ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.235

Solar energy and weather conditions in the Caribbean

Luz E Torres Molina [1] Ahmad Ali [1]

[1]Department of Civil Engineering Universidad Ana G Méndez, Gurabo, PR, TORRESL6@uagm.edu, ahmadrafiqali33@gmail.com

Abstract*— During the day, the earth's energy budget in tropical countries ensures a positive net radiation throughout the year. Net Radiation is the difference between all the incoming and outgoing Radiation. The geographical location of Puerto Rico is optimal. At the low latitude of the Island, the incoming solar Radiation exceeds the longwave Radiation, and therefore, there is an energy surplus. The energy flows from a low latitude to a higher latitude. The circulation of energy throughout the atmosphere and ocean currents supports the earth's reaching radioactive balance. This makes the earth have proper temperatures according to the location. The main goal of this research is to study the atmospheric factors with energy balance and to determine a correlation with the behavior of atmospheric phenomena during the hurricane season. A connection has been seen between the periods where solar Radiation increases with the surge of atmospheric phenomena. Ten years of data were collected from GOES satellites, meteorological stations, and historical data during the process.

Keywords*— Net radiation, Solar radiation, temperature, Puerto Rico.

I. Introduction

Energy goes back to space from the Earth system in two ways, reflection and emission. Part of the solar energy that comes to Earth is reflected to space in long wavelengths. The Earth's atmospheric system maintains a balance between solar irradiance and reflected radiation (albedo).

The irradiance has a typical peak value of 1000 W/m2 on a Puerto Rico clear day around solar noon. The albedo value depends on factors such as land use, surface type, temperature, local climate conditions, and clouds. Albedo is the solar energy that is reflected in space. Diverse parts of the Earth have different albedos. For example, asphalt has 5-10%, concrete 15-25%, and grass and forest have 10-25%. Asphalt has a lower albedo than forest or grass. Because of this, when cities replace natural vegetation, the area usually increases in temperature. Climatologists call this the effect of urban heat island. Other factors may contribute to urban heat islands, but lower albedo is a significant influence.

Ocean's surface and rain forests have a low albedo, which means that they reflect only a tiny portion of the sun's energy. Over the whole surface of the Earth, only about 30 percent of incoming solar energy is reflected to space. In general, the greater the albedo is, the cooler the surface will be due to the decrease in the amount of absorbed sunlight.

An important fraction of the longwave radiation emitted (albedo) by the surface isn't reflected out to space instead it is absorbed by trace gases in the air, such as carbon dioxide, methane, and other infrared-absorbing gases. This absorption causes it to radiate energy back toward the Earth's surface and heats the air. The energy emitted back to the surface causes it to heat up more, which then results in greater emission from the surface. This heating effect of air on the surface called the atmospheric greenhouse effect.

Throughout the years many scientists have studied this effect, detecting a significant influence with storms developing prematurely, the rapid intensification of hurricanes, and other atmospheric parameters. Recognize that the ocean and air heat is the main power of the development of storms with high winds and great precipitations.

Recently, Hurricane Maria hit Puerto Rico with winds higher than 150 mi/hr and rainfalls over 32 inches in just one day, Figure 1.

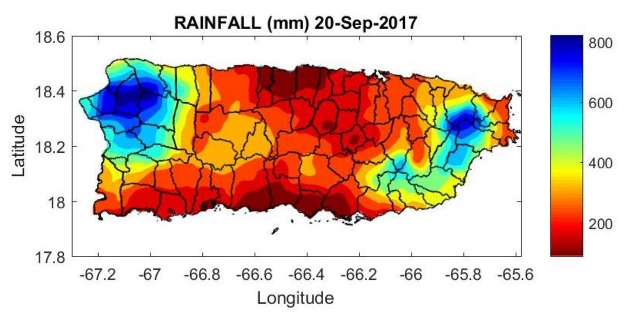

Fig. 1. Rainfall september 20-2017 [1]

For a hurricane to form, two things must be present: a weather disturbance, that pulls in warm surface air from all directions, and water at the ocean's surface that is at least 80° Fahrenheit. Because it is the interaction of warm air and warm seawater that spawns these storms, they form over tropical oceans between about 5 and 20 degrees of latitude. At these latitudes, seawater is hot enough to give the storms strength and the rotation of the Earth makes them spin. Hurricanes start simply with the evaporation of warm seawater, which pumps water into the lower atmosphere. This humid air is then dragged aloft when converging winds collide and turn upwards.

At higher altitudes, water vapor starts to condense into clouds and rain, releasing heat that warms the surrounding air, causing it to rise as well. As the air far above the sea rushes upward, even more warm moist air spirals in from along the surface to replace it. If the base of this weather system remains over warm water and its top is not sheared apart by high-altitude winds, it will strengthen and grow. More and more heat and water will be pumped into the air. The pressure at its core will drop further and further, sucking in wind at ever-increasing speeds.

II. Objective

The primary aim of this research is to meticulously analyze climatological data, encompassing solar radiation, net radiation, temperature, and relative humidity, from 2009 to 2018. The specific focus will be on the crucial months of August and September, which are known for their significant impact on Puerto Rico's climate.

The comprehensive development of this research will involve a meticulous process of collecting, comparing, analyzing, and evaluating the effects of solar radiation and precipitation during the critical months of August and September. It will also aim to identify the correlation between hurricane formation, growth, and strengthening, and the increase in temperature. A decade of data is considered necessary to accurately predict the behavior and tendencies of the climatic components.

Puerto Rico's geographic location is suitable for research studies on solar radiation since the island receives more than 8 hours of solar irradiance throughout the year. However, factors such as excessive population growth, lack of urban planning, changes in land use, and the emission of methane and carbon dioxide contribute to the effect of diffuse radiation, increasing the temperature and causing changes in atmospheric factors, which may only be visualized in decades.

III. Solar Radiation

For this research, satellite data and specialized meteorological equipment were used at two locations: Gurabo and Mayaguez.

GOES-PRWEB provided satellite data, which was diligently collected for every month of each year, spanning from January 2009 to May 2018. Various weather conditions were meticulously analysed for comparison. The specific Atmospheric products to be compared include solar radiation, net radiation, relative humidity, and air temperature.

GOES satellite's visible channel is in orbit, some 40,000 km above the surface of the earth. These data are input into a relatively simple radiative transfer model, which attempts to quantify the partitioning of electromagnetic radiation in the atmosphere. The model, while effective in many ways, does have some limitations. For instance, it ignores the presence of aerosols and makes other simplifying assumptions.

Each pixel has an area of 1,00,000 m2, this could be a source of uncertainty; however, recently the data resolution has been increased to 250 m2. Another possible source of uncertainty is the physical properties of the land surface vary over short distances. For example, soil texture can change significantly over distances of 10 meters. However, the model uses a 1-km pixel resolution, so it can only use one soil texture over the area of the pixel (1,000,000 m2). Soil texture has a direct influence on the soil moisture. In other words, if two soil profiles, with different soil textures have identical amounts of water in them, their volumetric soil moisture content will be different. [2].

Solar radiation is derived from a physical model for estimating incident solar radiation at the surface from GOES satellite data, first proposed by Gautier et al. (1980) [3]. The ground-level, 1-km resolution solar radiation product became available in Puerto Rico in January 2009. Net radiation is estimated from the solar radiation using the method of Allen et al., 1998 [4].

IV. Analysis of Results

The data collected from the satellite provided by GOES-PRWEB began in January 2009 and ended in May 2018. The collected data was placed in two different weather stations, one located in Turabo, with a latitude of 18.23834121 and a longitude of—66.00569546. Figure 2.

Fig. 2. Weather Station Turabo

To use the correct data from the satellite provided by GOES-PRWEB, each latitude and longitude has a specific pixel. Each pixel from the Excel sheet covers an area of 1,000,000 m2. The other station was in Mayaguez with a latitude 18.220191 of and a longitude of -67.145055.

The processing of the data was done by utilizing the operative system Excel, also MATLAB could have been utilized and other programs. Figure 3 demonstrates an example of the selected pixels, to avoid errors the closest pixels to the area of the study were used as well, and an average of the data in the area was calculated, this process was done to the atmospheric products, air temperature, net radiation, and solar radiation.

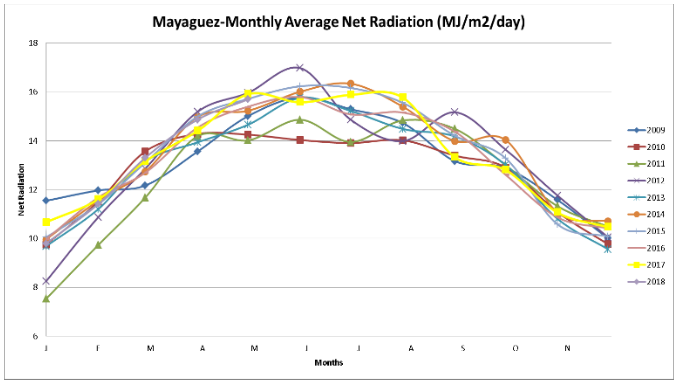

Fig. 3. Example of Data from GOES

After collecting all the needed data, a study and comparing both Stations were analyzed. Also, year by year, specifically for the behavior of the solar radiation, was observed between both stations.

The first step was to find the difference in the annual solar radiation between the two stations, as shown in Figure 4. This figure shows that Turabo has higher solar radiation, which can lead to an increase in air temperatures, as shown in Figure 5.

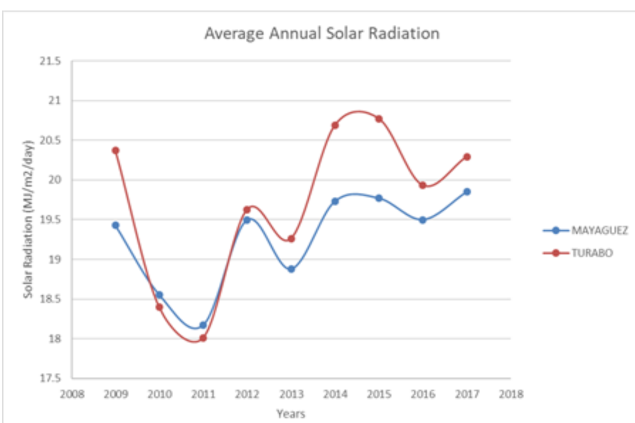

Fig. 4. Solar Radiation in both locations (MJ/m^2/day).

After collecting all the needed data, a study was conducted, and both stations were compared. Also, r by year, the behaviour of solar radiation was studied between two locations (Puerto Rico's west area and Puerto Rico's east area). The image shows a similitude in the behaviour. However, the Turabo station presents greater solar radiation values.

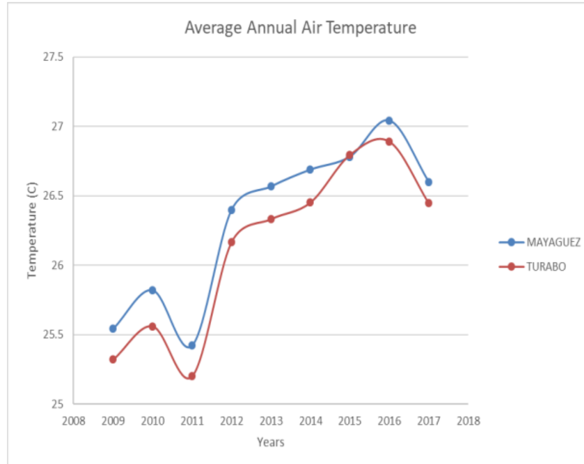

Fig. 5. Average Annual Air Temperature (C).

The causes of this could be the different use of land, constructions, emissions, and less vegetation in the area. This characteristic can result in a lower albedo area, meaning that the reflected solar energy is less, and the earth's surface absorbs more solar energy, which can increase the air temperature.

Another property selected for comparison between the two seasons is relative humidity. The increase in average relative humidity gives rise to a decrease in solar radiation and vice versa. This depicts an inverse relationship between humidity and solar radiation intensity. The result was inversely proportional; as the temperature rises, the relative humidity decreases see Figure 6

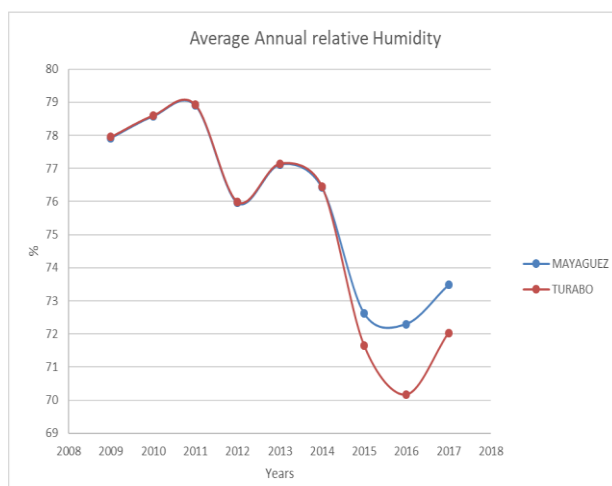

Fig. 6. The Average Annual relative humidity.

Now, observing the behavior of solar radiation from 2009 to 2018, we can see that a similar tendency was found in the western and Eastern stations. The lowest value in solar radiation was obtained in 2011, while the highest value was in 2017. This is also the same year with the highest storm formation. Relating the solar radiation data with the estimated formation of the storms between the years 2011 and 2017, NOAA detected that the most severe activity occurred in 2017 (Figure 7).

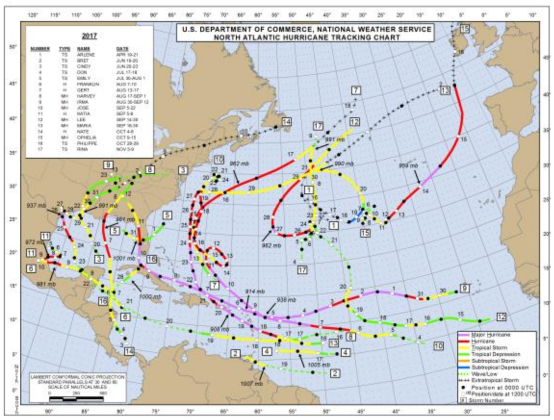

Fig. 7. Atlantic hurrican season 2017.(taken: National Hurrican Center)

On the other hand, when the season of hurricanes 2011 (Figure 8) is observed, the intensity of those phenomena decreases, and the latitudes close to Puerto Rico only reach the level of Tropical storms.

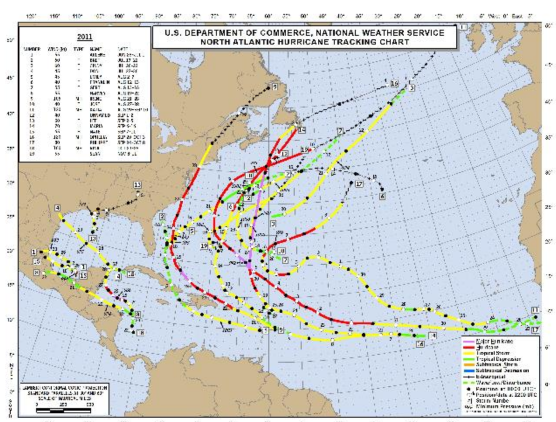

Fig. 8. Atlantic hurrican season 2011. .(taken: National Hurrican Center)

Different researchers utilizing empirical methods have found that the increase in solar activity contributes to warming the ocean's waters and altering the atmospheric circulation [5]. They complicate the role solar variability plays in modulating hurricane activity.

Another atmospheric data that was analysed is the air temperature, which presents a tendency similar to solar radiation. Similar to solar radiation, the same pixels were used for the air temperature to find the needed data for both stations located in the east and west areas of Puerto Rico. As part of this analysis, we can observe that the tendency in Puerto Rico from 2009 to the present is the same. It is possible to see the increment in air temperature. We determined an ascendant slope that almost coincides with both locations. The slopes for the temperatures were 0.19 for the station located in the east (Turabo) and 0.18 for the station located in the west (Mayaguez), as demonstrated in (Figure 9). The difference in the ascendant slopes between the stations was calculated, and the result obtained was a percentage difference of 9.6%.

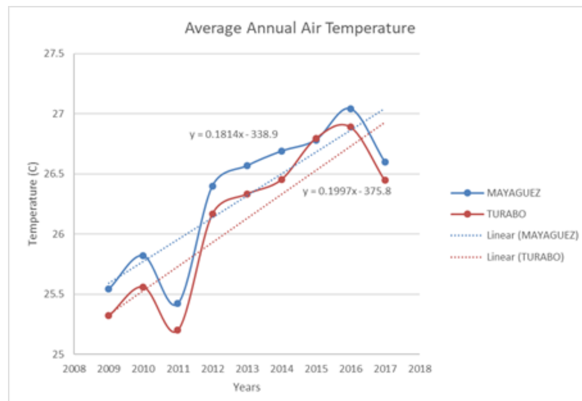

Fig. 9. Behalf of the annual Temperature in both locations (C)

Other atmospheric properties were considered during this investigation. These considerations are Net Radiation, Solar Radiation, and Air Temperature. The data was collected monthly (January to December) for 9 years. Figure 10 shows the conduct of the solar radiation in Mayaguez, and Figure 11 shows the behaviour in the Turabo weather station. Both stations maintain the same behaviour, increasing during June and July and decreasing in the months with lower temperatures (winter).

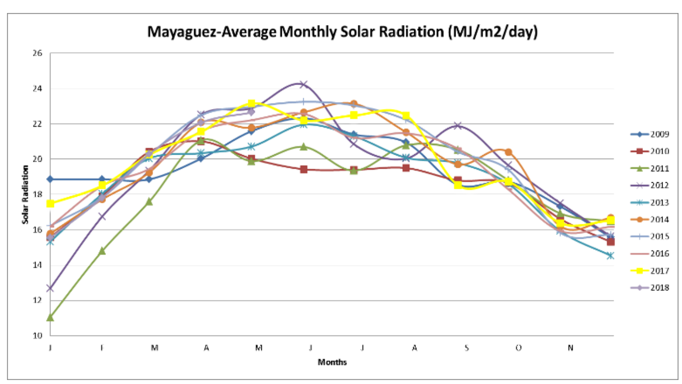

Fig. 10. Solar Radiation Monthly - Mayaguez Station

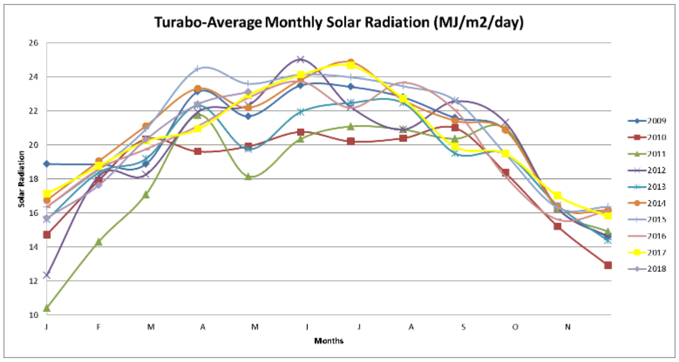

Fig. 11. Solar Radiation Monthly - Turabo Station

It was also observed that in 2011, both stations had the lowest value in solar radiation. The Net radiation was observed to have the same tendency as the solar radiation. Figure 12 presents the net radiation at Mayaguez station and Figure 13 shows the net radiation at Turabo station.

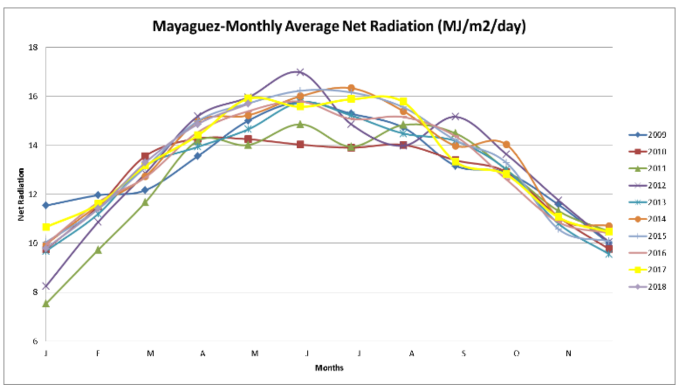

Fig. 12. Net Radiation Monthly - Mayaguez Station

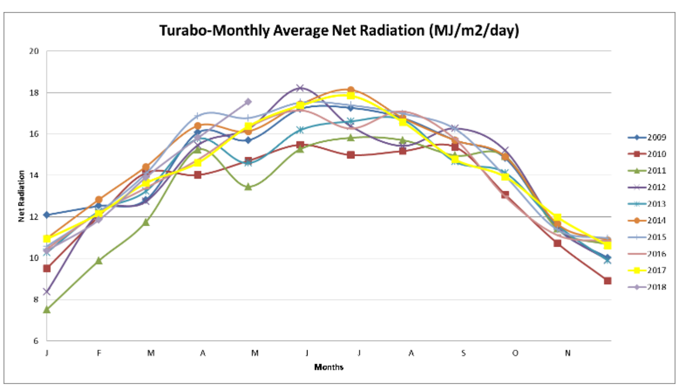

Fig. 13. Net Radiation Monthly - Turabo Station

Also, the air temperature was observed to have the highest values in July and August (Figure 14, Station Mayaguez, and Figure 15, Station Turabo). The data coincides with the hurricane season.

An observation of the behaviour of temperature in the year 2017 shows an absolute fall in September. It could be concluded that this is due to the passing of hurricanes Irma and Maria, which brought winds and precipitations of high magnitudes, decreasing the temperature for prolonged periods.

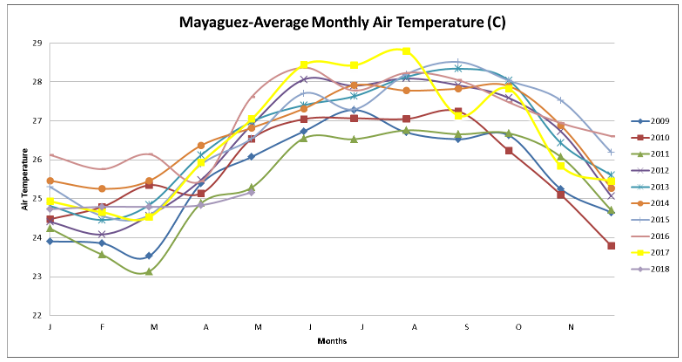

Fig. 14. Air Temperature Monthly - Mayaguez Station

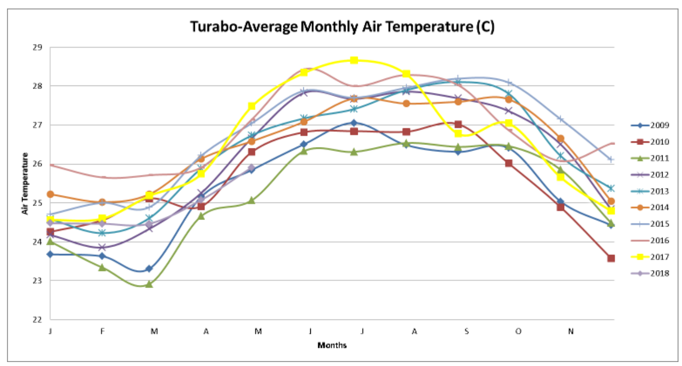

Fig. 15. Air Temperature Monthly - Turabo Station

V. Conclusion

After the analysis of this investigation was done, a possible correlation between the atmospheric data and the formation of natural disasters could be found. The increase in solar radiation throughout the years has led to an increase in air temperature.

Examining the most recent data, it's evident that all the atmospheric variables in this study reach their peak values in the months of June, July, and August, coinciding with the onset of many atmospheric phenomena. For instance, the formation of a hurricane necessitates two key elements: a weather disturbance, which draws in warm surface air from all directions, and ocean surface water that is at least 26°celsius. The consistent surge in solar radiation could be a catalyst for weather disturbances, as solar radiation has a direct correlation with temperature increases.

A map of how solar radiation has changed in Puerto Rico, specifically over the coast, from 2009 to 2017, is appreciable in Figure 16 and Figure 17. The increase of solar radiation over the coast of Puerto Rico can be related to the change in land use, such as constructions close to the coast, which results in changing the albedo.

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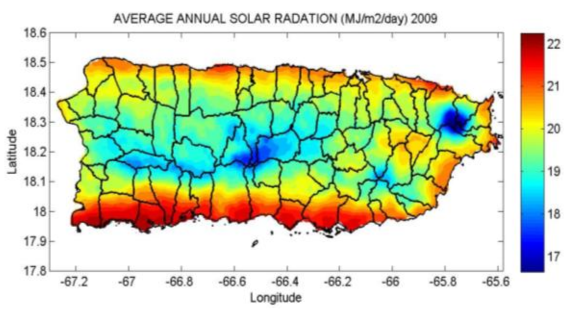

Fig 16. Average annual radiation (2009) (pragwater.com)

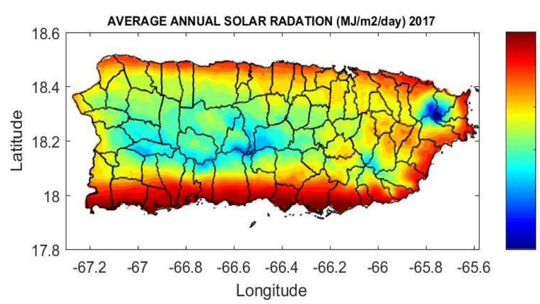

Fig 17. Average annual radiation (2017) (pragwater.com/)

X. References

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