Observing and Analyzing Variations of Daily Precipitation: The Impact of the El Niño/Southern Oscillation on Kiritimati Island

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SOARS® Summer 2017

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10 August 2017

Abstract:

In 2016, a very strong El Niño increased the amount of precipitation measured on Kiritimati Island (2 °N, 157.4 °W) during the El Niño Rapid Response (ENRR) field campaign. ENRR collected surface meteorological data from January–March 2016. This project focuses on daily precipitation data collected from 1971–2016 during the time of year when ENRR took place, and evaluates how the El Niño/Southern Oscillation (ENSO) influences the daily rainfall distribution on Kiritimati Island. We analyzed daily rainfall measurements from the automated weather station at the ENRR campaign site, and the official Kiribati Meteorological Service station (PLCH). The long-term data from PLCH (1971–1990, 1996–2003, and 2015–2016) provides a historical context which supports the study of the historical distribution of daily rainfall. We investigated the distribution of daily rainfall on the island during different phases of the ENSO phenomena and found the range of daily rainfall amounts increased as did the likelihood of rain in most rain-rate categories during the El Niño phase, compared to the neutral phase; and La Niña phase had higher probabilities of very little rainfall, narrower ranges of rainfall amounts, and reduced probability of high daily rainfall amount over the island. The daily rainfall collected at the ENRR compaign site matches the general aspects of the El Niño pattern obtained from the PLCH records. Our results provide useful reference for water resource management on the island and evaluation of ENSO impact on daily rainfall in different products of observational analysis and climate model simulations.

This work was performed under the auspices of the Significant Opportunities in Atmospheric Research and Science Program. SOARS is managed by the University Corporation for Atmospheric Research and is funded by the National Science Foundation, the National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration, the Woods Hole Oceanographic Institute, the Constellation Observing System for Meteorology, Ionosphere, and Climate and the University of Colorado at Boulder.

1. Introduction

Global-scale winds play a large part in how weather conditions, including precipitation, are geographically distributed. In some situations, global-scale winds are influenced by different phenomena, such as the El Niño/Southern Oscillation (ENSO). ENSO occurs when trade winds in the equatorial Pacific slow down or, in some cases, reverse, which results in the reduction of upwelling along the western coasts of landmasses near and on the equator. Upwelling is the oceanic process in which cold water from deep in the ocean is brought up to the surface; the reduction of upwelling causes sea surface temperatures (SSTs) to increase (Ackerman and Knox 2015). The warming of the SSTs in the equatorial Pacific extends further throughout the Pacific Ocean and influences weather patterns in different countries (Dole et al. 2017).

During the neutral phase of the ENSO phenomena, the rainfall on or near the equator is heavily correlated with the strong trade winds from north and south of the equator. The trade winds from both directions converge and rise in the atmosphere to form clouds and produce precipitation. The region where the trade winds converge is referred to as the Intertropical Convergence Zone (ITCZ). During the El Niño phase of ENSO, the warmer SSTs create a lower pressure in the central equatorial region. The warmer SSTs, coupled with the low-pressure system, shift the ITCZ eastward. These three weather and atmospheric changes cause the formation of more clouds and precipitation in the central equatorial Pacific.

From 25 January 2016 to 28 March 2016 UTC[1], the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory's (ESRL) Physical Sciences Division (PSD) and collaborating partners conducted the El Niño Rapid Response (ENRR) field

[1] Coordinated Universal Time

campaign to observe the weather conditions in the central equatorial Pacific during the El Niño phase of ENSO (Hartten et al. 2017a). ENRR was created to gather information that could help with the forecasting of ENSO-related events in the U.S. (Dole et al. 2017). ENRR scientists launched weather balloons twice daily and collected surface meteorological data from Kiritimati[2] Island which is located at (2.0° N, 157.4° W). The average annual amount of rainfall on Kiritimati Island is approximately one meter. However, during the three-month field campaign, scientists collected 0.938 meters of rain. The large amount of rainfall collected during ENRR shows that ENSO influences the amount of precipitation on Kiritimati Island (Hartten et al. 2017b).

It is important to see how ENSO affects rainfall patterns of regions that rely heavily on rain such as Kiritimati Island in the central equatorial Pacific and California in the United States. The people of Kiritimati Island depend on rainwater for drinking and washing, and have two methods to collect and store rain. As on many islands and atolls, there are freshwater lenses on Kiritimati Island, which are underground layers of fresh water on top of a layer of denser, brackish water. Precipitation replenishes the layer of fresh water in the lens as the rain seeps into the ground and undergoes a geological filtration process (Tanjal et al. 2017). Directly extracting the fresh water from the lenses on the island is one method in which residents of Kiritimati collect their water supply. The second method consists of collecting rain from the sky using storage tanks; massive cylindrical containers placed outside in areas convenient for Kiritimati residents to collect water from (Dole et al. 2017).

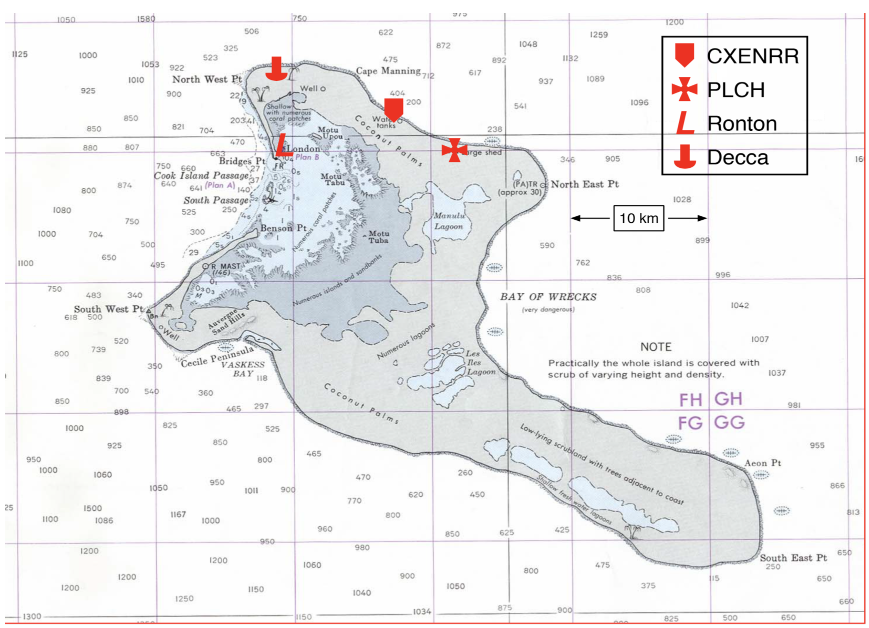
[2] Pronounced “Christmas”

This research project examines collected surface meteorological data from Kiritimati Island to determine the distribution of daily rainfall on the island during phases of the ENSO phenomena. Analyzing the potential influence ENSO has on Kiritimati Island can generate future research questions about ENSO, the influence it has on Kiritimati Island, and, hopefully, on certain regions in the United States.

2. Data

a. Overview

The data used for this project were collected observations from the ENRR field campaign (CXENRR) and the Kiribati[3] Meteorological Service's station at Ronton[4], which relocated to the Cassidy International Airport (PLCH). Data from CXENRR was short-term.



[3] Pronounced "KEER-eh-bahss"
[4] Pronounced "London"

Figure 1: A map of Kiritimati Island and the four data collection sites. Map courtesy of the Perry-Castañeda Library Map Collection, University of Texas Libraries; annotations by L.M. Hartten.

b. El Niño Rapid Response field campaign on Kiritimati Island

The dataset from CXENRR was collected from 25 January 2016 through 29 March 2016 LINT[5], during a robust El Niño phase of ENSO on Kiritimati Island. For the duration of the ENRR project, scientists measured one- to two- minute resolution surface meteorological and sonde data. The high-resolution surface observations collected include: precipitation, temperature, wind speed and direction, surface pressure, and relative humidity (Hartten et al. 2017a).

[5] Line Islands Time (UTC+14)

Figure 2: The tripod holding the surface meteorology instruments at the CXENRR data collection site on Kiritimati Island. The tipping bucket that was used to measure the rainfall is on the end of the left cross arm. Image provided by L. M. Hartten.

The data was collected through an automated weather station with a tipping bucket every two minutes. On 2 February 2017, the software was edited and the accumulation time was changed from every two minutes to every minute.

The time frame of the collection of surface meteorological data on Kiritimati Island during ENRR was a deciding factor for what dates to include for the method. The high-resolution rain data collected during ENRR was turned into an hourly dataset for this study and then was used to create three slightly different daily datasets: 09 LINT to 09 LINT, 00 LINT to 00 LINT, and 00 UTC to 00 UTC.

c. The official Kiribati Meteorological Service station

While data from CXENRR had short-term time ranges for the datasets, PLCH observations had a long-term dataset with a time range from 1971–present. PLCH is the official Kiribati Meteorological Service station. The data collected there include rainfall measured via a manual rain gauge. The PLCH dataset used, for this project, was acquired from various sources, and has been vetted and annotated accordingly by Tony Falkland of the Kiritimati Island Water Project. (T. Falkland, 2016, personal communication)

Although the data from PLCH covers a long range of time, there are gaps from 1991–1995, 01 September 2003–01 February 2015, and 02 April 2016–present. There is data in full years from 1971–1995 and 1996–2002. The data resolution of PLCH is daily, with an accumulation period of 09 LINT to 09 LINT.

The official Kiribati Meteorological Service site moved locations mid-1997, from Ronton (Northwest side of Kiritimati Island) to Cassidy International Airport (Northeast side of Kiritimati Island).

d. Oceanic Niño Index

Time Series of ONI Anomaly

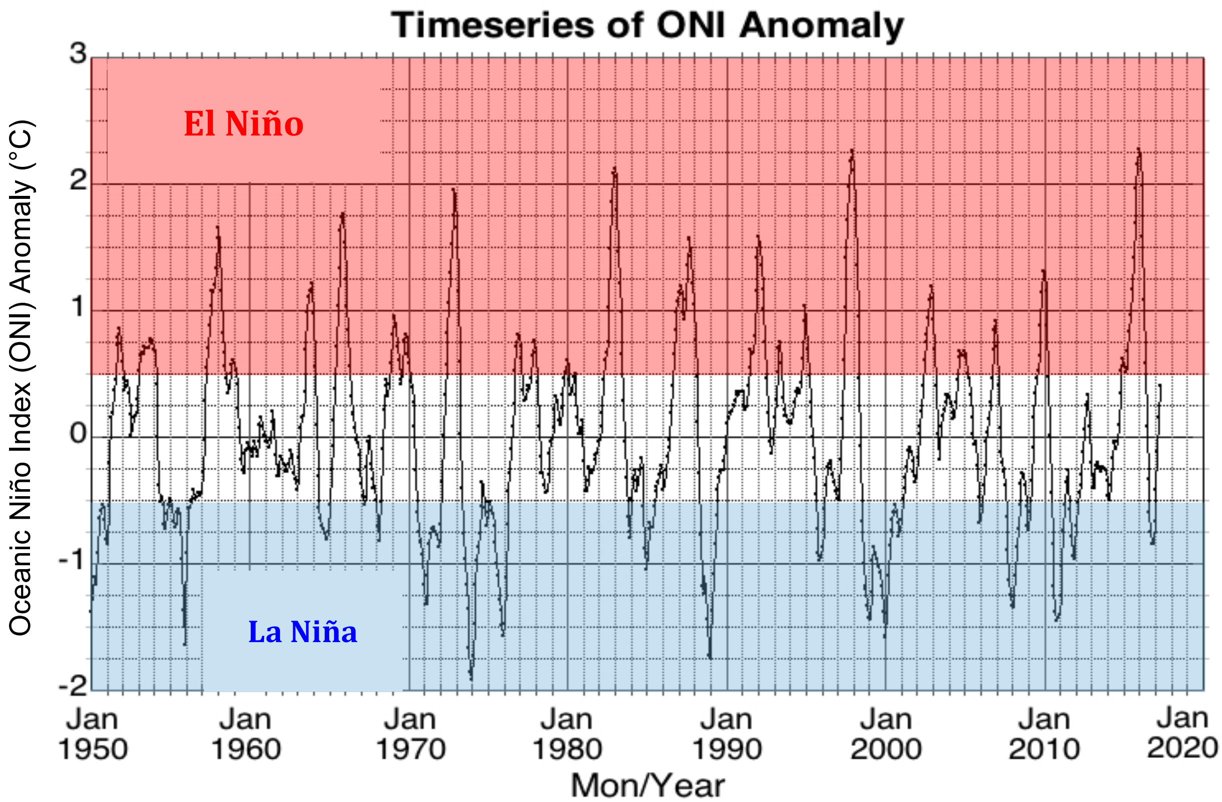


Figure 3: The monthly Oceanic Niño Index anomaly values from 1950–2020. The region that is not shaded from -0.5°C to +0.5°C is the neutral phase region, whereas when the ONI anomaly is -0.5°C or below, the region is shaded blue for the La Niña phase, and +0.5°C or above is the red El Niño phase region.

ONI[6] is an index that diagnoses the three different phases of ENSO. The ONI is based on the SST anomalies from the Niño 3.4 region, in the east-central equatorial Pacific (5°S to 5°N; 170°W to 120°W), and uses the 3-month-running mean to monitor whether an El Niño, La Niña, or neutral phase is in effect. From the average SST, the anomalies of 0.5°C above or below the mean are indicators of the three phases of the ENSO phenomena. The neutral phase of the ENSO phenomena has anomaly SSTs values between -0.5°C and +0.5°C of the average. The El Niño

[6] Oceanic Niño Index

phase of the ENSO phenomena are anomalies above the average by +0.5°C and anomalies below the average by -0.5°C are indication of La Niña.

The monthly-resolution ONI dataset used to indicate the various phases of the ENSO was obtained from the National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) (Dahlman 2009).

3. Methods

a. Time Series Plots

Time series were plotted with the PLCH data and included the years 1970–2020. These time series were used to compare data representations, calculate statistics, and describe how the plots show several aspects of the data. The plots were generated through Kaleidagraph software.

After plotting the time series, they were thoroughly examined to answer the following questions:

1) What was the maximum and when did it take place?
2) When were the extreme rainfall events?
3) What phase of ENSO did the maximum and extremes take place?
4) What was the average (mean)?
5) What was the range of rainfall amounts?

The observations and answers to the questions listed above for the time series plots allowed for understanding the distribution of daily rainfall amounts in the histograms.

b. Histograms

Histograms were plotted to examine how different quantities of daily precipitation were distributed on Kiritimati Island. The histograms were made using MATLAB software. When plotting the histograms, a consistent bin size of 10 mm was chosen to allow for bins to be evenly distributed and effectively highlight both the extremes of high amounts of daily rainfall and the low amounts of daily rainfall. The histograms were annotated to highlight the probability of very little rainfall events (0–10 mm), light rainfall events (10–70 mm), moderately heavy rainfall events (70–150 mm), and heavy rainfall events (150–250 mm). These categories were based on the high probability of very little to no rainfall events and the distribution of higher rainfall amounts for the El Niño years. To get the probability of daily rainfall events, the data was normalized through the MATLAB 'Normalization' function and then converted to a probability. In addition to plotting the probabilities, the counts of each rainfall event were also plotted to show the number of events the probability was associated with.

The histogram plots used data from the assignment of years to El Niño, La Niña, and Neutral, which was based on the value of the ONI. Each of the years focused on January, February, and March, which are the three months that the nine-week ENRR field campaign took place. The categorized years were chosen based on the availability of data from the PLCH dataset and the phase of ENSO for each of the three months. For each categorized type of year, the three consecutive months of January through March had to consistently meet the conditions of one of the three phases of ENSO.

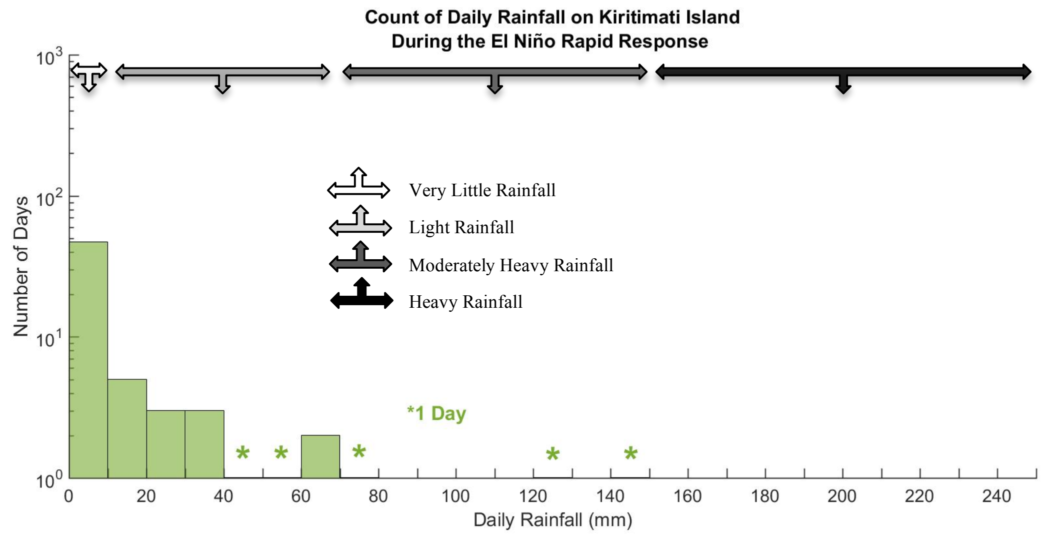
For the 'Neutral' years, each of the months had to meet the conditions for the neutral phase of ENSO based on the ONI. This allowed for data used from 2002, 1997, 1990, 1986, 1984, 1982, 1981, and 1979 for the 'Neutral' years. The same process was used for choosing the 'El Niño' and 'La Niña' years except the three months had to consistently meet the respective conditions for either the El Niño or La Niña phase. The El Niño years consisted of data from 2016, 2015, 1998, 1987, 1983, and 1973. The La Niña years consisted of data from 2000, 1999, 1996, 1989, 1985, 1976, 1975, 1974, and 1971.

For this project, the ONI was used to see which of the of the three months examined from January through March had undergone three continuous months of one of the three phases of the ENSO.

4. Results

a. Daily rainfall during the ENRR period

a



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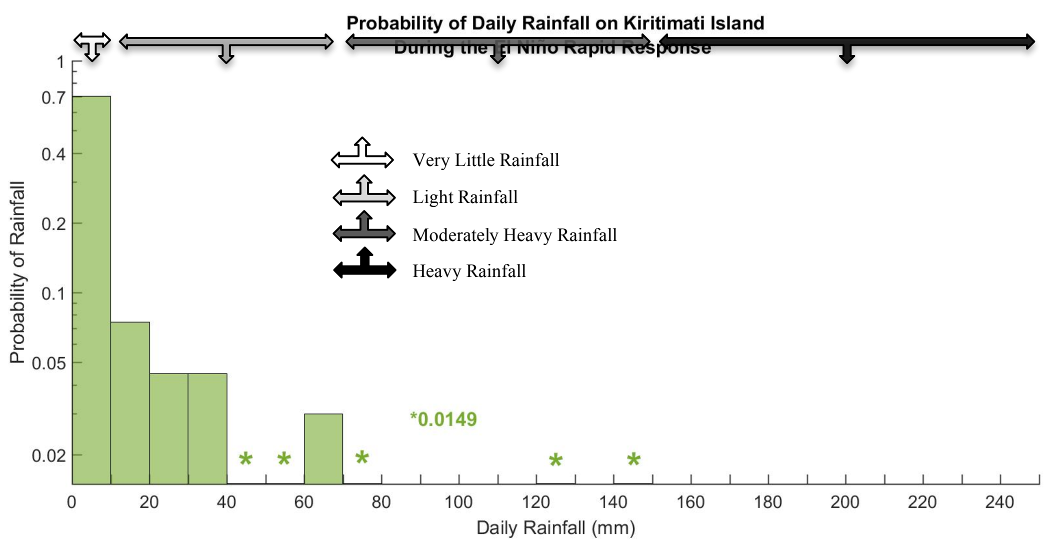


Figure 4: Histograms of daily rainfall distribution on Kiritimati Island during the ENRR project with the categories shown – Very Little Rainfall, Light Rainfall, Moderately Heavy Rainfall, and Heavy Rainfall. The data used in this plot is from CXENRR.

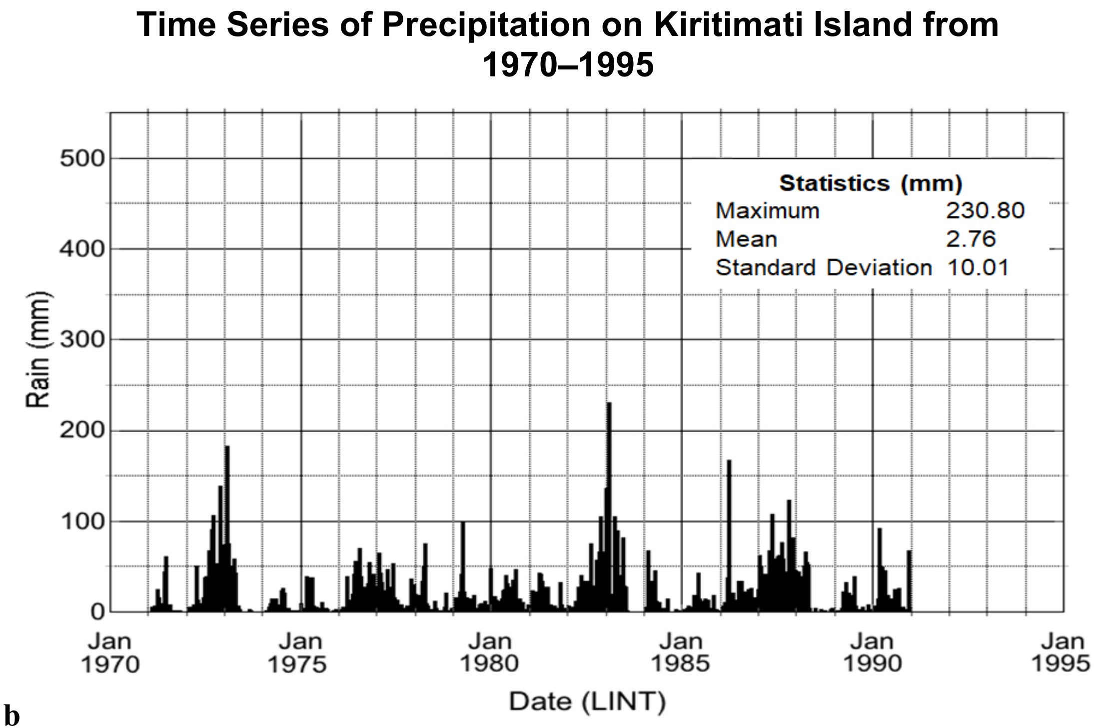
Table 1: The number of daily rain events, during the ENRR field campaign on Kiritimati Island, that took place in each of the various bins. In addition, the percent probability is shown.

Bins	**Number of Days**	**Probability** (%)
0–10 mm	47	70.15
10–20 mm	5	7.46
20–30 mm	3	4.48
30–40 mm	3	4.48
40–50 mm	1	1.49
50–60 mm	1	1.49
60–70 mm	2	2.99
70–80 mm	1	1.49
80–90 mm	0	0
90–100 mm	0	0
100–110 mm	0	0
110–120 mm	0	0
120–130 mm	1	1.49
130–140 mm	0	0
140–150 mm	1	1.49
150–160 mm	0	0
160–170 mm	0	0
170–180 mm	0	0
180–190 mm	0	0
190–200 mm	0	0
200–210 mm	0	0
210–220 mm	0	0
220–230 mm	0	0
230–240 mm	0	0
240–250 mm	0	0

Figure 4 is two histograms of daily rainfall amounts measured during the ENRR field campaign from 25 January to 29 March 2016. The ENRR field campaign took place during a very strong El Niño. The histograms plot the number of days that daily rainfall events occurred within each 10-mm bin and the probability for the rainfall events that fit into each 10-mm bin.

The range of daily rain amounts fell between 0 to 150 mm. The total number of data points available for CXENRR was 65 — this is including ‘not a numbers’ (NaN). The leading probable rainfall amount was between 0 to 10 mm with a chance of 70.00%. Daily precipitation events with a rainfall amount between 0 to 10 mm occurred 47 times during the ENRR project on Kiritimati Island. The maximum amount of rain collected during the ENRR was in the 140–150 mm bin, with a single rainfall event of 147.57 mm. The maximum bin size had a probability of 1.49%. The average daily rainfall event was 14.43 mm and the standard deviation was 28.03 mm. The total amount of rainfall collected during CXENRRs was 937.77 mm.

b. Daily rainfall in history records since 1971 a



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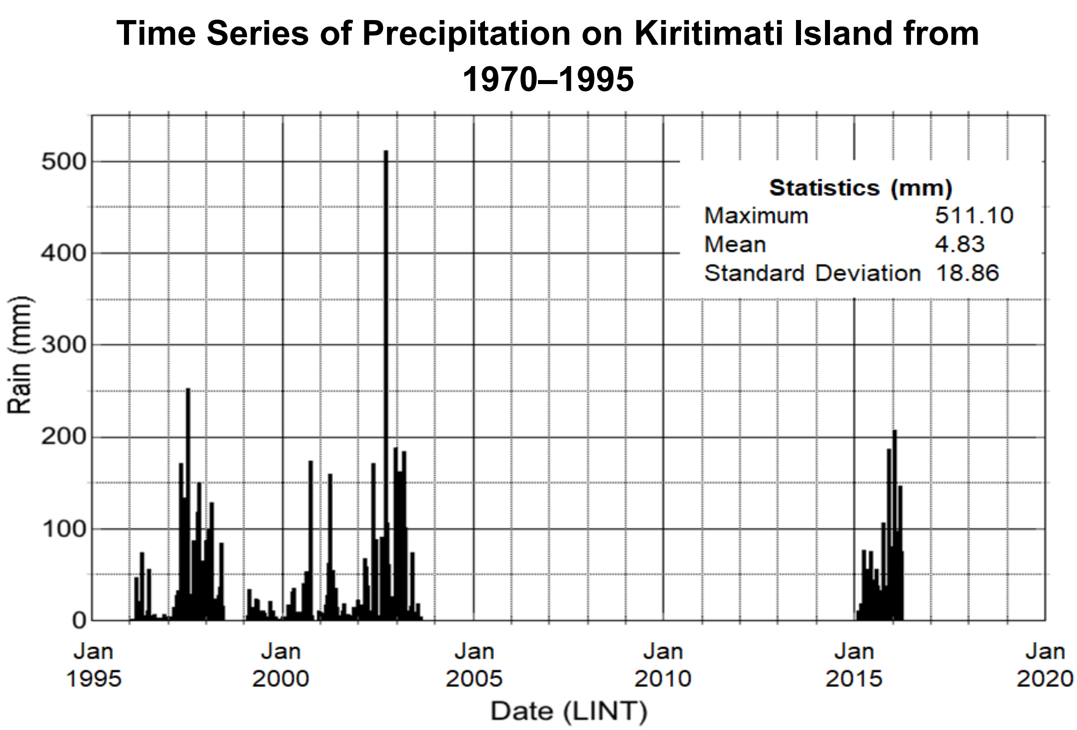


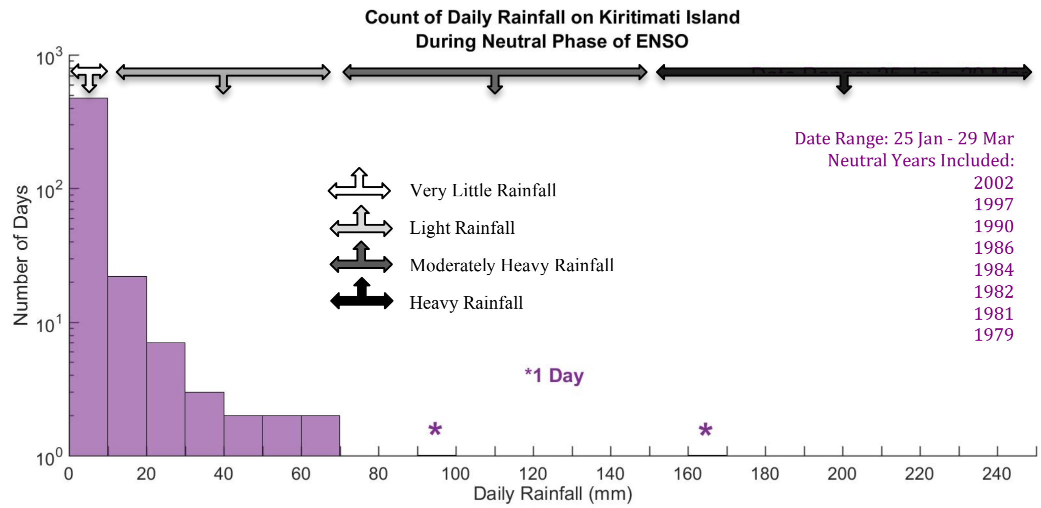
Figure 5: Time series of the historical records of daily rainfall on Kiritimati Island collected at PLCH from 1971–1990 and 1996–2016 with a time gap from 2003–2014.

Figure 5 is a two time series plots of the daily rainfall measurements from PLCH on Kiritimati Island from 1971–1990 and 1996–2016. In Figures 5a and 5b, there are extreme rain events where there was over 200 mm collected: early 1984, mid 1997, late 2002, and early 2016. Early 1984 was in the neutral phase of the ENSO while the rainfall events in mid-1997, late 2002, and early 2016 were all in the El Niño phase of the ENSO.

The highest amount of rain fell on 15 September 2002, with a large amount of 511.10 mm. The average amount of rain from 1971–2016 was 3.40 mm and the standard deviation was 13.40 mm. The amount of rain measured from 1971–2016 totaled 35,706 mm. The range of rainfall amounts was between 0 and 512 mm; however, without the large 511.10 mm rain event, the range is between 0 to 253 mm, with the largest rain event being 252.70 mm which fell on 14 July 1997.

1) *Distribution of daily rainfall during the neutral-phase of ENSO:*

a



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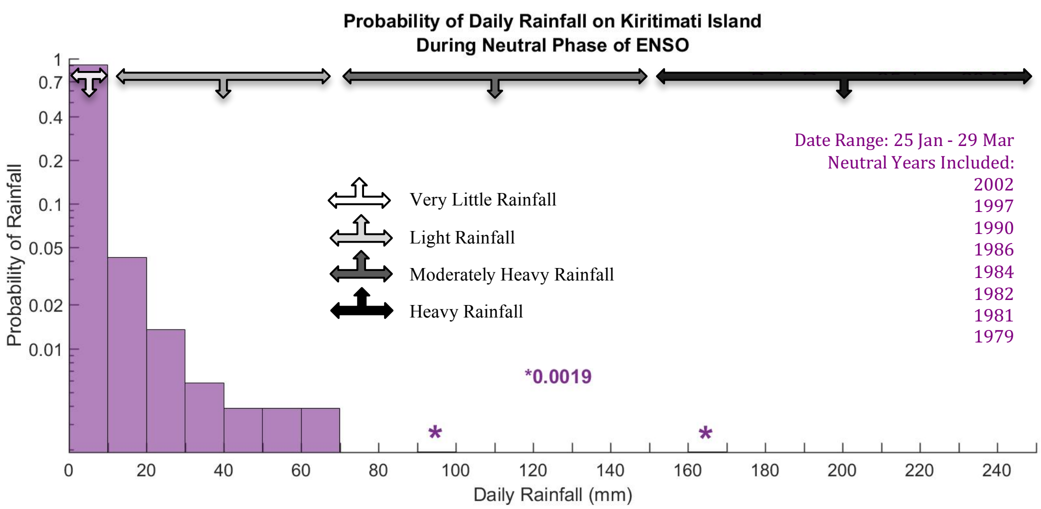


Figure 6: Histograms of daily rainfall distribution on Kiritimati Island during the "Neutral" years with the categories shown – Very Little Rainfall, Light Rainfall, Moderately Heavy Rainfall, and Heavy Rainfall. The 'Count' histogram is based on the 64 days – or 65 days for leap years – for the nine-week time frame that was selected based on the ENRR project. The data used in this plot is from PLCH.

Table 2: The number of daily rain events, during the neutral phase of ENSO on Kiritimati Island, that took place in each of the various bins. In addition, the percent probability is shown.

Bins	**Number of Days**	**Probability** (%)
0–10 mm	473	90.96
10–20 mm	22	4.23
20–30 mm	7	1.35
30–40 mm	3	0.58
40–50 mm	2	0.38
50–60 mm	2	0.38
60–70 mm	2	0.38
70–80 mm	0	0
80–90 mm	0	0
90–100 mm	1	0.19
100–110 mm	0	0
110–120 mm	0	0
120–130 mm	0	0
130–140 mm	0	0
140–150 mm	0	0
150–160 mm	0	0
160–170 mm	1	0.19
170–180 mm	0	0
180–190 mm	0	0
190–200 mm	0	0
200–210 mm	0	0
210–220 mm	0	0
220–230 mm	0	0
230–240 mm	0	0
240–250 mm	0	0

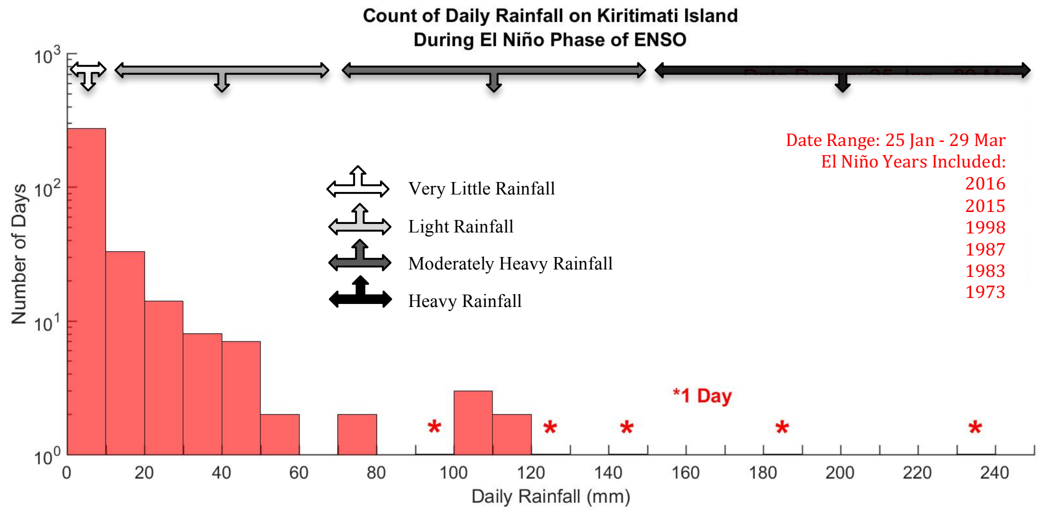
The neutral years plotted in the histogram above include 2002, 1997, 1990, 1986, 1984, 1982, 1981, and 1979. These years were chosen for two reasons: 1) each of the years demonstrated neutral ONI value anomalies for the three consecutive months of January, February, and March; 2) each of the years had data available from PLCH. (CPC.NCEP.NOAA.gov)

Figure 6 is two histograms of daily rainfall amounts measured at PLCH from 25 January to 29 Mar for each of the neutral years. The histogram is a measure of probability for different daily rainfall amounts in intervals of ten. For 2002, 1997, 1990, 1986, 1984, 1982, 1981, and 1979, the distribution of daily rainfall amounts ranges from 0 to 170 mm. The total number of data points available for the neutral years is 520 — this is including 'not a numbers' (NaN).

The leading probable rainfall amount was between 0 to 10 mm with a chance of 90.96%. Daily precipitation events with a rainfall amount between 0 to 10 mm occurred 473 times during the neutral years with three consecutive months of neutral ONI values since 1971. The maximum amount of rain collected during the neutral years was in the 160–170 mm bin, with a single rainfall event of 166.60 mm. The maximum bin size had a probability of 0.19%. The average daily rainfall event was 3.22 mm and the standard deviation was 11.23 mm. The total amount of rainfall collected during the neutral years was 1650.70 mm.

2) Distribution of daily rainfall during the El Niño-phase of ENSO:

a



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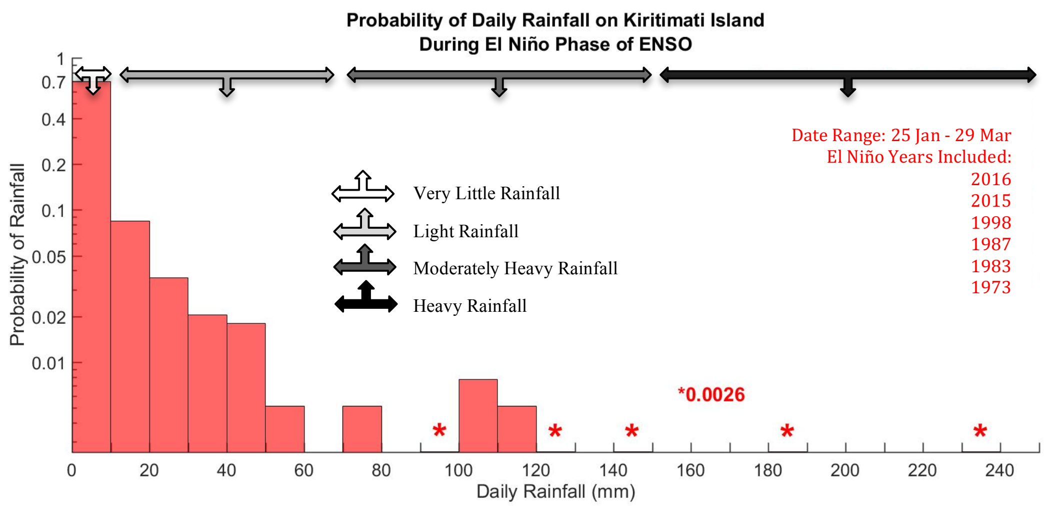


Figures 7: Histograms of daily rainfall distribution on Kiritimati Island during the 'El Niño' years with the categories shown – Very Little Rainfall, Light Rainfall, Moderately Heavy Rainfall, and Heavy Rainfall. The 'Count' histogram is based on the 64 days – or 65 days for leap years – for the nine-week time frame that was selected based on the ENRR project. The data used in this plot is from PLCH.

Table 3: The number of daily rain events, during the El Niño phase of ENSO on Kiritimati Island, that took place in each of the various bins. In addition, the percent probability is shown.

Bins	Number of Days	Probability (%)
0–10 mm	273	70
10–20 mm	33	8.45
20–30 mm	14	3.59
30–40 mm	8	2.05
40–50 mm	7	1.80
50–60 mm	2	0.51
60–70 mm	0	0
70–80 mm	2	0.51
80–90 mm	0	0
90–100 mm	1	0.26
100–110 mm	3	0.77
110–120 mm	2	0.51
120–130 mm	1	0.26
130–140 mm	0	0
140–150 mm	1	0.26
150–160 mm	0	0
160–170 mm	0	0
170–180 mm	0	0
180–190 mm	1	0.26
190–200 mm	0	0
200–210 mm	0	0
210–220 mm	0	0
220–230 mm	0	0
230–240 mm	1	0.26
240–250 mm	0	0

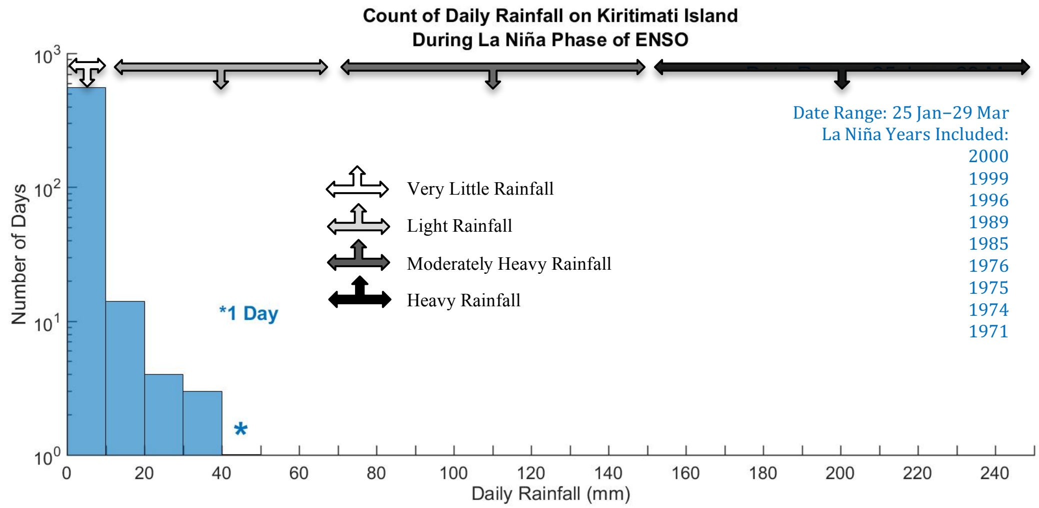
The El Niño years plotted in the histogram above include 2016, 2015, 1998, 1987, 1983, and 1973. These years were chosen for two reasons: 1) each of the years demonstrated El Niño ONI value anomalies for the three consecutive months of January, February, and March; 2) each of the years had data available from PLCH. (CPC.NCEP.NOAA.gov)

Figure 7 is two histograms of daily rainfall amounts measured at PLCH from 25 January to 29 Mar for each of the El Niño years. The histograms are a measure of probability for various daily rainfall amounts in bin sizes of 10 mm. For 2016, 2015, 1998, 1987, 1983, and 1973, the distribution of daily rainfall amounts ranges from 0 to 240 mm. The total number of data points available for the El Niño years is 390 — this is including 'not a numbers' (NaN).

The leading probable rainfall amount was between 0 to 10 mm with a chance of 70.00%. Daily precipitation events with a rainfall amount between 0 to 10 mm occurred 273 times during the El Niño years with three consecutive months of El Niño ONI values since 1971. The maximum amount of rain collected during the El Niño years was in the 230-240 mm bin, with a single rainfall amount of 230.80 mm. The maximum bin size had a probability of 0.26%. The average daily rainfall event was 9.98 mm and the standard deviation was 24.92 mm. The total amount of rainfall collected during the El Niño years was 3484.40 mm.

3) Distribution of daily rainfall during the La Niña-phase of ENSO:

a



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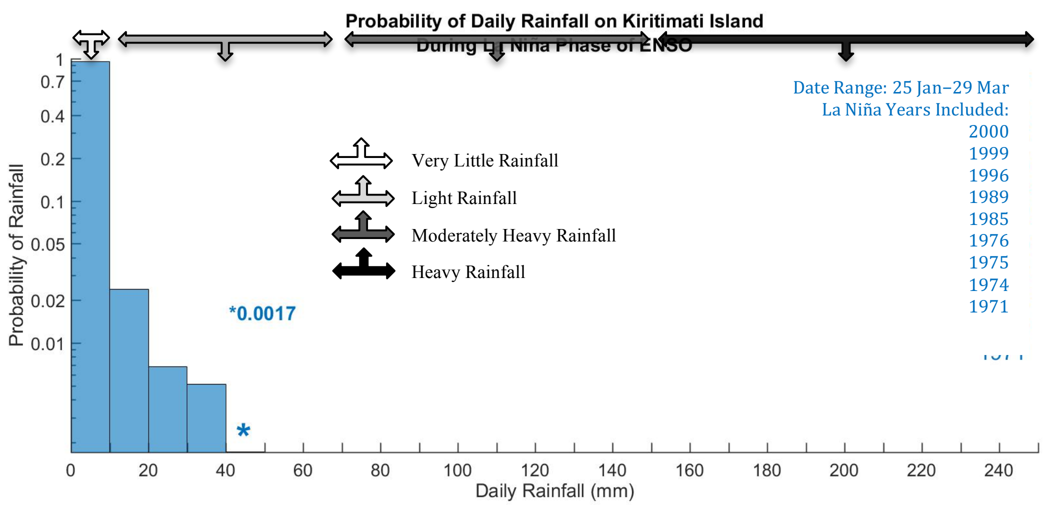

Figure 8: Histograms of daily rainfall distribution on Kiritimati Island during the 'La Niña' years with the categories shown – Very Little Rainfall, Light Rainfall, Moderately Heavy Rainfall, and Heavy Rainfall. The 'Count' histogram is based on the 64 days – or 65 days for leap years – for the nine-week time frame that was selected based on the ENRR project. The data used in this plot is from PLCH.

Table 4: The number of daily rain events, during the La Niña phase of ENSO on Kiritimati Island, that took place in each of the various bins. In addition, the percent probability is shown.

Bins	**Number of Days**	**Probability (%)**
0–10 mm	557	95.21
10–20 mm	14	2.39
20–30 mm	4	0.68
30–40 mm	3	0.51
40–50 mm	1	0.17
50–60 mm	0	0
60–70 mm	0	0
70–80 mm	0	0
80–90 mm	0	0
90–100 mm	0	0
100–110 mm	0	0
110–120 mm	0	0
120–130 mm	0	0
130–140 mm	0	0
140–150 mm	0	0
150–160 mm	0	0
160–170 mm	0	0
170–180 mm	0	0
180–190 mm	0	0
190–200 mm	0	0
200–210 mm	0	0
210–220 mm	0	0
220–230 mm	0	0
230–240 mm	0	0
240–250 mm	0	0

The La Niña years plotted in the histogram above include 2000, 1999, 1996, 1989, 1985, 1976, 1975, 1974, and 1971. These years were chosen for two reasons: 1) each of the years demonstrated La Niña ONI value anomalies for the three consecutive months of January, February, and March; 2) each of the years had data available from PLCH. (Climate Prediction Center 2017)

Figure 8 is two histograms of daily rainfall amounts measured at PLCH from 25 January to 29 Mar for each of the La Niña years. The histogram is a measure of probability for different daily rainfall amounts in intervals of ten. For 2000, 1999, 1996, 1989, 1985, 1976, 1975, 1974, and 1971, the distribution of daily rainfall amounts ranges from 0 to 50 mm. The total number of data points available for the La Niña years is 585 — this is including 'not a numbers' (NaN).

The leading probable rainfall amount was between 0 to 10 mm with a chance of 95.21%. Daily precipitation events with a rainfall amount between 0 to 10 mm occurred 557 times during the La Niña years with three consecutive months of La Niña ONI values since 1971. The maximum amount of rain collected during the La Niña years was in the 40-50 mm bin, with a single rainfall amount of 46.20 mm. The maximum bin size had a probability of 0.17%. The average daily rainfall event was 1.54 mm and the standard deviation was 4.5312 mm. The total amount of rainfall collected during the La Niña years was 889.22 mm.

5. Summary

The results showed that rainfall varies along with the phase change of ENSO. Rainfall amounts increased during the El Niño phase, and fell during the La Niña phase. For the El Niño years, the percent probability for the number of days that would have rainfall amounts between 0–10 mm was 70.00% whereas, for the La Niña years, the percent probability was 95.21% and, for the Neutral years, the percent probability was 90.96%. The El Niño years had 165 days of trace rainfall amounts while the neutral years had 361 days and La Niña years had 451 days.

A plausible reason for the lower percentage during the El Niño years could be due to the warmer SSTs during an El Niño phase. The warmer moisture rises and produces more convective clouds which results in more rainfall events of larger rainfall amounts. During the

Neutral and La Niña phases of ENSO, the SSTs are not as warm which is a plausible reason for less frequent rainfall event.

The difference in the number of days could be due to the different amount of years that were used for each phase. In future work, the conditions for which years are analyzed should be changed to see how the number of days will behave.

The future work will consist of reanalysis of the analysis done in this research project with various reanalysis products, climate simulation models, and satellite observations.

6. Acknowledgements

This work was performed under the auspices of the Significant Opportunities in Atmospheric Research and Science Program (SOARS). SOARS is managed by the University Corporation for Atmospheric Research and is funded by the National Science Foundation, the National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration, the Woods Hole Oceanographic Institute, the Constellation Observing System for Meteorology, Ionosphere, and Climate, and the University of Colorado at Boulder.

I would like to express my gratitude to the Republic of Kiribati and the Captain Cook Hotel for allowing my mentors and copartners to conduct their field campaigns.

Thank you to Dr. Tony Falkland of the Kiritimati Island Water Project for generously sharing the historical data. The Kiritimati Island Water Project is funded by the European Union (EU) and implemented by the Secretariat of the Pacific Community (SPC).

I also would like to thank NOAA/OAR for funding and NOAA's Earth System Research Laboratory's Physical Sciences Division for hosting me, creating this research project, and providing the guidance/support I needed to complete it.

I would like to express my utmost appreciation to my Research Mentors, Leslie Hartten and Xiao-Wei Quan, my Writing & Communication Mentor, Annie Reiser, my Coach, Kevin Manross. The combination of all your help and support, inspired me and strengthened my interest in atmospheric research.

Thank you to SOARS for providing me with the opportunity to be conduct this research project, supporting me throughout the research experience and, and training me to develop new skills to advance my research.

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