Climatic Anomalies in the Tropical Pacific Ocean and Corn Yields in the United States

Abstract. *The association between climatic anomalies in the tropical Pacific Ocean, often called El Niño events, and annual corn production in the United States was investigated. Temperature and atmospheric pressure in parts of the United States have been correlated with El Niño events. This research suggests that in years in which an El Niño event causes surface temperatures in the tropical Pacific to become warmer than normal, there is a higher probability of an above-average corn crop in the United States. For years when sea surface temperatures are average or cool, no significant association is observed.*

Reported relations between U.S. winter temperatures and sea surface pressure and temperature anomalies in the South Pacific Ocean suggest the possibility of atmospheric teleconnections with other climate-related variables, such as crops (*1*). If climatic indicators such as the sea level pressure in the South Pacific and the sea surface temperature (SST) of the eastern tropical Pacific could be used in a model to help explain variance in climatic variables, then the inclusion of crop yields as a climatic index would have practical implications. While use of the equatorial teleconnection to explain Northern Hemisphere climate requires caution, the potential benefits of long-range forecasting are great.

More traditional climatological research has related South Pacific SST and sea level pressure to North American air temperature (*2*) and air pressure (*3*). We followed the lead of Steyaert *et al.* (*4*), Starr and Kostrow (*5*), Huff and Neill (*6*), and Mostek and Walsh (*7*) by using crops, specifically U.S. corn yields, as a climatic index. One advantage of using agricultural yields as a primary climatic index of traditional variables such as precipitation and air temperature is that crop outcome is a proxy for a climatic index over the crop region under study. It does not depend on data from stations that may be remote or only adjacent to the crop region. In general, station coverage over a crop region is inadequate. Therefore, the use of crop yields as a climatic index can avoid such problems, especially those associated with specifying precipitation (*8*).

Table 1. Deviation of U.S. corn yield in case 1 El Niño years and non–El Niño years [χ^2 (1) = 4.48, $P < .05$].

Corn yield	El Niño years (case 1)	Non–El Niño years	Total
Above trend	34	30	64
Below trend	15	33	48
Total	49	63	112

Table 2. Deviation of U.S. corn yield in case 2 El Niño years and other years [χ^2 (1) = 4.17, $P < .05$].

Corn yield	El Niño years (case 2)	Other years	Total
Above trend	23	41	64
Below trend	8	40	48
Total	31	81	112

Using data on corn production supplied by the Department of Agriculture, we studied the relation between U.S. corn yields and the presence or absence of El Niño conditions from 1868 to 1979. Two major indicators of an El Niño event are (i) the difference in sea level pressure between the eastern and western South Pacific, called southern oscillation index, and (ii) SST anomalies of the eastern tropical Pacific.

For the time period under consideration, Quinn *et al.* (*9*), using primarily the pressure difference index, specified 49 of the 112 years as El Niño years, hereafter called case 1 years. Since some warming events may have set in late in the year, after the corn growing season, 31 of the 49 years were selected that showed warm SST's over the whole growing season. This second set of years is called case 2. Data for the seasonal SST anomalies over the region extending from 90° to 180°W and 0° to 10°S were obtained from Angell (*10*). Figure 1 shows the percentage deviation of corn yields from 1868 to 1979. The standard deviation is about 9.5 percent. The large negative deviations of 1901, 1934, and 1936 are much greater than any observed positive deviation.

As a first step, we used a simple, dichotomous division of the dependent variable: corn yield above trend and corn yield below trend. Cases that were very near trend seemed to divide equally into cells above and below, depending on the particular moving average used, and therefore did not affect the results.

For our statistical calculations, we assumed that the occurrence of an El Niño year was a random event. According to Quinn *et al.* (*9*), 9 of the 49 El Niño events were contained in a sequence of three successive years, 18 were part of a sequence of two consecutive years, and 22 were single-year events. As a first approximation, the data were analyzed in 2 × 2 contingency tables (Tables 1 and 2) and χ^2 were calculated. With 1 degree of freedom both χ^2 were significant at $P < .05$. In Table 2 the crop yields in years other than case 2 years are almost equally divided above and below trend. In Table 1 the crop yield deviations for non–El Niño years follow a pattern opposite to El Niño occurrences.

The results support the hypothesis of Bjerknes (*11*), which suggests that when SST's are warmer than normal (an El Niño event), the average position of the jet stream is closer to the equator than

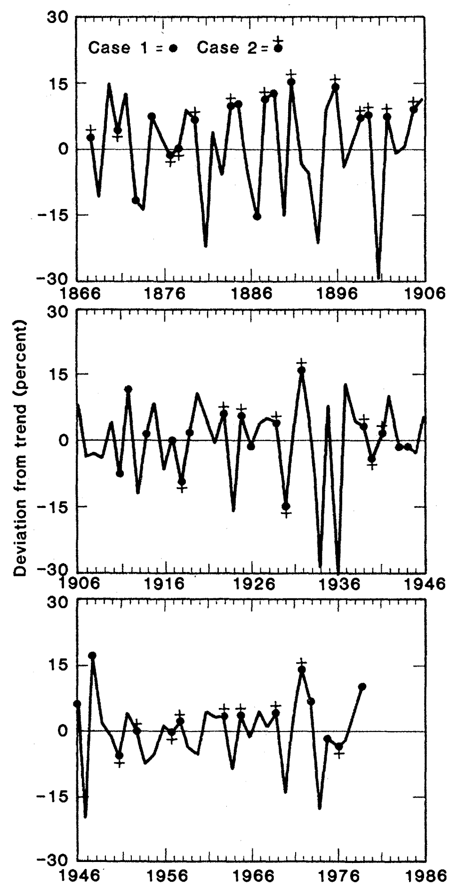

Fig. 1. Percentage deviation of U.S. corn yields from trend for the period 1868 to 1979. The deviations were obtained by using a 9-year weighted moving average to obtain base and trend values. Thus the zero line represents 26 bushels per acre in 1868 and 100 bushels in 1979. The trend was extrapolated at the end points. When trends from moving averages as long as 15 years or as short as 7 years were used the outcome was not significantly altered. This finding is consistent with the results of Mostek and Walsh (*7*).

normal. The hypothesis is supported by Angell (*10*), who found that the circumpolar vortex was expanded in all seasons (displaced toward the equator) during episodes of warm SST's, and Pittock (*12*), who showed that Australian rainfall in all seasons was highly correlated with tropical SST anomalies. In support of this last observation, Angell (*10*) also found that rainfall in the Indian summer monsoon over the period 1868 to 1977 was less than normal during warm tropical SST's. The correlation between tropical SST anomalies and the monsoon rainfall was significant at $P < .01$.

Further examination of the crop yield data strengthens the hypothesis. When the 15 El Niño years (case 1) with below-trend corn yields were analyzed for component climatic factors, it was found that in about half of those years the below-trend yield could have resulted from excessive precipitation during the planting season in one or more major regions of the U.S. Corn Belt, rather than from drought. For example, in 1957, a strong El Niño year, rainfall in the eastern Corn Belt during April and May was more than 200 percent above normal, delaying planting beyond the optimum time and consequently causing lower yields. Note in Fig. 1 that the percentage deviation for corn yield in 1957 is marginally below trend.

In further calculations, we analyzed corn yield separately for many of the corn-producing states to determine whether the outcome would have been different had the dependent variables been the deviation of the corn yield for any one of these states rather than for the United States as a whole. The results show little difference. For the entire United States, 34 El Niño years (case 1) showed yields at or above trend, compared with 38 for Illinois, 36 for Iowa, 34 for Minnesota, 33 for Ohio, and 29 for Indiana. Corn yields of states south of the Corn Belt showed much lower levels of association with El Niño events. The similarity in the results for individual states raises confidence in the overall finding for the United States.

These results suggest a relation between spring and summer temperatures and precipitation in the Corn Belt and El Niño years. Therefore, one of the questions raised by these results concerns the apparent lack of a significant correlation between SST anomalies and the southern oscillation index on the one hand and summer climate in the Corn Belt on the other (*2, 3*). Several explanations might account for these differences. We used a short-term moving average, whereas other researchers have used periods ranging from 25 to 80 years. Thus, fluctuations such as the warm summers of the 1930's would produce very large deviations in their data. In addition, in prior research seasonal data were used. Huff and Neill (*6*) have shown that July temperature and precipitation and June temperatures are among the most important factors in determining corn yield. With these three variables they could account for about 35 percent of the yield variance for the major states of the Corn Belt. Additional variables, such as August temperature and precipitation, did not add significantly to the explained variance. Thus, studies that rely on seasonal data might be insensitive to short-period fluctuations, which seem to have a large effect on the crop outcome.

Finally, the treatment of the data is different in this study. Other researchers have used all the years of data available for their correlations. Our study shows a strong association only for the subset of years that exhibited warm SST's. Table 1 suggests that the other years have no significant bias above or below trend for corn yield. For some recent years with warm SST's, Hanson (*13*) has shown that the westerlies are enhanced and farther south than normal in June, but as yet no coherent data for the whole growing season have been presented to our knowledge.

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Thermodiffusional Transport in Pelagic Clay: Implications for Nuclear Waste Disposal in Geological Media

Abstract. *Thermal gradient experiments in sediment-seawater systems revealed large-scale fluxes of aqueous electrolytic components away from the heat source through thermal diffusion. These findings indicate a need for similar studies in other geological materials of low permeability in order to assess the implications of this phenomenon for various nuclear waste disposal options.*

Many studies of high-level radioactive waste disposal have proposed containment within geological materials of low permeability, on the grounds that these materials can effectively minimize environmental contamination by restricting transport of waste components by fluid convection. Among the options being considered is subseabed disposal within marine pelagic clays (*1*). Desirable features of marine sediments include extremely low permeability and high plasticity, which promotes healing of fractures that may develop during emplacement of waste canisters and thus restricts fluid circulation. The high adsorptive capacity of marine pelagic clay should also inhibit diffusional release of radionuclides.

Table 1. Experimental values of the Soret coefficients.

Element	Soret coefficient ($°C^{-1}$) Control experiment (673 hours)	Soret coefficient ($°C^{-1}$) Sediment experiment (768 hours)
Chlorine	0.0041	0.0040
Sodium	0.0040	0.0037
Magnesium	0.0046	0.0109
Potassium	0.0043	0.0039
Calcium	0.0048	0.0065

Most studies designed to model the chemical environment in the immediate vicinity (near-field region) of a buried canister containing radioactive waste have been concerned primarily with the effect of temperature on solution-mineral equilibria and adsorption processes. Numerous closed-system, constant-temperature experiments have been performed with solutions and solid forms consistent with various disposal options. The near field, however, will be characterized by distinct thermal gradients, which may significantly influence pore fluid chemistry and chemical transport processes. Thus, to supplement information from constant-temperature experiments with seawater and subseabed sediments (*2*), we have modeled the mass