Surface Hydrology (71630)

Final Project

Mount St. Helens, WA, USA

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Introduction

Research Question

What are the short-term and long-term impacts of volcanic eruption at Mount St. Helens on local climate variables (Temperature and Precipitation)?

Location

Mount St. Helens is a volcano located in southwestern Washington state, is one of the most active volcanoes within the Cascade Range, which stretches from British Columbia through Washington and Oregon to northern California. This range forms a segment of the Pacific Ring of Fire, a zone known for its frequent volcanic and seismic activity encircling the Pacific Ocean. (Figure 1) (1).

Eruptions history

For thousands of years, Mount St. Helens has experienced cycle of intense volcanic activity, altering with long period of relative quiet. However, on May 18, 1980, following several months of seismic disturbances and minor eruptions, Mount St. Helens erupted violently, decimating everything in its path. After this significant event, the volcano became active again in 2004 (2). From September 2004 to January 2008, a series of eruptions occurred, primarily characterized by the slow extrusion of lava, which gradually rebuilt the lava dome inside the crater left by the 1980 eruption. These eruptions were less explosive and more contained, with minimal ash emissions compared to the 1980 event. The 2004-2008 activity marked the most recent significant eruptive period, reflecting Mount St. Helens' ongoing volcanic activity in modern times.

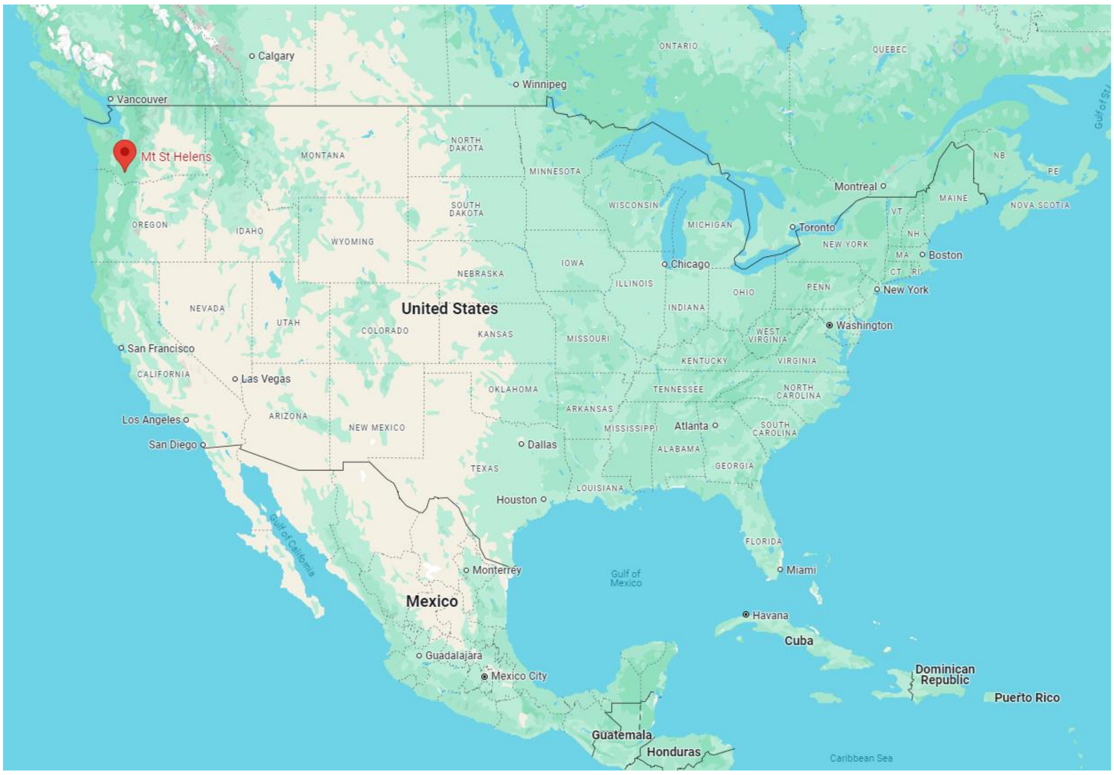

Figure 1: United States Map included the Eruption Site

Volcanic impacts

The 1980 volcanic explosion claimed more than 50 lives, destroyed thousands of acres of land and wiped-out entire ecosystems, both flora and fauna. The eruption sent a massive ash cloud into the atmosphere, obscured the sky over a wide area and dramatically changed the landscape of the mountain and its surrounding areas (2).

Volcanic eruptions can lead to notable changes in surface temperatures, with the most notable changes occurring near the eruption site. While studies show that global temperatures and regional climates were affected for up to 3-5 years, the intensity and duration of cooling varied depending on location and global circulation patterns. Research by Angel and Korshover (1985) indicates that eruptions like Tambora (1815), caused significant and prolonged temperature reduction in areas close to the volcano due to their proximity to the ash cloud and fallout zone (3).

In the immediate aftermath of the May 18 eruption, dramatic **short-term** effects were observed. Robock and Mass (1983) documented **temperature** drops of up to 8°C during the day due to the volcanic dust cloud blocking sunlight, and nighttime temperatures rose by up to 8°C as the dust trapped heat. These changes were short-lived, with daytime cooling persisting for just one day and nighttime warming lasting about two days. Despite this immediate cooling, the overall net effect following the eruption was a temporary warming, contrasting with the **longer-term** cooling typically observed after volcanic events (4).

Precipitation patterns also exhibit distinct short-term and long-term responses to volcanic eruptions. In the **short term**, volcanic eruptions can cause increased precipitation due to enhanced moisture in the atmosphere and changes in cloud formation. This was observed following the eruption of Mount Pinatubo, where significant increases in precipitation were recorded in the months immediately following the eruption (5). However, these short-term effects are often temporary and can be influenced by other factors such as seasonal climate variability.

In contrast, the **long-term** effects on **precipitation** are even less straightforward. Volcanic eruptions can alter atmospheric circulation patterns, potentially leading to shifts in regional precipitation or prolonged drought conditions. These long-term impacts are harder to examine as they may be influenced by complex interactions between global weather patterns and ocean currents (5).

Based on this understanding, my project aims to examine both the short-term and long-term effects of the Mount St. Helens eruption on temperature and precipitation patterns. I hypothesize that the eruption will result in significant short-term cooling and an increase in precipitation due to the ash released into the atmosphere This cooling is expected to persist for a few days. For the long term, I expect that the eruption will lead to sustained cooling in the local areas, similar to those observed in other volcanic events, potentially lasting several years to a decade. This cooling will likely not be dramatic as the initial drop but could still have a noticeable impact on local climate. In term of precipitation, I hypothesize a long-term decrease in precipitation, though this effect will likely be less pronounced.

Methods

To investigate the short and long-term impacts of the Mount St. Helens eruptions on local climate variables, I utilized data from NOAA (National Oceanic and Atmospheric Administration) weather stations. Two stations were selected for analysis: Quinault (47°30'36"N, 123°48'36"W) and Paradise (46°47'11"N, 121°44'32"W). Quinault was chosen for analyzing meteorological parameters related to the Penman-Monteith equation, while Paradise was used for all the other analyses. These stations were selected due to their proximity to the eruption site and their extensive historical data. The distance between the two stations is approximately 150 km. Paradise is about 80 km far from Mount St. Helens, whereas Quinault is approximately 200 km away (Figure 2).

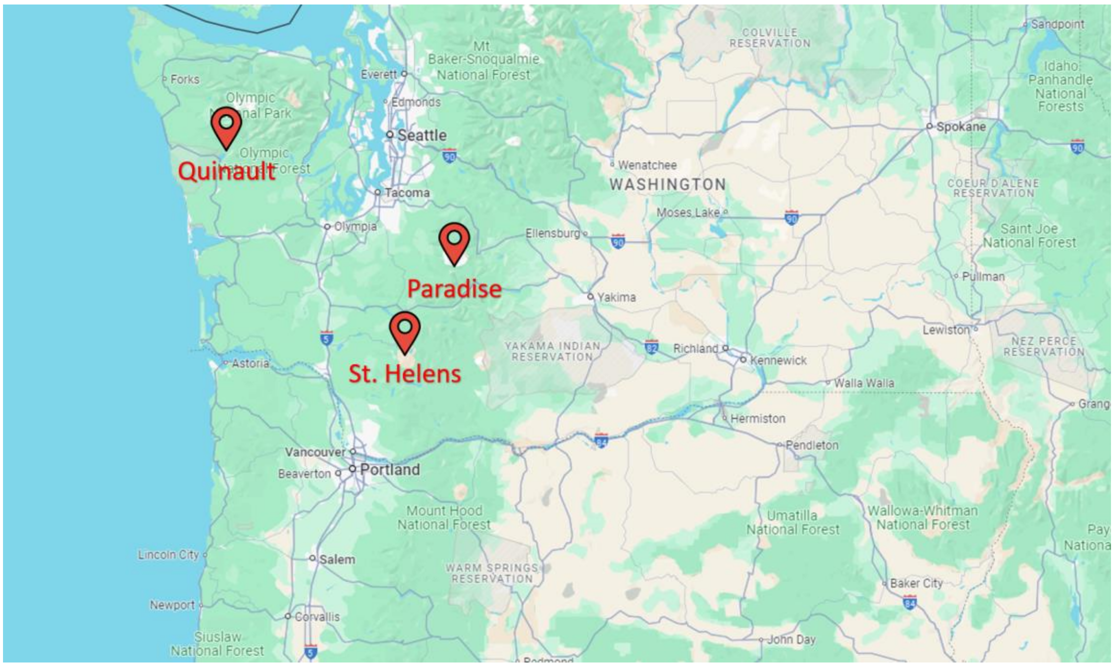

Figure 2: Washington Map included Stations Location and the Eruption Site

Data processing and analysis were performed using Python, with valuable assistance from OpenAI's ChatGPT. This support included help with language refinement and spelling, as well as guidance in structuring the code. The analysis aimed to examine changes in temperature and precipitation patterns before, during, and after the eruption to identify any significant deviations attributable to the volcanic event. Data was visualized to observe trends and correlations, ensuring a comprehensive understanding of the eruption's climatic impacts.

Results & Discussion

Our analysis of the impacts of the 1980 Mount St. Helens eruption on local climate reveals both long-term and short-term effects on precipitation and temperature patterns.

1. Long-Term Impacts

1.1 Precipitation

1.1.1 Seasonal Changes

Figure 3, displays the monthly average data for Paradise station, while the blue boxes represent the overall data from 1920 to 2023, the pink one represents the period before the eruption, while the green is for the period after the eruption. As shown in the graph, the overall seasonality of precipitation near Mount St. Helens remains largely unchanged after 1980 eruption. The general pattern, with the wettest months occurring between October and March, is consistent across both the pre-eruption and post-eruption periods. The driest month, July, remains the same across all time scales, demonstrating no significant shift in seasonal dryness. According to the National Weather Service (6) Washington state's hydrological year starts on October 1st, and while the Western Washington typically receives above-normal precipitation, which aligns with the data presented in Figure 3.

When comparing two time-scales (pre and post eruption), notable changes in precipitation amounts are observed. The largest difference is observed in **November**, where the average precipitation increased from around **300 mm before the eruption** to approximately **420 mm per month afterward**. Another significant change is seen in **March**, with an increase of about **60 mm** after the eruption. These monthly differences contribute to a small but measurable increase in the total yearly average precipitation, which rose by **23 mm** post-eruption. Overall, it appears that most months in the post-eruption period show an increase in precipitation, except for the driest months (July-September), which show a slight decrease.

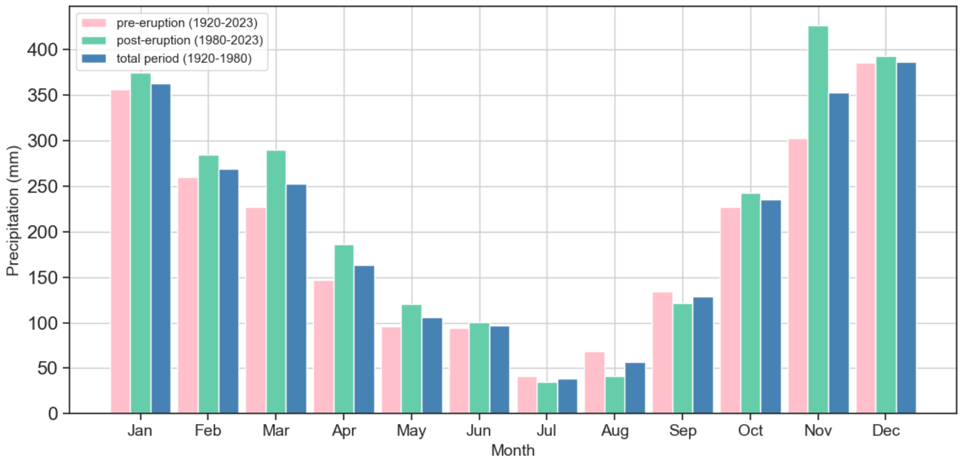

Figure 3: Monthly Average Precipitation, Paradise (Mount St. Helens)

1.1.2. Inter-Annual Variability

Figure 4 displays the daily precipitation data from 1920 to 2023. The graph reveals a very slight change in the long-term trend of daily precipitation rates over this period, with a modest increase. Notably, most of the extreme precipitation events occurred after the 1980 eruption, with the most extreme event recorded on November 6th, 2006, where the daily precipitation reached 287 mm. This extreme event was also documented as the wettest recorded day by NOAA's report. This event caused many floods in the whole state, as well closing the National Park for more than 6 months, even though the rain lasted only 36 hours (7). As mentioned in the introduction, the latest volcanic activity occurred between 2004 and 2008, which may explain this significant precipitation event, even though I couldn't find any connection between those two events in the literature. However, other factors, such as climate variability, regional weather patterns, or even human influence, could also contribute to this anomaly. The small increase in the average daily precipitation could be also partly attributed to the gaps in data collection around the 1940s and 1950s. The absence of complete records during these periods may skew the overall trend, underestimating the average precipitation in earlier decades and thereby making the increase in recent years appear more pronounced.

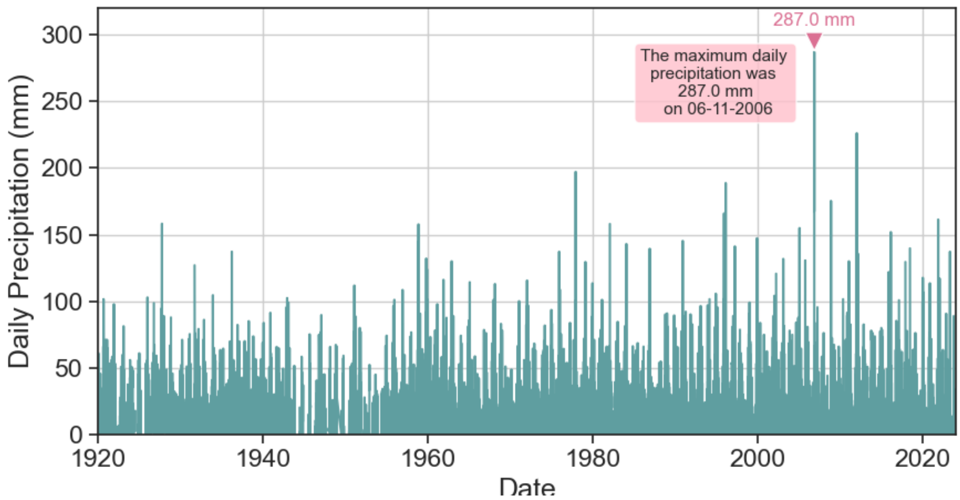

Figure 4: Daily Precipitation along 1920-2023, Paradise (Mount St. Helens)

1.1.3. Extreme Precipitation Events

In Figure 5, the top panel presents the Probability Density Function (PDF) for daily maximum precipitation at Paradise, while the bottom panel illustrates the Cumulative Distribution Function (CDF). The Generalized Extreme Value (GEV) distribution generally fits the data well, capturing the overall trend. However, a notable discrepancy is observed in the 200-300 mm bin of the PDF, where the observed values exceed those predicted by the GEV model. This deviation suggests that the GEV distribution underestimates the frequency of very rare and extreme precipitation events.

Interestingly, approximately four extreme rainfall events occurred in this range, with three happening after the eruption, potentially indicating a shift in climatic conditions that may influence these deviations from the GEV model.

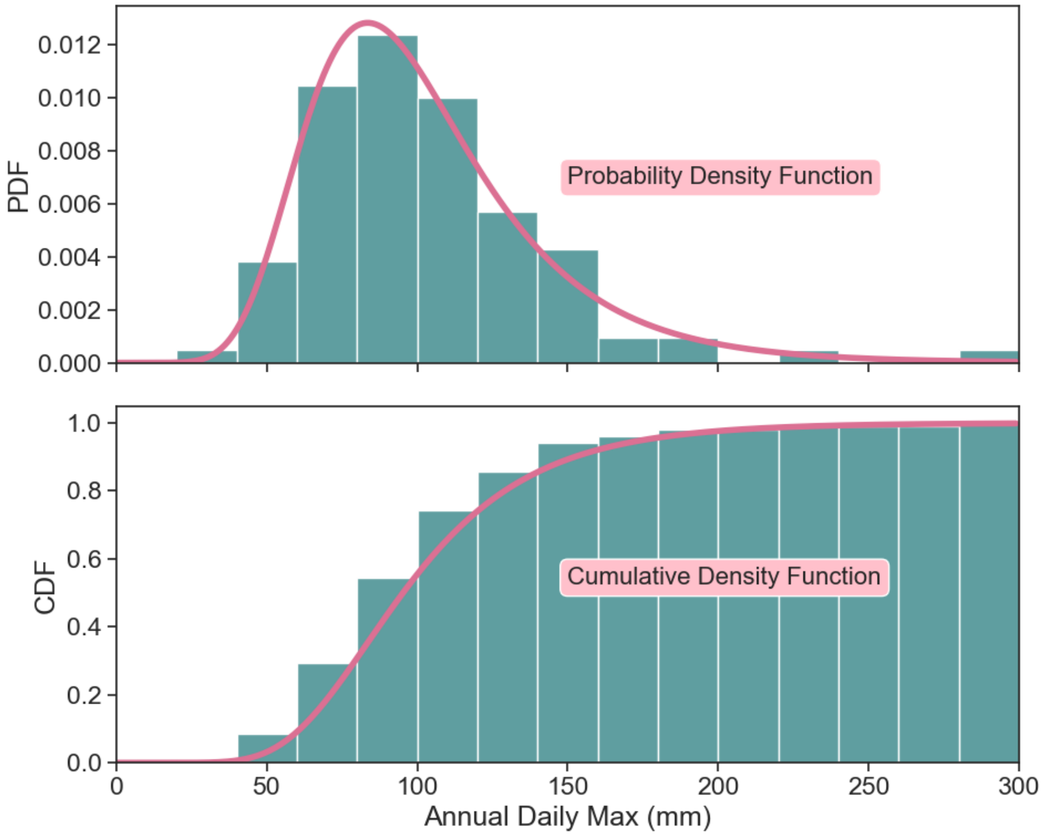

Figure 5: Probability and Cumulative Density Function of Annual Daily Maximum Precipitation, Paradise (Mount St. Helens)

1.1.4. Return period

Figure 6 shows the relationship between the annual maximum daily precipitation and their corresponding return periods, with observed data points and GEV distribution line. The GEV model generally follows the observed data well, particularly for events with shorter return periods. However, several instance, including the most extreme event, significantly exceed the GEV predictions. Notably, as seen in Fig 4, most extreme events accrued after the 1980 eruption, with the most significant event happening during the latest eruption period (2004-2008). This pattern suggests that volcanic activity may have influenced the precipitation extremes, which are not fully accounted for in the GEV model, or that extreme events at general are harder to predict.

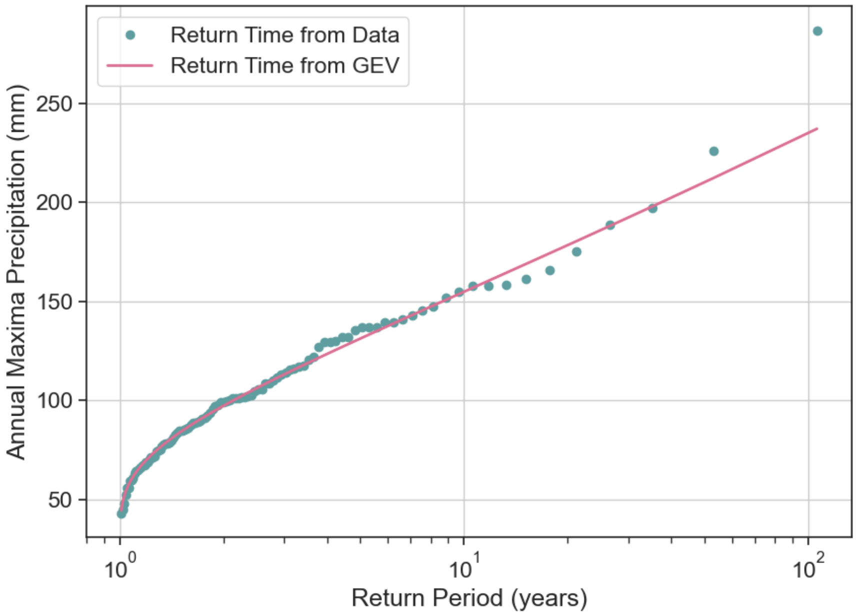

Figure 6: Annual Maximum Precipitation and Return Period: Observed Data and GEV Model, Paradise (Mount St. Helens)

Table 1 shows the expected maximum daily precipitation values for different return periods. For instance. Notably, the extreme precipitation event that occurred on November 2006 (Fig 4), with an observed precipitation of 287 mm, matches the 500-years return period, classifying it as a rare 500-year event.

Period (years)	Level (mm)
5	129.1
10	152.3
20	175.2
50	206.0
100	229.7
500	287.3

Table 1: Precipitation Return Levels

1.2.Temperature

1.2.1. Seasonal changes

Figure 7 illustrates the monthly averaged minimum and maximum temperatures recorded at the station, comparing the periods before (blue) and after (red) the 1980 eruption. As with precipitation, the overall temperature seasonality remains relatively consistent across both time periods. with the warmest months being June to September and the coldest months from November to February which is also the wettest months as shown in figure 3. For the minimum temperatures (the lower lines), the post-eruption period consistently shows higher values across almost all months, this could suggest that the eruption contributed to a milder climate in the colder months. On the other hand, the maximum temperatures display more varied changes, but mostly it seems that it decreased except of August, the warmest month, shows an increase in the maximum temperature, as well as January, the coldest month.

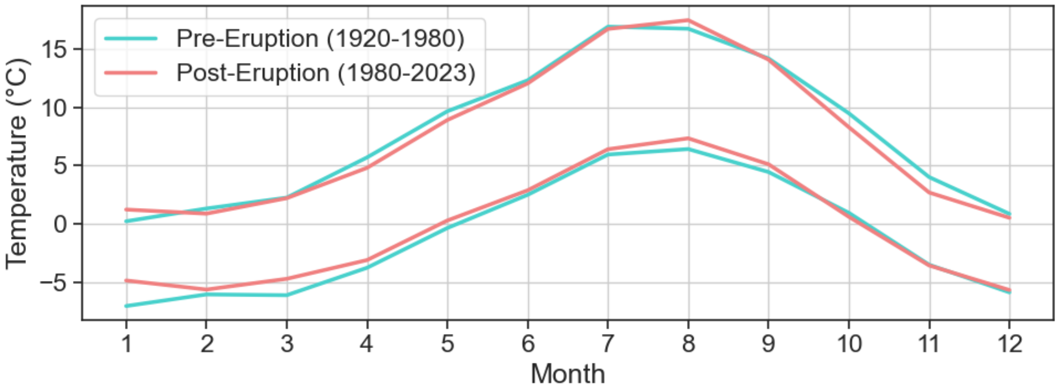

Figure 7: Monthly Averaged Minimum and Maximum Temperatures, Paradise (Mount St. Helens)

1.2.1. Annual Trends

Figure 8 shows the annual minimum (blue) and maximum (red) averaged temperatures undergoing changes through the century. To better analyze long-term temperature shifts before and after the eruption, a 10-year rolling average was applied to smooth short-term fluctuations, and emphasize broader trends. Up until the 1950s, there is a distinct warming, followed by significant cooling, which stabilize around the 1970s and balances out until approximately the 1980s. post-1980, a slight warming trend is evident, with maximum temperatures showing more pronounced variations than minimum temperatures, aligning with the observations in figure 7. This suggests a gradual warming post-eruption. The highly fluctuations around the 1950's can be attributed to the missing data in those years.

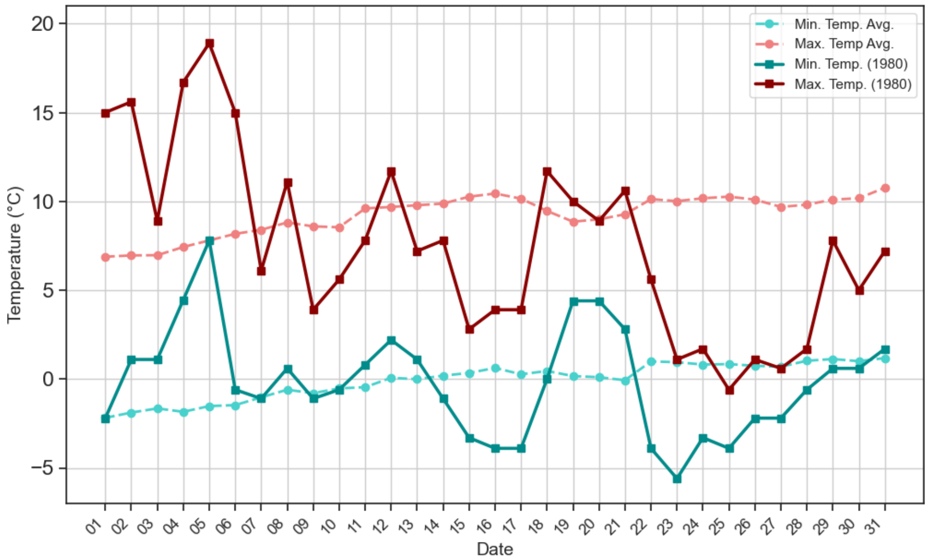

Figure 8: Annual Average Maximum and Minimum Temperatures (1920-2023), with 10-year Rolling Averages, Paradise (Mount St. Helens)

2. Short-Term Impacts

2.1.Precipitation

2.1.1. Seasonality, 1980 vs. different time-scales

For analyzing the short-term impact on the precipitation, it is needed firstly to understand how did the specific eruption year (1980) compared to the total average. For that so Figure 9 compares the monthly precipitation averages for the entire period (1920-2023) with the monthly averages specifically for the eruption year (1980). The graph shows that in most months, the precipitation levels in 1980 were generally higher than the long-term average, particularly in November and December. It suggests that 1980 experienced unusually higher precipitation compared to the other years, but on October for some reason it shows the opposite, when the 1980 precipitation average was lower than the entire period. For all that in said it is difficult to attribute these differences directly to the 1980 eruption based on this data alone, so more analyze is needed.

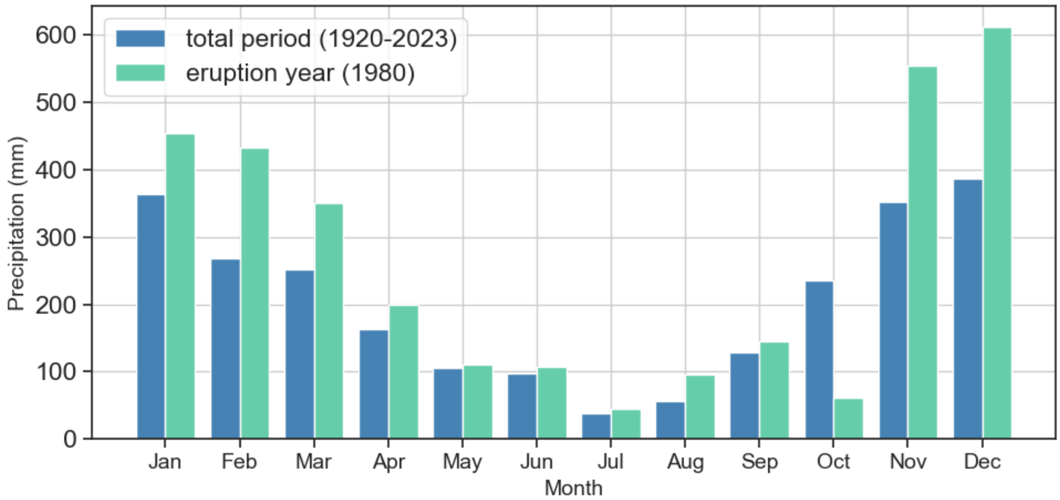

Figure 9: Monthly Precipitation Comparison Between 1920-2023 Average and 1980, Paradise (Mount St. Helens)

When comparing the 1980 precipitation (– light-green) to the years before (1978-1979 – red) and after (1981 – dark-green), Figure 10 shows no clear trend. In some months, like January and March, 1980 has higher values, but in other months, such as April, July, and October, it shows lower values. Overall, from Figure 10, we don't see any specific pattern or significant trend in the short term.

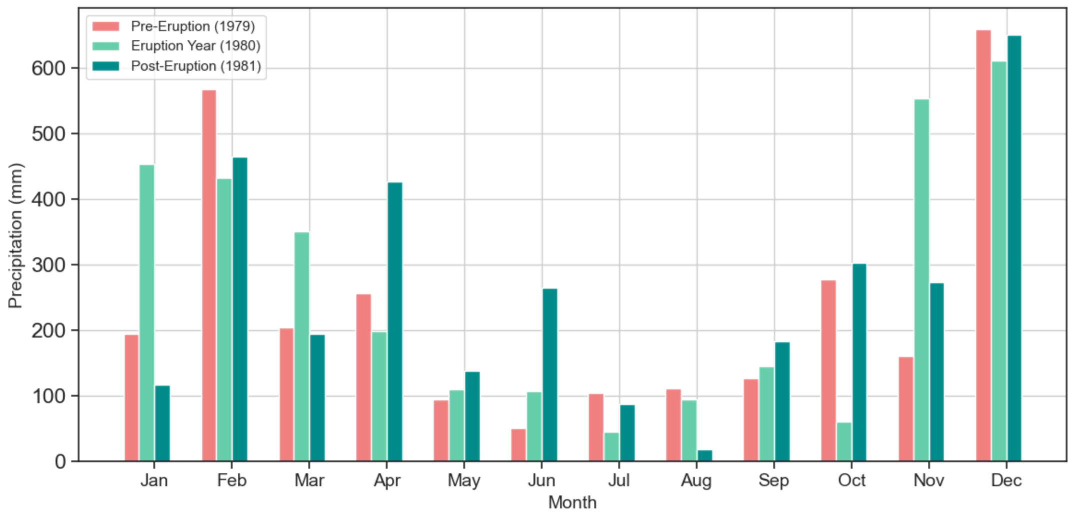

Figure 10: Monthly Precipitation Comparison Between 1978-1981 Around the 1980 eruption, Paradise (Mount St. Helens)

2.1.2. Daily Changes at the Eruption Month

When scaling-up for analysis for the eruption month – May – Figure 11 shows that the daily average precipitation for May is generally stable over time. However, a closer look at 1980 reveals significant deviations compared to surrounding years. Precipitation remained low before May 18, 1980, but increased sharply a few days later, with notable picks toward the end of the month. This contrasts with 1979 and 1981, which also have lower mid-month precipitation but lack the pronounced post-eruption spikes seen in 1980. In fact, the daily precipitation peak on May 27, 1980, 9 days after the eruption, is almost double that of the other years in this period. While this may not definitively indicate a direct link to the eruption, it suggests the possibility of a disruption in weather patterns following the event.

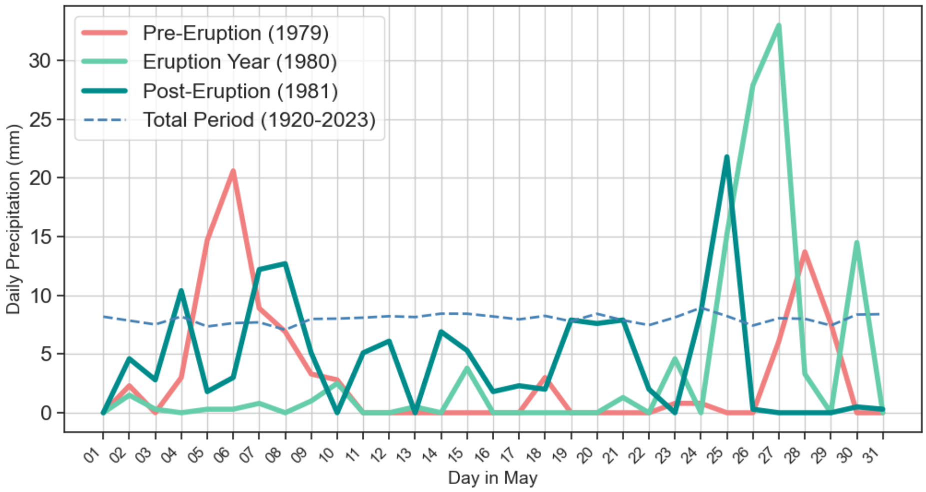

Figure 11: Daily Precipitation in May: 1979–1981 Compared to the Long-Term Average (1920–2023), Paradise (Mount St. Helens)

2.2. Temperature

2.2.1. Seasonality, 1980 vs. different time-scales

In Figure 12, we compare the monthly average temperatures two years before (blue) and two years after (red) the 1980 eruption, when the higher lines are for the maximum temperatures, and the lower for the minimum which measured. A notable trend is the slight cooling in post-eruption temperatures. Although most monthly temperatures decreased, the winter months from November to February show an opposite trend of warming. Overall, we can suggest that the eruption made the winter warmer, and the summer cooler in the short-term.

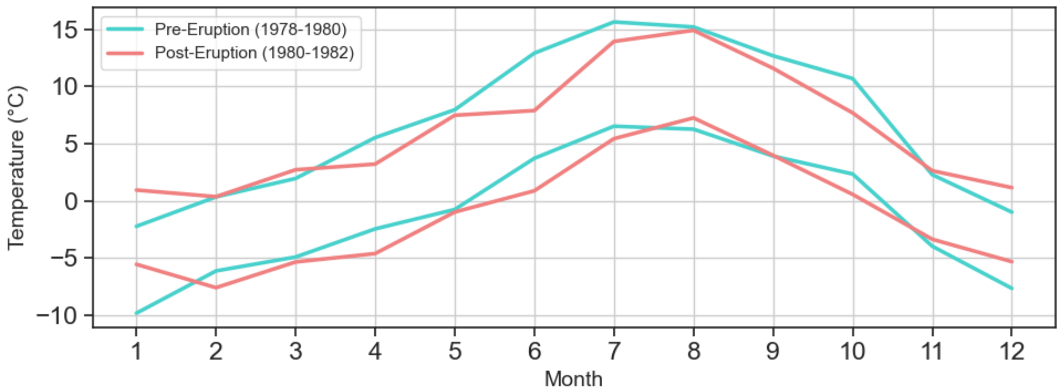

Figure 12: Monthly Min & Max Temperature Comparison Between Pre- (1978-1980) and Post-Eruption (1980-1982), Paradise (Mount St. Helens)

2.2.2. Daily Changes at the Eruption Month

Figure 13 presents a comparison between the daily minimum and maximum temperatures recorded in May 1980 at Paradise, and the long-term average (1920-2023) for the same period. The temperature trends around the eruption are particularly significant. On the day of the eruption, there was a noticeable increase in both minimum and maximum temperatures, but the day following exhibited a cooling in the maximum temperature while the minimum temperature remained elevated. This pattern aligns with findings by Robock and Mass [], who observed a similar response in stations directly beneath the ash cloud. Robock and Mass explain that the eruption's ash cloud initially caused daytime cooling by blocking sunlight, but this was followed by nighttime warming as the cloud trapped heat closer to the surface. They noted that "the cooling effects of the volcanic cloud lasted for only 1 day, while the nighttime warming persisted for at least 2 days" (5). In my analysis, this effect appears slightly delayed, likely due to the specific conditions at the Paradise station. Factors such as wind patterns influencing the ash cloud's movement, or the station's high elevation (1650 m above sea level) compared to the lower-altitude stations measured by Robock and Mass (e.g., Toledo and Kelso-Longview), could contribute to this discrepancy. Additionally, the Paradise station only provides daily measurements of minimum and maximum temperatures, which may limit the ability to capture more immediate, short-term effects seen in sub-daily measurements.

Overall, while the temperature anomalies at Paradise do not perfectly match those closer to the eruption site, the general trends – daytime cooling (indicated by the maximum temperatures) followed by nighttime warming (reflected in the minimum temperatures) – are consistent with the volcanic ash effects observed in similar studies.

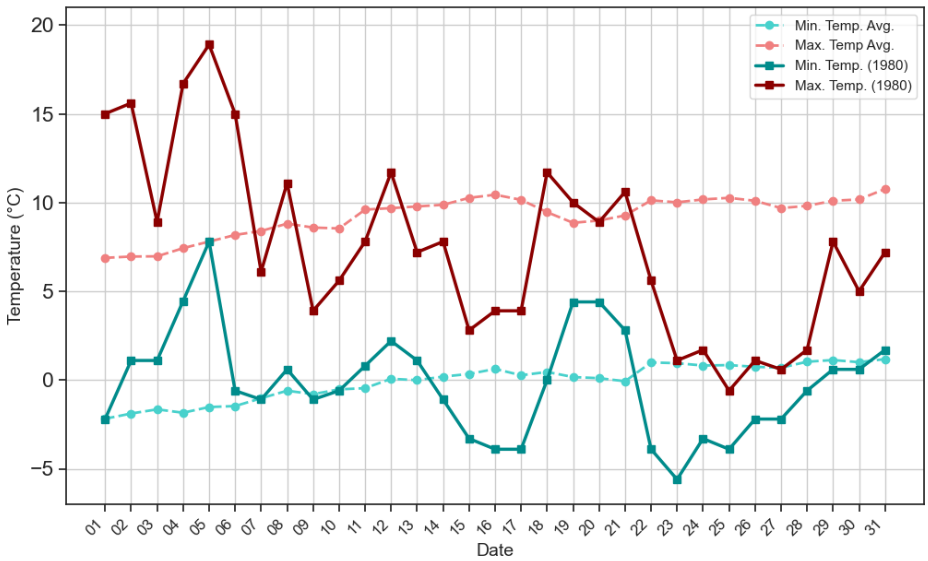

Figure 13: Daily Minimum and Maximum Temperature in May: 1980 Compared to the Long-Term Average (1920–2023), Paradise (Mount St. Helens)

3. Evapotranspiration (ET)

Figure 14 displays a clear seasonal cycle in potential evapotranspiration (ET), temperature, solar radiation, and other variables at Quinault, WA from 2019 to 2024. The potential ET (top plot) peaks in summer (June-July) each year, which is primarily driven by solar radiation (fifth plot) and temperature (second plot). These peaks coincide with lower relative humidity (third plot), which creates a higher vapor pressure deficit (VPD, sixth plot), further driving ET rates. Wind speed (fourth plot) plays a secondary role in ET dynamics, as higher wind speeds in summer help facilitate moisture exchange, though its influence varies with atmospheric conditions.

While the seasonal trends are consistent, the data also reveal a few anomalies. For instance, there were sharp increases in temperature during mid-2021, which led to a sharp increase in ET. Unlike in 2020, where peaks were irregular, the high temperatures in mid-2021 lasted for a few months. Another anomaly is the very low relative humidity in early 2019, which cannot be fully understood due to missing temperature data for that period.

While these trends cannot be directly linked to the 1980 eruption of Mount St. Helens, understanding them provides context for comparing long-term changes in the region. For instance, the eruption is known of its impact on temperature patterns as shown in previous figures also as solar radiation decreases due to the ash-cloud that is spreading right after the eruption, from knowing the connection between those to the PET, we can assume also there might had changes also in the PET during the eruption period.

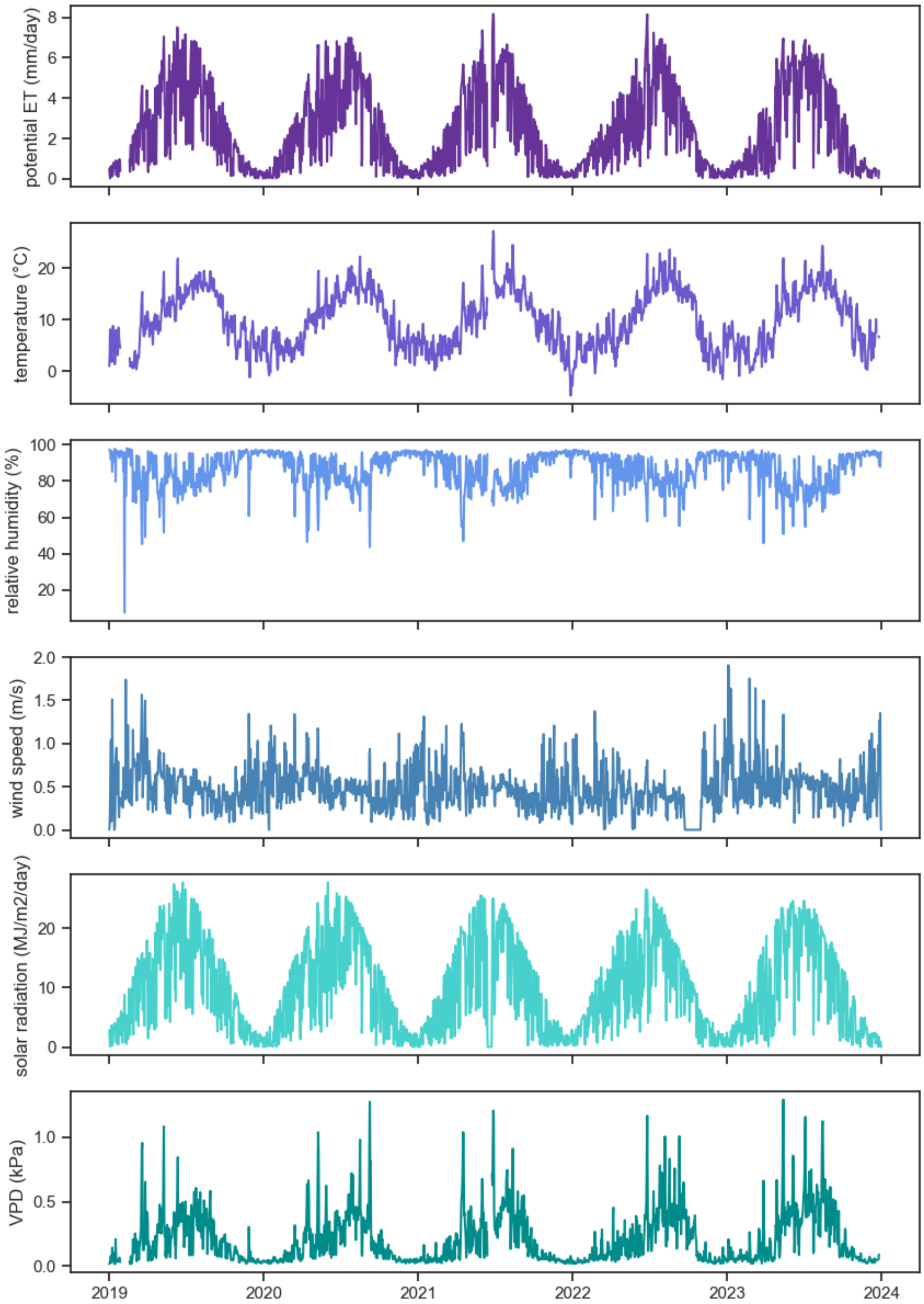

Figure 14: Seasonal Trends in Potential Evapotranspiration and Climatic Variables at Quinault, WA (2019-2024)

Conclusions

The study aimed to investigate the short-term and long-term impacts of the 1980 Mount St. Helens eruption on local temperature and precipitation patterns, based on historical climate data from the Paradise and Quinault weather stations.

The 1980 eruption had significant **short-term** effects. My hypothesis that the eruption would lead to temporary cooling was confirmed by a sharp drop in **temperatures**, likely caused by ash and particulates blocking sunlight. This cooling effect occurred a few days after the eruption, not within the 24-hour timeframe mentioned in earlier articles. Additionally, there was a notable increase in **precipitation** in late May 1980, supporting my hypothesis of increased rainfall, but this too was delayed by a few days. The delay in both temperature and precipitation suggests that the eruption's effects were influenced by local conditions such as wind direction and topography, which could have impacted how the ash and weather systems moved across the region.

In the **long-term**, the results were more complex. Although immediate disruptions to temperature and precipitation were observed, the hypothesized long-term cooling effect was not strongly supported. Instead, data suggested a slight increase in **temperature** over the following years. More notably, there was an increase in the range between daily minimum and maximum temperatures, indicating milder fluctuations between day and night. Long-term **precipitation** changes were less pronounced, though the seasonal pattern remained consistent, with a slight increase in winter precipitation averages.

While the analysis provides insights into the localized climatic effects of the eruption, it is important to recognize that the conclusions are based on data from only one weather station. This limitation means that the results may not fully represent the broader regional climate response. For this reason, more serious studies are incorporating data from multiple locations to obtain a more comprehensive understanding of both short-term and long-term volcanic impacts on climate. Additionally, the observed effects may have been influenced by broader climate changes, making it difficult to attribute all findings solely to the volcanic event.

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