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The impacts of the model assimilated wind stress data in the initialization of an intermediate ocean and the ENSO predictability

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Abstract. A historical wind stress data is obtained based on the 925hPa winds of NCEP reanalysis data and is compared to the FSU wind stress. A particular difference between the two wind stress data appears in the eastern Pacific. The prediction experiments with an intermediate ocean and statistical atmosphere model indicate that the prediction skill of the tropical Pacific SST with the NCEP wind stress data is better than that of FSU wind stress for the period of 1980-1999. In particular, the prediction skill is considerably improved for the recent years of 1992-1999, when the NCEP wind stress is used for the ocean initialization.

Introduction

Coupled ocean-atmosphere models have been developed during the last decade and a half for predicting El Nino/ Southern Oscillation (ENSO). Among them, intermediate coupled models such as the Lamont model [*Zebiak and Cane*, 1987] have been widely used in prediction and predictability studies [*Cane*, 1991; *Chen et al.*, 1997, 1998, 1999]. These intermediate models have a prediction skill not lower than that of the coupled GCMs, which contain complicated physical processes [*Barnett et al.*, 1993]. The prediction skill of the Lamont model has been improved by a modification of initialization scheme with nudged wind stress [*Chen et al.*, 1997] and more recently by assimilating sea level data [*Chen et al.*, 1998]. These studies indicate that the predictability of the coupled model depends on the initialization method of ocean model.

Many El Nino prediction models have used the Florida State University (FSU) wind stress for initialization. But, Chen et al. [1999] showed that the FSU wind stress has a spatial pattern somewhat different from that of the NASA scatterometer (NSCAT) winds. They further showed that the prediction of 1997/98 El Nino with the Lamont model is much improved by replacing the FSU wind stress by that from the NSCAT winds in the initialization. The improvement was mostly attributed to a better-resolved wind field in the southeast tropical Pacific. However, because of a short record of the NSCAT data, their study was limited to a case study and could not evaluate overall forecast skill during a longer period. The NCEP/NCAR reanalysis data provides a longer historical record, it is a model based assimilation product, incorporating a complex atmosphere fields [*Kalnay et al.* 1996, @]. Because of the assimilation, the NCEP near surface winds are more physically consistent with the observed SST forcing than the analysis utilizing only near surface wind observation such as FSU. Therefore, it is worthwhile to examine the predictability skill of El Nino using the wind stress based on the NCEP data and to compare the skill to that of the FSU wind stress. In this work, we calculate the wind stress using the NCEP reanalysis data, compare it with the FSU wind stress, and examine the predictability skill of a ENSO prediction system using each wind stress data.

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Model and Data

El Nino prediction system used in the present study is based on the intermediate ocean and statistical atmosphere model developed by Kang and Kug [2000]. The present ocean model is modified version of the Lamont Model [*Zebiak and Cane*, 1987]. The primary change is the subsurface temperature parameterization. The parameterization of subsurface temperature is replaced by a statistical relationship constructed based on the Singular Value Decomposition (SVD) of the 20^oC isotherm depth and the water temperature at 45m depth from the NCEP ocean assimilation data. The statistical atmosphere model is based on the SVD of FSU wind stress and SST. The wind stress used for the initialization of the ocean model is made by combining the observed wind stress and the wind stress derived from the observed SST anomalies. Details of the prediction system were presented previously [*Kang and Kug* 2000, @].

The SST data utilized is obtained from NCEP, which was constructed based on the method of Reynolds and Smith [1994]. To filter out short time scale perturbations, 5-month running mean is applied to the SST data. The wind stress data utilized are the FSU wind stress and the wind stress calculated using the NCEP/NCAR reanalysis wind data and the following formula

$$\vec{\tau} = \rho C_D |\vec{V}| \vec{V}$$

where $\vec{V}$ indicates wind vector at 925hPa. The value of $\rho C_D = 0.01kg/m^3$, is obtained by comparing the magnitude of the calculated wind stress to that of the FSU wind stress. We also used the winds from 1000 to 850 hPa with adjustments of the value of ρC_D. But, the 925hPa wind provides a better forecast skill. The monthly wind stress data used in the present work is obtained by averaging the daily wind stress. The anomalies are obtained by subtracting 30 years (1970-99) monthly means. Hereafter, the monthly wind stress is referred to as "NCEP wind stress".

The time evolution of FSU zonal wind stress along the equator (Fig. 1a) is compared to that of the NCEP zonal wind stress (Fig. 1b). Both FSU and NCEP wind stress anomalies show large interannual variations associated with ENSO. A clear difference is found in the two figures. The center of FSU wind variation locates in the central Pacific along the date line. On the other hands, the center of NCEP wind variation appears in the eastern Pacific near 150^oW. Chen et al. [1997] compared the wind stresses with and without a nudged procedure of model wind stress and found that the wind stress with a nudged procedure is shifted to the east compared to that without it (their Fig. 1a). Note that the forecast skill of the former was better than that of the latter. We can also find a clear difference between the two wind stress fields in recent years. Chen et al. [1999] pointed out that during the onset period of 1997/98 El-Nino from March to June 1997, the FSU wind stress in the eastern Pacific, which is easterly, is different from the NSCAT data. Note that the NCEP wind appears to be similar to that of the NSCAT data. After the 1997/98 El Nino, the FSU wind stress remains westerly in the eastern Pacific. But it is quite different from the NCEP wind stress. This difference can induce different initial conditions during the transition phase to the recent La Nina, affecting the prediction skill of ENSO.

Model Results

The hindcast experiments are carried out with the same ocean model but with the two different sets of wind stress data for the period from January 1970 to December 1999. The model responses to the FSU and NCEP wind stress are

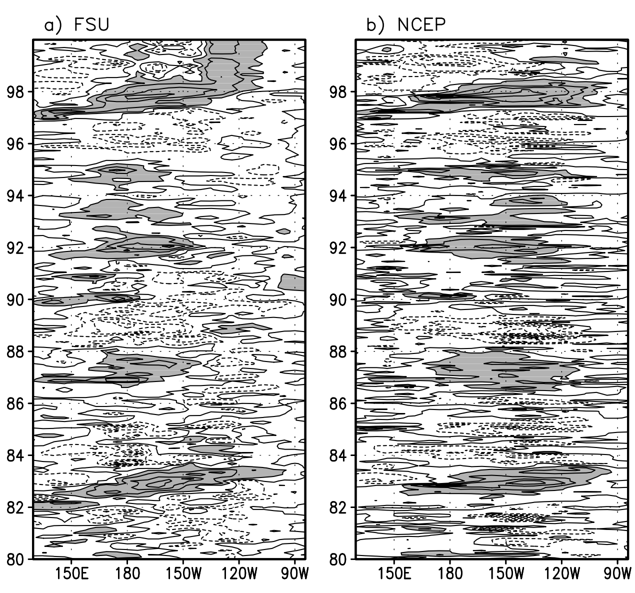

Figure 1. Wind stress anomaly along the equator from (a) FSU and (b) NCEP. Contour interval is $0.2dyne/cm^2$, positive and negative values are plotted by the solid and dash lines, respectively. Shading indicates values greater than $0.2dyne/cm^2$

Table 1. The correlation between 12 month forecast and observed NINO3 SST for the 1980-1992 and 1992-1999 verification periods. FSUatm and NCEPatm indicate the results using the statistical atmosphere model constructed with FSU and NCEP wind stress, respectively. FSU and NCEP indicate wind stress used in initialization.

	1980-1999		1992-1999	
	FSU	NCEP	FSU	NCEP
FSUatm	0.57	0.61	0.40	0.56
NCEPatm	0.54	0.59	0.37	0.54

referred to as "FSU_{hind}" and "$NCEP_{hind}$", respectively. Among the model outputs, the SST anomalies of FSU_{hind} and $NCEP_{hind}$ along the equator from January 1980 to December 1999 are shown in Figs. 2b and 2c,pries are shown in Fig. 2a. Both model results show a reasonably good simulation of El Nino's and La Nina's. However, a close comparison of the two figures with the observation indicates that $NCEP_{hind}$ is generally better than FSU_{hind}. In particular, FSU_{hind} fails to simulate weak positive SST anomalies in 1990-91 and 1992-95, and the La Nina for 1999. The simulation with NCEP forcing is better in each instance. Over the dynamically important upwelling regions within the domain, SST is closely related to thermocline depth. The latter is controlled mainly by wind stress forcing. We compared the hindcast thermocline depths with sea level from NCEP ocean assimilation data [*Behringer et al.*, 1998]. The correlations of the sea level and the hindcast thermocline depth in NINO3 region (150^oW-90^oW and 5^oS-5^oN) with FSU and NCEP wind stress anomalies are 0.71, 0.84 , respectively. The results are consistent with those of hindcast SST anomalies.

Chen et al. [1999] found an improvement in the prediction of the 1997/98 El Nino by replacing the FSU wind stress with the NSCAT winds. They pointed out the failure of prediction with the FSU wind stress is due to weak easterly wind stress anomalies in the eastern Pacific compared to the observed anomalies. Kang and Kug [2000], on the other hands, made a better prediction of the 1997/98 El Nino using FSU wind stress. Their better simulation may result from the use of observed SST information in addition to the wind stress in the initialization process. Chen et al. [1998] also improved the prediction of 1997/98 El Nino with assimilating the sea level data. Those two studies indicate that a better prediction requires other observed information. Figure 2, on the other hand, indicates that the NCEP winds may provide a better wind stress data for the initialization, at least in the context of the present model.

Now we examine how the different wind stress affects the forecast skill of the present model. The forecast initial conditions are produced for each month from January 1980 to December 1999 using the FSU and NCEP wind stress. Starting from each initial condition, the model is integrated up to 24 months. Henceforth the predictions using FSU wind stress and NCEP wind stress are referred to as "FSU_{fcst}" and "$NCEP_{fcst}$", respectively. Figure 3 compares the forecast skills of FSU_{fcst} and $NCEP_{fcst}$ for the NINO3 SST. The figures show the correlation coefficients between the forecast of NINO3 SST anomaly and the observed NINO3 SST anomaly. The $NCEP_{fcst}$ gives a higher correlation at all

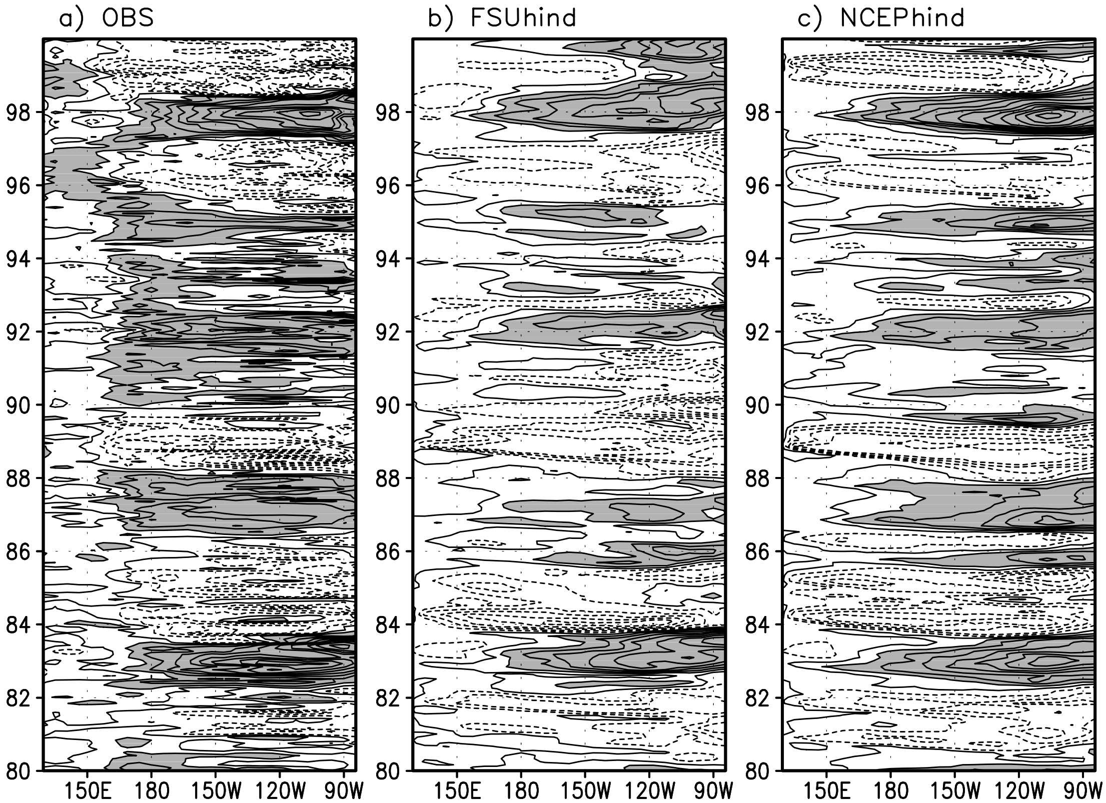

Figure 2. (a) NCEP SST anomaly along the equator. (b) and (c) are intermediate model SST simulations with (b) FSU and (c) NCEP wind stress. Contour interval is 0.5^oC, positive and negative values are plotted by the solid and dash lines, respectively. Shading indicates values more than 0.5^oC

lead times, particularly for the period of 1992-1999. Note that the $NCEP_{fcst}$ produces similar forecast skill during the 1980-1991 and 1992-1999 periods, while the forecast skill of FSU_{fcst} has degraded considerably in the recent decade. The better forecast with the NCEP wind stress is conspicuous lead times around one year, particularly in the 1990's. Figure 4 shows the spatial distribution of correlation coefficient over the tropical Pacific between the observed SST and the 12 month forecast SST. The correlations are obtained for the period of 1992 - 1999. It is seen that the $NCEP_{fcst}$ is better than the FSU_{fcst}, particularly in the regions of the central and eastern equatorial Pacific.

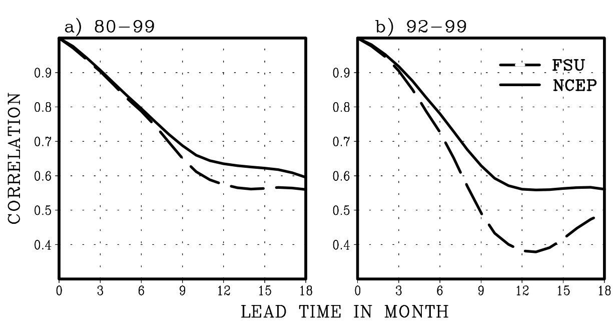

Figure 3. Correlation coefficient between the model forecast and observed NINO3 SST, as a function of lead time, for the verification periods (a) 1980-99 and (b)1992-1999.

It is noted that the statistical atmosphere model used so far is the one developed based on the FSU wind stress. But the forecast skill can be changed if the model developed using the NCEP wind stress. To check this possibility, we constructed the atmosphere model using the NCEP wind stress and the forecast experiments are repeated. As shown in Table 1, regardless of which statistical atmosphere model is used, the forecasts initialized with NCEP wind stress in perform better than those initialized with FSU wind stress.

Discussion

In the present study, the NCEP reanalysis wind stress is used for the initialization of the intermediate El Nino prediction model of Kang and Kug [2000], and the forecast skill is improved compared to that using FSU wind stress. We emphasize that this doesn't necessarily imply that NCEP wind stress is closer to "truth" than the FSU wind stress. However, the NCEP wind stress is most likely better balanced with the large scale SST forcing because of the model based assimilation system with the observed SST. This balance can be important for prediction with intermediate model in particular.

As shown in Fig. 1a and Fig. 2a, the FSU wind stress appears not to be well balanced with observed SST forcing during certain periods. For example, during the 1998-1999 La Nina period anomalous westerly wind stress anomalies appear in the central and eastern Pacific, although the SST forcing should favor anomalous easterly wind stress. The im-

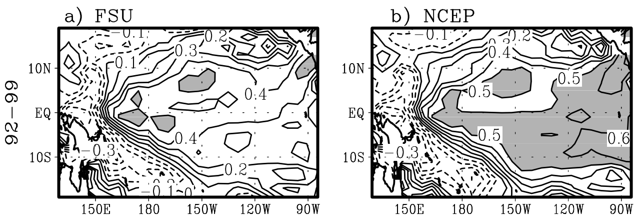

Figure 4. Correlation between the observed SST and 12 month lead forecast SST using the (a) FSU and (b) NCEP wind stress in initialization during the 1992-1999. Shading indicates values more than 0.5

balance between SST and wind stress can result in "initial shock" when the data are used for initialization. This study implies the possibility of improvement for ENSO prediction using other intermediate models, and potentially more complex models when assimilation based wind stress are used for initialization

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