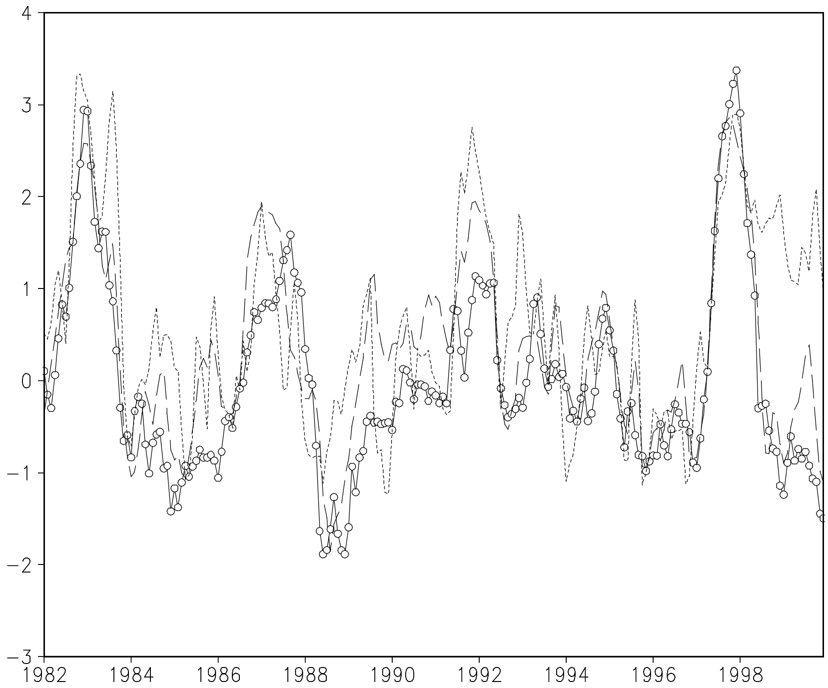

Fig.3 The Niño3N, Niño3F and Niño3O distribution from 1982 to 1999 (Unit: ℃), the solid line denotes the Niño3O, and the dashed line and dot line denote the Niño3N and Niño3F, respectively.

event 6-8 months ahead. At the onset stage (Fig.5b), with NCEPWSA used as the initial forced wind of ZC coupled model its forecast of the warmer event is successful, while with FSUWSA used as the initial forced wind the corresponding forecast is a failure. It also shows that at the onset stage with NCEPWSA instead of FSUWSA used as the initial forced wind, the forecast skill of the coupled model to 1997/1998 El Niño event can also be very significantly improved. For the development (Fig.5c) and transition (Fig.5d) stage, the El Niño event has already formally appeared and is quickly growing, beginning from each month at both stages with NCEPWSA or FSUWSA used as the initial forced wind, the ZC coupled model can forecast the time-varying trend and amplitude of the warmer event, and both forecast skills are basically comparable. At the mature (figures omitted) and decay (figures omitted) stages, the impacts of NCEPWSA and FSUWSA on the ZC coupled model are also comparable.

Therefore, in general, when the NCEPWSA is used as the initial forced wind, the ZC coupled model can predict the development trend and amplitude of the event very successfully for the time before and after the formal appearance of the 1997/1998 El Niño event. However, when FSUWSA is used as the initial forced wind, the model cannot predict the warmer event and even give the opposite phase before the El Niño event formally appears (at the antecedent or onset stage). In other words, the forecast of the warmer event is a failure. Only after the El Niño event formally appears, the model can predict the warmer event and its development trend. Obviously, before the warmer event formally appears, if NCEPWSA instead of FSUWSA is used as the initial forced wind of the ZC coupled model, it can predict the 1997/1998 El Niño event 6-8 months ahead. This also indicates that by improving the initial forced wind of the ZC coupled model, its forecast skills can be improved.

In section 5.1 and 5.2 of the paper the research results are similar to the conclusions of Kug et al.[12]. It shows that for the same coupled ocean-atmosphere model the different initial forced wind can have much different influence on the forecast skills of the model.

5.3 Discussion and analysis

Why can the ZC coupled model with NCEPWSA as initial forced wind successfully predict the 1997/1998 El Niño event before its formal appearance, i.e. at the antecedent and onset stage, while with FSUWSA as the initial forced wind it fails to forecast the event? Next we will carry out a specific analysis.

We know that for the ZC coupled model[1] to forecast the ENSO event, the unique external forced factor which can enter the forecast system is the wind stress anomaly which is used as the initialization of the ZC coupled ocean model. Therefore, the forecast skill of the ZC coupled model is closely associated with the wind, that is to say, the wind is an important factor which can enter the forecast system and influences the forecast skill of the coupled model. In fact, this problem is also very easily comprehended. If the wind, which is used as the initialization of the ocean model, has large error, the SSTA obtained from the initialization of the ocean model differs from the observation. The simulated SSTA with errors is used to drive the atmosphere model, thus the output model variables simulated from the atmosphere model also have errors, in the end these air-sea model variables with errors are used as the initial condition of the coupled model, so the forecast results of the coupled model will also produce errors. Generally speaking, as far as the same forecast model is concerned, two kinds of errors directly influence and determine the forecast result of the model: one is the system error of the model oneself, which is associated to the original design of the model; the other is the initialization error, which is close related with the initial condition of the model[16, 17]. For the interannual climate change phenomenon such as El Niño, some researchers tend to think that the initialization error has large effect on the predictability[17]. For the above-mentioned reason, we will emphasize on the analysis of the differences between mean NCEPWSA and FSUWSA and between mean SSTAs produced by NCEPWSA and FSUWSA as they drive the ocean model at the antecedent and onset stage of 1997/1998 El Niño event.

With regard to the comparison between NCEPWSA and FSUWSA, we only focus on analyzing the difference between both horizontal distributive characteristics (HDC); as for the amplitude (or strength) we do not make the comparison. Concerning the comparison between mean SSTAs produced by the ocean model with NCEPWSA and FSUWSA used as the initialization, called as SSTANM and SSTAFM, respectively, we compare the HDC and amplitude of both, at the same time each of them is separately compared with counterparts of mean corresponding observed SSTA (SSTAOM), in order to see which of SSTANM and SSTAFM is closer to the SSTAOM with respect to the HDC and amplitude?

At the antecedent stage (figures omitted), in

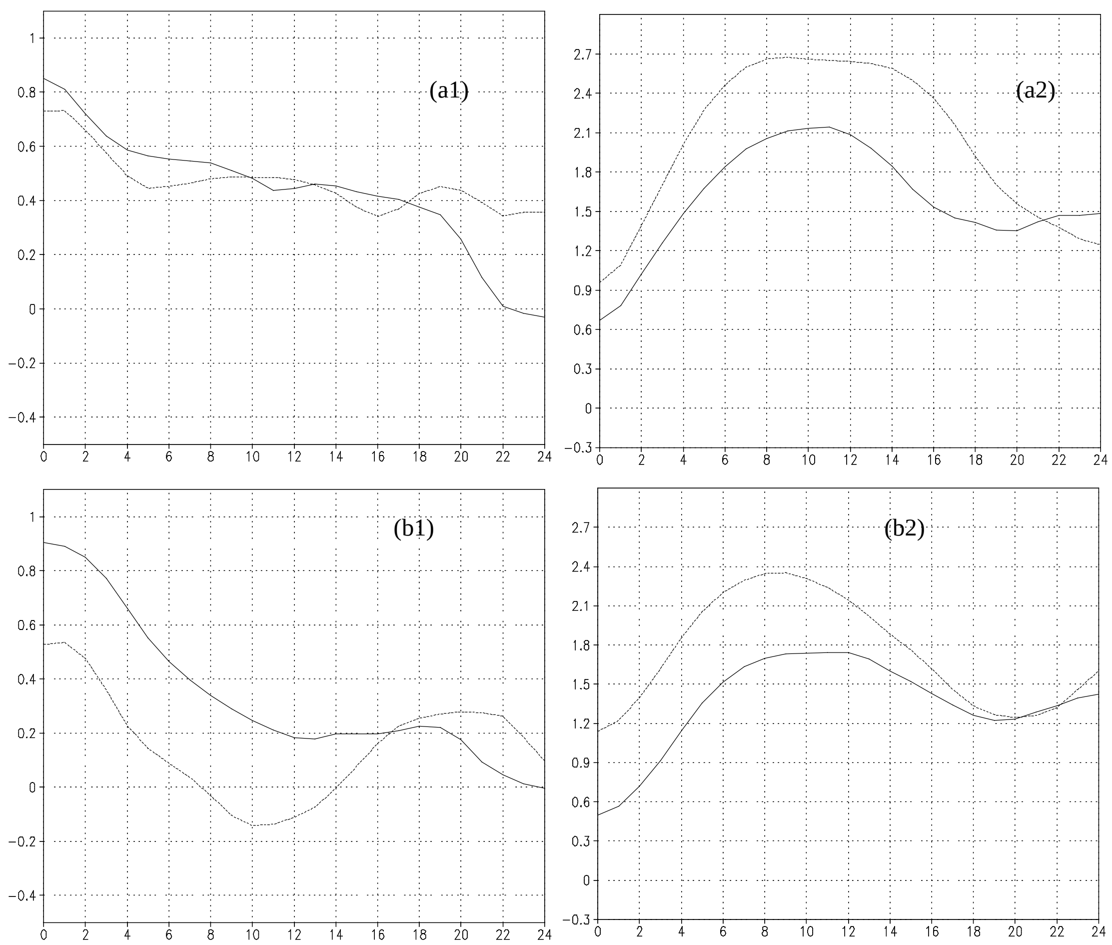

Fig.4 The correlation coefficient (left panel) and root mean square error (right panel) between Niño3N and Niño3O and between Niño3F and Niño3O, the solid line and dashed line denote the Niño3N and Niño3F, respectively. Here the time is from 1982 to 1989 in (a1) and (a2), from 1990 to 1999 in (b1) and (b2).

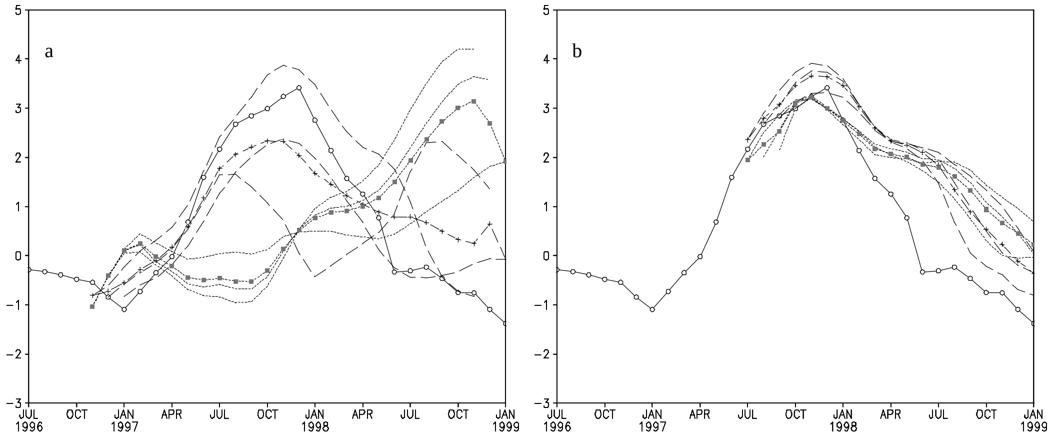

Fig.5 The Niño3N, the Niño3F and the Niño3O (Unit: ℃), the solid line denotes the Niño3O, the dashed line and dot line denote the Niño3N and Niño3F, respectively, here the time is from Aug. to Oct. 1996 in (a), from Nov. 1996 to Jan. 1997 in (b), from Mar. to May 1997 in (c), from Jul. to Sept. 1997 in (d).

general, the HDC difference between NCEPWSA and FSUWSA is obvious within 10° from the equator. With NCEPWSA and FSUWSA respectively used as the initialization, the mean SSTA produced by the ocean model has obvious difference not only in the HDC but also in the amplitude; the SSTAFM is colder than the SSTANM. The HDC of SSTANM is basically consistent with that of STAOM, which is cold in the

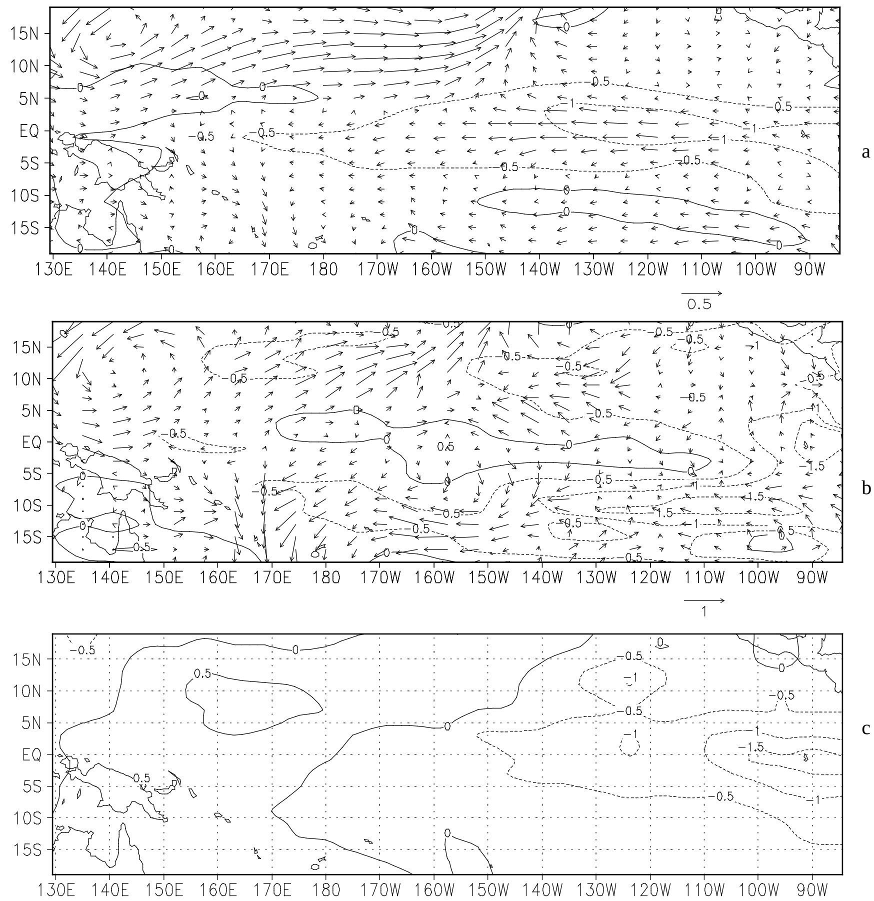

Fig.6 The mean wind stress anomaly (Unit: dyne/cm^2) and mean SSTA (Unit: ℃) at the onset stage of 1997/1998 El Niño event from Nov. 1996 to Jan. 1997, the NCEPWSA and FSUWSA and the corresponding mean SSTA simulated by the ocean model are plotted in (a) and (b), respectively, where the vector denotes the wind field, the contour denotes SSTA, and the solid (dashed) line indicates the positive (negative) SSTA, and the SSTAOM is plotted in (c), where the contour interval is 0.5 ℃.

east and warm in the west. However, the cold strength in the east and warm strength in the west of SSTANM are weaker than those of SSTAOM. As for the SSTAFM, its characteristic is that the cold SSTA covers almost the whole ocean surface. Differing from the cold-warm HDC of SSTAOM, the SSTAFM is much colder than the SSTAOM. In a word, the HDC of the SSTANM is closer to that of SSTAOM than that of SSTAFM.

At the onset stage, the HDC difference between mean NCEPWSA (Fig.6a) and FSUWSA (Fig.6b) is significant and mainly exists in two areas. One is from 150°W to the west and from 5°N to the north. NCEPWSA presents significant west wind stress anomaly, but the characteristic of FSUWSA in this region is not obvious; The other is from 160°W to 110°W and from 5°S to 5°N, NCEPWSA is covered by more significant east wind stress anomaly, but the HDC of FSUWSA in the region is not as significant. For the mean SSTANM (Fig.6a) and SSTAFM (Fig.6b), the cold-warm HDC difference between SSTANM and SSTAFM is very obvious. The cold-warm HDC of SSTANM is that from the dateline to the east and from 5°S to 5° N it is basically occupied by cold SSTA below -0.5℃, and from 150°E to the west the ocean surface is basically covered by warm SSTA above 0℃. But the HDC of SSTAFM differs from that of the former, with their cold-warm HDC being almost in the opposite phase. If each of them is compared with SSTAOM (Fig.6c), the clod-warm HDC of SSTANM is very similar to that of SSTAOM, and from 150°W to the east near equator the strengths of cold SSTA are very alike, only from 180° W to the west the simulated warm SSTA is weaker than the observed one. But the cold-warm HDC of SSTAFM differs from that of SSTAOM, for their cold-warm HDC is almost in the opposite phase. It is thus clear that at the onset stage not only the HDC difference between NCEPWSA and FSUWSA but also the cold-warm HDC difference between SSTAFM and SSTAFM are obvious. By further comparison with SSTAOM we discover that the cold-warm HDC and cold strength of SSTANM are very close to those of SSTAOM, however the cold-warm HDC difference between SSTAFM and SSTAOM is obvious and they are of opposite phase.

By the comparison between NCEPWSA and FSUWSA and between SSTANM and SSTAFM and between each simulated SSTA and the SSTAOM at the above-mentioned antecedent and onset stages we find that the HDC difference between NCEPWSA and FSUWSA and the cold-warm HDC difference between SSTAFM and SSTANM are also obvious. Compared with the SSTAOM, the cold-warm HDC of the SSTANM is closer to that of the SSTAOM than that of SSTAFM, thus it can provide a reasonable forecast initialization for the ZC coupled model, consequently its forecast skill can be improved.

6 CONCLUSIONS

(1) In the 1980’s and 1990’s the NCEPWSA is more consistent with the observed SSTA than the FSUWSA, and has better initialization of the ZC ocean model, particularly in 1990’s.

(2) In the 1980’s and 1990’s, the ZC coupled model has better forecast skill when the NCEPWSA instead of FSUWSA is used as the initial forced wind. In other words, if the initial forced wind is provided with NCEPWSA instead of FSUWSA, the forecast ability of the ZC coupled model will be improved.

(3) If the FSUWSA instead of NCEPWSA is used as the initial forced wind of the ZC coupled model, the coupled model can predict the 1997/1998 El Niño event the 6-8 months ahead.

(4) Further analysis shows that at the antecedent and onset stages of the 1997/1998 El Niño event there is the difference between the HDCs of NCEPWSA and FSUWSA, and the cold-warm HDC difference between SSTAFM and SSTANM is more obvious, and there is even a case of opposite phase. Compared with the SSTAOM, the cold-warm HDC of the SSTANM is closer to that of the SSTAOM than that of SSTAFM, providing a more reasonable forecast initialization for the ZC coupled model and thus improving its forecast skill.

In fact, the objective quantitative analysis in the text is not yet enough and a lot of quantitative statistic contrast of the case is also insufficient. They can limit the universal adaptability and stability of the conclusions.

Acknowledgement: We are whole-heartedly grateful to the Lamont- Doherty Earth observatory (LDEO) of Columbia University in USA for the FSU wind data and the sea surface temperature data, the atmosphere data service center of the Nanjing University of Information Science and Technology for the NCEP/ NCAR reanalysis wind data, Professor Cane and Doctor Zebiak in the LDEO center for the coupled model (version 1987) and Professor QIAN Wei-hong in Peking University for his help.

REFERENCES

[1] ZEBIAK S E, CANE M A. A model El Nino-Southern oscillation [J]. Monthly Weather Review, 1987, 115(10): 2262-2278.
[2] CANE M A, ZEBIAK S E, DOLAN S C. Experimental forecasts of El Nino [J]. Nature, 1986, 321(26): 827-832.
[3] BATTISTI D S. Dynamics and thermodynamics of a warming event in a coupled tropical atmosphere-ocean model [J]. Journal of Atmospheric Sciences, 1988, 45(20): 2889-

2819.
[4] GOSWAMI B N, SHUKLA J. Predictability of a coupled ocean-atmosphere model [J]. Journal of Climate, 1991, 4(1): 3-22.
[5] CHEN D, ZEBIAK S E, CANE M A. Initialization and predictability of a coupled ENSO forecast model [J]. Monthly Weather Review, 1997, 125(5): 773-788.
[6] CHEN D, CANE M A, ZEBIAK S E, et al. The impact of sea level data assimilation on the Lamont model prediction of the 1997/1998 El Nino [J]. Geophysical Research Letters, 1998, 25(15): 2837-2840.
[7] CHEN D, CANE M A, ZEBIAK S E. The impact of NSCAT winds on predicting the 1997/1998 El Nino: A study with the Lamont model [J]. Journal of Geophysical Research, 1999, 104(C5): 11321-11327.
[8] ZHANG Zu-qiang, ZHAO Zong-ci, YU Zhan-jiang. Modification of the simplified coupled model for ENSO [J]. Journal of Tropical Meteorology, 2004, 20(4): 337-345.
[9] YUE Cai-jun, LU Wei-song, LI Qing-quan, et al. The advances on the research of Zebiak-Cane ocean-atmosphere coupled model [J]. Journal of Tropical Meteorology, 2004, 20(6): 723-730.
[10] LI Q Q, ZHAO Z C, DING Y H. Prediction and verification of the 1997-1999 El Nino and La Nina by using an intermediate ocean-atmosphere coupled mode [J]. Acta Meteorologica Sinica, 2001, 15(2): 144-159.
[11] KALNAY E, COAUTHORS. The NCEP/NCAR 40-year reanalysis project [J]. Bulletin of American Meteorological Society, 1996, 77(3): 437-472.
[12] KUG J S, KANG I S, ZEBIAK S E. The impacts of the model assimilated wind stress data in the initialization of an intermediate ocean and the ENSO predictability [J]. Geophysical Research Letters, 2001, 28(19): 3713-3716.
[13] KANG I S, KUG J S. An El Nino prediction system using an intermediate ocean and a statistical atmosphere [J]. Geophysical Research Letters, 2000, 27(8): 1167-1170.
[14] ZEBIAK S E. Tropical atmosphere-ocean interaction and the El Niño /Southern Oscillation phenomenon D]. Cambridge: Massachusetts Institute of Technology, 1984.
[15] WANG C, WEISBERG R H. The 1997-98 El Niño evolution relative to previous El Niño events [J]. Journal of Climate, 2000, 13(2): 488-501.
[16] BLUMENTHAL M B. Predictability of a coupled ocean-atmosphere model [J]. Journal of Climate, 1991, 4(8): 766-784..
[17] MU M, DUAN W S, WAN J C. The predictability problems in numerical weather and climate prediction [J]. Advances in Atmospheric Sciences, 2002, 19(2): 191-204.