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ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 09, Issue, 05, pp.8165-8175, May, 2018

RESEARCH ARTICLE

TEMPERATURE AND PRECIPITATION TRENDS IN THE UNITED STATES ISLAND STATE AND TERRITORIES (1901 – 2015)

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ARTICLE INFO

Article History:
Received 25th February, 2018
Received in revised form
29th March, 2018
Accepted 20th April, 2018
Published online 30th May, 2018

Key words:

Global Warning; Climate Change, Temperature and Precipitation Trends, Tropical Islands.

ABSTRACT

The temperature and precipitation trends from 1901 to 2015 for the United States island state and territories are presented. The area of study has similar climate and topographic characteristics. The data shows a slight temperature increase with time and a variable increase rate for the study area. The precipitation trend is variable for the study area and ranges from no significant changes in precipitation patterns with time to a slight decrease in precipitation with time. The precipitation ratio between rainy and dry season is also studied and discussed.

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INTRODUCTION

Over the past 50 years, the average global temperature has increased at the fastest rate in recorded history. Experts see the trend is accelerating: All but one of the 16 hottest years in NASA's 134-year record have occurred since 2000.Recent analyses of climate trends indicate that the global mean surface temperature has increased by about 0.3 to 0.6°C since the late 19th century, and by about 0.2 to0.3°C over the last 40 years (Nicholls *et al.,* 1996].The potential effects of global warming have increased the interest within the scientific community to study temperature and precipitation trends for different parts of the world. These temperature and precipitation trends have not been globally uniform. Scientists agree that the earth's rising temperatures are fueling longer and hotter heat waves, more frequent droughts, heavier rainfall, and more powerful hurricanes. The earth's ocean temperatures are getting warmer, too—which means that tropical storms can pick up more energy. So global warming could turn, say, category 3 storms into a more dangerous category 4 storm. In fact, scientists have found that the frequency of North Atlantic hurricanes has increased since the early 1980s, as well as the number of storms that reach categories 4 and 5. In 2005, Hurricane Katrina—the costliest hurricane in continental U.S. history—struck New Orleans; the second-costliest, Hurricane Sandy, hit the East Coast in 2012. In 2017 hurricane Harvey struck Texas and hurricanes Irma and Maria (category 4 and 5 storms) struck the Caribbean and Florida causing tremendous destruction in their path. The impacts of global warming are being felt across the globe. Extreme heat waves have caused tens of thousands of deaths around the world in recent years. And in an alarming sign of events to come, Antarctica has been losing about 134 billion metric tons of ice per year since 2002. This rate could speed up if we keep burning fossil fuels at our current pace, some experts say, and causing sea levels to rise several meters over the next 50 to 150 years. In order to predict future effects of global warming, especially in most vulnerable places, temperature and precipitation trends are required. Presented here are temperature and precipitation trends for Hawaii and the other inhabited US island territories. Hawaii is the only island state under the United States jurisdiction. The territories of the United States are sub-national administrative divisions directly overseen by the United States federal government (unlike U.S. states, which share sovereignty with the federal government). These territories are classified by whether they are incorporated (part of the United States proper) and whether they have an organized government through an Organic Act passed by the U.S. Congress. The five US territories which are permanently inhabited are: Puerto Rico, Guam, Northern Mariana Islands, United States Virgin Islands and American Samoa. Table 1 summarizes the demographic information, location, and the political relationship with the United States for each of the islands studied. Hawaii and four of the US territories are located in the northern hemisphere. Only American Samoa is located in the southern hemisphere. All are within 2,400 kilometers from the Equator.

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All fall in the Koppen (Nicholls *et al.,* 1996] climate classification as tropical, in the broader sense. Guam and Puerto Rico also showed characteristics of a tropical rainforest climate. Table 2 shows a summary of the climate characteristics for each territory studied. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (Köppen, Wladimir, 1884) concluded that the global surface temperature "has shown a much smaller increasing linear trend over the past 15 years (1998–2012] than over the past 30 to 60 years." The more recent trend was "estimated to be around one-third to one-half of the trend over 1951–2012." The apparent slowdown was termed a "hiatus" and inspired a suite of physical explanations for its cause, including changes in radiative forcing, deep ocean heat uptake, and atmospheric circulation changes (Thomas, 2015). Although these analyses and theories have considerable merit in helping to understand the global climate system, other important aspects of the "hiatus" related to observational biases in global surface temperature data have not received similar attention. In particular, residual data bases in the modern era could well have muted recent warming, and as stated by IPCC, the trend period itself was short and commenced with a strong El Niño in 1998. Given recent improvements in the observed record and additional years of global data (including a record-warm 2014), we reexamine the observational evidence related to a "hiatus" in recent global surface warming (Thomas *et al.,* 2015). Climate change deniers have argued that there has been a "pause" or a "slowdown" in rising global temperatures, but several recent studies, including a 2015 paper published in the journal Science, have disproved this claim (Thomas *et al.,* 2015). And scientists say that unless we curb global-warming emissions, average U.S. temperatures could increase by up to 10 degrees Fahrenheit over the next century. Climate change indicators for the territory of Puerto Rico was studied from 1902 to 2010 (*Rafael Infante* Méndez, 2013; *Rafael Infante* Méndez, 2013). The climate change for Hawaii's and the other US territories are summarized in US Environmental Protection Agency publications (US Environmental Protection Agency, 2016). Similar trends are observed for these places. The air and ocean are warming, heavy rainstorms are becoming more severe, sea level is rising, and the ocean is becoming more acidic.

MATERIALS AND METHODS

Average temperatures and rainfall data were obtained from The Word Bank Group – Climate Change Knowledge Portal (http://sdwebx.worldbank.org/climateportal/index] and from the National Oceanic and Atmospheric Administration (NOAA) for Hawaii. The average temperature for Hawaii corresponds to the average annual temperatures for the six Hawaiian Islands. The average annual temperatures for the 1901 to 2015 time period was divided into two groups to better asses the temperature trend. The first group covered the years 1901 to 1999 and the second group from 2000 to 2015 (Climatological Data Annual Summary Hawaii and Pacific Islands, 1905-2015). Also annual temperatures were grouped in twenty year time periods and plotted against time. The temperature increase rate and correlation coefficient were calculated usinglinear regression analysis techniques. In order to determine if the rain pattern have shifted in the last 116 years the average annual rainfall was divided into twogroups, the dry season and the rainy season. Rain to dry season ratios were calculated based on rain patterns for each state or territory. Both temperature and precipitation averages were compared using the statistical t-test analysis.

RESULTS AND DISCUSSION

A summary of the average monthly temperature, average maximum temperature, and average minimum temperature from 1901 to 1999 for the study area is shown in Table 3. In order to better visualize temperature changes, average monthly temperatures, average maximum temperature, and average minimum temperature from 2000 to 2015 are shown in Table 4. A summary of the average temperature difference from between 1901 to 1999 and 2000 to 2015 is shown in Table 5. The average temperature increase among the study area between the periods of 2000 to 2015 and 1901 to 1999 was 0.50^{o}C. The maximum increase was observed for American Samoa, 1.0^{o}C and the minimum increase was 0.1^{o}C for the Mariana Islands,an indication of the gradual temperature increase that has occurred in the last one hundred and fifteen years. The average temperature increase was compared and showed that there are statistical differences at the 99.95 confidence interval for the study area.

Hawaii: Figure 1 shows the temperature trend for the Islands of Hawaii. Average temperatures were calculated from the monthly temperatures averages for each of the six islands. The graph shows the annual temperature averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. All of the average annual temperatures data fall within the confidence limits except for the year 1955 that fall below the lower confidence limit. There is no clear trend in temperature variation with time for the 1905 to 1999 study period. However from 2011 to 2015 the average annual temperature has been increasing steadily. Figure 2 shows the precipitation trend for the Islands of Hawaii. Average precipitation was calculated from the monthly precipitation averages for each of the six Islands. The graph shows the annual precipitation averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. Average annual precipitation showed a linear decrease trend with time for the 1905 to 2015 study period. The trend line corresponds to a -0.7 correlation of precipitation with time.

USVI: Figure 3 shows the temperature trend for the United States Virgin Islands (USVI). Average temperatures were calculated from the monthly temperatures averages for the two islands (http://sdwebx.worldbank.org/climateportal/index). The graph shows the annual temperature averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. All of the average annual temperatures data fall within the confidence limits. There is an increasing trend in temperature variation with time for the 1901 to 2015 study period. The trend line corresponds to a +0.8 correlation of temperature with time. Figure 4 shows the precipitation trend for the USVI. Average precipitation was calculated from the monthly precipitation averages for each of the Islands (Climatological Data Annual Summary Hawaii And Pacific, 1905-2015). The graph shows the annual precipitation averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. Average annual precipitation fall within the confidence limits without a significant trend with time for the 1901 to 2015 study period. The trend line corresponds to a -0.7 correlation of precipitation with time.

Table 1. Island State and Territories Data

STATE/ TERRITORY	LOCATION	AREA/ POPULATION	DISTANCE FROM THE EQUATOR, Km	POLITICAL RELATIONSHIP
Hawaii	19.8968° N, 155.5828° W	28,311 km^2/ 1,428,557	2,372	Statehood
Guam	13.4443° N, 144.7937° E	543 km^2/159,358	1,500	Unincorporated and organized territory of the United States
Northern Mariana Islands	15.0979° N, 145.6739° E	463.63 km^2/ 77,000	1,693	Commonwealth since 1978.
American Samoa	14.2710° S, 170.1322° W	197.1 km^2/ 55,519	1,589	Territory since 1898. Locally self-governing under a constitution last revised in 1967.
US Virgin Islands	18.3358° N, 64.8963° W	346.36 km^2/ 106,405	2,092	Organized, unincorporated United States territory.
Puerto Rico	18.2208° N, 66.5901° W	9,104 km^2/ 3,667,084	2,056	Unincorporated territory since 1898, a commonwealth since 1952.

Table 2. Islands State and Territories Climate Data

State/territory	Climate
Hawaii	Hawaii's climate is typical for the tropics, although temperatures and humidity tend to be less extreme because of near-constant trade winds from the east. Snow, not usually associated with the tropics, falls at 13,800 feet (4,200 m) on Mauna Kea and Mauna Loa on Hawaii Island in some winter months. Hawaii's rainfall pattern is spectacularly diverse. In general, high mean rainfall is found on the windward mountain slopes, and low rainfall prevails in leeward lowlands and on the upper slopes of the highest mountains.
Guam	Guam experiences a tropical rainforest climate – though its driest month of March is almost dry enough to qualify as a tropical monsoon climate – moderated by seasonal easterly trade winds. The weather is generally very warm and humid throughout the year with little seasonal temperature variation. The rainy season occurs during July through November. The rest of the months are considered to be the dry season. Overall, Guam averages an annual rainfall of 80-110 inches per year.
Northern Mariana Islands	The climate is tropical, hot and humid all year round, with a relatively cool and dry season from December to June, and a warmer and rainy season from July to November. Temperatures are stable throughout the year, especially in the southern islands, which are closer to the equator, and are also the inhabited ones, where the daytime temperature goes from 28/29 °C (82/84 °F) in the coolest period, to 30/31 °C (86/88 °F) in the warmest. The heat is tempered by the trade winds. Rainfall is abundant, since it reaches 94.5 inches per year in the southernmost island (Rota) and 79 inches in Saipan and Tinian. The wettest months are August, September and October; the least rainy months are from February to May.
American Samoa	The climate is hot, humid and rainy throughout the year**,** with a maximum in rainfall from December to March, and a relative minimum from June to September. Temperatures are stable, with little variations between the hottest period (December to April), when highs are about 31 °C (88 °F), and the coolest period (June to August) when they are around 29 °C (84 °F).
US Virgin Islands	The United States Virgin Islands enjoy a tropical climate, with little seasonal change throughout the year. Summer and winter high temperatures differ by 5 °F (3 °C) or less on average. As regards the rainfall**,** there is a rainy season from May to December, with a relative decrease in precipitation in June and July. The least rainy months are February and March. The rainfall averages around 40/47 inches per year, and is generally slightly more abundant in the northern slopes of each island.
Puerto Rico	Climate classification is tropical rainforest. Temperatures throughout the year are warm to hot, averaging near 85 °F (29 °C) in lower elevations and 70 °F (21 °C) in the mountains. There is a pronounced rainy season from April to November. Due to the topography, rainfall varies greatly across the island. Rainfall averages29.32 to 171.09 inches a year depending on the location.

Table 3. Average Temperature Table for the Study Area (1901 – 1999)

Country	Hawaii[a]	USVI	Guam	American Samoa	Mariana Islands	Puerto Rico
Avg. Temp. ^oC	22.0	25.2	27.4	26.6	27.4	24.8
Avg. Max. Temp. ^oC	22.8	26.5	27.9	28.2	27.8	25.9
Avg. Min. Temp. ^oC	20.7	24.3	27.0	25.7	27.0	23.8
Standard Deviation	0.376	0.566	0.157	0.424	0.134	0.553
% RSD	1.71	2.25	0.57	1.60	0.49	2.23

[a] – 1905 - 1999

Table 4. Average Temperature Table for the Study Area (2000 – 2015)

Country	Hawaii	USVI	Guam	American Samoa	Mariana Islands	Puerto Rico
Avg. Temp. ^oC	22.4	25.8	27.7	27.6	27.5	25.3
Avg. Max. Temp. ^oC	23.3	26.3	27.9	28.4	27.6	25.9
Avg. Min. Temp. ^oC	21.9	25.4	27.4	27.1	27.4	24.9
Standard Deviation	0.350	0.288	0.102	0.330	0.062	0.319
% RSD	1.56	1.12	0.37	1.20	0.23	1.26

Table 5. Average temperature differences from the periods between 1901 to 1999[b] and 2000 to 2015[c].

Country	Hawaii[a]	USVI	Guam	American Samoa	Mariana Islands	Puerto Rico
Avg. Temp. ^oC[c]	22.4	25.8	27.7	27.6	27.5	25.3
Avg. Temp. ^oC[b]	22.0	25.2	27.4	26.6	27.4	24.7
ΔT, ^oC	0.4	0.6	0.3	1.0	0.1	0.6

[a] – 1905 - 2015

Table 6. Average temperature in twenty year time periods between 1901 to 2015[a]

Time Period	Hawaii[a]	USVI	Guam	American Samoa	Mariana Islands	Puerto Rico
1901 - 1920	21.9	24.7	27.4	26.1	27.4	24.2
1921 - 1940	22.3	24.8	27.3	26.4	27.3	24.3
1941 – 1960	22.1	25.1	27.4	26.6	27.4	24.6
1961– 1980	21.9	25.5	27.4	26.5	27.3	25.1
1981 – 2000	22.0	25.9	27.5	27.1	27.5	25.3
2001 – 2015	22.4	25.9	27.7	27.6	27.5	25.4
Temperature Increase Rate	0.002	0.014	0.003	0.014	0.002	0.014
Correlation	0.33	0.98	0.76	0.93	0.77	0.98

[a] – 1905 – 2015

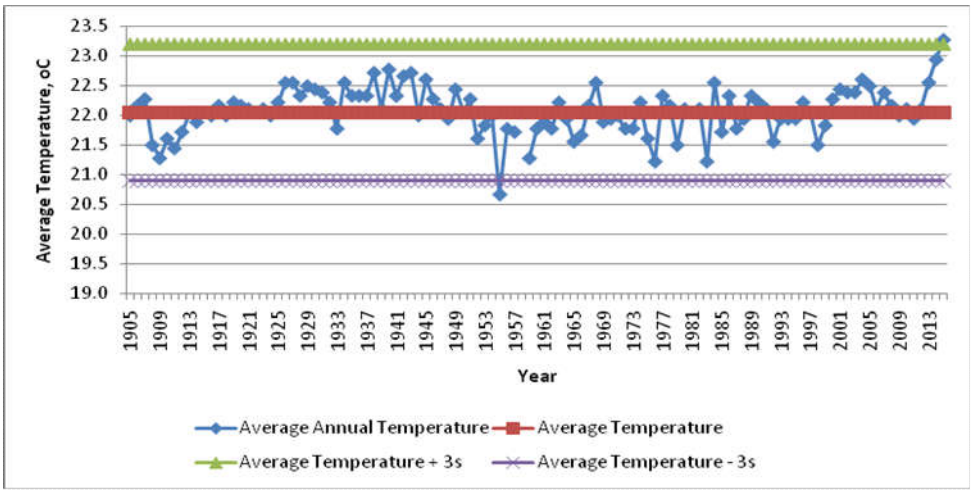

Figure 1. Average Annual Temperatures for the Islands of Hawaii (1905 – 2015)

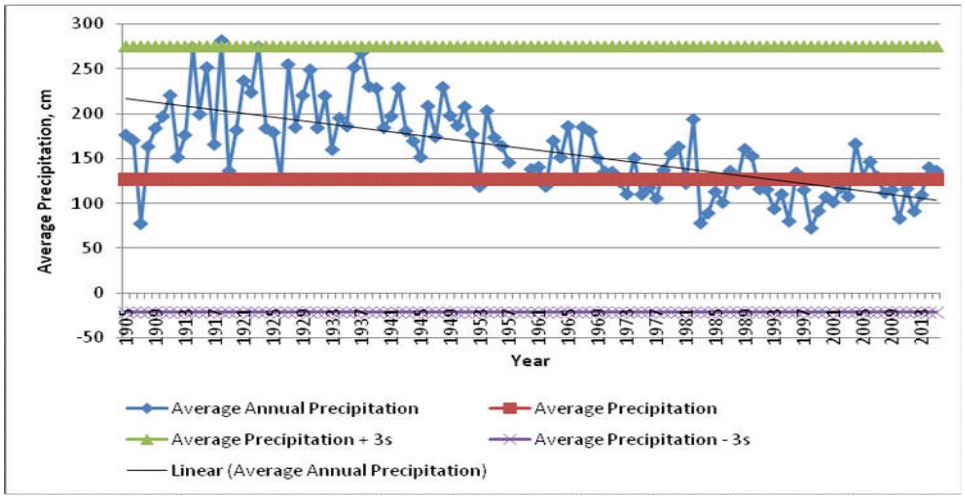

Figure 2. Average Annual Precipitation for the Islands of Hawaii (1905 – 2015)

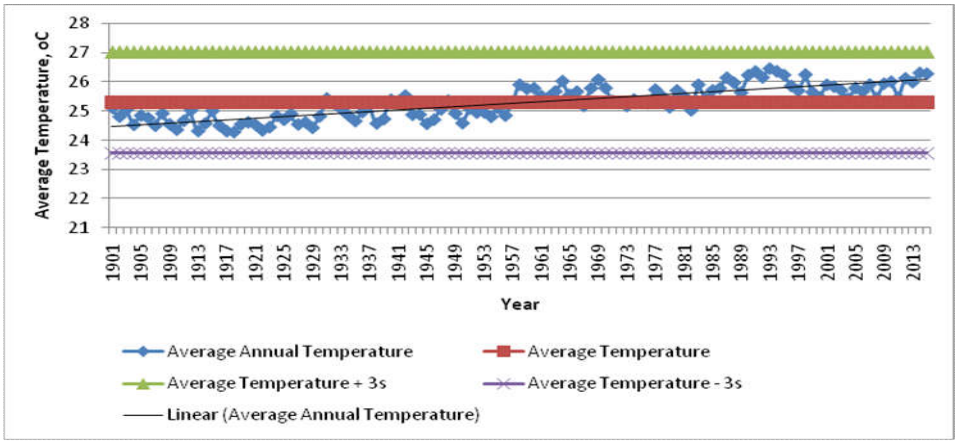

Figure 3. Average Annual Temperatures for the USVI (1901 – 2015)

Tofurther study the effectthe increasing temperature trend on precipitation pattern we studied if changes in the rainy to dry season precipitation ratios for the USVI. The USVI have a rainy season during the months of May and July thru. November, the other months of the year are considered the dry months. Figure 5 shows the rainy to dry precipitation ratios for the 1901 – 2015 study periods. The rainy to dry season precipitation ratio falls within the confidence limits except for the years 1936 and 1944. In 1936 the rainy season was high compared to Islands average and in 1944 was the opposite – the dry season was low compared to the Islands average.

Guam: Figure 6 shows the temperature trend for Guam. Average temperatures were calculated from the monthly temperatures averages (http://sdwebx.worldbank.org/ climateportal/index.). The graph shows the annual temperature averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. All of the average annual temperatures data fall within the confidence limits. There is aslight increasing trend in temperature variation with time for the 1901 to 2015 study period. The trend line corresponds to a +0.5 correlation of temperature with time. Figure 7 shows the precipitation trend for Guam. Average precipitation was calculated from the monthly precipitation averages for each of the Islands (http://sdwebx.worldbank.org/climateportal/index). The graph shows the annual precipitation averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. Average annual precipitation fall within the confidence limits with a slight increasing precipitation trend with time for the 1901 to 2015 study period. The trend line corresponds to a +0.07 correlation of precipitation with time. To further study the effect the increasing temperature trend on precipitation pattern we studied if changes in the rainy to dry season precipitation ratios for Guam. Guam have a rainy season during the months of May thru December, the dry months are January thru April. Figure 8 shows the rainy to dry precipitation ratios for the 1901 – 2015 study periods. The rainy to dry season precipitation ratio falls within the confidence limits except for the years1906 and 1926. In both years the dry season was significantly below the dry season average for Guam.

American Samoa

American Samoa: Figure 9 shows the temperature trend for American Samoa. Average temperatures were calculated from the monthly temperatures averages (Climatological Data Annual Summary Hawaii and Pacific Islands, 1905-2015). The graph shows the annual temperature averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. All of the average annual temperatures data fall within the confidence limits. There is a slight increasing trend in temperature variation with time for the 1901 to 2015 study period. The trend line corresponds to a +0.8 correlation of temperature with time. Figure 10 shows the precipitation trend for American Samoa. Average precipitation was calculated from the monthly precipitation averages for each of the Islands (Climatological data annual summary hawaii and pacific, 1905-2015). The graph shows the annual precipitation averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. Average annual precipitation fall within the confidence limits without a particular precipitation trend with time for the 1901 to 2015 study period. To further study the effect the increasing temperature trend on precipitation pattern we studied if changes in the rainy to dry season precipitation ratios for American Samoa. American Samoa have a dry season during the months of July thru September, the rainy months are October thru June. Figure 11 shows the rainy to dry precipitation ratios for the 1901 – 2015 study periods. The rainy to dry season precipitation ratio falls within the confidence limits except for the years 1909were the dry season was significantly below the dry season precipitation average for American Samoa.

Northern Mariana Islands: Figure 12 shows the temperature trend for the Northern Mariana Islands. Average temperatures were calculated from the monthly temperatures averages (http://sdwebx.worldbank.org/ climateportal/index). The graph shows the annual temperature averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. All of the average annual temperatures data fall within the confidence limits except for the year 1991 when the average temperature was above the upper limit. The temperature spread was the lowest among the study area. There is a slight increasing trend in temperature variation with time for the 1901 to 2015 study period. The trend line corresponds to a +0.4 correlation of temperature with time. Figure 13 shows the precipitation trend for the Northern Mariana Islands. Average precipitation was calculated from the monthly precipitation averages for each of the Islands (http://sdwebx.worldbank.org/climateportal/index). The graph shows the annual precipitation averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. Average annual precipitation fall within the confidence limits without a particular precipitation trend with time for the 1901 to 2015 study period. To further study the effect the increasing temperature trend on precipitation pattern we studied if changes in the rainy to dry season precipitation ratios for the Northern Mariana Islands. The Mariana Islands have a dry season during the months of July thru November, the rainy months are December thru June. Figure 14 shows the rainy to dry precipitation ratios for the 1901 – 2015 study periods. The rainy to dry season precipitation ratio falls within the confidence limits. There is a slight decreasing trend in rainy/dry precipitation ratio with time. The trend line corresponds to a -0.2 correlation of rainy/dry precipitation ratio with time. This indicates that while the annual precipitation had remained fairly constant there have been shifts in the rain patterns.

Puerto Rico: Figure 15 shows the temperature trend for Puerto Rico. Average temperatures were calculated from the monthly temperatures averages (http://sdwebx.worldbank.org/ climateportal/index). The graph shows the annual temperature averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations. All of the average annual temperatures data fall within the confidence limits. There is an increasing trend in temperature variation with time for the 1901 to 2015 study period. The trend line corresponds to a +0.8 correlation of temperature with time. Figure 16 shows the precipitation trend for Puerto Rico. Average precipitation was calculated from the monthly precipitation averages for each of the Islands (http://sdwebx. worldbank.org/climateportal/index).). The graph shows the annual precipitation averages, the overall average, and the 99 % confidence limits calculated as the overall average $\pm$ three standard deviations.

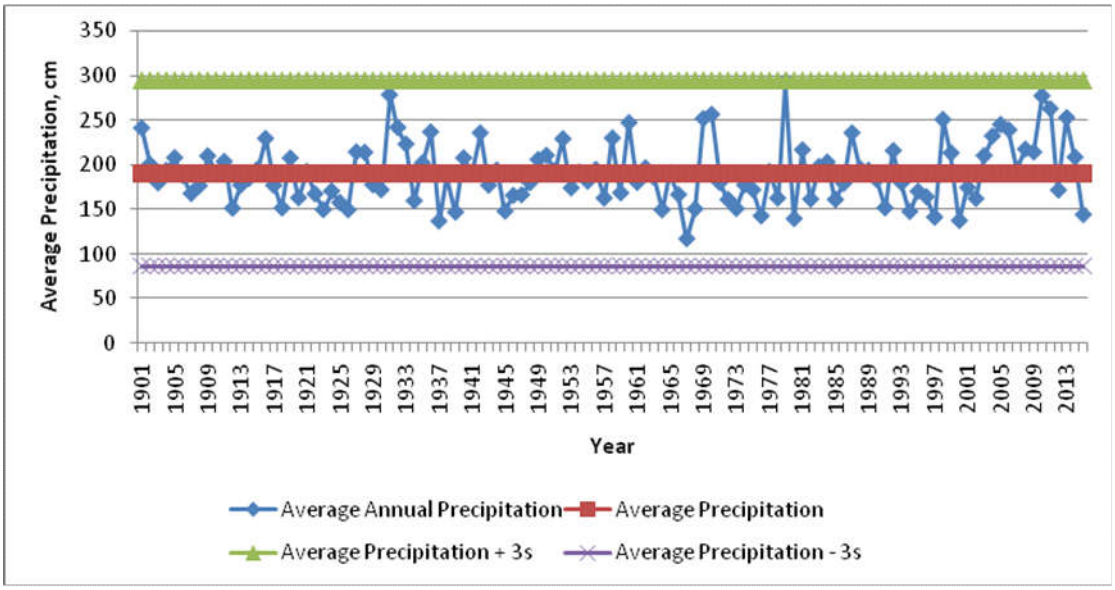

Figure 4. Average Annual Precipitation for the USVI (1901 – 2015)

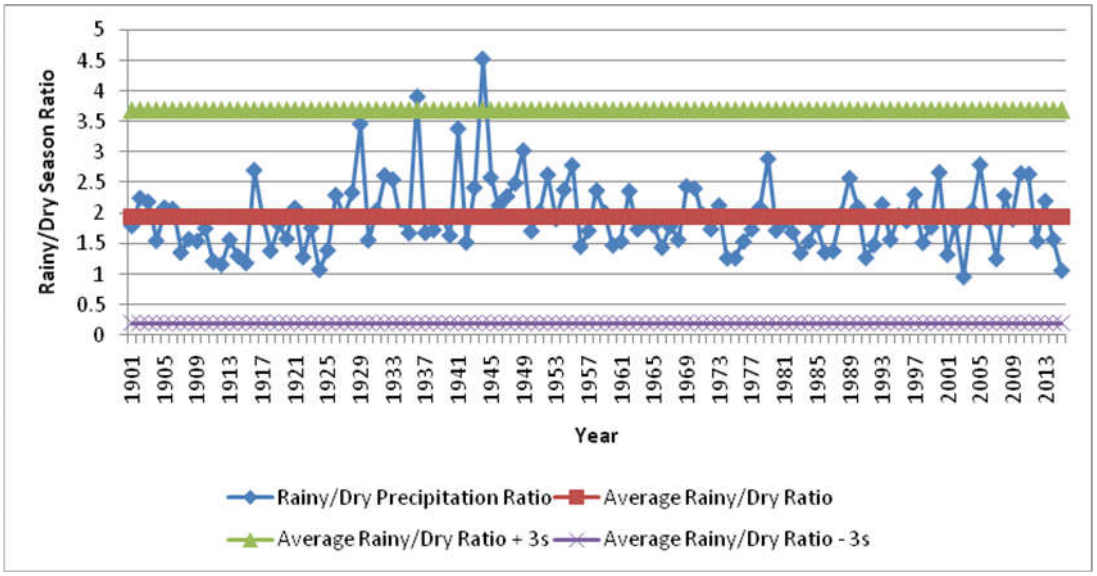

Figure 5. Average Rainy/Dry Precipitation Ration for the USVI (1901 – 2015)

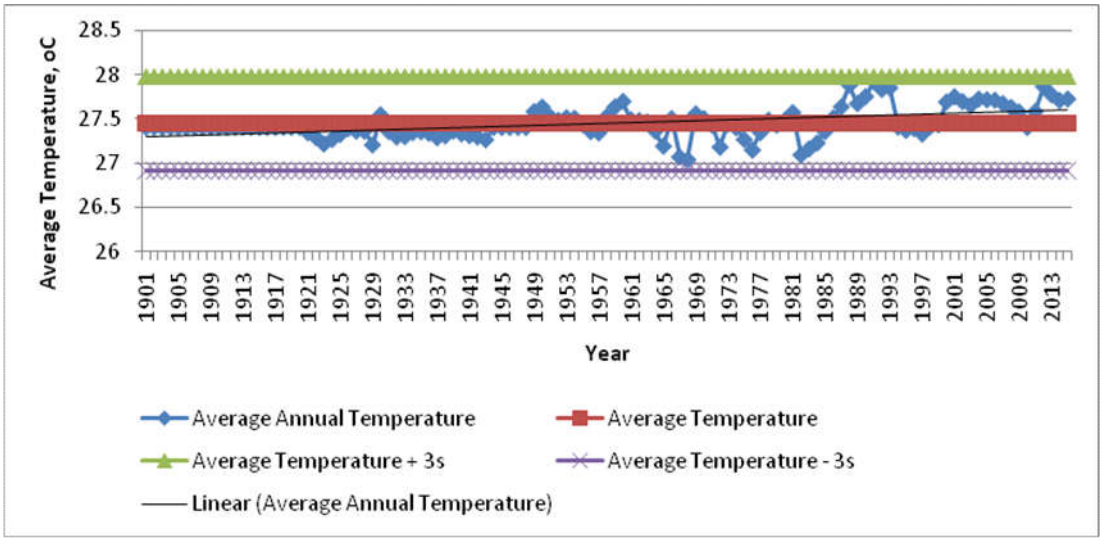

Figure 6. Average Annual Temperature for Guam (1901 – 2015)

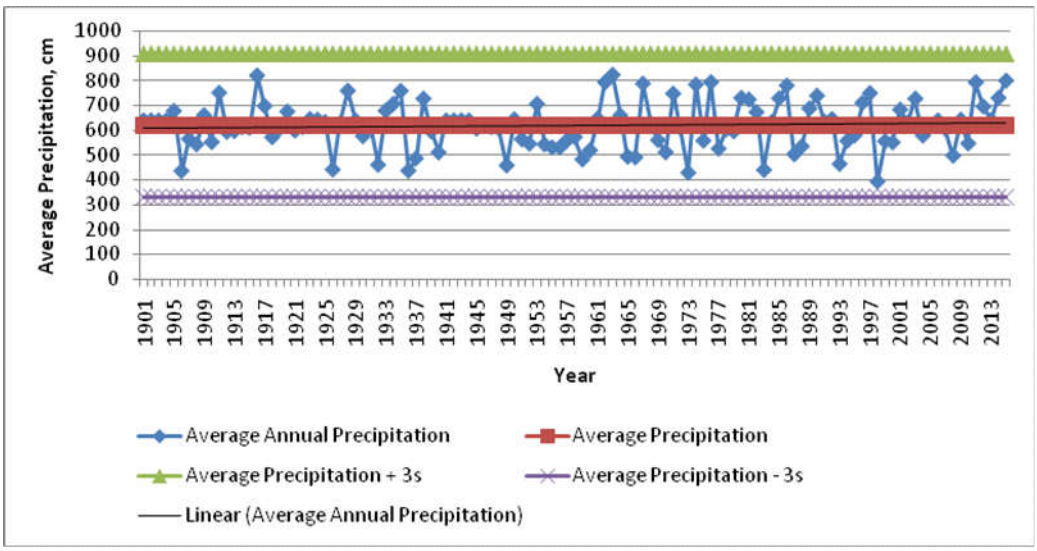

Figure 7. Average Annual Precipitation for Guam (1901 – 2015)

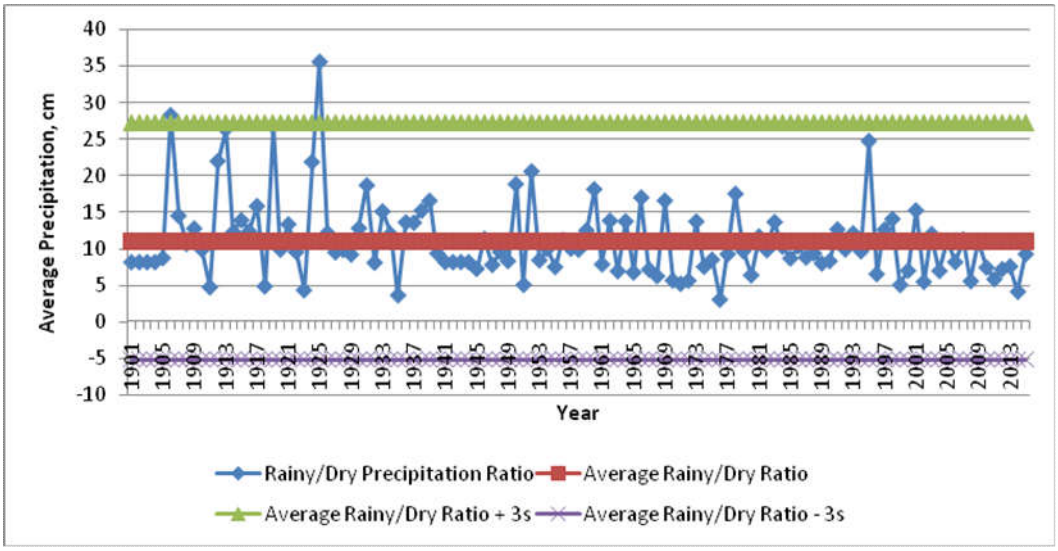

Figure 8.Average Rainy/Dry Precipitation Ration for Guam (1901 – 2015)

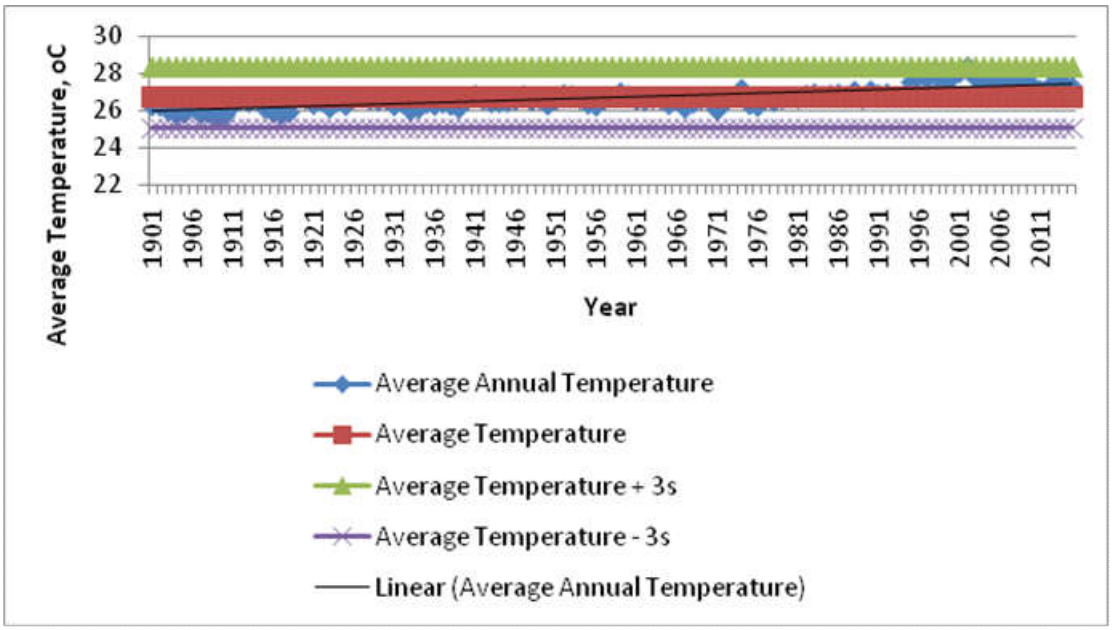

Figure 9. Average Annual Temperature for American Samoa (1901 – 2015)

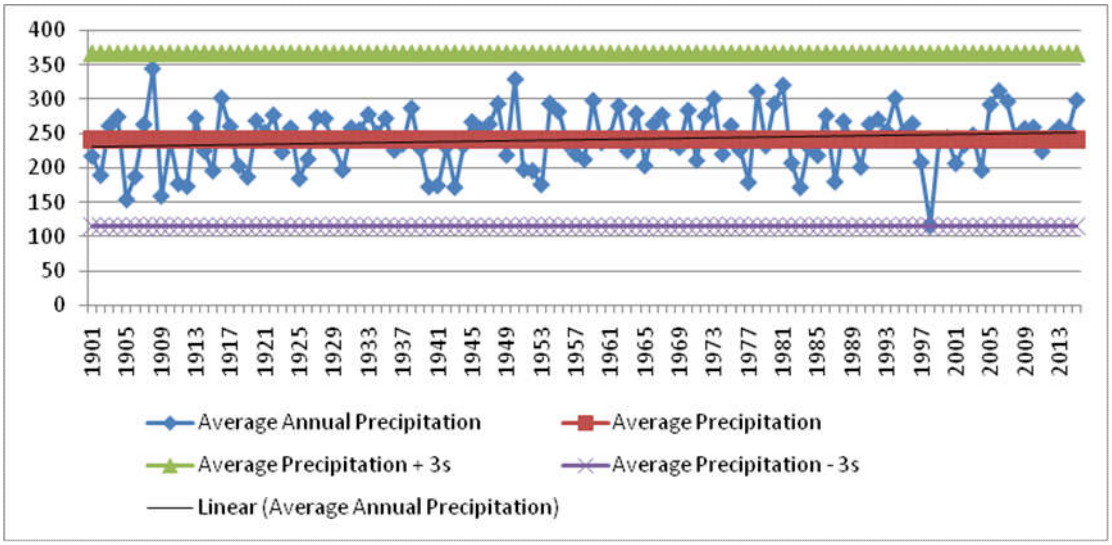

Figure 10. Average Annual Precipitation for American Samoa (1901 – 2015)

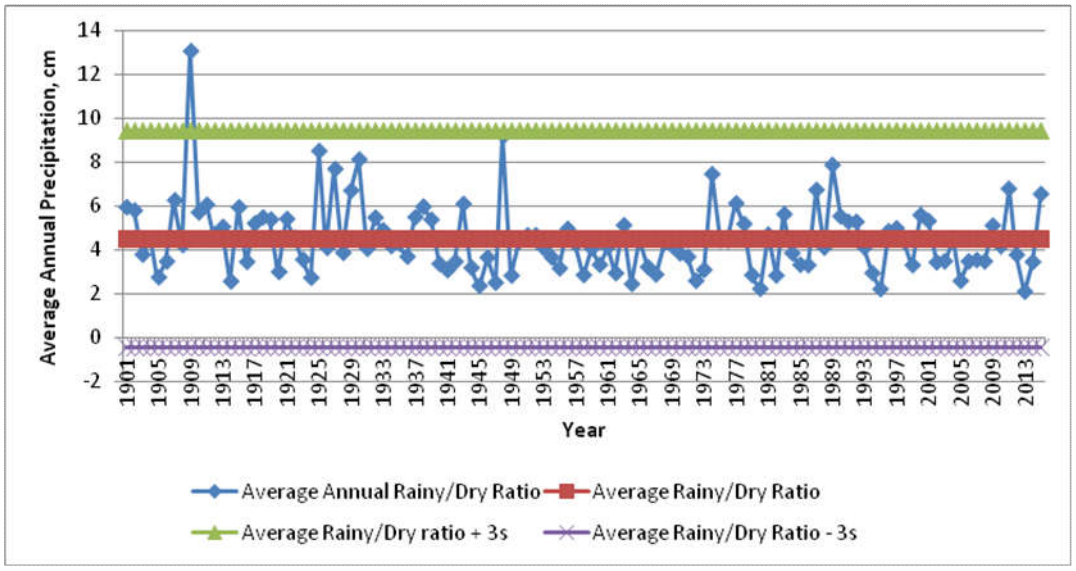

Figure 11. Average Rainy/Dry Precipitation Ration for American Samoa (1901 – 15)

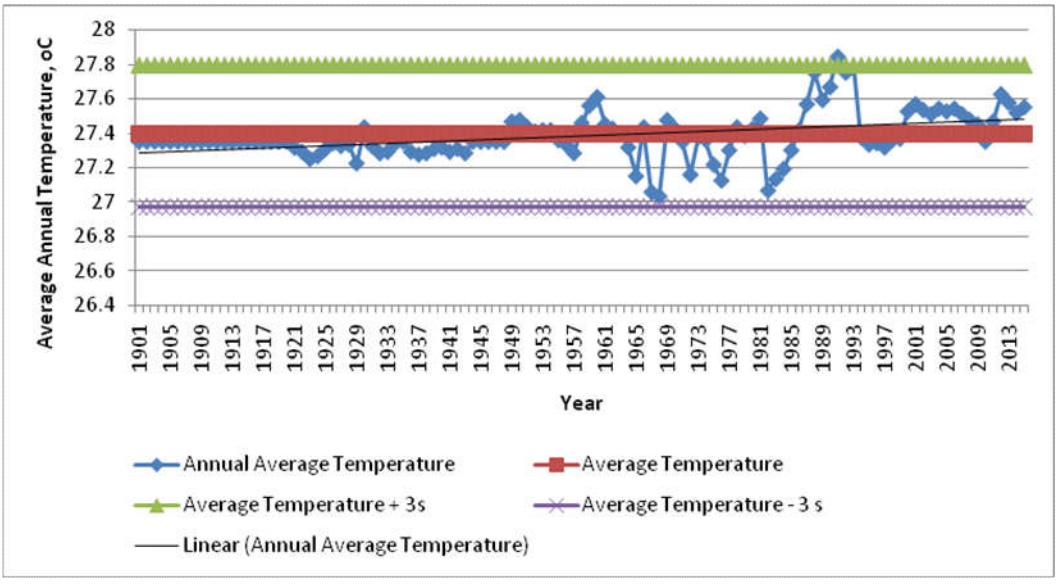

Figure 12. Average Annual Temperature for the Northern Mariana Islands (1901 – 2015)

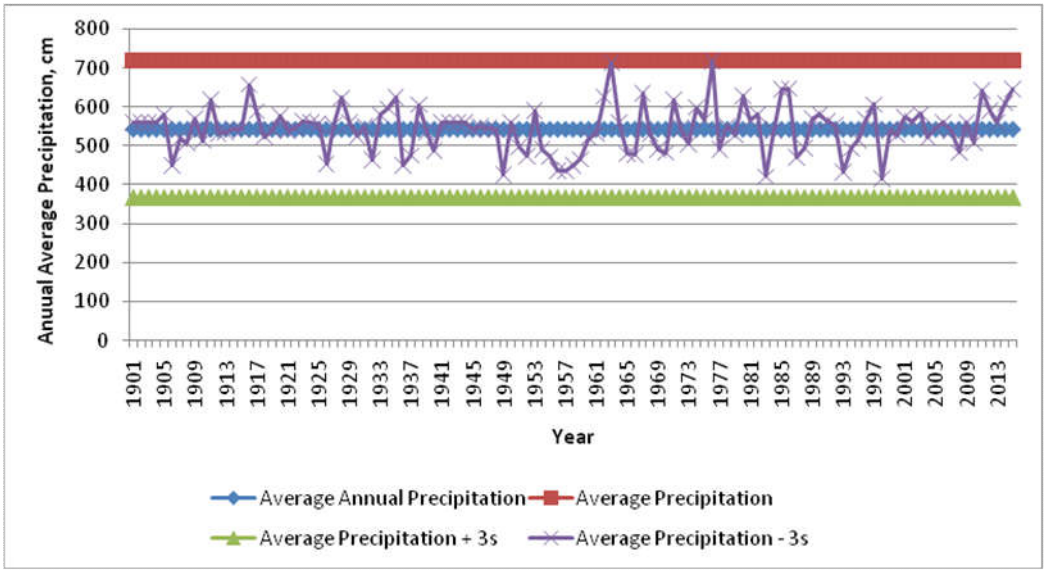

Figure 13. Average Annual Precipitation for the Northern Mariana Islands (1901 – 2015)

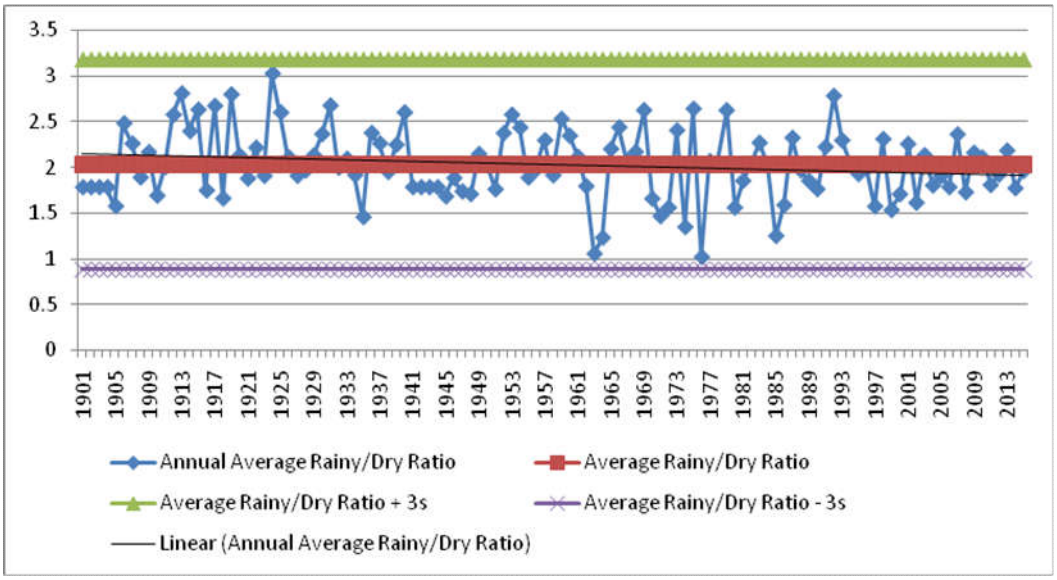

Figure 14. Average Rainy/Dry Precipitation Ratio for the Northern Mariana Islands (1901 – 2015)

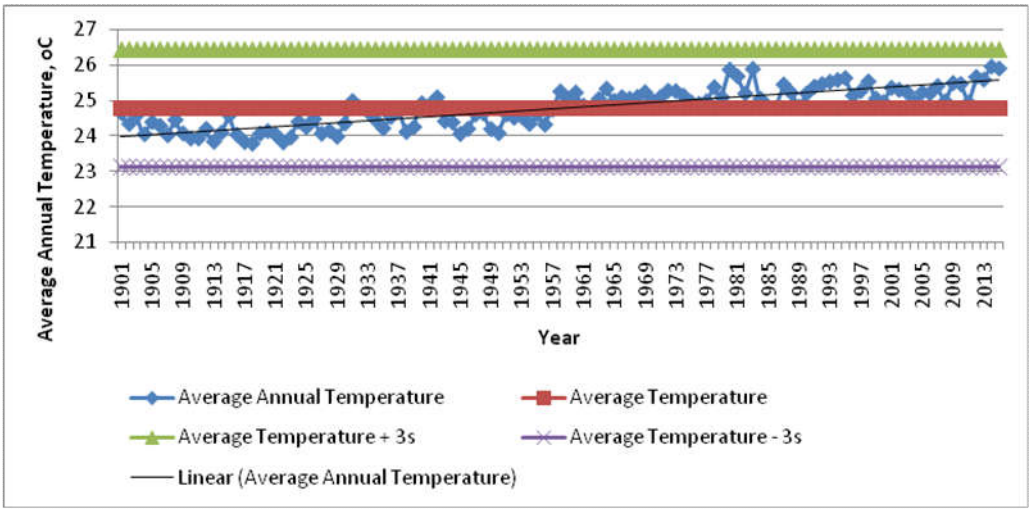

Figure 15. Average Annual Temperature for Puerto Rico (1901 – 2015)

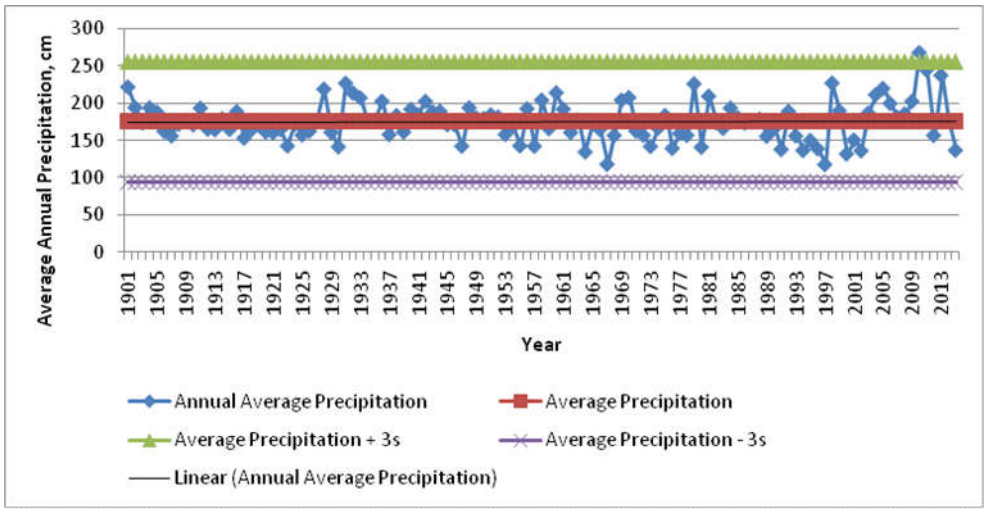

Figure 16. Annual Average Precipitation for Puerto Rico (1901 – 2015)

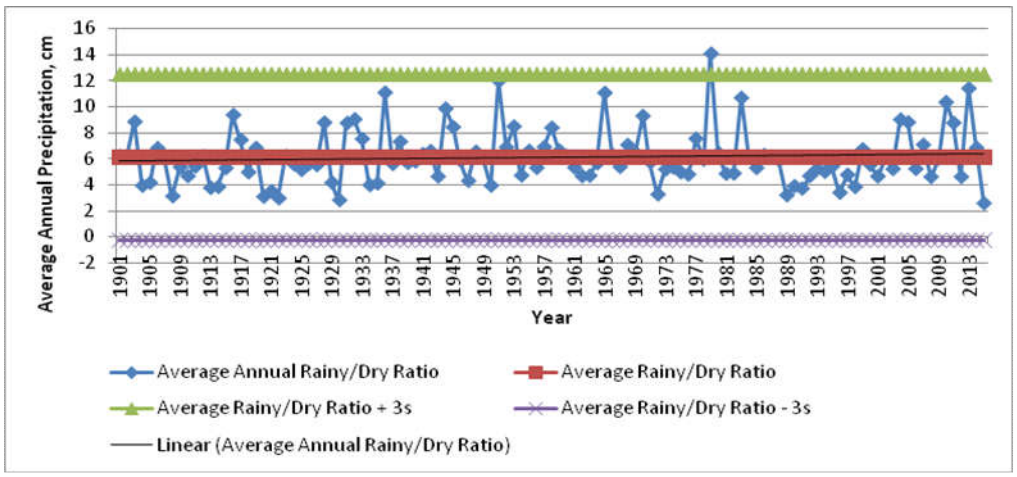

Figure 17. Average Rainy/Dry Precipitation Ratio for Puerto Rico (1901 – 2015)

Average annual precipitation fall within the confidence limits without a particular precipitation trend with time for the 1901 to 2015 study period except for the year 2010. In 2010 average rainfall was higher than the period average. To further study the effect the increasing temperature trend on precipitation pattern we studied if changes in the rainy to dry season precipitation ratios for Puerto Rico. Puerto Rico have a dry season during the months of December thru March, the rainy months are April thru November. Figure 17 shows the rainy to dry precipitation ratios for the 1901 – 2015 study periods. The rainy to dry season precipitation ratio falls within the confidence limits except for the year 1979. During 1979 the rainy season was higher that normal and the dry season were lower than normal. There is a slight increasing trend in rainy/dry precipitation ratio with time. The trend line corresponds to a +0.1 correlation of rainy/dry precipitation ratio with time. This indicates that while the annual precipitation had remained fairly constant there have been shifts in the rain patterns. In order to better visualize temperature increase in the study area with time we have averaged the annual temperatures in twenty year time periods. Table 6 summarizes the results. For the study area there is a positive temperature increase rate and correlation with time. American Samoa, Puerto Rico, and the USVI have the higher temperature increase rate while the temperature increase rate for Hawaii, Guam, and the Mariana Islands is approximately one fifth lower.

Conclusion

The temperature and precipitation trends from 1901 to 2015 for the United States island state and territories were studied. The study area has similar climate and topographic characteristics. The data shows a slight temperature increase with time and a variable increase rate for the study area. The precipitation trend is variable for the study area and ranges from no significant changes in precipitation patterns with time to a slight decrease in precipitation with time. The precipitation ratio between rainy and dry season was also studied and for some of the island studied a shift in precipitation from the rain to dry season was observed.

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