# NOTES AND CORRESPONDENCE

## El Niño–Southern Oscillation and North Atlantic Oscillation Control of Climate in Puerto Rico

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ABSTRACT

Many studies have shown that the El Niño–Southern Oscillation (ENSO) has a significant influence on climate in many parts of the globe, mostly in the Pacific Basin. The objective of this study is to examine the possible impact of ENSO on climatic patterns on the island of Puerto Rico in the Caribbean. The authors find that annual mean air temperatures are controlled by ENSO since 1914. El Niño years are associated with warm air temperatures, whereas El Viejo (La Niña) years, which are the opposite of El Niño, are cooler. On the other hand, since 1911 fluctuations in annual rainfall amounts are synchronous with variations in the North Atlantic Oscillation (NAO) during the winter and are not controlled by ENSO. During years of a high winter NAO index, when the axis of moisture transport in the North Atlantic changes to a more southwesterly–northeasterly orientation, annual precipitation in Puerto Rico is lower than average.

### 1. Introduction

A strong signal of climate variability in the Tropics is derived from El Niño, which is a relaxation of trade winds in the central and western Pacific leading to a lowered thermocline in the eastern Pacific and an elevated thermocline in the western Pacific (Cane 1983; Rasmusson and Carpenter 1982). El Niño can have severe consequences for the living conditions on earth (Philander 1990).

Many investigators have shown that ENSO significantly influences climate in many parts of the globe. One of the two objectives of this study is to examine the possible impact of ENSO on climate in Puerto Rico.

The North Atlantic Oscillation (NAO) is associated with changes in the system of westerly winds across the North Atlantic onto Europe (Barnston and Livezey 1987; Hurrell 1995). During some years the axis of maximum moisture transport changes to a more southwest-to-northeast orientation across the Atlantic and reaches considerably farther to the north and east over northern Europe and Scandinavia (high NAO) than during ''normal'' or low NAO years (Hurrell 1995). The NAO can be seen as a reflection of the fluctuation of the normal winter tropospheric flow (Barnston and Livezey 1987). During high NAO, the Icelandic low is strong and causes increased production of cold Labrador sea currents. This, in turn, has an influence on the air–sea interaction in the entire North Atlantic Basin. The NAO has been shown to influence climatic conditions in northern Europe (Rogers 1985). During high NAO years, winter temperatures are higher there than during years with a normal or low NAO.

Most of Puerto Rico precipitation is orographic in nature. Moisture-laden air from the ocean is carried by the trade winds that embed tropical waves to cyclones producing precipitation.

### 2. Methodology

Instrumental records from the Tropics are generally short, spanning only the past 40–50 years, but we were fortunate to have access to mean air temperature and

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TABLE 1. Lengths of temperature and precipitation records at five climatic stations from Puerto Rico, and locations and altitudes of the stations.

| Station | Lat (N) | Long (W) | Location | Altitude (m) | Temperature | Precipitation |
|---|---|---|---|---|---|---|
| Coloso | 18°23′ | 67°09′ | NW | 12 | 1907–95 | 1907–95 |
| Guayama | 17°58′ | 66°07′ | SE | 55 | 1914–95 | 1911–95 |
| Isabela | 18°28′ | 67°04′ | NW | 128 | 1901–95 | 1901–95 |
| Manatí | 18°25′ | 66°26′ | N | 76 | 1900–95 | 1900–95 |
| Mayagüez | 18°15′ | 67°09′ | W | 18 | 1900–95 | 1900–95 |

precipitation records from five climate stations in Puerto Rico extending back to the beginning of this century (Table 1). We used Troup's Southern Oscillation Index (SOI) as a measure of the intensity of ENSO (Troup 1965). Troup's SOI is derived from the normalized Tahiti minus Darwin mean sea level pressure. We defined an El Niño year as extending between October of the year identified as an ENSO year and September of the following year (O'Brien et al. 1996).

The annual mean SOI series analyzed here covers the interval 1914–94 (the first year thus includes October–December 1914 and January–September 1915). Annual mean temperatures over the five stations were computed in the same way.

The NAO index is defined as the difference in normalized air pressures between Lisbon, Portugal, and Stykisholmur, Iceland (Hurrell 1995). We used the December–March mean NAO for a comparison with fluctuations in precipitation in Puerto Rico in accordance with common practice (Hurrell 1995). Barnston and Livezey (1987) showed that the NAO is present throughout the year in the North Atlantic, but that it is more strongly manifested during the winter. The NAO data comprise the years 1910–94 (the first years covered December 1910 and January–March 1911). We determined mean amounts of precipitation over the five stations on a calendar-year basis over the years 1911–94.

For determinations of the relationships between SOI and NAO and the climate records we employed the statistical procedure described by Burnaby (1953). The Burnaby test has several advantages over the product-moment correlation coefficient and cross-correlation coefficient for testing the agreement between time series. Correlation analysis should not be indiscriminately applied to observations arranged in the form of a time series because they are generally not independent. In addition, the Burnaby test is independent of positive first-order autocorrelation in the individual time series (Burnaby 1953). The test gives rise to an $E_{r,r+1}$ value from computations of the cross-difference product, $E_{r,r+1} = \Sigma\,[(p_r - q_{r+1})(q_r - p_{r+1})]/n$ for two series $p_1, p_2, \ldots, p_r, \ldots, p_n$ and $q_1, q_2, \ldots, q_r, \ldots, q_n$ of length $n$. The significance of an $E$ value can be tested using a one-sided $t$ test. A significant positive $E$ value indicates a direct relationship between the series, whereas a negative value indicates an inverse relationship. The analyses were based on standardized data in order to fulfill the requirement of equality of means and variances.

TABLE 2. Burnaby tests of the relationships between Troup's SOI and mean annual temperature over five Puerto Rican climate stations and at individual stations 1914–94, and of the relationships between winter (Dec–Mar) NAO and mean precipitation over the stations and at individual stations 1911–94. The significance of the $E$ values, resulting from the Burnaby tests, was tested using a $t$ test. Negative $E$ values indicate an inverse relationship. Here, $p$ is the probability of an $E$ value deviating significantly from an expected value of zero.

| | | $E$ | $p$ |
|---|---|---|---|
| SOI | Mean | −1.82 | <0.001 |
| | Coloso | −1.51 | <0.001 |
| | Guayama | −1.46 | <0.001 |
| | Isabela | −1.20 | <0.001 |
| | Manatí | −1.09 | <0.001 |
| | Mayagüez | −2.05 | <0.001 |
| NAO | Mean | −0.91 | <0.01 |
| | Coloso | −0.67 | <0.05 |
| | Guayama | −0.63 | <0.05 |
| | Isabela | −1.07 | <0.001 |
| | Manatí | −1.05 | <0.01 |
| | Mayagüez | −0.14 | >0.05 |

## 3. Relationship between the climate and ENSO and NAO

Variation in mean air temperature is shown by the Burnaby test to be inversely related to ENSO events (Fig. 1 and Table 2). The same inverse relationship is also apparent at all individual stations (Table 2). Thus, the temperature in Puerto Rico is generally warmer during El Niño years and cooler during El Viejo years. Most El Niño years, for example, the severe 1940, 1982, and 1986 events and the extended 1990–94 event, are marked by higher-than-average air temperatures in Puerto Rico. Although the magnitude of the peaks do not match exactly, most other El Niño years coincide in detail with increased mean temperatures. Similarly, El Viejo years, for example, 1949, 1955, 1970, 1973, and 1988, are marked by lower-than-average mean air temperatures in Puerto Rico. Since it is known that the Tahiti barometer may have been somewhat erroneous before 1935 (Trenberth and Hoar 1996), we also ran the Burnaby tests for the years 1935 through 1994, but this does not in any way affect the results.

The very close connection between the Comprehensive Ocean–Atmosphere Dataset (COADS) sea surface temperature (SST) for waters around Puerto Rico (Woodruff et al. 1987) and the mean air temperature through the years for which continuous COADS series are most reliable (1946–95; Fig. 1) suggests that the SSTs drive the atmospheric temperatures, which should be expected on a relatively small island such as Puerto Rico. During El Niño years there is a transfer of warm SSTs from the eastern equatorial Pacific to the western equatorial Atlantic, which is very distinct up to 10°N

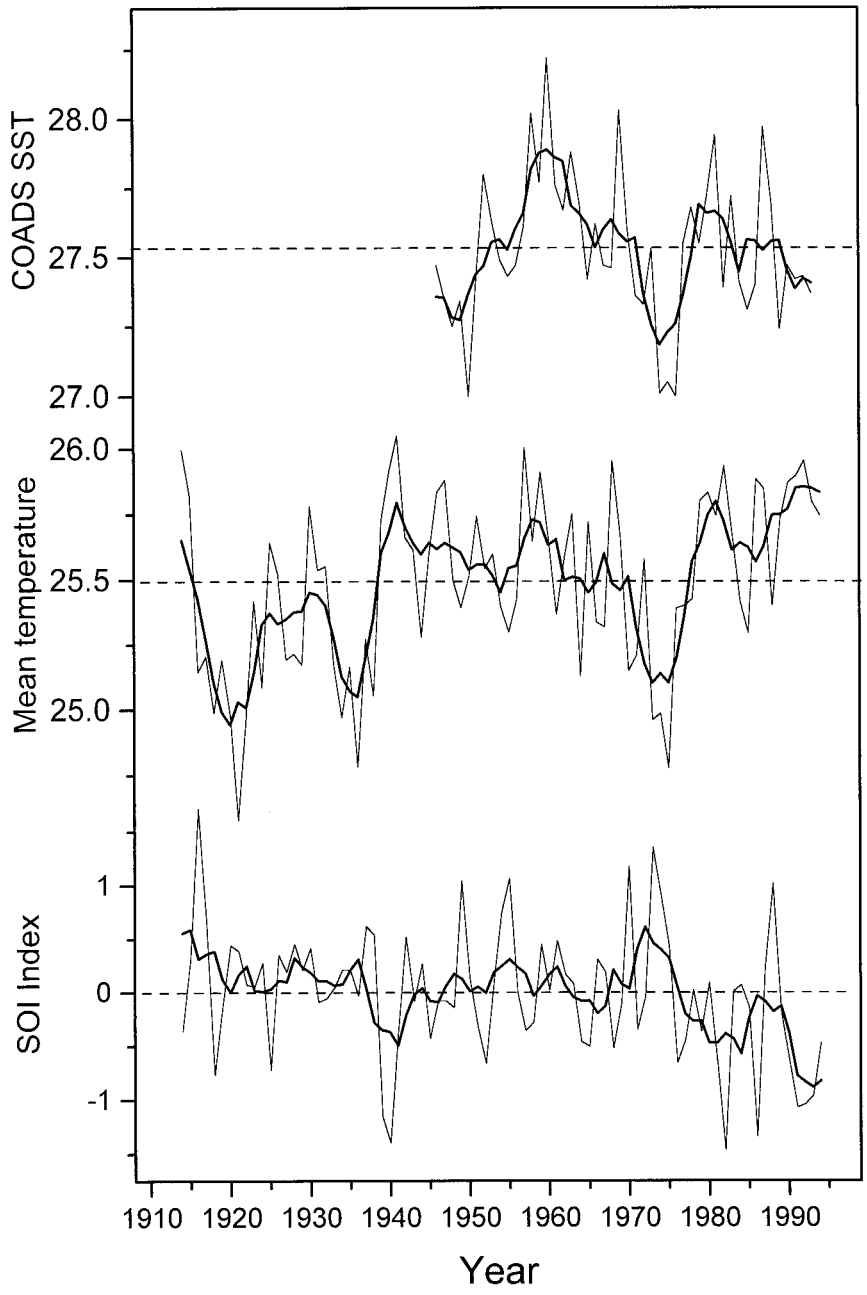



FIG. 1. Relationships between fluctuations in the El Niño–Southern Oscillation (ENSO) index (Troup 1965) and mean annual air temperature variation over five climatic stations from Puerto Rico since 1914 (Table 1) and variation in COADS SSTs for waters around Puerto Rico since 1946. El Niño years are marked by low SOI values. The El Niño year was defined as extending between October of the year identified as an ENSO year and September of the following year. Thick lines represent five-point moving averages.

but also incorporates the latitude of Puerto Rico (18°N) (Kawamura 1994).

We do not find any evidence of a relationship between precipitation patterns in Puerto Rico and ENSO. Even though ENSO influences precipitation in many regions around the globe, the Caribbean shows little ENSO-related precipitation (Ropelewski and Halpert 1987). However, variation in the NAO index during the winter is closely inversely related to the annual mean precipitation pattern (Fig. 2 and Table 2). A negative correlation between NAO and rainfall is also documented at all individual stations except Mayagüez (Table 2). The

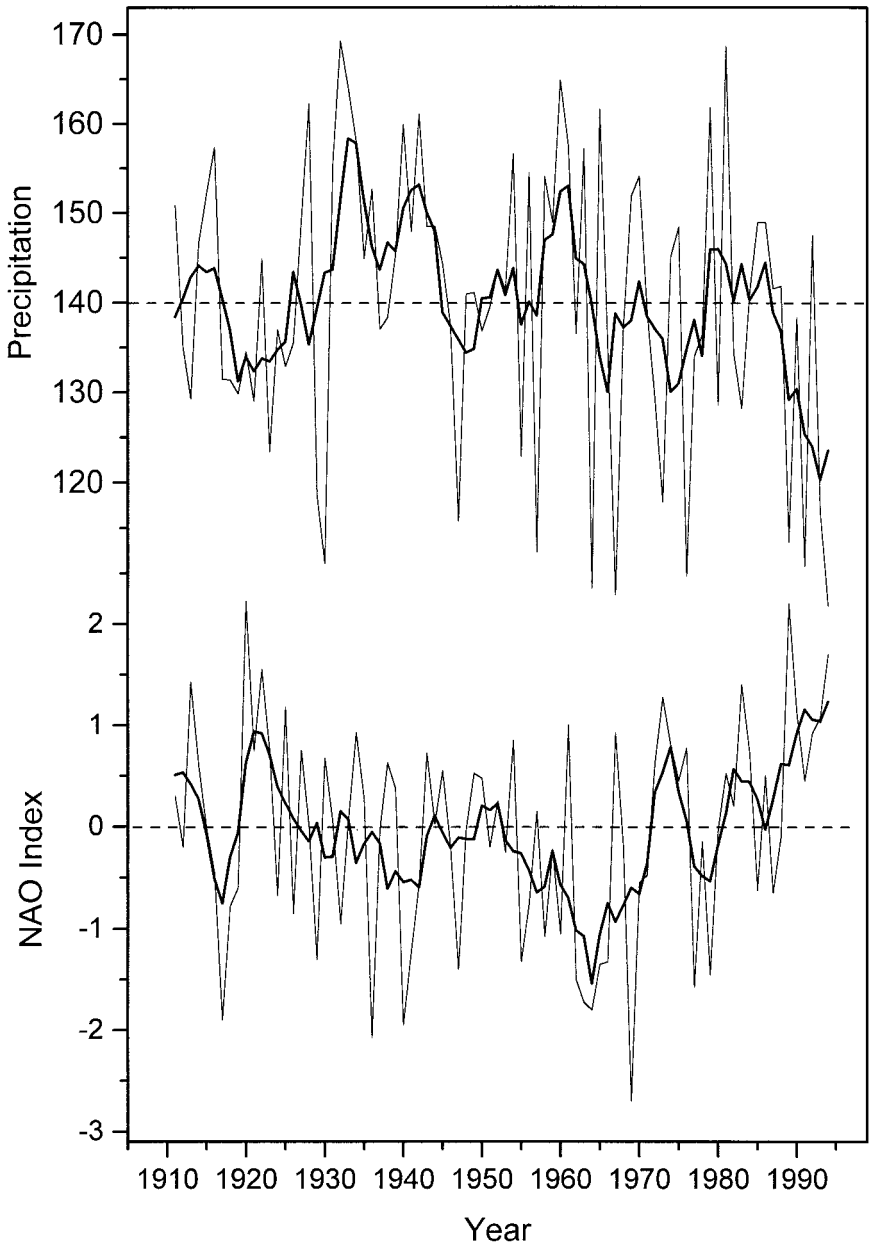



FIG. 2. Relationship between the winter (Dec–Mar) North Atlantic Oscillation index and mean annual precipitation over five climatic stations in Puerto Rico since 1911 (Table 1). Thick lines represent five-point moving averages.

patterns show a direct, peak-to-peak correlation. For example, generally decreased precipitation between 1919–23, 1972–76, and 1988–94 are matched by high values of NAO. Similarly, the high-precipitation peaks during the 1930s and early 1940s, and late 1950s and early 1960s coincide with low values of the NAO. Most other major peaks also match closely.

As the precipitation in the Caribbean is believed to be strongly influenced by the North Atlantic high, which is closely connected to the Icelandic low (Hastenrath 1976), the relationship between the NAO and precipitation patterns in the Caribbean may result from variations in displacement and strength of the high and the associated trade wind.

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