Application of altimeter observation to El Niño prediction

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Abstract. A new version of the Lamont forecast model is used to assess the impact of TOPEX/POSEIDON altimeter data on predicting short-term climate change, with emphasis on the 1997/98 El Niño and subsequent La Niña. As compared to forecasts initialized with only wind data, the model's predictive accuracy was improved when the altimeter sea level data are used for model initialization. This is due to the effectiveness of sea level data in correcting the model ocean state. For this particular application, the effect of altimeter sea level observations is comparable to that of tide gauge measurements.

1. Introduction

Prediction is an important goal of developing models and observing systems. For more than a decade, the Lamont model (Cane *et al*. 1986, Zebiak and Cane 1987) has played a significant role in our understanding and prediction of El Niño and the Southern Oscillation (ENSO), the largest short-term fluctuation in the Earth's climate system. However, the model's forecast accuracy has decreased in recent years, most notable is its failure to predict the onset of the 1997/98 El Niño. In a series of recent studies (Chen *et al*. 1998, 1999, 2000), we have found that the Lamont forecast system is more limited by the observational data used for initialization than by its simplified model physics and that higher prediction accuracy can be achieved by assimilating more accurate or simply more data. For example, by either replacing the Florida State University (FSU) wind analyses with the NASA Scatterometer (NSCAT) winds (Chen *et al*. 1999), or using sea level data in addition to winds (Chen *et al*. 1998), we could greatly improve our prediction of the 1997–98 El Niño.

Data sets from satellite sensors have limited use for climate studies because of their relatively short temporal records. For this reason we chose tide gauge data in our previous evaluation of the impact of sea level observation on ENSO prediction (Chen *et al*. 1998). Presumably, the much-better-resolved satellite products, such as the sea level data from TOPEX/POSEIDON altimeter, should lead to a further improvement of model simulation and prediction. To assess the impact of these products, even at a preliminary level, is of great interest to both scientific community and space agencies. Here we evaluate the effect of nearly 8 years of TOPEX/POSEIDON sea level observation on the Lamont model prediction. This study differs from Chen *et al*. (1998) not only in the data set under consideration, but also in the study period and in the model itself.

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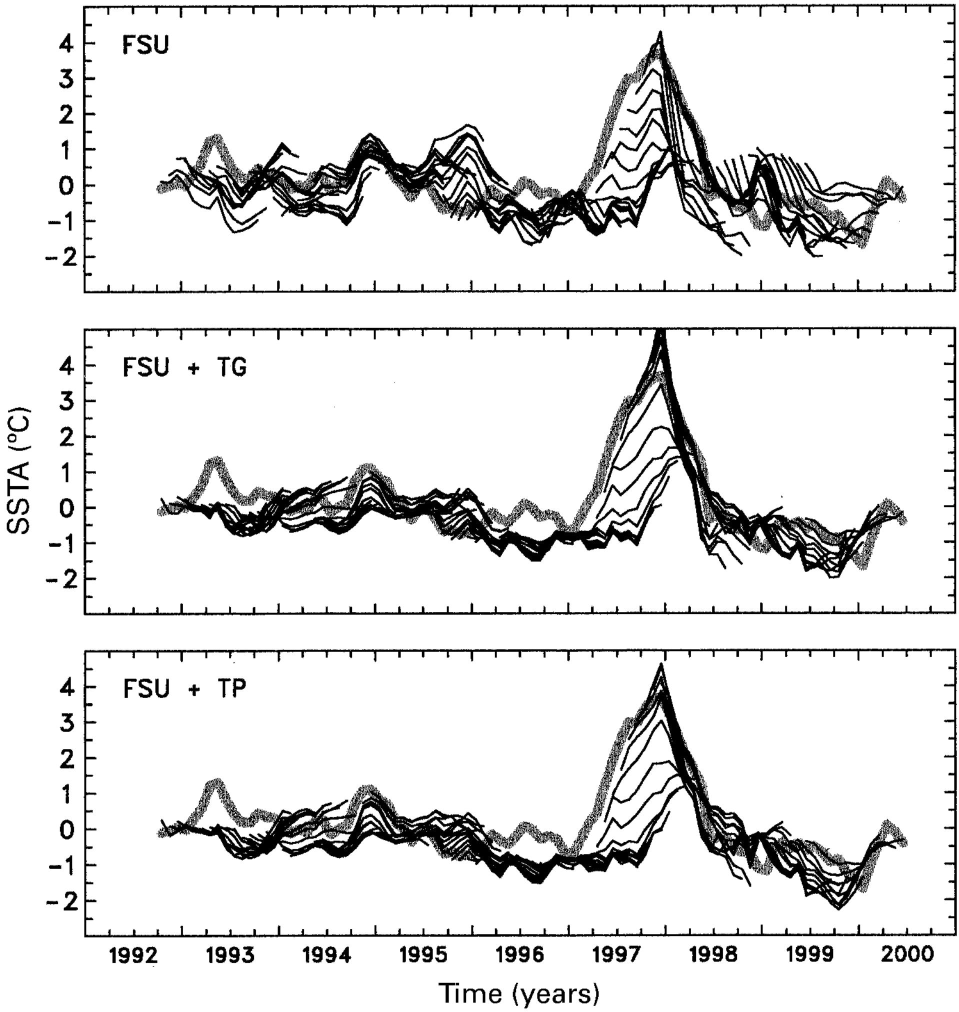

Figure 1. Model forecasts of NINO3 initialized with FSU wind (upper panel), FSU wind plus TG sea level (middle panel), and FSU wind plus TP sea level (lower panel). The thick grey curve is observed values. Each thin curve is the trajectory of a 12-month forecast starting from the middle of each month.

2. Data and model

The TOPEX/POSEIDON sea level data used here are gridded anomalies produced by the Laboratory for Satellite Altimetry of National Oceanic and Atmospheric Administration (Cheney *et al.* 1994), which covers a 93-month period from October 1992 to June 2000. For comparison, the sea level product based on 34 tropical Pacific tide gauge stations (Cane *et al.* 1996) was also used in this study. The same two-step data assimilation procedure (Chen *et al.* 1998) was applied to these two different products. The wind stress data came from the Florida State University (FSU) analyses (Goldenberg and O'Brien 1981).

The model used in this study is LDEO4, the latest version of the Lamont model (Chen *et al.* 2000). This version is intrinsically different from the previous three due to the addition of an interactive bias correction component. The systematic biases

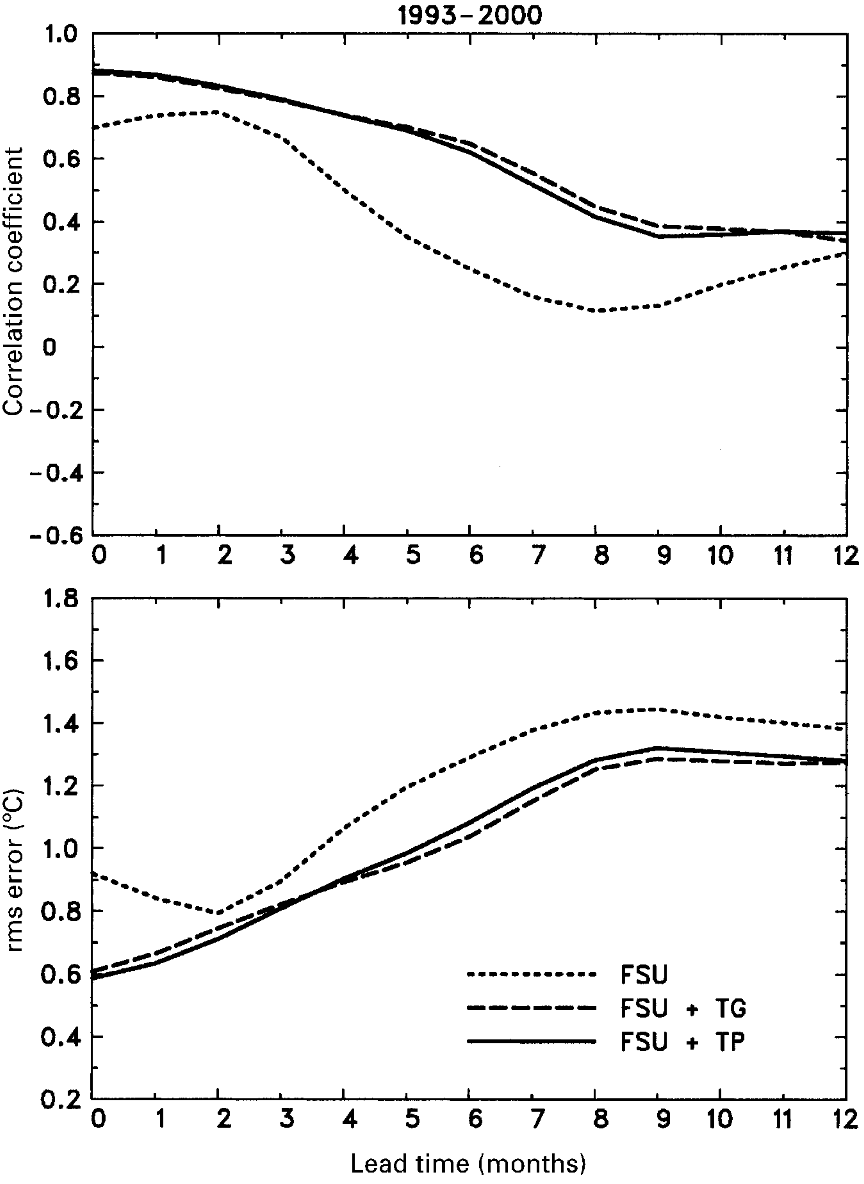

Figure 2. Correlations and rms errors between model forecast and observed NINO3 index for the 1993–2000 period. Different grey-scales are assigned to the three cases with different data for initialization.

of the original Lamont model is effectively reduced by this statistical correction, which is based on the regression between the leading empirical orthogonal functions (EOFs) of the model errors and the leading multivariate EOFs of the model states. The bias-corrected model not only performs better in ENSO forecasting, but also exhibits a more realistic internal variability. Assimilating data into this new version of the model should cause much less initialization shock.

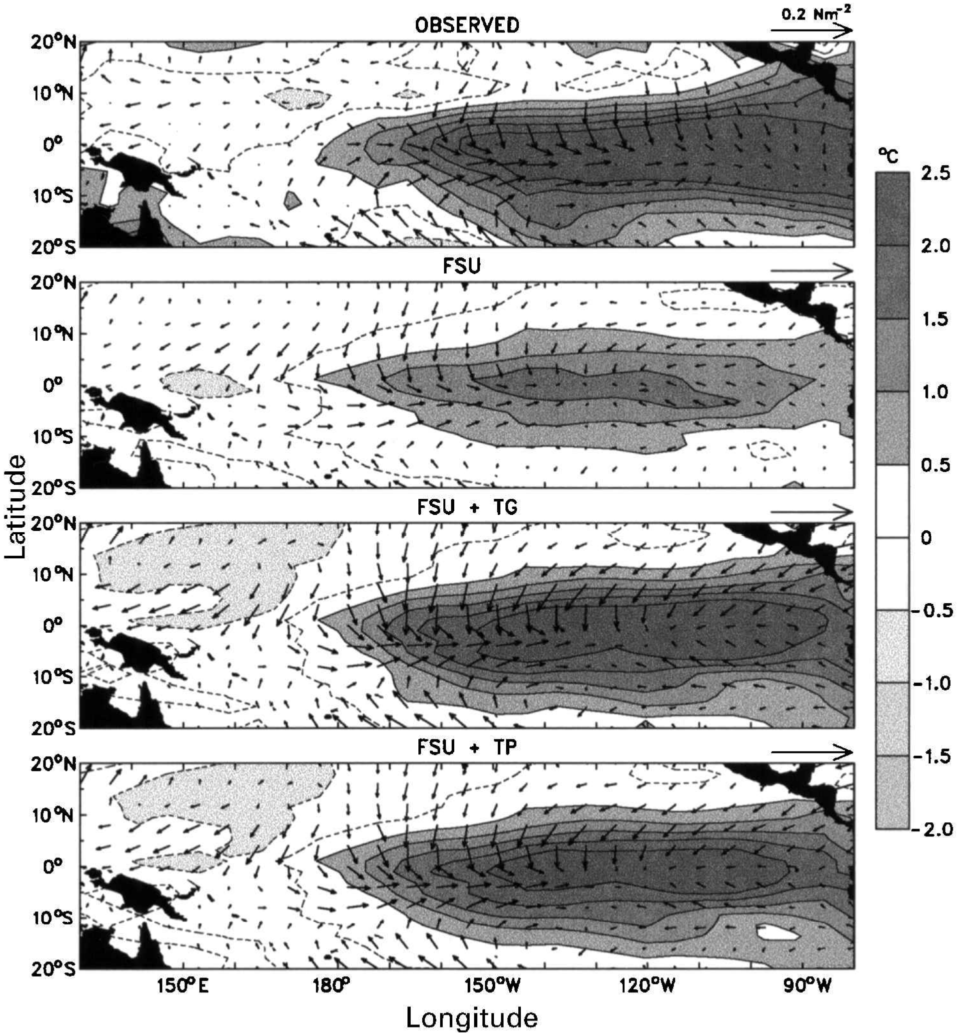

Figure 3. Observed and forecast SST and wind stress anomalies in December-January-February 1997–1998. Forecasts are made two seasons in advance. Areas with SSTA amplitude greater than 0.5° C are shaded, and dashed contour lines are used for values equal or below zero.

3. Results

The impact of the altimeter sea level observation is evaluated through the comparison of three sets of model forecasts, which were initialized with the following data sets, respectively: (1) FSU wind only; (2) FSU wind plus tide gauge (TG) sea level; and (3) FSU wind plus TOPEX/POSEIDON (TP) sea level.

Figure 1 shows the observed and model predicted NINO3 (SST anomaly averaged over 90°–150° W and 5° S–5° N) for the three cases. When the model is initialized with only the FSU wind, forecasts are inaccurate. The probems include the under-predicted magnitude and duration of the 1997–98 El Niño, and the much too warm initial state (start point of each thin curve) for the subsequent La Niña period. The situation is much improved when sea level data (either TG or TP) are included for

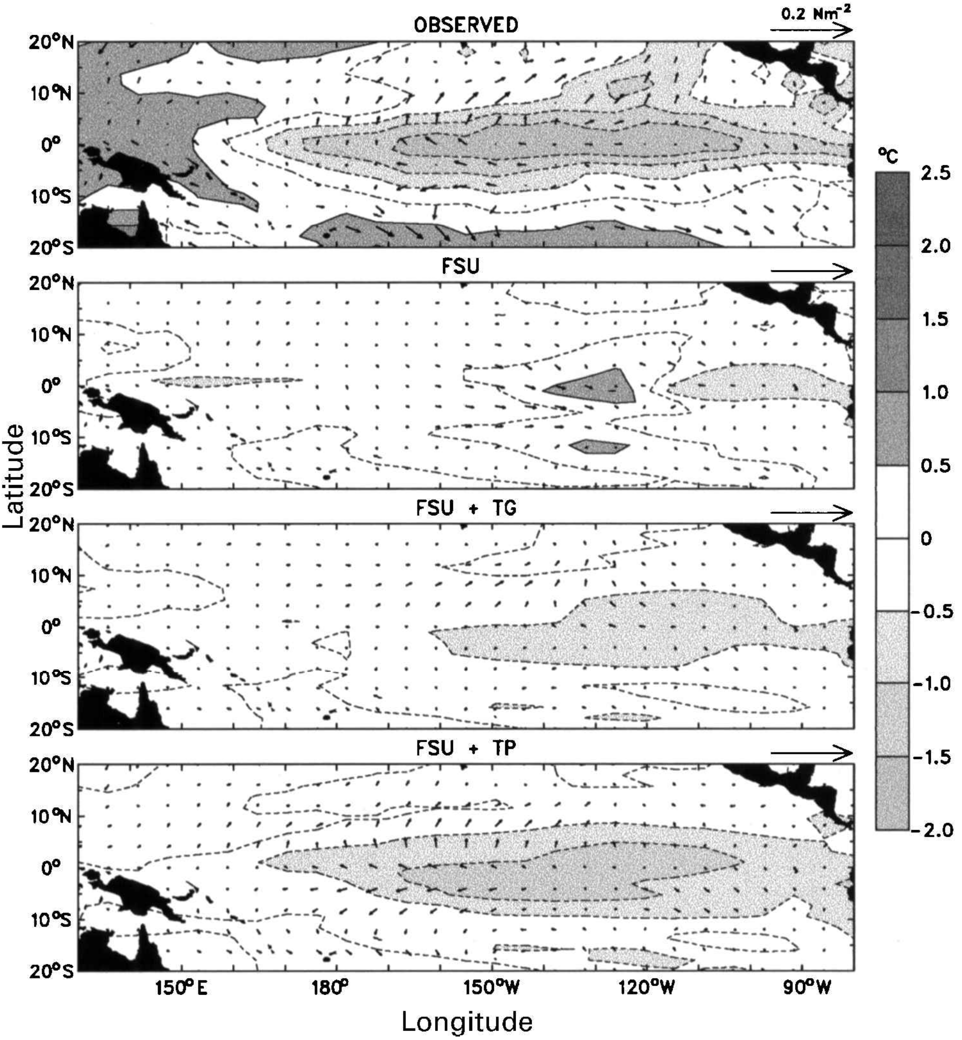

Figure 4. Same as figure 3 except for December-January-February 1999–2000.

initialization. Forecasts are now more consistent, with more accurate predictions of growth and decay of the 1997–98 warm event and the subsequent cool conditions.

Figure 2 compares the three cases in terms of the forecast skill measured by the correlation and the root-mean-square (rms) error between monthly model forecast and observed NINO3. The cases with sea level data assimilation give much higher correlation and lower rms error at all lead times as compared to the case with only wind, but the effects of TG and TP data sets are indistinguishable in a statistical sense. Note that figure 2 should be interpreted with caution because the study period is relatively short and is dominated by one big event.

Figure 3 displays the maps of the observed and predicted 1997–98 El Niño at its mature phase. Again, in the case with only FSU wind assimilation, the warm event is severely underpredicted. When either TG or TP sea level data are assimilated, the model does a remarkable job in predicting both the strength and the shape of the El Niño. Figure 4 shows the same type of plots for the La Niña conditions in the winter of

1999–2000. Now the forecast with TP sea level data assimilation seems to stand out as the best, although the predicted SST is still not as cool as it should be at this time.

4. Discussion

We have demonstrated that the TOPEX/POSEIDON altimeter observation does have a strong positive impact on the Lamont model prediction of the tropical Pacific SST and wind anomalies during the 1990s, especially for the 1997–98 El Niño and subsequent La Niña. As compared to forecasts initialized with only wind data, the model's predictive skill is largely improved at all lead times when the altimeter sea level data are included for model initialization. This reinforces our previous conclusion that sea level data are effective in correcting the model ocean state and preconditioning it for ENSO prediction. The reason is that the sea level contains a great deal of information about the subsurface ocean where lies the memory of the ocean-atmosphere coupled system.

As compared to the tide gauge measurements, however, the altimeter sea level observations do not exhibit significant advantages in improving our model forecasts, despite the large disparity of the two products in spatial resolution. This is probably because of the large-scale nature of ENSO. The evolution of ENSO is dominated by the lowest mode variability and may not be sensitive to the small-scale patterns associated with higher modes. Another possible explanation is that our model is too simple to take full advantage of the high-spatial resolution satellite sensor data. Its coarse spatial resolution and lack of higher modes may prevent it from being sensitive to the small-area variations resolved by the TOPEX/POSEIDON altimetry.

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