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The impact of NSCAT winds on predicting the 1997/1998 El Niño: A case study with the Lamont-Doherty Earth Observatory model

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Abstract. Using the NASA scatterometer (NSCAT) winds for initialization has greatly improved the Lamont-Doherty Earth Observatory model forecasts of the 1997/1998 El Niño. The improvement is mostly attributed to the better resolved wind field in the southeast tropical Pacific. Because of the simplicity of the model and the short record of the NSCAT data, our model results should be taken as indicative rather than conclusive. Nevertheless, it is crucial to assimilate accurate information into the initial model state to predict the development of El Niño. Satellite-derived wind products certainly have the potential to provide such information for real-time forecasting.

1. Introduction

The huge 1997/1998 El Niño has not only caught the public eye but also posed new challenges to the scientific community. One question we have to address is how well we can predict an El Niño like this with the models and observational data presently available. Prediction is the ultimate goal of our efforts in developing models and observing systems. It seems puzzling that some well-established El Niño–Southern Oscillation (ENSO) forecast models failed to predict the onset of this warm event. For example, despite the apparent success of the Lamont-Doherty Earth Observatory model (hereinafter referred to as the Lamont model) in the past [*Cane et al.*, 1986; *Zebiak and Cane*, 1987; *Chen et al.*, 1995], it experienced a failure this time. A possible explanation is that the climate has changed in a manner not well captured by the models and that they can no longer perform well without assimilating more or better data. This is supported by the fact that the general circulation models (GCMs) with extensive data assimilation have done a better job in recent years [e.g., *Ji et al.*, 1997]. This is also supported by our present results, based on a series of forecast experiments using two different wind products for model initialization.

Here we evaluate the impact of the 9 months of NSCAT wind product on the model prediction of 1997/1998 El Niño. Generally speaking, a short data set like this would have very limited use for studying climate variability, and its impact on climate prediction would be difficult to assess. Since the spin-up over several years has an influence on present conditions, ideally, we would have had NSCAT winds for several years prior to 1997. However, we are fortunate to have NSCAT launched at an auspicious time. In spite of its tragic disappearance, NSCAT does cover the whole onset phase of the recent El Niño. Because of the large amplitude of this event, the impact of NSCAT winds can be evaluated unambiguously by examining the actual model forecasts initialized with this wind product. The Lamont model is ideal for this kind of experiment, since in its standard setting it takes only wind data for initialization, so that the impact of winds can be estimated independent of other data. More importantly, we would like to see if we can save the Lamont model from its recent failure by replacing the ship-based wind analyses used in the model with the more spatially uniform NSCAT winds.

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2. Results

2.1. Initial Conditions

In this study the model was spun up with the Florida State University (FSU) wind stress as before, but for the period from October 1996 to June 1997, the FSU wind anomalies were replaced by the NSCAT wind anomalies for model initialization. The climatology used to calculate the NSCAT wind anomalies is from the FSU analyses. To reduce the transition error and systematic bias in amplitude, the mean standard deviation of the NSCAT wind stress anomalies in the equatorial Pacific was scaled to that of the FSU analyses for this 9-month period, which amounted to only about 5% correction. This indicates that the wind stress anomalies of the two products have similar amplitudes, and their differences, if any, are mostly in their spatial patterns. Therefore the different model responses discussed below reflect the real differences in the wind products rather than artifacts introduced by our scaling or other procedures.

Figure 1 compares the monthly averaged wind stress anomalies of FSU and NSCAT in the tropical Pacific for the 9 months when the NSCAT winds are available. The corresponding model sea surface temperature (SST) anomalies, which are used as initial conditions for forecasts, are also shown in Figure 1. The two wind products were generally similar in the western Pacific, but in the east, much stronger easterlies were found in the FSU analysis. As a result, the SST in the eastern equatorial Pacific was much cooler in the case with the FSU winds than in the case with the NSCAT winds. The differences in wind pattern and model response are more clearly seen in Figures 2a and 2b, where the 9-month-averaged anomalies of wind stress, SST, and thermocline depth are displayed. The stronger easterlies in the FSU analysis east of 150°W not only enhanced equatorial and coastal upwelling, which gave a cooler SST field, but also generated convergent flows and an associated mid-ocean maximum in thermocline depth.

The temporal variations of these quantities at the equator are shown in Figure 3 for the two cases. In both wind products

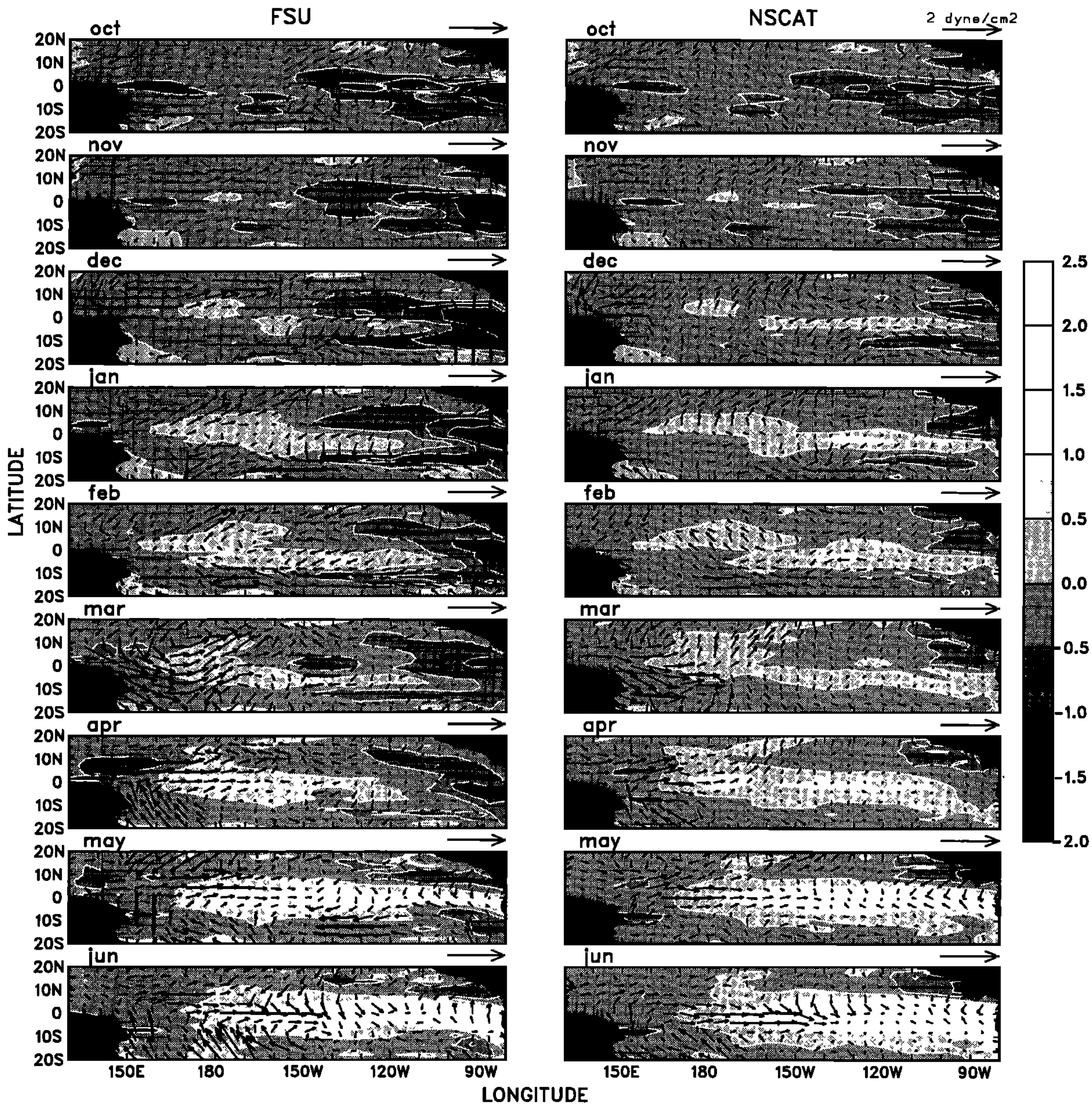

Figure 1. Florida State University (FSU) and NASA scatterometer (NSCAT) wind stress anomalies (vectors) and corresponding model sea surface temperature (SST) (degrees Celsius) anomalies (shading) in the tropical Pacific for the 9-month period from October 1996 to June 1997.

there were two westerly wind bursts in the western equatorial Pacific during this 9-month period, one in December 1996 and the other in March 1997. These bursts generated eastward propagating, downwelling Kelvin waves which resulted in surface warming in the eastern part of the ocean. Although the warming rates were about the same for the two cases, the resulting SST was warmer in the case with the NSCAT winds because it was warmer before the arrival of these waves. The stronger easterlies in the central and eastern Pacific were obviously responsible for the cooler SST in the case with the FSU winds. For example, the more intensive and prolonged easterly winds centered in February 1997 produced a more energetic upwelling Kelvin wave and a stronger cooling, which made the subsequent westerly-induced warming less effective. The effect of these different initial conditions on model prediction is examined next.

2.2. Forecasts

The model forecasts of NINO 3 index (SST anomaly averaged over the region from 5°S to 5°N and from 90°W to 150°W) are compared in Figure 4 for the two cases. In the case with the FSU winds the mode failed to predict a large warm event, even when the El Niño was already well under way. It warmed up reluctantly in the forced mode, as indicated by the initial condition of each forecast (the starting point of each curve); but in the forecast model the initial warm anomalies only grew for a short period of time and then decayed. It seems that the model was just not ready for an El Niño. The situation is greatly changed in the case with the NSCAT winds. Although the model still did not show much activity for the first few months, it started to predict a warm event in March, and after that the forecasts became consistent and produced a rapid warming,

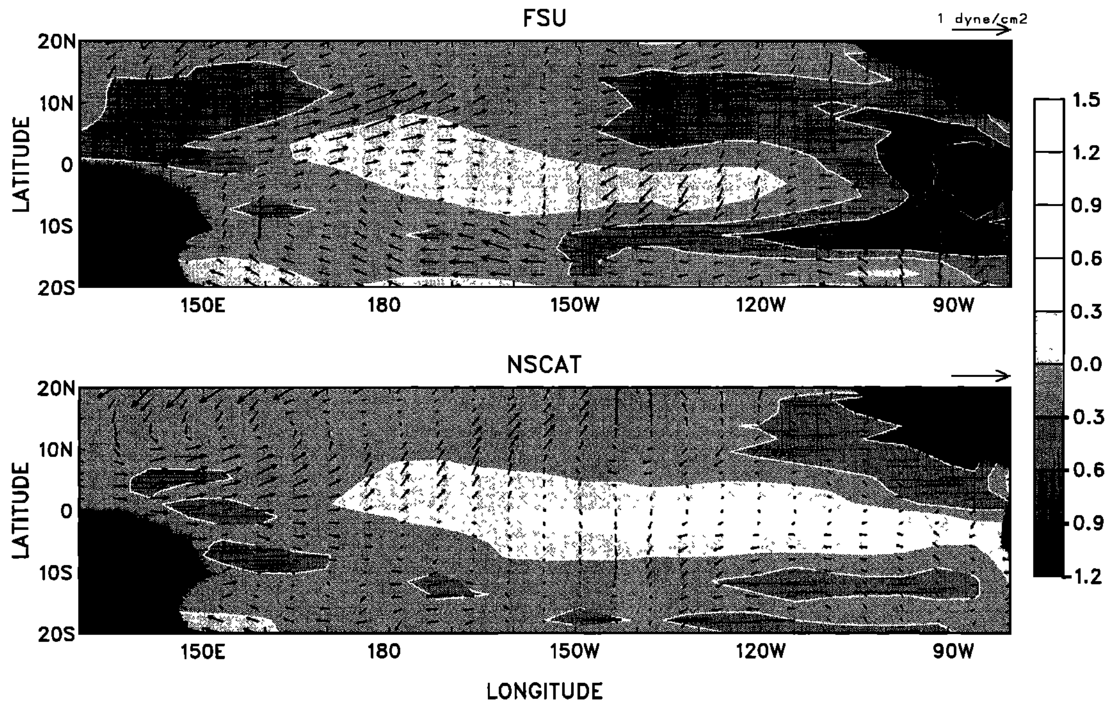

Figure 2a. Nine-month (October 1996 to June 1997) averaged anomalies of wind stress (vectors) and SST (degrees Celsius) anomalies (shading). Units for SST and thermocline depth.

similar to observations. The impact of NSCAT winds is positive and unmistakable.

Now we have to find out what is responsible for this rather large improvement. Figure 5 compares the wind stress anomaly fields of the two products in the tropical Pacific, averaged over the 4-month period from March to June 1997. In the western Pacific both FSU and NSCAT winds had strong westerly anomalies although they were a bit different off the equator. In the regions east of 150°W, however, the two products showed little resemblance. The relatively strong easterly anomalies in the FSU winds are responsible for the cooler initial SST in that case, as we pointed out earlier. However, the difference in initial SST fields cannot be fully responsible for the vast difference in forecast behavior, since with the NSCAT winds the

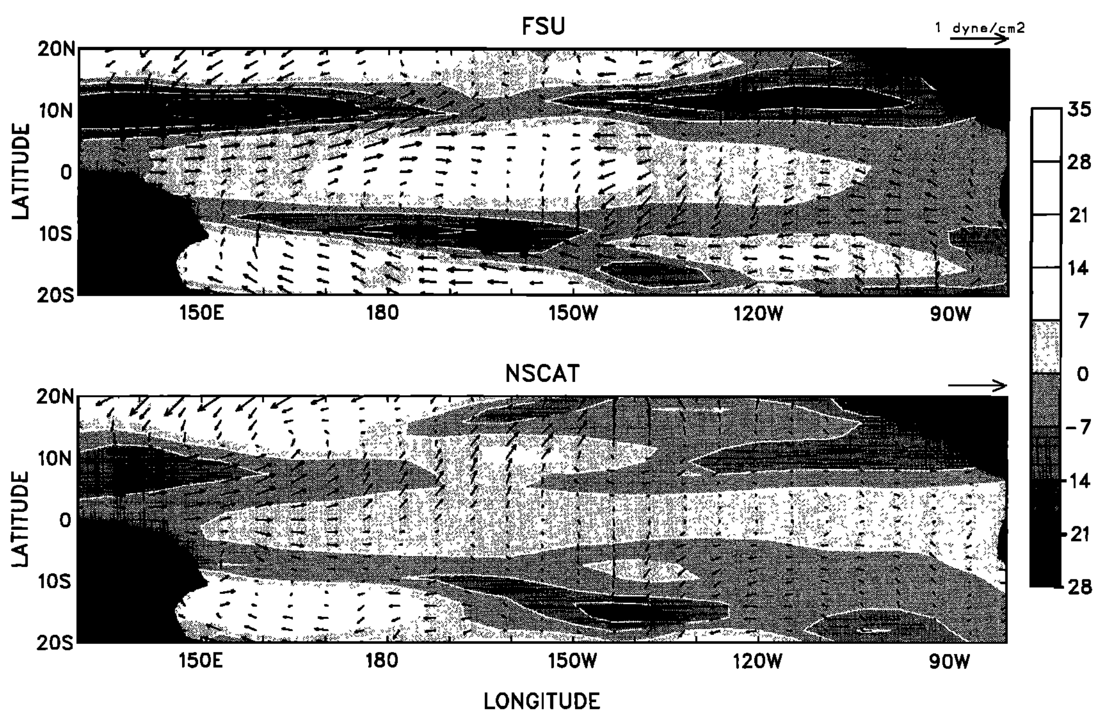

Figure 2b. Same as Figure 2a, but for wind stress (vectors) and thermocline depth (meters) (shading).

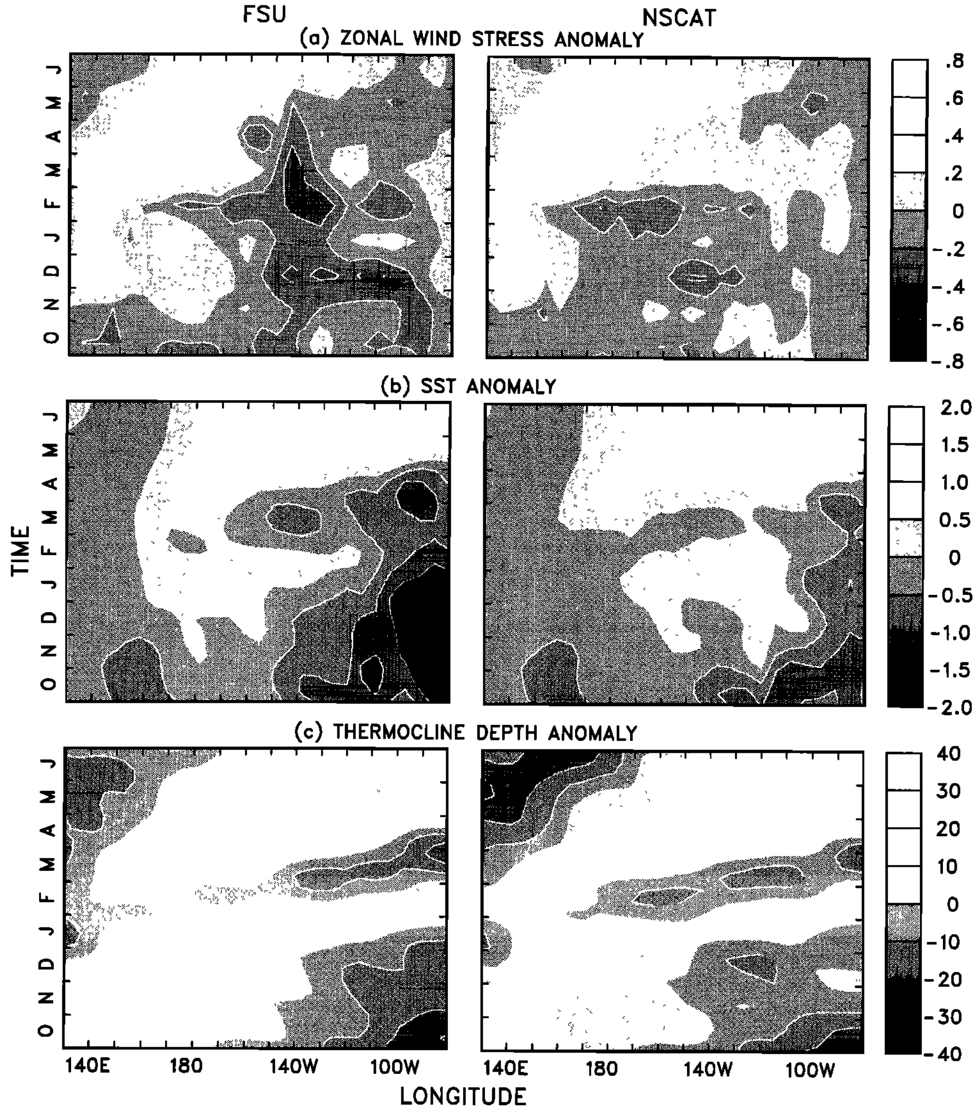

Figure 3. Time-longitude plots of initial (a) zonal wind stress, (b) SST, and (c) thermocline depth anomalies at the equator for the two different wind products.

model succeeded in the relatively cool months of March and April, while with the FSU winds it failed even in June. The memory of the system, which largely determines the development of the initial anomalies, is mostly contained in the subsurface ocean. This is represented by the initial thermocline depth anomalies shown in Figure 5.

The thermal structure in Figure 5 (bottom), which corresponds to the NSCAT winds, shows some similarities to observations and to the fast growing mode of singular vector analysis [*Xue et al.*, 1997], but it is not yet clear why such a pattern is more favorable for El Niño development. The physical processes at work need to be further explored. Thus far, we have tried to pinpoint exactly what differences in the wind fields cause the difference in the initial thermal states and the subsequent forecasts. This was done by replacing the FSU winds with the NSCAT winds in different subregions. Figure 6 shows the model forecasts initialized with the NSCAT winds applied only west or east of 150°W. It is obvious that the improvement of forecasts was almost entirely due to the improved winds in the east. When we further divided the eastern Pacific (east of 150°W) into southeast and northeast regions separated by the equator, we found that the wind difference in the southeast matters the most (Figure 7). This makes sense because data are particularly lacking in that region for the conventional wind products such as the FSU analyses.

We can verify this point by examining the data availability of the FSU analyses and comparing it with that of the NSCAT wind product. Figure 8 shows the number of wind observations used in the FSU analyses for January 1997, which is representative of the data density and distribution for the 9-month study period. The coverage was obviously enhanced near the equator by including the Tropical Ocean–Global Atmosphere/Tropical Atmosphere Ocean (TOGA/TAO) measurements, but there were still many data gaps, especially in the southeastern tropical Pacific. In contrast, the satellite data used for the NSCAT wind product were quite uniform in both space and time, with approximately 5000 observations in each 10° × 2° box shown in Figure 8 for each month of the study period. It is clear that the NSCAT product provides a much better resolved wind data set as compared to the FSU analyses, and, as shown above, this does make a huge difference in initializing the Lamont model for ENSO forecasting.

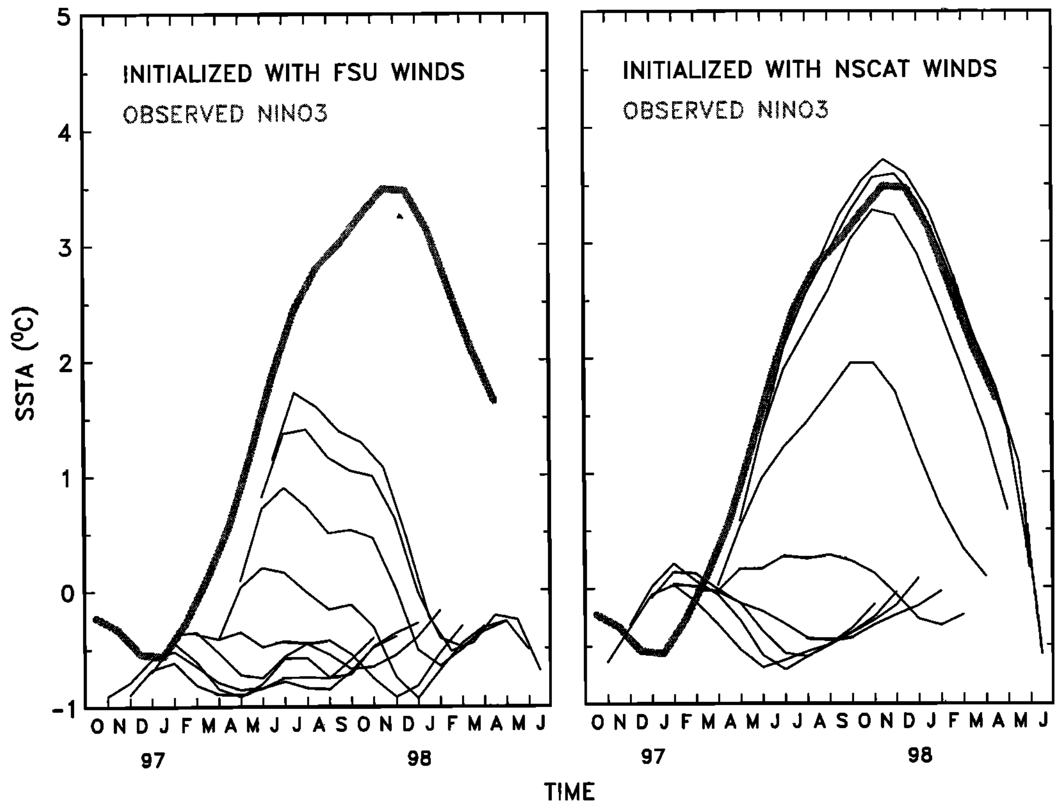

Figure 4. Model forecasts of NINO 3 initialized with FSU and NSCAT winds. Each solid curve is a 12-month forecast starting at each month from October 1996 to June 1997. Stippled curve is observed NINO 3.

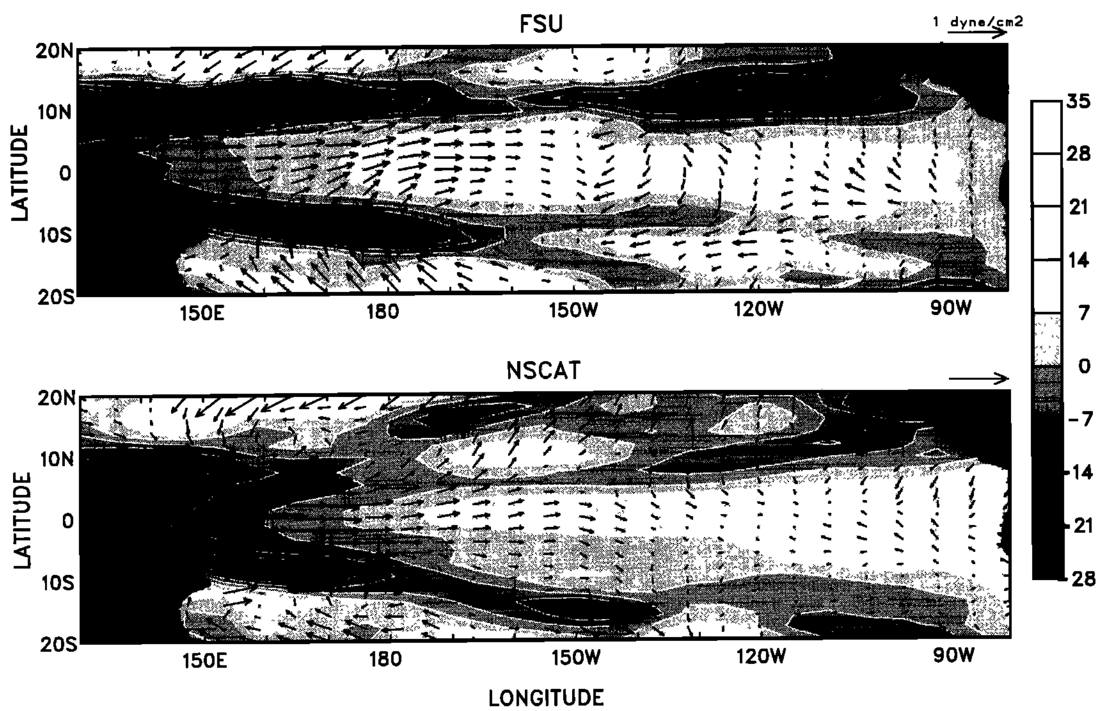

Figure 5. Same as Figure 2b, except for 4-month average (March–June 1997).

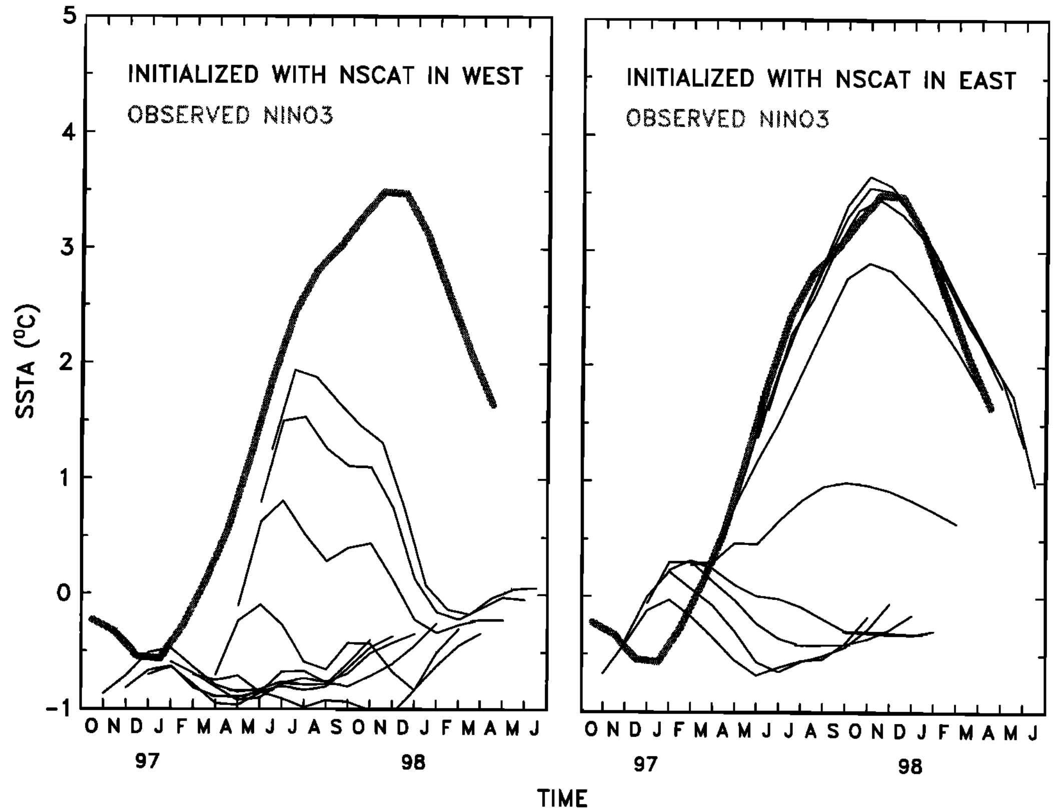

Figure 6. Same as Figure 4, except for cases with NSCAT winds applied only to the west or east of 150°W.

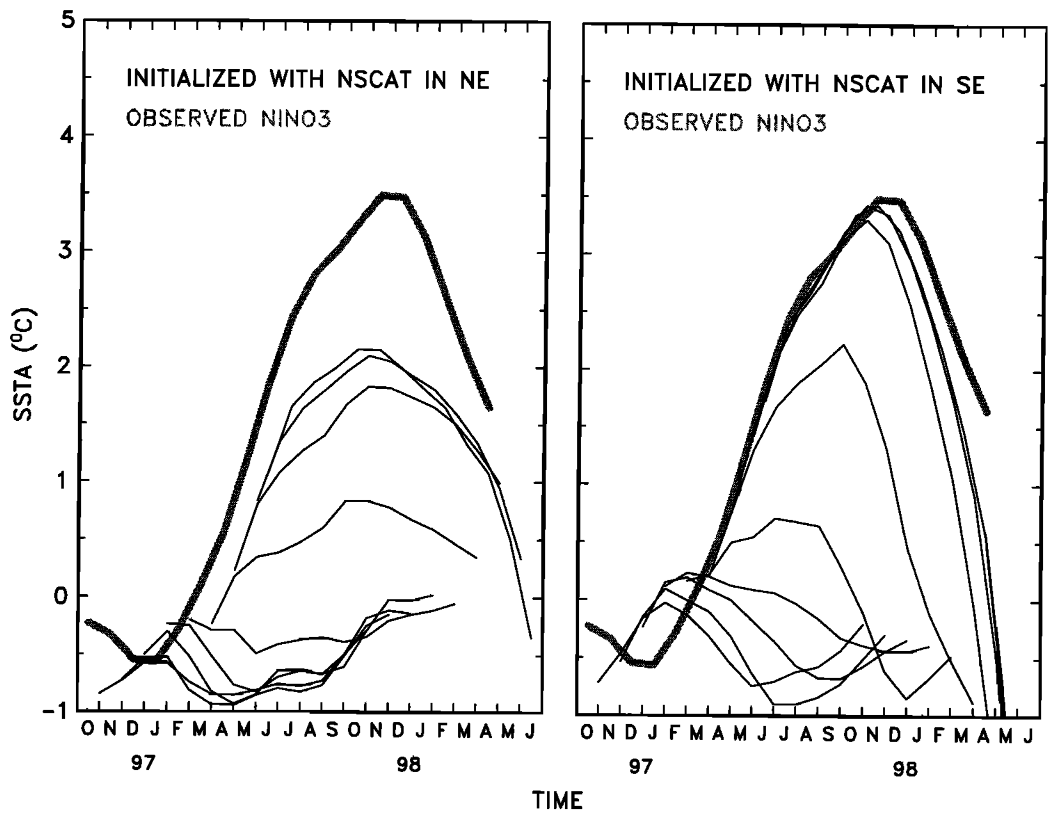

Figure 7. Same as Figure 4, except for cases with NSCAT winds applied only in the northeast (east of 150°W and north of the equator) or southeast (east of 150°W and south of the equator).

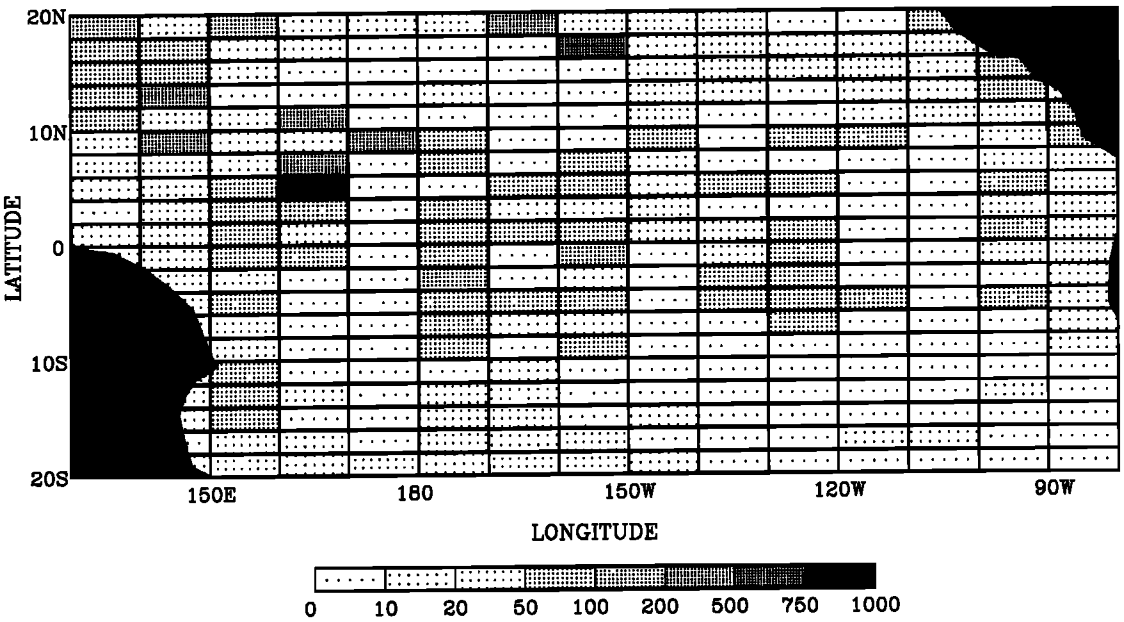

Figure 8. Density and distribution of the wind data used in the FSU analyses, measured by the number of observations in every 10° × 2° box in the tropical Pacific for January 1997.

3. Summary and Discussion

We have demonstrated that the NSCAT wind product has a strong positive impact on the Lamont model prediction of the 1997/1998 El Niño. The improvement of the model initial state and forecasts is mostly attributed to the better resolved wind field in the southeast tropical Pacific. Specifically, the NSCAT observations eliminated the large easterly wind anomalies found in the FSU analyses that tend to cool SST and produce oceanic initial conditions unfavorable for the development of El Niño. However, there is little evidence that the model is particularly sensitive to the wind forcing in the southeast tropical Pacific compared with other areas. Presumably, the NSCAT winds are most helpful in that region because of the lack of in situ data there.

There are two limitations of this study that make the results less conclusive. First, the Lamont model has highly simplified physics and there are systematic biases in model fields. Moderate errors in initial conditions can grow rapidly in forecast mode. This could have made the model prediction too sensitive to the wind data used for initialization. Second, there are only 9 months of NSCAT data, so that we cannot afford a smooth enough transition from the FSU to the NSCAT winds. Although a scaling correction was applied to reduce the transition errors, some spurious transients could still be generated in the model. These transients might be partly responsible for the inability of the model to predict the El Niño prior to March 1997, which remains a major default of this study.

It is also worth noting that the sensitivity to wind data reported here may not be found in other models that assimilate various data sets in addition to winds, because the correct information contained in other data, especially oceanic subsurface data, can make up for the deficiency in winds. As a matter of fact, we have tried to assimilate sea level observations (dynamically equivalent to thermocline depth in this model) for model initialization, which also greatly improved the prediction of the 1997/1998 El Niño [*Chen et al.*, 1998]. Nonetheless, a reliable wind product is always needed, and its importance to ocean and climate modeling can never be overemphasized. This study provides an example of the great potential of the satellite-derived wind products.

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