Prediction of the El Niño of 1982–83

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ABSTRACT

The large growth of SST anomalies during 1982–83 in the equatorial Pacific could have been predicted 4–5 months in advance via advanced statistical models. The decay of the warmth was not well predicted, a result attributed to the need for local forcing and thermodynamic considerations in the modeling process. "Kelvin-wave" models will likely have this same deficiency. The success of the statistical models indicates that the development of the SST anomalies during 1982–83 was not unusual.

1. Introduction

The recent climatic changes in the tropical Pacific during 1982–83 have caused much excitement and interest. A number of papers have already been written describing the events, and more are sure to follow. The one thing that seems reasonably clear at this stage is that the size of the sea surface temperature (SST) anomalies observed in the equatorial ocean during the last 1–2 years are as large or larger than any observed during this century.

Given the dramatic happenings of the last two years, it is logical to ask if the SST anomalies could have been predicted. Indeed, there are several suggestions in the literature that large ocean warming events such as El Niño could be predicted (Barnett, 1977, 1981a; Hasselmann and Barnett, 1981). The key predictor found to be important in these studies, as well as in theoretical studies (e.g., McCreary, 1976), was knowledge of the zonal wind in the equatorial regions of the western and central Pacific. More recent work (e.g., Busalacchi and O'Brien, 1980, 1981) have substantiated these early findings although they did not explicitly use a forecast model. Given this past work, it seemed worthwhile to determine if it would have been possible to predict the large ocean event of 1982–83; that is the purpose of this study.

2. Data and methods

The data for this study come from ships' weather observations. These data are used to define SST variations in the "predictand" regions shown in the lower panel of Fig. 1. Anomalies relative to a long term mean were computed for each 1° square within the large averaging areas shown in Fig. 1 (lower). For a given month, all the anomalies within the region were averaged to give a grand anomaly for the area under consideration. Note that the area off South America (SST5) corresponds closely to the classical El Niño region much discussed in the literature. The area in the central Pacific corresponds closely to the region thought to have a significant impact on climatic variation over North America. Indeed, the region off South America also is known to have significant skill in forecasting subsequent cold season conditions over North America (e.g., Barnett, 1981b).

The "predictors" used in this study are anomalous components of the zonal and meridional wind fields in the near equatorial region. These predictors were again represented as large area averages; the anomalies representative of the areas were obtained in the same manner as the SST anomalies. The predictor regions are shown in the upper panel of Fig. 1. These regions were selected based on their empirical and theoretical importance as defined in the work cited above.

The methods used in developing the prediction model are those described by Barnett and Hasselmann (1979) and Hasselmann and Barnett (1981). The idea was to make a regression model relating variations in sea-surface temperatures in the predictand regions to prior variations in the wind fields over the predictor areas. The modeling approach is general enough to allow for variation of the prediction coefficients with respect to the annual cycle. It turns out that this is an absolute necessity in trying to predict variations in tropical Pacific SSTs, as we shall see later. The approach also made it possible to include the prior year's evolution of the predictor fields in the modeling process (see the Appendix).

The time series for the predictor/predictands for the period 1950–81 were used to develop the statistical prediction models. These models were then applied to the independent predictor/predictand data extending from January 1982 through June 1983. The lead times

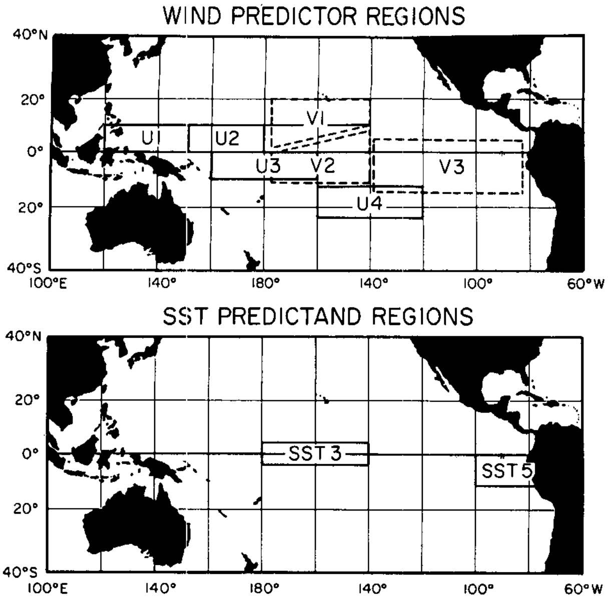

FIG. 1. Upper: Wind predictor regions used in this study. Lower: Regions for which average sea-surface temperature anomalies were predicted in this study.

associated with the forecast models were varied from 1 to 12 months.

3. Results

a. Eastern equatorial Pacific

The *hindcast* skill, expressed as a percent of the variance for the predictand region off the coast of South America, is shown in Fig. 2 for lead times of 2–8 months. The main feature of this illustration is that variations off South America are relatively well hindcast during the summer months, particularly August. During the period December–March, however, the hindcast skill was generally less than twice the artificial skill and so is not shown in Fig. 2. This leads immediately to the conclusion that SST variations in this region during this particular period of the year will not be predicted. Note that the hindcast skills are quite similar for lead times between 2 and 4 months. Beyond the 4-month lead time, the skill drops rather sharply and appears to change its phase with respect to the annual cycle. This skill appears low enough to be of questionable practical value. In summary, the forecast model should be most successful in predicting summer values at lead times of 4 months or less.

The *forecast* SST anomaly for 1982–83 is shown in Fig. 3. The values have been normalized by the standard deviation of the hindcast model. The normalized anomaly *observed* for the SST region off South America is also shown. The onset of the El Niño event is quite well predicted by the simple statistical model. The peak magnitude of the event is also quite well forecast although this success is not expected on average since the hindcast is low in this part of the year (cf. Fig. 2). In any event, the prediction of the El Niño some 4 months in advance was a success.

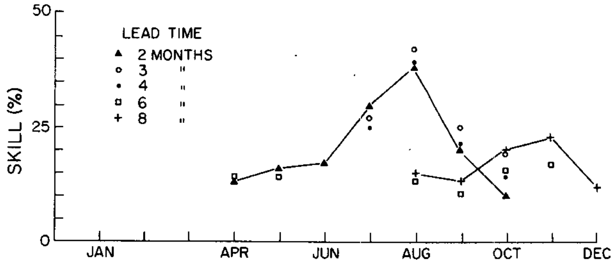

FIG. 2. Hindcast skill (percent of the variance) for the SST area off South America. The skills are shown for lead times of 2–8 months as a function of time of the year.

The success may be quantified by making the following statement based on the simple statistical model: "A warming of SST off the coast of South America with magnitude exceeding two standard deviations will be expected to occur in the October–November time frame." This statement could have been made at the end of July 1982. The maximum of the event did not occur until December 1982 and could have been forecast by midsummer although the confidence in this forecast would have been low for the reasons noted above. This result also suggests that the 1982–83 event followed a more or less normal pattern of evolution; it was not all that unusual, as has been suggested by some.

The second item of considerable importance to note in Fig. 3 is the failure of the simple statistical model to predict the decline of El Niño. The model calls for a rapid decline and an abrupt switch to cold conditions

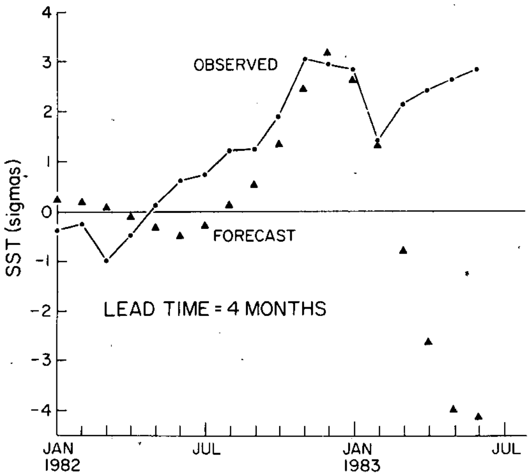

FIG. 3. Actual forecast of the SST anomaly off the coast of South America for the period January 1982 through June 1983. The forecast lead time was 4 months.

off South America. The data indicate that the SST anomaly remained in place and of nearly equal strength during the spring of 1983. The failure of the model can be traced directly to the predictor regions that give rise to the model skill.

The important predictor regions were found to be in the far western Pacific, a result suggested some years ago by Barnett (1977). Toward the end of 1982 and in early 1983, the normal wind systems reestablished themselves in this region and were, in fact, stronger than normal in a sense opposed to that which gave rise to the El Niño. The model keyed on this fact and therefore predicted colder than normal SST off South America. The model failure makes it clear that more than remote forcing is involved in the heat budget of the region off the South American coast. It is suggested that local wind forcing may also be important. Such forcing was not included in this simple statistical model and may, therefore, be the reason for failure of the forecast plus the inability of the model to even hindcast the winter/spring SST off South America (cf. Fig. 2).

It may be noted finally that models which seek to explain the variability of SST at the coast of South America solely in terms of remotely forced Kelvin waves (e.g., Busalacchi and O'Brien, 1980; Inoue and O'Brien, 1984) are apt to fail in explaining the spindown phase of the 1982–83 El Niño. The reasons are similar to those for failure of the simple statistical model, i.e., local forcing, not remote forcing, appears to be responsible for the continued warmth off the coast of South America.

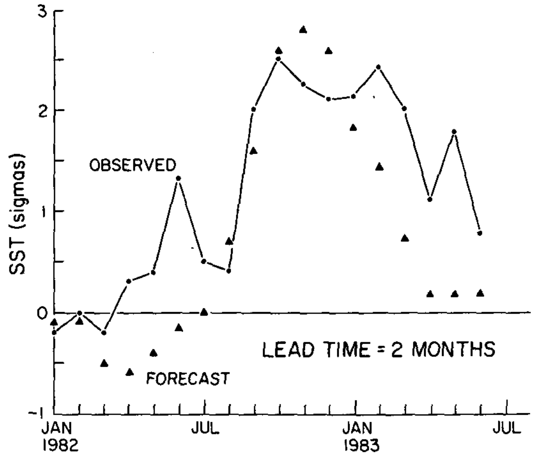

FIG. 5. Observed versus forecast SST anomalies for the central equatorial Pacific, January through June 1983. The forecast lead time was 2 months.

b. Central Pacific

The hindcast skills for the central Pacific SST region are shown in Fig. 4. Note the extraordinarily high skill (70%) at lead times of 2 months. The skill decay is rather regular with lead time up to 5 month lead times. Beyond lead times of 5 months, no skillful hindcast model could be developed during any month of the year for the central Pacific region. Note that, as with the region off South America, the predictive skill in the central ocean is confined to the northern spring through fall period. Relatively large hindcast skills were not found during the December–March period.

The results of the independent forecast experiment at a lead time of 2 months is shown in Fig. 5. Again, the build-up of the SST anomaly is well captured by the model. Note that the decay of the event is less well predicted but nonetheless apparent in the forecast experiment. These results again suggest that the 1982–83 event evolved in a more or less "normal" manner; otherwise, the statistical model would have failed.

The skill of the forecast model at lead times of both 4 and 5 months is shown in Fig. 6. Again, the build-up phase of the SST anomaly event is rather well predicted, although there does appear to be perhaps a 1–

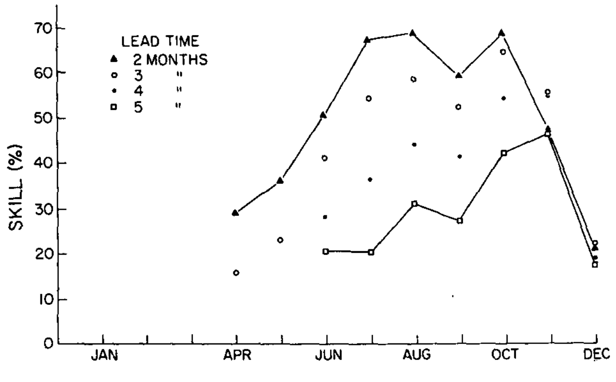

FIG. 4. Hindcast skill (percent of the variance) for SST anomalies in the central equatorial Pacific. Results are shown for hindcast models with lead times of 2–5 months.

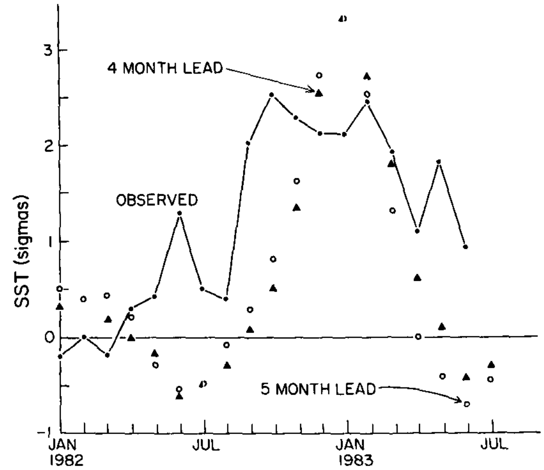

FIG. 6. As in Fig. 5, but with forecast lead times of 4 and 5 months.

2 month lag in the model's predictions relative to the observations. Even in spite of this, it is clear that a statement could have been made at the end of July that a warming event of magnitude at least two standard deviations could be expected to occur before the end of the year. Thus the SST event in the central ocean was successfully predicted 4–5 months in advance.

Note again that the predicted decay of the El Niño is more dramatic than actually observed. This was not so much the case with a two-month-in-advance forecast, but the model had good hindcast skill in all but 3 months of the year (cf. Fig. 4). The reasons for this differential performance are as follows. At the longer lead time the forecast is again based on variations in the zonal wind field in the far western Pacific. As noted above, winds in this area return to stronger than normal by mid to late 1982, thereby suggesting colder than normal water in the central ocean. At the shorter lead forecast interval, however, the most important wind predictors are those occurring more or less over the SST predictand region. This wind information, therefore, represents a local forcing and more closely reproduces the observed SST pattern. The one-month-in-advance forecast (not shown), which is based almost entirely on local wind predictors, reproduces the SST decay even better than the two-month-in-advance forecast.

4. Conclusions

Based on the results shown here, plus earlier work, it appears that many key features of the warming in the equatorial Pacific Ocean during 1982–83 could have been predicted 4–5 months in advance. It certainly appears that the large magnitude of the event could have been successfully predicted at these lead times. On the other hand, the spindown or decay of the warming events is not well predicted.

The reasons for the model's success and failure lie in the way in which it chose the predictor information. The success in forecasting the build-up phase of the warming at long lead times rests almost entirely with variations in the zonal wind component in the far western equatorial Pacific. Apparently, the spindown, or return to normal of the SST field, need not depend strongly on that variable. Instead, it appears that the rather local characteristics of the windfield are more important in representing the spindown phase of the warm event than is remote wind forcing. This result, if generally true, suggests that the ability of simple numerical models to reproduce the equatorial warming events via Kelvin-wave dynamics will be unsuccessful in explaining the return to normal conditions of the tropical ocean without inclusion of some additional "local" physics.

In summary, it appears that major El Niño events can be predicted some months in advance by rather simple statistical methods. Hopefully, more sophisticated oceanographic models will have even greater skill than that demonstrated here. These models, which include additional physics, should also produce more reliable forecasts of the decline of major warm events in the equatorial Pacific. The current results (Figs. 2–6) represent a lower limit against which the success of these more sophisticated models can be measured.

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APPENDIX

The Statistical Prediction Approach

The statistical prediction approach used here is described in detail in Barnett and Hasselmann (1979, hereafter BH) and Hasselmann and Barnett (1981, hereafter HB). An exceedingly brief summary of the approach is given here.

The prediction equation is

$$\hat{y}(t_j + p\Delta t) = \sum_{i=1}^{1} \sum_{k=0}^{m-1} D_{ik} x_i(t_j - k\Delta t), \qquad \text{(A1)}$$

where $\hat{y}$ is the predictand, x_i the predictors, p the lead time, and D_{ik} the predictor coefficients for the ith predictor at lag k. The D_{ik} were expanded as a low-order Fourier series [HB, Eq. (7)] to allow them to vary throughout the annual cycle. After some algebra, Eq. (A1), including the Fourier coefficients of D_{ik}, becomes [HB, Eq. (12)]

$$\hat{y}(t + p\Delta t) = \sum_{r=1}^{n} a_r z_r(t). \qquad \text{(A2)}$$

Orthogonalizing the predictors according to the variance [HB, Eq. (13)] and filtering to retain the highest-order model that is statistically significant gives

$$\hat{y}(t + p\Delta t) = \sum_{r=1}^{n'} a'_r z'_r(t). \qquad \text{(A3)}$$

The prediction equation (A3) is in terms of physically complicated quantities and is difficult to interpret. However, it is in an optimal framework for evaluation of the coefficients [BH, Eq. (6)] and significance testing (BH, Section 4).

Given a successful model, the predictor set can be rotated again to yield maximum predictive skill with increasing predictor number (e.g., Davis, 1978; Barnett, 1981b). Back transformations of these principal predictors to physical space are limited by the several filtering operations performed on the predictor sets.

The principal predictors, however, can be useful qualitatively; see, for example, the discussion of HB regarding El Niño prediction and the discussion in Section 3 of this paper.

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