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Teleconnections between tropical Pacific sea surface temperature anomalies and North Carolina precipitation anomalies during El Niño events

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Abstract. Linear teleconnections of El Niño events and precipitation over a regional coastal land mass were analyzed. Two statistical techniques were used. First, the Empirical Orthogonal Function extracted major variances of the monthly tropical Pacific sea surface temperature anomalies and coastal North Carolina precipitation anomalies. Second, the Canonical Correlation Analysis calculated the linear combinations of the anomaly data sets that were highly correlated. The results show that El Niño-related precipitation anomalies along the North Carolina coast were positive from November to May and negative between June and October consistent with large-scale studies. Results indicate simple, linear statistical techniques can be effectively adopted to determine teleconnections on a local scale.

1. Introduction

El Niño is the term applied to the anomalous warming of the eastern and central tropical Ocean. This warming occurs irregularly every 2-7 years and lasts for several months. El Niño is one of the most important phenomena in the tropical ocean system at the interannual time scale. El Niño episodes can have variable amplitudes, but tend to have a similar phase. Early signs of the warming generally appear in March to May, building to a peak between December and February of the following year, and by May to July the sea surface temperatures (SSTs) tend to be normal again [*Rasmusson and Carpenter*, 1982]. The anomalous cooling of the tropical Pacific Ocean, on the other hand, is known as a La Niña event. Between the period 1950 to 1996, there were 15 El Niño and 10 La Niña events [*Trenberth*, 1997]. These events have a profound impact on regional as well as global precipitation patterns.

This study examines the ability of two simple, linear statistical techniques to extract the impact of El Niño on precipitation at a local to regional scale. For validation, the spatial and temporal evolutions of the monthly precipitation anomalies along the North Carolina coast and their teleconnections with El Niño are studied. This region, incidentally, is also of particular interest, because of the potential for beach erosion and property damage due to increased coastal storm frequencies. Thus, determining the possible correlation between the North Carolina coastal precipitation and El Niño events, is the other related objective of this study. Results from several large-scale studies that correlate and predict the impact of El Niño on climate variations over the United States are available [e. g., *Hoerling et al.*, 1997; *Livezey et al.*, 1997]. In the southeastern United States and northern Mexico, *Ropelewski and Halpert* [1986,1987] found that 81% of the El Niño events from 1885 to 1980 were associated with above normal precipitation starting in October of the El Niño year to March of the following year. More recently, *Montroy* [1997] showed that during El Niño, the eastern and central tropical Pacific SST anomalies have a positive correlation with precipitation in the southeastern United States between November and March, and a negative correlation occurs in July and August. The ability of linear statistical techniques to extract these features for a regional domain (coastal North Carolina) is investigated in the following sections.

Data and methodology are given in section 2. Section 3 provides results and discussion. Conclusions are presented in section 4.

2. Data and Methodology

Predictor data used in this study were monthly SST anomalies of the tropical Pacific Ocean (122.5°E to 67.5°W and 30.5°N to 29.5°S) from January 1982 to December 1997 with a horizontal resolution of 3° x 3°. The individual monthly SST values were obtained and interpolated from the Optimum Interpolation (OI) data sets of the Climate Prediction Center / National Oceanic and Atmospheric Administration. This time-series carries signatures of six El Niño events (1982-83, 1986-88, 1991-92, 1993, 1994-95, and 1997). The data field to be predicted (predictand) was the monthly precipitation anomalies for zero-month lead over coastal North Carolina. Locations of the 28 North Carolina coastal stations used in this study are shown in Fig.1. Monthly

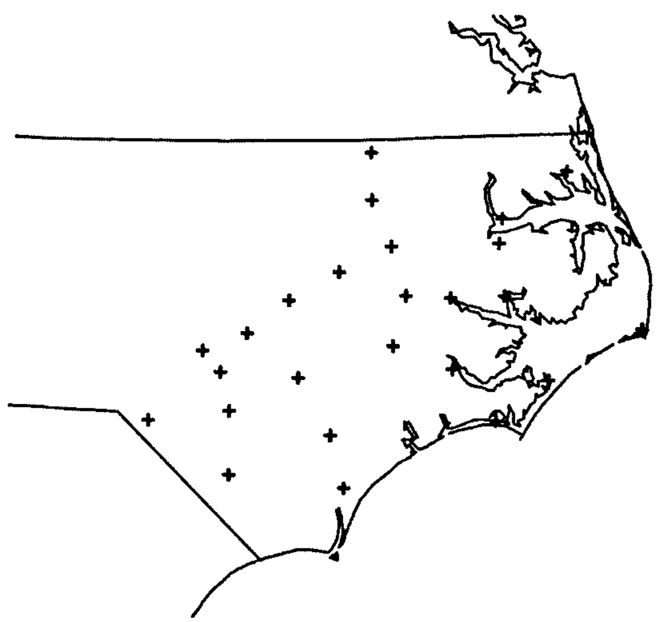

Figure 1. Locations of North Carolina coastal precipitation stations.

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Table 1. The correlation coefficients between the first CCA's principal components of the tropical Pacific SST anomalies and precipitation anomalies along the North Carolina coast with their variances.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corr.	0.88	0.76	0.76	0.79	0.82	-0.77	-0.90	0.84	-0.65	-0.74	0.80	0.95
Variance	83%	57 %	51 %	55 %	54 %	70 %	63 %	56 %	60 %	53 %	69 %	68 %

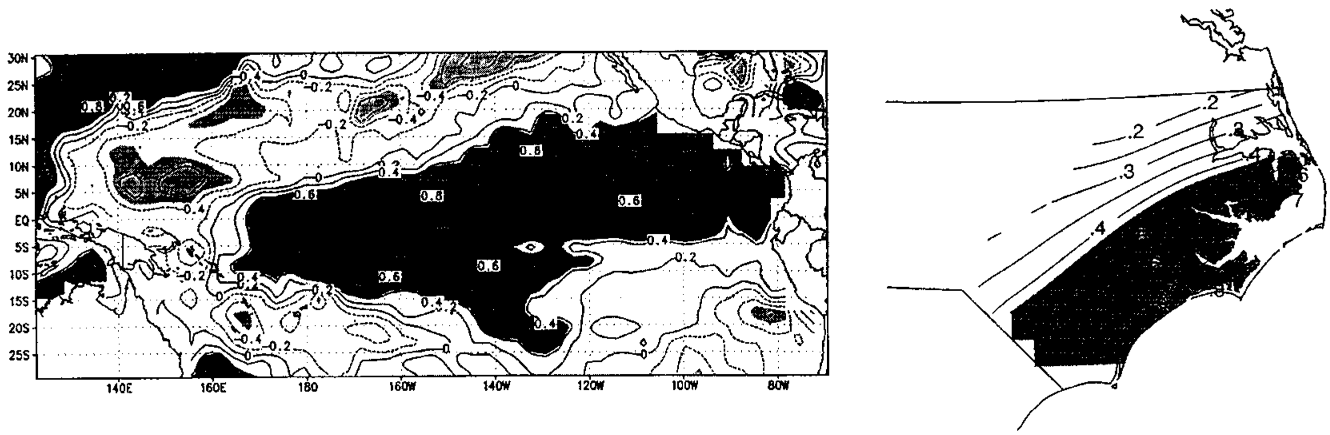

Figure 2. The first CCA's spatial maps of the tropical Pacific SST anomalies (left) and precipitation anomalies over the North Carolina coast (right) for January. Positive (negative) correlations greater than 90% level of significance are shaded dark (light).

precipitation data were obtained for these stations. Missing data were replaced by adjacent (time-space interpolated) data points, as described in *Niyogi et al.* [1997]. All anomaly values were defined as departures from the 1982-1997 normal.

We applied two statistical techniques: unrotated Empirical Orthogonal Function (EOF) and Canonical Correlation Analysis (CCA). The EOF was used to compress geophysical predictor and predictand data sets in both space and time. This reduction was accomplished by projecting the temporal variance onto uncorrelated orthogonal spatial patterns (eigen vectors) and associated time coefficients (principal components). The eigen vector patterns accounting for large variances are, in general, considered to be physically meaningful and connected with important centers of action. On the other hand, the remaining modes accounting for smaller variances were regarded as statistically and physically insignificant (noise). The EOF technique used in this study is described in *Peixoto and Oort* [1992]. It should be noted that only unrotated EOF was considered, since the main purpose of this analysis was data compaction and filtering [see *Barnston and Smith,* 1996]. The CCA is a multivariate statistical technique that correlates linear combinations of a set of predictors that maximize relationships, in a least-square error sense, to similarly calculated linear combinations of a set of predictands. In other words, the CCA was used to find linear combinations of predictor and predictand data sets that were well correlated. It is desirable to use the first few EOF modes that account for important patterns of variability for the canonical correlation analysis. The CCA method described in *Barnett and Preisendorfer* [1987] and *Graham et al.* [1992] is used in this study.

3. Results and Discussion

The EOF analysis applied prior to the CCA quantitatively identified the dominant spatial patterns of both the SST and precipitation anomaly fields. In general, the first EOF mode that accounts for the largest variance was associated with El Niño or La Niña signals. For the domain chosen, results from the first EOFs of the monthly tropical Pacific SST anomalies showed that during El Niño events, early warming in the eastern part appeared in April, reached a maximum in December and January of the following year, and returned to normalcy in July. Correspondingly, the first EOFs of monthly precipitation anomalies over coastal North Carolina, in general, decreased in intensity from the coast to inland or towards the north. The strongest and weakest gradients occurred in September and the weakest in April, respectively. The SST anomalies in the tropical Pacific Ocean varied in-phase with precipitation anomalies along the North Carolina coast between November and May, and were

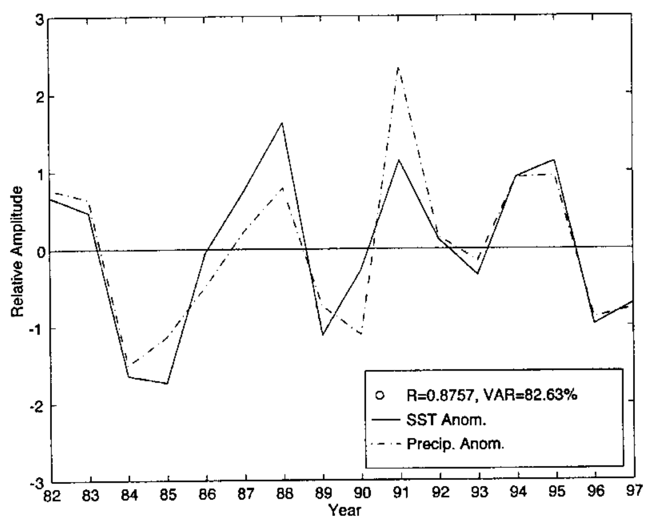

Figure 3. The first CCA's principal components between the tropical Pacific SST anomalies and precipitation anomalies over the North Carolina coast with corresponding correlation coefficient (R) and variance (VAR) for January.

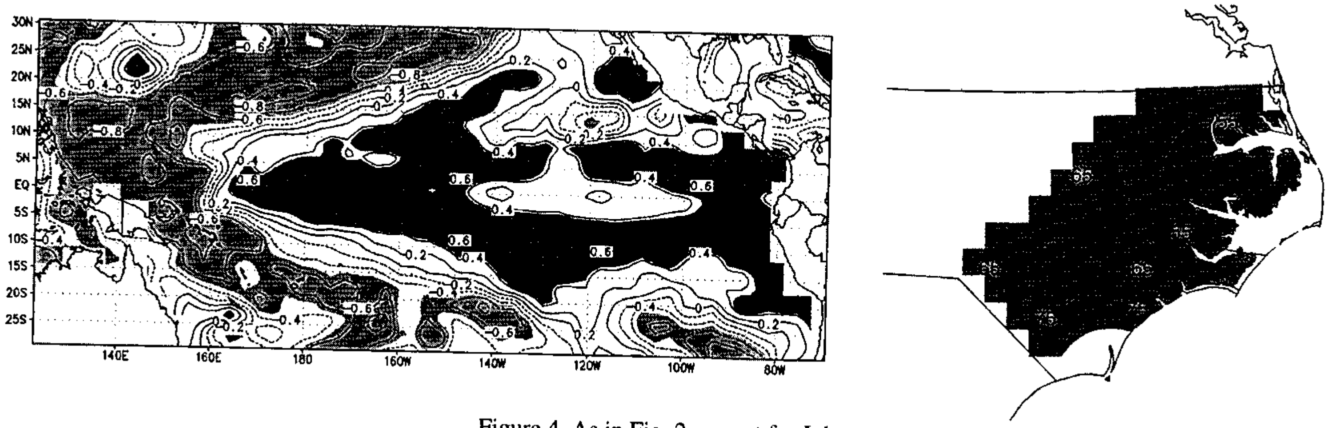

Figure 4. As in Fig. 2, except for July.

out-of-phase at other times. Overall, these results are consistent with other large-scale analyses for this region [see *Montroy*, 1997]. The other EOF modes correspond to the other time scale variabilities unrelated to El Niño. Although some of these variabilities are invariably present in the analysis, their behaviors are not our main focus in this paper.

Five EOF modes of SST anomalies and three to four EOF modes of precipitation anomalies that explained at least 80% of the cumulative variance were used for CCA inputs. These numbers were determined based on a dominant variance test using a Monte-Carlo simulation. A summary of the monthly correlation coefficients and variances between the first CCA's principal components of the tropical Pacific SST anomalies and the precipitation anomalies along the coastal North Carolina is shown in Table 1. During winter months (DJF), the most pronounced spatial correlations (significance level higher than 90%) between the warming in the eastern and central Pacific Ocean and increased precipitation along the North Carolina coast occurred in January. Figure 2 shows spatial maps of the first CCA between the tropical Pacific SST anomalies and precipitation anomalies over the North Carolina coast for January. These maps are given as grid point correlation distributions; that is, each grid point's value is the correlation coefficient between the SST, North Carolina precipitation anomaly values, and their principal components. High correlation values during this month were largely due to the strongest El Niño signals and the link between tropical convection and extratropical circulations. Corresponding principal components, with their correlation coefficients and variance, are shown in Fig. 3. Furthermore, these in-phase teleconnections tended to be weaker during spring months (MAM), except in March where the eastern tropical Pacific SST anomalies still had high correlations with precipitation anomalies in the southern part of the North Carolina coast (not shown). During these months, the lower correlation values could be due to weaker links between tropical and extratropical circulations, as the jet stream over southeast United States migrates northward. Moreover, these conditions could also be a result of the transition phase that exists during the beginning and decaying stages of the El Niño events.

The analysis further suggests, that during the summer months (JJA), the correlations were negative. The warm SST anomalies tended to be associated with decreases in precipitation, indicating suppressed local convection. It can be noted that a high-pressure system generally forms over the eastern part of the United States

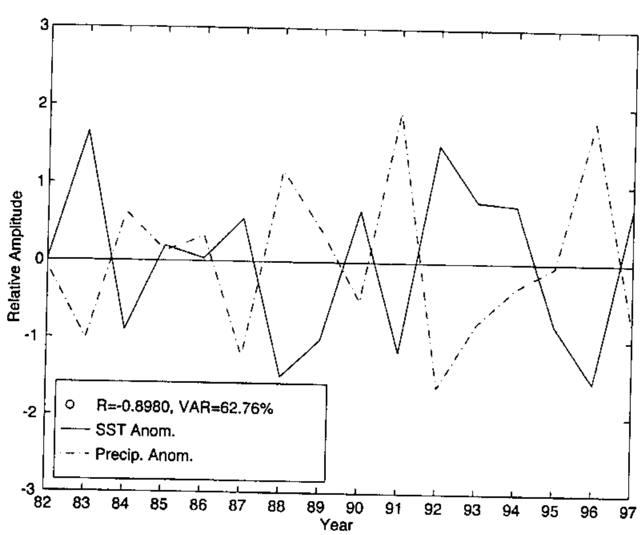

Figure 5. As in Fig. 3, except for July.

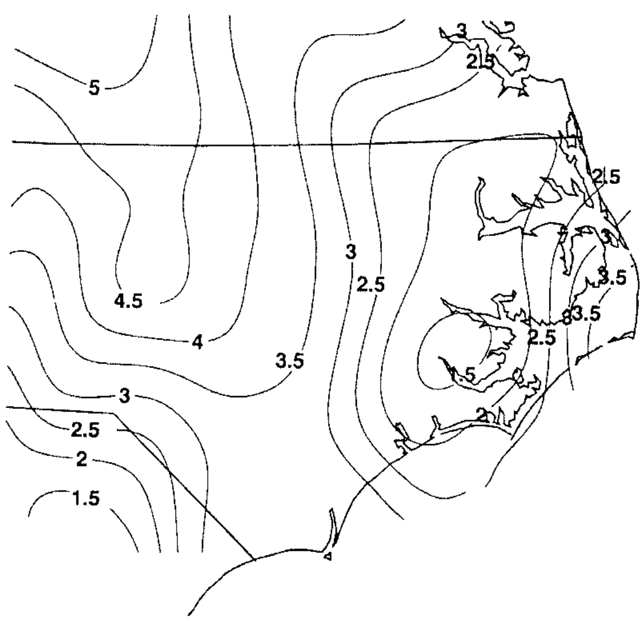

Figure 6. Observed precipitation anomalies (in.) along the North Carolina coast for January 1998.

during these periods. Strongest negative correlations obtained in mid-summer (July) are consistent with this phenomenon (Figs. 4 and 5). Moreover, a transition from negative to positive correlations was observed during the fall months (SON). These correlations were negative in September and October, but became positive in November (not shown). The CCA results thus showed consistent correlation between the SST anomalies and the precipitation anomalies along the coastal North Carolina domain. Observed patterns confirmed these statistical results. For instance, Fig. 6 is the observed positive precipitation anomaly for January 1998, which shows a decrease in intensity from south to north and coast to inland. This observation is consistent with the modeled outcome from the CCA/EOF analysis. Coastal North Carolina experienced above normal precipitation in February and March 1998 as well (see *SCO Newsletter Vol. 2/No. 2/1998*). A total of 12 storms generated over the Gulf of Mexico passed over North Carolina east of the Appalachian this winter as compared to around 4 during a non-El Niño year. These storms resulted in excess precipitation over North Carolina. Thus, overall good agreement exists between the modeled outcome at the regional scale and observations at the local-scale. This further supports the hypothesis of adopting linear methods for regional analysis to extract impacts of large-scale climatic features such as the El Niño events for developing local or regional climatology.

4. Conclusions

Two statistical linear methods (EOF and CCA) were applied to analyze the impact of El Niño on the precipitation patterns at a regional scale. The results were validated by studying the teleconnections between the tropical Pacific SST anomalies and the precipitation anomalies along the North Carolina coast. The results agreed well with observations and various other large-scale statistical analyses. For North Carolina, the El Niño-related precipitation anomalies had positive correlations between November and May and negative correlations between June and October. Substantial increases in precipitation during January 1998 confirmed the validity of the results from the statistical analysis. North Carolina's weather and climate are significantly influenced by El Niño events in the tropical Pacific Ocean. The results provide a confidence in the applicability of EOF and CCA analysis for understanding El Niño-like climatic events under regional or local perspectives.

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