Vol.16 No.1 JOURNAL OF TROPICAL METEOROLOGY March 2010

Article ID: 1006-8775(2010) 01-0010-10

A STUDY ON THE IMPACTS OF LATENT HEAT PARAMETERIZATION SCHEME ON PREDICTION SKILL OF ENSO WITH A SIMPLE OCEAN-ATMOSPHERE COUPLED MODEL

YUE Cai-jun(岳彩军)[1, 2], LU Wei-song(陆维松)[3], Xiaofan LI (李小凡)[4]

(1. Shanghai Typhoon Institute of the China Meteorological Administration, Shanghai 200030 China; 2. Laboratory of Typhoon Forecast Technique/CMA, Shanghai 200030 China; 3. School of Atmospheric Sciences, Nanjing University of Information Science and Technology, Nanjing 210044 China; 4. Joint Center for Satellite Data Assimilation and NOAA/NESDIS/Center for Satellite Applications and Research Camp Springs, Maryland, USA)

Abstract: This study revises Weare's latent heat parameterization scheme and conducts an associated theoretic analysis. The revised Weare's scheme is found to present potentially better results than Zebiak's scheme. The Zebiak-Cane coupled ocean-atmosphere model, initialized by the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) reanalysis of wind stress anomaly at 925 hPa, is referred to as the ZCW coupled model. The atmosphere models of the ZCW coupled model that use Zebiak's scheme and the revised Weare's scheme are referred to as the ZCW_0 and ZCW_N atmosphere models, respectively. The coupled ocean-atmosphere models that use Zebiak's scheme and the revised Weare's scheme are referred to as the $ZCW_0$and ZCW_N coupled models, respectively. The simulations between the ZCW_0 and ZCW_N atmosphere models and between the ZCW_0 and ZCW_N coupled models are analyzed. The results include: (1) The evolution of heat, meridional wind and divergence anomalies simulated by similar ZCW_0 and ZCW_N atmosphere models, although the magnitudes of the former are larger than those of the latter; (2) The prediction skill of the Niño3 index from 1982 to 1999 by the ZCW_N coupled model shows improvement compared with those by the ZCW_0 coupled model; (3) The analysis of El Niño events in 1982/1983, 1986/1987, and 1997/1998 and La Niña events in 1984/1985, 1988/1989, and 1998/2000 suggests that the ZCW_N coupled model is better than the ZCW_0 coupled model in predicting warm event evolution and cold event generation. The results also show the disadvantage of the ZCW_N coupled model for predicting El Niño.

Key words: Zebiak-Cane ocean-atmosphere coupled model; ENSO; latent heat parameterization scheme

CLC number: P435 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2010.01.002

1 INTRODUCTION

The Zebiak-Cane ocean-atmosphere coupled model[1] (ZC coupled model) developed by the Lamont-Doherty Earth Observatory (LDEO), Columbia University, USA in 1980 has been used to study and predict El Niño-Southern Oscillation (ENSO) events. Generally, two factors affect model prediction skill, one from the errors of the initial conditions and the other from a systematic bias of the model itself[2, 3]. Chen et al.[4-8], Qian et al.[9, 10], Li et al.[11, 12], and Duan et al.[13] conducted studies on improving the ZC coupled model, which is summarized in Yue et al.[14]. Recently, Yue et al.[15] conducted ZC coupled model experiments by replacing Florida State University (FSU) wind stress anomaly with NCEP/NCAR reanalysis wind stress anomaly at 925 hPa. They improved the prediction of ENSO events in the 1980s and the 1990s, particularly in the successful forecast of the ENSO event in 1997/1998, which was the strongest of the last century. This indicates that the NCEP wind stress anomaly as the initial force in the ZC coupled model

Received date: 2009-03-02; **revised date:** 2009-09-22
Foundation item: National Natural Science Foundation of China (40875025, 40875030, 40775033), Shanghai Natural Science Foundation of China (08ZR1422900), Key Promotion Project of New Meteorology Technology of the China Meteorological Administration in 2009 (09A13).
Biography: YUE Cai-jun, assistant professor, Ph.D., mainly undertaking the research on ocean-atmosphere interaction and mesoscale dynamics.
E-mail for correspondence author: yuecaijun2000@163.com

(ZCW coupled model hereafter) has effectively improved its prediction skill. Yue et al.[16] also conducted an overall evaluation of the prediction skills of the ZCW coupled model. One advantage of the ZC coupled model is its use of a simple physics package[11, 17].

The atmosphere model of the ZC coupled model is a single-layer shallow water model[18]; thus, the latent heat in the model is calculated with the parameterization scheme[19, 20]. In the parameterization scheme, latent heat is estimated with water vapor convergence in the lower troposphere[21-23]. The lower-tropospheric moisture anomaly favors atmospheric instability and enhances convective development and associated latent heat. Thus, the lower-tropospheric moisture convergence apparently leads to atmospheric latent heat release. The water vapor convergence also relies on circulations and their convergence. The wind convergence is used to parameterize atmospheric latent heat. However, early studies[24-27] revealed that cumulus heating does not result from lower-tropospheric wind convergence (at time scales shorter than one week), since the peak of cumulus heating usually occurs in the upper troposphere and associated vertical motions weaken dramatically downward. The atmospheric latent heat does not necessarily respond to the lower-tropospheric wind convergence. The lower-tropospheric wind convergence does not mean atmospheric latent heat. This implies that the wind convergence and latent heat do not have a one-to-one relationship; thus, the parameterization of latent heat with wind convergence may not be logical. The failure of assumptions used in the latent heat parameterization scheme of the ZC coupled model may be a factor that lowers its prediction skill[28-30]. To address this important issue, the new latent heat parameterization scheme will be introduced into the atmosphere model of the ZCW coupled model to examine the impacts of latent heat parameterization scheme on the prediction skill of the ZCW coupled model.

2 MODEL AND EXPERIMENTS

The simple coupled dynamic model (ZC coupled model) developed by LDEO, Columbia University, USA, mainly comprises a ZC ocean model and a ZC atmosphere model. The ZC ocean model domain covers 124°E – 80°W, 29°S – 29°N, and the horizontal resolution of longitude by latitude is 2.0°×0.5°. The ZC atmosphere model domain covers 101.25°E – 73.125°W, 29°S – 29°N, and the horizontal resolution of longitude by latitude is 5.625°×2.0°. In the coupled system, the ocean is driven by anomalous wind stress and the atmosphere is forced by latent heat. Latent heat is a function of wind convergence and sea surface temperature anomalies (SSTA). The two forcing terms are nonlinear. The time step of model integration is 10 d. The wind responses to the atmosphere heated by sea surface temperature (SST) reach an equilibrium state within 10 d, whereas the decay of the water vapor convergence's feedback needs about one month. The detailed coupled model can be found in Zebiak[19]. There are three steps in predicting the ZC coupled model. First, the ZC ocean model is integrated to the initial forecast time to get initial ocean anomalies in response to external wind stress anomaly. Second, the SSTA is used to force the ZC atmosphere model to generate atmospheric anomalies for the initial forecast time. Finally, the constructed anomalies from both ocean and atmosphere models are used in the coupled model as the initial conditions to make predictions.

NCEP/NCAR reanalysis monthly mean wind stress data with a horizontal resolution of 2.5°×2.5° are provided by the Service Center for Atmospheric Data, Nanjing University of Information Science and Technology. The calculation of NCEP/NCAR reanalysis wind stress can be referred to Kug et al.[31], and the calculation of wind stress anomaly can be referred to Zebiak[19]. The ZC coupled model subject to the initial forcing of NCEP/NCAR reanalysis wind stress anomaly at 925 hPa is called the ZCW coupled model. Correspondingly, the ZC ocean and atmospheric models are called ZCW ocean and atmospheric models, respectively. Monthly mean SST data are from the LDEO Data Center, and its horizontal resolution and cover are 2°×2° and 124°E – 70°W, 29°S – 29°N, respectively. The data are regarded as the observed SST data.

3 LATENT HEAT PARAMETERIZATION SCHEMES

3.1 *Zebiak's latent heat parameterization scheme*

The latent heat parameterization scheme in the ZCW atmosphere model was originally developed by Zebiak[19, 20] (Zebiak scheme, hereafter) based on the water vapor convergence in the lower troposphere. The scheme can be expressed by

$$\dot{Q}_1 = \beta[M(\bar{C}+C) - M(\bar{C})], \quad (1)$$

$$C = -[\left(\frac{\partial u_a}{\partial x}\right) + \left(\frac{\partial v_a}{\partial y}\right)], \quad (2)$$

$$M(x) = \begin{cases} 0, x \le 0 \\ x, x > 0 \end{cases}, \quad (3)$$

where, β is the exchange coefficient, u_a and v_a are the zonal and meridional wind anomalies over the ocean surface, respectively, C is the wind convergence anomaly over the ocean surface, and $\overline{C}$ is the climatologic mean of wind convergence over the ocean surface. The feedback of water vapor convergence is nonlinear because the latent heat occurs only when the wind converges. Thus, the calculation relies on both anomaly and climatologic means of wind convergence.

3.2 *Revised Weare's latent heat parameterization scheme*

Latent heat consists of large-scale condensational heat in stable atmosphere and meso- and small-scale condensational heat during convective development. The latent heat release is associated with surface rainfall. Thus, latent heat can be estimated with rainfall amount. Weare[32, 33] estimated latent heat by analyzing water vapor budget with the assumption that precipitation amount is evaporation minus water vapor convergence. Latent heat is the rainfall amount multiplied by condensational heat factor.

$$A = \beta L \rho_a C_E [|\overline{U}|(q_s(T_a') - q') + |\vec{V}'|(q_s(\overline{T}_a) - \overline{q})], \quad (4)$$

$$B = \beta L \lambda [\overline{U}\frac{\partial q'}{\partial x} + \overline{q}\nabla \cdot \vec{V}' + \vec{V}' \cdot \nabla \overline{q}]. \quad (5)$$

The latent heat anomaly is $Q' = A - B$ when $A>B$, otherwise, Q' = 0. When evaporation is larger than water vapor convergence, the atmosphere moistens, rainfall occurs, and latent heat is released. Water vapor convergence seems to meet this condition. When evaporation is equal to or less than water vapor convergence, atmospheric moistening, rainfall, and latent heating do not occur.

In Eq. (4), $|\vec{V}'| = [(\overline{U} + U')^2 + V'^2]^{1/2} - |\overline{U}| \cdot \alpha$, α = 0.5. To adjust the wind anomaly over the ocean surface to the wind anomaly observed in the tropical Pacific, L(= 2.45×10^6 Jkg^{-1}) is the condensation coefficient; C_E(= 1.4×10^{-3}) is an exchange coefficient for evaporation; β (= 0.5) is a heating factor to excite the first baroclinic mode; λ (= 600 kgm^{-2}) is the "equivalent height" of water vapor convergence; $\overline{U}$ (= -5 m s^{-1}) is the wind speed of the basic state over the ocean surface; and $q = \overline{q} + q'$, $q_s(\overline{T}_a + T_a') = q_s(\overline{T}_a) + q_s(T_a')$, $T_o = \overline{T}_o + T_o'$, $T_a = \overline{T}_a + T_a'$, where the overbar denotes the climatologic mean and the prime is the anomaly.

In this study, the following relations are used.

1. From Kleeman[28], $T_a = T_o - 1.5$ °C, $\overline{T}_a = \overline{T}_o - 1.5$ °C.

2. From David and Held[34] and Kleeman[28], $q = 0.8 q_s$, $\overline{q} = 0.8\overline{q}_s$.

3. From Moor and Kleeman[35], $\overline{q}_s = q_s(\overline{T}_a)$, $\overline{q} = 0.8 q_s(\overline{T}_a)$.

4. From Ding[36], $q_s = \dfrac{0.622 e_s}{P - 0.378 e_s}$, $e_s = 6.11\exp[\dfrac{a(T-273.16)}{(T-b)}]$, a = 17.1543, b = 36, P = 925 hPa, $T = T_a$.

5. The constraint that rainfall occurs only if the wind converges from the original parameterization scheme used in the ZCW atmosphere model is valid in this study.

6. The climatologic mean of ocean surface temperature in the original ZCW coupled model uses the average from 1982 to 1999 in calculating atmospheric latent heat.

Note that these relations are different from those used by Weare[32, 33]. This revised scheme will be referred to as the revised Weare scheme in subsequent discussions. For consistency of unit, β = 0.0012. For convenience, the ZCW atmosphere (coupled) models with Zebiak's scheme and the revised Weare's schemes are referred to as ZCW_0 and ZCW_N atmosphere (coupled) models, respectively.

In Zebiak's scheme, the anomalous wind convergence leads to latent heat release under the condition that the total wind converges. Thus, the latent heat may not respond to wind convergence. This suggests that the results may not be good when atmospheric latent heat is parameterized by wind convergence. In the revised Weare's scheme, rainfall occurs and associated latent heat is released when the total wind converges and the evaporation is larger than water vapor convergence.

4 COMPARISON BETWEEN SIMULATIONS OF ZCW_0 AND ZCW_N ATMOSPHERE MODELS

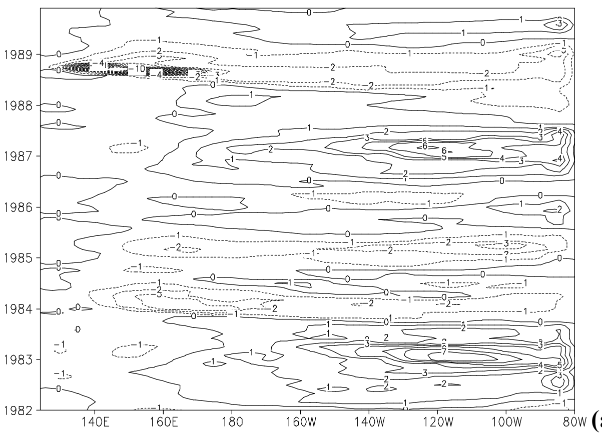
The ocean model of the ZCW coupled model (ZCW ocean model hereafter) is first forced by the NCEP wind stress anomaly from January 1964 to December 1999. SSTA from the simulation of the ZCW ocean model is then used to force ZCW_0 and ZCW_N atmosphere models from January 1970 to December 1999. The simulation data of ZCW_0 and ZCW_N atmosphere models from January 1982 to December 1999 are analyzed and compared in terms of the anomalies of heating, zonal wind, meridional wind, and divergence.

During the 1980s and 1990s, the heating anomalies simulated by the ZCW_0 and ZCW_N atmosphere models show similar evolution (Fig. 1). Positive heating anomalies occur in warm events (El Niño events in 1982/1983, 1986/1987, 1991/1992, and 1997/1998), whereas negative heating anomalies appear in cold events (La Niña events in 1984/1985, 1988/1989, and 1998/2000). The magnitudes of heating anomalies simulated by the ZCW_N atmosphere model are smaller than those simulated by the ZCW_0 atmosphere model. The evolution of heating anomalies is similar to that of SSTA simulated by the ZCW ocean model (not shown). The anomalies of zonal winds simulated by the ZCW_0 and ZCW_N atmosphere models also show similar evolution (not shown). Westerly wind anomalies are associated with warm events, while easterly wind anomalies are associated with cold events. The magnitudes of zonal wind anomalies simulated by the ZCW_N atmosphere model are smaller than those simulated by the ZCW_0 atmosphere model. The anomalies of meridional winds and divergence simulated by both the atmosphere models display similar evolution (not shown), but their magnitudes simulated by the ZCW_N atmosphere model are smaller than those simulated by the ZCW_0 atmosphere model.

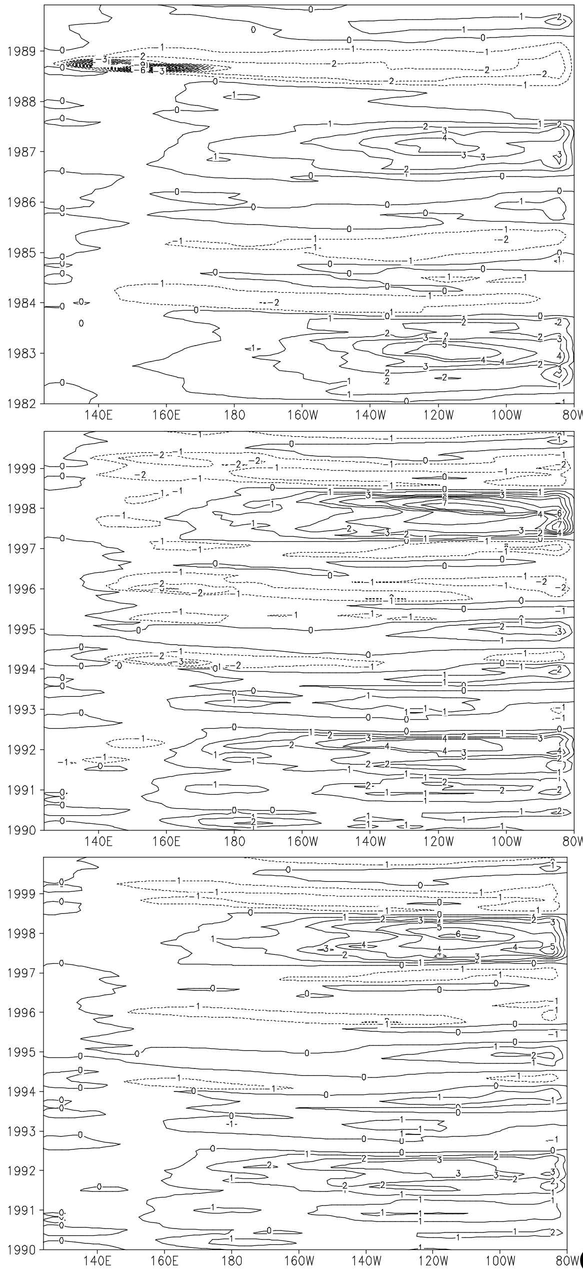
5 COMPARISON BETWEEN PREDICTION SKILLS OF ZCW_0 AND ZCW_N COUPLED MODELS

5.1 *1980s and 1990s*

Figure 2 shows Niño3 indices based on 24-month predictions by the ZCW_0 and ZCW_N coupled models from January 1982 to December 1999, compared with the observations by the correlation coefficients (R_0 and R_N) and root mean square (RMS) differences (RMS_0 and RMS_N). R_N is larger than R_0, whereas RMS_N is smaller than RMS_0. This indicates that the prediction skills of the Niño3 index by the ZCW_N coupled model are higher than those by the ZCW_0 coupled model. The detailed comparison between the prediction skills of ZCW_0 and ZCW_N coupled models will be conducted in terms of typical warm and cold events occurring in the 1980s and 1990s.



(a1)



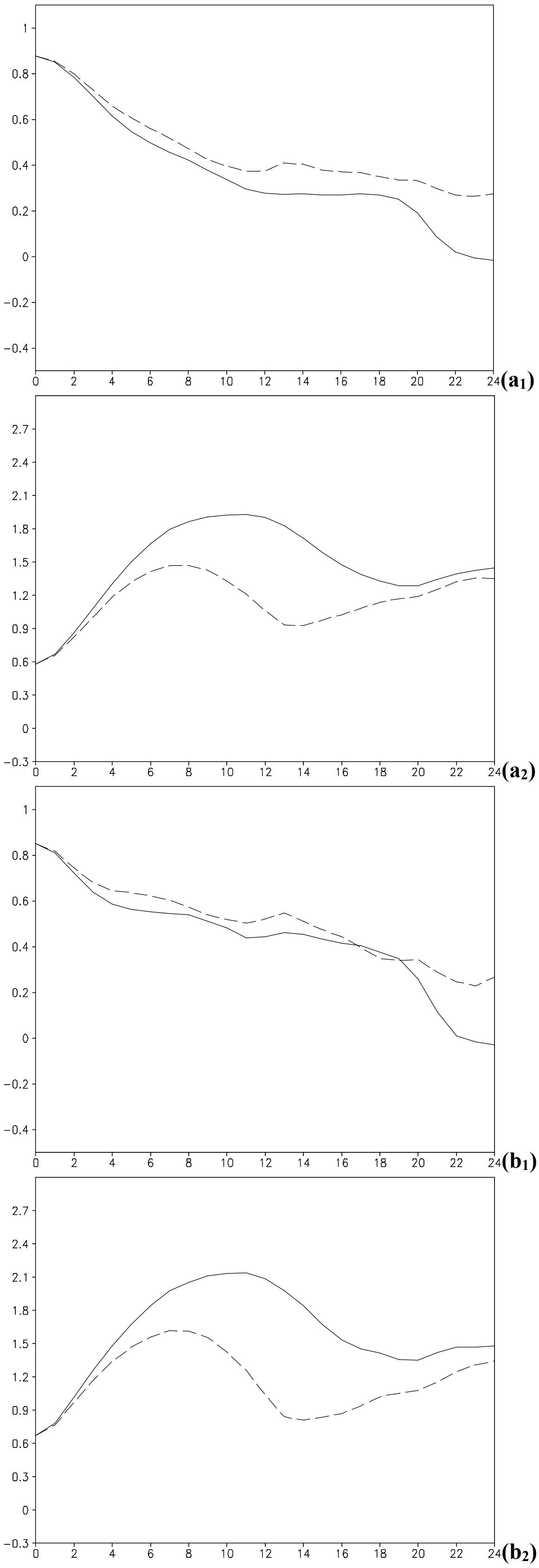
(a2) (b1) (b2)

Fig.1 Heating anomalies simulated by ZCW_0 [(a1)(b1)] and ZCW_N [(a2)(b2)] in $(a_1)(a_2)$ 1982-1989 and $(b_1)(b_2)$ 1990-1999. The contour interval is 1. Positive and negative values denote anomalies of atmospheric heat gain and loss, respectively. The unit is dimensionless.

5.2 *Analysis of ENSO events*

Three strong warm events occurred during 1982－1999 (May 1982－September 1983, September 1986－January 1988, April 1997－May 1998), and three strong cold events followed these warm events (October 1984－October 1985, April 1988－May 1989, October 1998－March 2000)[37]. The differences in prediction skills of warm and cold events by the ZCW_0 and ZCW_N coupled models will be analyzed next. For convenience, the Niño3 indices averaged from the ensemble forecast by the ZCW_0 and ZCW_N

coupled model (using six consecutive months as the initial month) are referred to as Niño3F and Niño3N, respectively. The observed Niño3 index is Niño3O.



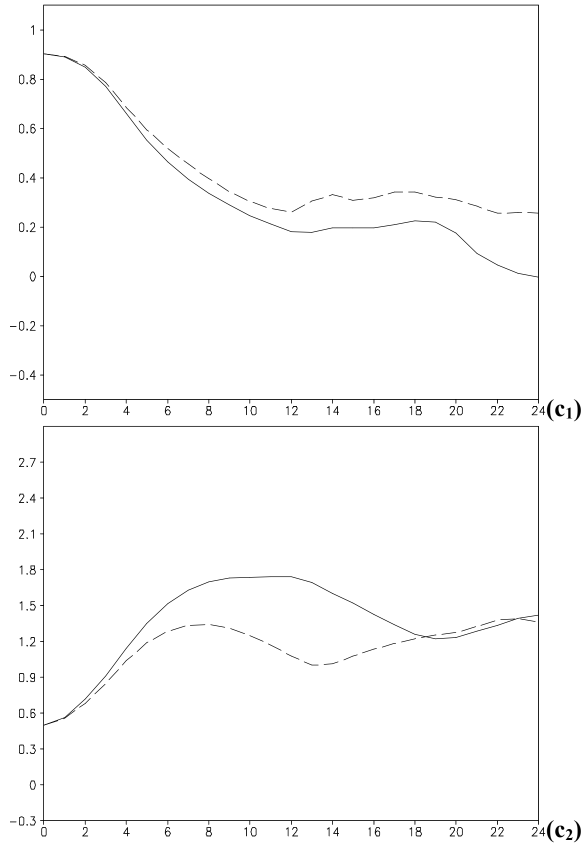


Fig.2 Correlation coefficients [(a1)-(c1)]) and RMS differences [(a2)-(c2)] between predicted Niño3 indices from coupled model and observations in (a_1) (a_2) 1982-1999, (b_1) (b_2) 1982-1989, and (c1) (c2) 1990-1999. Solid and dashed lines denote predictions from ZCW_0 and ZCW_N coupled models, respectively.

During the 1982/1983 El Niño event (Fig. 3), the ZCW_N coupled model showed better improvement compared with the ZCW_0 coupled model. For the 1984/1985 La Niña event, the ensemble forecast by the ZCW_N coupled model during February 1983 – July 1983 and August 1983 – January 1984 predicted this cold event, particularly the ensemble forecast made during August 1983 – January 1984, in both occurrence and magnitude. In contrast, the Niño3 index averaged by the ensemble forecast by the ZCW_0 coupled model is larger than the observed index; the model did not predict the 1984/1985 La Niña event.

Figure 4 shows that both ZCW_0 and ZCW_N have similar prediction skills for evolution after the 1986/1987 El Niño occurrence. However, the ZCW_N coupled model made a better forecast for the decay phase of the event than the ZCW_0 coupled model. Specifically, the ZCW_N coupled model successfully predicted the 1988/1989 La Niña event, while the ZCW_0 failed to predict it.

Both ZCW_0 and ZCW_N have similar prediction skills for evolution after the 1997/1998 El Niño occurrence (figure omitted). However, the prediction skill for the decay phase of the event by the ZCW_N coupled model is better than that by the ZCW_0 coupled model. The ZCW_N coupled model during August 1998 –January 1999 successfully predicted the 1998/2000 La Niña event, while the ZCW_0 failed to predict it.

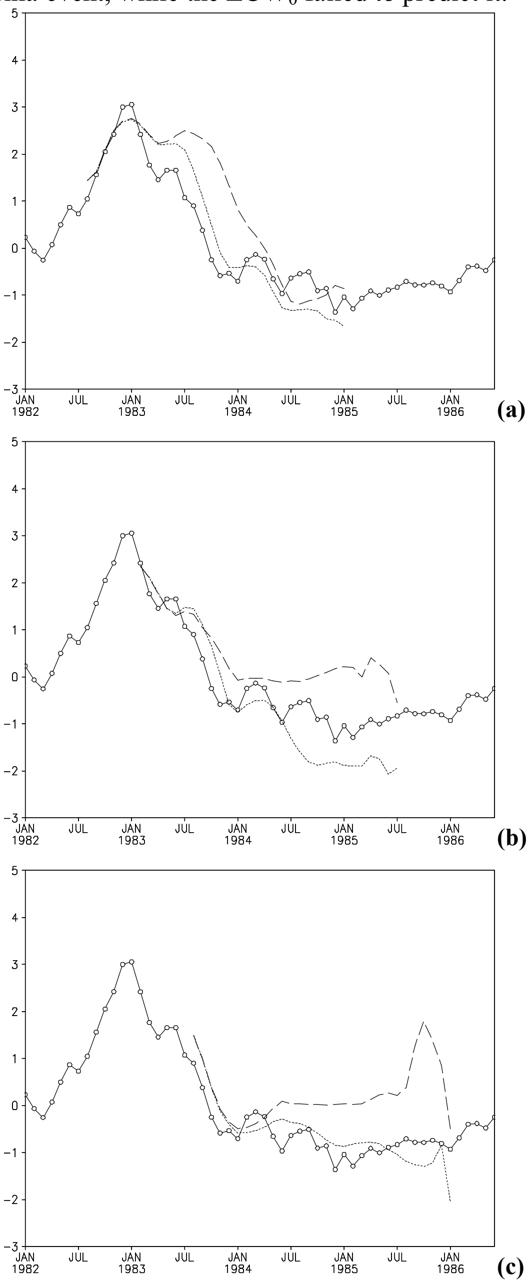


Fig.3 Niño3 (°C) indices from observations and ensemble mean predicted by the models initialized in (a) August 1982-January 1983, (b) February-July 1983, and (c) August 1983-January 1984. Solid, dashed, and dotted lines denote Niño3O, Niño3N, and Niño3F, respectively.

The ZCW_N coupled model has better prediction skill for warm events after the occurrence of an El Niño event than the ZCW_0 coupled model. Specifically, for the prediction skill of La Niña events after the occurrence of an El Niño event, the ZCW_N coupled model has better improvement on the evolution and strengths of cold events. The ZCW_0 coupled model failed to make a reasonable forecast.

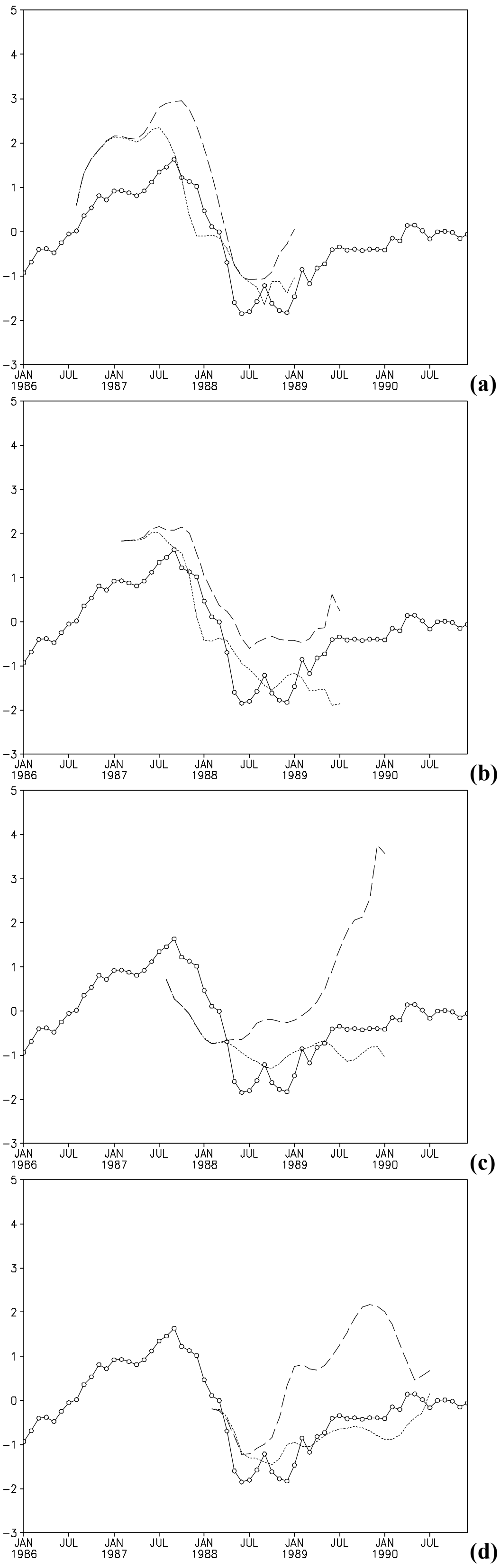
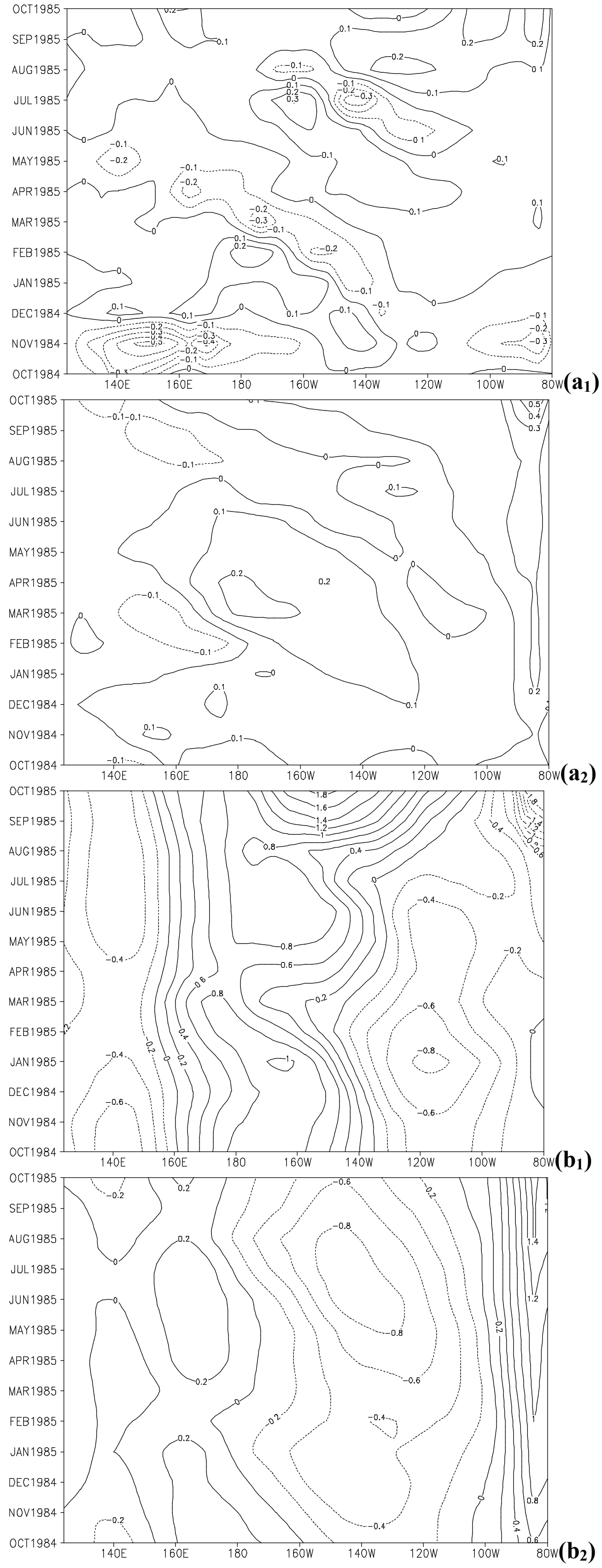


Fig.4 As in Fig.3 except the prediction initialized in (a) August 1986-January 1987, (b) February-July 1987, (c) August 1987-January 1988, and (d) February-July 1988.

5.3 *Discussions*

The difference between the ZCW_0 and ZCW_N coupled models is in latent heat parameterization schemes. The different latent heat parameterization schemes affect the prediction skill for warm events and the advanced prediction skill for cold events. In summary, the latent heat first affects the simulation skill of wind anomaly by the ZCW atmosphere model and then the simulation skill of anomalous ocean current and upwelling by the ZCW ocean model, which then affects the simulations of anomalous SST. The simulation of anomalous SST in turn affects the simulations of surface sensible and latent heat. Finally, the latent heat scheme affects the prediction skill of SSTA. In the following discussion regarding a La Niña event, the differences between the coupled models will be discussed in terms of the anomalies of heating, zonal and meridional winds, and wind divergence (Fig. 5). Figures 5a1 and 5a2 reveal a significant difference in the heating anomalies simulated by both coupled models. The heating anomalies simulated by the ZCW_0 coupled model generally show wave-like evolution, whereas those simulated by the ZCW_N coupled model display wave-like evolution west of the dateline and positive values east of it during the La Niña event. The difference in predicting heating anomaly results in the difference in the prediction of wind anomaly: the ZCW_0 coupled model simulates westerly anomalies over 180° – 140°W, whereas the ZCW_N coupled model simulates easterly anomalies (Figs. 5b1 and 5b2). The ZCW_0 coupled model produces southerly anomalies over 150-130° W and northerly anomalies of 0.2 m s^{-1} over the other regions east of the dateline (Fig.5 c1). In comparison, the ZCW_N coupled model produces southerly anomalies east of the dateline with stronger than 0.2 m s^{-1} east of 160° W (Fig.5 c2). Further analysis of divergence anomaly (Figs. 5d1 and 5d2) reveals that the divergence anomalies predicted by the two models are out of phase: the ZCW_0 coupled model generates divergence and convergence anomalies west and east of the dateline, respectively, whereas the ZCW_N coupled model generates convergence and divergence anomalies west and east of the dateline, respectively. Similar results are also evident for the 1988/1989 La Niña and 1998/2000 La Niña events.



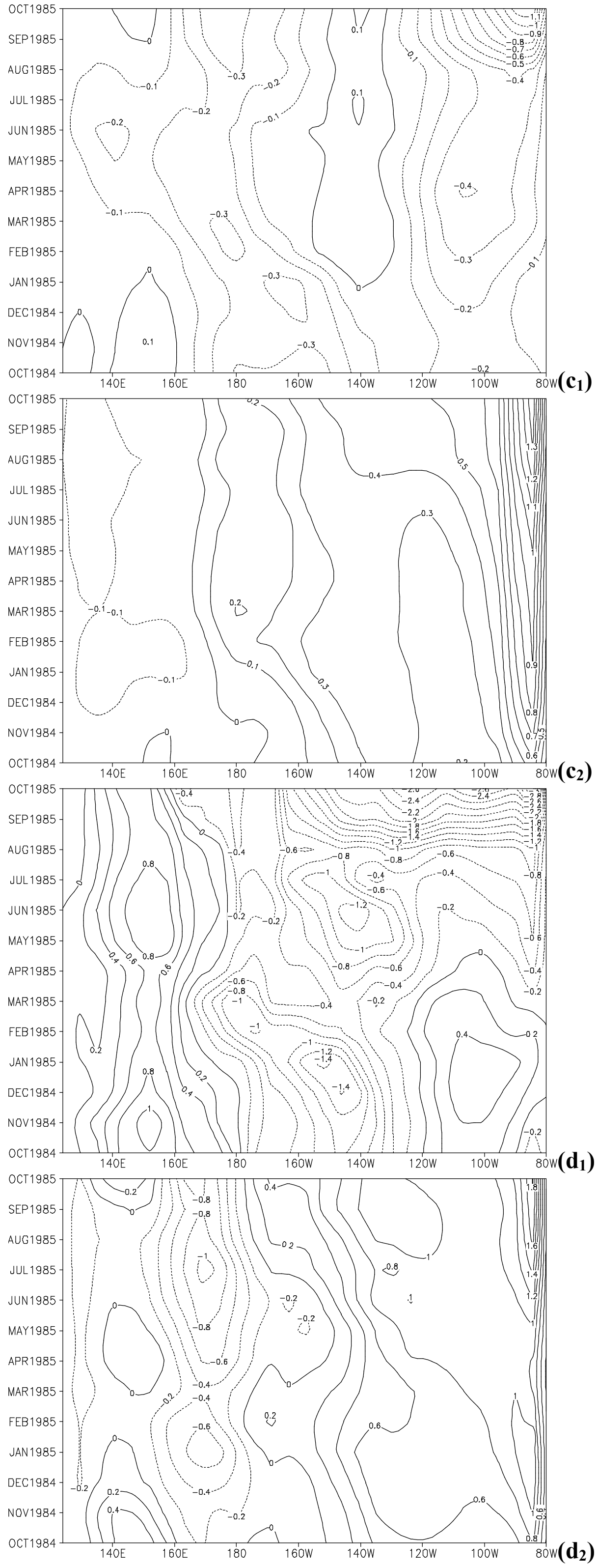


Fig.5 Temporal-longitude distributions of (a_1) (a_2) heating anomalies (dimensionless), (b_1) (b_2) zonal wind anomalies (m s^{-1}), (c_1) (c_2) meridional wind anomalies (m s^{-1}), and (d_1) (d_2) divergence (dimensionless) anomalies, simulated by the ZCW_0 [(a1)-(d1)] and ZCW_N [(a2)-(d2)] coupled models. The contour intervals are 0.1 for heating anomaly, 0.2 m s^{-1} for zonal wind anomaly, 0.1 m s^{-1} for meridional wind anomaly, and 0.2 for divergence anomaly.

During a La Niña event, easterly wind anomalies, southerly wind anomalies, and divergence anomalies occur east of the dateline. These anomalies enhance the cooling of the ocean surface over the Niño3 regions, which leads to a La Niña event. Westerly wind anomalies, northerly wind anomalies, and convergence anomalies favor the warming of the ocean surface and then the occurrence of an El Niño event. As aforementioned, the wind anomalies and divergence anomalies simulated by the ZCW_0 coupled model are not conditions required by a La Niña event, which results in a large bias in the ocean model simulation. The wind anomalies and divergence anomalies simulated by the ZCW_N coupled model are in phase with the conditions for La Niña development, which leads to the successful prediction of a La Niña event.

Figures 3 and 4 show that Niño3F and Niño3N have differences four months after the prediction. The prediction skills of the first four months by the two coupled models are similar. However, different predictions result when the models make longer predictions. Similar first four-month predictions by the two models may be due to feedback of the latent heat, which does not affect prediction skills. The different longer predictions by the two models may result from the impacts of feedback of latent heat on model prediction skills. The latent heat may affect the prediction skills of wind anomaly, as well as the anomalies of ocean current and upwelling/downwelling, ocean temperature anomalies, and sensible and latent heat fluxes. Finally, this affects the prediction skill of SSTA with the ZCW coupled model. The difference between the simulations of ZCW_0 and ZCW_N coupled models mainly stem from the difference in the latent heat parameterization scheme.

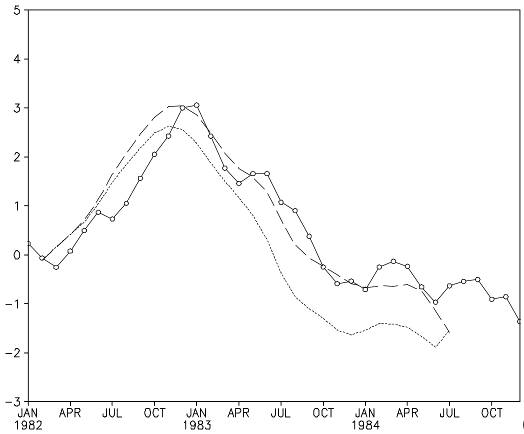
6 COMPARISON BETWEEN ADVANCED PREDICTION SKILLS OF WARM EVENTS BY THE TWO COUPLED MODELS

In Section 5.2, the ensemble predictions of the ZCW coupled model start after El Niño events occur. The results indicate that the ZCW_N coupled model make better predictions than the ZCW_0 coupled model of evolutions of warm events followed by cold events. When ensemble predictions of the ZCW coupled model start before the El Niño events occur, does the ZCW_N coupled model make better predictions of warm events than the ZCW_0 coupled model? The advanced prediction skills of the three El Niño events occurring in May 1982 – September 1983, September 1986 – January 1988, and April 1997 – May 1998 by the ZCW_0 and ZCW_N coupled models initialized in six consecutive months of February – July 1982, February

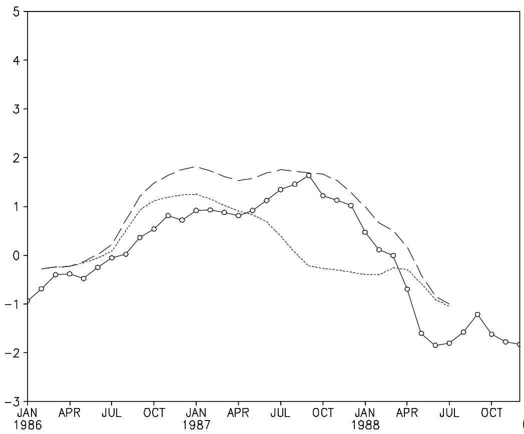
– July 1986, and August 1996 – January 1997 will be analyzed.

Niño3F is very close to Niño3O. Before November 1982, Niño3N and Niño3F were similar (Fig. 6a). After November 1982, Niño3N became smaller than Niño3F and Niño3O. Niño3N was similar to Niño3F before November 1986, while Niño3N was significantly smaller than Niño3F after November 1986 (Fig. 6b). After April 1987, Niño3N became much smaller than Niño3O, while Niño3F became closer to Niño3O. Niño3N and Niño3F were similar before June 1997 (Fig. 6c). After June 1997, Niño3N became much smaller than Niño3F, and was away from Niño3O, while Niño3F was similar to Niño3O. This suggests that the prediction skills of the three warm events by the ZCW_N coupled model with initial conditions before the occurrence of El Niño events are not as good as those by the ZCW_0 coupled model.

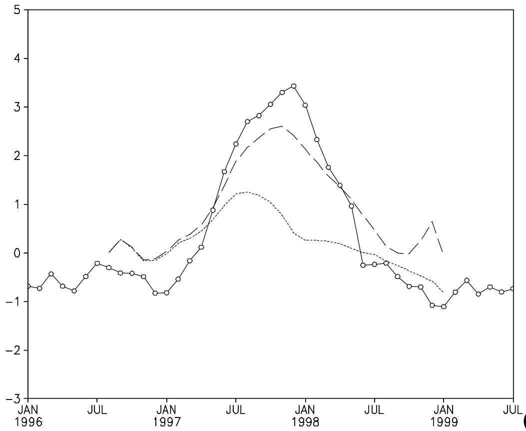
The inclusion of a revised latent heat parameterization scheme in the ZCW coupled model improves the evolution prediction skill of El Niño events and the advanced prediction skill of La Niña events. However, it might not make effective advanced predictions for El Niño events. Thus, improving the latent heat parameterization scheme is not enough. The overall improvement of the coupled model is needed to further improve the advanced prediction skills of warm and cold events.



(a)



(b)



(c)

Fig.6 As in Fig.3 except the prediction initialized in (a) February-July 1982, (b) February-July 1986, and (c) August 1996-January 1997.

7 SUMMARY

The Weare latent heat parameterization scheme is revised in this study, and simulations with this revised scheme are compared with those in the Zebiak scheme. The results are presented as follows.

(1) The analysis of the predictions of ZCW_0 and ZCW_N atmosphere models forced by SSTA and produced by the ZCW ocean model shows that the anomalies of model heating, zonal and meridional winds, and convergence predicted by the two models have similar evolution. However, the magnitudes by the ZCW_0 atmosphere model are larger than those by the ZCW_N atmosphere model.

(2) The inclusion of the revised Weare latent heat parameterization scheme improves the prediction skills of the Niño3 index in the 1980s and 1990s, as well as the evolution of El Niño events and the advanced prediction skill of La Niña events.

(3) The revised scheme cannot improve the advanced prediction skills of warm events.

The Weare scheme has room for improvement. For example, water vapor source may not be fully used for precipitation from clouds. Thus, the latent heat derived from net water vapor gain may not be accurate. Nevertheless, this study demonstrates that the revised scheme improved prediction skills, which is consistent with the results from Zebiak[19]. Improved prediction skills need improvement in physics presentation in the model, as well as improvement in the model itself.

Acknowledgement: The authors wish to thank LDEO, Columbia University, USA for providing ocean surface data, the Service Center for Atmospheric Data, Nanjing University of Information Science and Technology for providing NCEP/NCAR reanalysis wind data, Professors Cane and Zebiak at LDEO for allowing us to use their 1987 version of the coupled model, and Dr. Q. Li at the National Climate Center, CMA for her invaluable assistance.

REFERENCES:

[1] ZEBIAK S E, CANE M A. A model El Niño-Southern Oscillation [J]. Mon. Wea. Rev., 1987, 115: 2262-2278.
[2] BLUMENTHAL M B. Predictability of a coupled ocean-atmosphere model [J]. J. Climate, 1991, 4: 766-784.
[3] MU Mu, DUAN Wan-suo, WANG Jia-cheng. The predictability problems in numerical weather and climate prediction [J]. Adv. Atmos. Sci., 2002, 19(2): 191-204.
[4] CHEN D, ZEBIAK S E, BUSALACCHI A J, et al. An improved procedure for El Niño forecasting: implications for predictability [J]. Science, 1995, 269: 1699-1702.
[5] CHEN D, ZEBIAK S E, CANE M A. Initialization and predictability of a coupled ENSO forecast model [J]. Mon. Wea. Rev., 1997, 125: 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 Niño [J]. Geophys. Res. Lett., 1998, 25: 2837-2840.
[7] CHEN D, CANE M A, ZEBIAK S E. The impact of NSCAT winds on predicting the 1997/1998 El Niño: A study with the Lamont model [J]. J. Geophys. Res., 1999, 104: 11321-11327.
[8] CHEN D, CANE M A, ZEBIAK S E, et al. Bias correction of an ocean-atmosphere coupled model [J]. Geophys. Res. Lett., 2000, 27: 2585-2588.
[9] QIAN Wei-hong, WANG Shao-wu. Multiple spatial-temporal scale of ocean-atmosphere interaction and improvement of Zebiak-Cane model [J]. Sci. in China (Ser. D), 1997, 27(6): 554-559.
[10] QIAN Wei-hong, Li Li, WANG Shao-wu. An improved Zebiak-Cane model for simulating the spatial structure of wind field [J]. Chin. J. Atmos. Sci., 1998, 22(3): 257-264.
[11] LI Qing-quan, ZHAO Zong-ci, DING Yi-hui. Prediction and verification of the 1997-1999 El Niño and La Niña by using an intermediate ocean-atmosphere coupled mode [J]. Acta Meteor. Sin., 2001, 15(2): 144-159.
[12] LI Qing-quan, ZHAO Zong-ci. The development of NCC intermediate ocean-atmosphere coupled model and numerical simulation [J]. Acta Meteor. Sin., 2000, 58(Suppl.): 790-803.
[13] DUAN Yi-hong, LIANG Xu-dong, LI Yong-ping, et al. Application of the four dimensional variational data assimilation technique on optimizing the initial conditions of Z-C model [J]. Acta Meteor. Sin., 2000, 58(5): 524-533.
[14] YUE Cai-jun, LU Wei-song, LI Qing-quan, et al. The advances on the research of Zebiak-Cane ocean-atmosphere coupled model [J]. J. Trop. Meteor., 2004, 20(6): 723-730.
[15] YUE Cai-jun, LU Wei-song, LI Qing-quan. The effect of initialization impact wind on Zebiak-Cane coupled ocean-atmosphere model predictability [J]. J. Trop. Meteor., 2005, 21(5): 506-516.
[16] YUE Cai-jun, LU Wei-song, TAO Li. Evaluation of the prediction performance of a simple coupled ocean-atmosphere model [J]. J. Nanjing Inst. Meteor., 2005, 28(5): 704-709.
[17] ZHOU Z X, CARTON J A. Latent heat flux and interannual variability of the coupled atmosphere-ocean system [J]. J. Atmos. Sci., 1998, 55: 494-501.
[18] GILL A E. Some simple solutions for heat-induced tropical circulation [J]. Quart. J. Roy. Meteor. Soc., 1980, 106: 447-462.
[19] ZEBIAK S E. Tropical atmosphere-ocean interaction and the El Niño/Southern Oscillation phenomenon [D]. Ph. D. thesis, Mass, Inst. of Technol., Cambridge, 1984, 26-27.
[20] ZEBIAK S E. Atmospheric convergence feedback in a simple model for El Niño [J]. Mon. Wea. Rev., 1986, 114: 1263-1271.
[21] NEWELL R E, KIDSON J W, VINCENT D G, et al. The General Circulation of the Tropical Atmosphere and Interactions with Extra-Tropical Latitudes [M]. MIT Press, 1974, 371.
[22] CORNEJO-GARRIDO A G, STONE P H. On the heat balance of the Walker circulation [J]. J. Atmos. Sci., 1977, 34: 1152-1162.
[23] RAMAGE C S. Sea surface temperature and local weather [J]. Mon. Wea. Rev., 1977, 105: 540-544.
[24] SCHNEIDER E K, LINDZEN R S. Axially symmetric steady-state models of the basic state for instability and climate studies. Part I: linearized calculations [J]. J. Atmos. Sci., 1977, 34: 263-179.
[25] SCHNEIDER E K. Axially symmetric steady-state models of the basic state for instability and climate studies. Part II: Nonlinear calculations [J]. J. Atmos. Sci., 1977, 34: 280-296.
[26] STEVENS D E, LINDZEN R S, SHAPRIO L J. A new model of tropical waves incorporating momentum mixing by cumulus convection [J]. Dyn. Atmos. Oceans. 1977, 1: 365-425.
[27] STEVENS D E, LINDZEN R S. Tropical Wave-CISK with a moisture and cumulus friction [J]. J. Atmos. Sci., 1978, 35: 940-961.
[28] KLEEMAN R. A simple model of the atmospheric response to ENSO sea surface temperature anomalies [J]. J. Atmos. Sci., 1991, 48: 3-18.
[29] PERIGAUD C, DEWITTE B. El Niño-La Niña events simulated with Cane and Zebiak's model and observed with satellite and in situ data. Part I: Model data comparison [J]. J. Climate, 1996, 9: 66-84.
[30] WANG C. On the atmospheric responses to tropical Pacific heating during the mature phase of El Niño [J]. J. Atmos. Sci., 2000, 57: 3767-3781.
[31] 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]. Geophys. Res. Lett., 2001, 28(19): 3713-3716.
[32] WEARE B C. A simple model of the tropical atmosphere driven by a circulation dependent forcing [J]. Quart. J. Roy. Meteor. Soc., 1986, 112: 409-429.
[33] WEARE B C. A simple model of the tropical atmosphere with circulation dependent heating and specific humidity [J]. J. Atmos. Sci., 1986, 43(19): 2001-2016.
[34] DAVID N J, HELD I M. Modeling tropical convergence based on the moist static energy budget [J]. Mon. Wea. Rev., 1987, 115: 3-12.
[35] MOORE A M, KLEEMAN R. Stochastic forcing of ENSO by the intraseasonal oscillation [J]. J. Climate, 1999, 12(5): 1199-1220.
[36] DING Yi-hui. Diagnostic and Analytical Methods in Synoptic Dynamics [M]. Beijing: Science Press, 1989, 114-116.
[37] LI Xiao-yan, ZHAI Pan-mao. On indices and indicators of ENSO episodes [J]. Acta Meteor. Sinica, 2000, 58(1): 102-109.

Citation: YUE Cai-jun, LU Wei-song and Xiaofan LI. A study on the impacts of latent heat parameterization scheme on prediction skill of ENSO with a simple ocean-atmosphere coupled model. *J. Trop. Meteor.*, 2010, 16(1): 10-19.