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Sea surface temperature related to rain in Ceará, north-eastern Brazil

RAINFALL in Ceará is correlated with sea surface temperature in the south Atlantic Ocean. Knowledge of sea surface temperature makes possible a useful rainfall forecast before the rainy season begins. The mechanism may be that sea temperature affects the height of the trade wind inversion, and thus the height of the moist layer. The data also suggest in association between below normal sea temperatures in the south Atlantic and the El Niño in the Pacific.

Ceará is the node of Brazil's drought-prone north-east. Here severe drought, and its antithesis, flooding, both occur about once per decade, arriving without warning. The human misery that follows in their wake might be reduced if they could be forecast. We found that sea surface temperature (SST) in the south Atlantic Ocean and rainfall in Ceará are correlated in time, and if SST is known, a useful preliminary rainfall forecast can be made.

Brazilian climatologists have long believed rain in the north-east to be related to fluctuations in SST, but have been unable to show such a relationship owing to lack of sufficient SST reports. We investigated this relation by using a data file containing all available surface marine weather reports from ships of many nations. This file, Tape Data Family -11, was assembled by NOAA's National Climatic Center. Working in conjunction with the Fleet Numerical Weather Central and the North Pacific Experiment (NORPAX) the National Marine Fisheries Service has used the tape data file to compute mean sea surface temperatures by 5° latitude-longitude quadrants for each month in the period October 1947 to December 1967. We used these computations to map the correlation coefficient between SST and a rainfall index in Ceará. Later, after we had identified a key 5° quadrant where correlation was particularly high, monthly SSTs were recomputed for the period 1907–72, and used in a regression analysis to develop a forecasting equation. Our results may be somewhat biased by the selection of this particular quadrant, and further research may show that improved forecasts can be made using data from other areas.

The density of SST observations is far from uniform over the South Atlantic. Reports are most abundant along shipping lanes between the Cape of Good Hope and Cape

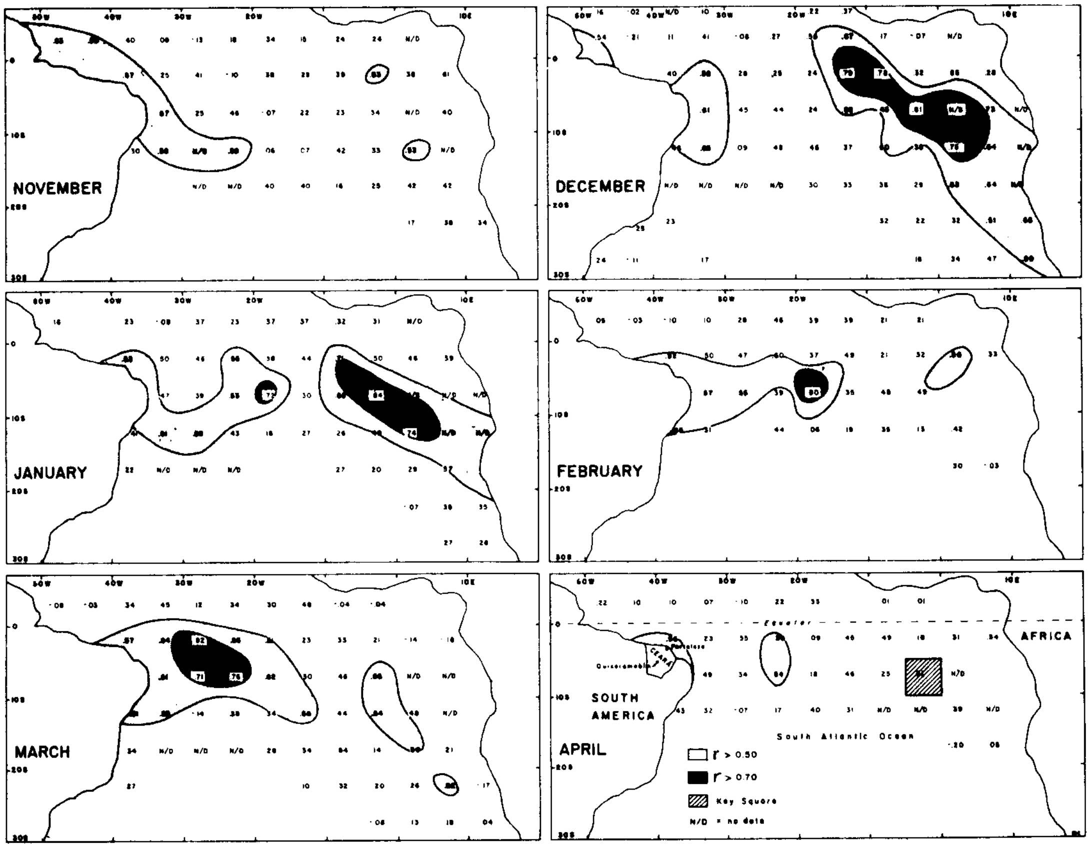

Fig. 1 Correlation between SST and January-February-March rainfall indices in Ceará. An area of high coefficient of correlation appears off the African coast in November, becomes strong in December, moves westward with the South Equatorial Current during January, February and March, and disappears in April.

Verde, and along the South American coast. Data are extremely sparse over the central South Atlantic, and are not sufficient to map correlation coefficients over the entire area. Data are not available in all quadrants in all years, and different years are missing from different quadrants. Nevertheless, when considered as a whole, the data form a picture that is coherent and of predictive value.

The rains in Ceará are highly seasonal, about 40% coming in January-February-March, and about half in April-May-June. Almost no rainfall occurs in the months August to November. Fortaleza and Quixeramobím are two weather stations in Ceará about 120 km apart that have long series of rainfall observations extending back to 1849 and 1896, respectively. We correlated monthly mean SST data with rainfall at both stations, but found that a combined index of simultaneous data from both stations gave higher correlation coefficients. The combined index smooths local variations of rainfall to emphasise large scale influences affecting both stations. Since the mean annual rainfall at Fortaleza, on the coast, is about twice that of Quixeramobím, in the interior, we gave each station equal weight in the index by using twice Quixeramobím's rainfall plus Fortaleza's.

We computed correlation coefficients (r) for each of the 5° quadrants in the South Atlantic for which data are available, between the monthly values of SST and the rainfall index for the combined months of January-February-March, as well as for the annual rainfall indices. SSTs for November and December were correlated with rainfall indices for the coming year, while SSTs for January through April were correlated with the current year.

Maps of correlation coefficients (Fig. 1) show an apparent westward movement of high correlation during November to April. This may be related to the westward drift of water in the South Equatorial Current. In December the quadrant where correlation is highest is centred at 7°30'S, 2°30'W (Marsden Square 300, Quadrant 3). For this area r was 0.81 for January-February-March rainfall, and 0.73 for annual rainfall. Ceará tends to be dry when water here is cold, and wet when it is warm. Moreover, since December precedes the rainy season in Ceará, December SST can be used to forecast rainfall with useful lead time. Thus we selected Quadrant 300-3 as the key area for regression analysis with Ceará's rainfall.

The 1947-67 data used for our correlation maps are means of all reports within a given 5° quadrant and thus might be biased by clustered reports. This possible bias can be reduced by making individual means for each 1° area, then averaging the 1° means to obtain a 5° mean. This latter procedure was used to obtain data points for our long term regression analysis (Fig. 2).

We noticed a long term warming trend of 0.51 °C between the years of 1907 and 1972, in our SST means at Quadrant 300-3. The trend could be caused by real warming, or by differences in measurement techniques that have occurred over the period. If it is assumed that the latter is true, and if the effects of the trend are removed from the regression, r for the period increases from 0.61 to 0.66. Kendall's rank-order coefficient, τ increases from 0.20 to 0.41. This increase in order through detrending suggests that the apparent trend is instrumental and not a real warming.

Depending on the sets of data, r values range from 0.61 in the 1907–72 data uncorrected for trend, to 0.81 in the 1947–67 data used in making the correlation maps. Values of τ range from 0.21 to 0.50. All are for correlation

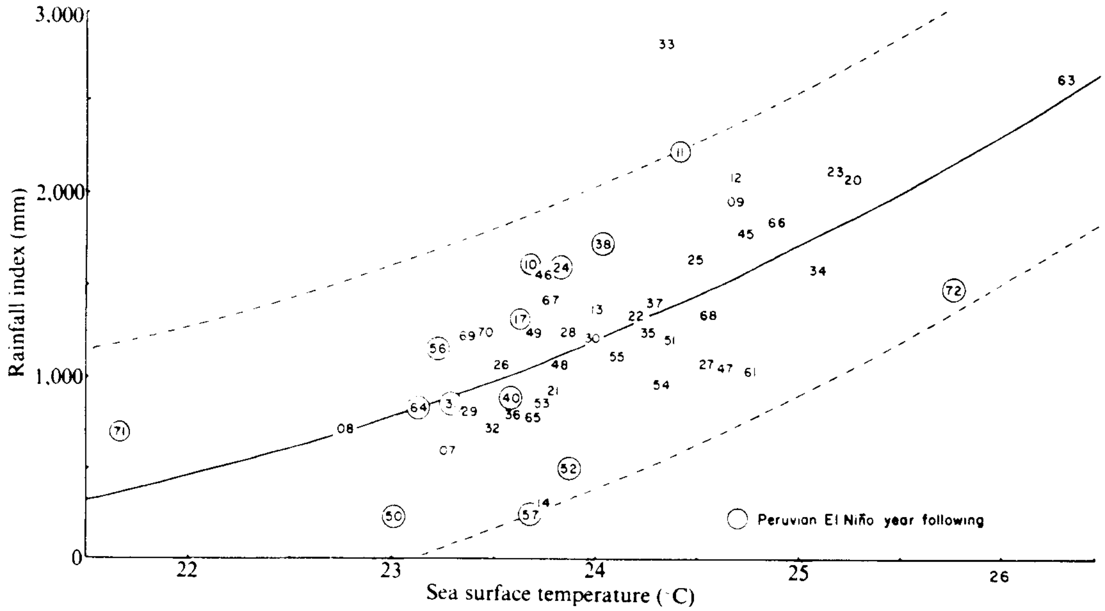

Fig. 2 January-February-March rainfall indices in Ceará plotted against December SST in Marsden Square 300, Quadrant 3. Years indicated are for December SST values. Data has been detrended by adding 0.0078 °C times the number of years before 1972. Second degree regression lines and 95% confidence limits are shown. El Niño years (taken from Caviedes (1973) and Quinn[6]) are circled.

	1907–72 Detrended	1907–72 Not detrended	1947–67 From Fig. 1
n	53	53	16
r	0.66	0.61	0.81
α	0.001	0.001	0.001
τ	0.41	0.20	0.50
α	0.001	0.04	0.007

between December SST and the Ceará rainfall index for the following January-February-March period. If we assume r to be 0.71, then r^2, the coefficient of determination, is 0.50, indicating that half of Ceará's January-February-March rainfall can be predicted by mean SST in Quadrant 300-3 in December. If we assume $\tau = 0.40$, we can say that the odds are 70/30 that a change in SST will be followed by a change in rainfall index of the same sign. Our rainfall forecast ranges from 500 mm with an SST of 22 °C to 2300 mm with an SST of 26 °C; a considerable improvement over the climatic normal value of 1267 mm. If we define drought as the lack of rainfall and flooding as an excess of it, from Fig. 2 we can state that drought is unlikely when SSTs at Quadrant 300-3 are warmer than 24.5 °C, and that flooding is unlikely when SSTs are colder than 23.5 °C. If we are given some particular SST value, say 24.0 °C, our best estimate for the rainfall index is 1200 mm, and we can say with 95% confidence that it will fall between 350 and 2050 mm. These are much wider limits than we should like but suggest that eastern Atlantic SST in December, albeit important, is only one of a number of factors influencing Ceará's rainfall.

A suggested mechanism for the correlation is as follows: cold water stabilises the overlying air and decreases wind flow and convection over the Atlantic. The trade wind inversion represents the boundary between subsiding air from aloft and convective air from below. When convection is weak and winds are light, the trade wind inversion is lowered, and the thickness of the layer carrying moisture into north-eastern Brazil is reduced. Similarly, warm seas strengthen wind flow, and mixing and increased convection raise the trade inversion to deepen the moist layer. Further, the Intertropical Convergence Zone (ITC) and its attendant raininess would tend to lie in the region of warmest water, and would retreat from the hemisphere with cold water.

Namias[1] found intense cyclonic activity near Newfoundland to be highly correlated with rain at Quixeramobím. He hypothesises the following chain of events. The North Atlantic Subtropical High is strengthened when the trough in the Newfoundland land area deepens. The trough is held in place by blocking toward the east. The strengthened subtropical High increases the north-east trade winds which in turn require the south-east trades to respond by strengthening, thus increasing the flow of moisture into Ceará. An alternative explanation for Namias' correlation is its reverse. Warm South Atlantic sea temperatures produce heavy equatorial rains. These release large quantities of latent heat, strengthening the Hadley circulation in both hemispheres, and inducing a blocking High in the North Atlantic. The increased flow from the Equator, accompanied by the blocking, results in increased cyclonic activity in the Newfoundland area, with a concurrent deepening of the trough. To support this latter explanation, Markham[2] found that a strong South Atlantic High and strong south-east trades seem to decrease, rather than increase, rain in Ceará. The rainiest periods do not occur when the south-east trades are strong, but when the High is weak or has retreated toward the south, allowing flow with a northerly component to penetrate Ceará. There is little doubt that the Newfoundland trough and rain in Ceará related, but which is the cause and which the effect is unclear. In any event, precipitation over northeastern Brazil is important to the general circulation because it represents a significant energy input to the atmosphere, and with large variations from year to year. The magnitude of this variation is shown by the annual rainfall index which varied from a low of 884 mm in 1915 to a high of 5505 mm in 1964.

From the work of Namias[3] and Bjerknes[4], a body of literature on large scale ocean–atmospheric interactions is growing. Recently Caviedes[5] has related drought in northeastern Brazil with the El Niño—the appearance of anomalously warm water off the Peruvian coast. Temperatures in Quadrant 300-3 also seem to be related to El Niño. The years preceding El Niño are circled in Fig. 2. The hypothesis that cold December SSTs precede El Niño has a one-tailed significance level of about 0.0125 when the non-parametric Wilcoxson two-sample test is applied[7]. The coldest December temperature in Quadrant 300-3, 21.67 °C in 1971, was followed by an El Niño of exceptional severity in 1972. The El Niño of 1972 may have persisted into 1973 and thus may account for the anomalous point for 1972 circled in Fig. 2. If this did occur, the correlation is greatly improved. Quinn[6] has related El Niño to the difference in surface pressures between Easter Island and Darwin, Australia. This difference is an index of the Southern Oscillation and suggests that the occurrence of warm water off Peru simultaneously with cold water off Africa is related to the Southern Oscillation. The mechanisms for this phenomenon are poorly understood.

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CHARLES G. MARKHAM

Department of Geography,
California State University,
Fresno, California 93740

DOUGLAS R. MCLAIN

Pacific Environmental Group,
National Marine Fisheries Service, NOAA,
c/o Fleet Numerical Weather Central,
Monterey, California 93940

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