ELSEVIER

Remote Sensing of Environment 77 (2001) 275–278

Remote Sensing of Environment

www.elsevier.com/locate/rse

Applying satellite remote sensing to predicting 1999–2000 La Niña

Dake Chen*

Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964-8000, USA

Received 15 October 2000; accepted 26 February 2001

Abstract

The usability of altimeter sea level data (TOPEX/POSEIDON) and scatterometer wind data (QuikSCAT) in El Niño and the Southern Oscillation (ENSO) prediction is investigated with the latest version of the Lamont forecast model. The emphasis of this study is on the effectiveness of these data sets in initializing the model to forecast the 1999–2000 La Niña conditions. Both the altimeter and scatterometer observations helped to improve the model, with the former being more effective for this period. It is possible and extremely useful to apply these data to real-time ENSO forecasting. In principle, it is advisable to assimilate multiple data sets so that they can complement one another in providing the correct initial conditions for the model.

Keywords: Remote sensing; ENSO prediction; Data assimilation

1. Introduction

Application of satellite remote sensing to climate prediction is still in its infancy. Presumably, the superiority of satellite measurements in both spatial and temporal coverage should lead to much improved data sets for forecast model initialization. It is of great interest to the scientific community and space agencies to evaluate the impact of these data sets on predicting climate fluctuations such as El Niño and the Southern Oscillation (ENSO). In a series of recent studies, we have demonstrated that satellite-derived products did have a positive impact on model simulation and prediction (Chen, 2001; Chen, Cane, & Zebiak, 1999; Chen, Cane, Zebiak, & Kaplan, 1998; Chen, Liu et al., 1999). In particular, by applying either the NSCAT wind data or the TOPEX/POSEIDON sea level data to initialize the Lamont forecast model (an intermediate ocean–atmosphere coupled model), we resurrected the model from its failure of predicting the 1997/1998 El Niño. The improvement was attributed to the better-resolved wind fields in the eastern tropical Pacific by the scatterometer, and to the effectiveness of sea level data in correcting and preconditioning the model ocean state.

Here we use the latest version of the Lamont model (Chen, Cane, Zebiak, Canizares, & Kaplan, 2000) to further explore the impact of scatterometer wind and altimeter sea level data on ENSO prediction in terms of the retrospective forecasts of the 1999–2000 La Niña conditions. The new QuikSCAT wind product and the updated TOPEX sea level product are evaluated in this study. Since the QuikSCAT was launched in July 1999, we have only about 13 months of data to date. This makes it impossible to assess the usability of the data in a statistically satisfactory way. Instead, the assessment has to be based on individual forecasts made from this short period. This is a typical problem in applying satellite-derived data sets to climate studies. The relatively short records of these data are the main reason for the obvious lack of their application to ENSO prediction. The situation will undoubtedly improve when data records become longer. In the meantime, it is desirable to start applying available satellite products to climate forecasting. This kind of application, including the one described here, has to be considered experimental at present.

2. Data and model

The wind stress analyses of Florida State University (FSU) (Goldenberg & O'Brien, 1981) are used to spin up the model in the base experiment to be compared to. The

* Tel.: +1-845-365-8496; fax: +1-845-365-8736.
E-mail address: dchen@ldeo.columbia.edu (D. Chen).

0034-4257/01/$ – see front matter
PII: S0034-4257(01)00216-4

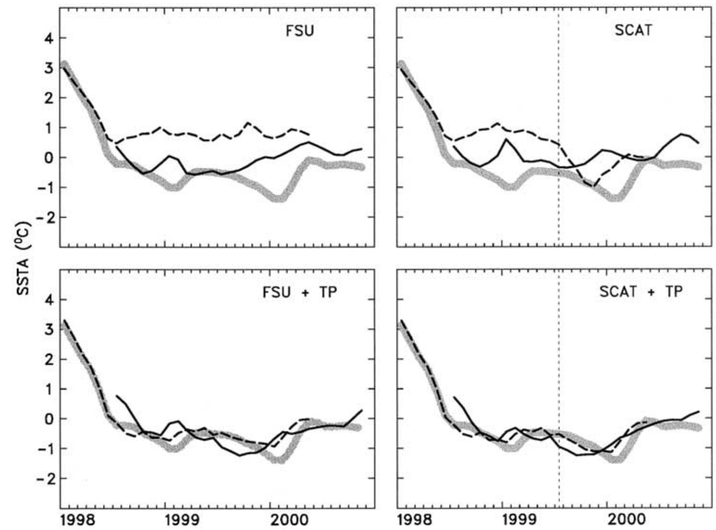

Fig. 1. Lamont model forecasts of NINO3 SST anomaly. The thick grey curve is observation, the dashed curve is initial condition and the black solid curve is the ensemble mean of forecasts at 3–6 months lead times. Wind stress data (either FSU or SCAT) are used for predictions shown in the upper panels, while both wind stress and sea level data (TP) are used for predictions shown in the lower panels. The thin vertical dashed lines in the right panels indicate the time when the QuikSCAT wind data became available.

impact of the scatterometer winds is evaluated by initializing the model with a "blended" wind stress product (SCAT), which is obtained by replacing the FSU winds with the NSCAT winds for the 9-month period from October 1996 to June 1997, and with the QuikSCAT winds for the 13-month period from July 1999 to July 2000. The TOPEX/POSEIDON sea level data (TP) used for model initialization are produced by the NOAA Laboratory for Satellite Altimetry (Cheney, Miller, Agreen, Doyle, & Lillibridge, 1994), which covers a 93-month period from October 1992 to June 2000. The data assimilation method follows the two-step procedure described in Chen et al. (1998).

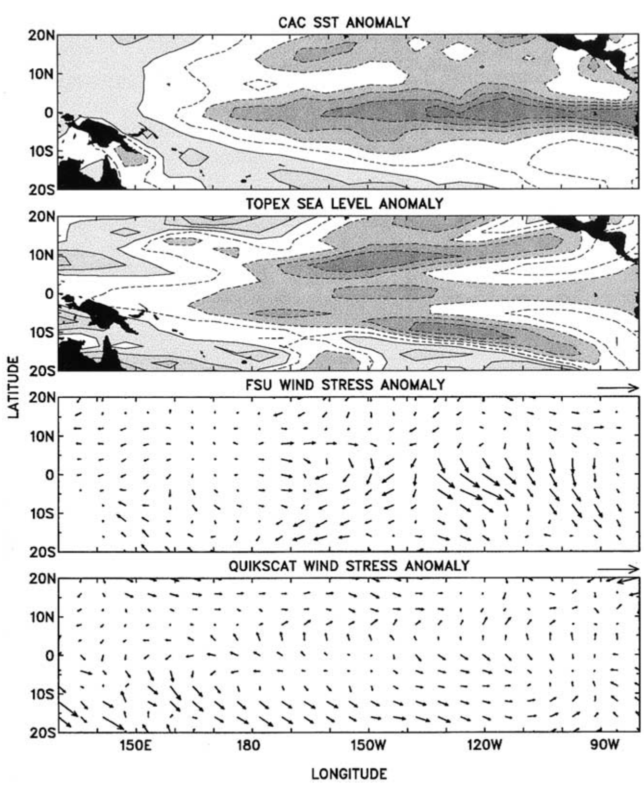

Fig. 2. Observed anomalies in the tropical Pacific averaged from July to December 1999. The contour interval is 0.3°C for SST anomaly and 2 cm for sea level anomaly. Regions with anomaly amplitude larger than 0.3°C and 2 cm are shaded, and dashed contour lines are used for values equal or below zero. Wind stress vectors are measured against the large arrow (1 dyn/cm^2) above the upper right corner of the lower two panels.

The model used in this study is LDEO4, the latest version of the Lamont model. This version is intrinsically different from the original model (Cane, Zebiak, & Dolan, 1986; Zebiak & Cane, 1987) due to the addition of an interactive bias correction component (Chen et al., 2000). The large systematic biases of the original model are 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.

3. Results

The effects of the altimeter sea level data and the scatterometer wind data are evaluated through the comparison of four model experiments, which were initialized with the following data sets, respectively: (1) FSU wind only; (2) SCAT wind only; (3) FSU wind plus TP sea level; and (4) SCAT wind plus TP sea level. Note that SCAT differs from

FSU only in two short periods in 1996/1997 and in 1999/2000. In our previous studies, we have already discussed the impact of the altimeter and scatterometer data on predicting the 1997/1998 El Niño (Chen, 2000; Chen, Cane et al., 1999). Thus, our attention here is on the La Niña period following that huge warm event.

Fig. 1 shows the observed and model-predicted NINO3 (SST anomaly averaged over 90°–150°W and 5°S–5°N) for the 1998–2000 period. The rapid cooling in the early half of 1998 was well simulated in all cases, but the model behaved differently in these experiments for the subsequent period. When only the FSU wind data were assimilated, the model was not able to capture the La Niña conditions. The initial state was about 1.5°C too warm. In the case with the SCAT winds, the initial condition and forecast were very similar to those of the FSU case before July 1999, suggesting that the memory of the NSCAT wind data (assimilated during October 1996–June 1997) had almost been lost by this time. The QuikSCAT winds did bring the initial state closer to reality for the period after July 1999, but did not do much good for forecast. The situation was much improved when TP sea level data were included for initialization. Both initial condition and forecast were much better, generally following the observed NINO3.

The reasons for the large differences in model behavior have to lie in the data being assimilated. Fig. 2 displays the observed anomaly fields averaged for the 6-month period from July to December 1999. The SST pattern during this period was characterized by rather strong cold anomalies in the central and eastern equatorial Pacific Ocean. Correspondingly, there were negative sea level anomalies (thermocline elevations) in those regions. This sea level anomaly pattern was not found in the experiments without sea level data assimilation. The FSU wind anomaly field was dominated by strong westerlies in the eastern Pacific, which is not dynamically consistent with the observed SST anomaly field. The SCAT wind anomalies bore little resemblance to those of the FSU analyses, and seemed more in line with the heating patterns associated with the SSTA.

The average initial SST anomalies from different model experiments are compared in Fig. 3. In response to the spurious westerlies in the FSU data, the model produced a large warm anomaly in the eastern Pacific. This error was eliminated by either replacing the FSU winds with the QuikSCAT winds or including TP sea level data for initialization, but the latter seemed to be more effective. The best simulation came from the experiment with both scatterometer winds and altimeter sea level, indicating the advantage of assimilating multiple data sets. The model forecasts from this experiment are shown in Fig. 4 for the same La Niña period. Initialized with the satellite-derived wind and sea level data, the model was able to forecast this cold phase of ENSO at

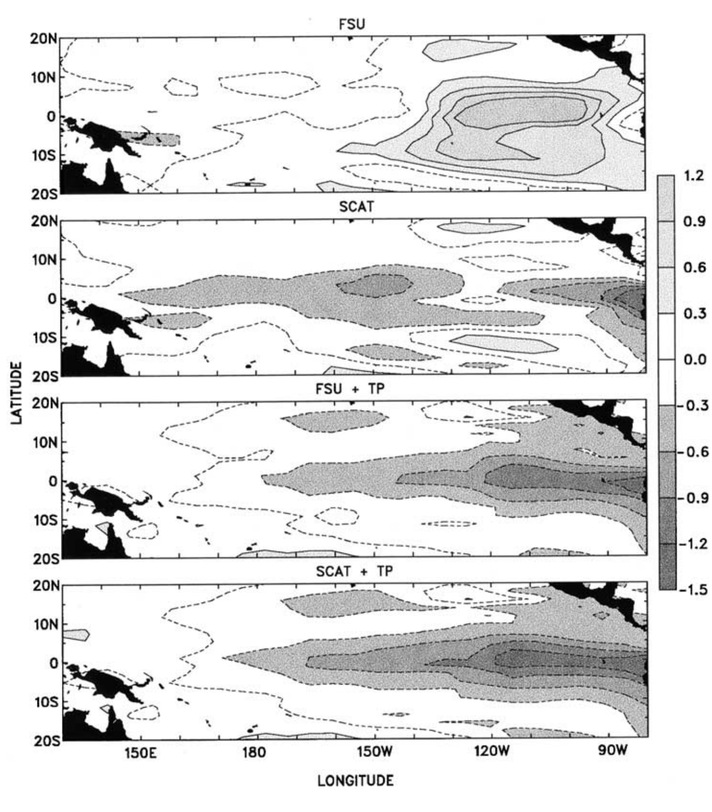

Fig. 3. Model SST anomalies averaged from July to December 1999, with different data assimilated. Regions with anomaly amplitude larger than 0.3°C are shaded, and dashed contour lines are used for values equal or below zero.

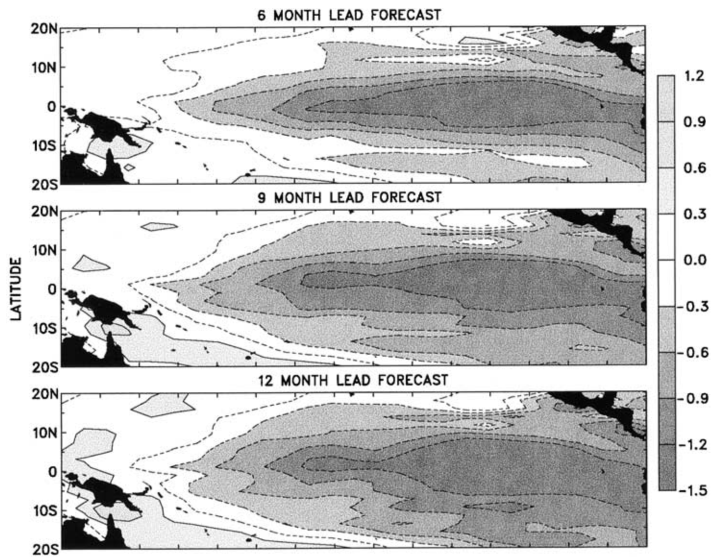

Fig. 4. Forecast mean SST anomalies of July to December 1999 at different lead times. Regions with anomaly amplitude larger than 0.3°C are shaded, and dashed contour lines are used for values equal or below zero.

lead times up to 12 months, although the model-predicted cold tongue tends to be broader than the observed.

4. Summary and discussion

In this study, we have demonstrated the usability of altimeter sea level data and scatterometer wind data in ENSO prediction. It is possible and potentially very useful to apply these data to real-time forecasting. Either the TOPEX/POSEIDON or the QuikSCAT observations could have improved our model prediction of the 1999–2000 La Niña conditions in the tropical Pacific, with the former being more effective. Yet the best simulation and prediction were obtained when both of these data sets were applied. Therefore, it is advisable to assimilate multiple data sets so that they can complement each other in providing the correct initial conditions for the model. The TOPEX/POSEIDON and QuikSCAT data are now being routinely used in our operational experimental forecasting.

A notable problem in our forecasts of the 1999–2000 La Niña is that the predicted cold anomalies are not as confined to the equator as those observed, especially at long lead times. This has nothing to do with the data being assimilated, but has everything to do with the internal variability of the model. The ENSO cycle produced by the Lamont model is more symmetric than that found in nature. Thus, the model-predicted cold events are as widespread as the warm events, as evident in Fig. 4. The best remedy for this problem is to find the physical mechanism responsible for the asymmetry between El Niño and La Niña, and include it specifically in the model. In the meantime, the easy solution is to treat this as a systematic model bias and correct it using statistical methods.

Acknowledgments

This research was supported by the National Oceanic and Atmospheric Administration through grants NA56GP0221 and NA76GP0500, and the National Aeronautics and Space Administration through grant JPLCIT 1217618. This is LDEO contribution number 6163.

References

Cane, M. A., Zebiak, S. E., & Dolan, S. C. (1986). Experimental forecasts of El Niño. *Nature*, *321*, 827–832.

Chen, D. (2001). Application of altimeter observation to El Niño prediction. *International Journal of Remote Sensing*, (accepted).

Chen, D., Cane, M. A., & Zebiak, S. E. (1999). The impact of NSCAT winds on predicting the 1997/98 El Niño: a case study with the Lamont model. *Journal of Geophysical Research*, *104*, 11321–11327.

Chen, D., Cane, M. A., Zebiak, S. E., Canizares, R., & Kaplan, A. (2000). Bias correction of an ocean–atmosphere coupled model. *Geophysical Research Letters*, *27*, 2585–2588.

Chen, D., Cane, M. A., Zebiak, S. E., & Kaplan, A. (1998). The impact of sea level data assimilation on the Lamont model prediction of the 1997/98 El Niño. *Geophysical Research Letters*, *25*, 2837–2840.

Chen, D., Liu, T., Zebiak, S. E., Cane, M. A., Kushnir, Y., & Witter, D. (1999). The sensitivity of the tropical Pacific ocean simulation to the spatial and temporal resolution of wind forcing. *Journal of Geophysical Research*, *104*, 11261–11271.

Cheney, R., Miller, L., Agreen, R., Doyle, N., & Lillibridge, J. (1994). TOPEX/POSEIDON: the 2-cm solution. *Journal of Geophysical Research*, *99*, 24555–24564.

Goldenberg, S. B., & O'Brien, J. J. (1981). Time and space variability of tropical Pacific wind stress. *Monthly Weather Review*, *109*, 1190–1207.

Zebiak, S. E., & Cane, M. A. (1987). A model El Niño Southern Oscillation. *Monthly Weather Review*, *115*, 2262–2278.