Increase in the Number of Hot Days for Decades in Puerto Rico 1950-2014

Rafael Méndez-Tejeda[1]

[1] Natural Science Department, Atmospherical Science Laboratory, University of Puerto Rico, Carolina Puerto Rico, PO. Box 4800. Carolina P.R. 00966, USA

Correspondence: Rafael Méndez-Tejeda, Natural Science Department, Atmospherical Science Laboratory, University of Puerto Rico, Carolina Puerto Rico, PO. Box 4800. Carolina P.R. 00966, USA. E-mail: rafael.mendez@upr.edu

Abstract

The results show that the number of days with temperatures higher than 32 °C has increased, and the number of days with a minimum temperature of 15 °C has decreased. The average temperature on the island has increased by 2.24 °C in the period analyzed. The increase in the minimum temperature is more than two times greater than the increase in the maximum temperature in the analyzed period. The number of days with temperatures over 32 °C is three times more than the number of days with temperatures below 15 °C.

When analyzing the behavior per decade it is found that there is an increase in the ratio between cold and warm days, from the 1950s, which was from 1: 1.79 to that of 2000-2019, which is 1: 3.28.

Keywords: Temperature variability, climate change, Caribbean, Puerto Rico

1. Introduction

Several researchers have found that the projected changes in global climate have caused serious negative consequences for the Caribbean as a whole. It is becoming increasingly evident that the impacts of climate change will not be felt uniformly throughout the region (PRCC, 2014, Strelich, 2015; Nurse et al., 2014; Taylor et al., 2012). Their findings reported that the climate of the Caribbean region is changing and that the range of intra-annual extreme temperatures is decreasing. According to the National Climate Assessment, average annual air temperatures in the Caribbean islands increased by more than 0.6 °C in the last century.

In the United States (Meehl et al., 2009), reports an analysis of the annual ratio of US record daily maximum to record daily minimum temperatures, showing that recent values of about 2 to 1 are just transients, and that the ratio is increasing with average annual mean over the US in the period from 1950 to 2000.

Observational records for the Caribbean beginning as early as the late 1950s have shown that the number of very hot days (Tmax greater than or equal to 30 °C) and very hot nights (Tmin greater than or equal to 25 °C) have been increasing throughout the region (Rhiney, 2015, Peterson et al., 2002; Stephenson et al., 2014). Studies have also shown that the Caribbean Sea has warmed by approximately 1.5 °C over the last century and that sea surface levels have risen in line with that of the global mean (~1.8mm/yr) since 1950 (Palanisamy, 2012).

The number of very hot days and nights is increasing drastically, while the numbers of cool days and nights are declining. An analysis carried out by (Méndez-Lázaro, 2016) establishes a relation between the increase of the episodes of heat and with health problems. The main finding of the paper is the increase in the significant effect of high temperatures on mortality for the summers of 2012 and 2013.

Added to these trends is a moderate decline in precipitation across the northern Caribbean basin, coupled with evidence of greater seasonal and inter-annual rainfall variability and increasingly frequent and prolonged dry spells, especially during the summer (Gamble, 2009). The latter trend is particularly important, given the fact that the Caribbean's climate regime has traditionally been characterized by dry winter months and wet summer months (Chen & Taylor, 2002; Méndez-Lázaro, 2015).

The model for the Special Report on Emissions Scenarios (SRES IPCC) A2 and B2 projects a one to five °C increase in annual mean temperature for the Caribbean by the 2080s, compared to the 1960–1990 baseline

(Climate Change, 2014). This warming will be greater in the northwest sub-region (Jamaica, Cuba, Hispaniola, and Belize) in comparison to the eastern Caribbean island chain, and greater in the summer months than in the drier early months of the year. These results compare favorably with other regional modeling studies. For example, the study by Hall et al. (Hall et al., 2013) has also predicted a general increase in the mean surface temperature across the entire Caribbean basin by the end of the century (2–3 °C, scenario A1B), but with slightly greater warming projected for the northern Caribbean (2.5–3 °C) compared to the eastern and southern Caribbean sub-regions (2–2.5 °C).

Several authors such as (Foltz & McPhaden, 2007; Chunzai, 2011) suggest that the Sahara dust exerts a great influence on the Sea surface temperature (SST) of the tropical North, which plays an important role in increasing the temperatures in this region. Lau and Kim (2007) based on estimates of Sea Surface Temperature (SST) cooling due to solar attenuation by Saharan dust, and analyses of correlations from historical data, we have provided preliminary evidences supporting the notion that solar attenuation effects due to increased (decreased) Saharan dust loading over the Atlantic may contribute to widespread cooling (warming) of the underlying sea surface in the early hurricane season.

Table 1. Shows the selection of some papers that have reported temperature trends in the Caribbean

Article	Period	Method	Remarks
Duchon 1986	28 years (1958-1983)	Surface Temperature Data from NOAA	San Juan, Puerto Rico, International aeropuerto 2.1ºC.
Singh 1997	5-year	5-year equilibrium runs of the Canadian Climate Centre (CCC) general circulation model (GCM)	An increase in the average temperature 1.5ºC, while in Rizet (Guadaloupe) the increase is 1.3 ° C, however in San Juan, Puerto Rico is (2.3 ° C), this increase is slightly lower in Kingston (Jamaica) Is of (0.7 ° C).
Kilbourne (2008)	254-year record of coral since the year 1751	Method δ^{18}O and Sr/Ca	indicating 2.1 ± 0.8ºC and δ18 0 data indicating 2.7 ± 0.5ºC.
Comarazamy et al (2010)	50 years (1955–1959 to 2000–2004)	The model chosen for the study is the Regional Atmospheric Modeling System	air temperature increase between 2.5 and 3º C
Jury (2011)	1980 -2010	Observed and projected	Sea surface height trends were found to be highest (+.0014m/yr.) at 14° and 23°N and lower (+.0008m/yr.) at 10° and 18ºN.
Murphy (2011)	Air-temperature measurements were logged automatically at 5-min intervals, and then aggregated into hourly averages for data analysis.	Two methods to capture the variation of the UHI over space and time: (a) a series of fixed-station temperature sensors and (b) a series of mobile measurements from a vehicle-mounted temperature sensor	The maximum UHI value for northeastern was calculated as 4.7ºC between the urban and forest sites and 3.9ºC between the urban and an open, rural site.
Van Beusekom et al (2014)	100 years	Global Climate Models (GCMs)	an increasing trend for temperature of 0.01ºC/yr. to +0.03ºC/yr. (+ 1º to 3ºC in 100 years).

Since the 1990's, Puerto Rico has been affected by many climatic phenomena, including two extensive periods of drought, the first of which began in February 1994 and lasted until September 1996, affecting the entire island. The second episode of drought began in mid-2013 and lasted until November 2015, in this case affecting the eastern third of the island, causing great economic losses and a great social impact (Drought report, 2016).

The increase in temperature on the island is expected to have several adverse effects. (Burrowes, 2004) reported impacts on the population of amphibians (coquies) due to increased temperatures. In marine turtles, sex is determined by temperature in the middle third of incubation, with female offspring produced at higher temperatures and males at lower temperatures, and a thermal tolerance range of 23–35 °C. Other research has concluded that nesting habitat loss from the expected sea level rise would have serious consequences for sea turtle

populations in the Caribbean regions. Sea level rise will also affect foraging grounds, such as seagrass beds, coral reefs, and the open ocean. Species with limited geographic distribution living in mountainous areas (i.e., in Puerto Rico, the Dwarf Coqui and Yellow-Shinned Anole) will be forced to migrate upland to keep pace with the increased ambient temperature (Ackerman, 1997).

The current evidence presented by (Hernández-Pacheco et al., 2011), among others, also indicates an increase in mortality and bleaching of corals, observed since 2005, where approximately 70% of the northeastern corals of Puerto Rico. This has caused great economic losses to the fishing and tourism sector. Other researchers report for 2013-14 an increase in the number of forest fires, this increase is aided by favorable climatic conditions for the occurrence and propagation of these phenomena (Méndez-Tejeda et al., 2016).

2. Material and Methods

2.1 Study Area

Puerto Rico is located in the center of the Caribbean (between latitudes 18° 31' and 17° 55' N and longitudes 65° 37' and 67° 17' W, between the Atlantic Ocean and the Caribbean Sea), and includes five smaller nearby islands. Puerto Rico is 180 km long and 65 km wide and encompasses a total land area of 11,700 km^2 (fig.1). Precipitation is primarily effected by troughs embedded in easterly waves during the summer months and in cold fronts during winter months. The lowest amount of precipitation in Puerto Rico occurs from December to March. The Caribbean climate depends on several factors, such as the so-called Caribbean Regulators Climate Centers (CRCCs) (Méndez-Tejeda et al., 2016) the North Atlantic Oscillation (NAO), the El Niño Southern Oscillation (ENSO), the trade winds, and the Warm Water Pool North Atlantic, Multidecadal Oscillation, as well as the behavior of the Azores anticyclone. The presence of ENSO, specifically in the 3.4 phase, is associated with drought in the Central Caribbean (Cuba, Hispaniola, Puerto Rico, and Jamaica) and an increase in the intensity of hurricanes in the region (Chen & Taylor, 2002).

Table 2. Selected stations included in the study, period covered, total day data series, latitude, longitude elevation

Station	Period	% data	Lat (N)	Long. (W)	Elevation (m)
Aguada	1950-2014	95	18° 23'	67°09'	12
Aibonito	1950-2014	90	18° 13'	66° 26'	710
Ceiba	1950-2014	94	18° 26'	65° 64'	10
Corozal	1950-2011	92	18° 20'	66° 22'	198
Guayama	1950-2014	96	17° 59'	66° 05'	22
Isabela	1950-2014	97	18° 28'	67° 10'	128
Juncos	1950-2012	98	18° 22'	65° 92'	65
Lajas	1950-2012	93	18° 02'	67° 04'	27
Manatí	1950-2014	95	18° 26'	66° 28'	76
Mayagüez	1950-2013	92	18° 11'	67° 08'	18
Ponce	1954-2014	91	18° 02'	66°32'	21
San Juan	1956-2014	98	18° 26'	66° 00'	3
Utuado	1950-1998	90	18°16'	66° 41'	158

3. Methodology

This analysis has been divided into two parts:

In the first part: to determine the trend of the average temperature, the series has been used since 1950-2014 (see following equations)

A selection of 13 meteorological stations of Puerto Rico (see table 1 and fig. 2) was made meeting the following conditions:

• The stations should cover the entire geography of the island and its different climatic zones.

• The data should be validated by NOAA's National Climatic Data Center (NCDC).

• The stations must have less than 10% missing data.

• Warm days must have temperatures > 32 °C.

• The days should be considered cold if temperatures are <15 °C.

Part I

Daily maximum and minimum surface air temperature data were taken from 13 meteorological stations across Puerto Rico, in general, for the period between 1950 - 2014. The station locations are Shown in Figure 2; The numbers indicating the stations and their names and locations are shown in Table 2. The National Data Climate Center-NOAA. After meeting the established criteria, the daily minimum and maximum temperatures are taken and the average daily temperatures are obtained for the complete series. (Qu, 2014)

$$\bar{T}min = \frac{1}{n}\sum_{i=1}^{n} Timin$$

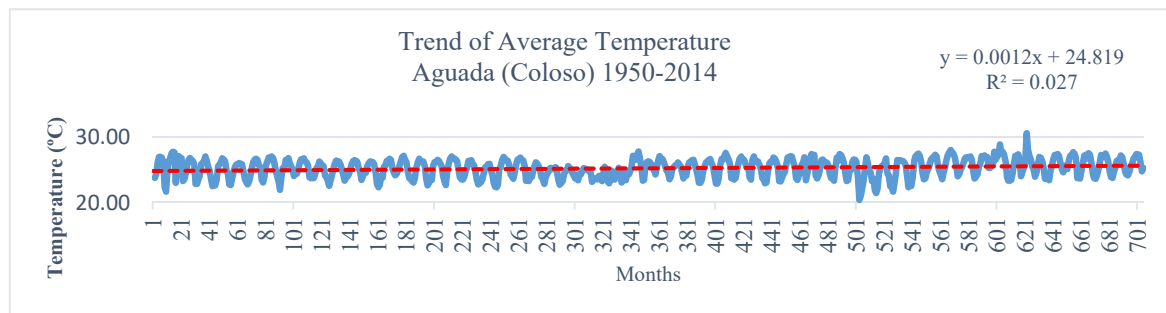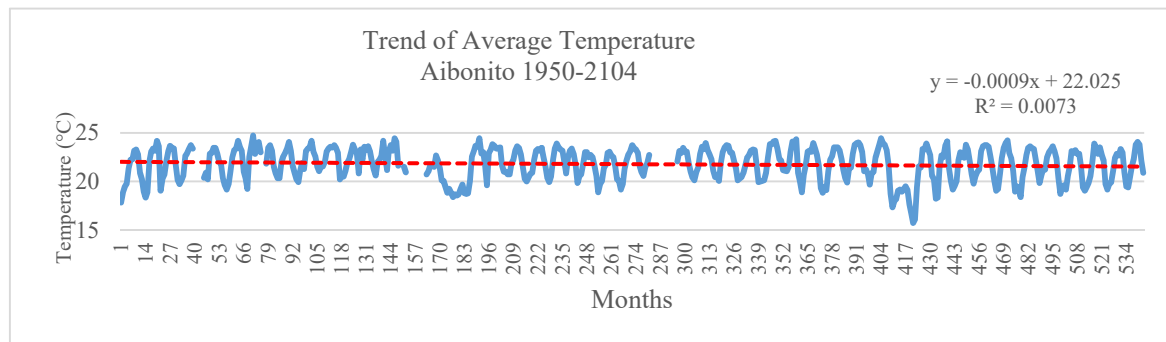$\bar{T}$min Average minimum temperature

Timin Minimum daily temperature

$$\bar{T}max = \frac{1}{n}\sum_{i=1}^{n} Timax$$

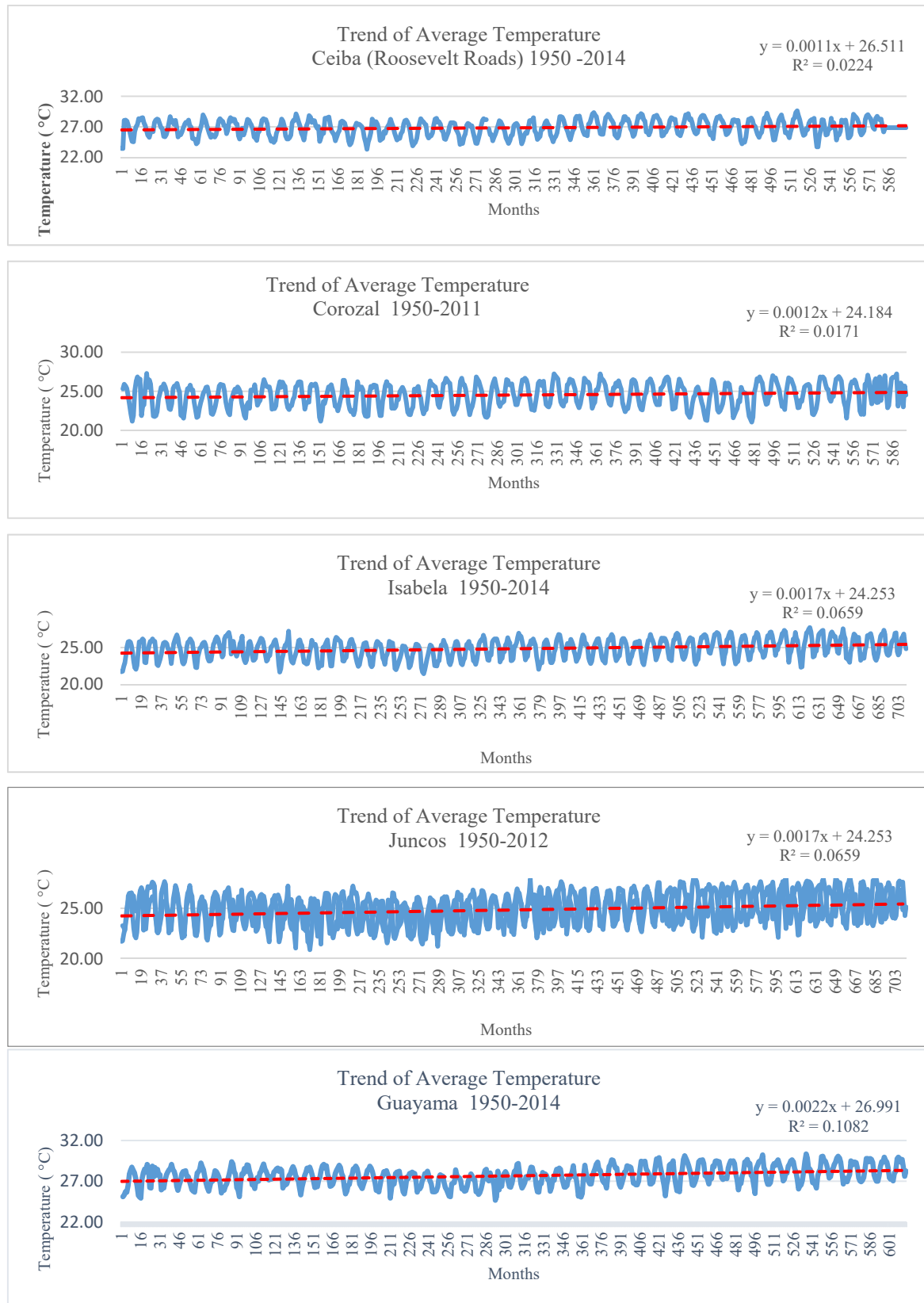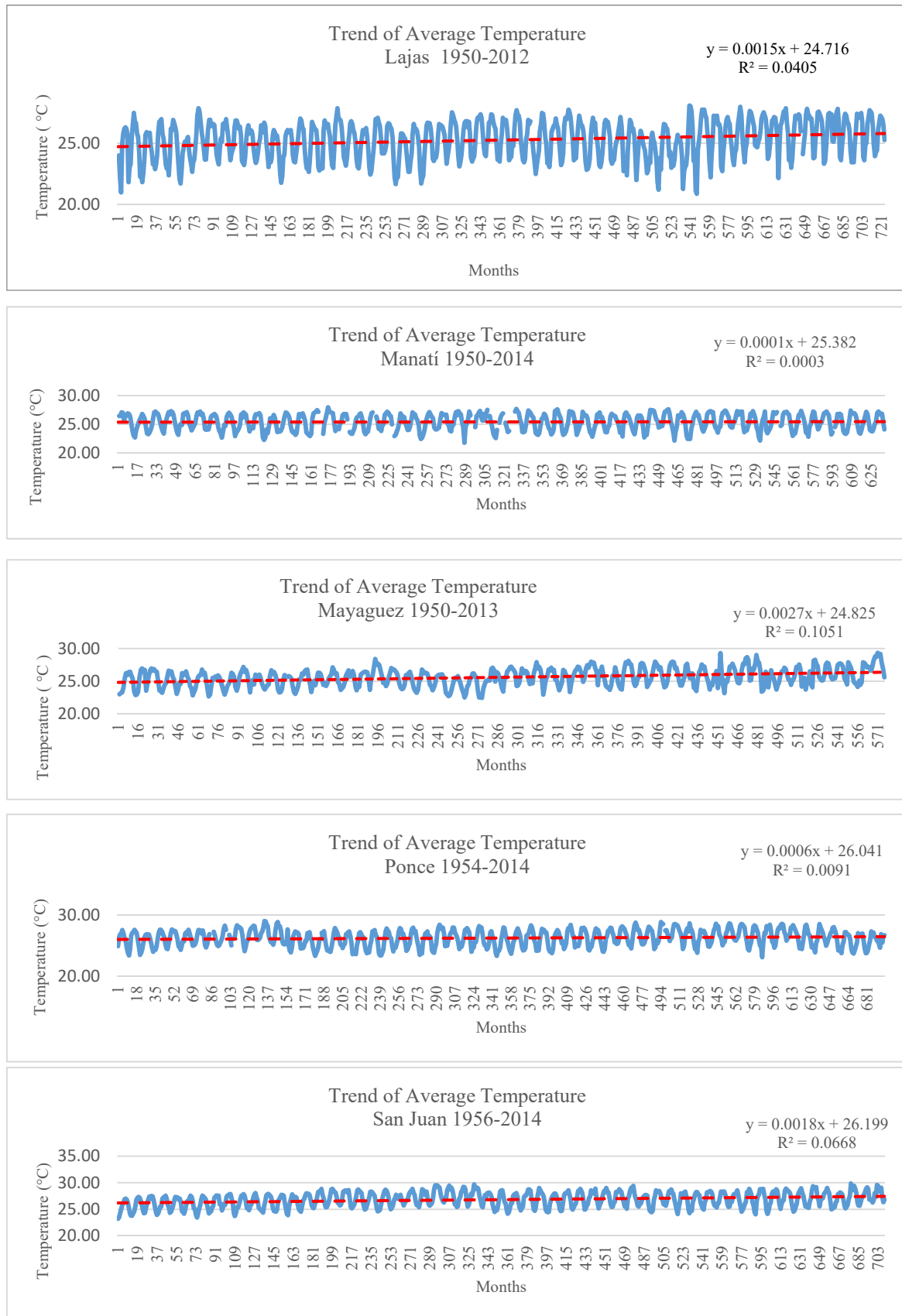$\bar{T}$max Average minimum temperature

Timax Minimum daily temperature

$$\bar{T}av = \frac{1}{n}\sum_{i=1}^{n} [\bar{T}max - \bar{T}max]$$
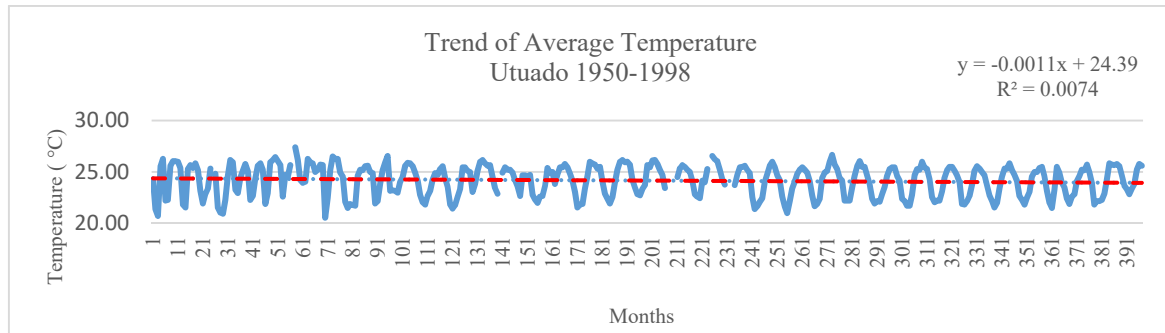
$\bar{T}av$ Average temperature

Trend of Average Temperature
Ceiba (Roosevelt Roads) 1950 -2014

$y = 0.0011x + 26.511$
$R^2 = 0.0224$

Trend of Average Temperature
Corozal 1950-2011

$y = 0.0012x + 24.184$
$R^2 = 0.0171$

Trend of Average Temperature
Isabela 1950-2014

$y = 0.0017x + 24.253$
$R^2 = 0.0659$

Trend of Average Temperature
Juncos 1950-2012

$y = 0.0017x + 24.253$
$R^2 = 0.0659$

Trend of Average Temperature
Guayama 1950-2014

$y = 0.0022x + 26.991$
$R^2 = 0.1082$

Trend of Average Temperature
Lajas 1950-2012

$y = 0.0015x + 24.716$
$R^2 = 0.0405$

Trend of Average Temperature
Manatí 1950-2014

$y = 0.0001x + 25.382$
$R^2 = 0.0003$

Trend of Average Temperature
Mayaguez 1950-2013

$y = 0.0027x + 24.825$
$R^2 = 0.1051$

Trend of Average Temperature
Ponce 1954-2014

$y = 0.0006x + 26.041$
$R^2 = 0.0091$

Trend of Average Temperature
San Juan 1956-2014

$y = 0.0018x + 26.199$
$R^2 = 0.0668$

Trend of Average Temperature Utuado 1950-1998

$y = -0.0011x + 24.39$
$R^2 = 0.0074$

Figure 1. Shows the behavior of the average temperature in the period analyzed for the thirteen (13) meteorological stations

Part II

In the Second part, the series from 1950 to 2009 was used to determine the relationship between hot and cold days in the seven decades analyzed, with the conditions set out below. The meteorological stations are distributed on all the island (Figure 2).

Figure 2. shows the location of the meteorological stations used in the study

During the period analyzed, the stations of Aibonito and Utuado showed a negative tendency in the series of average temperatures, this indicates that the minimum values exceeded the maximums in the series, it should be noted that these stations are located in the center of the island (More mountainous area). In the case of Aibonito has a height of 710 m above sea level. Stations with a coastal maritime component showed positive slopes (see Figure 1and Table 1)
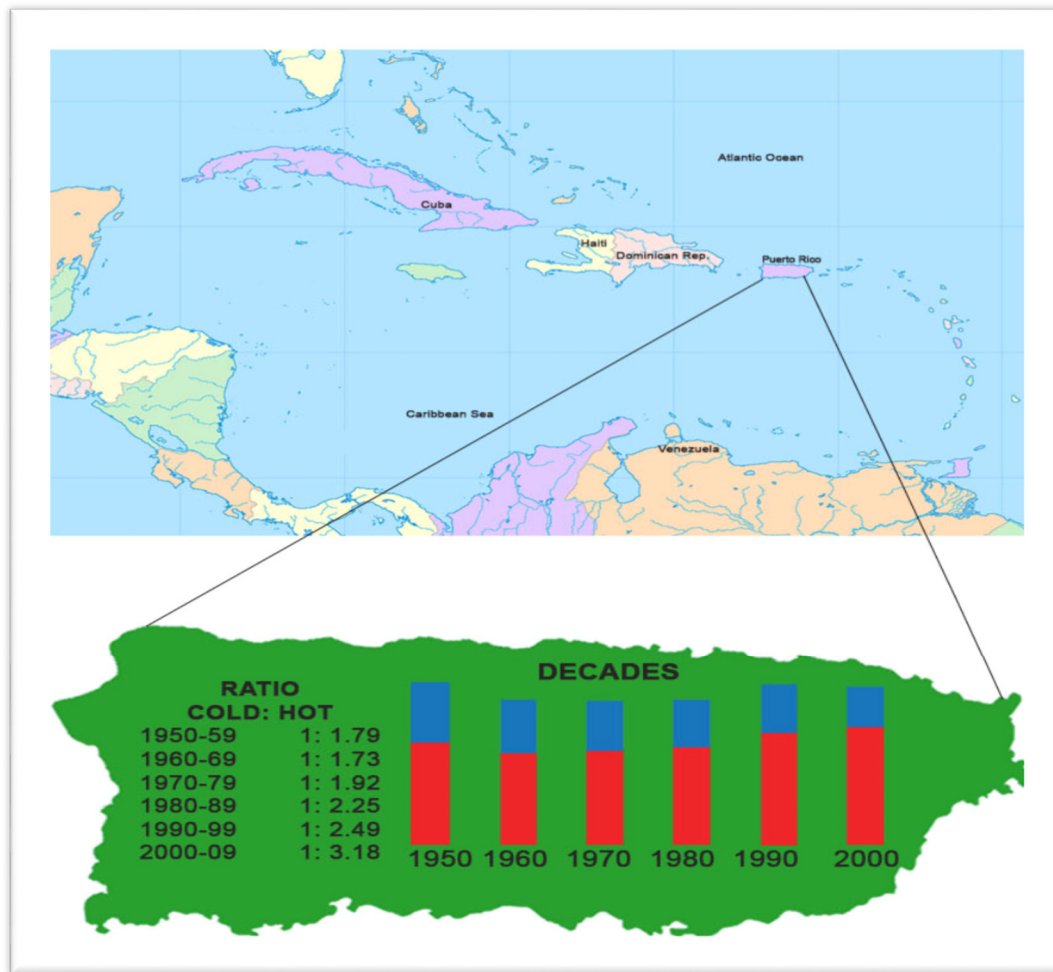
Figure 3. Ratio of record daily highs to record daily lows observed at 13 weather stations across 13 municipalities of Puerto Rico from January 1950 through December 2009. Created by El Centro de Recursos Educaticativos y Produccion (CREP)

4. Results and Discussion

In the 1950s, the ratio of warm to cold days was 1.79 hot days for every cold day. An increasing trend ensued, so that, during the 2000s, this ratio increased to 3.18 warm days for each cold day (fig.3). The 1960s decade had a lower hot-to-cold days' ratio, according to analysis of the temperature variability, which indicated increases in the minimum temperature of 0.052 °C/year and a maximum temperature increase of 0.024 °C/year.

Rising temperatures have affected Caribbean ecosystems, which enabled an increase in mosquito-borne diseases. Consequently, thousands of people have been infected with diseases such as dengue, chinkungunya, zika and malaria (Hennesse & Staples, 2016).

Due to the geographic location of the island of Puerto Rico, whose tropical climate (Caribbean region) with high levels of relative humidity, which contributes to a greater heat sensation (heat index). The number of days with temperatures over 32 ° C is three times more than the number of days with temperatures below 15 °C, With the exception of Aibonito which has a height of 710 m above sea level.

The average temperature of the number of days with temperatures over 32 ° C is 35 °C. While the average temperature of the quantity with temperatures below 15 °C is 14 °C. This is explained by the weather conditions of the Caribbean region. The seven decades analyzed, only the decade of 1960 shows a decrease in the number of hot days versus the number of cold days, this behavior is in agreement with the findings of (Mehl et al., 2009)

5. Conclusion

- The number of days with temperatures above 32 °C, versus the number of days in which the temperature is below 15 °C, increased by 46% in the period from 1950–2009.

- The variability in the minimum temperature is more than twice that of the maximum temperature.

- The average temperature on the island has increased by about 2.24 °C over the period from 1950–2014.

- The increase minimum temperature of 0.048 °C/year and a maximum temperature increase of 0.022 °C/year in the analyzed period.

- The ratio per decade between cold days and warm days from 1950 to 2000 increases from 1:79 to 1: 3.18.

- The main factor contributing to the increase in temperature in the island of Puerto Rico is the marine component of both the Atlantic Ocean and the Caribbean Sea. Another two important factors are the deforestation process and the enormous urban growth. (Velázquez-Lozada, 2006).

- Our results coincide with those reported by (Lau & Kin, 2009) and (Prospero & Lamb, 2003), the results show that the estimated anomalous cooling pattern of the Atlantic during June 2006 compared to June 2005 due to attenuation of surface solar radiation by Saharan dust is remarkably similar to observations, representing approximately 30-40% of the observed change in sea surface temperature.

Acknowledgements

Competing interests

Author have declared that no competing interests exist.

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