All-India Summer Monsoon Rainfall and Sea Surface Temperatures around Northern Australia and Indonesia

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ABSTRACT

The relationship between Indian summer (June–September) monsoon rainfall and sea surface temperatures around northern Australia–Indonesia has been explored using data from 1949 to 1991. Warm sea surface temperatures are generally associated with a good monsoon; a poor monsoon is usually accompanied and preceded by low sea surface temperatures. This finding confirms, on independent data, a suggestion made a decade ago. This study also confirms a relationship between changes in Darwin pressure and Indian monsoon rainfall. These two relationships appear to provide a method for predicting Indian summer monsoon rainfall a month or two before the onset of the monsoon season. Two predictors (April sea surface temperatures and the change in Darwin pressure from January to April) together account for about 50% of the variance in Indian monsoon rainfall if the data are adjusted to remove possible artificial trends in the ocean temperatures. The northern Australia–Indonesia region is clearly an important component in the large-scale interaction between the Indian monsoon and the El Niño/Southern Oscillation.

1. Introduction

Nicholls (1983), using a very small dataset of only 16 years, suggested that significant correlations existed between Indian summer rainfall and sea surface temperature (SST) around northern Australia and Indonesia (specifically, the average SST in the box 120°–160°E, 5°–15°S). Warmer than usual SSTs between February and November appeared to be associated with a good monsoon. The relationship held promise for the prediction of Indian summer (June–September) rainfall if it could be confirmed on longer, independent datasets. This paper uses data from 1949 to 1991 to verify this relationship. An all-India summer monsoon rainfall index has been correlated with SSTs in the box 120°–160°E, 5–15°S (the region studied by Nicholls 1983), which surrounds northern Australia and southern Indonesia. Others have noted the importance of this region in the context of predicting Indian monsoon rainfall. Shukla and Paolino (1983) and Shukla and Mooley (1987) suggested that the change in Darwin pressure from January to April could be used to predict Indian summer monsoon rainfall. The performance of this predictor has been compared with the use of the SST in prediction. The possibility of combining the two predictors (SSTs and changes in Darwin pressure) to predict Indian summer monsoon rainfall has been examined.

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2. Data

a. All-India summer monsoon rainfall

Sontakke et al. (1993) describe the construction of an all-India summer monsoon rainfall series for the period 1844–1991. The summer season extends from June to September. The series used a constant 36 stations from 1871. Sontakke et al. demonstrated that the rainfall series constructed from this small set of stations exhibited very similar behavior to an Indian rainfall index constructed from a much larger number of stations by Mooley and Parthasarathy (1984).

b. Northern Australia–Indonesia sea surface temperature

SSTs for the box 120°–160°E, 5°–15°S for the period 1949–1991 were obtained from the U. K. Meteorological Office's Global Sea-Ice and Sea Surface Temperature (GISST) dataset. Parker et al. (1994) describe the construction and characteristics of this dataset, which uses spatial and temporal interpolation to provide globally complete fields of SST in boxes of 1° latitude by 1° longitude. All 1° boxes in the area 120°–160°E, 5°–15°S were averaged to produce the mean SST for the northern Australia–Indonesia region. This was the region used by Nicholls (1983). Nicholls (1984) also used SSTs in the same area to demonstrate a relationship of the SSTs with the El Niño/Southern Oscillation.

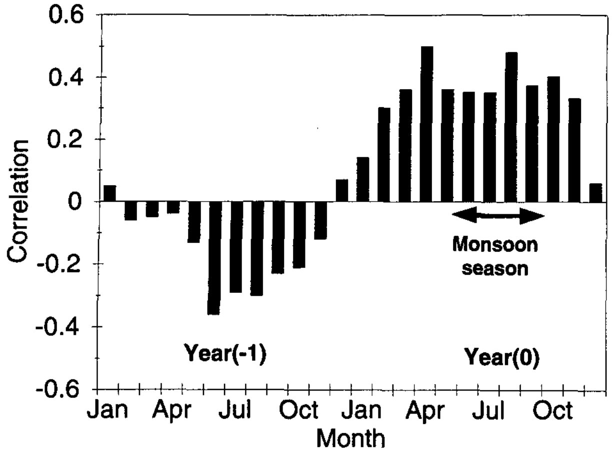

FIG. 1. Correlations between all-India summer monsoon rainfall and monthly SSTs in box 120°–160°E, 5°–15°S. All correlations calculated with 42 years of data. Year(−1) indicates correlations with SSTs in calendar year prior to the monsoon using SSTs from 1949–1990; Year(0) indicates correlations with SSTs in calendar years corresponding to the monsoon using SSTs from 1950–1991. Correlations of 0.3 are significant at 5% level.

c. Darwin pressure

Mean monthly 0900 LT sea level pressures at Darwin from 1949 to 1991 were provided by the National Climate Centre of the Bureau of Meteorology. Data were missing for 1951.

3. Results

Nicholls (1983) found positive correlations between Indian June–September rainfall and SSTs early in the year before the start of the summer monsoon. The pattern of correlations between monthly mean SST and Indian summer monsoon rainfall using data from 1949 to 1991 is shown in Fig. 1. Correlations of Indian summer monsoon rainfall with monthly SSTs in the year of the monsoon [designated Year(0)] and in the year preceding the monsoon [Year(−1)] are plotted in this figure. The correlations for Year(−1) used SST data from 1949 to 1990; the correlations for Year(0) used 1950–1991 SST data.

The pattern of correlations in Fig. 1 is similar to that found by Nicholls (1983) using only 1964–1979 data. Summer monsoon rainfall is negatively correlated with SSTs in the year preceding the monsoon (although only one month, June, has a correlation significant at the 5% level). The sign of the correlation changes to positive around the turn of the year. The positive correlations with SSTs in each month from February to November in Year(0) are significant at the 5% level. This confirms the finding of Nicholls (1983) that significant positive correlations appeared some months before the start of the Indian summer monsoon.

Yasunari (1990) correlated Indian summer monsoon rainfall with SSTs in the tropical western Pacific north of the equator. He found a similar temporal pattern of correlations to that of Fig. 1, but the correlations in the months immediately prior to the onset of the monsoon were not as large as those found in this study, that is, with SSTs south of the equator.

The dataset used by Nicholls (1983) produced the strongest correlation of Indian rainfall with February SSTs. In the longer time series used here, February, while still significantly correlated with Indian rainfall, is not the month with the strongest relationship. The correlation with April SST is larger at 0.50 ($n = 42$; significant at 1%). Time series of the all-India summer monsoon rainfall and the April SSTs are shown in Fig. 2. The relationship has been at least as strong on the data not available to Nicholls (1983), that is, post 1979, as before that year. The relationship was weak in the mid-1950s. The differences between the pattern of correlations in Nicholls (1983) and those reported here are presumably the result of sampling fluctuations and the different SSTs and Indian rainfall used in the two studies. Nicholls (1983) also used three-month averages of SSTs rather than the single-month averages used here.

The relationship is strong enough to provide some indication to the character of the ensuing summer monsoon. None of the 21 years with April SST above the median had monsoon rainfall less than 800 mm, while of the 21 other years 12 had rainfall less than 800 mm. Only four of the years with SST below the median received more than 900 mm, while 12 of the years with SST above the median received more than 900 mm. More than 950 mm was only received in the years when the SST was above the median.

There is a clear upward trend in the April SSTs (Fig. 2) and also generally through the year. A similar trend is not evident in the all-India rainfall series, so the trend in the SSTs is probably detracting from the relationship between interannual variations of the two time series.

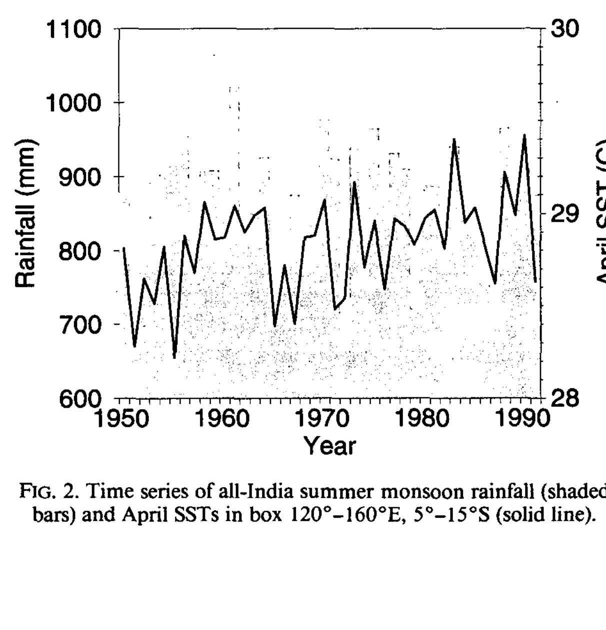

FIG. 2. Time series of all-India summer monsoon rainfall (shaded bars) and April SSTs in box 120°–160°E, 5°–15°S (solid line).

This has been tested by removing the linear trend of April SSTs and correlating the detrended SSTs with the rainfall. The correlation, 0.55, was slightly stronger than was the case for the original SSTs, confirming that the trend was offsetting the shorter-term relationship. Time series of Indian rainfall and detrended April SSTs are plotted in Fig. 3.

The relationship exhibited in Fig. 3 indicates that some skill in predicting Indian monsoon rainfall is achievable just from the April SSTs. Of the 23 years when the detrended April SST was positive, only 1 had summer monsoon rainfall less than 800 mm, 8 had 800–900 mm, and 14 received over 900 mm. So there was a 61% chance of receiving at least 900 mm rainfall when the detrended April SST was positive. When the detrended SST was negative, the chances of receiving at least 900 mm was only 11% (2 years out of 19). Positive detrended April SSTs were followed by low rainfall (less than 800 mm) on 4% of occasions; negative detrended SSTs were followed by rainfall of less than 800 mm 58% of the time. The 5 years with very low rainfall (less than 750 mm) all had negative detrended April SSTs.

The relationship between the Indian monsoon rainfall and the difference in Darwin pressure (January minus April) preceding the monsoon is illustrated in Fig. 4. As indicated by Shukla and Paolino (1983) and Shukla and Mooley (1987), a smaller change in pressure foreshadows higher rainfall. The correlation between the pressure difference and subsequent rainfall was 0.56 (significant at 1%), very slightly stronger than the correlation with the detrended SSTs. The relative strengths of the correlations change if only more recent data is used. For the 20-yr period 1972–1991, the correlation of the Indian monsoon rainfall with the detrended SST was 0.69, while that with the January minus April Darwin pressure difference was 0.58.

4. Discussion

a. Prediction of all-India summer monsoon rainfall

The relationship between all-India summer monsoon rainfall and April SSTs discussed in the previous section suggests that the April SSTs could be useful in prediction of the likelihood of a good, or poor, monsoon. This is especially so if the trend apparent in the SSTs is first removed. The confirmation, on independent data, of the relationship noted by Nicholls (1983) between Indian rainfall and earlier SSTs strongly suggests that the relationship is real and might be expected to continue.

The continuation of the lag relationship noted by Shukla and Paolino (1983) and Shukla and Mooley (1987), namely, that changes in Darwin pressure early in the year foreshadow the character of Indian summer monsoon rainfall, also suggests that events in the western Pacific and eastern equatorial Indian Oceans provide a means for prediction of the Indian summer monsoon. Combination of these two predictors might lead to improved predictions.

The apparent need to detrend the SST time series to maximize skill is, however, problematic. It is not obvious that the trend in the SSTs is real or, if it is, whether it could be expected to continue into the future. It is not obvious, therefore, whether the detrending used to remove the observed trend over the period 1950–1991 should be used in preparing predictions from SSTs in the future. Such detrending would presuppose that the observed trend is likely to continue in the future. This seems unjustified unless the physical cause of the trend can be identified and is expected to continue. However, nonremoval of the trend would have meant somewhat lower accuracy of the predictions in recent years.

One possible solution to this quandary is to relate first differences of the predictor (e.g., April SSTs) and predictand (rainfall). First differences are frequently used to remove trends or other aspects of nonstationarity in time series. Therefore, the difference in April SSTs [Year(0)–Year(−1)] would be regressed against the first differences of rainfall [Year(0)–Year(−1)]. This regression could then be used in predictive mode to predict the change in the Indian monsoon rainfall from last year to this year, given the observed change in April SST. Since last year's rainfall is already known, this could be added to the predicted change to provide a prediction of the upcoming Indian rainfall. Such an approach has been proposed by Nicholls (1992) for the prediction of Australian tropical cyclone activity to avoid complications due to secular changes or trends. The first differences of April SST and Darwin pressure difference (January minus April) and the all-India summer monsoon rainfall have been regressed, resulting in the following predictive relationship:

$$\text{rain}\,(\text{year}(0)) = \text{rain}\,(\text{year}(-1)) + 142\Delta\text{SST} + 24\Delta P_{\text{diff}},$$

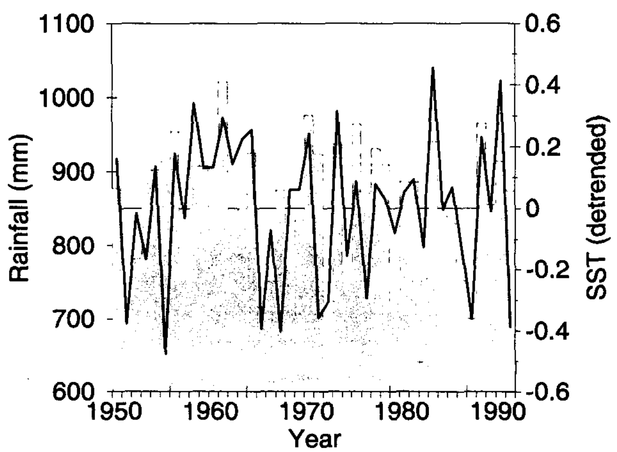

FIG. 3. As in Fig. 2 but with detrended April SSTs.

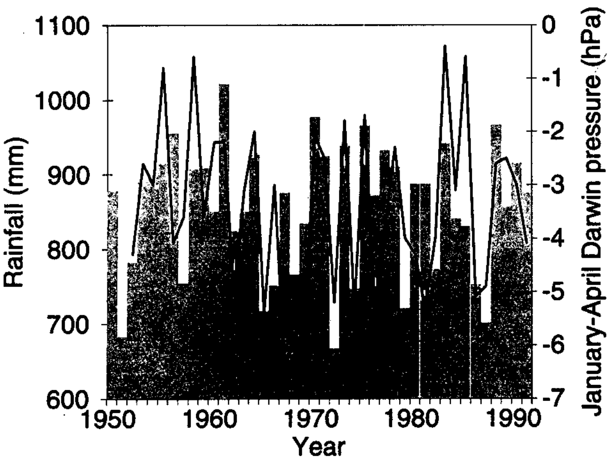

FIG. 4. As in Fig. 2 but with Darwin January minus April pressure difference instead of SST.

where ΔSST is the change in April SST from Year(−1) to Year(0), and ΔP_{diff} is the change in the Darwin January minus April pressure difference between Year(−1) and Year(0). The multiple correlation corresponding to this equation was 0.69 ($n = 40$; significant at 1%). The forecasts from this equation would be available very early in May, well before the start of the monsoon.

Predictions based solely on the April SSTs and the change in Darwin pressure would not, of course, always be correct, even though these two predictors account for almost 50% of the variance in the all-India monsoon rainfall. The remainder of the variance presumably reflects some other influence on Indian rainfall. Gowariker et al. (1989), Srivastava and Singh (1993), and Verma (1993) have examined many other potential predictors of Indian summer monsoon rainfall. Many of these also showed promise for prediction. Combination of some of these with northern Australia–Indonesia SSTs and Darwin pressure changes may enhance the predictions further. It may also be that SSTs from a slightly different area, rather than the 120°–160°E, 5°–15°S box used here, may also add to the predictability of the Indian monsoon.

A second variable describing the Indian summer monsoon is the date of onset. Joseph et al. (1994) listed dates of onset of the monsoon and examined its relationship with SSTs. They found no significant relationship with SSTs in the northern Australia–Indonesia region. This finding was confirmed by correlating the dates on monsoon onset of Kerala in southern India (from Joseph et al. 1994) with SSTs in the box 120°–160°E, 5°–15°S. No significant correlations were found with SSTs prior to the monsoon. Apparently, SSTs in this region reflect some influence on total monsoon rainfall, but not on its date of onset.

b. Interaction between the El Niño/Southern Oscillation and the Indian monsoon

Many early studies of the El Niño/Southern Oscillation attempted to develop systems for predicting the Indian summer monsoon. It was soon realized, however, that the "Southern Oscillation in June–August, at the height of the monsoon, has many significant correlations with later events and relatively few with earlier events" (Normand 1953). Webster and Yang (1992) described the annual cycle of lag correlations in the Southern Oscillation, noting, as had others, the low correlations across the Northern Hemisphere spring—the "predictability gap." This gap reduced the likelihood that simple Southern Oscillation lag relationships could be used to predict the Indian summer monsoon. Yasunari (1990) and Webster and Yang (1992) proposed that the Indian monsoon dominated the El Niño/Southern Oscillation during the Northern Hemisphere spring and/or summer. This would appear to preclude predictions of the Indian summer monsoon from indices of the El Niño/Southern Oscillation, as well as accounting for the predictability gap.

There have, however, been some studies that suggest that the El Niño/Southern Oscillation does influence, and may be used to predict, the monsoon. As noted earlier, Shukla and Paolino (1983) and Shukla and Mooley (1987) proposed that the *trend* in an index of the El Niño/Southern Oscillation could be used to predict the Indian monsoon. Rasmusson and Carpenter (1983) related Indian summer monsoon rainfall with the El Niño and proposed that the development of an El Niño early in the calendar year could be used to predict a weak monsoon. Kiladis and van Loon (1988) and Kiladis and Diaz (1989) also documented links between the El Niño/Southern Oscillation, Indian monsoon rainfall, and temperature (SST and air temperature) and pressure in the west equatorial Pacific.

Meehl (1987) proposed that interaction between the monsoon and the El Niño/Southern Oscillation could explain the seasonally varying relationships, as did Yasunari (1990) and Webster and Yang (1992). Meehl (1994) elaborated on the relationships between the El Niño/Southern Oscillation, the Indian monsoon, and events around Indonesia–north Australia, placing them in the context of a continuous evolution of coupled land–atmosphere–ocean and tropical–midlatitude interactions stretching from east Africa to the eastern Pacific. The confirmation in this study of the predictability of the Indian summer monsoon rainfall from SSTs around northern Australia–Indonesia (which are in turn related to the El Niño/Southern Oscillation; e.g., Nicholls 1984) and Darwin pressure changes (also part of the El Niño/Southern Oscillation) lends support to the notion of a continuously interacting and evolving Indian monsoon–El Niño–Southern Oscillation system. The results of this study demonstrate that the ocean–atmosphere system in the western equatorial

Pacific and the eastern equatorial Indian Oceans provides good indicators of this interacting, large-scale system in that ocean and atmosphere anomalies here are related to both the Indian monsoon and the El Niño/Southern Oscillation.

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