THE LINK BETWEEN CHANGES IN OCEAN SURFACE TEMPERATURE AND RAINFALL IN HAWAIʻI

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We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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ABSTRACT

Hawaii's climate is shaped by a unique interaction of tropical ocean conditions, trade winds, and geomorphic effects that create distinct microclimates. This study investigates the influence of large-scale climate indices on Hawaii's rainfall patterns, including the Oceanic Nino Index (ONI) as an anomaly of sea surface temperature (SST), the Pacific Decadal Oscillation (PDO), and the Madden-Julian Oscillation (MJO). The study uses Pearson correlations to assess the relationships on different time scales, including lagged monthly data, 3, 6, and 12-month data. The results show that the linear correlation between the two climate indices, ONI and PDO, and rainfall in Hawaii is relatively weak at these time scales. However, when rainfall is stratified by positive and negative phases of ONI, PDO, and MJO, the phase-conditional means show strong differences (0-70 mm/month), indicating a clear nonlinear association. These findings suggest that when the data are analyzed through certain characterizations, ONI, PDO, and MJO exert a strong but nonlinear control on rainfall in Hawaii, and may be able to provide different phase-based benchmarks for future rainfall forecasts in the Hawaii region and for future model evaluations.

Keywords: Hawaiian Islands, Rainfall, Oceanic Niño Index (ONI), Pacific Decadal Oscillation (PDO), Madden-Julian Oscillation (MJO), Sea Surface Temperature (SST)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

INTRODUCTION

Hawai‘i's climate is a microcosm global tropical variability and is influenced by trade winds, ocean conditions, and volcanic topography. Rainfall patterns vary widely across the islands as a result of these factors. Understanding the mechanisms driving rainfall variability in Hawai‘i is not only critical for ecosystem conservation, water resource management, and agricultural development in the region, but also has far-reaching practical implications for predicting and responding to future climate risks in the context of global climate change.

Sea surface temperature (SST) anomalies, in particular the Pacific El Niño phenomenon ---- is the anomalously high surface water temperatures in the eastern tropical Pacific Ocean, are recognized as one of the driving forces of precipitation variability in coastal areas. For example, the El Niño-Southern Oscillation (ENSO), a global climate phenomenon, can significantly modulate rainfall patterns in tropical and subtropical regions. Typically, El Niño events lead to a decrease in rainfall in areas such as Hawai‘i, while La Niña events may bring about an increase in rainfall(La Niña is the opposite of El Niño. During La Niña, the trade winds are stronger than usual, pushing more warm water into Asia) (O'Connor, 2014; Trenberth & Caron, 2000). In addition, Giambelluca and Nullet (1991) documented that trade wind reversals further influence rainfall formation and distribution by limiting vertical cloud development (Giambelluca & Nullet, 1991). These dynamics, combined with Hawaiian steep topography, create a complex interplay between global and regional climate drivers.

Among the many climate indices, the Oceanic Niño Index (ONI), the Pacific Decadal Intergenerational Oscillation (PDO), and the Madden-Julian Oscillation (MJO) are recognized as important indices influencing Hawai‘i's rainfall patterns. The ONI is a measure of the ENSO that tracks SST anomalies in the Nino 3.4 region of the equatorial Pacific Ocean (NOAA Climate Prediction Center, 2024); the PDO is a long term climate model characterized by SST anomalies in the North Pacific Ocean (Mantua et al.) Both the ONI and PDO are indicators of SST indicators, and their variations affect rainfall because SST anomalies lead to enhanced or weakened upward atmospheric motion, which in turn affects the increase or decrease in rainfall (Izumo et al., 2020), which is why the use of the ONI and the PDO were chosen as climate indices to be analyzed. Another climate index is the MJO, which is an intraseasonal climatic phenomenon that affects weather patterns in the tropics (Madden & Julian, 1971). MJO events have been shown to be associated with summer rainfall in the Northern Hemisphere-that is, as this MJO positive phase increases, atmospheric activity in the same longitude region is enhanced and rainfall increases (Waliser et al. 2003). Therefore, these three climate indices were introduced in the study of the relationship between rainfall and SST in Hawai‘i.

Although previous studies have explored the relationship between these climate indices and global or regional rainfall, in-depth analyses specific to rainfall variability in the Hawai‘i region are still lacking, especially with respect to multiple time scales and lagged effects. The purpose of this study is to analyze the relationship between ONI, PDO, and MJO and rainfall in Hawai‘i by analyzing historical rainfall data from 1950-2020 from multiple rainfall stations in Hawai‘i at different time scales (including monthly, 3-month, and 6-month cumulative data, as well as 3-month and 6-month lagged data), for lagged data, the current month's climate index is aligned with the rainfall that will occur in the next 3 months, or months, for lagged comparisons.. Also analyze changes in rainfall rates during positive and negative phases of the climate indices.

The study identifies the linear relationship between climate indices and rainfall in Hawai‘i through Pearson correlation analysis. The final goal of the study is to deepen the understanding of these climate mechanisms, provide a scientific basis for improving climate modeling, prediction, and water management strategies in Hawai‘i, and inform regional climate adaptation in the context of global climate change.

2.0 MATERIALS AND METHODS

2.1 STUDY AREA: HAWAIIAN ISLAND

This study investigates rainfall patterns across the Hawaiian Islands, an archipelago in the central Pacific Ocean comprising eight main islands: Niʻihau, Kauaʻi, Oʻahu, Molokaʻi, Lānaʻi, Maui, Kahoʻolawe, and Hawaiʻi (the Big Island). Located approximately between 18.5°N to 22.5°N latitude and 154°W to 160°W longitude.

2.2 DATA SOURCES

The rainfall data analyzed for the study were obtained from a Geographic Information System (GIS) database maintained by the State of Hawaii's GIS Portal, which initially consisted of more than 1,000 weather stations on the Hawaiian Islands. To ensure a reliable dataset suitable for long-term analysis, these weather stations were screened to include only those with continuous monthly rainfall records between 1950 and 2020.

Three primary climate indices were utilized to explore their relationships with rainfall:

ONI: Monthly ONI values, measuring SST anomalies in the Niño 3.4 region, were sourced from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (NOAA, 2024). ONI directly reflects the state of the ENSO, where different phases of the ONI can weaken or strengthen the trade winds, bringing changes in rainfall to the tropics.

PDO: Monthly PDO values were obtained from the NOAA Earth System Research Laboratory (NOAA ESRL, 2024). It fluctuates on longer (compared to ONI) time scales and has been described as a long-term pattern similar to ENSO; similarly, a change in PDO implies a change in SST, which affects rainfall.

MJO: Monthly MJO data were sourced from the NOAA Climate Prediction Center (NOAA CPC, 2024). The MJO is a 30-90 day intra-seasonal climatic phenomenon in the tropics that manifests itself as eastward moving clouds, rainfall, winds, and pressure perturbations that affect rainfall more directly than the ONI and PDO.

All climate index data (ONI, PDO, MJO) were aggregated into monthly datasets for the period 1950-2020 to allow direct comparison with rainfall datasets.

2.3 DATA PREPROCESSING

Data preprocessing was conducted to ensure quality and comparability. Missing values in both the rainfall and ONI datasets were processed by linear interpolation, supplemented by forward and backward padding to maintain temporal continuity ---- vacant values were supplemented with surrounding data. To standardize variability across stations and time, both datasets were normalized using Z-scores, calculated as:

$$Z = (x - \mu) / \sigma$$

where x represents the original data value, μ is the mean, and σ is the standard deviation. This method reduces the large number of vacant values in the rainfall dataset and ensures the realism of the data.

2.4 ANALYTICAL METHODS

The first part of the analysis was to explore the relationship between current-month, 3-month cumulative, and 6-month cumulative rainfall and each climate index (ONI, PDO, and MJO) using Pearson correlation (which captures only linear relationships)

• Cross-correlation analysis: was performed to determine the temporal lag at which the strongest relationship between 6-month cumulative ONI and rainfall occurs for each station. Lags ranging from 0 to 12 months were assessed, and the lag with the highest Pearson correlation coefficient was designated as the "best lag" for each station. The Pearson correlation coefficient was computed as:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

where xi and yi are the paired ONI and rainfall values, and $\bar{x}$ and $\bar{y}$ are their respective means. This approach quantified both the strength and timing of the association between SST anomalies and rainfall. An example of what the data looks like when compared on a time series after preprocessing (including normalization, and aligning the time axis, etc.) can be found in Figure 1, which is a plot of ONI and one of the rainfall stations.

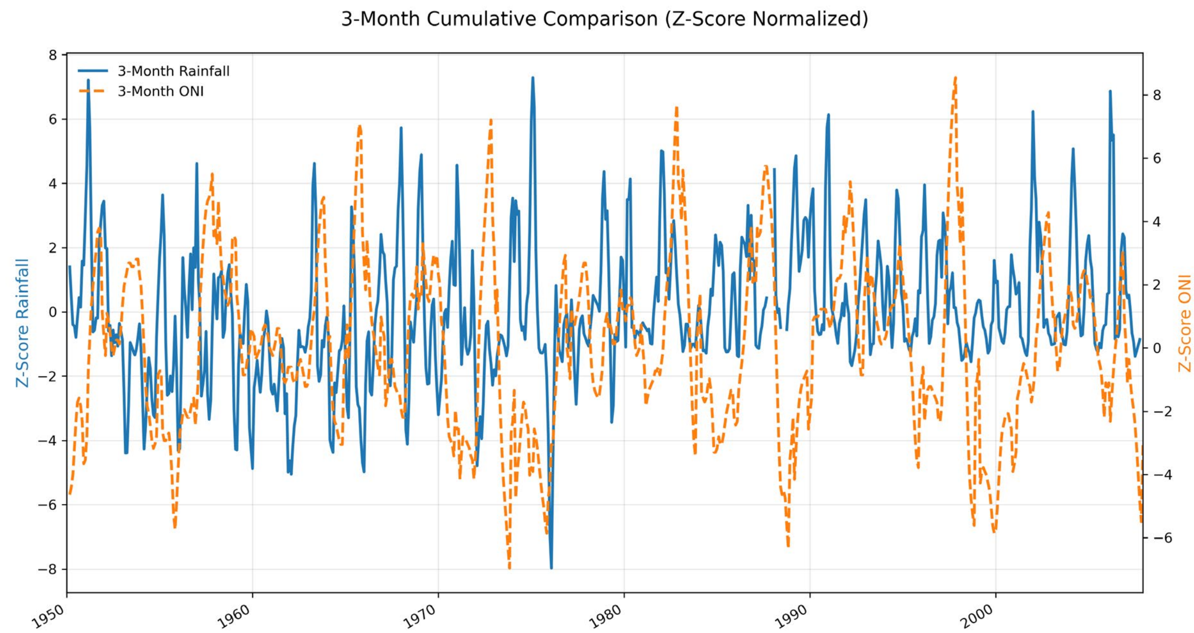

Figure 1. Comparison of normalized ONI and rainfall time series at one of the stations

2.5 Variation of rainfall rates in positive and negative phases of climate indexes

In this part, a methodology for mapping rainfall rate changes at specific rainfall stations under the influence of different climate indices was developed for determining rainfall rate increases and decreases during positive and negative phases of the climate indices, which was applied to all 363 rainfall stations with time scales greater than 60 months.

1. Data grouping by phase

For each climate index (ONI, PDO and MJO), all months in the 1950-2020 phase are divided into two groups based on the phase of the index:

• Positive phase months: Months in which the climate indices (ONI, PDO, and MJO) are in positive phase (i.e., phases in which the climate index is greater than 0).

• Negative-phase months: Months in which the climate indices (ONI, PDO, and MJO) are in positive phase (i.e., phases in which the climate index is less than 0).

In addition, rainfall totals were calculated for different phases of positive and negative phase months for the 363 stations.

2.Calculation of average rainfall rate

Calculate the monthly average rainfall for each site in two phases:

- Positive phase average rainfall: the sum of all monthly rainfalls in the positive phase months divided by the number of positive phase months.
- Negative-phase average rainfall: the sum of all monthly rainfalls in the negative-phase months divided by the number of negative-phase months.

This method of calculating the average rainfall rate over the different climate index phases takes into account the difference in the number of months in each phase. This results in the correct rainfall difference. The rainfall difference is the value derived by subtracting the average rainfall in the positive phase from the average rainfall in the negative phase.

3.0 RESULTS

To ensure the reliability of the lagged correlation analysis, the adequacy of rainfall data at each station for the study period (1950-2020) was first confirmed. Figure 1 presents a density plot depicting the monthly distribution of available rainfall data for the 366 stations.

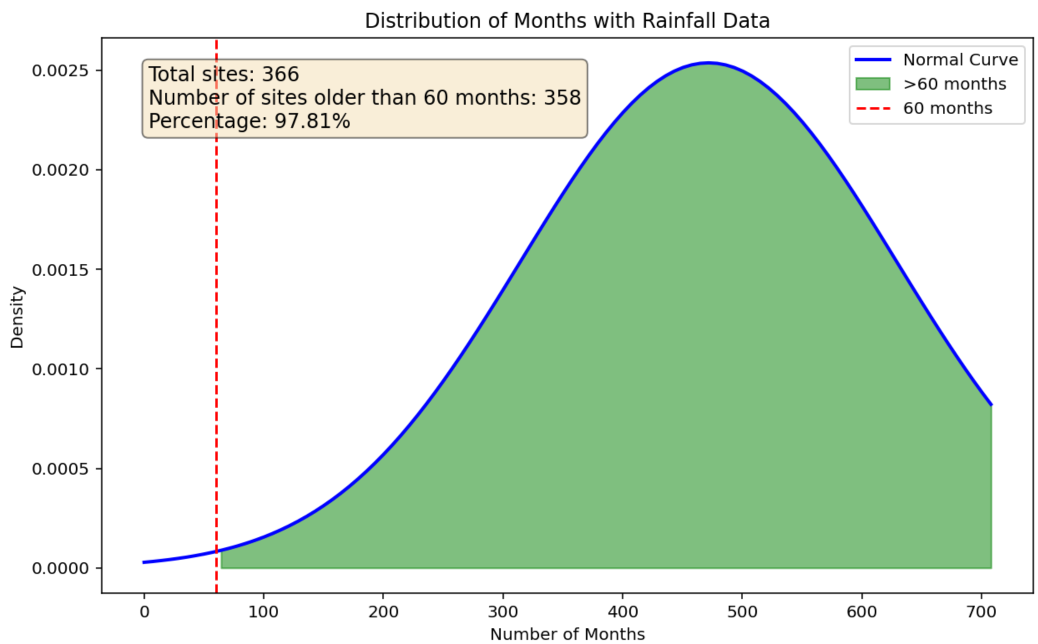

Figure 2. Monthly distribution of rainfall data

This density plot shows the distribution of the number of months of rainfall data available for the 366 sites. The red dashed line indicates the 60-month threshold, which was exceeded by 358 sites (97.81%), indicating that the data were sufficient to support a lagged correlation analysis. Only 8 sites (2.19%) had less than 60 months of data.

The analysis showed that most sites have about 471.89 months of data, with 358 sites (97.81%)

exceeding the 60-month threshold and only 8 sites (2.19%) having insufficient data. This high percentage of data adequacy is critical for examining the lagged effects of ONI and PDO on rainfall, as these analyses require longer time series to ensure the accuracy of the results.

3.1 CORRELATION ANALYSIS OF CLIMATE INDEX

The relationship between rainfall and ONI, PDO and MJO on different time scales (monthly, 3-month cumulative, and 6-month cumulative) was assessed by correlation analysis. For each time scale, the maximum correlation coefficients was calculated for stations with statistically significant correlations ($p < 0.05$).

3.1.1 ONI CORRELATION

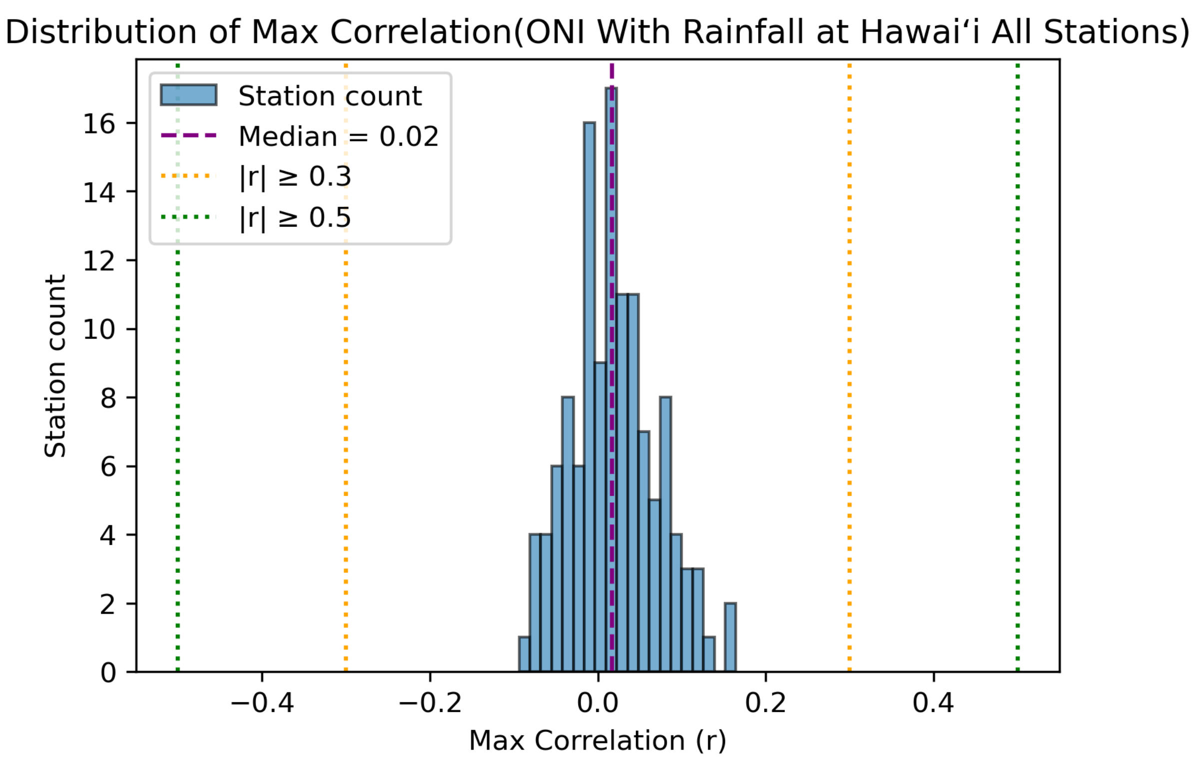

Figure. 3.Distribution of Maximum correlation coefficients of monthly, lag 3-month and lag

6-month ONI for each station

The y-axis line in Figure 2 is the number of different sites; the x-axis line is the Pearson's correlation coefficient (the correlation coefficient ranges between -1 and 1, with the closer to 1 the stronger the correlation, and the correlation coefficient usually needs to be greater than 0.5 to be statistically significant); The yellow line segments are markers of correlations at plus or minus 0.3, and it is clear that no station showed a statistically significant Pearson correlation between ONI and rainfall at any time scale (including lags), indicating an absence of a synchronous linear relationship at these scales.

3.1.2 PDO CORRELATION

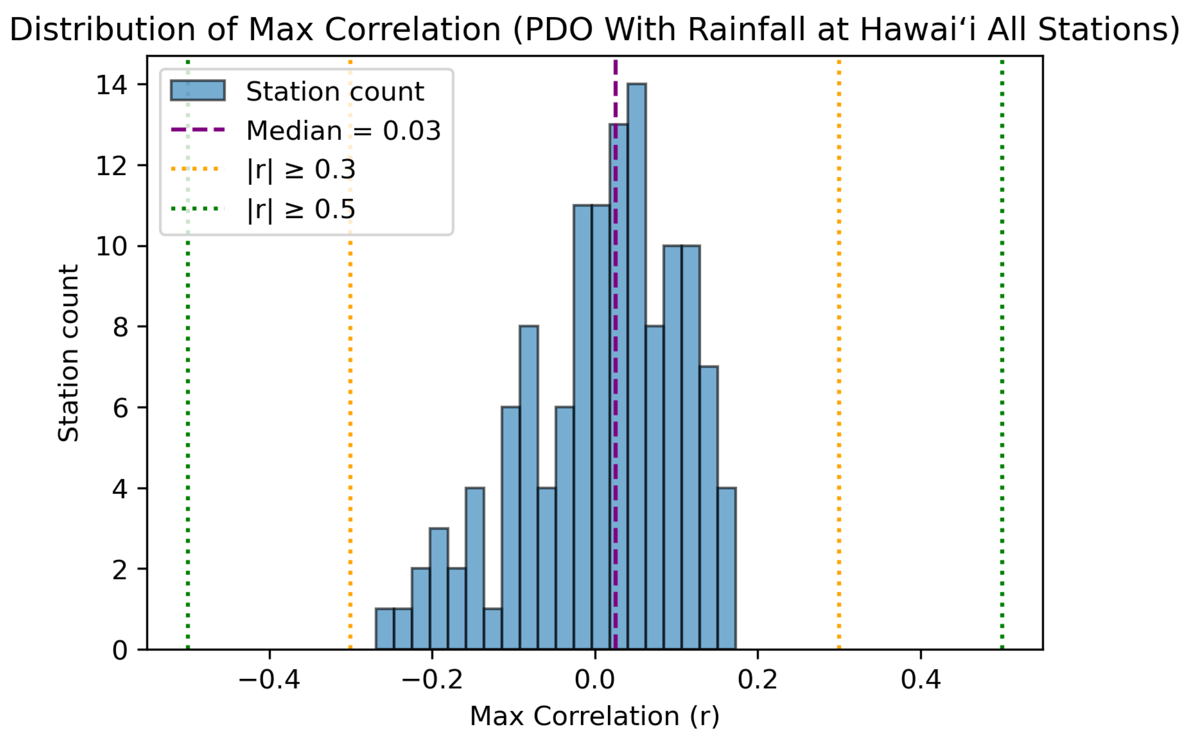

Figure. 4.Distribution of Maximum correlation coefficients of monthly, lag 3-month and lag 6-month PDO for each station

As with Figure 3, it is clear that none of the stations exhibited a significant Pearson correlation between PDO and rainfall at any time scale (including lags), reinforcing the lack of a direct linear association on these short-term scales.

3.1.3 MJO CORRELATION

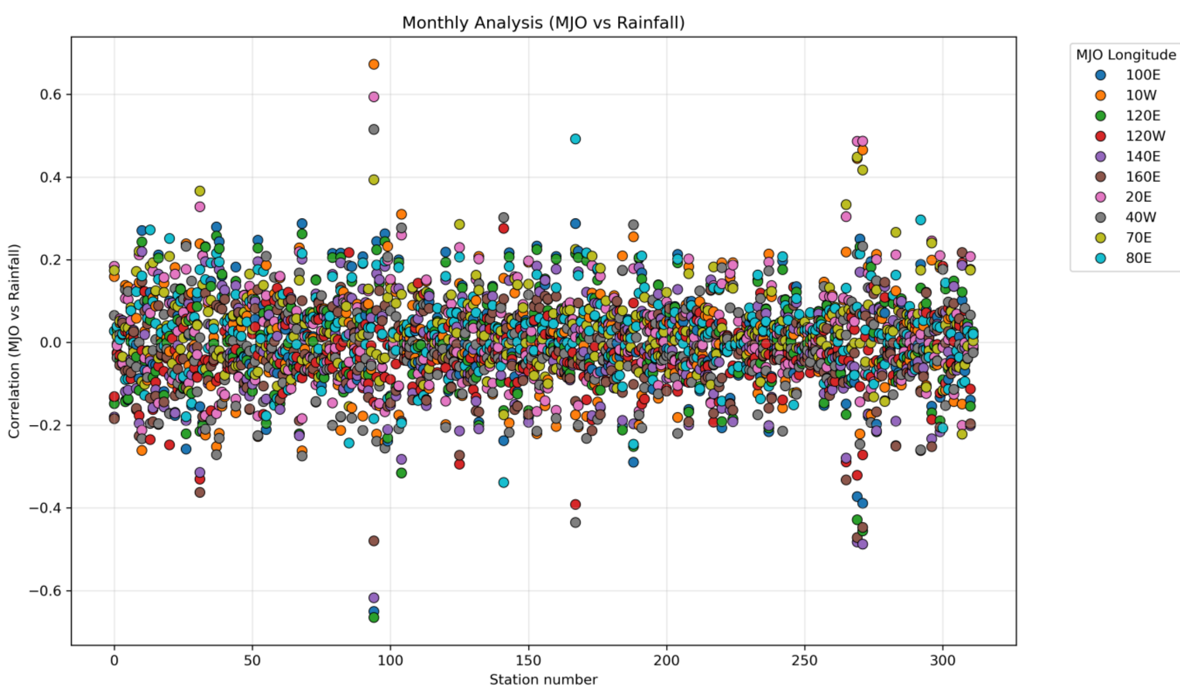

Figure 5. correlation between MJO and rainfall (MJO has values for 10 different longitudes)

The X-axis of Figure 8 shows the number of stations; the different colors represent the MJO indices for different longitudes; and the Y-axis is the Pearson's index representing the correlation with the correlation between MJO and rainfall. It is clear to see that except for a few stations that possess some correlation, the vast majority of stations show no correlation between MJO and rainfall on the time scale of the month, regardless of the longitude of the MJO.

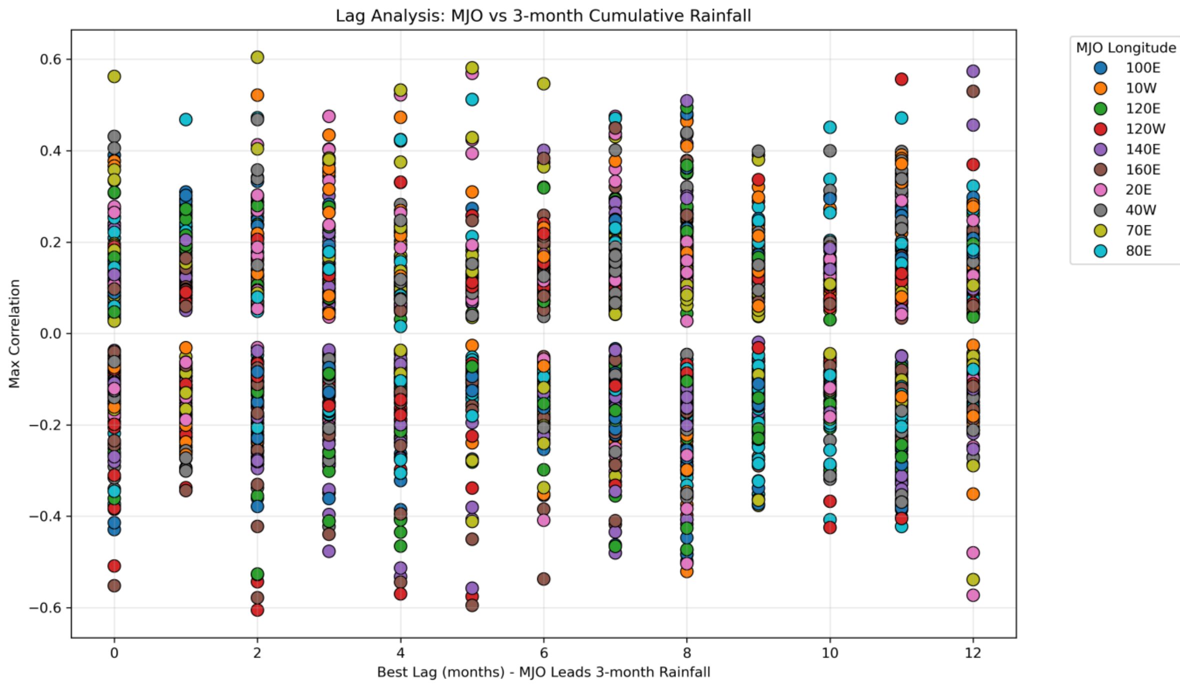

Figure 6. Correlation between rainfall and MJO with 3 months lag.

It can be noticed in the figure that even though a small number of stations have correlations above 0.5, it is still impossible to ignore the fact that most of the correlations between the MJO index and rainfall are below 0.4, indicating that there is still no correlation embodied between rainfall with a lag of 3 months and MJO.

3.2 ANALYSIS OF RAINFALL RATES AT DIFFERENT CLIMATE INDEX STAGES

A portion of stations with more than 6 months of consecutive vacancies and months with a climate index of 0 were excluded from the analysis of rainfall rates at 358 stations greater than 60

Months. Changes in average monthly rainfall rates at different phases of the climate index were calculated;

3.2.1 ONI AND RAINFALL RATE

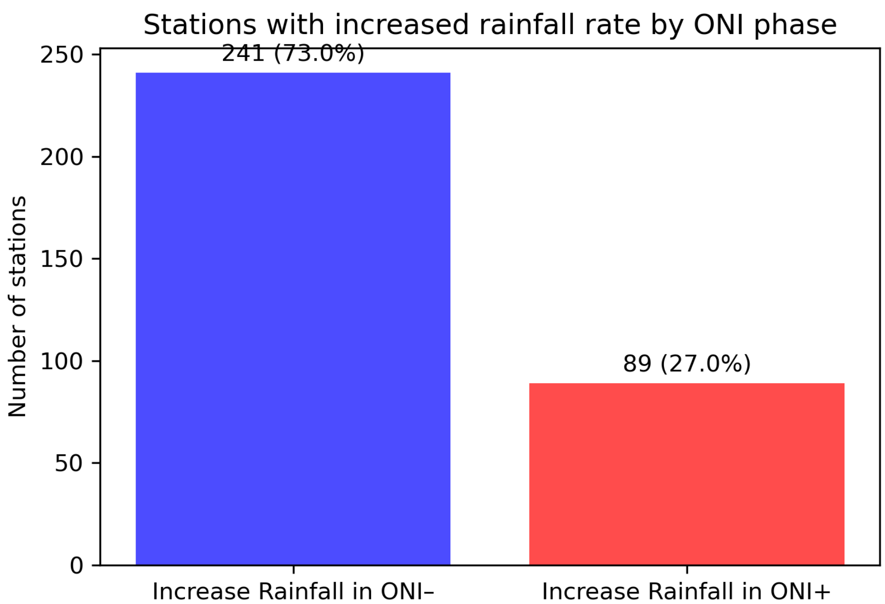

Figure 7.1 Increase in rainfall rates at sites by ONI- and ONI+ stages at different time scales (monthly)

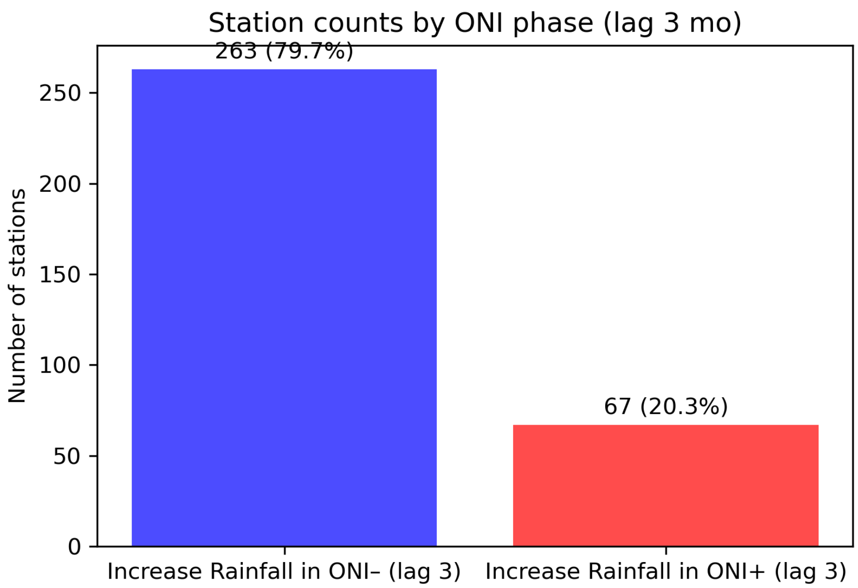

Figure 7.2 Increase in rainfall rates at sites by ONI- and ONI+ stages at different time scales (3 month lag)

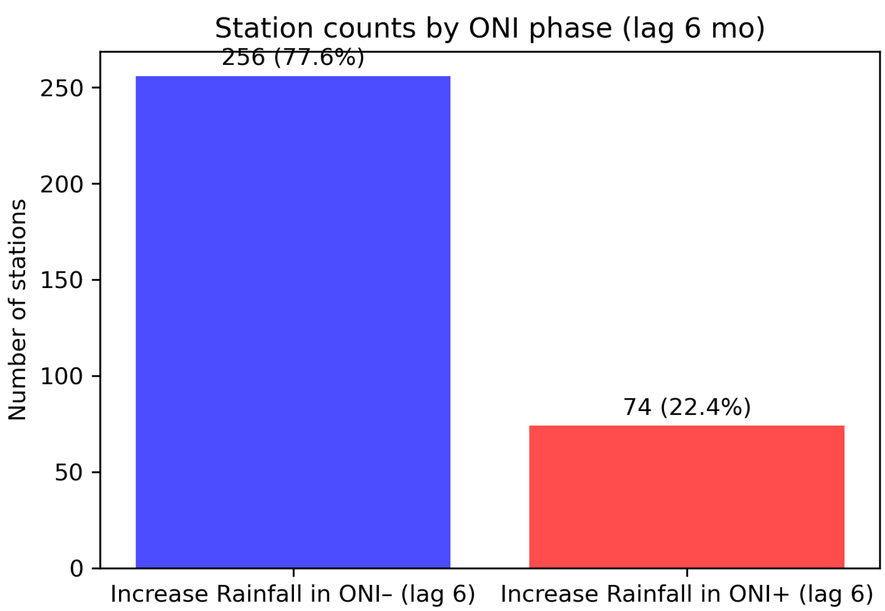

Figure 7.3 Increase in rainfall rates at sites by ONI- and ONI+ stages at different time scales (6 month lag)

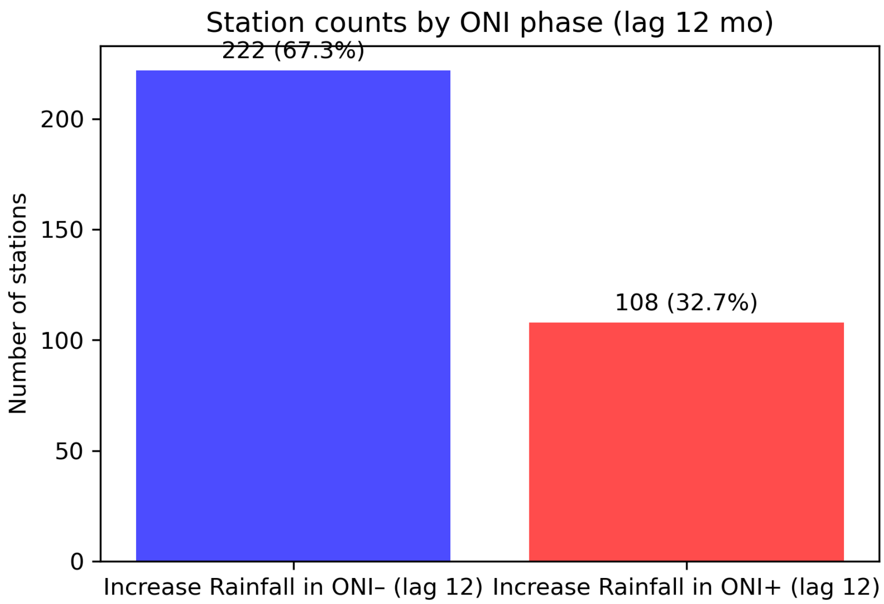

Figure 7.4 Increase in rainfall rates at sites by ONI- and ONI+ stages at different time scales (12 month lag)

The bar graphs indicate how many stations show an increase in rainfall compared to the average rainfall rate when the ONI is in a negative or positive phase. It can be clearly seen in plots 1-4 of Figure 7 that more Hawaii rainfall sites show an increase in rainfall when the ONI is in a negative phase and fewer percentage of sites show an increase in rainfall rate when the ONI is in a positive phase, both in comparisons for the current month and in comparisons that cover comparisons under the lag.

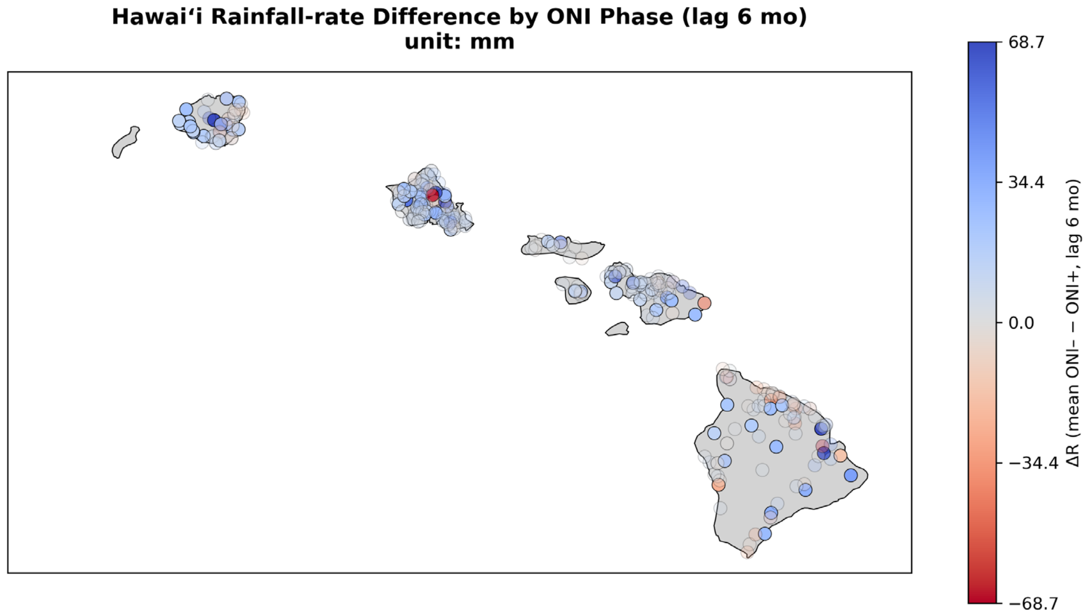

Figure 8. Numerical display of lagged 6-month rainfall rates for stations in Hawaii during positive and negative ONI phases.

The blue dots indicate that the station had an increase in rainfall rate during the negative phase of the ONI, and the red markers color the increase in rainfall rate during the positive phase of the ONI; it can be seen in the figure that not only do the blue stations make up the majority of the stations (as evidenced by Figure 7.3, and as evidenced by Figure 8, which is a geo-visualization of Figure 7.3), but also that there are quite a few increases in the rainfall rate. It can be shown that over the last 50 years, most of the Hawaii rainfall stations show a generalized increase in rainfall rate of 0-68.7 mm/month when the negative phase of the ONI occurs (lag month 6). The increased rainfall during ONI negative phase may be attributed to the contraction of the east-Pacific Walker circulation weakening, which facilitated the arrival of rain systems such as the Kona Low and cold fronts to Hawaii (National Oceanic and Atmospheric Administration, 2022). Administration, 2022).

Historical observations also support that La Niña events are typically associated with above-average rainfall in Hawaii (O'Connor et al., 2015)."

3.2.2 PDO AND RAINFALL RATE

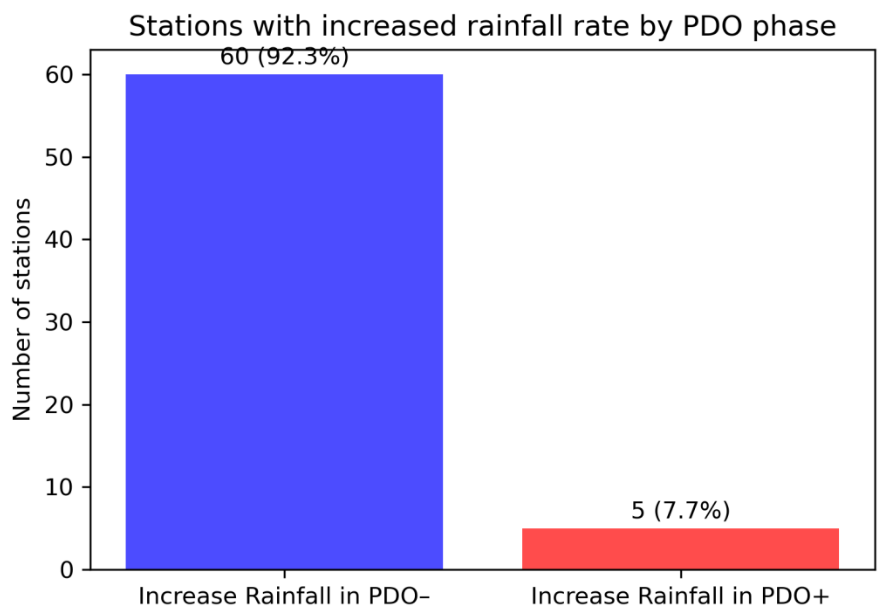

Figure 9.1 Increase in rainfall rates at sites by PDO- and PDO+ stages at different time scales (monthly)

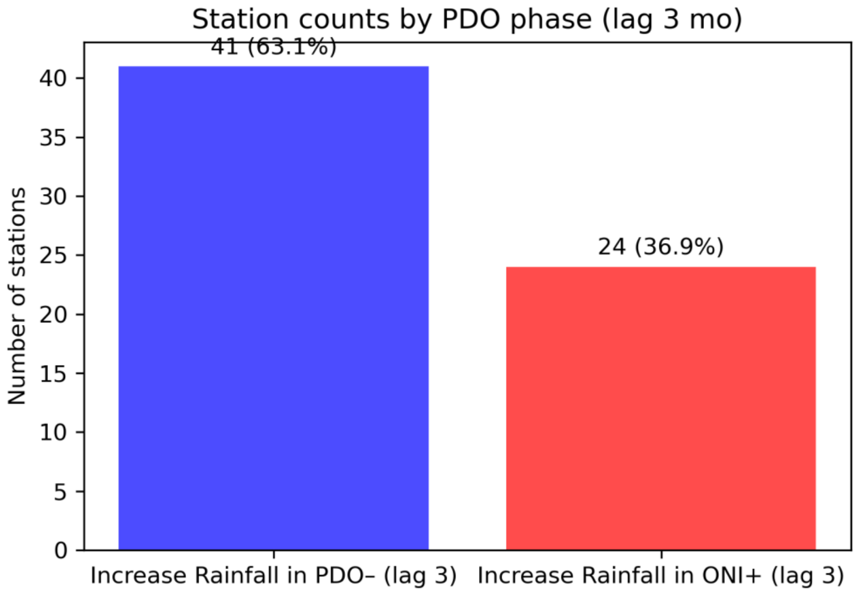

Figure 9.2 Increase in rainfall rates at sites by PDO- and PDO+ stages at different time scales (3 month lag)

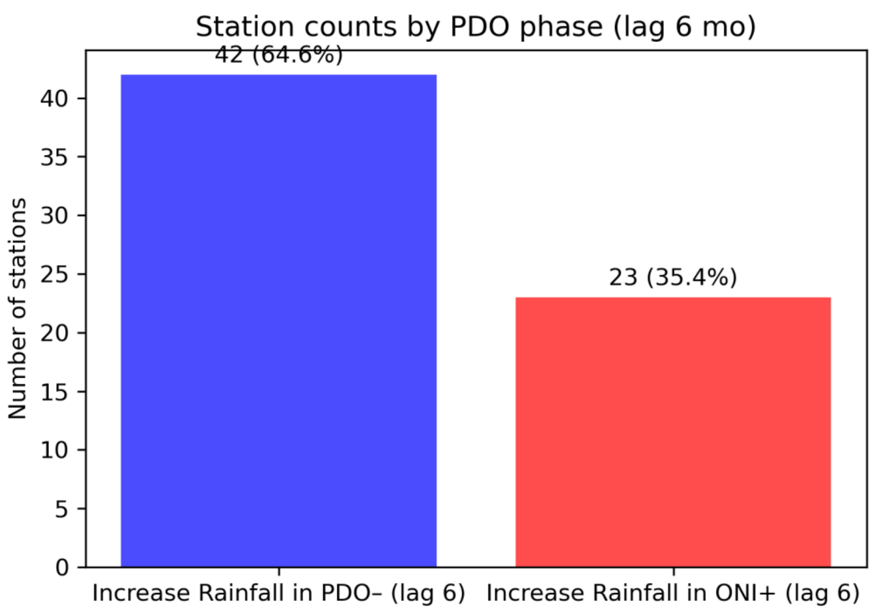

Figure 9.3 Increase in rainfall rates at sites by PDO- and PDO+ stages at different time scales (6 month lag)

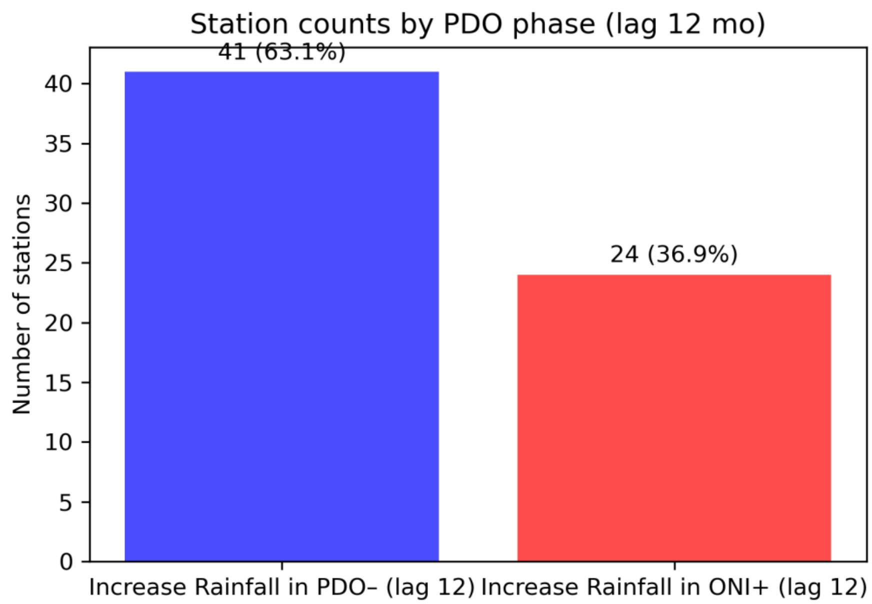

Figure 9.4 Increase in rainfall rates at sites by PDO- and PDO+ stages at different time scales (12 month lag)

It is clear from plots 1-4 in Figure 9 that when the ONI is in the negative phase, more Hawaii rainfall sites show increased rainfall, while when the ONI is in the positive phase, the percentage of sites with increased rainfall is lower, both for the current month's comparisons and for comparisons that cover comparisons under the lag.

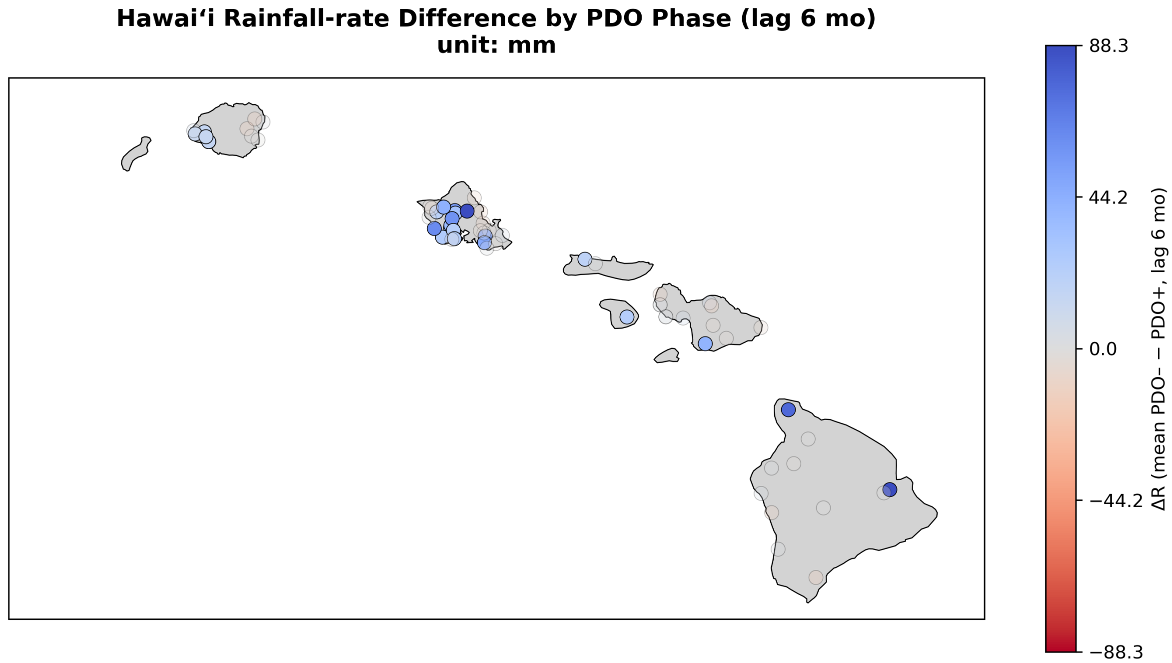

Figure 10. Numerical display of lagged 6-month rainfall rates for stations in Hawaii during positive and negative ONI phases.

The visualization of Figure 9.3 at Figure 10 shows that although there is a 35.4% share of PDO positive phase stations in Figure 9.3, the increased rainfall rates are all so small that it is not even possible to see in Figure 10 which stations are in red (PDO positive phase, increased rainfall rates); similarly, the majority of the stations are in the blue (PDO negative phase, increased rainfall rates) case. This further suggests that the Hawaii region is more susceptible to receiving a negative phase of the PDO, which results in increased rainfall rates at most of the Hawaii rainfall stations.

3.2.3 MJO AND RAINFALL RATE

The MJO, as a climate index that affects rainfall more directly than the SST, usually has an effect on rainfall 4-6 weeks after the MJO is changed. It has a shorter lag time than ONI and PDO. Therefore, when analyzing the MJO index, only the change between the positive and negative MJO phases and the monthly rainfall rate for the lag one month in this analyzed. Also out of the 10 different MJO index regions, 120W longitude and 140E longitude were selected for analysis as these are the two closest intervals to the Hawaiian Islands.

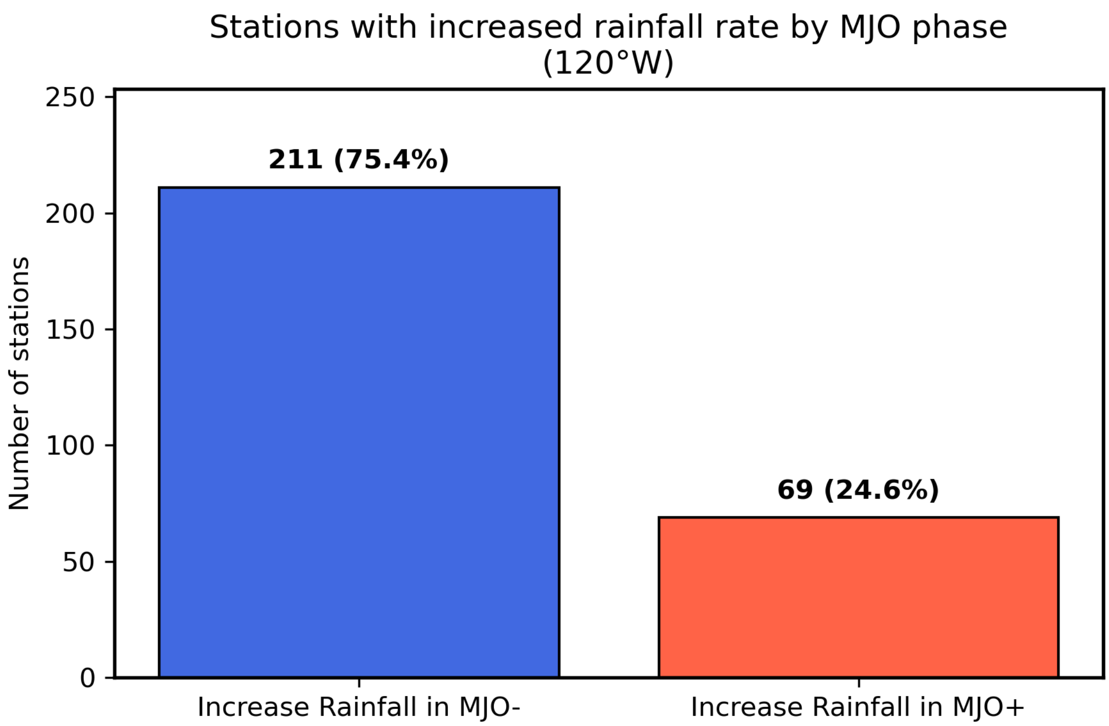

Figure 11.Percentage of rainfall rate under positive and negative phases of the MJO index at longitude 120W.

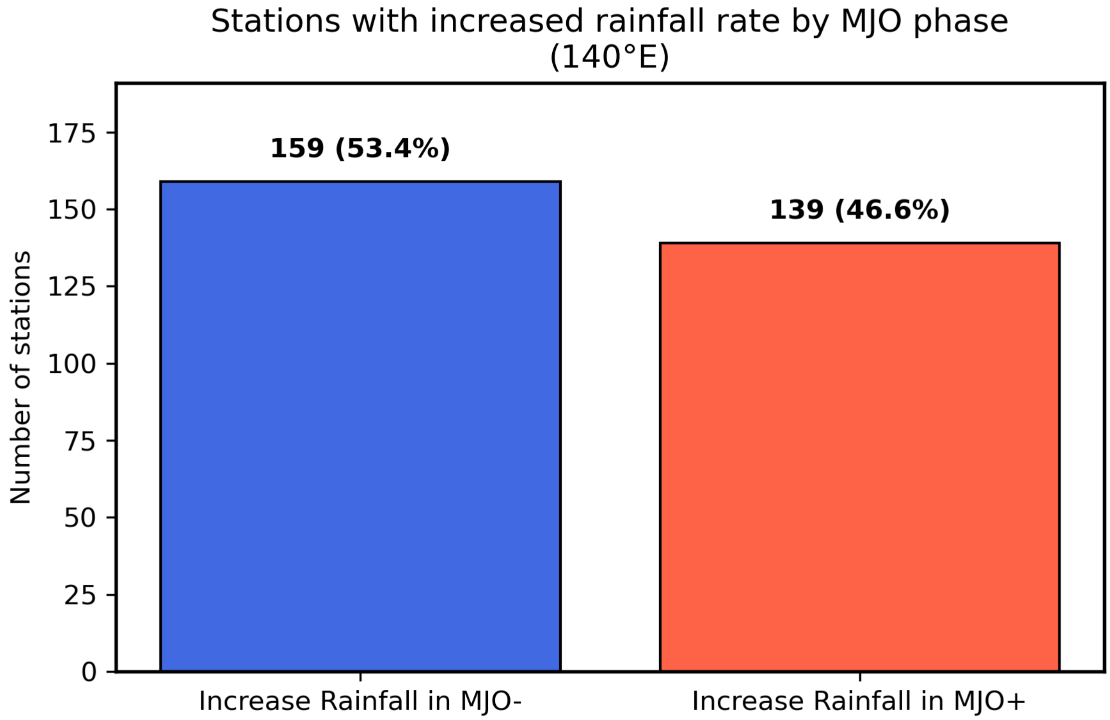

Figure 12. Percentage of rainfall rate under positive and negative phases of the MJO index at longitude 140E.

	120W MJO- (mm/month)	120W MJO+ (mm/month)	140E MJO- (mm/month)	140E MJO+ (mm/month)
Mean value of increase in rainfall rate for different phases	27.04	14.49	19.64	18.18

Table 1. Mean monthly increase in rainfall under positive and negative phases in different longitude areas.

Figure 11. shows the distribution of stations whose monthly mean rainfall rate increases during the negative (MJO-) and positive (MJO +) phases of the MJO centred at 120 °W.A total of 211 sites (75.4%) recorded higher rainfall during the MJO- phase, while 69 sites (24.6%) recorded higher rainfall during the MJO+ phase. the average increase (ΔR) during the MJO- phase (27.04 mm month-^{1}) was almost double that of the MJO+ phase (14.49 mm/month). The average increase (ΔR) during the MJO negative phase (27.04 mm/month) was almost double that during the MJO+ phase (14.49 mm/month). This apparent dominance of the negative phase suggests that convection associated with MJO negative events in the eastern Pacific effectively enhances moisture transport to the islands. However, the share of positive and negative phases of the MJO at 140E longitude is more evenly divided, while the magnitude of the response is smaller compared to the 120W MJO, suggesting that the eastern Pacific MJO negative event produces the clearest enhancement of

rainfall in Hawaii.

The results of this study show:

Data sufficiency: 97.81% (358) of the 366 sites had data older than 60 months, which was sufficient to support reliable lagged correlation analysis.

Correlation analysis: Most of the sites showed weak or no correlation between rainfall and ONI and PDO on monthly, 3-month and 6-month cumulative time scales. Only a few sites showed moderate correlation on the 3- and 6-month scales.

Rainfall Rate Analytics:

ONI：

Rainfall increases by a greater percentage occurring when the ONI is in negative phase, regardless of the time scale (0, 3, 6, 12 month) and Over the past 50 years, most Hawaii rainfall stations have increased rainfall by 0-68.7mm/month when ONI negative phases have occurred(on lag 6 month scale).

PDO：

Rainfall increases by a greater percentage occurring when the PDO is in negative phase, regardless of the time scale (0, 3, 6, 12 month) and Over the past 50 years, most Hawaii rainfall stations have increased rainfall by 0-88.3mm/month when PDO negative phases have occurred(on lag 6 month scale).

MJO：

At 120 °W, a full three-quarters of the stations recorded higher rainfall (27 mm/month) under MJO- conditions, while at 140 °E the distribution was more even (~53 % MJO- vs. ~47 %), while the magnitude of the increase in rainfall rate also appeared to be more evenly distributed over the positive and negative phases (~19-18 mm/month). This confirms the negative MJO This confirms that the negative phase of MJO 120W - especially when centered in the eastern Pacific - has the strongest and broadest positive impact on rainfall in Hawaii, whereas the feedback at 140E is more evenly distributed.

4.0 DISCUSSION

The results of this study show weak or inconsistent correlations between rainfall patterns in Hawai‘i and the Oceanic Niño Index (ONI) and the Pacific Decadal Oscillation (PDO), particularly on monthly, 3-month, and 6-month cumulative time scales.

4.1 LIMITED EFFECT OF ONI ,PDO AND MJO ON RAINFALL IN HAWAI‘I

Correlation analyses showed that rainfall at most Hawaiian stations had no statistically significant Pearson correlation with ONI, PDO, or MJO at any time scale up to 6 months. This is expected because Pearson’s analysis only reflects simultaneous changes, and Hawai‘i’s rainfall — driven by seasonal cycles and storm events — does not vary in synchronous with these indices.

However, analyzing rainfall by the climate indices’ phase (positive vs. negative) reveals significant but non-linear differences in rainfall between phases. For the PDO, the negative phase state is more strongly associated with increased rainfall rates when there is no lag effect, and also suggests that there may be a direct link between colder sea surface temperatures (SST) in the North Pacific and enhanced rainfall in Hawai‘i.

4.2 DOMINANCE OF LOCAL CLIMATIC FACTORS

Rainfall patterns in Hawai‘i are strongly influenced by local climatic factors such as trade winds and topography, which may explain the limited influence of large climate indices (Giambelluca and Nullet, 1991; Xie et al., 2001). It has been shown that topographic differences between windward slopes and leeward areas can lead to large spatial differences in rainfall, and that trade wind inversions can further modulate rainfall distribution by limiting the development of vertical clouds, especially between windward and leeward areas (Giambelluca and Nullet, 1991).

These localized processes may mask or diminish the effects of the ONI and PDO, thereby limiting their impact on rainfall in Hawaiʻi.

In addition, Xie et al. (2001) showed that the Hawaiʻian Islands have a significant impact on Pacific ocean-atmosphere interactions through island-induced atmospheric dynamics, potentially altering regional climate patterns. This localized effect further supports the view of this study that Hawaiʻian rainfall patterns are driven more by island-scale climate processes than by global climate indices.

4.3 COMPARISON AND INTEGRATION WITH EXISTING LITERATURE

The findings of this study contrast somewhat with those of O'Connor (2014) and Trenberth & Caron (2000), who concluded that ENSO events have a significant impact on rainfall in Hawaiʻi. However, those studies analyzed climate–rainfall relationships at seasonal to annual scales, whereas this study focused on much shorter time scales (monthly to 6-month periods). The absence of correlation at these shorter scales suggests that the influence of ONI and PDO only becomes apparent when rainfall is aggregated over longer periods (seasonal or annual averages), an approach limited by the relatively short length of most station records. In addition, previous studies may not have adequately considered the dominant role of localized climatic factors in Hawaiʻi, which may have overestimated the impact of large climate indices.

Zhang et al.'s (2016) study emphasized the key role of topography and local processes in Hawaiʻi's rainfall patterns through a high-resolution climate model, which is consistent with the results of this study. This study further confirms the importance of localized climate drivers through empirical data.

4.4 POSSIBLE LIMITATIONS OF THE STUDY

There are a number of limitations to this study that need to be considered when interpreting the results. First, the analysis relies on historical rainfall data and climate indices, which, while a more comprehensive 70-year record, may not adequately reflect long-term variability in the context of climate change, especially in the current context of increased climate change. Second, this study focuses only on ONI and PDO (visualization maps and analytical maps for MJO have not been included) and does not include other climate indices that may affect rainfall in Hawai‘i, which may limit the comprehensiveness of the analysis.

CONCLUSION

This study provides an in-depth analysis of the relationship between rainfall patterns in Hawai‘i and the Oceanic Nino Index (ONI) and the Pacific Interdecadal Oscillation (PDO), and the results indicate that these large-scale climate indices have a limited and inconsistent influence on Hawai‘i’s rainfall when evaluated via direct Pearson correlation; however, notable rainfall differences between the indices’ positive and negative phases point to a non-linear influence. Pearson correlation analyses showed little to no significant linear relationship between ONI or PDO and rainfall at most stations on monthly, 3-month, and 6-month cumulative scales. Even when moderate correlations were observed(MJO) at a few sites, these relationships were unstable and therefore difficult to use as a reliable basis for prediction.

Research further suggests that local climatic factors may play a dominant role in shaping rainfall patterns in Hawai‘i. Hawai‘i's unique geographic and climatic conditions - such as trade winds, topographic differences (windward slopes vs. leeward areas), and the influence of the trade wind inversion layer - greatly influence rainfall variability. The importance of these localized processes in the climate response may go beyond the driving role of global climate phenomena such as the El Niño/Southern Oscillation (ENSO). In the traditional hypothesis, global climate patterns have a significant effect on Hawai‘i's rainfall, but in further analyses, it may be necessary to focus the study to include some element of local climate.

It is recommended that the impact of localized climate factors on rainfall patterns be further investigated in the future, while using high-resolution data and climate models to reveal more detailed rainfall and what other climate factors are associated with it. At the same time, the analysis should be expanded to include other climate indices and to assess the long-term impacts of climate change on rainfall in Hawaiʻi. These directions will provide a solid scientific foundation for the development of more effective climate adaptation strategies in Hawaiʻi.

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