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An El-Nino prediction system using an intermediate ocean and a statistical atmosphere

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Abstract. An El-Nino prediction model is developed based on an intermediate ocean model similar to the Cane and Zebiak (CZ) and a statistical atmosphere model. The present ocean model differs from CZ in the parameterization of subsurface temperature and the basic state. The predictability skill of the present model is better than that of CZ. The better performance is particularly distinctive for early stage of the prediction everywhere in the domain and in the central Pacific for all period of prediction. It is suggested that the better performance for the early stage is due to the use of SST anomalies in the initialization, and the better performance in the central Pacific results from a better representation of subsurface temperature in the present model.

1. Introduction

A milestone of ENSO prediction was made after the development of the intermediate coupled model by *Cane and Zebiak* [1987]. Hereafter the model will be referred to as the "CZ model". The model has been used routinely for El-Nino forecasts, widely used in the predictability studies [*Goswami and Shukla*, 1991; *Cane*, 1991; *Chen et al.*, 1995], and for understanding ENSO related dynamics [*Zebiak and Cane*, 1987; *Battisti*, 1988; *An et al.*, 1999]. Although it is simple, the intermediate model is known to have a predictability skill not lower than coupled GCMs have.

The predictability skill of the CZ model has been improved mainly by changes of the initialization scheme [*Chen et al.*, 1995, 1998]. In particular, *Chen et al.*[1998] improved the El-Nino prediction by assimilating observed sea level data in the model. However, a major improvement of the prediction has not been accomplished by a modification of the model itself, although some deficiencies of the CZ model were reported by several authors. Among them are the simulated wind shifted to the east about 30 degree and a crude parameterization of the subsurface temperature [*Dewitte and Perigaud*, 1996]. Also the model is too sensitive to the basic state, which may affect the decadal variation of the model predictability [*Kirtman and Schopf*, 1998]. In the present study, the CZ model is modified by considering the above problems, and the predictability of El-Nino is examined based on the modified CZ model.

2. Data

The data utilized are the sea surface temperature, subsurface temperature, and 20^{o}C isotherm depth obtained from National Center for Environmental Prediction (NCEP) and the wind stress from Florida State University (FSU). The NCEP SST is the one constructed based on the EOF of observed SST and reconstructed after January 1981 using an optimum interpolation [*Reynolds and Smith*, 1994]. The data period of the SST and wind stress is from 1970 to 1998. The monthly-mean subsurface temperature and 20^{o}C isotherm data for the period of 1980 - 1997 are obtained from the reanalysis data set produced by the ocean data assimilation system in NCEP [*Behringer et al.*, 1998]. All data sets used here are converted to the CZ model grid using a linear interpolation.

3. Model

The CZ model is modified in the present study. Major changes include the atmosphere model replaced by an empirical model and the subsurface temperature parameterization. The basic state is also changed by using the observed means for 1979-98. The statistical atmosphere model is developed based on the singular value decomposition (SVD) of wind stress and SST. The statistical model, which produces the wind stress, is expressed as

$$\tau(x,y) = \sum_{n}^{N} c(n) \left(\sum_{x,y} S_{SST}(x,y,n) SST(x,y) \right) S_\tau(x,y) \quad (1)$$

$$c(n) = \left(\sum_{t} T_{SST}(t,n) T_\tau(t,n) \right) / \sum_{t} T_{SST}(t,n)^2$$

where x and y indicate the zonal and latitudinal grid points, respectively, and t the time. S_{SST} and S_τ are the SVD singular vectors for SST and wind stress, respectively, and T_{SST} and T_τ the associated time series. n indicates the nth mode of SVD, and N=2 the maximum number of the mode. The zonal and meridional wind stresses are separately computed based on the above equation. The present statistical model uses the two leading singular vectors since other singular vectors explain negligible fractions of covariance. Experiments with more singular vectors produces similar results. It is also noted that the first and second modes explain the mature and transition phases of ENSO, respectively

In the CZ model, the sea water temperature anomaly below the mixed layer, hereafter referred to the subsurface temperature, is estimated based on a hypertangent function of thermocline depth anomaly. But in the present model, the function is replaced by a statistical relationship constructed based on the SVD singular vectors of the 20^{o}C isotherm depth and the water temperature at 45m depth from the NCEP ocean assimilation data. In the present model, the former variable corresponds to the thermocline depth and the latter to the subsurface temperature. The 45m depth is

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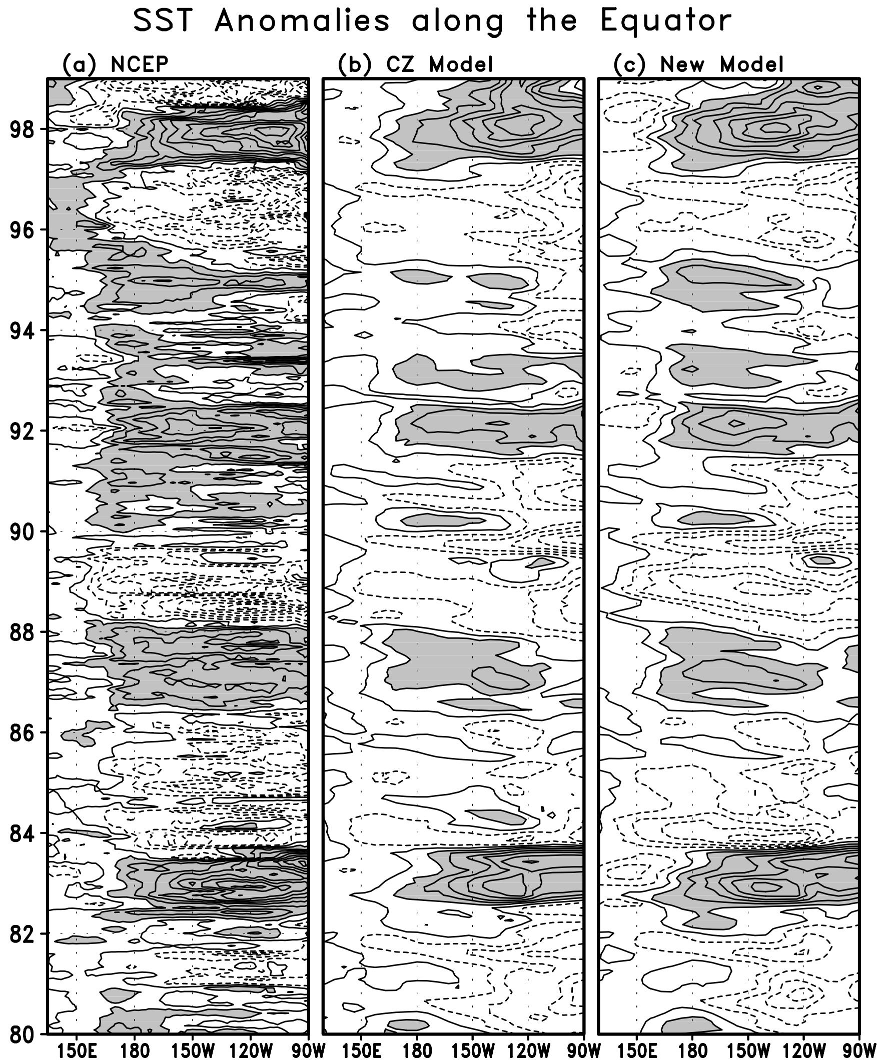

Figure 1. (a) NECP monthly mean SST anomaly along the equator from January 1980 to December 1998. (b) and (c) are as in Fig. 1a except the Cane and Zebiak model and present model products, respectively, obtained with the prescribed FSU wind stress. Contour interval is 0.5^{o}C, positive and negative values are plotted by the solid and dashed lines, respectively. Shading indicated values more than 0.5^{o}C

chosen because the depth is close to the mixed layer depth (50m) of CZ model. We also used 55m and other depths, but the results are not sensitive to the depth chosen. The formula for estimating the subsurface temperature is same as Eq.(1) except that ten singular vectors are used (N=10) and c(n) is now multiplied by the ratio between the standard deviations of observed 20^{o}C isotherm depth and the thermocline depth of the ocean model. As in the CZ model, the ratio is computed separately for the positive and negative values of thermocline depth. It is also noted that in the present model, the efficiency factor relating entrainement to the upwelling in the CZ model is replaced by the factors computed by the formula suggested by *Dewitte* [1999]. The basic state of the ocean model is also modified to consider the recent climatology for the 20 years of 1979-98. In particular, the basic state of ocean current is obtained by spinning up the ocean model using the FSU monthly-mean wind stress averaged for the 20 years period.

The SST of the present ocean model forced by the FSU wind stress is compared to that of CZ model and the NCEP SST. Figure 1a shows the NCEP SST anomaly along the equator from January 1980 to December 1998. Figures 1b and 1c are as in Fig.1a except those produced by the CZ model and the present model, respectively. Comparing to the observation, the CZ model produces SST anomalies too much confined near the eastern boundary, particularly for a negative phase. On the other hand, the present model produces large SST anomalies in the central Pacific. Not only this spatial pattern but also the intensity of SST anomaly are well simulated by the present model. Note that this better simulation is resulted mainly from the change of subsurface temperature parameterization. It is also noted that the present coupled model with the statistical atmosphere reproduces reasonably well the observed characteristics of ENSO (not shown). The long-term (100 years) variation of NINO3 SST generated by the coupled model shows the time scale of about 4 years and the amplitude of about 1.5^{o}C.

4. Prediction

The CZ model is initialized using the observed historical wind stress [*Chen et al.*, 1995]. In this case, the initial condition of SST anomalies differs from observation, resulting in a reduction of predictability of SST anomalies even

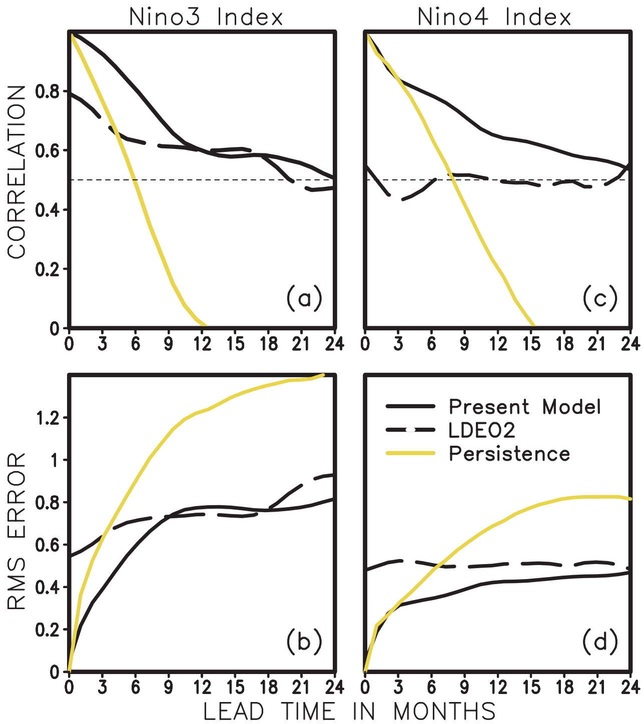

Figure 2. (a) and (b) are the correlation and rms errors between the model forecasts with lead times and observed SST averaged over the NINO3 region for the 1980-97 period. (c) and (d), respectively, are as in (a) and (b) except the NINO4 SST.

at the initial stage. However, the present model combines the observed SST and wind stress in the initialization. The initialization is done by spinning up the model with the following wind stress for the period from January 1970 to the time of initial condition

$$\tau = (1 - \beta/\beta_{max})\tau_o + (\beta/\beta_{max})\tau_{SST} \qquad (2)$$

where τ_o and τ_{SST} , respectively, indicate the observed wind stress and the wind stress obtained using observed SST anomaly based on Eq.(1). $\beta_{max} = 3$ and $\beta = C(1)S_{SST}(1)SST$ is obtained by projection of the first singular vector of SST into observed SST anomalies. Thus β has a relatively large value in mature phases of ENSO but a small value in a transition phase. Therefore, the formula of Eq.(2) minimizes noise signals in the observed wind during the mature phases of ENSO but keeps the observed signal other than the ENSO related during the transition phase.

Using Eq.(2), the initial conditions are produced for each month from January 1980 to December 1997. Starting from the initial condition, the present model is integrated up to 24 months, and the prediction results are compared with those of observation and the CZ model with an initialization of *Chen et al.* [1995]. This version of CZ model is called to as LDEO2 [*Chen et al.*, 1998]. Figure 2 compares the predictability skills of the present model and LDEO2. The skills are measured by the correlation and the rms error between monthly-mean model forecast and observed SST anomalies in the tropical Pacific. For the NINO3 SST averaged over 150^{o}W-90^{o}W and 5^{o}S-5^{o}N (Figs.2a and 2b), the present model produces relatively large correlations and low rms errors in most of lead times, particularly in the earlier lead times before one year. The better performance of the present model is more distinctive when the correlation and rms are compared for the NINO4 SST, the anomaly averaged over the central equatorial Pacific between 150^{o}E-150^{o}W and 5^{o}S-5^{o}N (Figs.2c and 2d). Noted is that the present model has a predictive skill, when judged with the correlation coefficient exceeding 0.5, for both the NINO3 and NINO4 SST up to 2 years. It is also noted that the correlations over the tropical central and eastern Pacific exceed 0.7 for a 6 months lead and 0.5 for a 12 months lead, but they are poor in the far western Pacific (not shown). Comparing to LDEO2, the present model has a better predictability skill (with a correlation about 0.1 larger than that of LDEO2) in most of the domain, particularly in the central tropical Pacific. It is pointed out that the better performance of SST prediction in the central Pacific is mainly due to a better representation of subsurface temperature in the present model

A most striking difference between the present model and LDEO2 is in their forecasts of the 1997/98 El-Nino, as illustrated in Fig.3. LDEO2 totally missed the onset of this big event, and the initial conditions were much weaker than the observation. On the other hand, the present model produces a better prediction. The initial condition follows observation closely. The model predicts the warming in early 1997 when the SST anomaly is very weak, and the rapid decay of warm condition after late 1997 is well captured by the model

5. Conclusion

An ENSO prediction system is constructed based on a modification of the CZ model, which includes a statistical atmosphere model, the parameterization of subsurface temperature, and the basic state. The model is initialized based on a combination of FSU wind stress and the wind stress obtained from a statistical relationship with observed SST anomalies. For the period of 1980-1998, the present model has a predictability skill up to 2 years for both NINO3 and NINO4 SST anomalies. The predictability skill of the present model is better than LDEO2 (the CZ model with an initialization of *Chen et al.* [1995]). The better performance is particularly distinctive for early stage of the prediction everywhere in the domain and in the central Pacific for all period of prediction. It is suggested that the better performance for the early stage is due to the use of SST anomalies in the initialization and the better performance in the central Pacific results from a better representation of

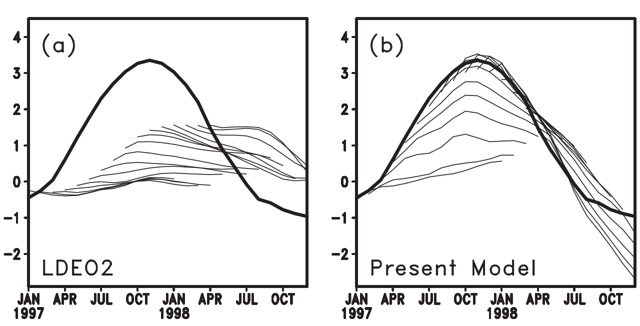

Figure 3. Observed and model predicted NINO3 SST for 1997/98 El-Nino. (a) and (b), respectively, are the prediction with the Cane and Zebiak model (the version LDEO2) and that with the present model. Each thin curve is the trajectory of a 12 month forecast.

subsurface temperature in the present model. It is also noted that the change of the basic state has a little impact in the predicitability. There may be more rooms in improvement of ENSO predictability with the present model. An improvement may be done by assimilating ocean dynamic variables in the initialization, as shown by *Chen et al.* [1998]

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