Journal of Scientific Research & Reports

19(5): 1-19, 2018; Article no.JSRR.42859
ISSN: 2320-0227

Change in the Diurnal Temperature Range over Puerto Rico between 1950-2014

Méndez-Tejeda, Rafael[1*]

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

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JSRR/2018/42859
Editor(s):
(1) Rahul Kumar Jaiswal, National Institute of Hydrology, WALMI Campus, Bhopal, India.
Reviewers:
(1) Mohsen Abbasnia, Istanbul Technical University, Turkey.
(2) Bharat Raj Singh, School of Management Sciences, Technical Campus, Dr. APJ Abdul Kalam Technical University, Lucknow, India.
(3) Wanderson Luiz Silva, Federal University of Rio de Janeiro, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/25678

Original Research Article

Received 14th May 2018
Accepted 21st July 2018
Published 26th July 2018

ABSTRACT

This paper analyzes the spatial dependence of annual trends in the diurnal temperature range (DTR) of Puerto Rico (PR) from 1950–2014. The DTR is a useful indicator of climate change and average temperature changes. Observation records indicate that the DTR has decreased in the last 64 years because of changes in the difference between the minimum and maximum temperatures. The 13 studied meteorological stations have shown a negative trend of −1.33 in the DTR for PR. The minimum temperature (Tmin) has shown a greater increase than the maximum temperature (Tmax) over the period analyzed. Because of this behavior, the stations can be categorized into two large groups. For nine stations (Aguada, Ceiba, Guayama, Isabela, Manatí, Mayaguez, Lajas, Ponce, and San Juan), the variability of the minimum temperature in the mountain of Puerto Rico increased during the 1970s, while for four stations (Aibonito, Corozal, Juncos, and Utuado), Such an increase in average temperature was manifested later, in the 1980s. The Mann-Kendall analysis shows that nine out of the thirteen stations have a p-value 0.005, this shows that the tendency to decrease of the DTR is strong. A more detailed analysis is recommended to determine the cause of this behavior.

**Corresponding author: E-mail: mendeztejeda@gmail.com, rafael.mendez@upr.edu;*

Keywords: Diurnal temperature range; temperature variation; trend analysis; maximum and minimum temperature; climate change.

1. INTRODUCTION

The variability of daily maximum (Tmax) and minimum (Tmin) temperatures is a basic climatic parameter that has been observed since the beginning of the 20th century in Europe and the USA. The variability study is very important to understanding changes in fields such as agriculture, water resources, tourism, health, etc. The diurnal temperature variability is called the daytime temperature range (DTR) [1,2,3] which can be defined as the difference between the maximum and minimum daily temperature. Changes in the DTR can be caused by cloudiness, urban heat, changes in land use, aerosols, water vapor, deforestation, or greenhouse gases.

[4,5] Observed changes in cloud cover in Spain and interpreted them as possibly relating to the increase in anthropogenic aerosols that produce the greenhouse effect and/or to natural climate variability [6,7], they found that, between 1900 and 1940, the Tmin in Spain indicated warming in the annual and seasonal series, they maintained certain trends and other abrupt changes. The magnitude of this increase is estimated between 1°C and 3°C. Concluding that both Tmax and Tmin show slight warming tendencies. It has a certain correlation, although with a smaller magnitude of increase than the report of [8], for PR.

Brunet, M., P. D. Jones, J. Sigro´, O. Saladie´, E. Aguilar, A. Moberg, P. M. Della-Marta, D. Lister, A. Walther, and D. Lo´pez (2007), Temporal and spatial temperature variability and change over Spain during 1850–2005, J. Geophys. Res., 112, D12117, doi:10.1029/2006JD008249.

The most recent studies on variability were done in European countries [2], who concentrated their investigations in the behavior of Tmax and Tmin. They showed that, from 1951 to 1990 over 37% of the global land mass, the increase in Tmin was three times that of the corresponding increase in Tmax (0.84ºC and 0.28ºC, respectively). For the same period, in Central Europe, which corresponds to 0.07% of the global land mass, [9] found values close to 0.60ºC for the change in Tmin and to 0.52ºC for that in Tmax. Comparing the variation in both temperatures showed that the increase in Tmin was 1.15 times that of Tmax.

Various investigations have amply confirmed that the DTR decreased globally during the second half of the 20th century. These changes in the DTR are an identifiable characteristic of recent climate change and provide a useful diagnostic index for evaluating global climate models [10]. The global trend of average land warming and DTR’s global decrease over the last 50 years are due to the stronger increases in Tmin than in Tmax [2,11].

[12,13] analyses of the year-month mean maximum and minimum surface thermometric records have now been updated and expanded to cover three large regions in the Northern Hemisphere (the contiguous United States, the area of the former old Soviet Union, and the People’s Republic of China). They indicate that most of the warming in these regions over the past four decades can be attributed to an increase in the mean minimum (mostly nighttime) temperatures. A increase in extreme Tmin and little or no changes in extreme Tmax. Continually increasing Tmin with little overall change in Tmax leads to a decrease in the mean (and extreme) temperature range, an important measure of climate variability.

[14] conclude that the observed changes in the diurnal cycle result neither from natural climate variability nor from a globally distributed forcing. Rather, they require the combination of a (negative) radiative forcing located primarily over continental regions and the known globally distributed forcing due to anthropogenic greenhouse gases. According to the findings of [15,16], the decreases observed in DTR could be a climatic response to the anthropogenic emission of greenhouse gases and aerosols.

It has been widely accepted that the DTR decreased globally during the second half of the 20th century. Here we show, however, that the long-term trend in the annual DTR was reversed from a decrease to an increase during the 1970s in Western Europe and during the 1980s in Eastern Europe. Similarly, [17] studied the changes in Tmax and Tmin in Finland since the 1950s and discovered that the coldest years were between 1960 and 1980, while the warmest years were from the mid-1950s until the 1960s. These episodes are clearly reflected in the most recent results, [16], for Europe where it confirms that the Tmin shows an annual increase greater than the Tmax.

[11,18] suggest that the analysis of the global average surface air temperature has shown that its increase is due, at least in part, to differential changes in maximum and minimum daily temperatures, resulting in a narrowing of the DTR. Similarly, [19] found a decreasing trend in the DTR of the United States over the last 100 years.

The main objective of the present study is to analyze the trends in the maximum and minimum daily temperature on the island of Puerto Rico (PR) using the Tmax and Tmin data from 13 climatological stations distributed throughout PR's geography. This work aims to reveal novel information about the variability of extreme temperatures in PR and therefore contribute to a better understanding of climate's impact on different facets of daily life. In addition, the results obtained can be considered in a wider climate context, which provides information on the long-term behavior of extreme temperatures and their effects on health, flora, agriculture, tourism, etc.

2. DIURNAL RANGE OF TEMPERATURE

The current increase in the temperature of the Earth's surface (land and ocean) and its atmosphere, called global warming, has caused the average temperatures worldwide to rise by 0.75°C (1.4°F) over the past 100 years. Approximately two-thirds of this increase has occurred since 1975, [20]. While past increases in Earth's temperature were the result of natural causes, today they are caused by the accumulation of greenhouse gases in the atmosphere produced by human activities, [12].

The mean monthly Tmax and Tmin are derived from an average of the daily maximum and minimum temperatures. The mean monthly DTR is defined as the difference between the mean monthly maximum and minimum temperatures [2]. The most recent studies on Tmax and Tmin temperatures show an asymmetric trend; in general, minimum temperatures have grown more rapidly than maximum temperatures. This phenomenon results in a decrease in the DTR, which may be related to the increases in cloudiness observed in several parts of the world. Similar results were presented by [21], who studied the mean monthly DTR of the temperatures at 23 different stations in Costa Rica.

There is a considerable amount of scientific evidence suggesting that the Caribbean is experiencing the effects of a changing climate [22,23,24,25,26,27,28,29]. Other research conducted by [30] indicates that the Caribbean region has experienced an average warming of approximately 0.6°C since the 1960s or ~0.12°C–0.14°C per decade during 1958–1999. The frequency of very hot days and very hot nights shows a growing trend, with nights that heat up faster than days. This implies a decrease in the DTR, that is, the difference between day and night temperatures. A trend analysis of extreme events suggests that there has been an increase in the frequency and intensity of hot extremes [31].

[30] also found that the frequency of very cold days and very cold nights in the Caribbean has exhibited a decreasing trend over a period 1958 to 1999 and that the difference between the highest and the lowest temperature of the year is decreasing, although the trend is not significant at the 10% level. [32] show that these changes in the Caribbean are consistent with those in the rest of the world, while a similar study on nearby Central America and northern South America also corroborates the Caribbean trends. [8] reports that the variability in the Tmin is more than double that of the Tmax, while the average temperature on Puerto Rico increased by approximately 2.24°C during 1950–2014.

3. A DECREASE IN DTR ON PUERTO RICO DIRECTLY IMPACTS FOUR FACTORS, AS FOLLOWS

3.1 Urban Island Heat

Urban areas are usually warmer than their rural surroundings, a phenomenon known as the "heat island effect." The effect of urban heat islands often tends to manifest itself most strongly during night hours [33,34]. In terms of large-scale global and regional drivers, there is a growing body of literature showing that land use and changes in land cover associated with anthropogenic activities, such as urbanization, paving, and deforestation, can affect local climates [35]. In addition, islands of heat can affect communities by increasing the maximum demand for energy in summer, increasing air pollution, greenhouse gas emissions, diseases, heat-related mortality, and the costs of air conditioning. The quality of the water in tropical cities can also have an impact on the tourist sector. Urban heat islands also have a significant impact on human health, especially in terms of respiratory diseases and heart attacks, tripling the number of visits to hospitals and increasing mortality in children, the elderly and people with respiratory problems [36].

3.2 Irrigation

Agriculture and crops may also be impacted by PR's decreases in DTR [37]. The evaporation associated with soil moisture may convert sensible heat into latent heat, and therefore significantly reduce the diurnal temperature, especially in the south and southeast of the island.

Agricultural land represents approximately 12% of the land area of USA. Approximately 3% of the United States population and 1.7% of the annual growth of its gross national product are related to agriculture. The potential impact of climate change (changes in mean temperature) on agriculture will be reflected through the responses of crops, livestock, soil, weeds, insects, and diseases to climatic elements in the environment, that are more sensitive [38]. In the large agricultural areas of North America, humidity and soil temperature are the climatic factors most susceptible to changes [3].

For the tropics, where some crops are close to their level of maximum tolerance to temperature and where reined agriculture and minor fruits predominate (tomatoes, melons, bananas, etc.) yields will generally decrease with minimum changes in temperature. In the temperate regions, on the other hand, the highest minimum temperatures will be beneficial for some crops.

3.3 Desertification

The opposite of the above theoretical effect on irrigation is greater desertification, resulting from an increase in DTR. This can be due to poor land practices, forest fires, urbanization, or deforestation [39,40].

The degradation of the soil throughout the planet in arid, semi-arid, and dry sub-humid areas, including the tropics, results from various factors, including climatic variations and human activities. This leads in some cases to desert regions. The definition of a desert region excludes areas that have a "hyper-arid or humid" climate. In low-input agricultural systems, stress zones occur in areas where the productive capacity of the land is affected by poor management and by the effects of climatic variability. In high-input systems, tension zones arise due to the excessive use of agrochemicals, the uncontrolled use of irrigation, and monoclonal plantations with minimal genetic diversity. In any case, the impact is greater on populations that have fewer ecological resources and are therefore more vulnerable.

3.4 Flora and Fauna

Climatic variations and consequent changes in DTR can cause species to move to new regions. There is ample evidence of species changes as a result of changing conditions [41]. Those that cannot adapt or be displaced from their newly inhospitable environments (trees, or species confined to the tops of mountains or small islands) are likely to disappear.

Changes in DTR can threaten endemic species, as invaders (predators and competitors) expand their ranges in response to a lack of food. DTR changes can also create ideal conditions for disease outbreaks. Many species have already been or are threatened, and those that are highly susceptible to environmental change are particularly vulnerable to extreme events and to the increases in invasive species, outbreaks of disease, and habitat changes that result from climate change [42].

Temperature changes will also lead insect species to reproduce more rapidly, causing the spread of diseases such as Zika, Chikungunya, and Dengue [43]. This is also true for some species of reptiles and amphibians, particularly the amphibious Coquí (a small endemic frog). Some minor crops may also be affected, especially those with broad leaves, as their exposure to solar radiation and evapotranspiration is high [44].

4. AREA OF STUDY

Puerto Rico is an island surrounded by the Caribbean Sea to the south and the Atlantic Ocean to the north. Measuring approximately 180 km by 65 km, it is the smallest island in the Greater Antilles. In truth, Puerto Rico covers several islands, including Vieques and Culebra to the east and Isla Mona to the west. These islands are densely populated within a small geographic area. Puerto Rico is situated at latitude 18ºN and longitude 66º–67ºW. The highest point in Puerto Rico is Cerro de Punta, a mountain peak in the Cordillera Central, at 1338 meters of elevation. Sierra de Luquillo is an isolated range located on the northeast part of the island. This range contains the peak El Yunque, which harbors a rainforest that receives some of the highest rainfall totals on the island.

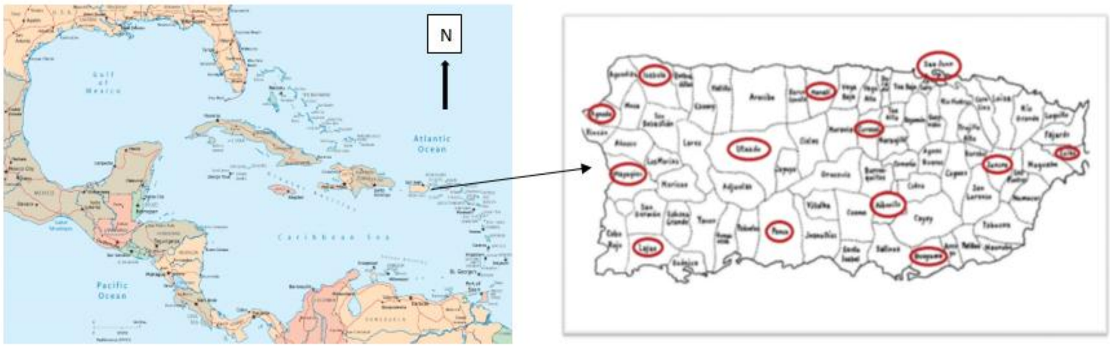


Fig. 1. Shows the geographical location of the island of Puerto Rico, located between the North Atlantic and the Caribbean Sea

Table 1. Shows the locations of the 13 meteorological stations studied, including the name of each station and its longitude, latitude, and altitude

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

Source: [8]

Table 2. Shows the number of samples (n), p-value, mean value, Standard Deviation (SD) and Diurnal Temperature Range (DTR), for the thirteen analyzed stations

Station	n	p - value	Mean value	Standard Deviation (SD)	DTR (°C)
Aguada (Coloso)	65	< 0.0011	0.009	-452	−0.61
Aibonito	65	0.428	0.0017	-241	−0.58
Ceiba	65	< 0.011	0.009	-552	−1.11
Corozal	63	0.275	-0.124	-185	−1.03
Guayama	65	< 0.0001	- 0.032	-1009	−1.43
Isabela	65	< 0.011	0.009	-455	−2.11
Juncos	65	< 0.011	-0.117	-452	−2.20
Lajas	65	0.508	-0.041	-118	−0.17
Manatí	65	< 0.0011	0.124	-1123	−2.17
Mayaguez	64	< 0.001	-0.672	-1123	−2.50
Ponce	63	0.198	-0.211	-218	−1.24
San Juan	59	< 0.001	-0.004	-507	−1.14
Utuado	49	< 0.001	0.150	-506	−1.96
				Average	**−1.33**

The non-parametric Mann-Kendall (M-K) test is commonly employed to detect monotonic trends in series of environmental data, climate (temperature, precipitation or hydrological data. When performing a M-K analysis, it is found that a very low negative value indicates a downward trend (Table 2). When the calculated p value is lower than the significance level alpha = 0.05, the negative trend is maintained in Aguada, Ceiba, Guayama, Isabela, Juncos, Manati, Mayaguez, San Juan and Utuado stations, standard deviation (SD) is analyzed, it can be observed that it is much more negative than the Mean value, so the negative trend of the remaining series can be justified (Aibonito, Corozal, Lajas y Ponce).

5. METHODOLOGY

An inspection of the station histories reveals a number of network improvements in automating temperature measurements in recent years. A full assessment of the homogeneity of the data awaits a detailed analysis. The station networks in PR include some stations from urban areas, but the countrywide decreases in DTR are not included by these stations. Incomplete information is available regarding systematic changes in instrumentation at these locations during the past several decades. The data were inspected and adjusted when necessary for station relocations based on temperature differences with neighboring stations. All stations in PR were adjusted using the procedures outlined by [1].

For each station the annual average maximum and minimum temperature was obtained by averaging the monthly values for each year the recording stations were used. The DTR was calculated from the difference between the average annual maximum and minimum temperatures. Changes in the Tmax, Tmin, and DTR were calculated by subtracting each of the respective yearly average values, and the average value of each series was analyzed.

The daily maximum and minimum surface air temperature data for 1950–2014 were taken from 13 meteorological stations across Puerto Rico between 17.7–18.7°N latitude and 67.5–65.2°W longitude. The station locations are shown in Fig. 1; the numbers indicating the stations and their names and locations are shown in Table 1. The series satisfy the following conditions:

- The stations cover the entire geography of the island.
- The data are validated by NOAA's National Climatic Data Center (NCDC).
- The stations have less than 10% missing data.
- The data has been validated by the Climate Data Center.

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

$$\Delta\bar{T}min = \frac{1}{n}\sum_{i=1}^{n} [\bar{T}min - Timin] \tag{2}$$

$\bar{T}$min: Average minimum temperature
Tmin: Minimum daily temperature
$\Delta\bar{T}$min: Variability of the minimum temperature

$$Tmax = \frac{1}{n}\sum_{i=1}^{n} Tmax \tag{3}$$

$$\Delta\bar{T}max = \frac{1}{n}\sum_{i=1}^{n} [\bar{T}max - Timax] \tag{4}$$

$\bar{T}$max: Average maximum temperature
$\Delta\bar{T}$max: Variability of the maximum temperature
$\bar{T}$max: Maximum daily temperature
$\bar{T}$min: Average minimum temperature
Tmin: Minimum daily temperature

$$DRT = \frac{1}{n}\sum_{i=1}^{n} [\Delta\bar{T}\imath max - \Delta\bar{T}imax] \tag{5}$$

6. RESULTS AND DISCUSSION

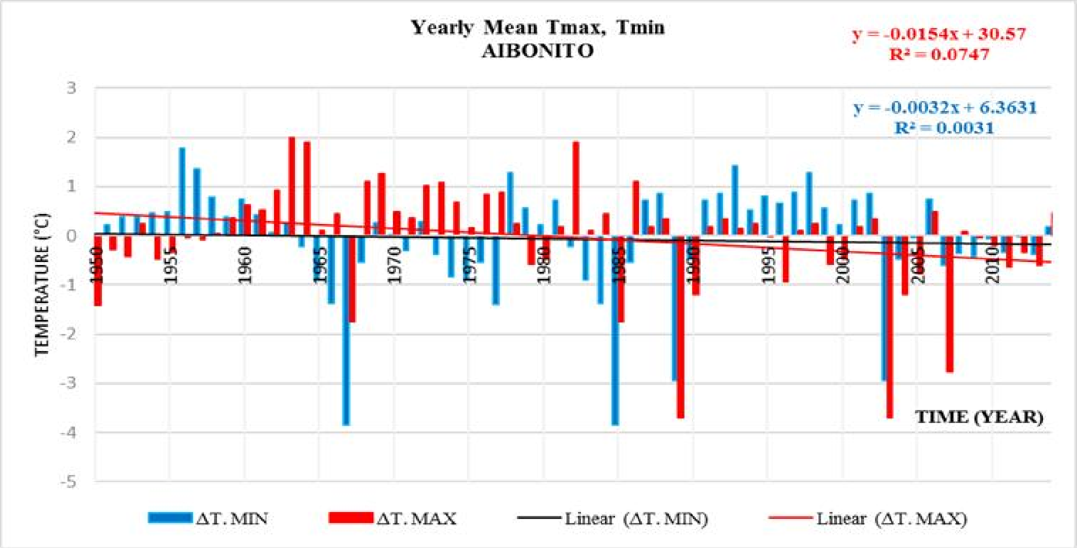
The DTR has decreased over many land areas since 1950, mostly as a result of larger increases in Tmin than in Tmax. In this paper, we have analyzed the spatial dependence of long-term trends in Tmax, Tmin, and DTR over land in Puerto Rico during 1950–2014.

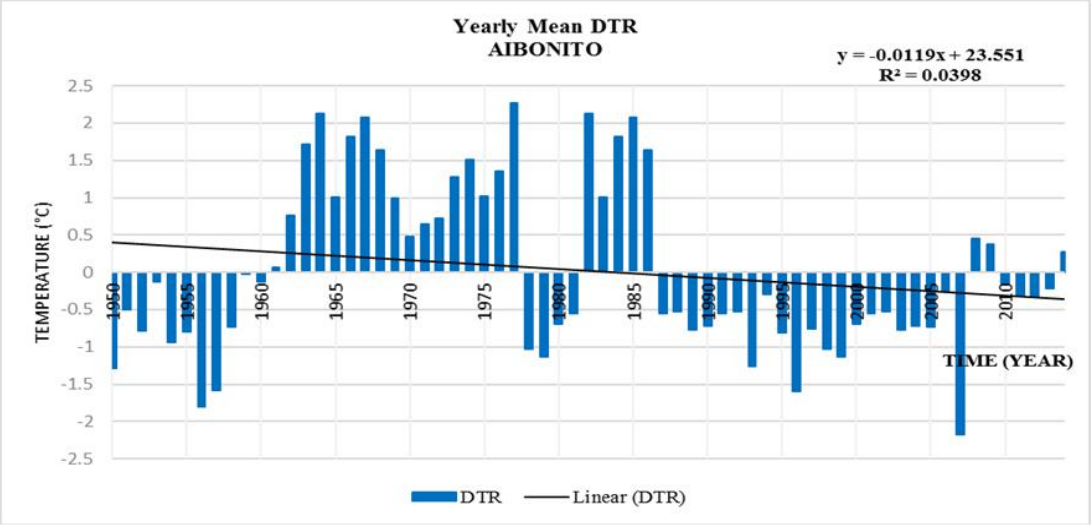
Of the meteorological stations studied, San Juan has the most detailed analysis because it is located at the Luis Muñoz Marin Airport very near Atlantic Ocean. The National Weather Service (NWS) reports that between January 1, 2008, and May 31, 2010, 143 record temperatures were tied or broken at the Luis Muñoz Marin International Airport station. Of these, 124 (87%) were warm temperatures, while only 19 (13%)

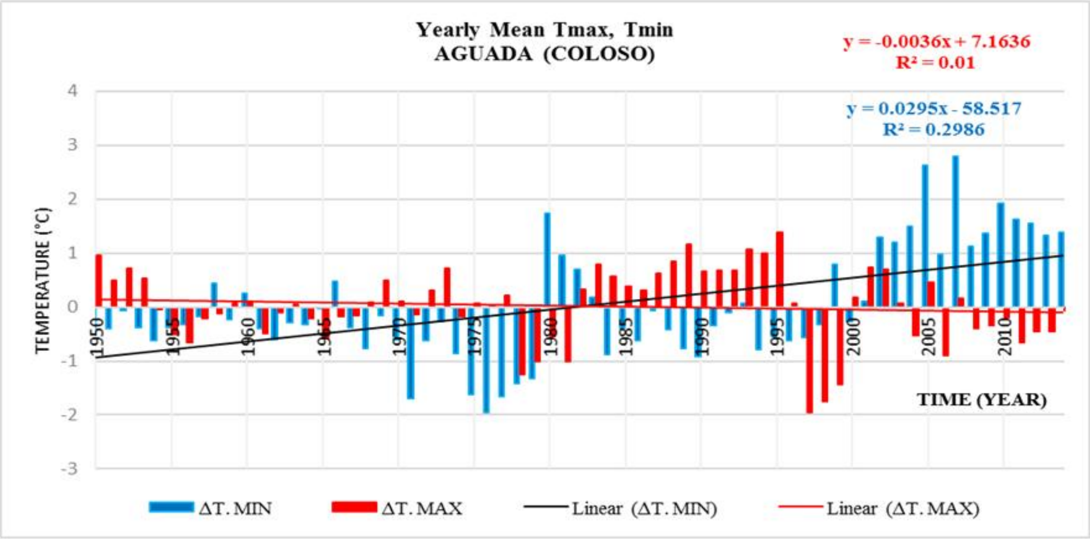
were cold temperatures. Extrapolating from the analysis carried out by the NWS, we can see that most of the stations studied have experienced similar environmental influences, i.e., increases in construction and poorly planned growth. The negative trend in the DTR is maintained at rural stations (Aibonito, Corozal, Juncos, and Utuado), although the values are more extreme at urban stations or at stations that correspond to the coast, in both the south and north of the island.

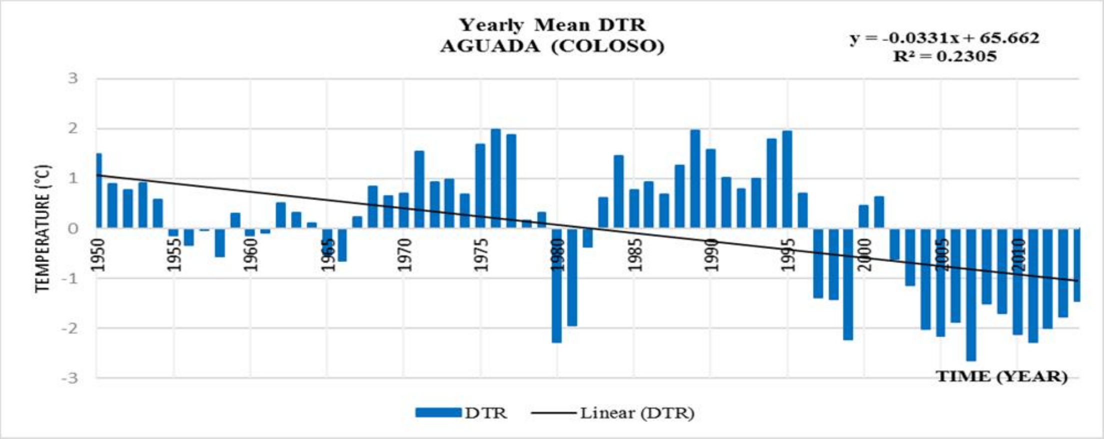
The station of Lajas behaves differently from the other stations studied. This station is located on the 7.2-hectare Isla Mayagüez, 50 meters (160 feet) from the southwest coast of the island of Puerto Rico. It is surrounded by mangroves and has an interior habitat of dry scrub. From 1965 to 1975, the trend in both temperatures on this island maintained an increasing slope and overlapped; however, from 1980 onward, the slope of Tmin has grown with respect to that of Tmax.

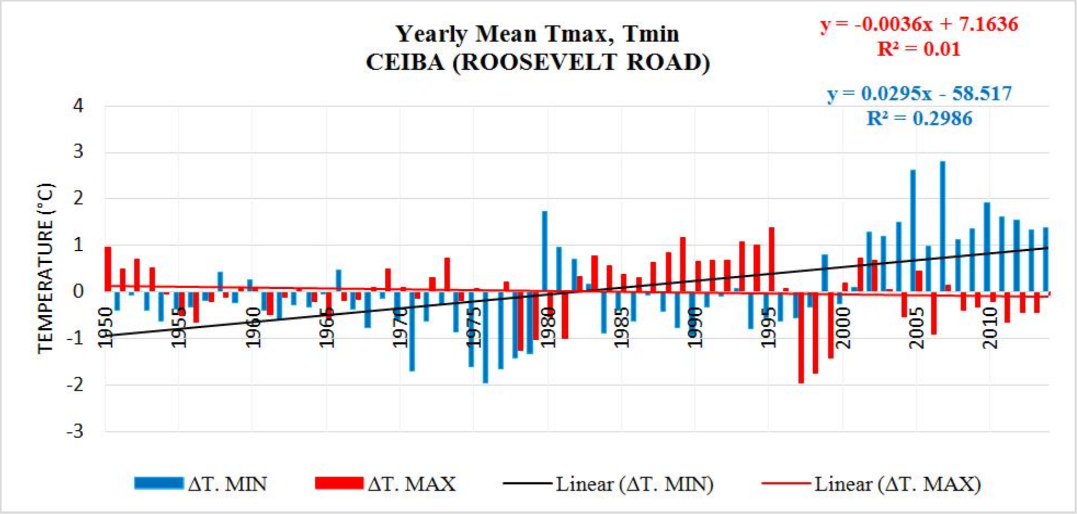
[2] reports that during the period from 1951 to 1990, the change in DTR was −1.50°C per year for USA. The current study found that in 64 years of data from 13 meteorological stations, Puerto Rico has an annual DTR of −1.33°C. These results are within the range of other investigations' findings.

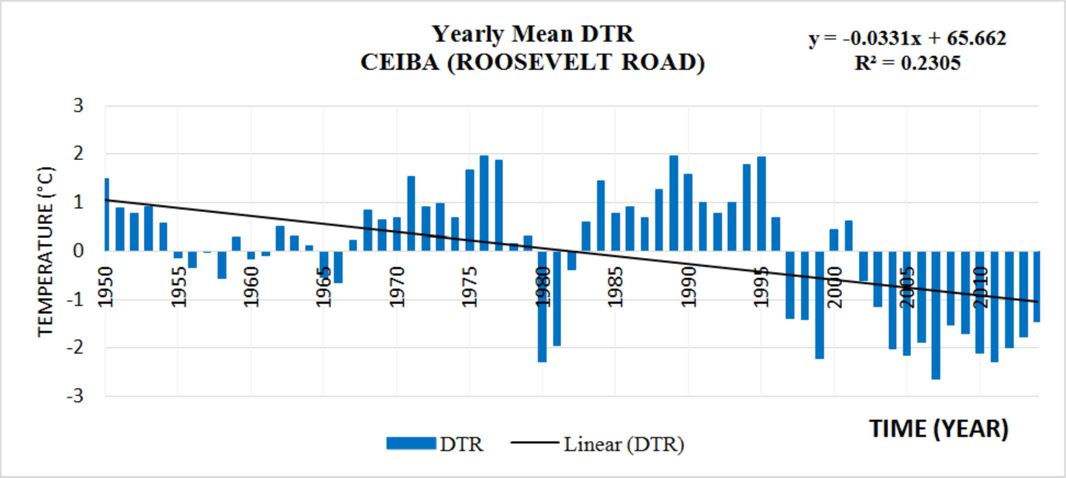


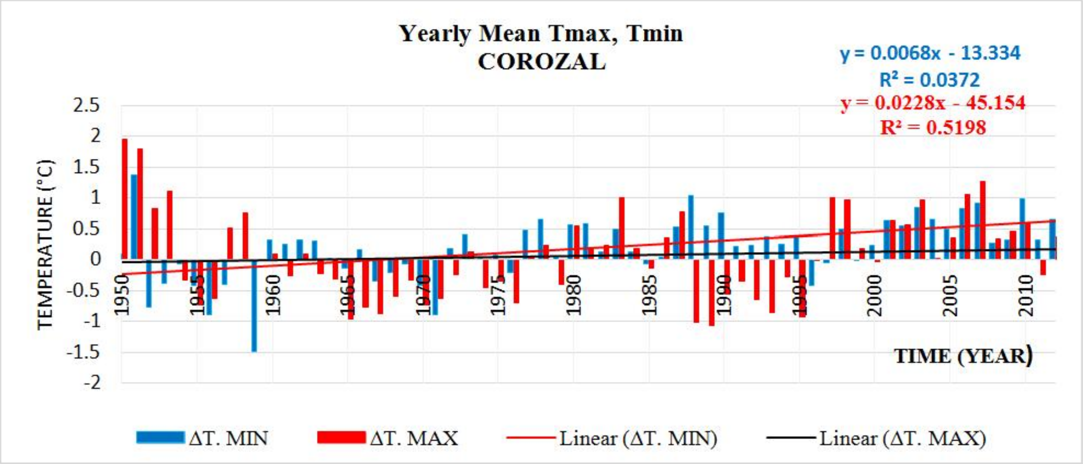


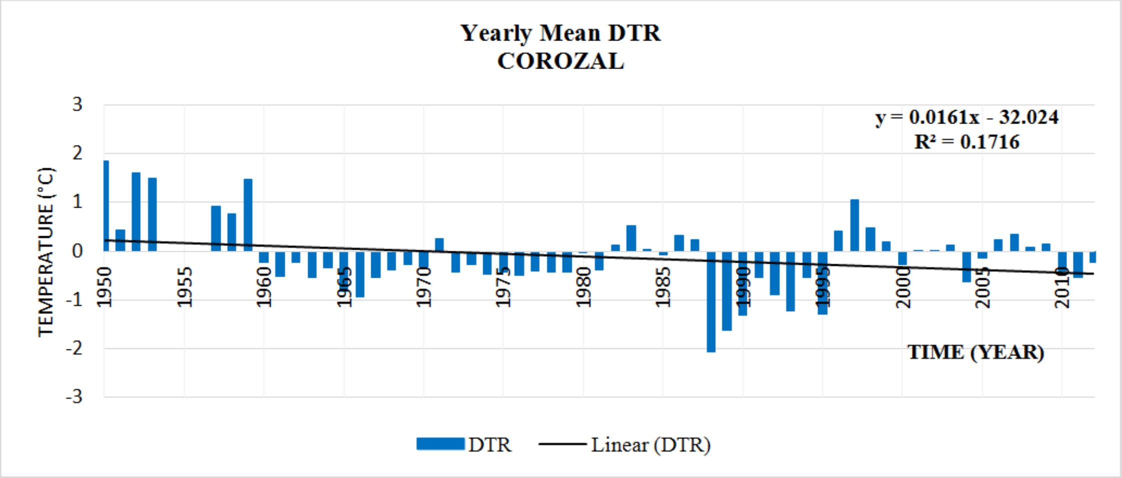

Yearly Mean Tmax, Tmin
AGUADA (COLOSO)
y = -0.0036x + 7.1636
R² = 0.01
y = 0.0295x - 58.517
R² = 0.2986
TEMPERATURE (°C)
4
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

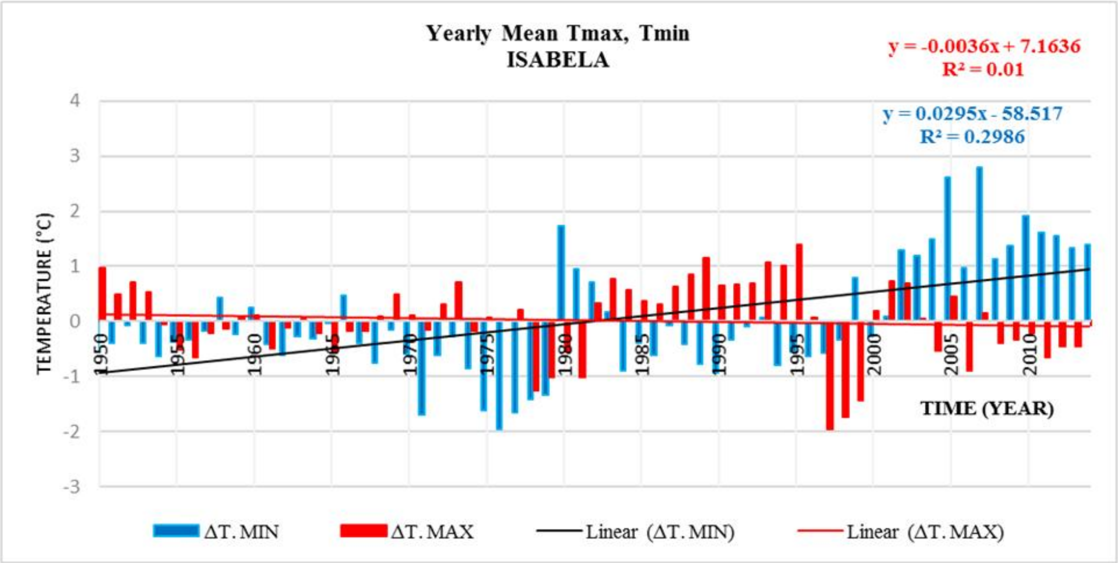

Yearly Mean DTR
AGUADA (COLOSO)
y = -0.0331x + 65.662
R² = 0.2305
TEMPERATURE (°C)
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)

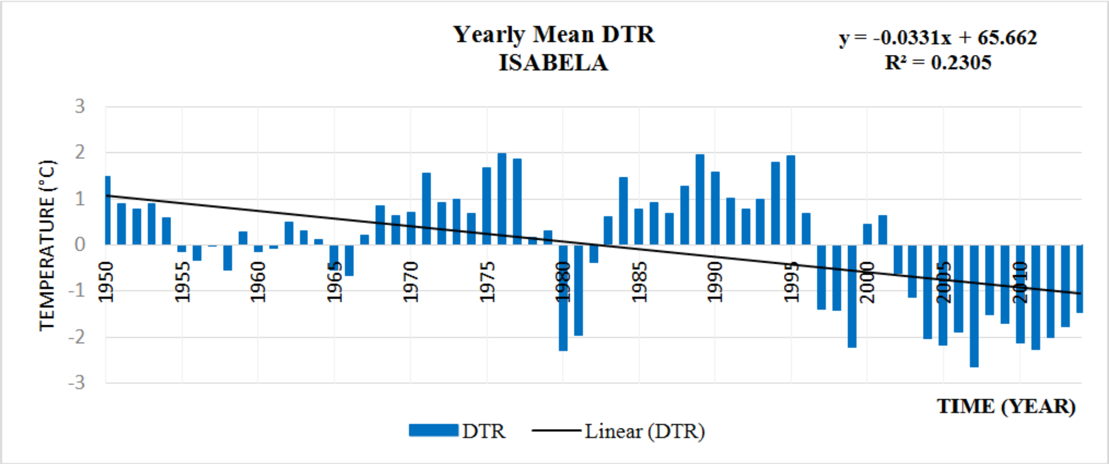

Yearly Mean Tmax, Tmin
CEIBA (ROOSEVELT ROAD)
y = -0.0036x + 7.1636
R² = 0.01
y = 0.0295x - 58.517
R² = 0.2986
TEMPERATURE (°C)
4
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

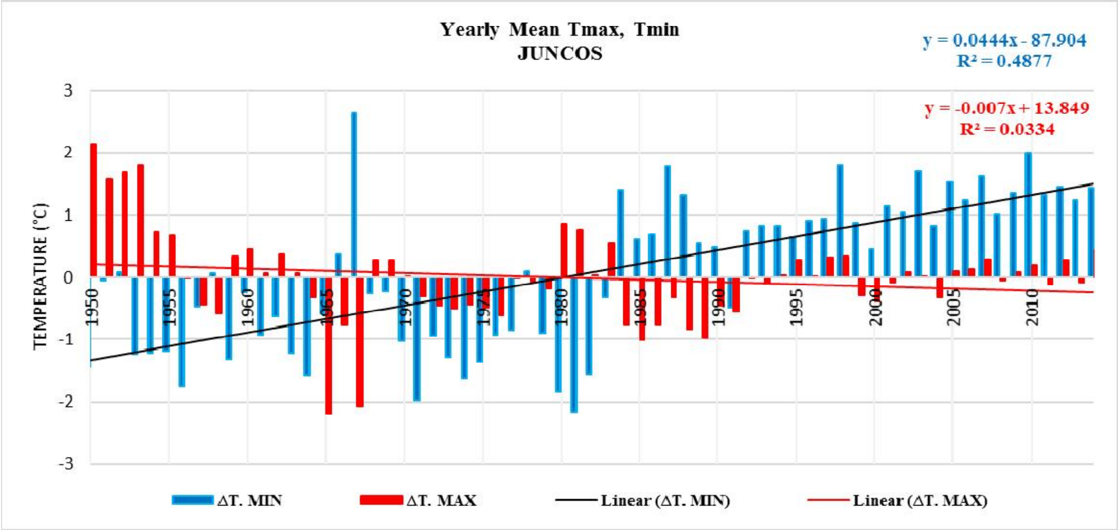

Yearly Mean DTR
CEIBA (ROOSEVELT ROAD)
y = -0.0331x + 65.662
R² = 0.2305
TEMPERATURE (°C)
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)

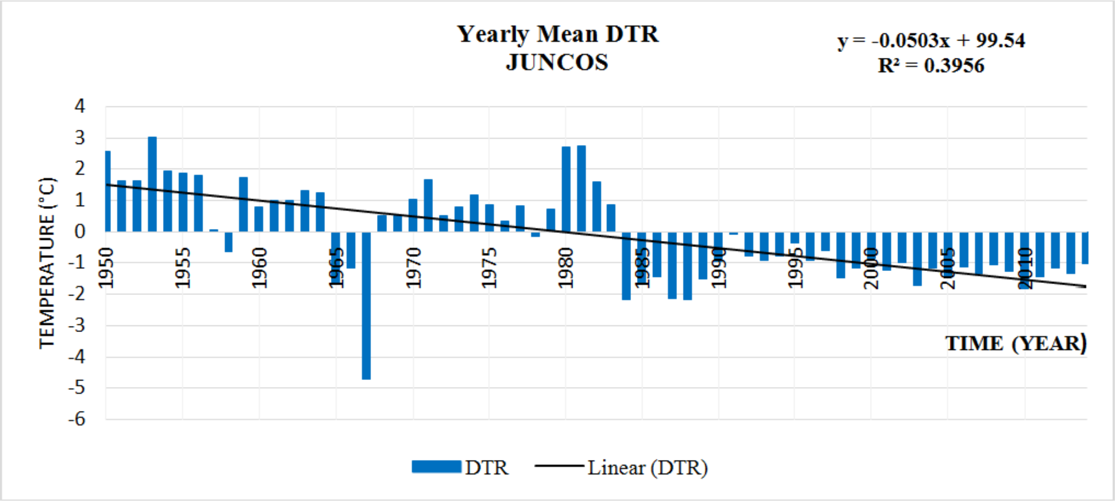

Yearly Mean Tmax, Tmin
COROZAL
y = 0.0068x - 13.334
R² = 0.0372
y = 0.0228x - 45.154
R² = 0.5198
TEMPERATURE (°C)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

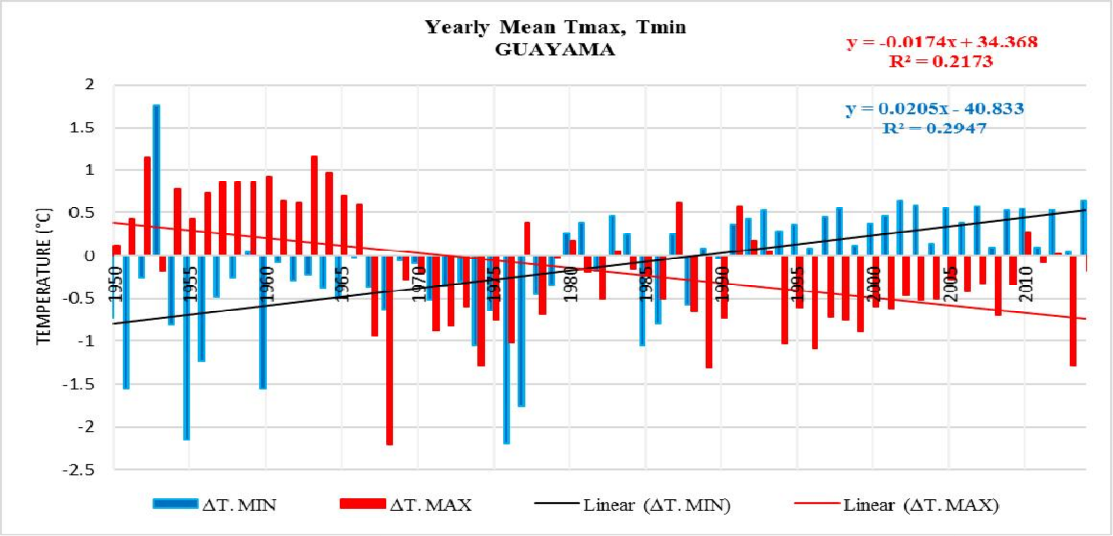

Yearly Mean DTR
COROZAL
y = 0.0161x - 32.024
R² = 0.1716
TEMPERATURE (°C)
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)

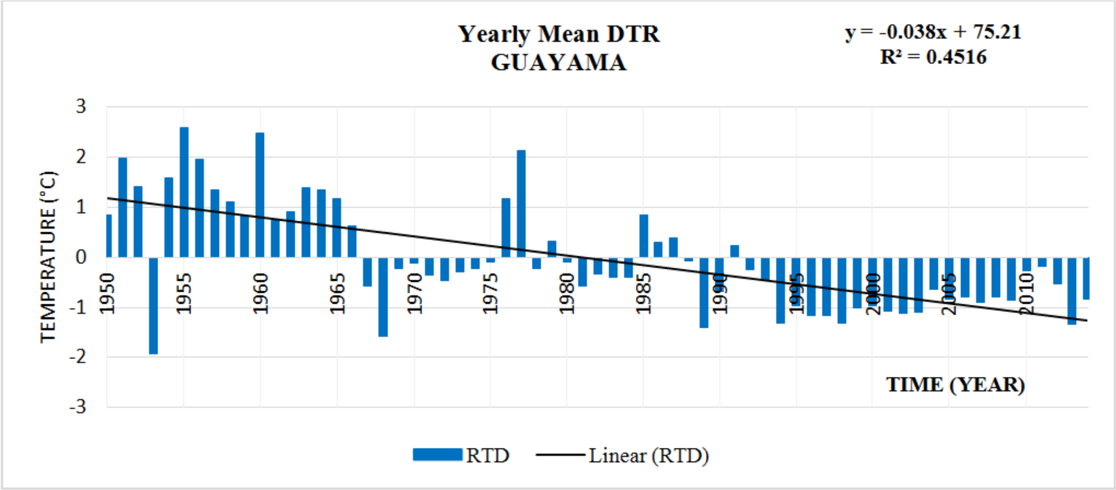

Yearly Mean Tmax, Tmin
ISABELA
y = -0.0036x + 7.1636
R² = 0.01
y = 0.0295x - 58.517
R² = 0.2986
TEMPERATURE (°C)
4
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

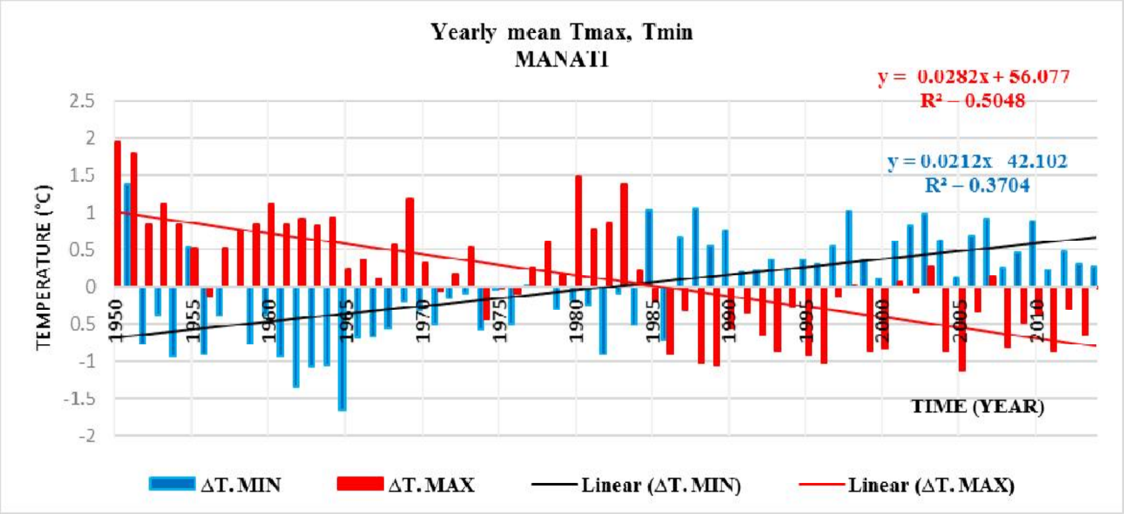

Yearly Mean DTR
ISABELA
y = -0.0331x + 65.662
R² = 0.2305
TEMPERATURE (°C)
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)

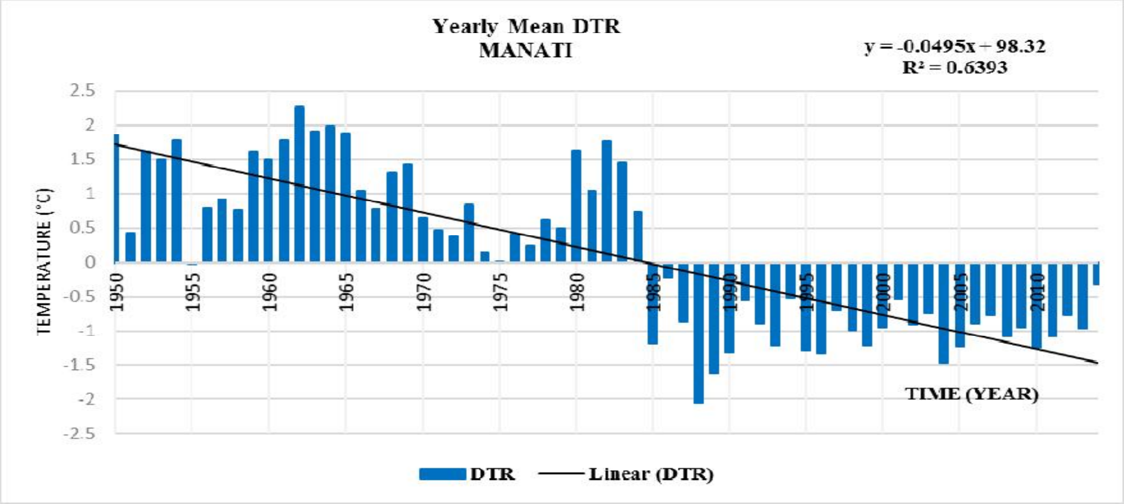

Yearly Mean Tmax, Tmin
JUNCOS
y = 0.0444x - 87.904
R² = 0.4877
y = -0.007x + 13.849
R² = 0.0334
TEMPERATURE (°C)
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

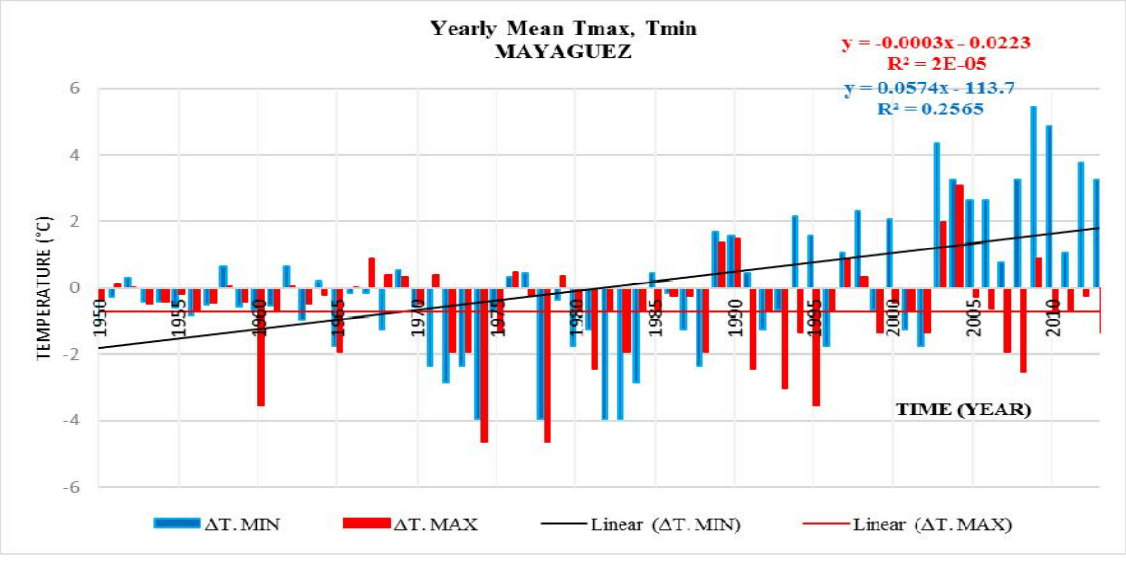

Yearly Mean DTR
JUNCOS
y = -0.0503x + 99.54
R² = 0.3956
TEMPERATURE (°C)
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)

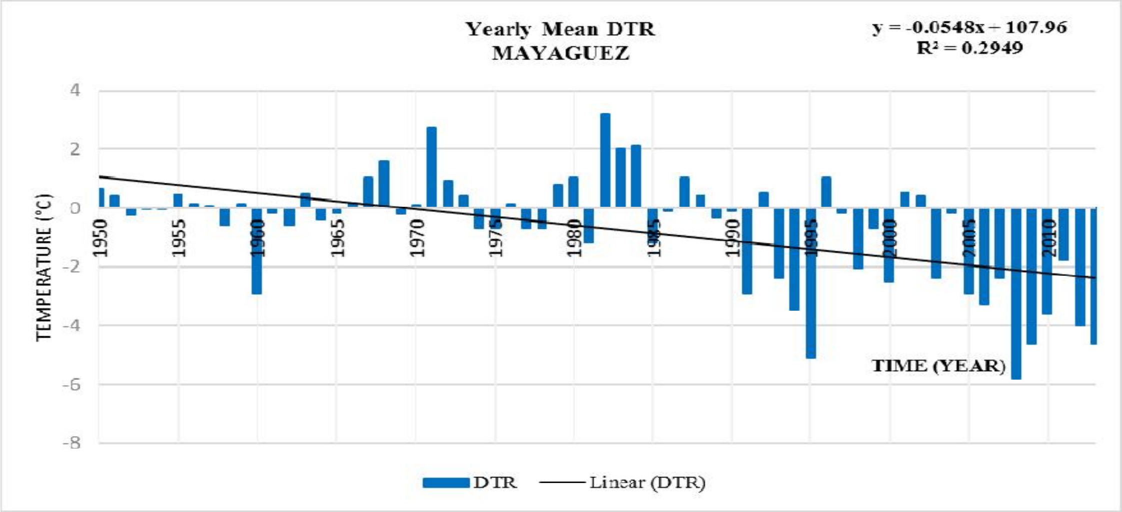

Yearly Mean Tmax, Tmin
GUAYAMA
y = -0.0174x + 34.368
R² = 0.2173
y = 0.0205x - 40.833
R² = 0.2947
TEMPERATURE (°C)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

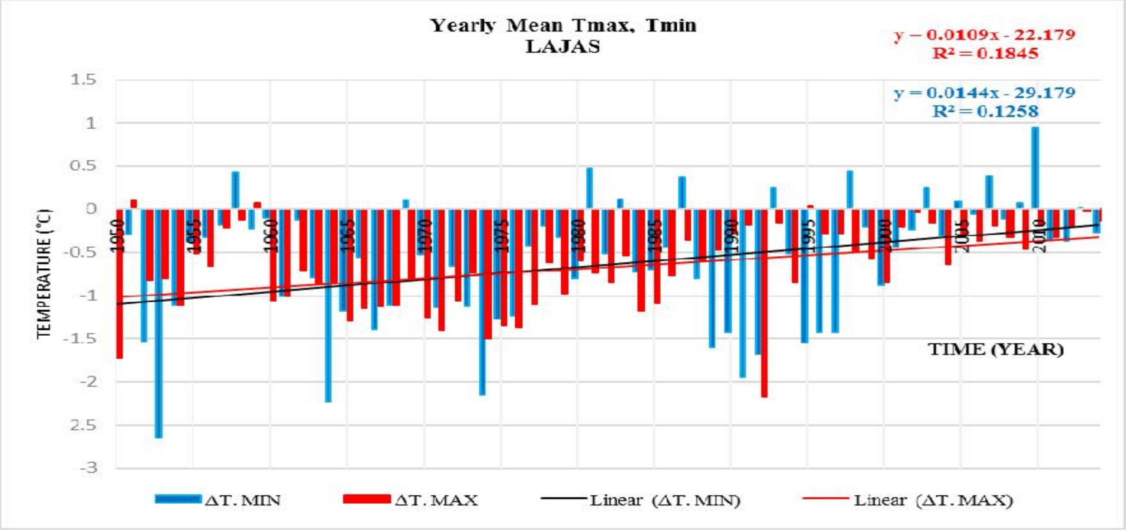

Yearly Mean DTR
GUAYAMA
y = -0.038x + 75.21
R² = 0.4516
TEMPERATURE (°C)
3
2
1
0
-1
-2
-3
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
RTD
Linear (RTD)

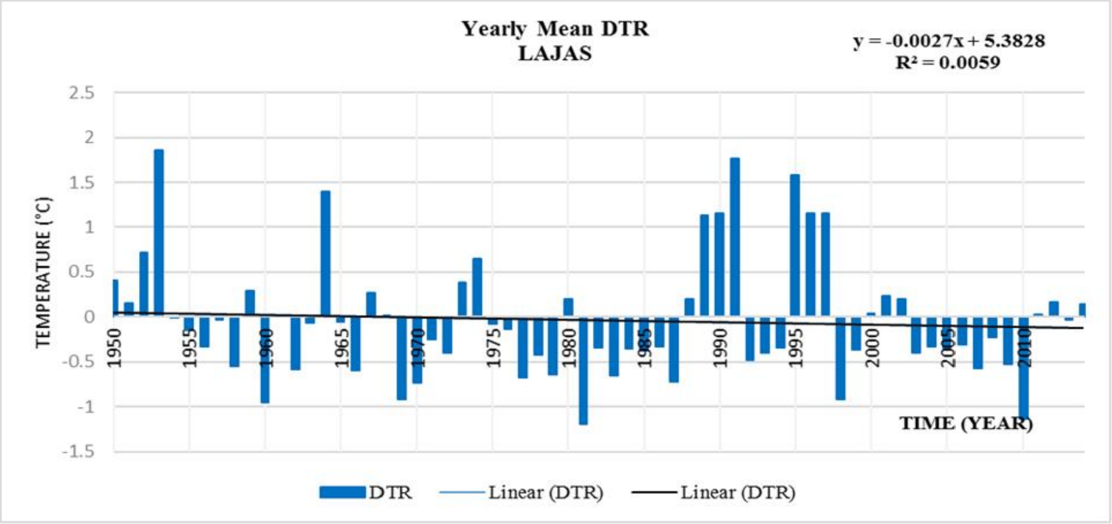

Yearly mean Tmax, Tmin
MANATI
y = 0.0282x + 56.077
R² – 0.5048
y = 0.0212x   42.102
R² – 0.3704
2.5
2
1.5
1
0.5
0
0.5
-1
-1.5
-2
TEMPERATURE (°C)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

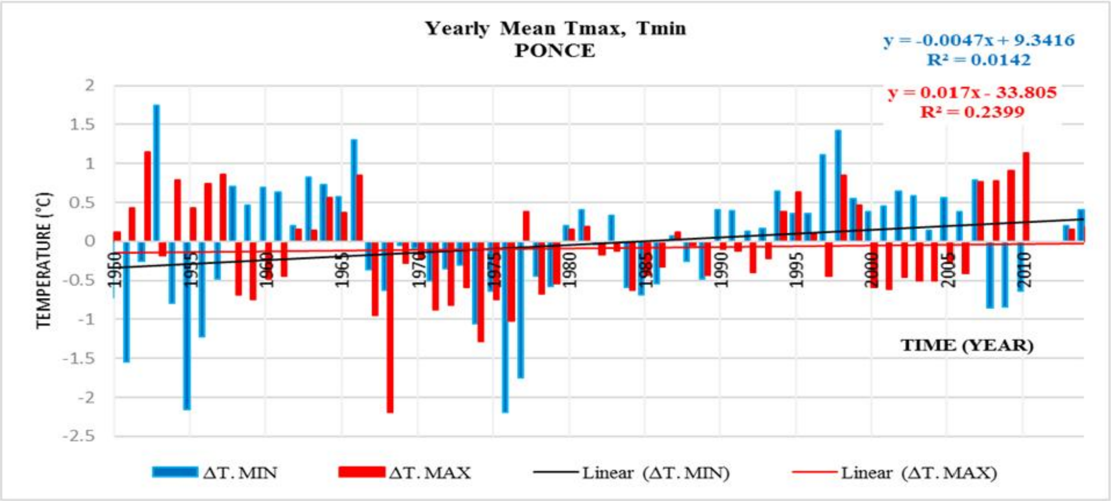

Yearly Mean DTR
MANATI
y = -0.0495x + 98.32
R² = 0.6393
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
TEMPERATURE (°C)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)

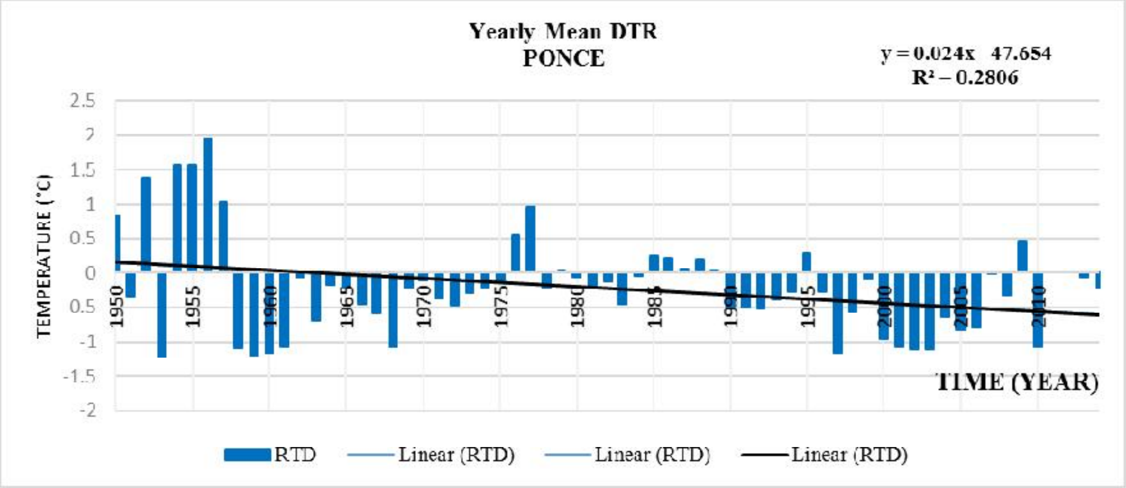

Yearly Mean Tmax, Tmin
MAYAGUEZ
y = -0.0003x - 0.0223
R² = 2E-05
y = 0.0574x - 113.7
R² = 0.2565
6
4
2
0
-2
-4
-6
TEMPERATURE (°C)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

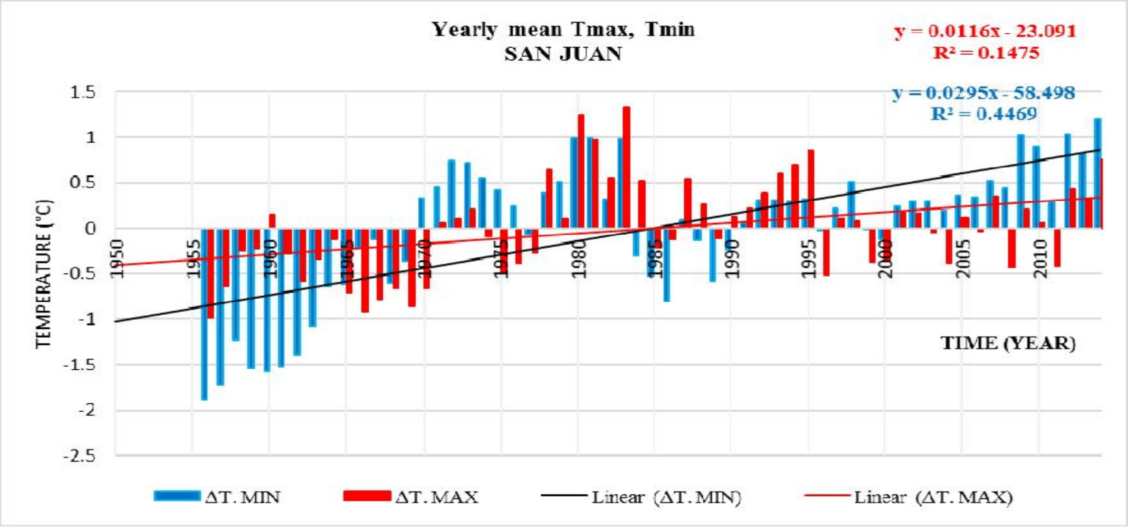

Yearly Mean DTR
MAYAGUEZ
y = -0.0548x + 107.96
R² = 0.2949
4
2
0
-2
-4
-6
-8
TEMPERATURE (°C)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)


Yearly Mean Tmax, Tmin
LAJAS
y = 0.0109x - 22.179
R² = 0.1845
y = 0.0144x - 29.179
R² = 0.1258
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2.5
-3
TEMPERATURE (°C)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)


Yearly Mean DTR
LAJAS
y = -0.0027x + 5.3828
R² = 0.0059
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
TEMPERATURE (°C)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
DTR
Linear (DTR)
Linear (DTR)


Yearly Mean Tmax, Tmin
PONCE
y = -0.0047x + 9.3416
R² = 0.0142
y = 0.017x - 33.805
R² = 0.2399
TEMPERATURE (°C)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)


Yearly Mean DTR
PONCE
y = 0.024x 47.654
R² – 0.2806
TEMPERATURE (°C)
2.5
2
1.5
1
0.5
0
0.5
-1
-1.5
-2
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
RTD
Linear (RTD)
Linear (RTD)
Linear (RTD)


Yearly mean Tmax, Tmin
SAN JUAN
y = 0.0116x - 23.091
R² = 0.1475
y = 0.0295x - 58.498
R² = 0.4469
TEMPERATURE (°C)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
TIME (YEAR)
ΔT. MIN
ΔT. MAX
Linear (ΔT. MIN)
Linear (ΔT. MAX)

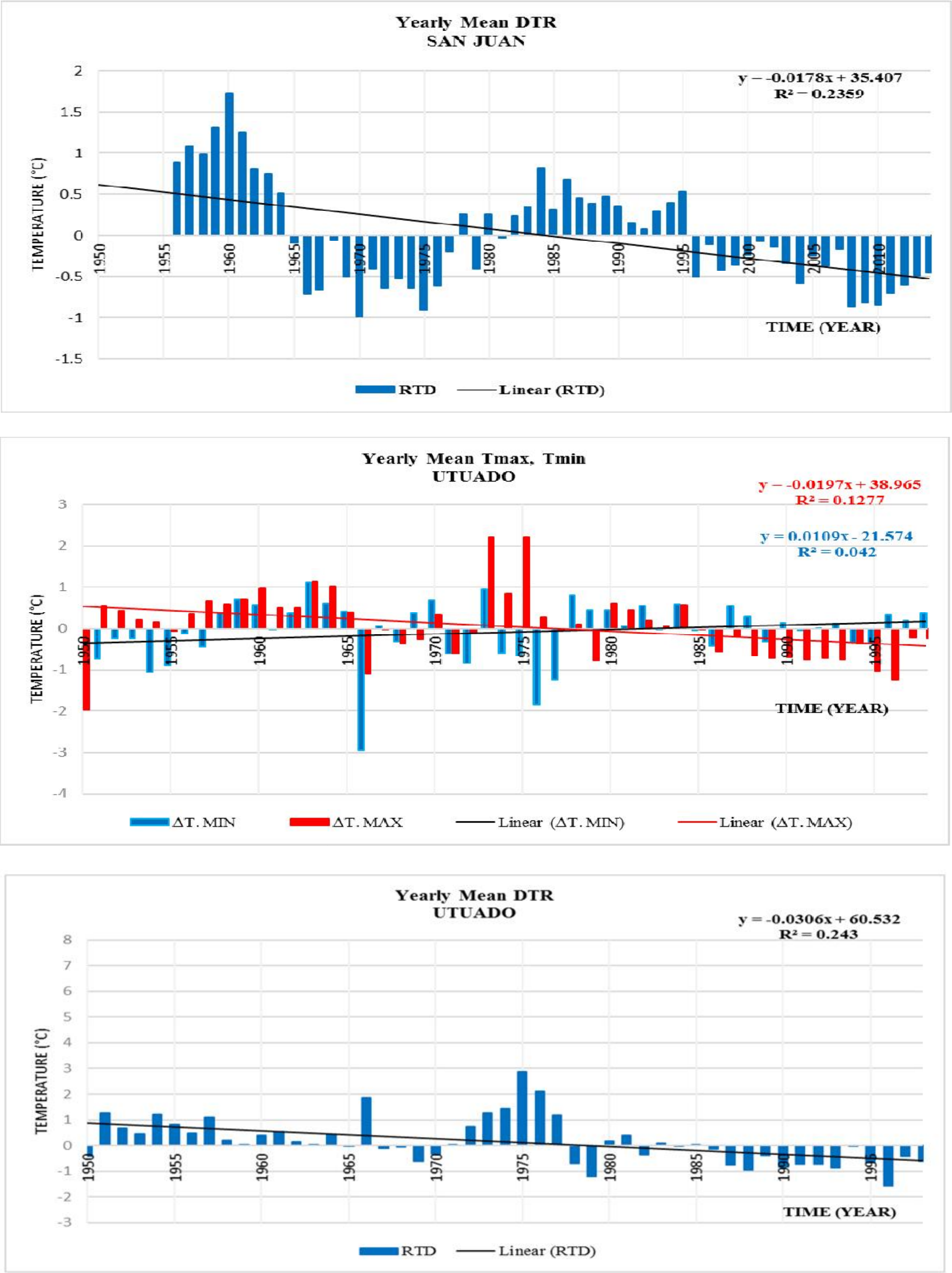


Fig. 2. Shows the behavior of the average temperature in the period analyzed for the 13 meteorological stations

7. CONCLUSION

These results indicate that the observed changes in DTR could be a climatic response to the anthropogenic emission of greenhouse gases and aerosols. Several global and regional research projects have accepted that the global DTR decreased during the second half of the 20th century. Our findings here, based on analyses of the DTR behavior at the studied meteorological stations, confirm this by revealing some important findings. First, all stations show a negative change in DTR (Fig. 2). This decrease is due to an increase in the average temperature of PR, generated by an increase in the Tmin almost three times that of the Tmax [8]. Due to the DTR behavior at these stations, they can be categorized into two large groups. The first group consists of nine stations (Aguada, Ceiba, Guayama, Isabela, Manatí, Mayaguez, Lajas, Ponce, and San Juan) where the increase in the variability of the Tmin in the mountain of Puerto Rico was observed in the 1970s, while the second group consists of four stations (Aibonito, Corozal, Juncos, and Utuado) where this increase was manifested a little later, in the 1980s.

- The M-K analysis shows a negative tendency in all the series, in nine stations, using the p-value as an indicator; are: Aguada, Ceiba, Guayama, Isabela, Juncos, Manatí, Mayagüez, San Juan and Utuado, in the remaining stations (Aibonito, Corozal, Lajas and Ponce), the trend is also decreasing, if we use SD as an indicator compared to the average of the series.
- The behavior of the Lajas station, located southwest of the island, shows a positive trend in the DTR, and the Tmin and Tmax present parallel slopes. However, this station maintains an increase in the Tmin with respect to the Tmax, although this is smaller than that of the other stations. This behavior may be due to the station's geographical location on Isla Magueyez, approximately 150 m from the island of Puerto Rico, which makes the wind regime less stable.
- Analysis shows that the DTR has decreased since the middle of the last century in PR, suggesting that this trend will continue. For this reason, a more detailed analysis is recommended for future studies to investigate the various factors related to spatial and temporal changes in the DTR trend.
- It has been confirmed that the change in the RTD has an important effect on the population of amphibians in PR [45], as well as in the population of Sea Turtles in Boca Ratón, Florida [46].

ACKNOWLEDGEMENT

The author wishes to thank Josue J. Ulloa for his contribution in the data analysis. Thanks to all my family for all the support during the development of this paper, as well as his presentation at the Junior Technical Meeting at the University of Puerto Rico in Carolina and the Institutional Funds for Research of the UPR Carolina 2017/18.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Jones PA, Raper SCB, Bradley RS, Diaz HF, Kelly PM, Wigley TML. Southern hemisphere surface air temperature variations, 1851-1 984. J. Climate Appl. Meteor. 1986;25(121):3-1 230.
2. Karl TR, Jones PD, Knight RW, Kukla G, Plummer N, Razuvayev V, Gallo KP, Lindseay J, Charlson RJ, Peterson TC. A new perspective on recent global warming: Asymmetric trend of daily maximum and minimum temperature. Bull. Am. Meteorol. Soc. 1993;74(6):1007-1023.
3. IPCC. Historical overview of climate change. In: Climate change 2007: The physical science basis. Contribution of working group i to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA; 2007.
4. Henderson-Sellers A. Cloud changes in a warmer Europe. Climatic Change. 1986;8: 25-52.
5. Plantico MS, Karl TR, Knight RW. Is recent climate change across the United States related to rising levels of anthropogenic greenhouse gases. J Geophys Res. 1994; 95:16617–16637.
6. Esteban-Parras MJ, Rodrigo FS, Castro-Diez Y. 1995. Temperature trend and an

change points in the northern Spain plateau during the last 100 years. International Journal of Climatology. 1994; 15:1031-1042.

7. Brunet M, Jones PD, Sigro´ J, Saladie´ O, Aguilar E, Moberg A, Della-Marta PM, Lister D, Walther A, López D. Temporal and spatial temperature variability and change over Spain during 1850–2005, J. Geophys. Res. 2007;112:D12117 DOI: 10.1029/2006JD008249.
8. Méndez Tejeda R. Increase in the number of hot days for decades in Puerto Rico 1950-2014. Environment and Natural Resources Research. 2017;7(3). ISSN 1927-0488 E-ISSN 1927-0496
9. Brázdil R, Budikova M, Auer I, Bohm R, Cegnar T, Ustrnul Z, Szalai S, Weber RO. Trend of maximum and minimum daily temperatures in Central and Southeastern Europe. Int. J. Climatol. 1996;16:765-782.
10. Braganza K, Karoly DJ, Hirst AC, Mann ME, Stott PA, Stouffer RJ, Tett SFB. Simple indices of global climate variability and change: Part I, Variability and correlation structure. Clim. Dyn. 2003;20: 491–502.
11. Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Salinger MJ, Razuvayev V, Plummer N, Jamason P, Folland CK. Maximum and Minimum Temperature Trends for the Globe, Science. 1997;277:364–367.
12. Karl TR, Kukla G, Razuvayev VN, Changery MJ, Quayle RG, Heim RR Jr, Easterling DR, Fu CB. Global warming: Evidence for asymmetric diurnal temperature change. Geophys. Res. Lett. 1991;18:2253-2256.
13. Meehl GA, Tebaldi C, Walton G, Easterling D, McDaniel L. Relative increase of record high maximum temperatures compared to record low minimum temperatures in the US. Geophysical Research Letters. 2009; 36(23). Available:https://doi.org/10.1029/2009GL04073
14. Hansen J, Nazarenko L, Ruedy R, Sato M, Willis J, Del Genio A, Koch D, Lacis A, Lo K, Menon S, Novakov T, Perlwitz, G. Russell J, Schmidt GA, Tausnev N. Earth's energy imbalance: Confirmation and implications. Science. 2005;308:1431-1435. DOI:10.1126/science.1110252
15. Stone A. Daithí and Weaver Andrew Daily maximum and minimum temperature trends in climate model. Geophysical Reseach Letter. 2002;29(9). DOI: 10.1029/2001GL014556,2002
16. Cony M, Hernández E, Del Teso T. Influence of synoptic scale in the generation of extremely cold days in Europe. Atmósfera. 2008;21(4):389-401.
17. Heino R. Climate in Finland during the period of meteorological observations. Finnish Meteorological Institute Contributions. 1994b;2:209.
18. Stephenson Tannecia, Vincent Lucie, Allen Theodore Van Meerbeeck Cedric and McLean Natalie. Trends and variability of daily and extreme temperature and precipitation in the Caribbean region, 1961-2010. Geophysical Research Abstracts. EGU2013-5958-1, 2013 EGU General Assembly. 2013;15.
19. Qu M, Wan J, Hao X. Analysis of diurnal air temperature range change in the continental United. States. Weather and Climate Extremes. 2014;4:86-95. Available:https://doi.org/10.1016/j.wace.2014.05.002
20. Hansen JR, Ruey M Sato, Lo K. Global Surface temperature change. Reviews of Geophysics. 2010;48(4): RG4004.
21. Gómez IE, Fernández W. Variación internual de la temperatura en Costa Rica. Top. Meteor. Oceanogr. 1996;3(1):27-44.
22. Duchon CE. Temperature trends at San Juan, Puerto Rico. Bulletin of the American Meteorological Society. 1986;67(11):1370-1377.
23. Mimura N, Nurse L, Mclean, et al. Small islands In climate change Impact, adaptation and vulnerability. IPCC, ed. 6870716: Cambridge University Press; 2007.
24. Gamble DW. Caribbean vulnerability: Development of an appropriate climatic framework. In D. F. M.McGregor, D. Dodman, & D. Barker (Eds.), Global Change and Caribbean Vulnerability: Environment, Economy and Society at Risk? UWI Press, Kingston. 2009;22–46.
25. McSweeney C, Lizcano G, New M, Lu X, The UNDP climate change country profiles: Improving the accessibility of observed and projected climate information for studies of climate change in developing countries. Bull. Amer. Meteor. Soc. 2010; 91:157–166. Available:https://doi.org/10.1175/2009BAMS2826.1

26. Singh B. Climate changes in the greater and Southern Caribbean. International Journal of Climatology. 1997;17:1093-1114.
27. Taylor Michael, Clarke Leonardo, Centella Abel, Bezanilla Arnoldo, Stephensn Tannecia. Jones Jhordanne, Jayaka Campell, Vichot Alejandro, Charlery John. Future Caribbean climates in a world of rising temperatures the 1.5 vs 2.0 dilemma. American Meteorological Society; 2018. Available:https://doi.org/10.1175/ JCLI-D-17-0074.s1
28. Nurse LA, Coauthors. Small islands. Climate change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional; 2014.
29. Rhiney K. Geographies of Caribbean vulnerability in a changing climate: Issues and trends. Geography Compass. 2015;9 (3), 97-114. Available:https://doi.org/10.1111/gec3.12199.
30. Peterson TC, Taylor MA, Demeritte R, Duncombe DL, Burton S, Thompson F, Klein Tank A. Recent changes in climate extremes in the Caribbean region. Journal of Geophysical Research: Atmospheres. 2002;107(D21). Available:https://doi.org/10.1029/2002JD002251PR-CCC.org
31. Kenawy A. López-Moreno EI JI, Vicente-Serrano SM. Recent trends in daily temperature extremes over northeastern Spain (1960–2006). Nat. Hazards Earth Syst. Sci. 2011;11:2583–2603. Available:www.nat-hazards-earth-syst-sci.net/11/2583/2011/ DOI: 10.5194/nhess-11-2583-2011
32. Alexander LV, Coauthors. Global observed changes in daily climate extremes of temperature and precipitation, J. Geophys. Res. Atmos. 2005;111:D05109. DOI:10.1029/2005JD006290
33. Landsberg HE. The urban climate. Academic Press; 1981.
34. Murphy DJ, Hall MH, Hall CA, Heisler GM, Stehman SV, Anselmi-Molina C. The relationship between land cover and the urban heat island in northeastern Puerto Rico. International Journal of Climatology. 2011; 31(8):1222-1239.
35. Kalnay E, Cai M. Impact of urbanization and land-use change on climate. Nature 2003;423:528–531.
36. Méndez-Lázaro PA, Pérez-Cardona CM, Rodríguez E, Martínez O, Taboas M, Bocanegra A, Méndez-Tejeda R. Climate change, heat, and mortality in the tropical urban area of San Juan, Puerto Rico. International Journal of Biometeorology. 2016;1-9. Available:https://doi.org/10.1007/s00484-016-1291-z
37. Harmsen EW. Fifty years of crop evapotranspiration studies in Puerto Rico. Journal of Soil and Water Conservation. 2003;58(4):214-223.
38. Harmsen Eric W, Miller Norman L, Schlegel Nicole, González JE. Seasonal climate change impacts on evapotranspiration, precipitation deficit and crop yield in Puerto Rico. Agricultural Water Management. 2009;96(7):1085-1095. DOI: 10.1016/j.agwat.2009.02.006
39. Larsen M. Analysis of 20th century rainfall and sreamflow to characterize drought and wat resources in Puerto Rico. Physcical Geography. 2000; 21(6):494-521.
40. Méndez-Tejeda, María SC, Sergio OM, Oscar CV. Environmental and economic impact of forest fires in Puerto Rico 2013-2014. Open Journal of Forestry. 2015; 5(04):353. Available:http://dx.doi.org/10.4236/ ojf.2015.54030.
41. Seebacher Frank, Post Eric. Climate change impacts on animal migration Seebacher and Post Climate Change Responses. 2015;2:5. DOI: 10.1186/s40665-015-0013-9
42. PR State of the climate, Final report; 2015. Available:http://pr-ccc.org/download/PR%20State%20of%20the%20Climate-FINAL_ENE2015.pdf
43. Lambrechts Louis, Paaijmans Krijn P, Fansiri Thanyalak, Carrogton Lauren B, Kramer Laura D, Thomas Matthew, Scott Thomas W. Impact of daily temperature fluctuations on dengue virus transmission by Aedes aegypti. PNAS. 2011;108(18): 7460-7465. Available:https://doi.org/10.1073/pnas.1101377108
44. Huey Raymond, Deutsch Curtis, Tewksbury Johsua WVitt Laurie J, Hertz Paul, Alvarez-Perez, Garland Theodore. Why tropical forest lizards are vulnerable to climate warming. Proc. R. Soc. B. 2009; 276:1939–1948 DOI:10.1098/rspb.2008

45. Ackerman RA. The nest environmental and the embryonic development of sea turtles. In Lutz PL, Musik JA. (Eds.), The Biology of Sea Turtles. Boca Raton, CRC Press. 1997;83–106.

46. Burrowes PA, Joglar RL, Green DE. Potential causes for amphibian declines in Puerto Rico. Herpetologica. 2004;60:141–154.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/25678