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Trends and Changes of Precipitation in Costa Rica

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Trends and Changes of Precipitation in Costa Rica

A Thesis Presented

by

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Abstract:

Measuring and using precipitation data in Costa Rica is a necessary subject matter when one carries out an experiment in this area, whether it be directly related to rainfall or the effects of it on ecosystems. Using geographical information systems (GIS), precipitation maps of Costa Rica were used and digitized to acquire data on where and in what regions precipitation was commonly found. With this information, we were able to track the dry and wet seasons throughout Costa Rica and determine where the precipitation is more likely to occur during certain times of the year. Additionally, trends between longitude, latitude, and elevation were sought in the areas around the Firestone Center for Restoration Ecology. The results found a huge difference of precipitation between August – October and January – March, as well as trends demonstrating a strong linear relationship between latitude and precipitation. Trends between elevation and longitude showed much weaker linear relationships.

Introduction:

The importance of knowing how much rainfall is going to come and in what areas has been an important part of human history. Our ancestors constructed their villages, towns, and cities around rainy areas to use it for growing crops that would feed their people. During times of drought, famine would occur driving down the population to critical levels. In this time, people would determine where these rainy areas were through observation of the land, such as what plants were able to grow without human interaction. Today, many types of technological equipment is used to tell us how much rain is expected, the probability of rain at certain hours of the day, what areas will experience the rain, and even how big the raindrops will be (Campos 2006). This information can be used in a variety of ways to benefit rainy countries such as Costa Rica. By better understanding when the "wet" and "dry" seasons occur and approximately how much rain comes, Costa Rica can get better flood warnings, know if the amount of rain will sufficiently water crops, what locations are best for research needing precipitation, planning for future buildings in the Firestone Center for Restoration Ecology (FCRE), and what time of year is best to conduct further research.

Overall, there is evidence that rainfall/precipitation has been decreasing globally due to "changes in regional land-cover and global climate" (Guswa 2007). By being able to better calculate the decrease in precipitation; one could use this information to predict how it would impact areas where they expect to have an abundance of yearly rain. An example of this would be the agricultural effects that could occur in Costa Rica with less rainfall. About 10% of Costa Rica is used for agricultural purposes and makes up 60% of export flows, not including free zone companies (Agriculture — Costa Rica Information). The biggest agricultural good that comes from Costa Rica is coffee, which makes up "14% of total agricultural export revenue" (Blackman 2012) and needs a significant amount of water to grow and process for export. It was calculated that 140 liters of water is needed to make 1 cup of coffee (Campbell 2008), although the coffee plant does give some water back to the environment, demonstrates why it is crucial to predict the amount of rainfall coming in during the year. If rainfall took a significant decline, products like coffee would be difficult to produce; hence, taking a huge blow to the economy of Costa Rica. With better approximations of rainfall during the "dry" season, one could better prepare a country for economic impacts by rationing how much water is needed and if a separate option should be considered to ensure the safety of Costa Rica's economy.

Having a better understanding of the amount of rain that can occur during the "wet" and "dry" seasons can be beneficial for more than economic purposes. Flood safety is one example of this, which is an important issue in Costa Rica. Floods are not atypical in Costa Rica and have caused damage earlier this year in July (Davies 2015) which forced about 1000 people to evacuate. Flooding in Costa Rica happens for a variety of reasons and is more likely to occur now due to deforestation (Bathurst 2011) because forests would have been able to reduce the amount of water built up on the ground. This has been a topic of interest, especially in Costa Rica, since they have experienced large amounts of deforestation, hitting its highest peak in 1960 - 1970 (Rosero-Bixby 1996). This could be the cause for the floods that have happened in the recent past. If there was more land cover in the area then the chance of there being a flood would be reduced in "more frequent, less intensive rainstorms" (Bathurst 2011). Areas like Costa Rica who are prone to floods need to have "accurate quantitative rainfall prediction" to determine the likelihood of heavy rain causing a flood, (Altunkaynak 2015) something that this analyzation of rainfall in certain seasons found. By analyzing rainfall trends, Costa Rica can further predict when the floods are most likely to happen and take precautionary measures to contain and minimize the damage that they can cause.

Other research is possible to do with better calculation of the rainfall in Costa Rica. The Firestone Center for Restoration Ecology (FCRE) is where many of these research opportunities take place (Firestone Center for Restoration Ecology) and has been under the management of Pitzer College since 2005 and for undergraduate research opportunities (Firestone Center for Restoration Ecology). Many students from Claremont McKenna, Pitzer, and Scripps College have conducted numerous experiments here throughout the years. With the use of rainfall data to their advantage, future groups will be able to pick the best time of year to travel to Costa Rica given the criteria of their experiment. An example of this would be a research experiment that looked at rainfall interception in the rain forest of Costa Rica (Holscher 2004). The rainfall was measured for 48 weeks and was taken weekly during the months of the “dry” season. Perhaps if they had more qualitative data, they would have been able to go during the rainy (wet) season and collect a wider range of data (Holscher 2004). This experiment’s data showed that mosses and epiphytes contributed to 6% of rainfall interception, giving more insight into the importance of precipitation and the relation to the land. Other research experiments include the one described earlier that calculated the distribution of raindrop size in Costa Rica (Campos 2006). The benefit of having this type of distribution can be valuable information when it comes to erosion data and how fast its effects will show on the land. By using regional precipitation data with the combination of raindrop sizes, Costa Rica can take protective measures for landslides and other dangers from erosion.

To acquire and conceptualize the rainfall data, people used geographic information systems (GIS) to conduct this study. GIS has been used to accomplish other studies in Costa Rica and all over the world. One such study that took place in Costa Rica looked at deforestation sites and identified them using geographic information systems (Van Laake 2004). By being able to identify these areas with overview maps of the area from 1986 and 1997, the researchers were able to make an accurate comparison and get results at a fast rate. On top of this, the researchers did not have to actually be present in Costa Rica to identify the regions that are considered deforestation sites first hand and had a much easier time using GIS technology. Similarly, this study looked at precipitation data, from maps, which ranged from 1961 to 1980. This allowed for accurate collection of data from all across Costa Rica through a time period of about 20 years, giving us a broad range to make comparisons.

Methods:

Digitizing

To begin the process of acquiring data, monthly precipitation maps from the years between 1961 and 1980 were attained. These maps came from the Ministerio de Agricultura y Ganaderia (Ministry of Agriculture and Livestock) (Art 1985), which were then digitized. To do so, the maps were scanned to produce a “TIFF” image which could be used in the GIS computer program (Figure 1). After doing this, the “TIFF” image was uploaded into our GIS computer program to have as a reference.

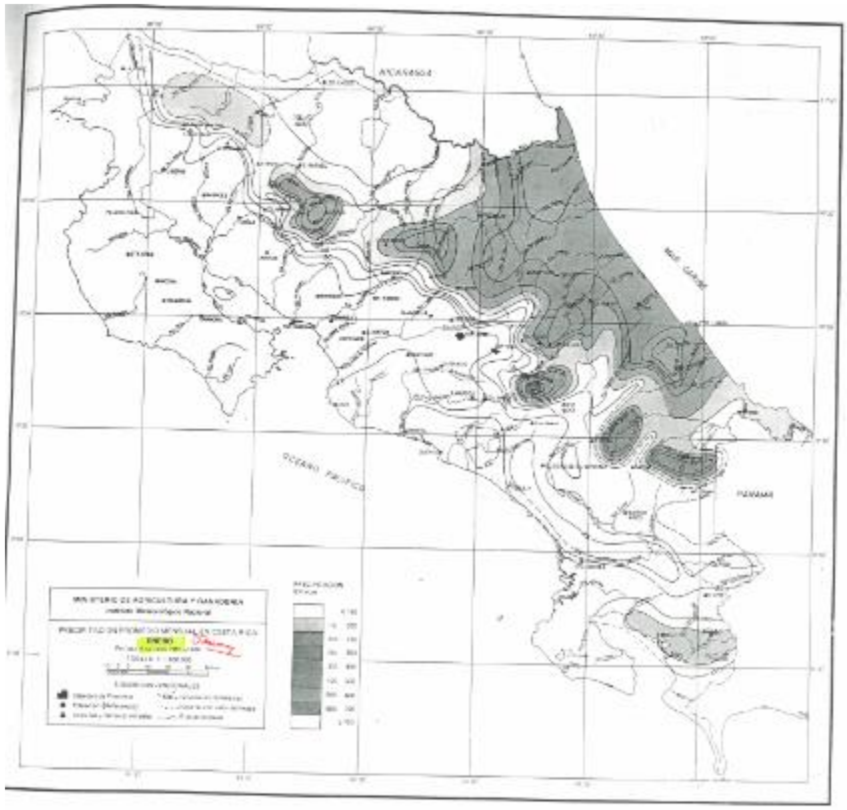


Figure 1. TIFF image of Costa Rica's average precipitation zones in January 1961-1980 (Art 1985).

At this point, a reference of Costa Rica's borders was needed. This was found as a "shapefile" on the ArcGIS website. After obtaining Costa Rica's boundary it had to be buffered to make a better fitting boundary that would fit the "TIFF" image. Additionally, the previous districts that were displayed on the inside of the "shapefile" had to be removed to have a simple shell of Costa Rica's boundaries. With both files uploaded to the computer program; data could then be obtained.

Creating precipitation regions

First the two files had to be bound together to have the borders of the "TIFF" image and the boundary of Costa Rica superimposed on each other. To do so, control points had to be assigned to the ends of both images to lock the boundary of Costa Rica around the precipitation map. As soon as this was done, the “shapefile” had to be broken down into multiple polygons that represented the different precipitation regions on the “TIFF” image that was below it (Figure 2). Each polygon that was created on the “shapefile” was given the value that appeared on the original map. To further differentiate the regions, a different color scheme was used where areas of higher precipitation had a dark shade of blue while lower precipitation regions had a lighter shade of blue (Figure 2). This was repeated for all the maps to get a visual comparison of all the months throughout the year.

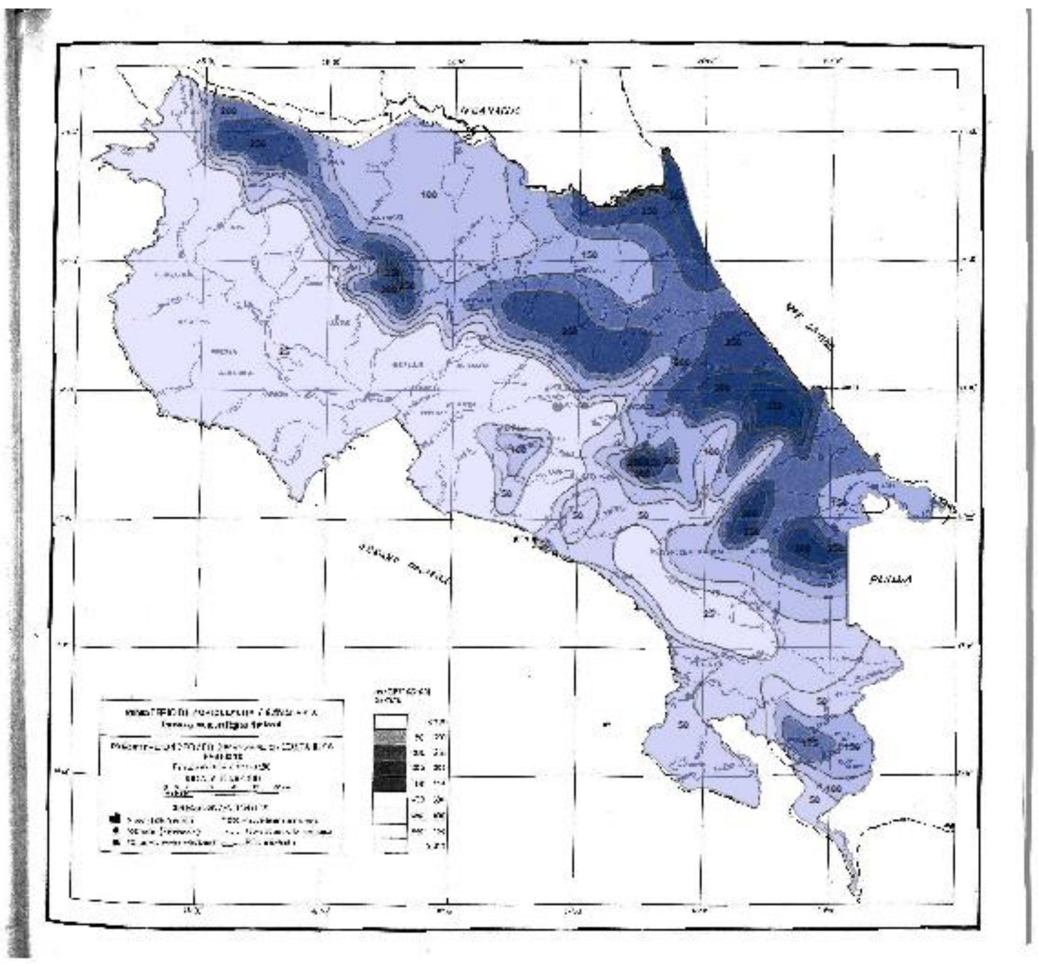


Figure 2. Superimposed image of completed “shapefile” on “TIFF” image of Costa Rica’s precipitation in February 1961-1980 (Art 1985).

Individual Data

Now that all the maps with the regions of precipitation were completed, individual point values had to be created to do statistical analysis. To accomplish this, the toolbox had to be used which would take the multiple polygons and convert them in point values on the map (Figure 3). Deciding how larger and what shape these point values should take was up for debate, but the conclusion was to use a hexagonal grid because it would better fit a map and more accurately differentiate the boundaries between regions than a square grid. For the size of the hexagons, a size of 10 km^2 was chosen because there would not be a huge change in precipitation between two points (Figure 4). This gave us about 5,000 data points, which makes sense since Costa Rica's surface area is about 50,000 km^2.

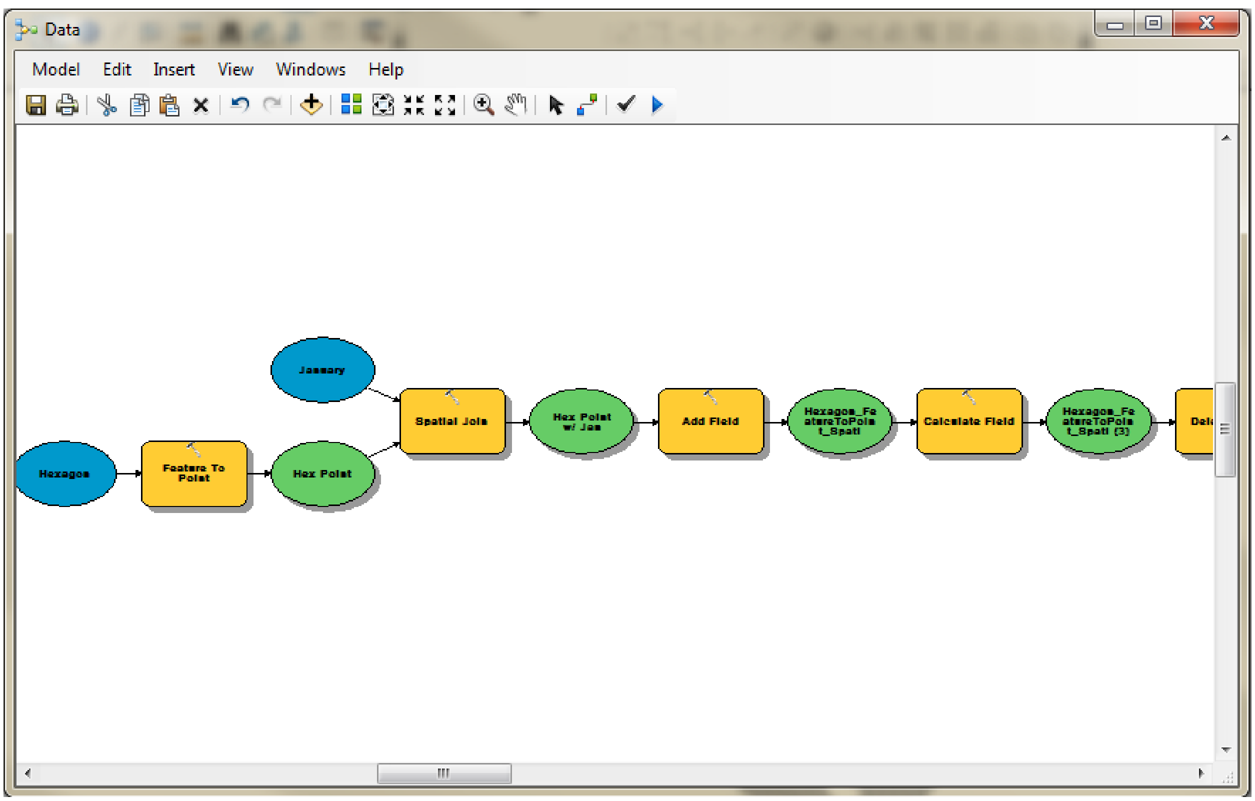


Figure 3. Zoom in of the toolbox model used to create the hexagon grid and give them the value of the polygon they reside in.

Figure 4. 10 km^2 hexagonal regions where the points represent the value of precipitation in the area.

Additional Data

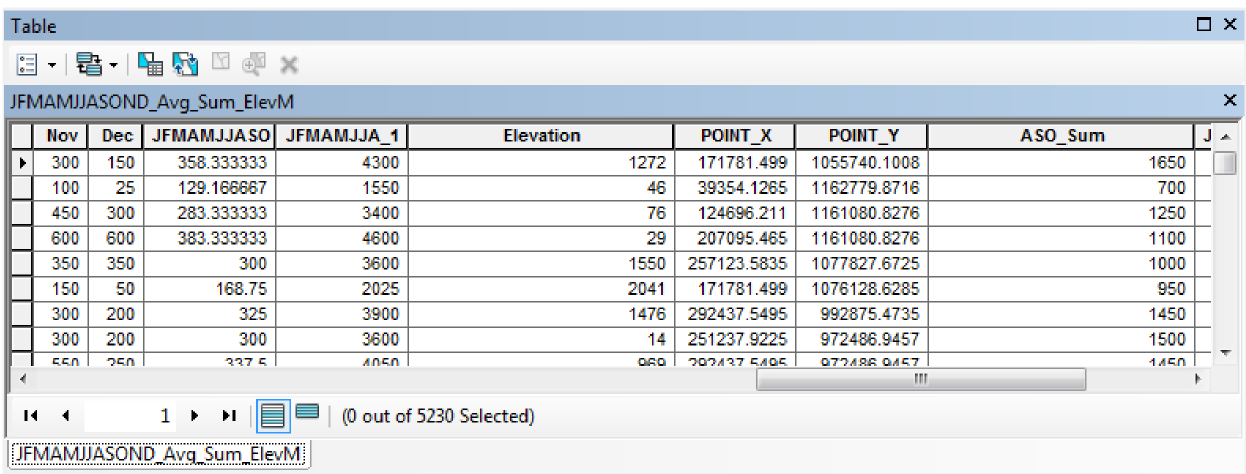
After being able to construct an immense amount of data from the "Atlas Climatologico De Costa Rica" maps, more commonly known data had to be added. One such example is elevation, which could show if precipitation is likely to be at higher and lower altitudes. This information was also found on the ArcGIS website that included the different elevations throughout the country of Costa Rica, and included a black and white image depicting mountainous areas (Figure 5) and where the higher elevation values will go. This data was added to the precipitation data and sorted according to the 10 km^2 point regions, which helped distinguish which area corresponded with what elevation.

Figure 5. Hill shade image of the elevation regions in Costa Rica.

To make further comparisons, location data was also sought out. Latitude and longitude data was the initial search criteria, but there was too small of a change with this scale to evaluate the 10 km^2 regions of the precipitation. Therefore, an Universal Transverse Mercator (UTM) corrdinate system was used in its place to determine the distance of Costa Rica, using meters, instead of longitude and latitude. This was already included with the "shapefile" of Costa Rica's district map that was used as the boundary to depict Costa Rica in

GIS. However, this data had to be added to the attribution table, much like the elevation data had to be added. To do this, a data management tool was used to convert the data on the map to the attribution table and have it correlate to the precipitation regions and the elevation data.

With all of this data combined into one attribution table (Figure 6), it was ready to be analyzed. To do this, a conversion tool was needed to be found in our ArcMap file. The tool used was named “Table to Excel (Conversion) (Tool)” that allowed for the attribution table to be added to an excel file, where statistical analysis could be done.



Nov	Dec	JFMAMJJASO	JFMAMJJA_1	Elevation	POINT_X	POINT_Y	ASO_Sum
300	150	358.333333	4300	1272	171781.499	1055740.1008	1650
100	25	129.166667	1550	46	39354.1265	1162779.8716	700
450	300	283.333333	3400	76	124696.211	1161080.8276	1250
600	600	383.333333	4600	29	207095.465	1161080.8276	1100
350	350	300	3600	1550	257123.5835	1077827.6725	1000
150	50	168.75	2025	2041	171781.499	1076128.6285	950
300	200	325	3900	1476	292437.5495	992875.4735	1450
300	200	300	3600	14	251237.9225	972486.9457	1500
550	250	337.5	4050	969	292437.5495	972486.9457	1450

Figure 6. Attribution table with precipitation, elevation, and UTM coordinate data.

Results:

Wet and Dry Seasons

Pinpointing the wet and dry seasons was one of the most anticipated results. Using the maps that were acquired from 1961 - 1980 of precipitation data, it showed that the driest periods of the year were January, February, and March having an average of 132, 105, and 92 mm of rain respectively. This is compared to the wet months which are August, September, and October with an average of 384, 404, and 423 mm of rain respectively. This can be seen visually on the graph of average precipitation (Figure 7). The average of the precipitation was taken from each month and plotted next to each other to find the wet and dry seasons. These averages were seen to be significantly different from one another (ANOVA, $p < 0.01$, $F = 12351.47$, $df = 3$) giving us the time frame of when the dry period begins and when it ends.

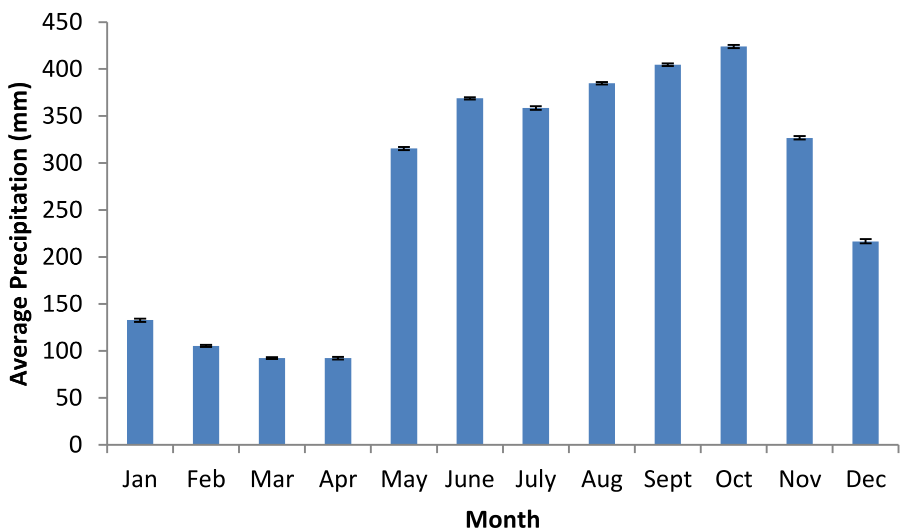


Figure 7. Average precipitation per month during the years 1961 - 1980 (mean $\pm$ SE; n = 5230).

References were made with data collected from a field station in Hacienda Baru that collected precipitation data from 1981 to 2014. This data was used to determine if the trend of rainfall continued like it did in our analysis, and as a reference to see if there was any dramatic change. When the data was analyzed, a similar graph appeared that demonstrates a dry early part of the year and a wet season in August, September, and October (Figure 8). Again, there was a significant difference between the wet and dry periods (ANOVA, $p < 0.01$, $F = 148.78$, $df = 4$) and no significant difference between the months of the dry period

(ANOVA, $p = 0.293$, $F = 1.24$, $df = 2$). There was a significant difference between the wet season (ANOVA, $p = 0.012$, $F = 4.56$, $df = 2$); however, since these three months had the highest average precipitation, they are still considered to be the wet season in Costa Rica, despite there being a difference between the months.

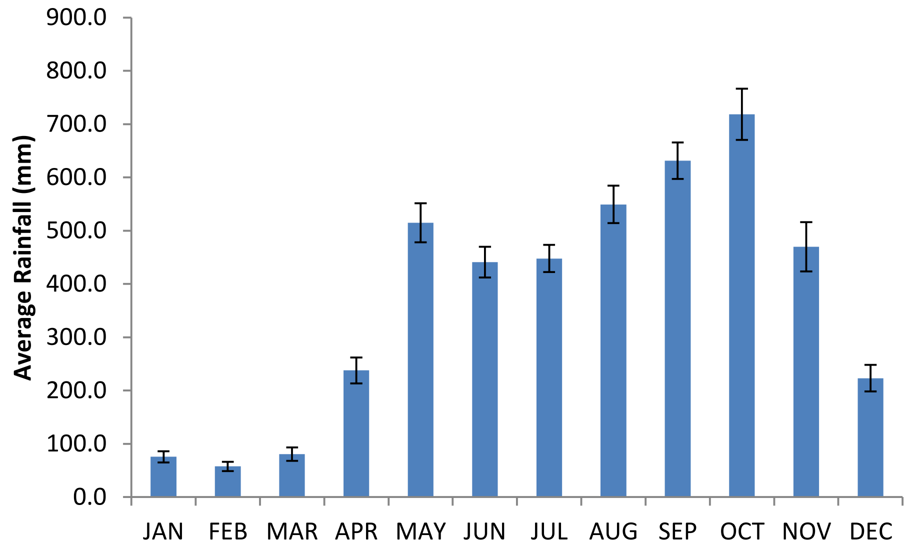


Figure 8. Average precipitation per month from Hacienda Baru, during the years 1981 – 2014 (mean $\pm$ SE; n = 38).

The times of dry and wet seasons were an important distinction that needed to be done, but the difference in rainfall had to be further illustrated. This was done by making classes that represented the total rain averages in certain areas in Costa Rica. Each 10 km^2 region was then placed into its appropriate category of how much average rain it reported throughout the 20 year period. This was done for both the dry and wet periods and evaluated side by side to see the drastic difference of how much rain is seen in these two different periods. The analysis done showed that the dry period had over 1800 areas that reported having 50 mm of rain (Figure 9) or less in this time frame. Given that each area is 10 km^2, the results determine that 18000 square kilometers of Costa Rica get less than 50 mm of rain in the dry season. This was compared to the wet season whose lowest recorded rainfall in 510 square kilometers (51 data points) was 200 mm (Figure 10). For a better comparison, the wet season reported 1250 areas where the average precipitation was between 401 and 450 mm of rain, which was the highest average rain found in the dry period. This demonstrates the enormous difference in rain throughout Costa Rica during these two time periods.

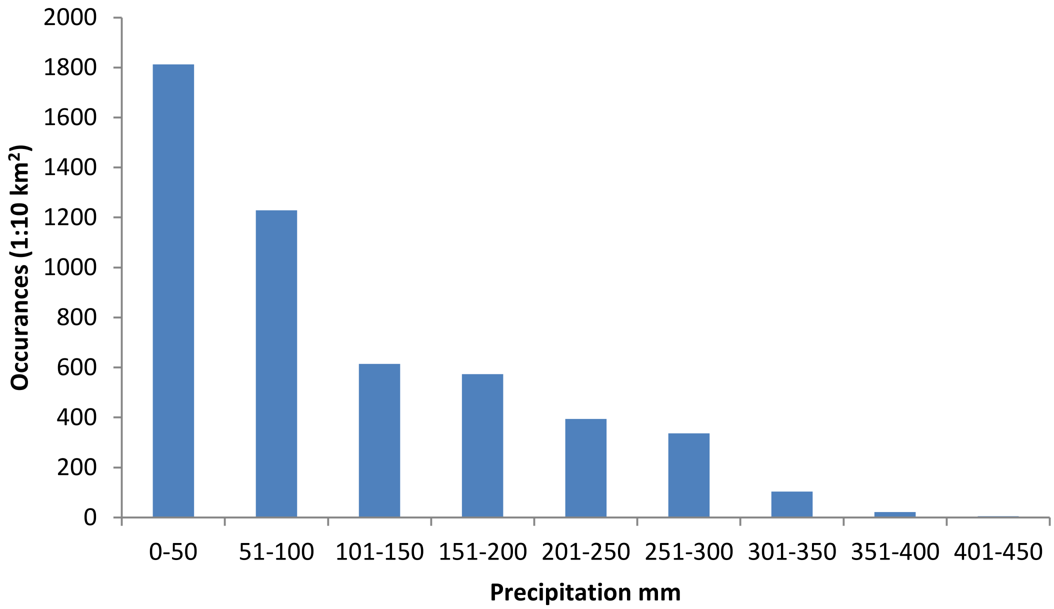


Figure 9. Count of 10 km^2 areas and the average amount of precipitation they received in the years between 1961 and 1980 during the dry period (January - March).

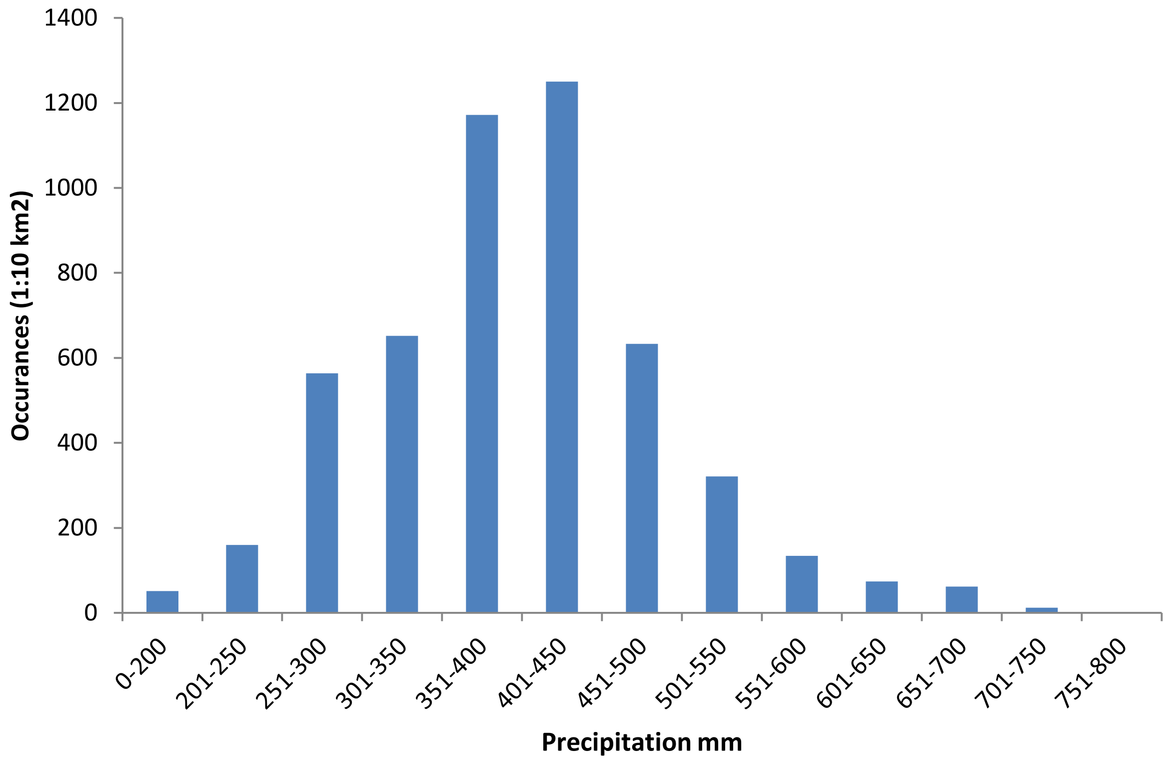


Figure 10. Count of 10 km^2 areas and the average amount of precipitation they received in the years between 1961 and 1980 during the wet season (August – October).

The final question that was asked was whether or not there was a bigger difference in rainfall in certain regions across Costa Rica between the dry and wet seasons. To answer this, the precipitation of January, February and March was averaged, as well as the average rainfall of August, September and October in two separate maps. These were then subtracted from each other to see an image of Costa Rica with the change in average rainfall shown in different regions (Figure 11). This map shows one region on the east side of Costa Rica (lightest blue) that has a drop in precipitation, by about 116 mm, during the wet season. However, other than this region, the majority of the map shows an increase of rainfall, up to about 666 mm of rain, in the darkest regions. This map visually demonstrates how much more rain Costa Rica experiences in the wet season and what areas experience an abundant increase of rain.

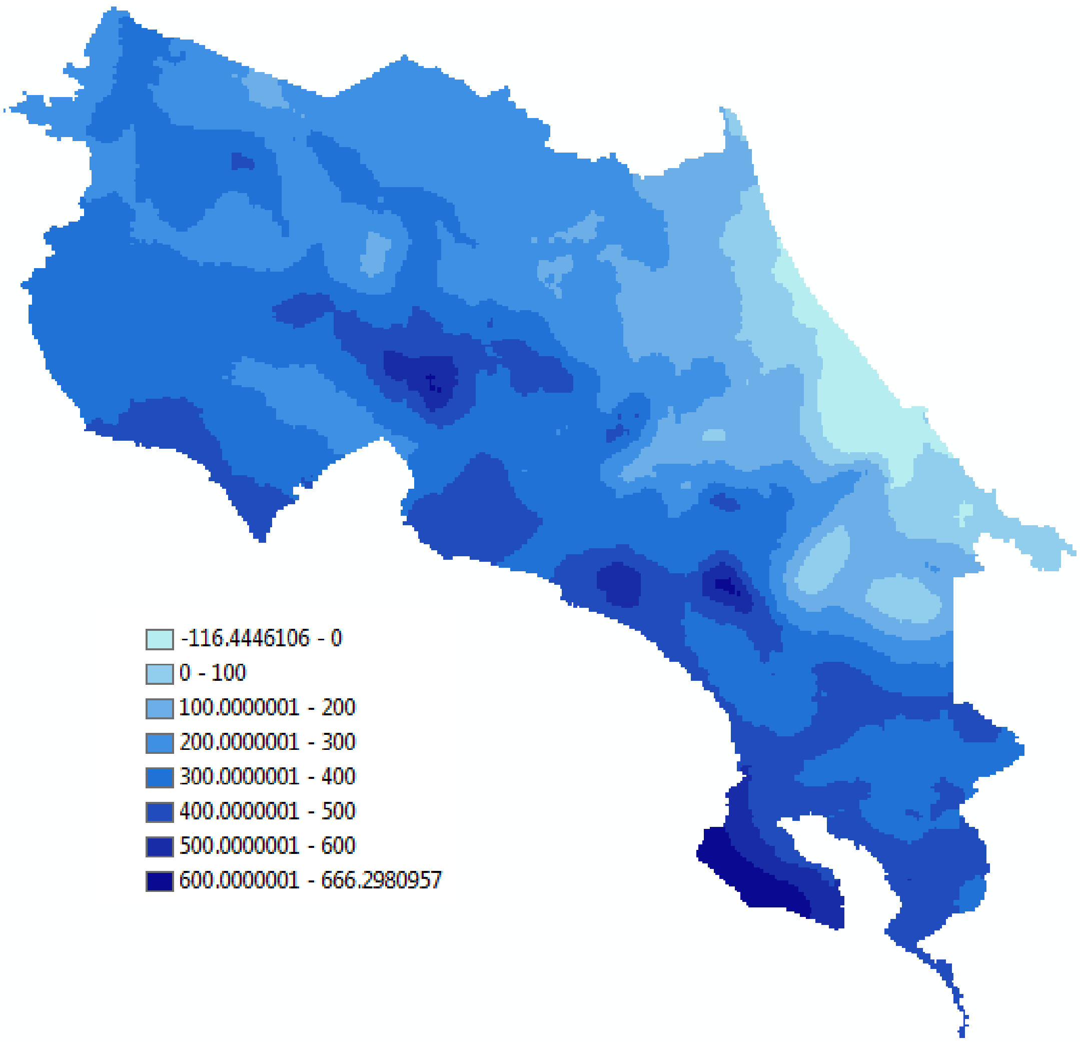


Figure 11. Difference in average rainfall between the dry and wet seasons. Wet season minus the dry season (mm) 1961 - 1980.

Relationships with Latitude and Longitude

The previous data analysis consisted of the total country of Costa Rica. When it comes to different trends, such as relationships with altitude, latitude, and longitude, the focus was in the area around Dominical, where the FCRE station is located (Figure 12).

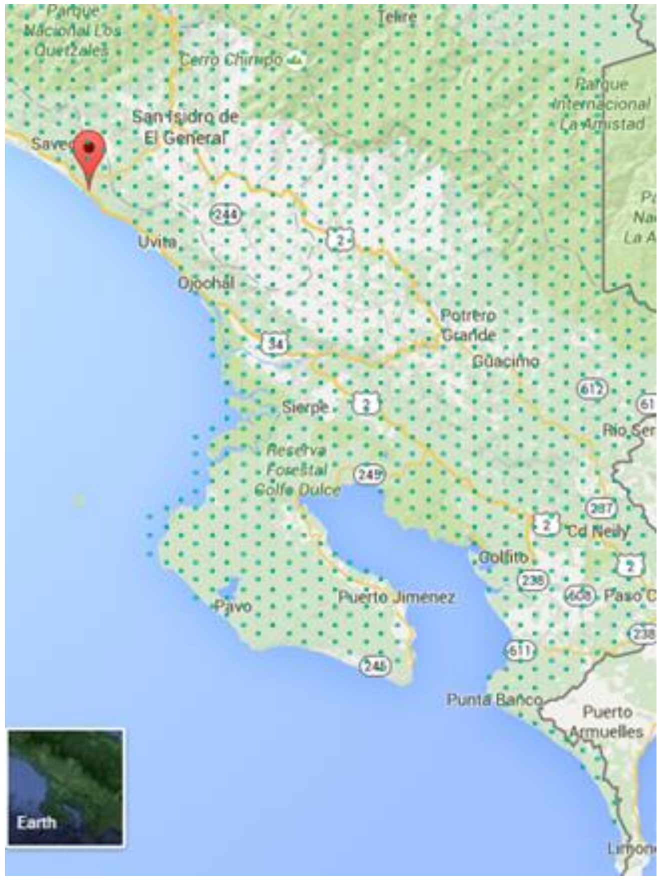


Figure 12. Precipitation data superimposed on Dominical, Costa Rica.

It would make little sense to calculate the relationship of precipitation and longitude of the whole country because it contains different geographical regions; therefore, a smaller region was used that contained Dominical (furthest West), the FCRE center, and Cerro Chirripó (furthest East). This was accomplished by taking precipitation data with the same longitude and averaging them to represent that area. The higher the number of the classes (x-axis), the further East the rainfall was calculated (Figure 13). As we see on the graph, there is a slightly negative trend of rainfall the further East one goes, but the linear relationship is poor according to the "r^2" value of 0.078. These values were seen to be significantly different

(ANOVA, p < 0.01, F = 4.37, df = 22) although the relationship between longitude and precipitation is poor.

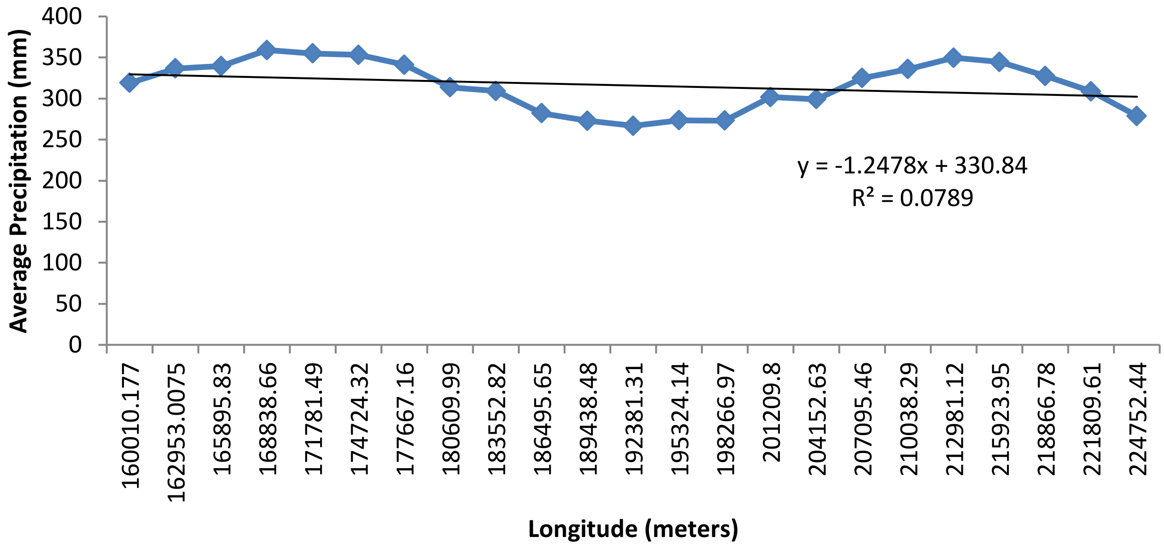


Figure 13. Average precipitation in millimeters across longitude of Costa Rica from Dominical to Cerro Chirripó (from West to East). Every class represents about 3000 meters or 3 kilometers. UTM coordinates. 1961 – 1980 (n = 227).

The same type of experiment was done with the latitude of this region in Costa Rica to determine if there was a significant change of rainfall from the Northern section to the Southern section. As we see from the analysis (Figure 14), a perpetual increase of rainfall is shown the further North one goes. According to the regression formula, an increase of 11.895 millimeters of rain is seen to happen every 3.5 kilometers. The regression line has an "r^2" value of 0.904, which means that a linear relationship this is a good predictor to determining the rainfall at different latitudes. This was determined to be a significant difference (ANOVA, p < 0.01, F = 4.16, df = 9), concluding that there is a strong linear relationship with latitude and precipitation in this area of Costa Rica.

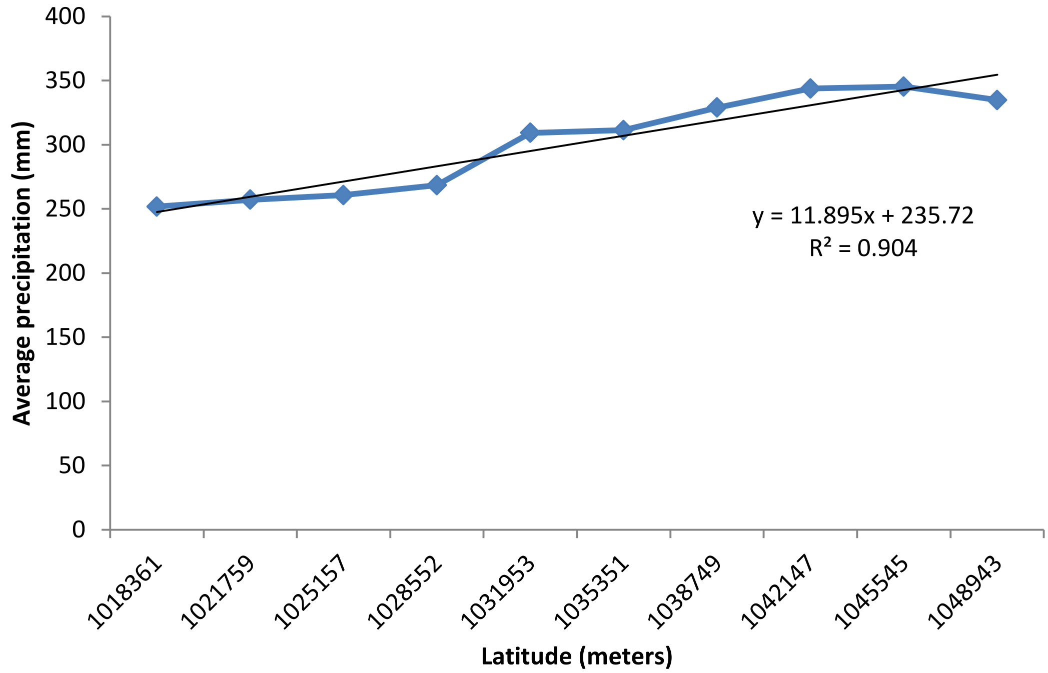


Figure 14. Average precipitation in millimeters across latitude of Dominical, Costa Rica (from South to North).Every class represents 3500 meters or 3.5 kilometers. UTM coordinates. 1961 – 1980 (n = 94).

Relationship with Elevation

It was thought that there would be a profound trend with precipitation and elevation from Dominical to Cerro Chirripó. A similar concept was used as the relationships between rainfall and longitude/latitude, but instead of taking averages, the data points from Dominical to Cerro Chirripó were individually recorded, from the superimposed map of Costa Rica on the data points. The elevation data starts at 0 meters (Dominical) and goes all the way to 3580 meters (Cerro Chirripó). When the precipitation data was calculated, there seemed to be a positive trend with more precipitation as the elevation increase; however, the precipitation began to decrease at around 1906 meters in altitude and hits a low of 254 mm of rain at the 3580 meters in altitude (Figure 15). The "r^2" value tells us that the linear regression formula is a poor fit to predict precipitation at different altitudes. Additionally, these values were not significantly different (ANOVA, $p = 0.055$, $F = 1.721$, $df = 14$), determining that there is no linear relationship between rainfall and elevation.

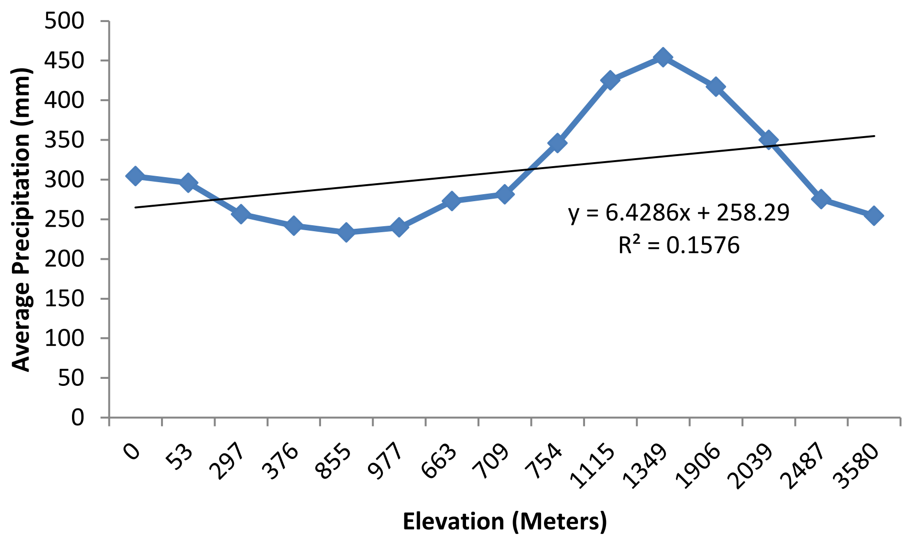


Figure 15. Average precipitation measured against elevation; from Dominical to Cerro Chirripó. 1961 – 1980 (n = 14).

Discussion:

This study was able to identify some of its preliminary questions about the rainfall in Costa Rica. Primarily, the results from the comparison of dry and wet seasons showed that there was in a huge difference between the two time periods (Figures 7 and 8). This data also allowed for the viewer to see at what point the wet season was beginning (August) and at what month the rain begins to decrease (December), ending the wet period. The ANOVA testing determined that there was a significant difference between the two seasons, showing that the amount of rain did in fact have a dramatic change around the middle of the year.

To further display the difference between the two seasons, GIS was used to produce a map of Costa Rica that displayed the precipitation regions of the dry season (January, February, and March) subtracted from the wet season (August, September, and October) (Figure 11). To our expectations, the map showed that the majority of Costa Rica experienced a dynamic increase in rainfall during the wet season up to about 666 mm more during the respected time frame. What was interesting from this map was that there were more regions than expected that had more precipitation in the dry period than in the wet period. Even more fascinating was that this happened in the eastern areas near the Caribbean where one would expect to see more rain than the western regions of Costa Rica. The information gathered from this part of the analysis could be used to warn and better prepare the areas that have substantial increases in precipitation about flood and landslide risk during the season. One problem with this analysis was with the large amount of observations (over 5000) that would make just about any data set have significant results.

To counter act this problem, the Hacienda Baru data was used to see if a similar trend occurred with years past 1980. Since this data set was much smaller, the ANOVA results would determine if there really was a significant difference between the wet and dry season. This data set showed a very similar trend, where the lowest precipitation happened at the beginning of the year and the highest amount of rain was found between August and October (Figure 8). The results showed that there was in fact a significant difference between the two periods, validating our previous results. Additionally, this analysis determined that the same trend of rainfall has continued for another 34 years.

Questions arose if there was a relationship with precipitation and where in Costa Rica one was located. To test this out, the average precipitation towards given longitudes was taken and graphed out (Figure 13). The results from this section showed a decrease in rain as one went from west to east in the specific region, but the results were inconclusive, determining that there was no linear trend between altitude and precipitation.

To fully answer the inquiry of relationships with rain and location in Costa Rica, the same type of analysis was done, but with latitude (Figure 14). In this case, the amount of precipitation was seen to increase as one went from the southern regions to the northern regions of the FCRE. The regression formula for this demonstrated that there was an increase of 11.8 mm of rain for every 3.5 km north one went on average. The "r^2" value was at a high of 0.904, making the regression line a good fit for the data, and the ANOVA analysis proved that this was significant.

Finally, precipitation was compared to the different elevations found throughout Costa Rica. A very similar approach was taken as with the comparisons to latitude and longitude, but instead of taking the region's average precipitation in various locations, a direct path was followed from Dominical (sea-level) to Cerro Chirripó (Figure 15). This analysis showed that there was no significant linear trend of precipitation from a low altitude to a high altitude in this section of Costa Rica. This was proved by the poor "r^2" value and by the ANOVA results.

All of these results can be used in further research where one would need to have a high or low amount of rainfall for their research. This can also be used to plan agricultural fields in better locations to maximize the amount of rain their crops will receive. For the FCRE center, this analysis can be used to carry out research at better parts of the month to prevent dangerous environments due to the rain or to account for different species being present in certain locations.

Acknowledgements:

I would like to thank Dr. McFarlane for guiding me and for providing the necessary information needed to carry out this long analysis. Secondly, I want to thank Warren Roberts for being my second reader and for spending countless hours helping me digitize the precipitation data as well as helping create the GIS maps that held all the data. Finally, I cannot thank my friends and family enough for helping me through my college experience and for all the memories we made together.

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