8.4 Examining the effect of Concurrent SST anomalies on Caribbean Rainfall

Jacqueline Spence* and Michael A. Taylor
University of the West Indies, Kingston 7, Jamaica

1. Introduction

A number of recent studies have investigated the joint role of the tropical Atlantic and tropical Pacific in modulating precipitation in the Caribbean. Chen et al. (1997) propose an enhancement of early season Caribbean rainfall due to positive sea surface temperature anomalies (SSTAs) in the north tropical Atlantic (NATL) during the declining phases of an El Niño. Giannini et al. (2000) suggest a variation in early season rainfall due to a sea level pressure link between the Pacific and the Atlantic. Enfield and Alfaro (1999) (hereafter EA-99), use singular value decomposition (SVD) analysis to confirm a relationship between an enhanced mean Caribbean wet season (May-November) and a concurrently warm tropical Atlantic and cool tropical Pacific.

We extend the above investigations, by considering the relative roles of both tropical basins on an *evolving* Caribbean rainy season. Caribbean rainfall peaks in May–July (the early wet season) and September–November (the late wet season), with a dry season that spans December to April. Taylor et al (2001) argue that meaningful analysis of Caribbean rainfall variability requires splitting the wet season into at least two seasons (early and late) as the tropical ocean of dominant influence changes as the Caribbean rainfall season progresses. Whereas the NATL influence dominates during the early season (a warm NATL yielding more rain), it is the equatorial Pacific influence which does so during the late season (a cool Pacific being associated with increased Caribbean rainfall).

Using the argument of Taylor et al as a basis for our investigation, we attempt to determine if the influence on Caribbean rainfall of oppositely signed concurrent SSTAs in the tropical Pacific and NATL (as noted by EA-99) is significant *throughout* the course of the year. That is, we attempt to determine the extent to which the EA-99 relationships are valid for the early (MJJ) and late (ASO) rainfall seasons and for an early and late dry season (NDJ and FMA). Recall that EA-99 considered only a mean wet and dry season. We therefore repeat the analysis of EA-99 for our study after however stratifying the year into three-month seasons.

Sections 2 and 3 outline the data and methodology employed. Section 4 gives the findings and their implications.

2. Data

The precipitation dataset used is the monthly gridded, hybrid (station and satellite) analysis of Magaña et al (1999) which spans the period 1958-99. Its resolution is $0.5^0 \times 0.5^0$ which is greater than that of the Xie -Arkin dataset used by EA-99. Only that portion covering the Caribbean and near Caribbean region (60^0–100^0 W, 6^0-25^0 N) was used.

Monthly SST anomalies over the region 177^0–3^0 W and 27^0 S–48^0 N (defined to include the NATL and eastern tropical Pacific) were from the global analyses of Kaplan et al (1998). The Kaplan analyses span the period 1856–99 and have a resolution of $5^0 \times 5^0$.

For the study, the period under consideration was 1958–1998.

3. Methodology

After removing climatology we extract four seasonal datasets of gridded anomalous precipitation (PCPA) from the Magaña data. To do so the data was averaged over NDJ, FMA, MJJ, and ASO, with NDJ and FMA representing two dry seasons and MJJ and ASO representing the early and late wet seasons. Given (i) our interest in interannual variability, and (ii) the strong decadal signal in Caribbean rainfall records (Taylor et al 2001), we subtract from each dataset the result of a 7-year running mean applied at each grid point. The detrending reduces the period studied to 1961-1995. Seasonal datasets were also extracted from the SSTA dataset, but these were not detrended.

As was done by EA-99, SVD analysis was performed on the SSTA and PCPA data for each season. SVD analysis decomposes the eigenvector of the cross-covariance matrix between two input variables - in this case SSTA and PCPA - into modes of decreasing explained crosscovariance between the two fields. Each mode is represented by a pair of singular vectors describing the spatial patterns of weights for the two variables, and two series of expansion coefficients describing the weighting of the mode on the two variables in the temporal domain. (For more on SVD analysis see Bretherton et al. 1992).

The results for each season are represented by a table of SVD statistics and a pair of heterogeneous correlation maps which give the correlation of the expansion coefficients of one field with the grid point values of the other. We also correlate (i) the PCPA and SSTA expansion coefficients for each season with common SSTA indices which have been similarly seasonally stratified (a list is given in Table 2), and (ii) the PCPA expansion coefficients with a seasonally stratified Caribbean precipitation index (CARP) (see again Table 2). The former allows us to associate the SVD modes with variability in one of the two ocean basins, while the latter is a check of the extent to which the PCPA mode captures the variability of the main Caribbean basin. The statistical significance of all correlations is determined by the random phase method (Ebisuzaki 1997), which accounts for serial correlation in the data.

* Corresponding author address: University of the West Indies, Mona Kingston 7, Jamaica. E-mail: jamspence21@yahoo.com

4. Results

(a) El Niño related variability (mode 1)

The summarized statistics of Table 1 show that for all seasons mode 1 has the highest squared covariance fraction, indicating that it captures the greater portion of the cross-covariance present between the two fields. Because the NSC statistic never exceeds 0.25 it is also true that much of the rainfall variability over the PCPA grid domain is unexplained by the SSTA dataset (and vice versa).

Table 1 Statistics for the first two modes of SSTA and PCPA for each three-month season. SCF is the squared covariance fraction and NSC is the normalized squared covariance. The last column shows the correlation of the temporal expansion coefficients for SSTA and PCPA.

Season	Mode	SCF	NSC	SSTA vs. PCPA
NDJ	1	0.8402	0.2517	0.8001
	2	0.0814	0.0784	0.7271
FMA	1	0.7164	0.1799	0.8094
	2	0.1066	0.0694	0.6156
MJJ	1	0.5257	0.1392	0.7956
	2	0.1919	0.0841	0.5862
ASO	1	0.6951	0.1732	0.6970
	2	0.0787	0.0583	0.6261

The correlation of the expansion coefficients of the first mode for each season with known global indices (Table 2a) confirms the first mode as ENSO. For all seasons the correlations with the NINO3 index exceeds 0.9, and with the exception of the NATL in FMA no other SSTA index correlates significantly with the mode 1 SSTA expansion coefficients. We share the view of EA-99 that the significant NATL correlation in FMA results from the known strong correlation between winter equatorial Pacific and NATL SSTAs (Enfield and Mayer 1997), and therefore is also indicative of ENSO related variability.

The panels of figure 1 show respectively the heterogeneous correlation maps for mode 1 for NDJ (panels a and b) and MJJ (panels c and d). In NDJ correlations of opposite sign to that in the Pacific exist over the Caribbean between 10^{o}-15^{o}N, with equally strong but oppositely signed correlations above 20^{o}N (panel b). There is strong ENSO modulation of Caribbean rainfall at the start of the dry season, with the modulating effect changing sign from northern (wetter during warm Pacific events) to southern (drier during warm events) Caribbean. The significant 0.744 correlation between PCPA/CARP for NDJ (Table 2) confirms that the mode captures much of the variability of the main Caribbean basin. There is similarity between panels a and b and the EA-99 mode 1 diagrams for the dry season. Our panels however indicate a stronger southern Caribbean response.

The ENSO-Caribbean influence quickly wanes and by the second half of the dry season (FMA), it is only the eastern Caribbean which exhibits noteworthy relationship with the phenomenon (not shown). Note that the PCPA/CARP correlation drops to 0.372.

Table 2 Correlations between the expansion coefficients of SSTA and PCPA (all seasons) for (a) Mode 1 and (b) Mode 2 with area averaged SSTA indices: NINO3 (6^{o}S-6^{o}N, 150°-90°W), and NATL (6^{o}S-22^{o}N, 80°-15°W). Correlations between PCPA and a Caribbean precipitation index CARP (66^{0}-83^{0}W, 10^{0}-18^{0}N) are also shown. Significant correlations are shown in bold.

(a) Mode 1

INDICES	NDJ	FMA	MJJ	ASO
Nino3/SSTA	**0.982**	**0.939**	**0.947**	**0.980**
NATL/SSTA	-0.031	**0.562**	0.181	0.133
Nino3 /PCPA	**0.794**	**0.798**	**0.759**	**-0.687**
NATL /PCPA	-0.287	**0.552**	0.006	**-0.232**
CARP/PCPA	**0.744**	**0.372**	0.077	**0.745**

(b) Mode 2

INDICES	NDJ	FMA	MJJ	ASO
Nino3/SSTA	-0.288	**0.311**	0.076	**0.488**
NATL/SSTA	**-0.541**	**-0.563**	**0.758**	0.338
Nino3 /PCPA	-0.016	0.107	-0.013	0.063
NATL /PCPA	**-0.394**	**-0.312**	**0.478**	**0.325**
CARP/PCPA	**0.645**	**0.412**	**0.937**	**0.621**

During the early rainfall season (panels c and d), there is little evidence of ENSO-Caribbean rainfall modulation, consistent with the rapid decline in ENSO influence seen at the end of the dry season. The insignificant correlation between MJJ PCPA/CARP reinforces this idea. We contrast this however with the late rainfall season (ASO) when the ENSO influence reappears in the region south of 20^{o}N (not shown). EA-99 observed the tendency for a drier rainfall season in the face of a warm equatorial Pacific, but they noted the tendency to be weak and not statistically significant. We observe a more robust tendency in ASO as also suggested by the significant correlations between ASO PCPA/NINO3 and PCPA/CPINDX. We suggest that EA-99's use of a mean rainfall season inclusive of MJJ dampened the ENSO-Caribbean response in their mode 1 wet season figures.

We also note a similarity between the maps for NDJ and ASO (not shown). ENSO modulation of Caribbean rainfall seems to span the latter half of the rainy season and the beginning of the dry season.

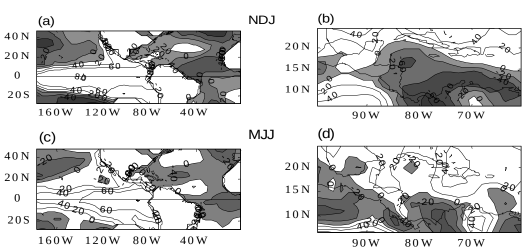
(b) Atlantic related variability (mode 2)

As for EA-99, mode 2 of the SVD analysis is an Atlantic-associated mode, which (except for ASO) is only marginally or insignificantly correlated with ENSO (Table 2b). The SCF statistic indicates that the Atlantic mode is strongest in MJJ and FMA - the two periods that exhibited weakest ENSO-Caribbean rainfall relationship. The NSC statistic shows MJJ as the season of strongest coupling between SSTA and PCPA for mode 2, with the statistic exceeding 60% of the corresponding value for mode 1 of the same season. The Atlantic mode in fact captures most of the variability of MJJ Caribbean precipitation as indicated by the robust correlation (0.937) between PCPA and CARP.

The SST pattern associated with enhanced MJJ Caribbean rainfall south of 20^{o}N (panels c and d of Fig. 2) is characterized by warm SSTAs across the NATL between 0^o and 20^{o}N. A similar SST pattern is observed in FMA though the tendency for a wetter Caribbean is weaker. A similar SSTA pattern has also been noted across the NATL due to the strong connectivity between winter equatorial Pacific and NATL SSTAs noted earlier. This likely accounts for the marginally significant correlation between mode 2 SSTA/NINO3 in FMA. The insignificant correlation between the same indices a season later however strongly suggests the NATL as the primary modulator of Caribbean rainfall during these two seasons, irrespective of whether its anomalies are induced by ENSO or its own internal variability.

We note also that in a similar manner to the ENSO related variability, the Atlantic influence spans the latter half of the Caribbean dry season and the beginning of the wet season.

Figure 1. Heterogeneous correlation maps for SVD Mode 1. Maps a and b are for NDJ, and c and d are for MJJ. a and c show the distribution of scalar correlation between gridded SSTA and mode 1 expansion coefficients for PCPA. Shading denotes regions of opposite sign to the equatorial Pacific. b and d show the correlation between gridded PCPA and expansion coefficients for SSTA. Shading denotes regions which are negatively correlated with the equatorial Pacific.



(c) SST Antisymmetries

During ASO and NDJ when the ENSO mode is the more significant modulator of Caribbean rainfall, a connection exists between a warm eastern equatorial Pacific and a cool equatorial Atlantic (Fig. 1 panel a). The pattern appears more pronounced in ASO (not shown) than in NDJ, and the zonal asymmetries in SSTA extend up to 15^{o}N in both basins during this period. We concur with EA-99 that zonal antisymmetries in SST are significant modulators of Caribbean rainfall south of 20^{o}N. However whereas they found this to be true for a mean wet season, we find it to be true only for the late rainfall season and the early dry season.

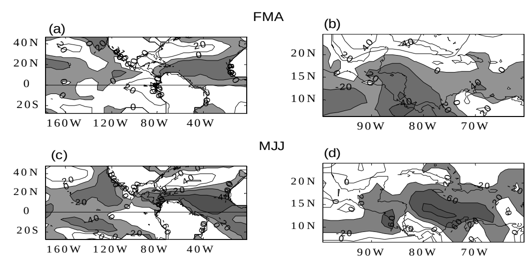
Antisymmetry in SST across the Atlantic ITCZ appears significant in FMA for both modes 1 and 2. This was however the period of weakest association between the temporal coefficients of PCPA and the Caribbean rainfall index. Finally, during MJJ when the Atlantic mode dominates, the SST features (Fig. 2c) are primarily confined north of the equator.

5. Conclusions

There is strong evidence of the impact of both the tropical Atlantic and tropical Pacific on Caribbean rainfall on the interannual timescale. SVD analysis suggests that El Niño occurrences have strongest impact in the Caribbean during ASO and NDJ, with the general tendency being a drying of those regions south of 20^{0}N, and an enhancement of rainfall north of this latitude. The ENSO impact diminishes rapidly and by the end of the dry season (FMA) and the beginning of the early rainfall season (MJJ) it is the tropical Atlantic which is primarily associated with Caribbean rainfall variability.

Importantly, for both tropical basins, the period of their dominant influence overlaps with the end of one rainfall regime (dry or wet) and the beginning of another. We therefore concur with Taylor et al (2001) that caution must be exercised when considering Caribbean rainfall variability as analysis of a mean wet or dry season masks potentially important influences that affect only a portion of the season. This would account for the fact that we find zonal asymmetries in SST across the two tropical oceans to be significant only for the late rainfall season and the start of the dry season, whereas EA-99 find it to be so for the mean Caribbean wet season.

Figure 2. As in Fig.1 but for FMA and MJJ season Mode 2. Shading in a and c shows positive correlations between SSTA and PCPA. Shading in b and d shows regions that are positively correlated with shaded TNA portion of a and c.



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