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LOCAL-SCALE ANALYSIS OF THE CARIBBEAN MID-SUMMER DRY SPELL ON SAN SALVADOR, BAHAMAS

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ABSTRACT

The annual rainfall pattern of the Caribbean is bimodal in nature with an early-season peak from April to June, and a second late-season peak from August to November. Both peaks are separated by a low period of rainfall termed the mid-summer drought or mid-summer dry spell (MSD). The origin of the Caribbean MSD is enigmatic due to an incomplete understanding of the atmospheric processes associated with its genesis. One reason for the incomplete understanding is that the majority of existing research has focused upon regional or global scale analysis. Few if any studies have focused upon daily weather patterns associated with development of the Caribbean MSD at one specific location. In order to expand this limited range in scale of analysis, the purpose of this research is to investigate the daily weather patterns associated with the Caribbean MSD for San Salvador Island, Bahamas. Results from the analysis indicate that the rainfall that does occur on San Salvador during the mid-summer drought period is associated with weak convection formed as easterly winds travel across the warm island surface perpendicular to topographic barriers. Such convective storms most likely develop due to the absence of cold air masses and/or blocking of northern frontal storms by the expansion of the North Atlantic high pressure.

INTRODUCTION

Drought is a widespread phenomenon in the Caribbean that has been overlooked in climatic and hazards research, particularly in comparison to hurricanes (Watts, 1995). Contributing to this limited study of drought hazards in the Caribbean is a poor understanding of the climatic phenomenon known as the Caribbean mid-summer drought or dry spell (MSD). Research to date indicates that the MSD varies in both timing and strength across the Caribbean basin (Small, de Szoeke, and Xie, 2007; Gamble and Curtis, 2008; Curtis and Gamble, 2007; Gamble, Parnell, and Curtis, 2008; Magaña, Amador, and Medina, 1999; Mapes, Liu, and Buenning, 2005). The MSD first appears in the eastern Caribbean in early-June and late-July in the western Caribbean. The MSD becomes stronger and more significant from east to west, and reaches a maximum in the waters bounded by Jamaica, Cuba, and the Yucatan peninsula. Stability that is associated with the westward expansion of the North American Subtropical High Pressure (NAHP) and further enhanced by an anomalous rise in surface pressure and divergence of surface winds west of Jamaica creates the high drought intensity in the area of the maxima.

Based upon these results and existing literature, a conceptual model of the regional atmospheric processes associated with the formation of the Caribbean mid-summer drought has been constructed (Gamble and Curtis, 2008). The components of this model include the North American Subtropical High Pressure, an intensification of the Caribbean low-level jet over the southern Caribbean, subsidence over Jamaica and adjacent waters caused by convection on the Central America isthmus, and wind divergence around Jamaica. Despite these advances in regional and global scale analysis, few, if any studies, have focused upon daily weather patterns associated with development of the Caribbean MSD at one specific location. In order to expand this limited range in scale of analysis, the purpose of this research is to investigate the daily weather patterns associated with the Caribbean MSD for San Salvador, Bahamas.

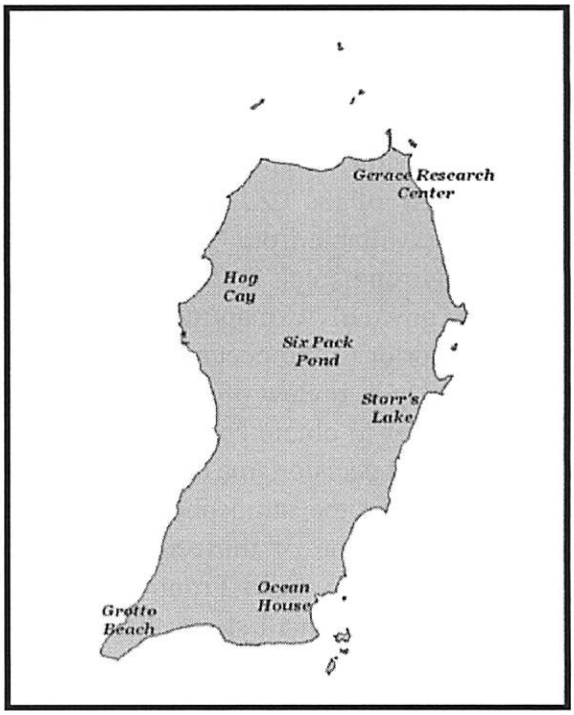

Figure 1. Location of weather station and rain gauges in the San Salvador MON. Map produced with data from San Salvador GIS Data base (Robinson and Davis 1999)

DATA AND METHODS

In January 2001, a meteorological observation network (MON) was established on San Salvador with the specific objectives of assessing spatial variability in precipitation and developing a daily precipitation climatology. The hub, or core, of this observation system is a weather station that has been located on the campus of the Gerace Research Center. This weather station records atmospheric pressure, air temperature, dew point, wind speed and direction and rainfall at 15 minute and hourly intervals. In addition to this hub, 'satellite' Davis tipping bucket rain gauges were deployed to record rainfall at different locations across the island (Grotto Beach, Hog Cay, Ocean House, Six Pack Pond, and Storr's Lake; Figure 1).

The establishment of the MON itself was a learning process in which the author, through a process of trial and error, discovered the most reliable equipment for precipitation observation. The corrosive, isolated environment of San Salvador provided challenges in terms of battery life, consistent power supply, damage from extreme winds and rain, and growth of salt crystals on instruments. The end result of the instrumentation trial and error process was a period of record with time spans of no recorded data at one or more locations across the island.

Despite such gaps in the data record, the observations from multiple locations were combined to construct a single continuous aspatial data set for San Salvador 2001-2006. This data set allowed for a general description of rainfall on the island for the entire period of record. Data from three locations, the Gerace Research Centre, Hog Cay, and Storr's Lake, were combined for the continuous record. An ANOVA of simultaneous precipitation observations from each of the locations indicated no significant difference (95% confidence) in the amount of rainfall recorded at the three locations.

Using this continuous aspatial data set, a manual environment-to-circulation synoptic cli-mate classification (Gamble and Meentemeyer, 1997), was completed for the 2001-2006 rain days using NOAA Daily Weather Maps. The classification entailed a review of the 0Z, 6Z, 12Z, and 18Z weather maps, (available from NOAA's Na-tional Center for Environmental Prediction at (www.hpc.ncep.noaa.gov/dailywxmap/index.html) for a 48 hr period prior to the occurrence of rain on San Salvador. Upon review of the daily weather maps, and in order to obtain consistency and objectivity, a detailed decision tree or flow chart was followed to classify the atmospheric conditions prior to rainfall as one of thirteen storm types (Cold Front, Stationary/Cold Front, Hurri-cane, Low, Non-synoptic (a small storm that develops on the regional or local scale), Stationary Front, Tropical Depression, Trough, Trough/Cold Front, Trough/Low, Tropical Storm, Tropical Wave, Warm Front). This classification was used as the basis for a daily precipitation climatology that can assess the atmospheric processes associated with precipitation on San Salvador, particularly during the MSD, and the frequency and magnitude of each storm type.

RESULTS AND DISCUSSION

Summary statistics of rainfall data in the 2001-2006 continuous aspatial record displays San Salvador's high inter and intra-annual variability as noted in previous research (Table 1) (Shaklee, 1996). The number of rain days per year ranged from 111 to 139 with a mean of 125 and the total annual rainfall ranges from 815 mm to 1355 mm with a mean of 1147 mm (these frequency and magnitude values exclude 2004 data due to twenty seven days with missing observation during that year). The variability in frequency and magnitude of rainfall events represents a 200 to 300 mm variability around San Salvador's reported mean annual rainfall of 1007mm (Shaklee, 1996). Such variability is also evident in monthly totals of rainfall, with variability in magnitude greater than 100% of the lowest precipitation magnitude for each month (Figure 2).

The variability is not limited to frequency and magnitude alone, but also occurs in storm type. The maximum daily rainfall storm type varied each year during the period of study (Table 1). Of the six years' maximum daily rainfall, two were associated with tropical systems, three were

Table 1. Summary statistics of continuous aspatial rainfall data set for San Salvador 2001-2006

	2001	**2002**	**2003**	**2004***	**2005**	**2006**	**Mean***
Number of Rain Days	118	136	139	86	111	120	125
Total Rain (mm)	1355	1337	1325	512	903	815	1147
Maximum Daily	150.4 Stat Front	140.22 Low	105.4 Non-synop	112.5 Hurr	69.1 Trop Wave	53.6 Cold Front	103.7

*= Precipitation observations missing for 27 days in 2004 and consequently calculated means only include 2001-2003, 2005-2006.

associated with non-tropical low pressure cells and fronts, and one was associated with non-synoptic scale storms. Thus, tropical cyclones alone are not responsible for the most intense rainfall on San Salvador. In fact, as Figure 2 indicates, the hurricane season (June-October) can be fairly dry (2001-2002 for example) in any given year on San Salvador. Further, Figure 3 indicates that the six year period included in this study had an anomalously wet spring and summer and an anomalously dry fall or tropical season. In short, it cannot be assumed that the tropical season is not the only time of year with heavy rainfall events.

The manual synoptic climate classification indicates that a wide variety of tropical and non-tropical atmospheric circulations were associated with rain days from 2001-2006 (Table 2). Of particular interest is that more rain days were associated with non-tropical systems (642 rain days) as compared to tropical systems (57 rain days). In addition, the majority of rain days (383) occurred on days without clearly distinguishable synoptic scale features (e.g. front, trough, pressure cell, tropical wave, or tropical depression/storm/hurricane).

Such a high occurrence of nonsynoptic rain days leads the author to conclude that some type of regional or meso-scale atmospheric circulation near or on San Salvador, such as interaction between warm sea surface temperatures, moisture convergence, and topographic barriers creates rain frequently on the island. However, it should be noted that even though the total rain caused by the non-synoptic storms is the greatest of all storm types, the amount produced during each non-synoptic storm/rain day was relatively low. Consequently, identifying the atmospheric conditions associated with such small rain events can be very difficult given that only subtle perturbations are required to produce such small amounts of rain. In terms of the highest magnitude per rain day, the Low storm type has the greatest mean daily value followed by the Warm Front type and the Trough, Low type (Table 2).

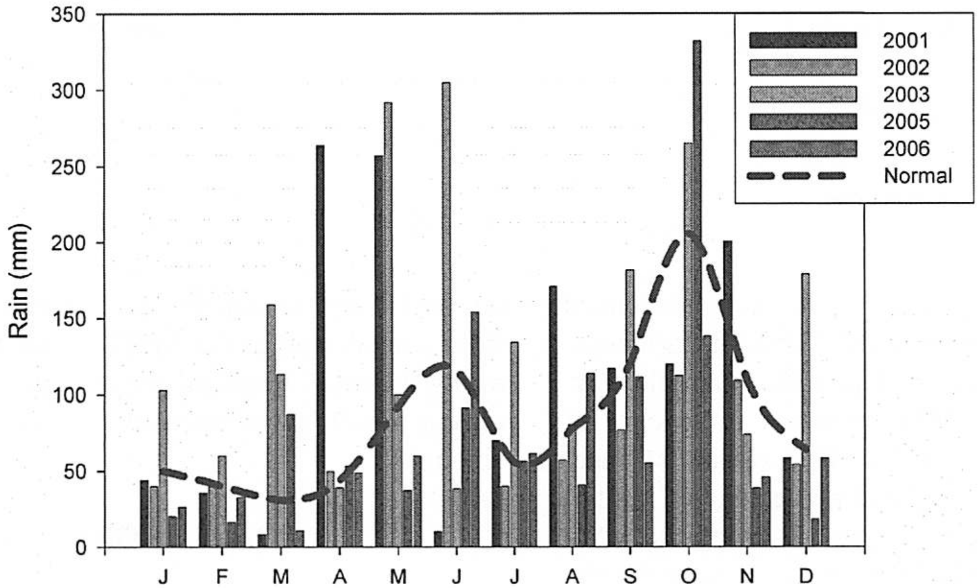

Figure 2. Total monthly aspatial rainfall for San Salvador, 2001-2006. Normal represents a 30 year mean precipitation value.

Table 2. Descriptive statistics for aspatial rainfall storm types for San Salvador 2001-2006.

	Frequency	Max Rainfall	Min Rainfall	Mean Rainfall	Standard Dev	Total Rainfall
Cold Front	113	75.4	0.2	7.4	11.0	836.2
Cold Front/Stationary Front	5	12.5	0.2	6.8	4.9	34.0
Hurricane	7	112.5	0.5	21.6	41.0	151.2
Low	4	140.2	1.0	38.9	68.0	155.6
Non-Synoptic	383	105.4	0.2	6.0	13.0	2282.7
Stationary Front	46	150.4	0.3	17.5	27.0	805.0
Tropical Depression	6	7.1	0.2	3.6	2.3	21.8
Trough	62	82.8	0.2	11.1	19.3	688.2
Trough, Cold Front	12	66.5	0.6	21.8	22.6	261.2
Trough, Low	14	69.9	0.5	25.3	22.1	354.1
Tropical Storm	17	33.8	0.3	14.1	12.5	239.2
Tropical Wave	27	69.1	0.3	9.6	15.8	259.7
Warm Front	3	45.2	2.8	27.4	22.0	82.2

An analysis of the storm types associated with the MSD season in the Northern Caribbean, mid-July to the end of September (Gamble, Parnell, and Curtis, 2008), indicates an absence of frontal storms during the MSD season. Consequently, the frequency and percentage of rainfall contributed by tropical systems during the MSD season increases (Table 3 and 4). Despite the absence of the frontal storms and a shift to greater contribution to precipitation by tropical systems, non-synoptic storms still remain the most frequent type of storm, in fact accounting for over 60% of all storm types. However, the contribution to total rainfall by the non-synoptic storms decreases from annual total to the MSD season total, indicating the more frequent storms during the MSD season are of lower intensity and lower rainfall amounts.

CONCLUSIONS

Through the development of a daily precipitation climatology, it was determined that rain, on average, occurred 125 days in a given year with an average daily amount of 9.1 mm on San Salvador. High variability exists across and within sea-

Table 3. Descriptive statistics of aspatial rainfall storm types during the mid-summer dry spell season (July-October) for San Salvador 2001-2006.

	Frequency	Max Rainfall	Min Rainfall	Mean Rainfall	Standard Dev	Total Rainfall
Cold Front	--	--	--	--	--	--
Cold Front/Stationary Front	--	--	--	--	--	--
Hurricane	4	23.9	0.5	34.5	53.1	137.9
Low	2	79.5	6.6	43.1	51.6	86.1
Non-Synoptic	156	37.6	0.2	4.1	6.4	637.6
Stationary Front	5	65.8	0.8	25.3	26.4	126.6
Tropical Depression	7	7.11	0.2	3.2	2.4	22.3
Trough	33	105.4	0.2	11.4	20.9	376.3
Trough, Cold Front	5	53.6	0.3	28.3	21.4	141.5
Trough, Low	6	69.9	0.5	18.4	26.4	110.2
Tropical Storm	11	32.5	0.5	11.9	12.3	130.4
Tropical Wave	25	91.8	0.2	11.9	22.8	295.8

sons and years in terms of frequency, magnitude, and storm type. For the period 2001-2006, the early season maxima in precipitation was anomalously wet and the late season precipitation maxima was anomalously dry. Nonsynoptic storms occur frequently on San Salvador contributing the largest portion of rainfall for the study period but on average each event has a low magnitude. Non-tropical storms, particularly stationary fronts, can contribute significantly to rain totals, sometimes exceeding totals from the hurricane season. In terms of the daily scale atmospheric processes associated with rain in the MSD season, the absence of cold fronts or stationary fronts due to a 'blocking' pattern of the NAHP contributes to formation of the MSD. When rain does occur during the MSD season it is due to the occasional tropical system or a low intensity thunder storm most likely formed through the interaction of warm sea surface temperatures, moisture convergence, and topographic barriers.

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Table 4. A comparison of storm type percent frequency and percent magnitude for annual and MSD season (July-October) precipitation on San Salvador 2001-2006.

	Annual Frequency	MSD Frequency	Annual Total Rainfall	MSD Total Rainfall
Cold Front	16.2	0.0	13.6	0.0
Cold Front/ Stationary Front	0.7	0.0	0.6	0.0
Hurricane	1.0	1.6	2.5	6.7
Low	0.6	0.8	2.5	4.2
Non-Synoptic	54.8	61.4	37.0	30.1
Stationary Front	6.6	2.0	13.0	6.1
Tropical Depression	0.9	2.8	0.4	1.1
Trough	8.9	13.0	11.2	18.2
Trough, Cold Front	1.7	2.0	4.2	6.9
Trough, Low	2.0	2.4	5.7	5.3
Tropical Storm	2.4	4.3	3.9	6.3
Tropical Wave	3.9	9.8	4.2	14.3
Warm Front	0.4	0.0	1.3	0.0

plete the research on San Salvador. Financial as-sistance provided for this project by Dr. Hans Paerl, UNC-Chapel Hill, the National Science Foundation (Geography and Regional Science/ Climate Dynamics #0718257), the Association of American Geographers, College of Arts and Sci-ences, UNCW, International Programs, UNCW, and the Honors program, UNCW is greatly appre-ciated.

REFERENCES

Curtis, S., and D. W. Gamble. 2008. Regional var-iations of the Caribbean midsummer drought. Theoretical and Applied Climatol-ogy 94: 25-34.

Gamble, D. W., and S. Curtis. 2008. Caribbean precipitation: Review, model, and prospect. Progress in Physical Geography 23 (3):265-276.

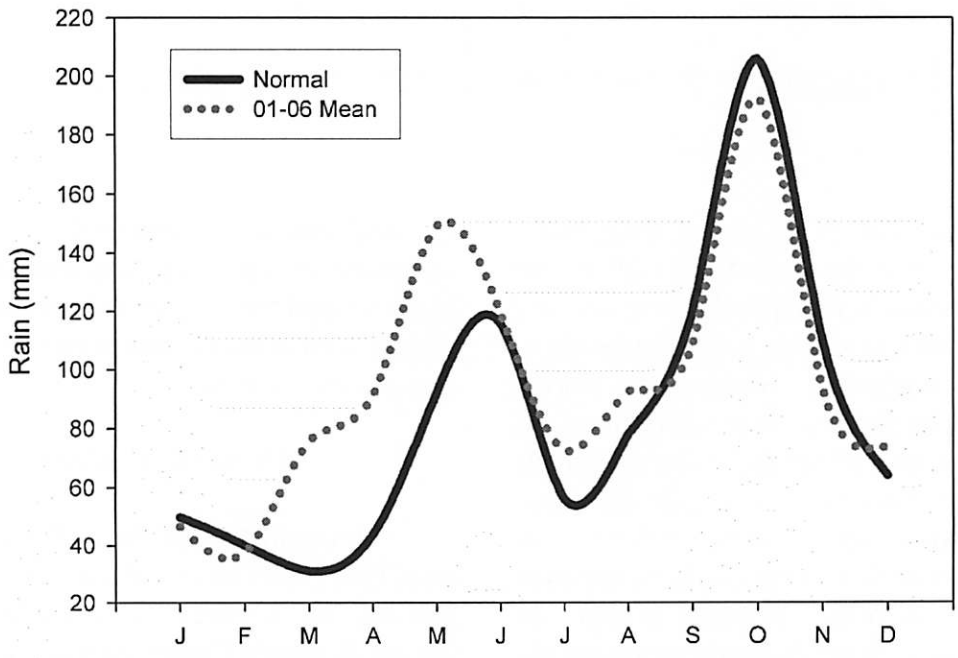

Figure 3. San Salvador mean monthly rainfall for the study period 2001-2006 and the reported climatic monthly normals (30 year average) (from Shaklee, 1996, p.11).

Gamble, D. W., and V. M. Meentemeyer. 1997. A synoptic climatology of extreme unseasonable floods in the southeastern United States, 1959-1990. Physical Geography 18 (6):496-524.

Gamble, D. W., D. B. Parnell, and S. Curtis. 2008. Spatial Variability of the Caribbean Midsummer Drought and Relation to the North Atlantic High. International Journal of Climatology 28:343-350.

Magaña, V., J. A. Amador, and S. Medina. 1999. The midsummer drought over Mexico and Central America. Journal of Climate 12:1577-1588.

Mapes, B. E., P. Liu, and N. Buenning. 2005. In-dian Monsoon Onset and the Americas Midsummer Drought: Out-of-Equilibrium Responses to Smooth Seasonal Forcing. Journal of Climate 18 (7):1109-1115.

Robinson, M. C., and R. L. Davis. 1999. San Salvador Island Geographic Information Systems database. San Salvador, Bahamas: The Bahamian Field Station Limited and University of New Haven.

Shaklee, R. V. 1996. Weather and Climate San Salvador, Bahamas. San Salvador, Bahamas: The Bahamian Field Station Limited.

Small, R. J. O., S. P. de Szoeke, and S. P. Xie. 2007. The Central American Midsummer Drought: Regional Aspects and Large-Scale Forcing. Journal of Climate 20 (19):4853-4873.

Watts, D. 1995. Environmental degradation, the water resource and sustainable development in the Eastern Caribbean. Caribbean Geography 6 (1):2-15.