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Seasonality in the Impact of ENSO and the North Atlantic High on Caribbean Rainfall

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Abstract. Caribbean rainfall is affected by climate variability of Pacific and Atlantic origin, e.g. the El Nino-Southern Oscillation (ENSO) phenomenon, and variability in the North Atlantic High sea level pressure (SLP) center, respectively. During the lifetime of an ENSO cycle, the basin experiences dry and wet extremes. In the case of a warm event, the dry extreme precedes the mature ENSO phase, and can be explained in terms of a direct response to the atmospheric anomaly generated by the warm sea surface temperatures (SST) in the eastern equatorial Pacific. The wet extreme follows the mature phase, and is consistent with the lagged warming effect of ENSO on tropical North Atlantic SSTs. The wintertime state of the North Atlantic High is hypothesized to affect Caribbean rainfall through its effect on tropical SST. A strong North Atlantic High SLP center during the early months of the calendar year strengthens the trade winds, hence cooling SSTs in the tropical latitudes of the North Atlantic. The effect lingers on most noticeably until the start of the Caribbean rainy season, in May-June, when cool SSTs are associated with deficient rainfall in the basin.

1 Introduction

The focus of this contribution is on the seasonal dependence of the prevalent large-scale patterns of ocean-atmosphere variability in the eastern Pacific and North Atlantic sectors, and how this intraseasonal variability interacts with the evolution of the annual rainfall cycle in the Caribbean/Central American region. The large-scale factors that influence rainfall in our region of interest are identified to be ENSO and the strength of the North Atlantic high SLP. (The reader is referred to Giannini et al. (2000) for a more detailed analysis.)

2 Background: The mean annual cycle in rainfall in the Caribbean/Central American region

Rainfall in the Caribbean/Central American region undergoes a very distinct annual cycle, which can be most aptly described in terms of Principal Component Analysis (PCA) of the mean monthly climatology (see Fig. 1). The first three Principal Components (PC) account for 89% of the total variance, or 65%, 14% and 10%, respectively. Most rain falls during the Northern Hemisphere warm season, between May and October, as characterized by PC1. A break in mid-summer, represented by PC2 minus PC3, is most pronounced in the 'interior' of the Caribbean basin, from the eastern provinces of Cuba, to Jamaica, Hispaniola and Puerto Rico, all the way to northwestern South America. The late-fall peak, represented by PC2 plus PC3, is enhanced along the northeast-facing coasts of the Antilles, as well as the Caribbean coast of Honduras.

3 ENSO and Caribbean rainfall

The 'canonical' ENSO lifecycle in the tropical Pacific has been extensively described, most notably by Rasmusson and Carpenter (1982). We focus here on its teleconnection to the Atlantic Ocean. Such a teleconnection, given our interest in 'short' timescales, when compared to the ocean circulation, has to necessarily receive its initial impulse through the atmosphere, before its impact on the ocean can be assessed. We describe the ENSO lifecycle in terms of correlation maps of sea level pressure (SLP) and sea surface temperature (SST) with the NINO3 index (SST averaged between 5S and 5N, 150W and 90W, in the equatorial eastern Pacific). The datasets used are the products of Kaplan's Reduced Space Analysis (Kaplan et al., 1997, 1998, 2000) of COADS SLP (Slutz et al., 1985) and MOHSST5 SST (Bottomley et al., 1990). The NINO3 index is averaged over the months of December and January, with the intent to capture the mature phase of each ENSO cycle on record, from 1881

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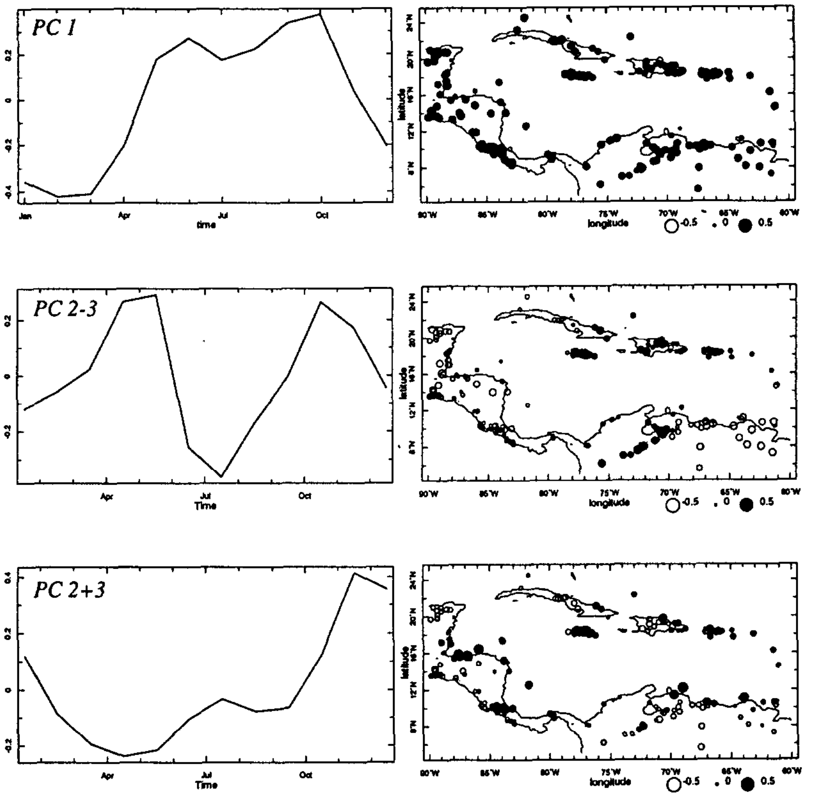


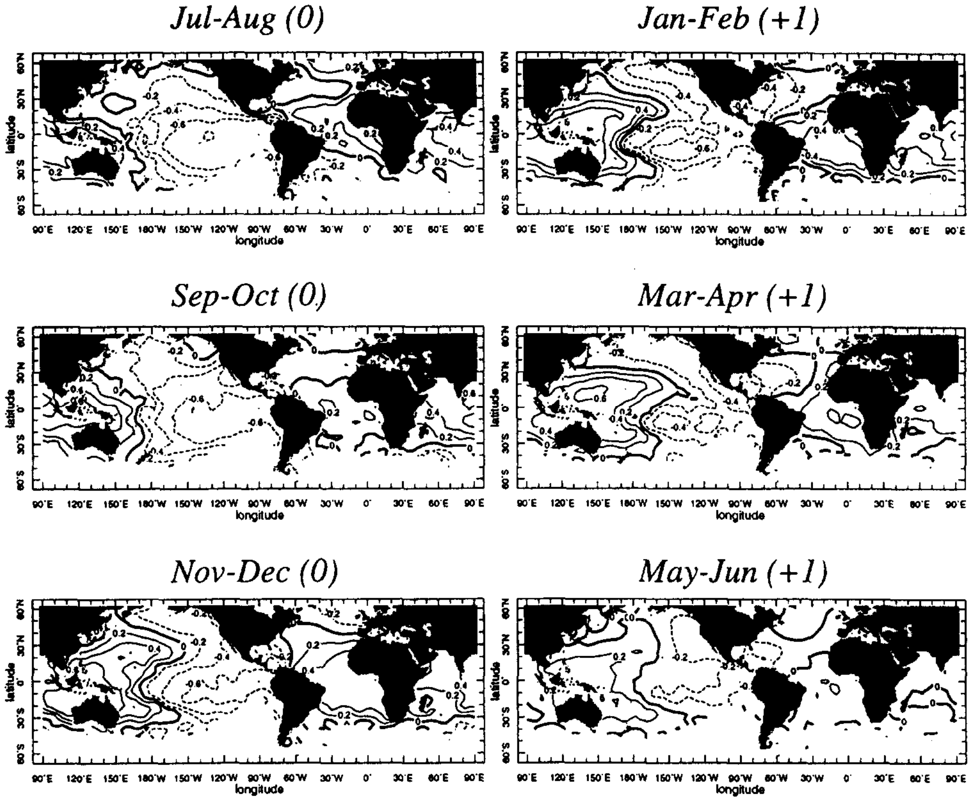
Fig. 1. Principal Component Analysis of the mean annual cycle of rainfall at 188 stations in the Caribbean/Central American region (taken from the NOAA NCDC GCPS Historical Monthly Station Rainfall Dataset). The monthly climatologies for each station were computed over the period 1951-1980. Left column: Principal Components. top: PC 1; middle: PC2-PC3; bottom: PC2+PC3. Right column: corresponding spatial patterns.

to 1991. It is then correlated with two-month averages of SLP and SST, from the July-August preceding the mature phase, i.e., following the terminology of Rasmusson and Carpenter (1982), the second half of year (0), to the May-June following it, i.e. the first half of year (+1).

The tropic-wide oscillation in SLP, known as the Southern Oscillation, is apparent from the onset phase of the ENSO episode, in May-June (0) (not shown). In the case of a warm episode, when SLP is low over the eastern and central equatorial Pacific, it tends to be higher than average not only over the maritime continent, in the western Pacific, but also over the equatorial Atlantic (see Fig. 2). As a consequence, the meridional gradient in SLP is diminished in the tropical North Atlantic, and so is the strength of the trade winds. As the wintertime nears, the response of the extratropical atmosphere, in the shape of the Pacific-North American pattern (Wallace and Gutzler, 1981), adds up to the zonal seesaw in tropical SLP between the eastern equatorial Pacific and the tropical Atlantic. It acts to enhance the weakening of the meridional SLP gradient in the tropical North Atlantic, between the low centered over the southeastern U.S. and the equatorial high, further weakening the trade winds in the Northern Hemisphere tropics. At the same time, the positive SLP anomaly is pushed towards the Southern Hemisphere, possibly strengthening the southeasterly trade winds there. The response of the tropical North Atlantic to decreased trade winds is an increase in SST, which peaks with a lag of about one season with respect to mature ENSO conditions in the central equatorial Pacific (Enfield and Mayer, 1997) (see Fig. 3). Caribbean rainfall is affected by the propagation of the signal from the eastern equatorial Pacific through the atmosphere first, and by the lagged oceanic response later (see Fig. 4). At first, during the second half of the rainy season which precedes the mature ENSO phase, and concomitant with the SST anomaly build-up in the eastern equatorial Pacific, a divergent surface circulation dominates the region, with winds, and moisture convergence, directed away from the Caribbean basin, to the south-west, onto the eastern Pacific ITCZ, and to the north-east, towards the Atlantic. Drier than average conditions prevail, with the only notable exception of the Caribbean side of Costa Rica (Waylen et al., 1996). During the winter only the northern portion of the basin is affected by anomalous storm activity of extratropical origin. Then, as the new rainy season kicks in, and ENSO, together with the anomalous atmospheric circulation that accompanies it, have let off, the retarded effect of warm tropical North Atlantic SST can be felt in terms of increased convection and rainfall (Chen et al., 1997).

4 The North Atlantic high and Caribbean rainfall

In a manner analogous to that done for ENSO, the role of North Atlantic climate in generating Caribbean rainfall vari-


Jul-Aug (0)

Jan-Feb (+1)

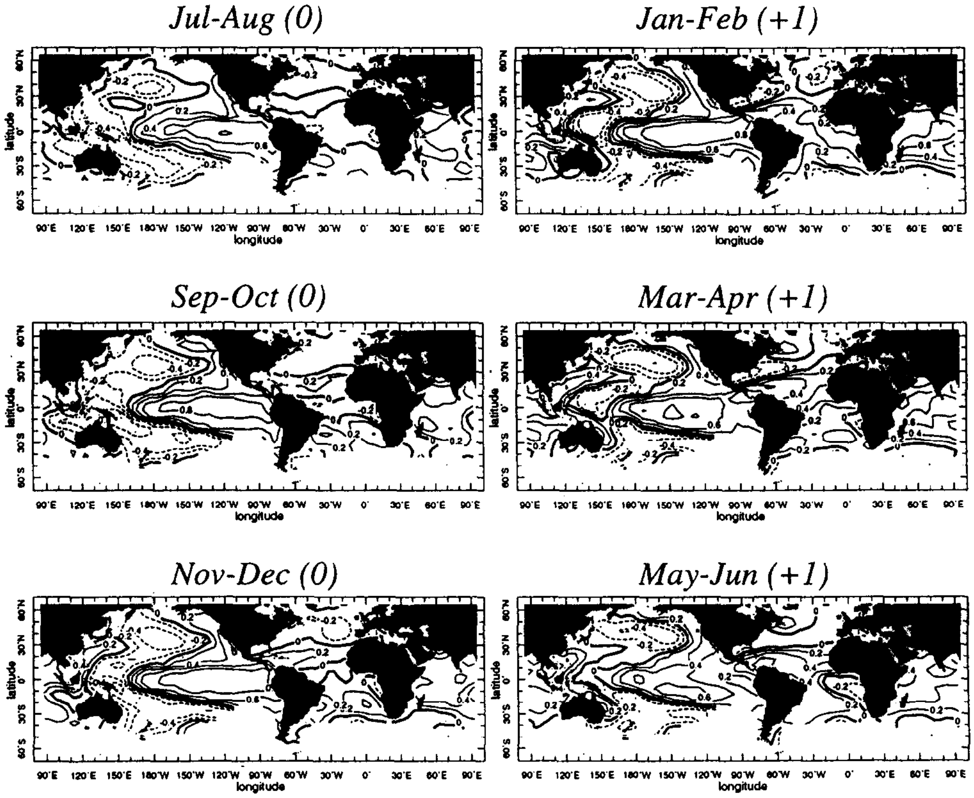
Sep-Oct (0)

Mar-Apr (+1)

Nov-Dec (0)

May-Jun (+1)

Fig. 2. Correlation maps of the NINO3 index (averaged over Dec(0)-Jan(+1)) with SLP. Left column: Jul-Aug(0) to Nov-Dec(0). Right column: Jan-Feb(+1) to May-Jun(+1). Correlations are computed over the 1881-1990 period. Statistical significance at the 95% level, assuming year-to-year independence, is 0.2.


Jul-Aug (0)

Jan-Feb (+1)

Sep-Oct (0)

Mar-Apr (+1)

Nov-Dec (0)

May-Jun (+1)

Fig. 3. Same as in Fig. 2, but for SST.

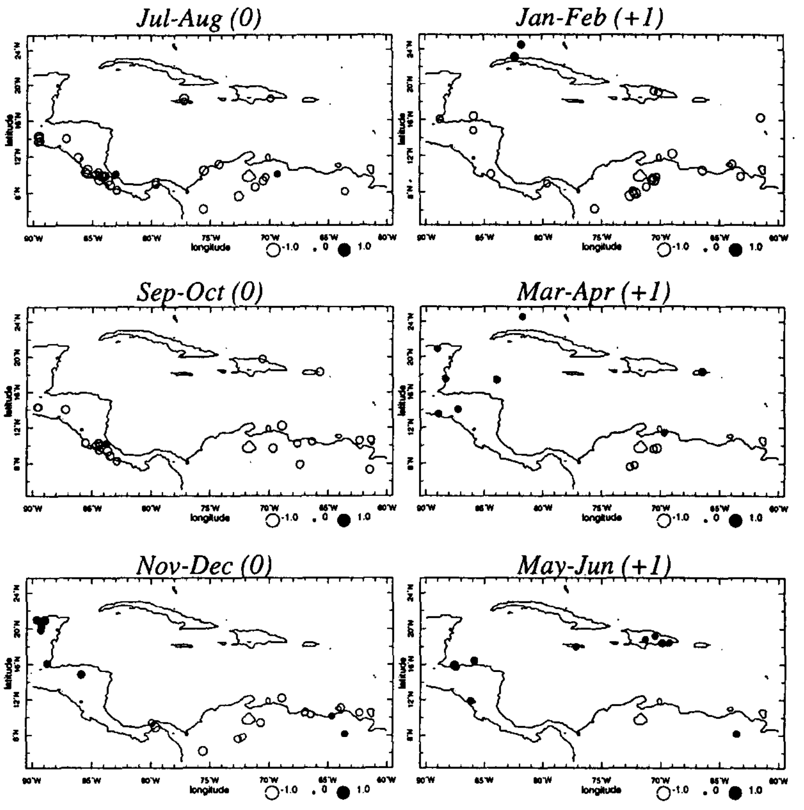


Fig. 4. Correlation maps of the NINO3 index (averaged over Dec(0)-Jan(+1)) with rainfall. Left column: Jul-Aug(0) to Nov-Dec(0). Right column: Jan-Feb(+1) to May-Jun(+1). Correlations are computed over the 1951-1980 period. Statistical significance at the 95% level, assuming year-to-year statistical independence, is 0.33. Only statistically significant stations are plotted.

ability is assessed by means of correlation maps of a North Atlantic High index, defined as SLP averaged between 20N and 40N, 60W and 30W, with SLP and SST (see Fig. 5). The index corresponds to the subtropical component of the North Atlantic Oscillation (NAO), and is calculated over January-February averages and then correlated with the simultaneous (January-February) as well as with the following two-month periods (March-April to November-December). It is a well-known fact that the extratropical atmosphere in general, and the NAO in particular, do not show signs of long-term memory or persistence, so it does not come as a surprise that the January-February North Atlantic High is very weakly correlated even with the immediately subsequent March-April SLP pattern. (A modest resurgence in correlation values can be noticed in July-August.) What is of greater interest to the Caribbean/Central American region is the longer lifetime of the signal in the surface ocean. The effect of a stronger than average wintertime North Atlantic High is to cool SST in the subtropical North Atlantic, and evidence of this cooling persists from winter to the beginning of the rainy season. The impact on rainfall is strongest at this time, in May-June, with negative SST anomalies associated with negative rainfall anomalies (see Fig. 6).

5 Conclusions

We have shown evidence that climate variability of Pacific and Atlantic origin has an impact on Caribbean/Central American rainfall. ENSO has opposite effects during portions of the rainy seasons preceding and following the mature phase of an event. The wintertime North Atlantic high affects convection in the Caribbean at the start of the rainy season, through its forcing of tropical North Atlantic SST anomalies.

Because ENSO has a prolonged lifecycle, tied in its development to the annual cycle, and because it affects Caribbean rainfall with outcomes of opposite sign depending on its phase, we should not be surprised that an analysis of the intraseasonal variations in the large-scale patterns of climate variability affecting Caribbean rainfall has highlighted the role of ENSO. On the other hand, precisely because we know so much about ENSO already, advances in our understanding and in the predictability of this system will be more likely to come from the Atlantic side.

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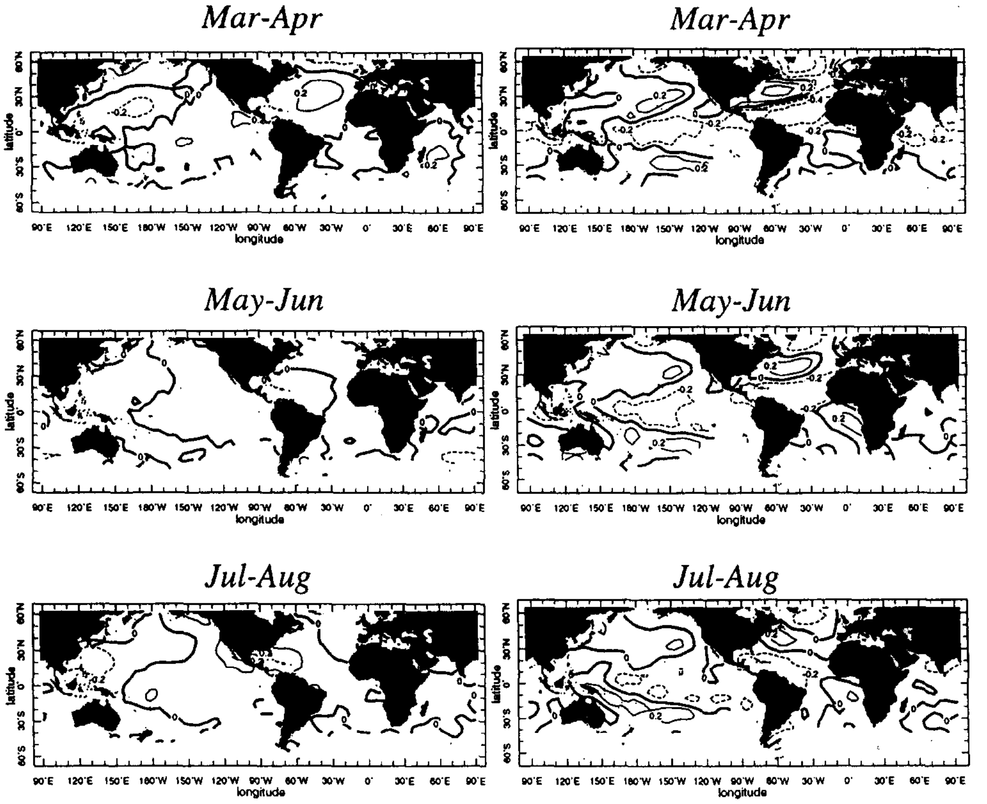

Fig. 5. Correlation maps of the North Atlantic high index (averaged over Jan-Feb) with SLP (left column) and SST (right column) in Mar-Apr, May-Jun and Jul-Aug. Correlations are computed over the 1881-1990 period. Statistical significance at the 95% level, assuming year-to-year independence, is 0.2.

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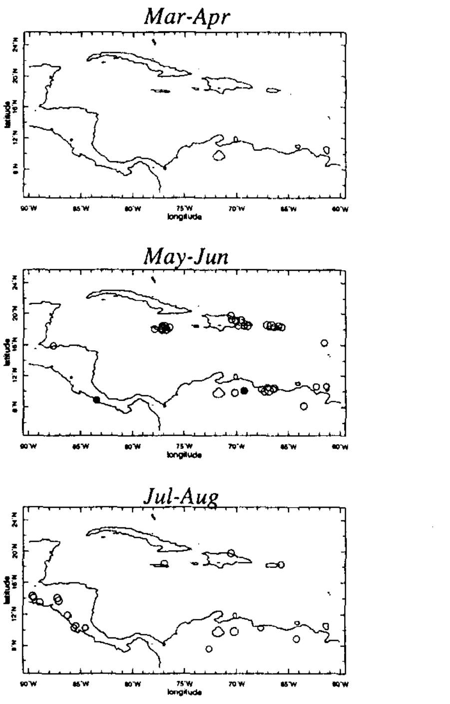

Fig. 6. Correlation maps of the North Atlantic high index (averaged over Jan-Feb) with rainfall in Mar-Apr, May-Jun and Jul-Aug. Correlations are computed over the 1951-1980 period. Statistical significance at the 95% level, assuming year-to-year statistical independence, is 0.33. Only statistically significant stations are plotted.