An Analysis of Precipitation Distribution in the Eastern Mojave Desert

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Abstract

Recent studies of arid lands have largely failed to include extensive precipitation analysis. This study analyzed precipitation data between 1999 and 2005 for nine stations in the eastern Mojave Desert revealing both spatial and temporal differences. The stations were located at Zzyzx, Little Cowhole Mountain, Baker, North Soda Lake, Balch, Crucero, Barstow, Daggett, and Needles.

Frontal systems characterize the winter, bringing the highest seasonal totals in the form of steady rains that have a longer duration than summer convective storms. Summers in the desert are characterized by storms formed by the influences of topography, tropical depressions and the Southwestern United States monsoon. They affect localized areas, thus causing higher rainfall variability between stations than frontal systems. As a result, the spatial variability of mean rainfall is lower in the winter months than summer months. Topography plays an important role in the influence of rainfall. For example, at Zzyzx, the Soda Mountains keep the station sheltered from most of the winter rains and increase its precipitation totals in the summer. Orographic uplift creates many localized convective cells raising annual totals at Zzyzx.

Temperature analysis yielded a preference of rainfall at 10º C while in the summer months, but rainfall temperatures varied between 22º C for nighttime rainfall events and 35º C for daytime rainfall events. Wind analysis suggested most rain falls in association with low wind speeds in winter (0-2 m/s) and high rainfall amounts in association with higher winds in the summer.

Rainfall analysis by hour during the winter season suggested that rain occurs at all times of day. Summer time precipitation was most common in the afternoon and evening.

Introduction

The Mojave Desert has been the subject of considerable geomorphic and biogeographic study over the past few decades. One aspect of the Mojave Desert that has seen less attention is its microclimates. A common theme in arid lands is a deficit of weather data. Stations tend to be set up in areas with higher population densities and the data derived from these stations are used to infer weather over a broader area. Studies of precipitation in arid lands in other parts of the world have revealed an extreme "spotty" pattern both spatially and temporally (Laity 2006). Although some work has been done on temperature variations in deserts (Reid 1987), more analysis is needed on precipitation distribution.

The eastern Mojave Desert is separated from the western half by its high degree of variance in topography. While the desert in general is created by the rain shadow effect of the bordering mountain ranges, the eastern section is characterized by many basins and valleys created by smaller mountain ranges. This causes significant microclimatic differences in precipitation and temperatures. The National Weather Service uses stations set up in Barstow, Daggett, and Needles to predict the weather throughout the eastern section of the Mojave Desert (Climate Prediction Center). Baker, CA, located between these two stations, is the project study area. This study will analyze data from six stations in the Baker area from 1999 through 2005 and compare the data between them and the National Weather Service stations in an attempt to examine spatial accuracy. This study will also compare the data from the Baker Valley stations in order to establish the degree of local spatial and temporal variation, including elements such as elevation, temperature, wind, and time.

Previous Work

The deserts of the world lack consistent spatial coverage, particularly at a finer scale (Laity 2006). As a result, little work has been to done analyze climatic pattern. Comrie et al. (2002) studied precipitation in the remote areas of the Sonoran Desert in order to discover the nature of localized spatial anomalies. Widespread variations in precipitation were discovered over short distances in mountainous terrain. The greatest variation was associated with summer convective precipitation.

Very little work has been done on the nature of precipitation variability in the Mojave Desert. Yoho (1999) analyzed weather data from two stations in the Baker area over a three year period in order to identify differences over space and time. He concluded that precipitation values between the two stations varied owing to seasonal patterns and local topographical differences. William Reid (1987) studied temperature differences in the eastern Mojave Desert and there are significant microclimatic differences.

Other work has incorporated precipitation data in desert analysis. Epps et al. (2004) studied the relationship between bighorn sheep populations in the Mojave Desert, rainfall, and elevation. Their work and that of Jayko (2005), show that precipitation increases semi-logarithmically with elevation up to 2500 m.

Lancaster (1997) concluded there is a correlation between precipitation and wind in the Mojave Desert. Wind speed increases and becomes more erratic in the presence of rainfall. Griffiths et al. (2006) used precipitation data in order to establish sediment yield and run off frequency.

Background

Desert Climate

Deserts are characterized by a scarcity of cloud cover. As a result, radiation is at a maximum, especially in the summer time. A common theme within desert climates is a low occurrence of precipitation and a high variability over space and time (Laity 2005). Deserts may be classified by the amount of precipitation received. Hyper-arid deserts are those that receive less than 25 mm of precipitation annually, whereas arid deserts are those which experience 25-200 mm annually, and semi-arid deserts receive 200-500 mm (Laity 2005). Temperature is another common way to classify deserts. Deserts can be categorized as hot, temperate, or coastal. Hot deserts are characterized by a persistence of high temperatures; with highs commonly over 40º C. Temperate deserts experience hot summer temperatures and cold winters, and a large diurnal range of temperatures. Coastal deserts are cold with temperatures commonly around 16-20º C (Laity 2005).

Local convective storms are the most common type of rainfall in the summer time in the deserts in the Southwestern United States (Comrie et. al 2002). These spatially random storms are distinguished by a short period of heavy rainfall in a concentrated area, often times accompanied by thunder and lightning. Two other common types of storms are frontal and non-frontal cyclonic storms, which are more prevalent in the U.S. Southwest during the winter months. Another type of precipitation-bearing weather system is hurricanes, which bring heavy residual rains in the late summer and fall months to deserts within hurricane zones.

Precipitation has been an ever increasing issue within deserts. Forty percent of the United States population growth between 1960 and 2000 was in the American deserts

(Scanlon et. al 2005). Water supply in these regions is scarce due to the increasing demand of growing populations. Establishing local precipitation patterns is important for water supply planning and flood control, and thus for the survival and well being of the growing desert communities. Schick et al. (1997) concluded that spatial precipitation variation in the Negev Desert affects runoff and therefore flooding in desert communities on alluvial fans.

Mojave Desert Climate

The Mojave Desert has a temperate climate, experiencing hot temperatures in the summer and sub-freezing temperatures during the winter. Great diurnal variation also exists. Temperatures can reach as low as -13º C and as high as 45º C (Mojave Desert Climate). The rainy seasons, as defined by Beatley (1974), are June through August for the summer season, and September through May for the winter season. Reid (1987) and Yoho (1999) define a summer (June through October) and winter (November through May) rainy seasons. The average yearly precipitation in the Mojave Desert is 127 mm (The Mojave Desert). Rainfall in the cool season averages 95 mm, whereas rainfall in the warm season averages 35 mm (Hereford 2004). The majority of rain falls during the winter as a result of frontal cyclonic storms that bring steady rains (Bullock 2003). The storms originate from the Gulf of Alaska and near the Hawaiian Islands. The summer season experiences precipitation in the form of local convective storms, which form as a product of the North American Monsoon and as remnants of hurricanes off Baja California. The former is a period of pronounced rainfall between July and September powered by the warm waters of the Gulf of Mexico and thermal heat lows that form

above the surface during summer months in the Southwestern United States (Comrie et al. 2002).

Rainfall variability in the Southwestern U.S. is linked to events in the Pacific Ocean. Variations are expressed on both short and long-term time scales. The short term time scales are related to the Southern Oscillation Index (SOI) and equatorial water temperatures. El Nino and La Nina are the resulting episodes which are opposite extremes that occur every 3 to 5 years. Warm sea surface temperatures (SST) and a negative SOI indicate an El Nino episode, which increases rainfall in the United States. Cold SST and a positive SOI indicate a La Nina event, decreasing rainfall in the Southwestern United States (Climate Prediction Center).

Long term climatic variations are related to the Pacific Decadal Oscillation (PDO). Variations in the Pacific Ocean SST cause cycles of dry and wet periods in the western United States on the order of every two to three decades. Cool SST's indicate a dry spell and warm SST's indicate a wet spell (Hereford 2004).

Many factors contribute to the variability of rainfall in deserts at a local scale. One such factor is topography. The eastern Mojave Desert is characterized by numerous mountains and basins that separate it from the western region (Reid 1987). Hereford (2004), notes that there are two noticeable precipitation patterns in the Mojave Desert, separated by the 117º meridian at Barstow, CA. One pattern is a biseasonal pattern which prevails at the stations lying east of Barstow. The other is a winter dominant pattern which prevails in the western half of the desert. Others factors include elevation. Jayko (2005) concluded that precipitation increases semi-logarithmically with an increase in

elevation up until the 2500 m. At this point, moisture content of the air determines rainfall amount and therefore no elevation correlation can be inferred.

In general, weather predictions are made based on the predictable movement of frontal storms. Beatley (1974) concluded that only an average rainfall value can be predicted given the variability of rain both spatially and temporally in deserts owing to topographical differences.

Study Area

Mojave Desert

The Mojave Desert is located in the Southwestern United States and is approximately 152,000 km^2 in area (Hereford 2004). The majority of the desert lies in southern California, occupying parts of Los Angeles, San Bernardino, Kern, and Inyo counties. The desert is the result of a rain shadow created by the San Bernardino and San Gabriel Mountains to the south, and the Tehachapi and Sierra Nevada Mountains to the north and west. The Mojave Desert is sometime considered a transition between the Sonoran Desert to the south and the Great Basin Desert to the north (Nelson 1957 in Reid 1987), incorporating vegetation characteristic of both neighboring deserts (Laity 2005). The mean elevation of the Mojave is approximately 900 m. Mountain peaks reach elevations up to 3350 m. The lowest parts of Death Valley sit at an elevation of 86 m below sea level.

The eastern Mojave Desert (figure 1a) is characterized by many playas and drainage basins which extend over 40,000 km^2 in area. These low points are separated by north-south trending mountain ranges such as the Soda, New York, Avawatz, and Turquoise Mountains. Notable dry playas and basins are Silver Lake, the Cronese playas and basin, and Ivanpah playa in the Primm Valley basin. Notable wet playas and basins are Soda Lake in the Baker Valley and Badwater Basin in Death Valley. Two ephemeral rivers, the Mojave and Amargosa Rivers, make their course through the desert.

Settlement in the Mojave Desert is sparse. The majority of the population in the desert is located within the desert population centers of Barstow/Daggett, Needles, and Palmdale/Lancaster. Barstow and Daggett lie on the western edge of the eastern Mojave

Desert and are the locations for two National Weather Service stations used in the analysis in this paper. The Barstow station is located at the Barstow Fire Station and the Daggett station in located at the Barstow/Daggett Airport. The station at Needles Airport is on the eastern edge of the Mojave Desert and is the third National Weather Service station used in this analysis. Other Mojave Desert towns include Baker, Primm and Twentynine Palms.

Baker

The weather stations that will be analyzed in this report are located in the Baker Valley area (figure 1b). The town of Baker is located off Interstate 15 in the eastern Mojave Desert between Barstow and the California/Nevada state line. Baker lies in a drainage basin flanked on the west by the Soda Mountains and northeast by the Turquoise Mountains (Reid 1987). At the south end of the Baker Valley are the Bristol Mountains, which are adjacent to the Devil's Playground and Kelso Dunes. To the north of Baker is Silver Dry Lake which interconnects to the south with Soda Lake. These playas mark the terminus of the Mojave River which originates in the San Bernardino Mountains. During flood periods, Silver Lake will fill first, and Soda Lake second (Reid 1987). On the east side of Soda Lake are the Cowhole and Little Cowhole Mountains.

Six weather stations are located in the Baker Valley area. The first is located off Interstate 15 in the town of Baker and is maintained by the National Park Service. The Zzyzx weather station is located at Soda Springs on the west shore of Soda Lake. It is maintained by the California State University Consortium Desert Studies Center. Balch (figure 2) and Crucero (figure 3) stations lie on the south end of Soda Lake

approximately 16 km from one another. These stations are maintained by the United States Geological Survey (USGS). The Little Cowhole Mountain station, maintained by Cal State Northridge, is situated on a low ridge crest on the eastern side of Little Cowhole Mountain, which lie east of Soda Lake and approximately 10 km south of Baker. The sixth station, North Soda Lake (figure 4), lies to the northeast of Soda Lake, 4.5 km south of the Baker station, and is also maintained by the USGS.

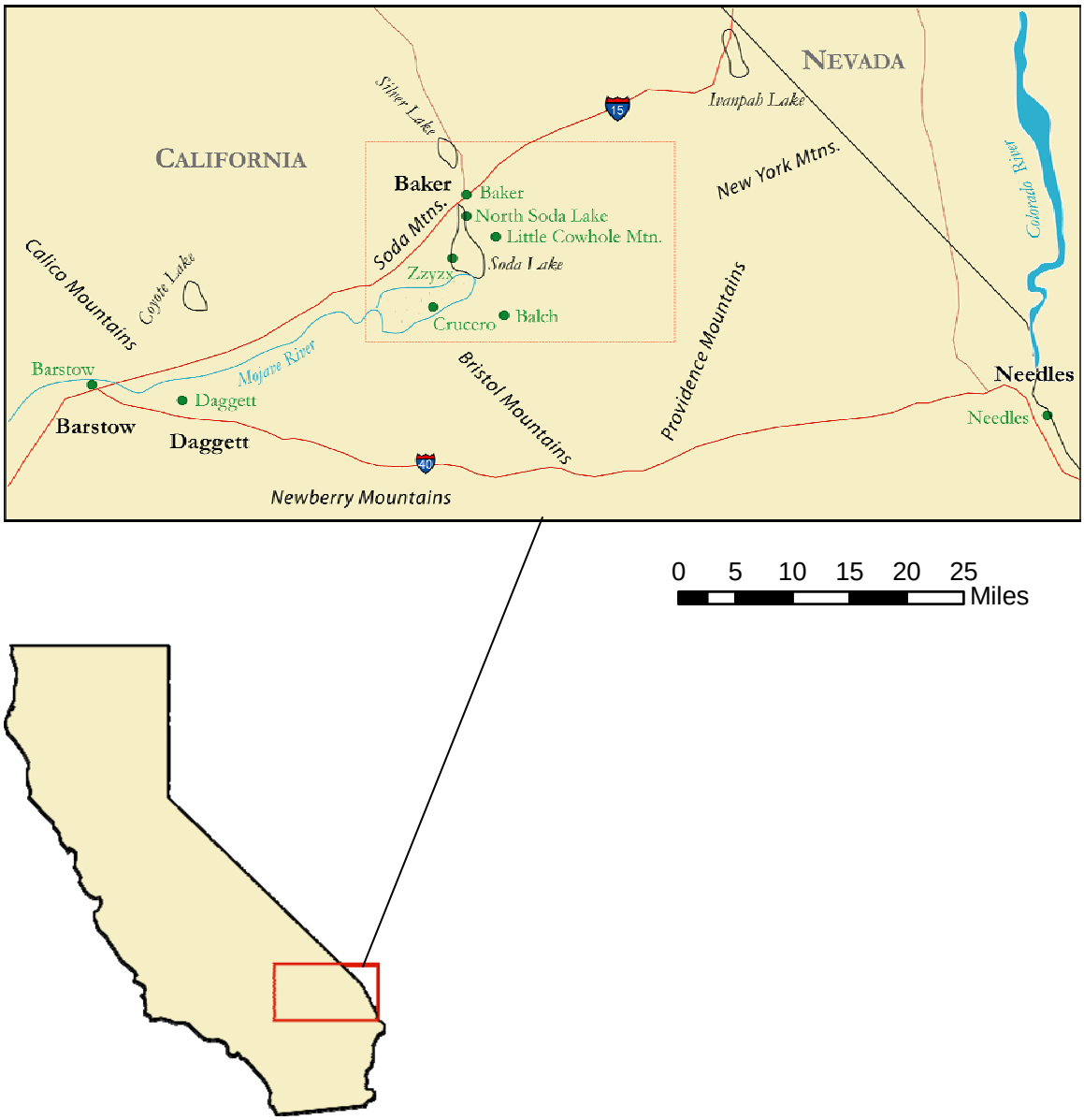


Figure 1a. *Map of the study area in the eastern Mojave Desert.*

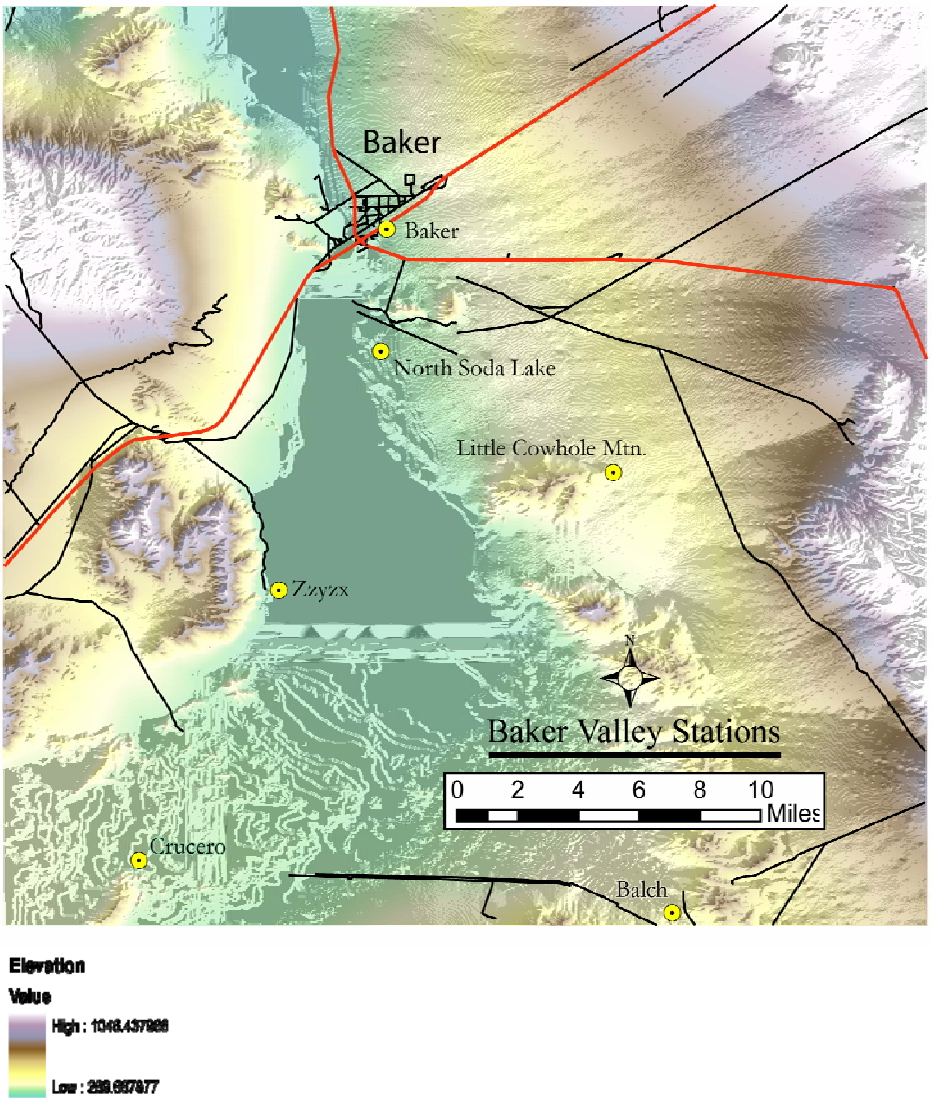


Figure 1b. *Map of the Baker Valley area and weather stations with elevation profile.*

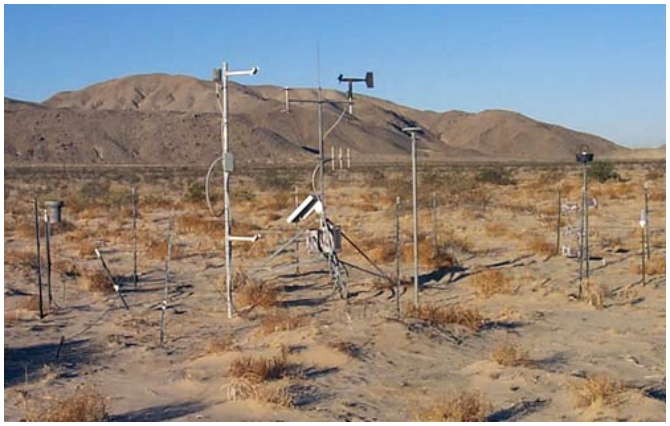


Figure 2. *The weather station at Balch. (Clim-Met)*

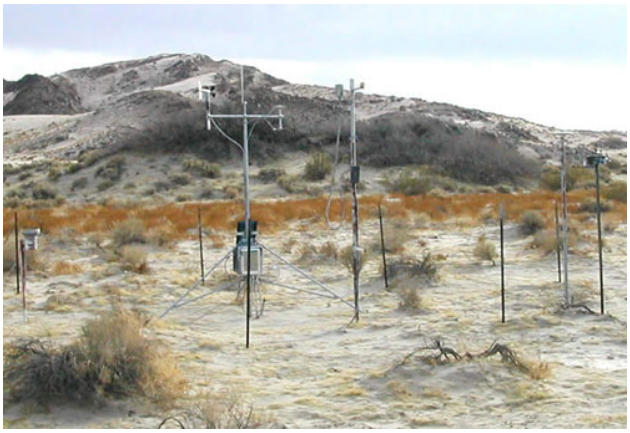


Figure 3. *The weather station at Crucero. (Clim-Met)*

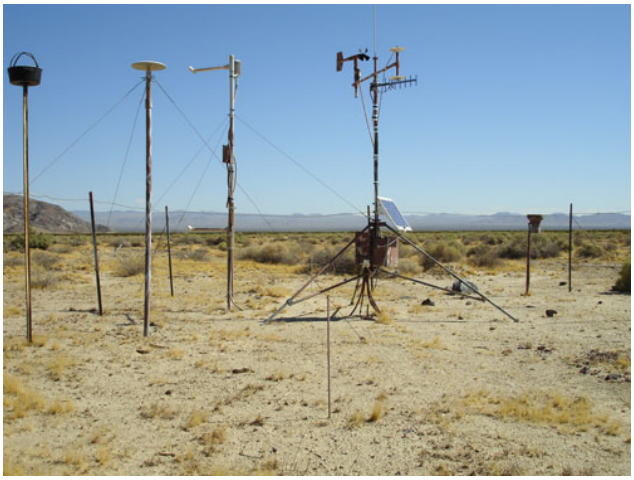


Figure 4. *The weather station at North Soda Lake. (Clim-Met)*

Methodology

Several agencies provided the precipitation data: California State Northridge weather station, the California State University Desert Studies Center at Zzyzx, the United States Geological Survey (USGS), the Mojave Natural Preserve, and the Western Regional Climate Data Center. Data collected includes both 24 hour and 60 minute data. No 60 minute data was available for the Baker, Barstow, Daggett, and Needles stations, excluding them from 60 minute analysis. After collection, the data was organized by keeping only relevant fields including precipitation, temperature, wind, and date.

Analysis was done primarily using Microsoft Excel using the statistical analysis and chart functions, similar to the study performed by Yoho (1999). The compiled data analyzed in this paper is separated into two distinct seasons by months. The seasons are defined by Reid (1987) and Yoho (1999) as winter (November-April) and summer (May-October). Each station for which data was collected included gaps, containing certain days when data was corrupted or not collected. In most cases, missing data was sporadic. Other stations had periods of one week to two months when reliable data was not collected. The Zzyzx station at Soda Springs included suspect data between the months of June and August in 2001. All corrupted data was excluded, though minor errors may still be present.

Beginning and end dates also differ for each data set. North Soda Lake and Balch stations' data range from November 10, 1999 through May 1, 2005. Balch station data ranges from May 1, 2000 through May 1, 2005. Zzyzx and Little Cowhole Mountain stations' data ranges from the beginning of 1999 through mid December, 2005. Start dates for the USGS stations are also their initiation dates and end dates are the end of data

publication. Baker station data terminates in this report in June 2004, when the station became inactive.

Additional analysis was performed using ESRI's ArcGIS. Digital Elevation Model analysis and spatial interpolation analysis tools were used to produce visual aids for spatial variability and between the stations and rainfall models.

Data Analysis and Interpretation

This section analyzes precipitation data between 1999-2005 by first comparing monthly and seasonal averages between the Baker Valley stations and the National Weather Service stations using daily averages. Correlation between rainfall and elevation is analyzed plotting station elevations with daily precipitation data. Next, this report compares variables such as time, temperature, and wind to the precipitation data of the Baker Valley stations in order to establish a correlation using hourly precipitation averages. The last part analyzes two separate rain events, one in the summer and one in the winter.

Baker Valley and National Weather Service Stations

Seasonal Variability

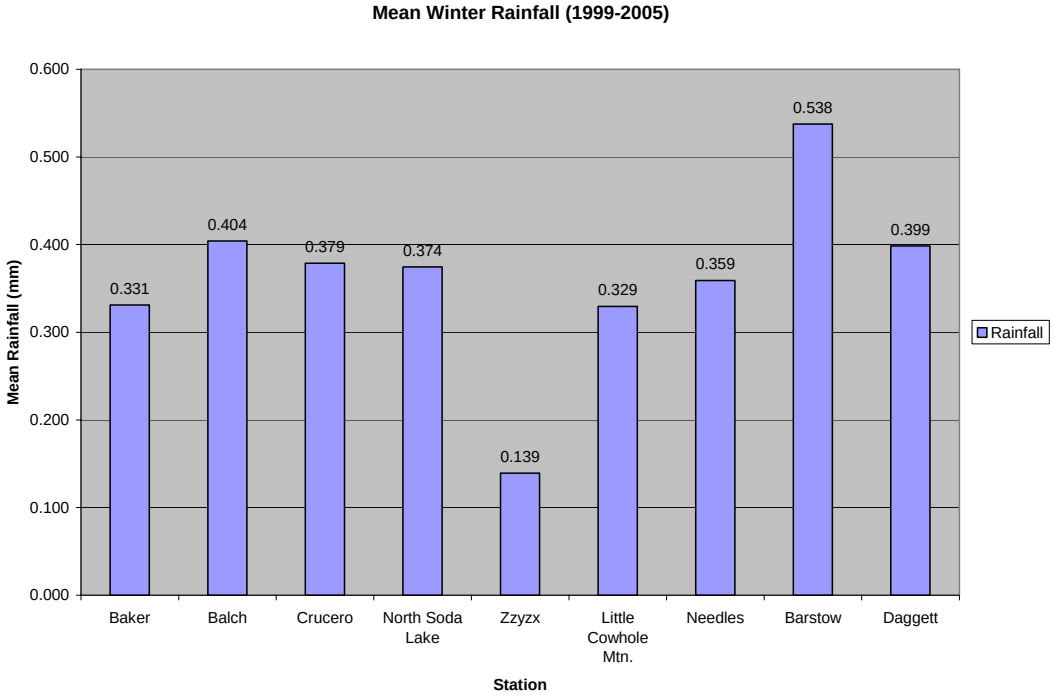


Figure 5. *Mean winter season rainfall by station.*

Figure 5 illustrates the mean rainfall between the nine stations during the winter months between 1999 and 2005. Barstow has highest precipitation at 0.538 mm per day. The lowest amount is at Zzyzx with 0.139 mm. The other seven stations are very close in means, ranging from 0.239 mm and 0.404 mm.

Winter in the Mojave Desert is characterized by frontal systems moving in from the north as a result of the Arctic Low. Zzyzx receives little rain during the winter months, probably due to the rainshadow effect caused by the Soda Mountains to its west. Barstow, which lies at the western edge of the eastern Mojave, receives less topographic influence than do the stations in the Baker Valley area. Although Daggett lies only a few kilometers from Barstow, it probably receives more protection due to its position relative to the Newberry Mountains to the south and the Calico Mountains to the north. The Needles Airport station with a mean rainfall of 0.359 mm would seem to be the best predictor of rainfall for the rest of the stations, being the median value. This station, however, lies 128 km from the study area.

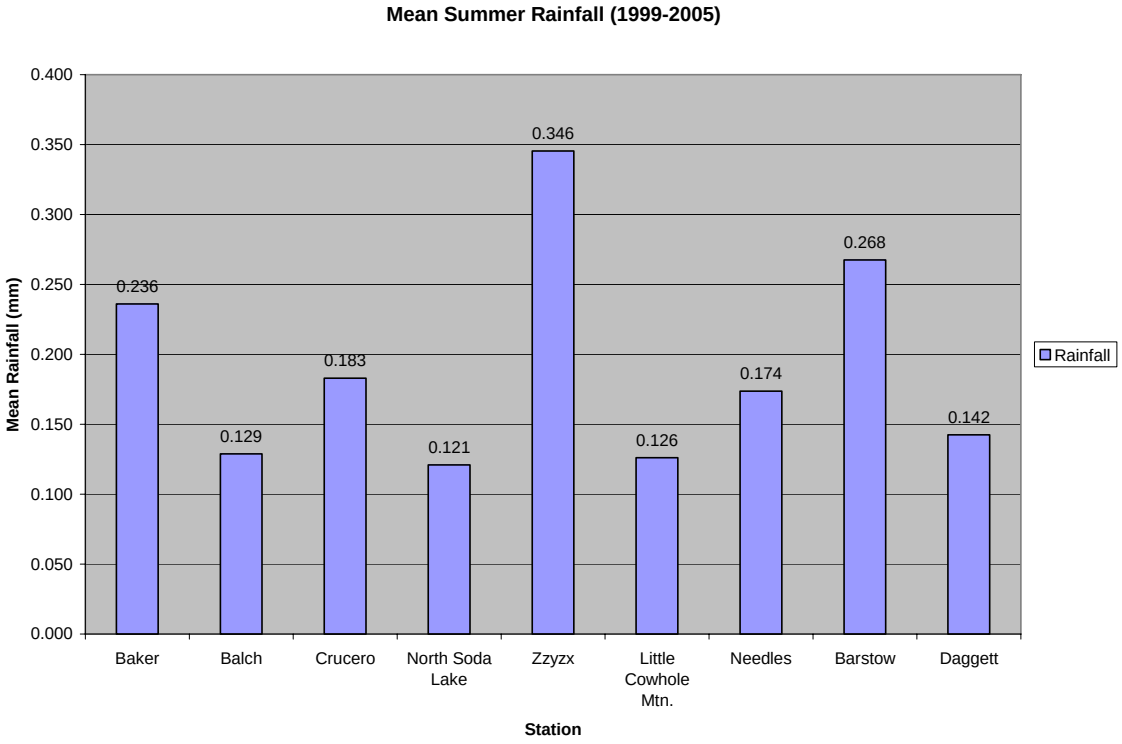


Figure 6. *Mean summer rainfall by station.*

Figure 6 illustrates the summer rainfall means between the nine stations between 1999 and 2005. A higher variation between the stations is more evident during the summer than during the winter. Zzyzx station exhibits the highest value (0.346 mm) in the summer months. The Soda Mountains, which provide protection from the rain during the winter months, prove to be the source of rain during the warmer months due to orographic effects. Local convective action in the Soda Mountains causes thunderstorms, bringing large amounts of rain in short spurts. Barstow and Baker receive a considerable amount of summer precipitation as well. The warm months in the eastern Mojave Desert are characterized by convective activity as a result of the Southwestern United States monsoon. Barstow lies to the southwestern Calico Mountains and Baker to the

northeastern Soda Mountains, suggesting an orographic influence at these sites. The other six stations received less rain, owing to their distance from mountain ranges.

Monthly Variability

Figures 7 and 8 show monthly means plotted both by month and by station. Comparing the two yields a similar pattern in all the stations but Zzyzx. Higher amounts of rain fall during the winter months and then start to decrease as the seasons warm, as denoted by the bimodal distribution in figure 7. The mean rainfall amounts peak in April, suggesting a transition period between the frontal systems that mark the winter and the local convective storms that identify the summer, thus increasing rain totals for the month. Rainfall dramatically drops in May marking the beginning of the warmer period in the Mojave Desert. Summer precipitation peaks between August and October, due to convective precipitation. The mean rainfall reaches another peak in November, marking another transition, as previously discussed.

Zzyzx experiences the opposite changes, as mentioned in the previous section. As the months warm, the totals increase at the Zzyzx station, then again drop when the cold fronts move in for the winter. Summer in the Mojave means an influx of warm, moist air as a result of the monsoon and tropical events off the coast. Thunderstorms result, bringing precipitation into the eastern Mojave Desert. Totals for Zzyzx are appreciably higher by adding the orographic effect of the Soda Mountains, bringing more intense convective events, adding to the stations totals. Yoho (1999) suggests that summer totals at Little Cowhole Mountain are less than those at Zzyzx as the mountains lack height and

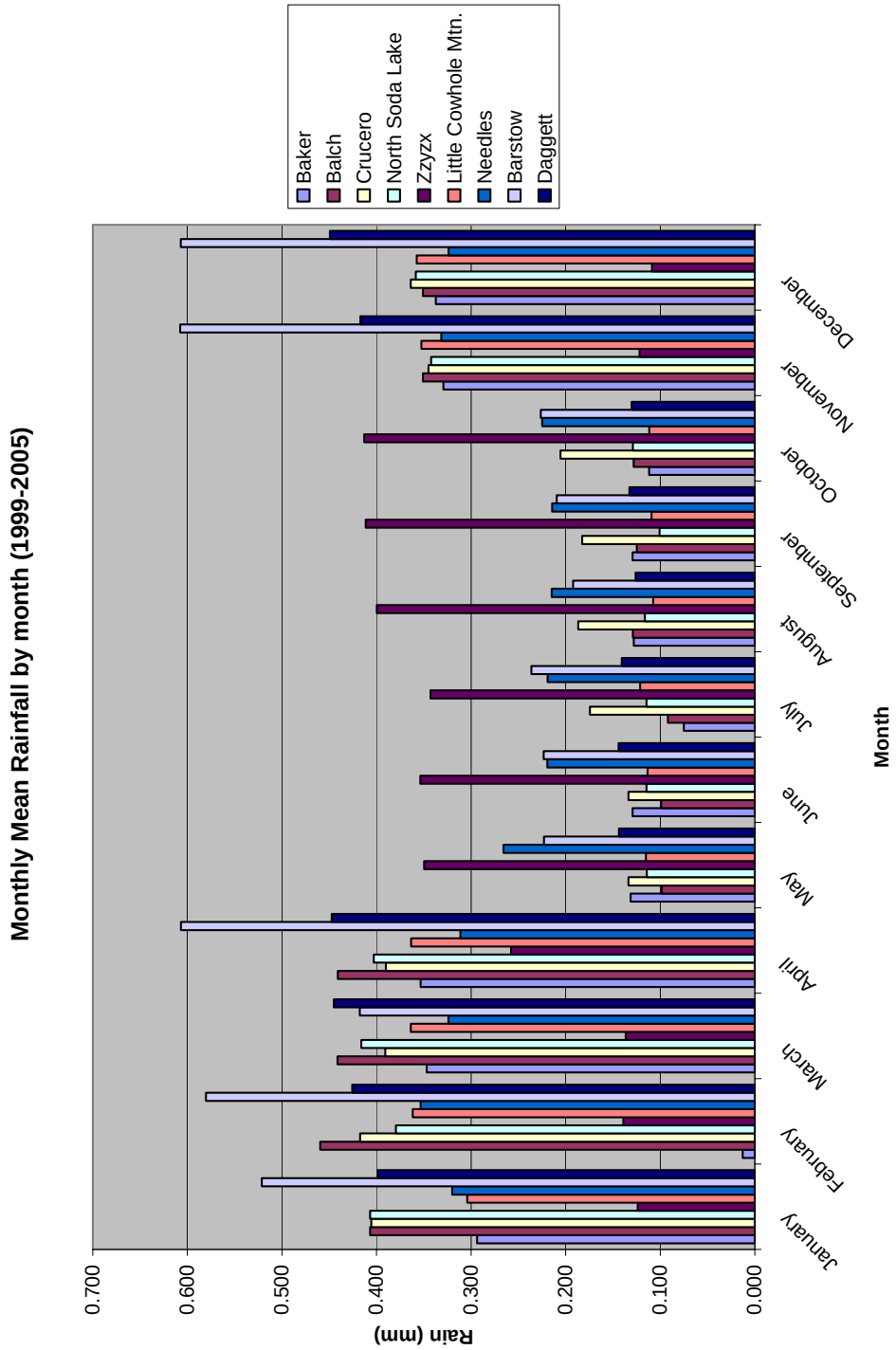


Figure 7. *Monthly averages plotted for each station for the study period.*

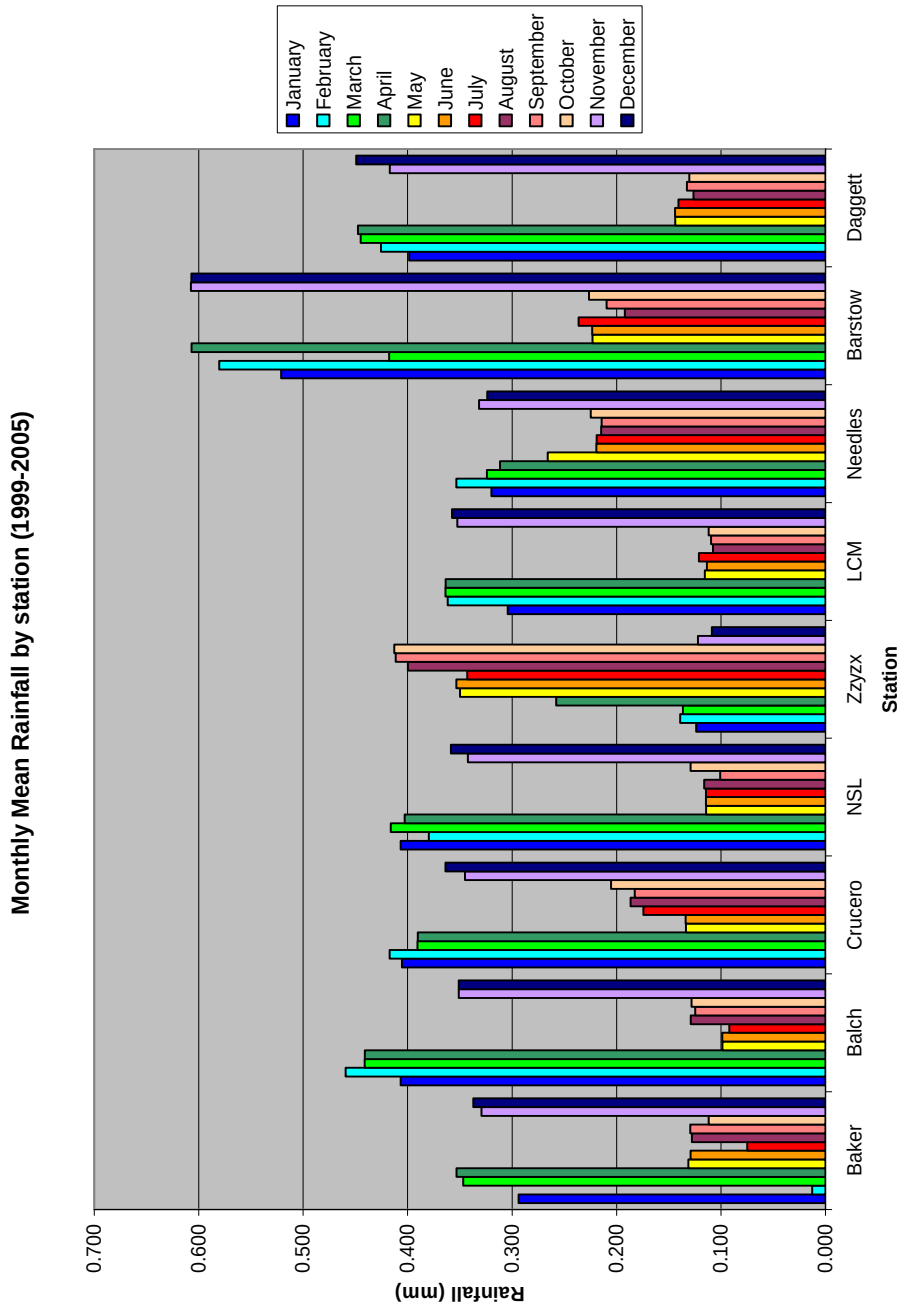


Figure 8. *Monthly averages for each station plotted by month*

spatial coverage of the Soda Mountains. As a result orographic precipitation is not a factor in the mean for the Little Cowhole Mountain station.

Elevation and Precipitation

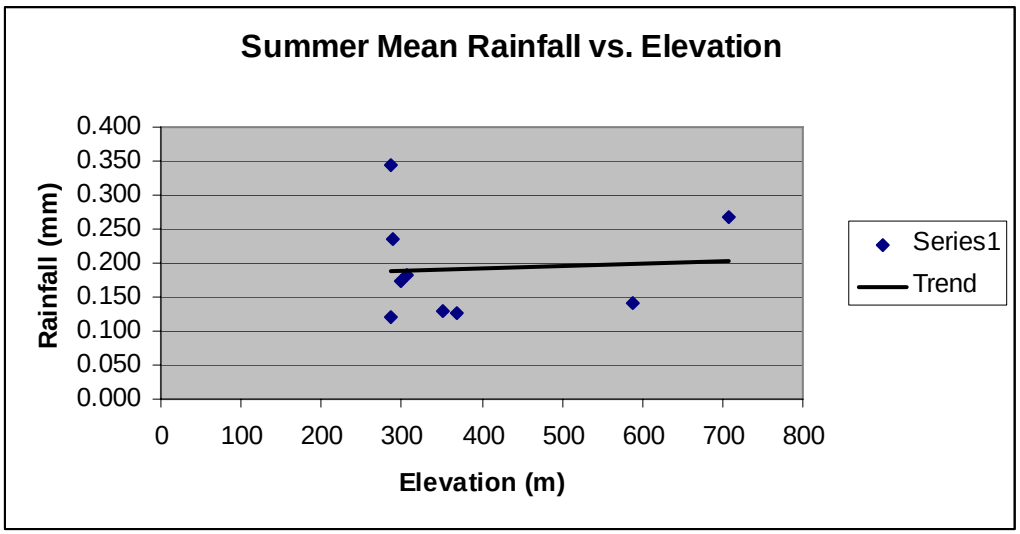


Figure 9. *Mean elevational influences on summer precipitation.*

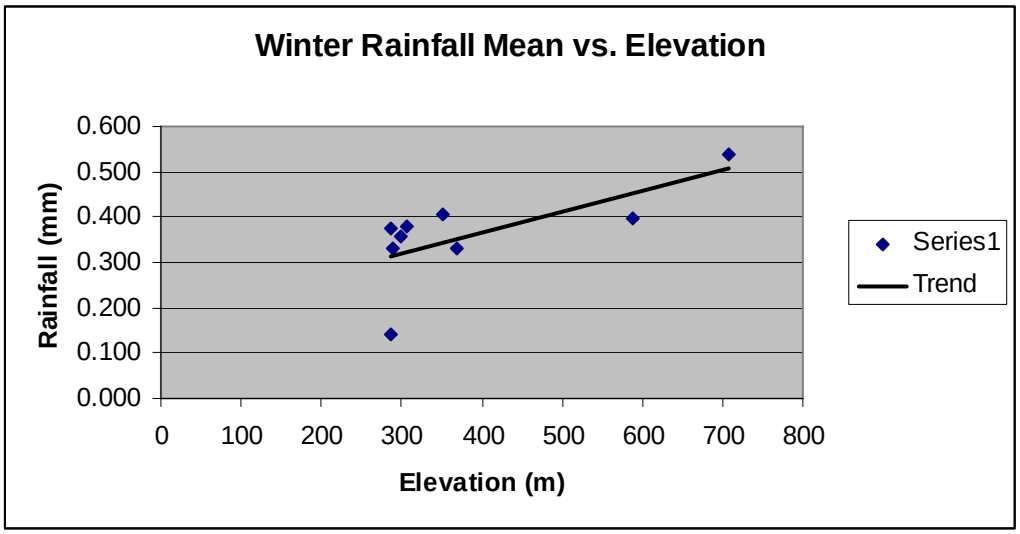


Figure 10. *Mean elevational influences on winter precipitation.*

Figures 9 and 10 show seasonal precipitation averages plotted against elevation. For Death Valley, rainfall increases logarithmically with elevation (Jayko 2005). Similar results were not apparent in this study (figures 9 and 10). The mean rainfall in figure 9, summer rainfall, exhibits no dependency on elevation, as exhibited by the trend line. The means start to increase from Baker at 289 m (figure 10) until Little Cowhole Mountain (370 m), where it then drops well below the rainfall mean for Balch (351 m). The means again start to increase and peak at 0.53 mm at the Barstow station (707 m), which is over twice as high as the stations in the Baker Valley. The trend line for figure 10 does show a slight dependence on elevation, although the stations are too close in altitude to discern a definite trend.

There is only a small range in elevations between the stations discussed in this study and a small number as well. Perhaps an analysis including stations at a greater array of altitudes would yield similar results to Jayko (2005).

Baker Valley Stations

Time and Precipitation

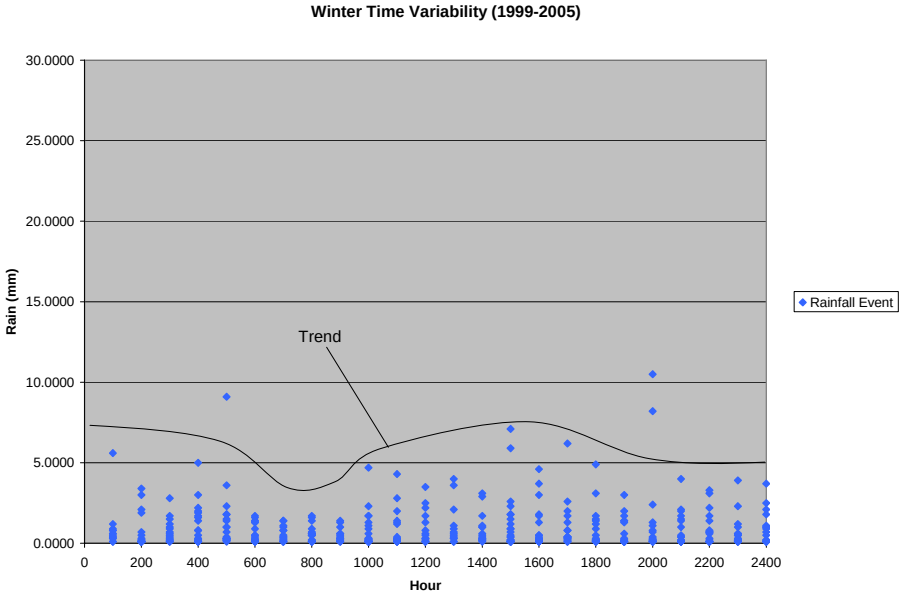


Figure 11. *The above graph contains dots representing hourly rainfall during the winter. Each station is color coded.*

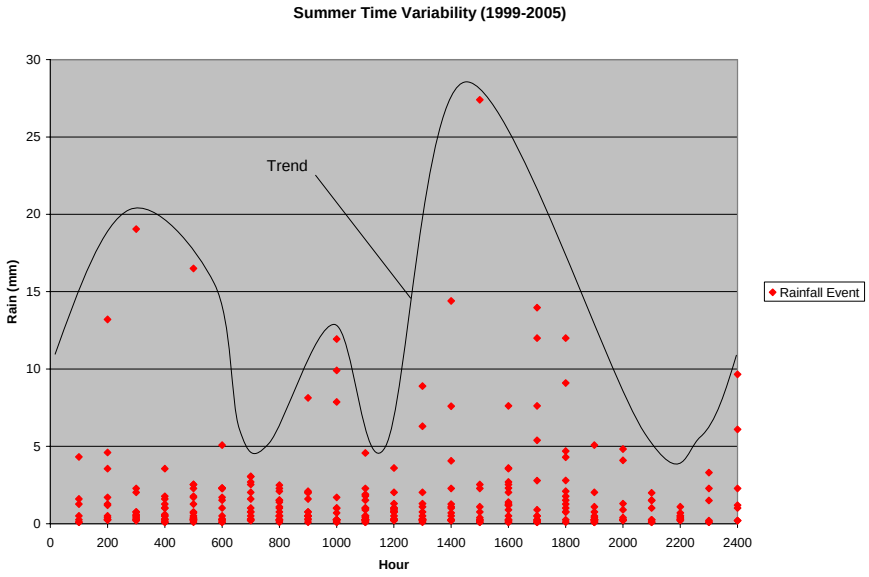


Figure 12. *The above graph contains dots representing hourly rainfall during the summer. Each station is color coded.*

Figures 11 and 12 display the relationship between rainfall and the time of day. During the summer months (figure 11), there is a peak in afternoon and evening rainfall. The heaviest rainfall was recorded in an eight hour period from 1400 to 2000. A noticeable drop in rainfall occurs at 400 and continues to through the morning hours. Yoho (1999) did not record any precipitation in the 1200 and 1300 hours in his study of the Zzyzx and Little Cowhole Mountain stations. This study recorded minimal precipitation during these same hours; however less was recorded at 1000. Figure 11 exhibits a pattern comparable to figures 7 and 8 (Yoho, 1999), which show minimal precipitation values between 1200 and 1300. It is possible that remnants of night storms dissipate in the morning hours before heating in the afternoon, dropping rainfall values (Yoho 1999). New storms begin their creation after maximum heating due to convection of low pressure air masses that take form in the later afternoon hours bringing new rainfall events.

Figure 12 displays variability over the winter months. The plot illustrates that the time of day has no impact on precipitation values. Individual events rarely exceeded 5 mm at any point in the day. One event delivered 14 mm to Little Cowhole Mountains during the 1400 hour.

Temperature and Precipitation

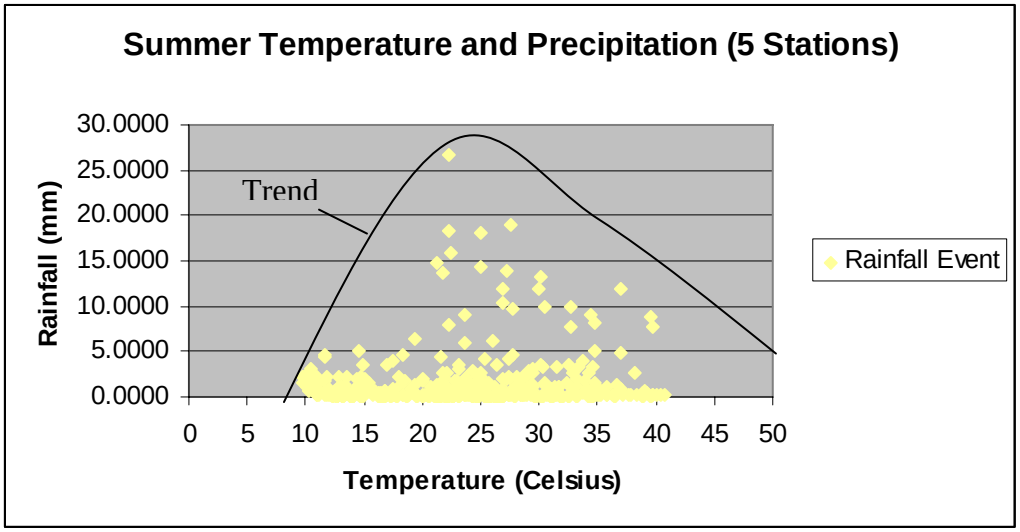
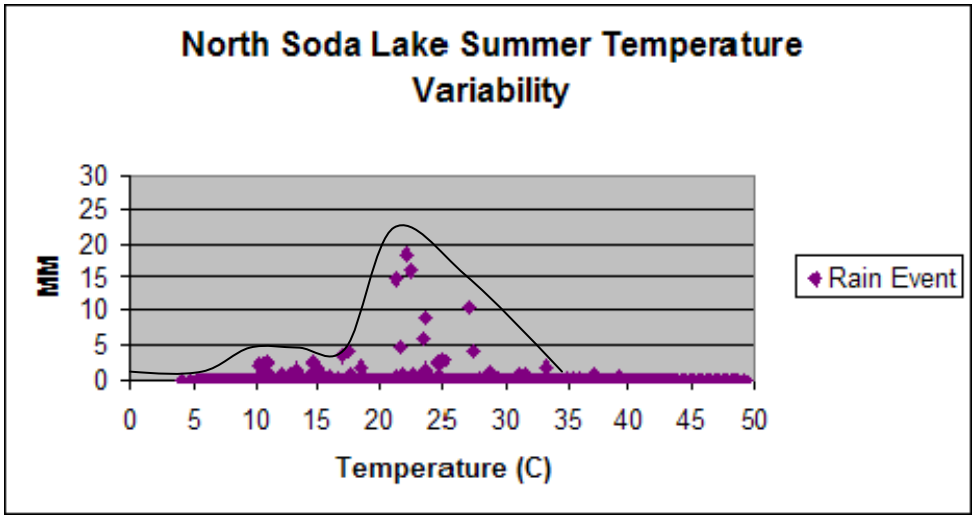
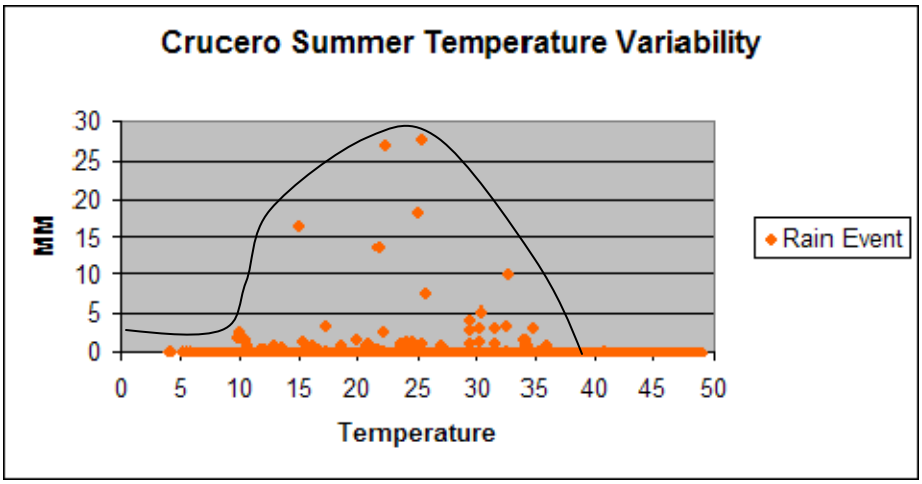
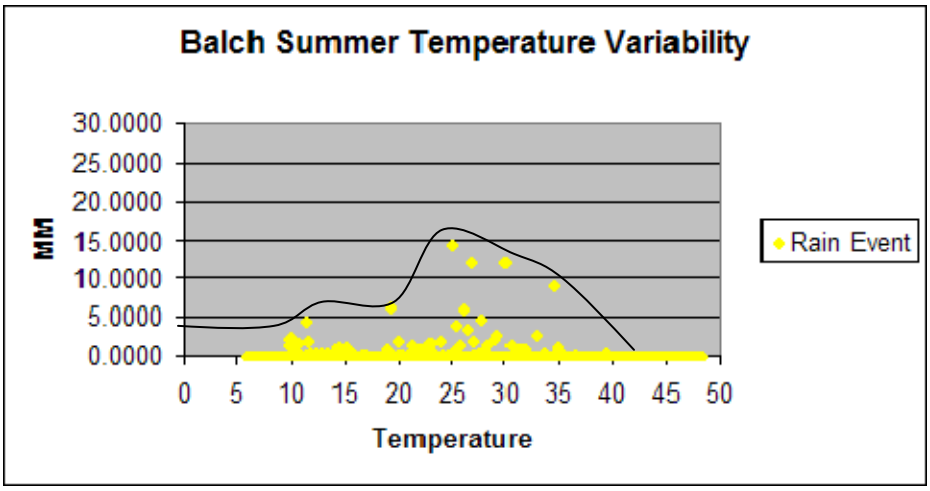
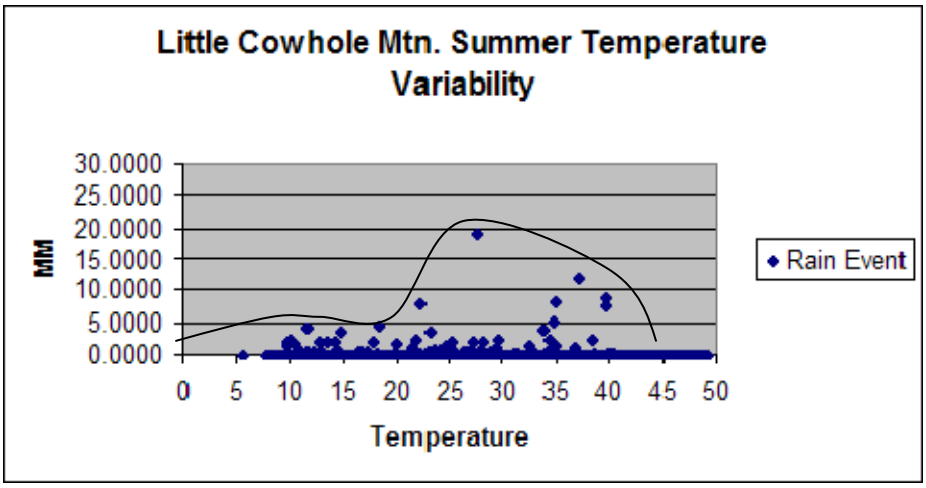


Figure 13a. *Combined graph showing summer temperature influences on rainfall.*




Crucero Summer Temperature Variability
MM
30
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45 50
Temperature
Rain Event


Balch Summer Temperature Variability
MM
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
0 5 10 15 20 25 30 35 40 45 50
Temperature
Rain Event


Little Cowhole Mtn. Summer Temperature Variability
MM
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
0 5 10 15 20 25 30 35 40 45 50
Temperature
Rain Event

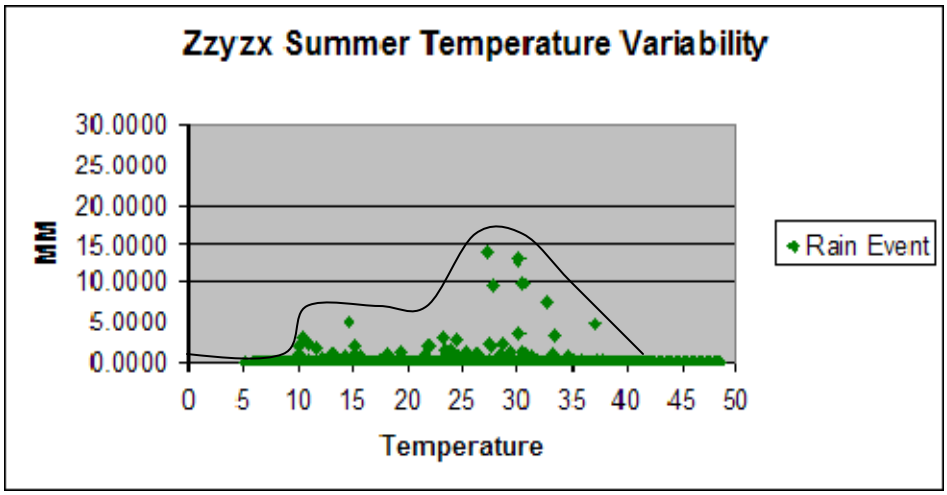


Figure 13b. *Separate station graphs showing summer temperature influences on rainfall.*

Summer rainfall is dependant on higher temperatures. Figures 13a and 13b show the temperatures at which rainfall events occurred for each station. Figure 13a combines the data from all five stations, whereas figure 13b displays a graph for each station. The chart for North Soda Lake has a normal distribution with the highest frequency of events and highest intensities occurring at 22º C. These temperatures indicate evening or nighttime precipitation from dissipating or late occurring thunderstorms. High daytime temperatures are needed for insulation heating, which powers convective cells.

Crucero has a bimodal distribution with peak values between 21º C and 25º C and then another peak at 32.5º C. The second peak might suggest afternoon thunderstorms due to orographic precipitation owing to the station's close proximity to the Soda Mountains. Balch station exhibits a unimodal distribution with peak intensities between 28º C and 30º C. Balch is in close proximity to Crucero, but farther from the Soda Mountains than Crucero, diminishing the possibility of the effects of orographic convective cells.

Little Cowhole Mountain shows rainfall values at many temperatures. Peak frequencies include 12º C, 22º C, 28º C, and 35º C, indicating frequent convective activity throughout the day. The majority of rainfall events occur at lower temperatures indicating the site often experiences convective activity in the evening hours. Another theory is that once the storm strikes, temperatures fall for the brief duration of the storm before rising again.

The Zzyzx station at Soda Springs recorded peak intensities and frequencies at 31º C. Zzyzx station displays the most normal distribution of the five stations, with frequency values rising up to 31º C and then falling with a further rise in temperature.

The high range of temperatures at which summer precipitation occurs indicates a loose relationship, owing to the three types of precipitation that occur in the summer months. Tropical cells and monsoonal storms are less dependant on temperature than local convective cells.

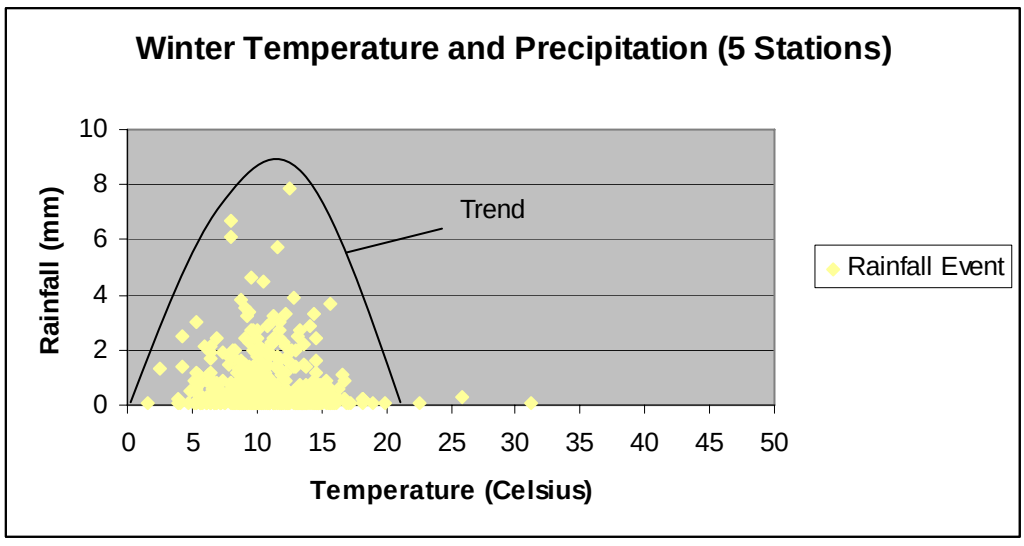
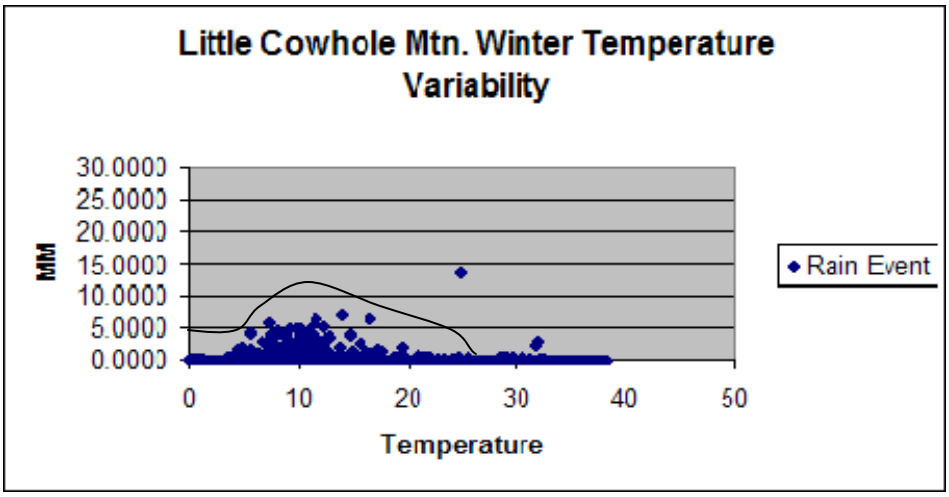
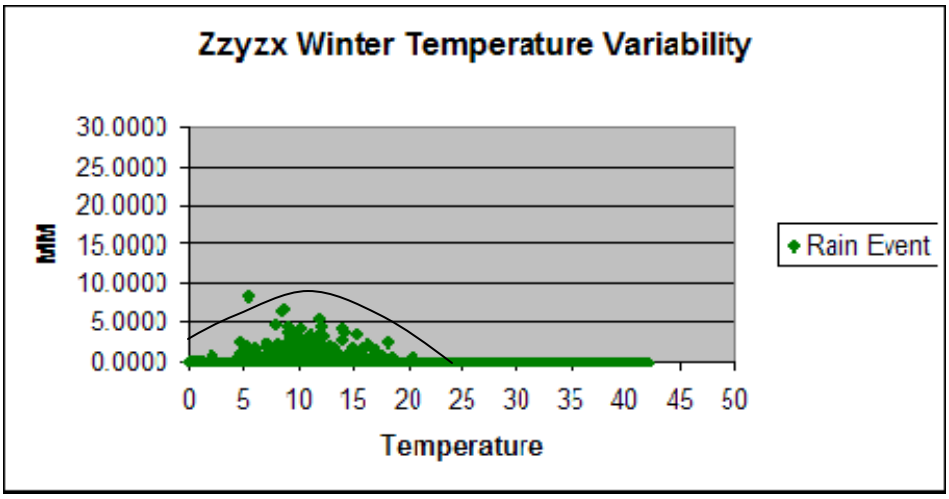
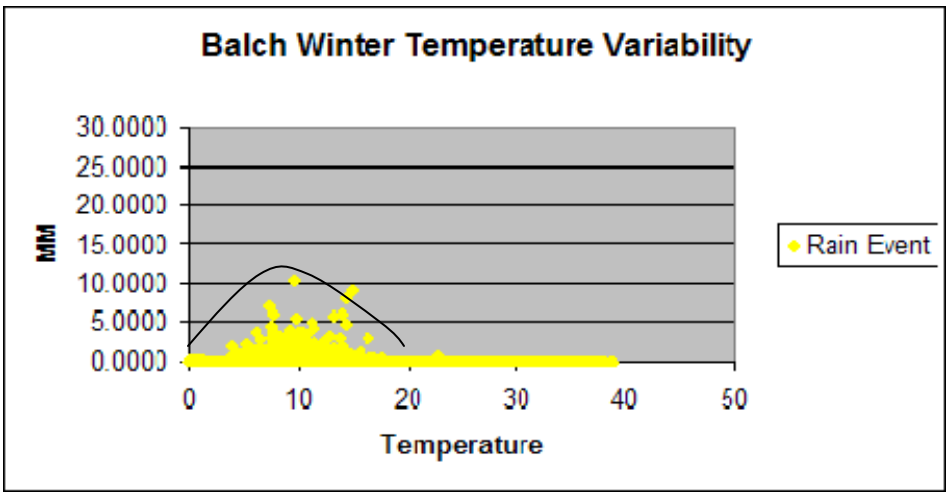


Figure 14a. *Combined graph showing winter temperature influences on rainfall.*


Little Cowhole Mtn. Winter Temperature Variability
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
MM
0
10
20
30
40
50
Temperature
Rain Event


Zzyzx Winter Temperature Variability
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
MM
0
5
10
15
20
25
30
35
40
45
50
Temperature
Rain Event


Balch Winter Temperature Variability
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
MM
0
10
20
30
40
50
Temperature
Rain Event

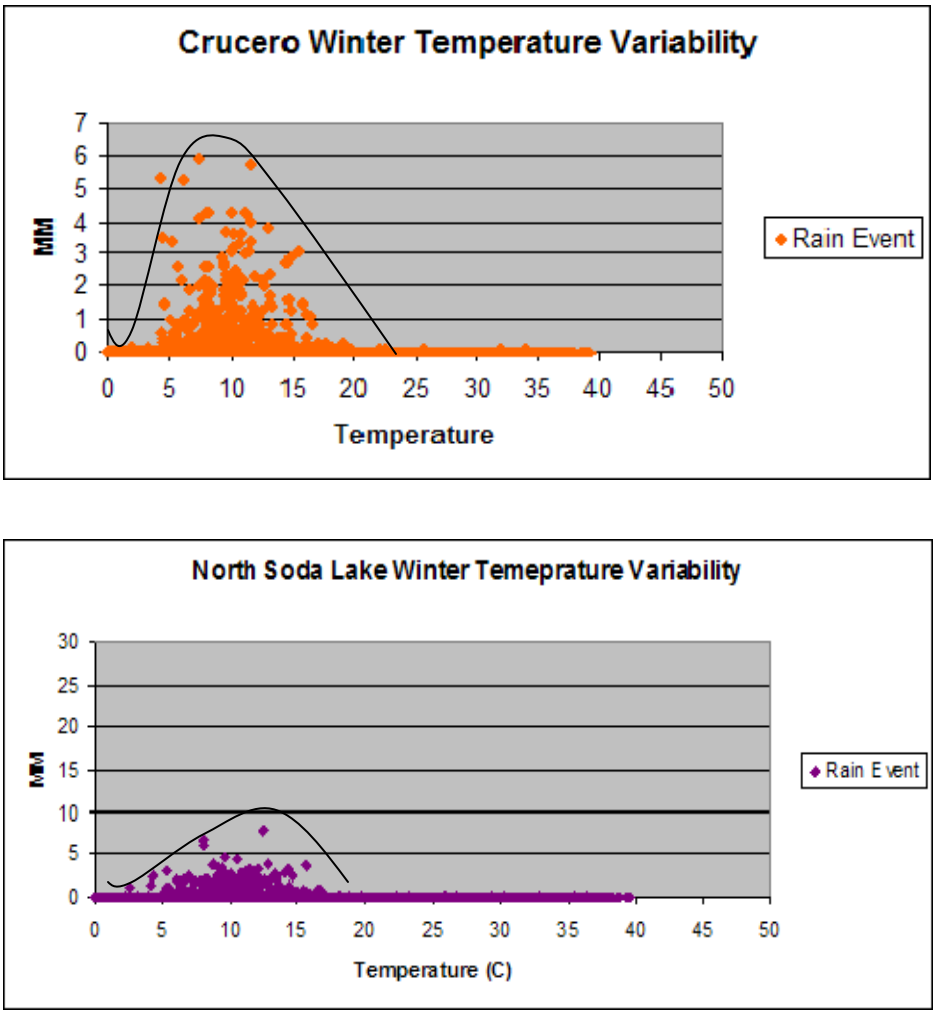


Figure 14b. *Separate station graphs showing winter temperature influences on rainfall.*

Winter precipitation is not dependant on temperature (Yoho 1999). However, analysis done on winter rainfall for the five stations show a normal distribution between all the stations with peak intensities and peak frequencies at 10º C (figure 14b). Below and above this temperature, rain events decrease steadily. In order for precipitation to occur, the temperature must reach the dew point. Temperatures above 10º C are above the dew point. During the passage of a cold front, the temperatures are relatively high. Once the front passes through, the temperatures steadily drop. A theory is the temperatures above the frequency are part of pre-frontal conditions and upon arrival of the frontal

system, temperatures begin to drop. Since post-frontal periods are marked by colder conditions, temperatures below 10º C are the temperatures of dissipating rain events from the passing frontal system.

Wind and Precipitation

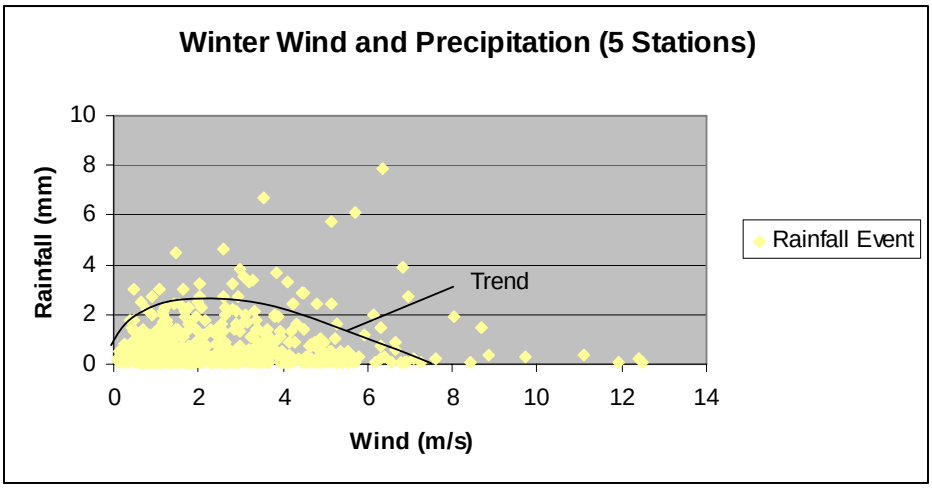
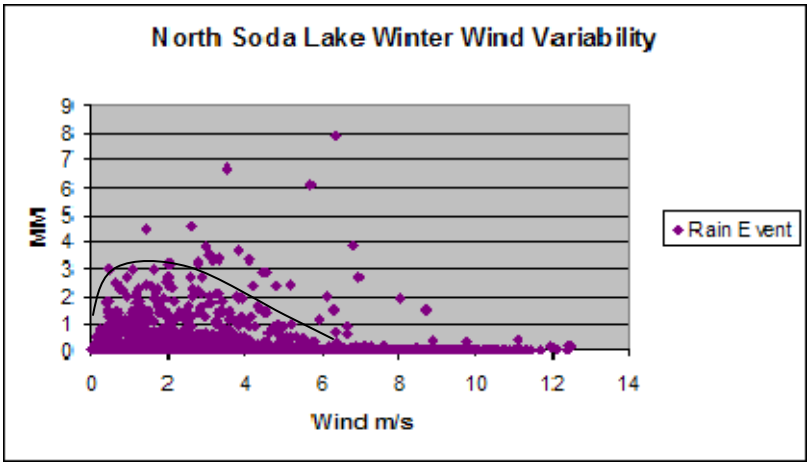
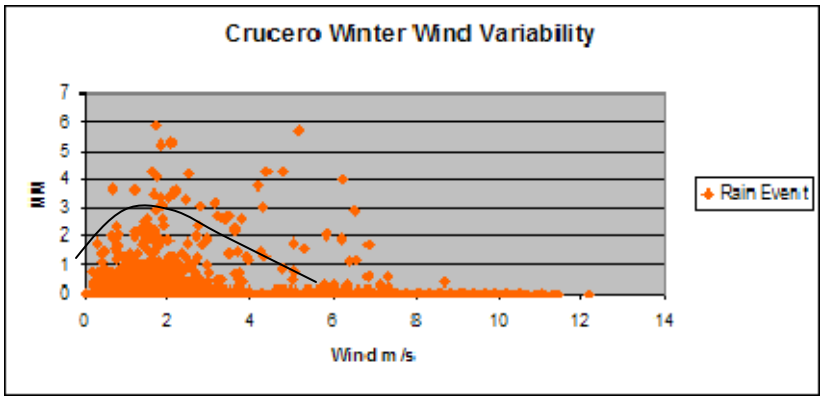
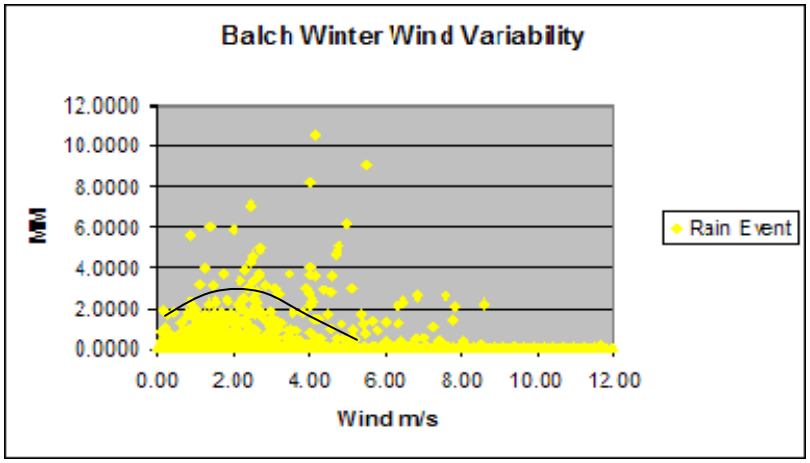
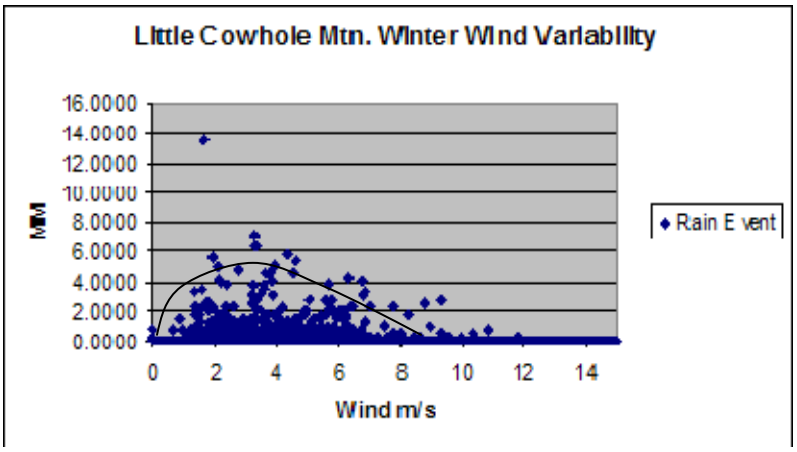


Figure 15a. *Combined graph showing winter wind influences on rainfall.*




Crucero Winter Wind Variability
MM
Wind m/s
Rain Event


Balch Winter Wind Variability
MM
Wind m/s
Rain Event


Little Cowhole Mtn. Winter Wind Variability
MM
Wind m/s
Rain Event

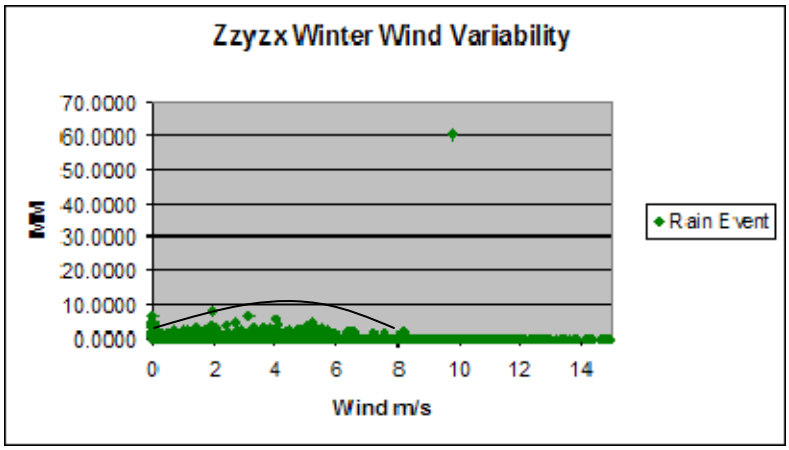


Figure 15b. *Separate station graphs showing winter wind influences on rainfall.*

Figures 15a and 15b depict the graphs for the effect of wind on precipitation in the study area during the winter months. The five charts exhibit a positively skewed distribution indicating that an increase in wind speed results is associated with a decrease in precipitation. Individual rain events are more numerous with wind speeds between 1 and 3 m/s. Few rainfall events were recorded with higher wind speeds.

The skewed distribution can be explained in terms of the measurement method of the weather station. Higher winds cause the rain to fall at an angle, prohibiting collection in the rain gauge at the station. Another theory is higher winds are fairly not common in frontal storms originating in the Arctic.

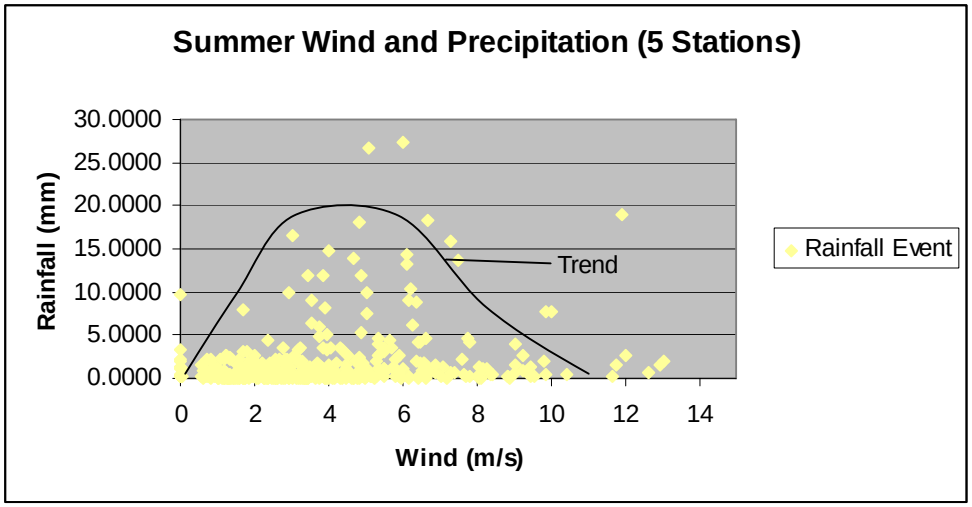
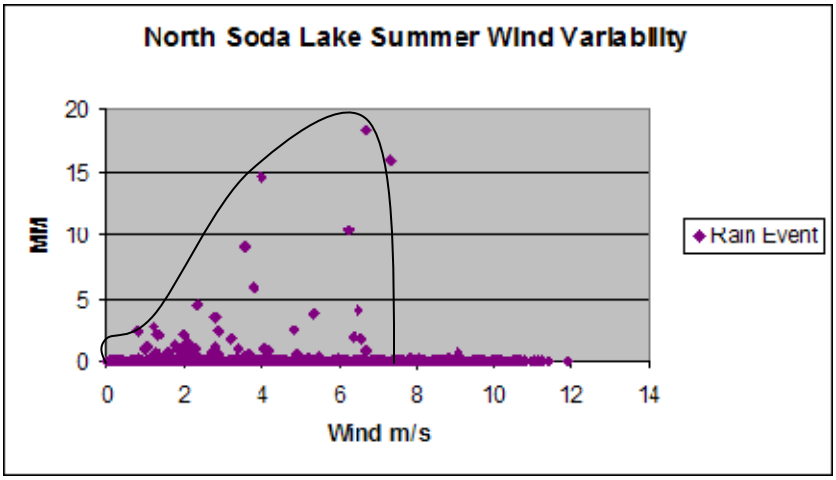
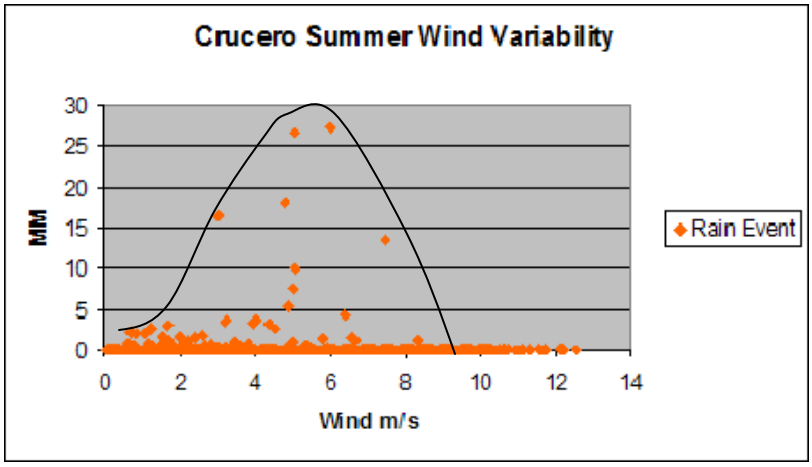
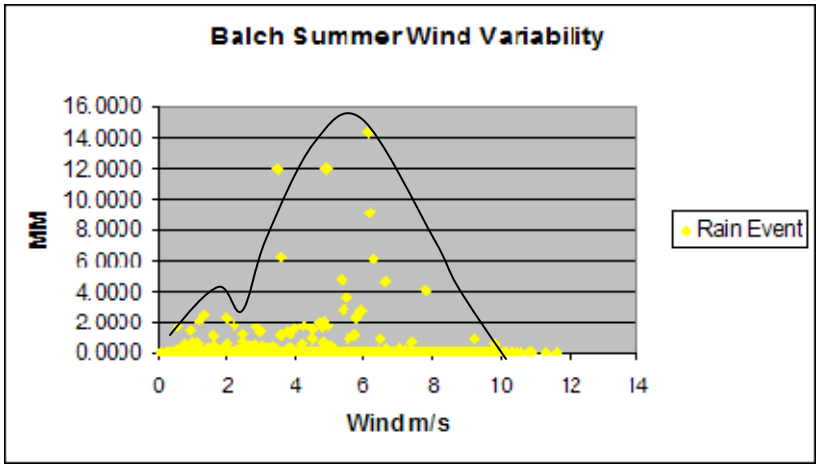
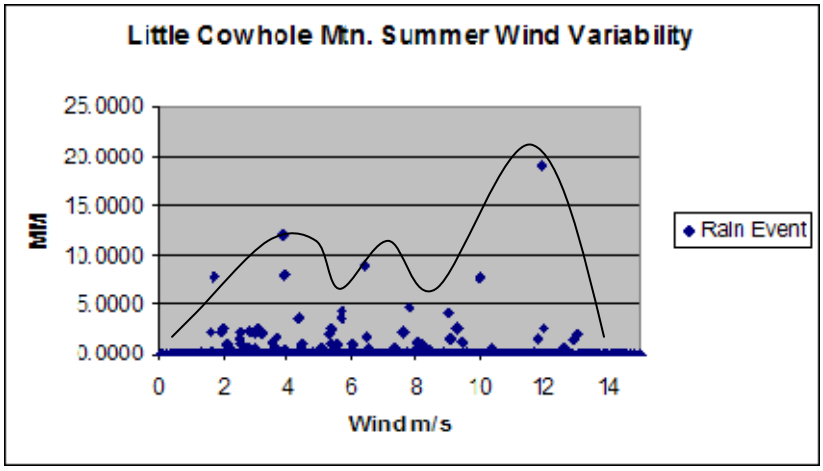


Figure 16a. *Combined graph showing summer wind influences on rainfall.*




Crucero Summer Wind Variability
MM
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
Wind m/s
Rain Event


Balch Summer Wind Variability
MM
16.0000
14.0000
12.0000
10.0000
8.0000
6.0000
4.0000
2.0000
0.0000
0
2
4
6
8
10
12
14
Wind m/s
Rain Event


Little Cowhole Mtn. Summer Wind Variability
MM
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
0
2
4
6
8
10
12
14
Wind m/s
Rain Event

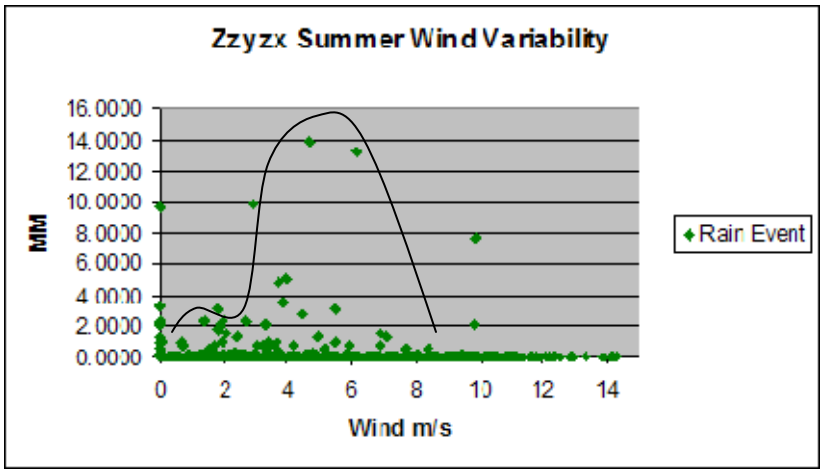


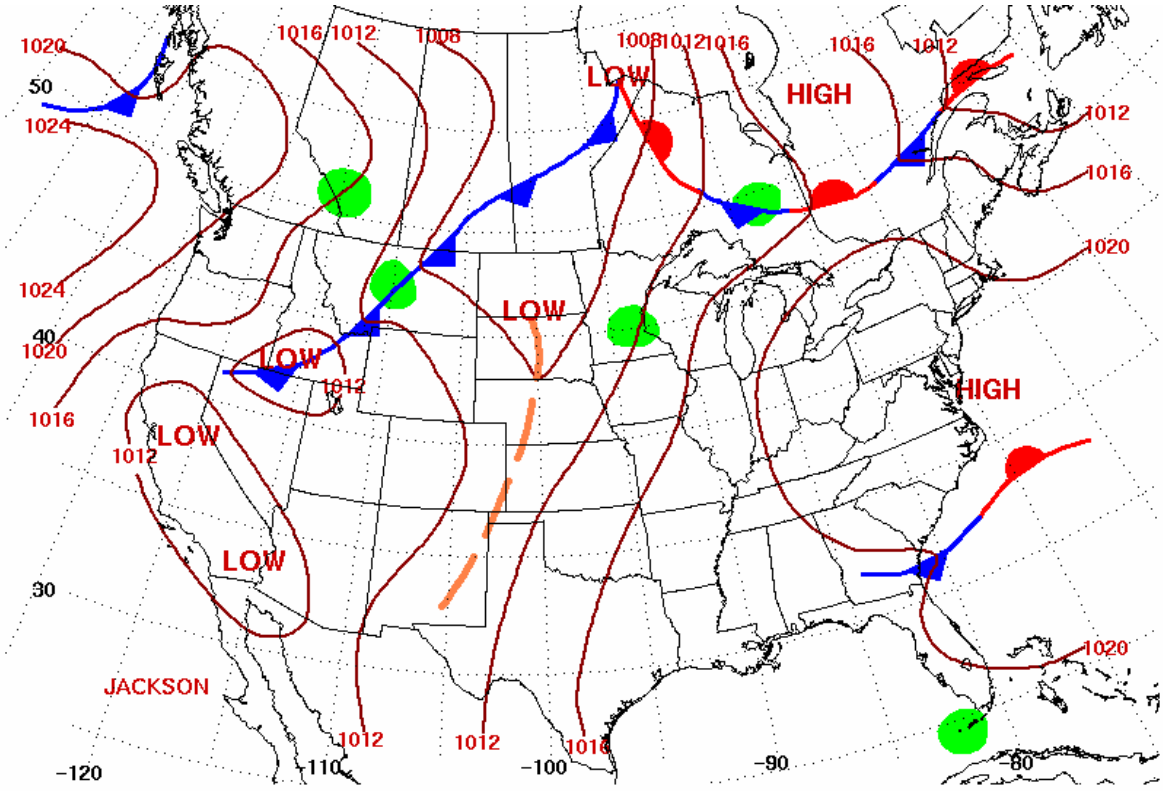
Figure 16b. *Separate station graphs showing summer wind influences on rainfall.*

The charts in figures 16a and 16b illustrate the relationship between rainfall and wind in the summer season. In general, higher wind speeds are associated with summer rainfall events. Examining the graphs for North Soda Lake, Balch, and Crucero, a mode frequency can be discerned at 2 m/s, although precipitation values at this speed are also low. Rainfall events with higher precipitation values are associated with higher winds. All five stations recorded intense rainfall events with wind speeds up to 14 m/s and hourly rainfall up to 18 mm. Common wind speeds associated with larger rain events are 4-6 m/s.

Variability in wind speeds suggests a difference in the source of storm events. Summer weather in the Mojave Desert is affected by the Southwestern United States monsoon, remnant tropical storms, and topographical influences. The convective activity produced by each of these sources brings a different pressure gradient, thus producing a variety of wind speeds. Surrounding weather patterns associated with each individual event also causes variability in air pressure and influencing wind speed as a result.

Precipitation Events

August 20, 2003 (Summer)



Surface Weather Map at 7:00 A.M. E.S.T.

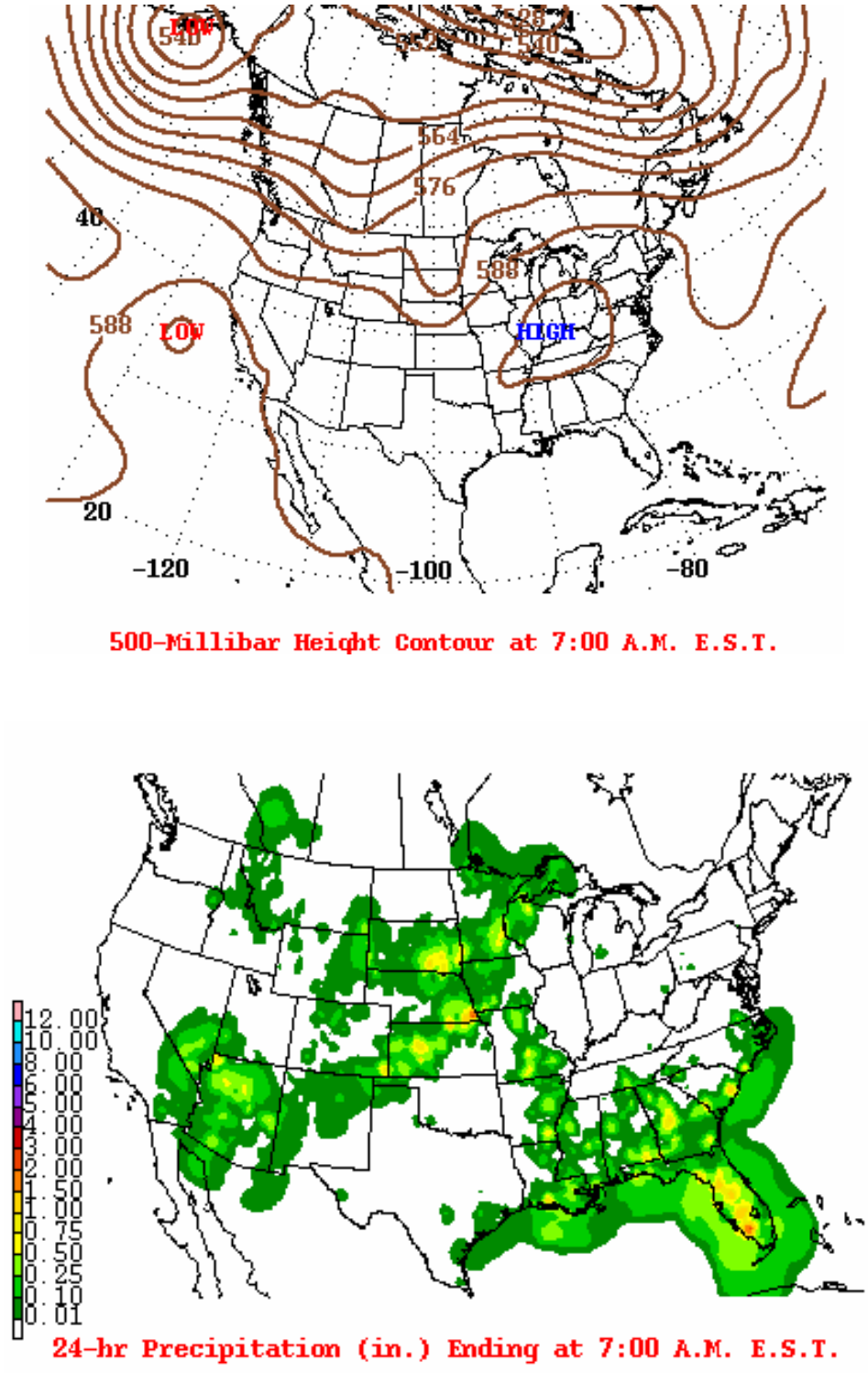


Figure 17. *Combined pressure and precipitation map (top) pressure map (middle) and rainfall map (bottom) for August 20, 2003. (Climate Prediction Center, U.S. Department of Commerce)*

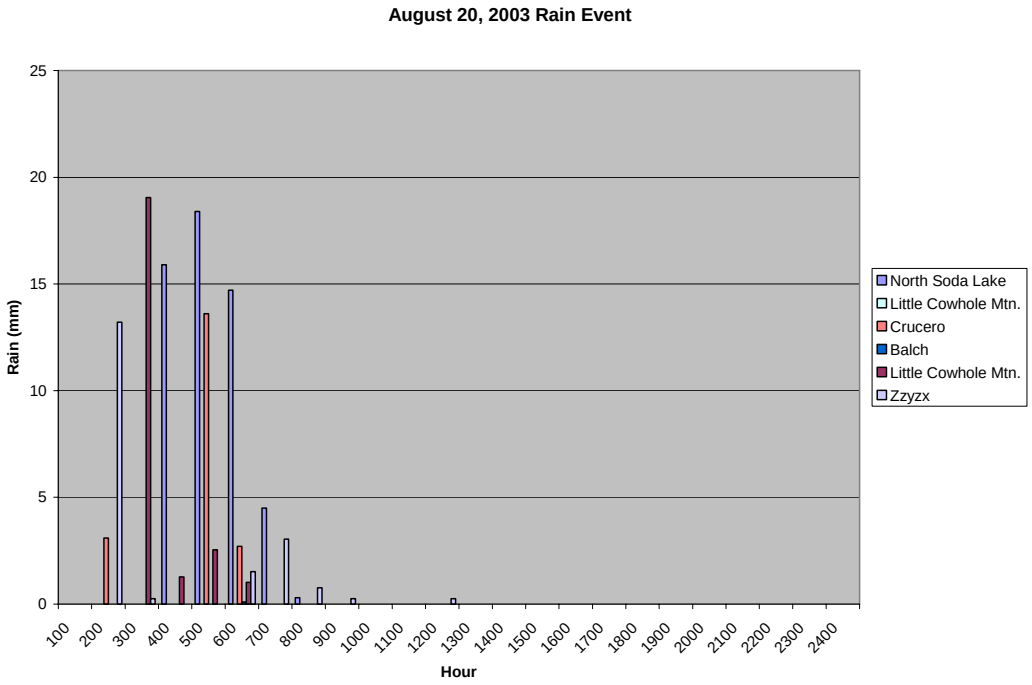


Figure 18. *Rainfall per station by the hour for August 20, 2003 rain event.*

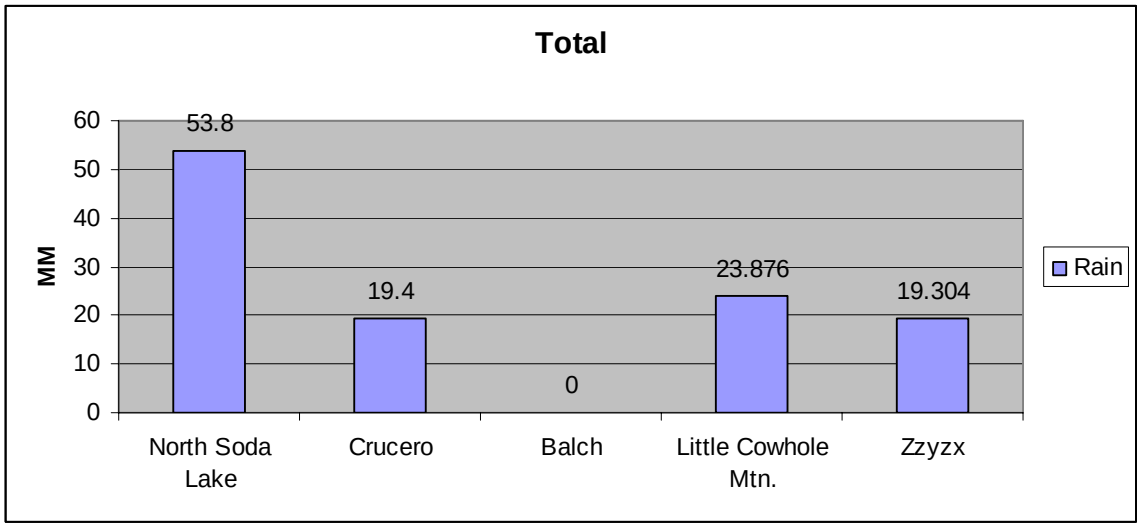


Figure 19. *Total rain for each station on August 20, 2003.*

The next section of this paper analyzes two precipitation events, one in the summer and one in the winter. As previously mentioned, summer rainfall can be caused by monsoonal effects, dissipating tropical storms, and local topographical effects. This particular summer rain event was associated with an incursion of the Arizona monsoon as

shown in figure 17. The monsoonal influence is evident from the low pressure system over the California and Arizona area. The entire southwestern United States desert regions received moderate to heavy rain that day. North Soda Lake received the most rainfall with 54.8 mm and Balch received none according to records. Of the four stations that received rainfall, Zzyzx received the least, indicating topographical influences were likely absent in this event.

The onset of the storm began at 200 and started tapering by 800 (figure 18). The storm began with downpours at Crucero and Zzyzx, which received most of its rain from the event in the 200 hour. The storm then reached its peak between 400 and 500, delivering large amounts of rain to Little Cowhole Mountain and North Soda Lake. The event concluded by delivering the last of the rainfall to the Zzyzx station in the 800 and 900 hours. Figure 20 illustrates the interpolated rainfall amounts received in the Baker Valley from this event.

High daytime temperatures on August 19, 2003 gave way to cooler night temperatures and thus fed the unstable low pressure air mass that characterizes monsoons. By 200, the instability peaked and thus precipitation commenced. The differences in rainfall values (as seen in figure 19) recorded between the stations with the lowest and highest values were 289%.

Balch recorded no hourly rainfall for this event. However, the daily records show 0.096 mm of rainfall. Hourly rainfall was likely not enough to register on an hourly basis, or data for that day and station is corrupted.

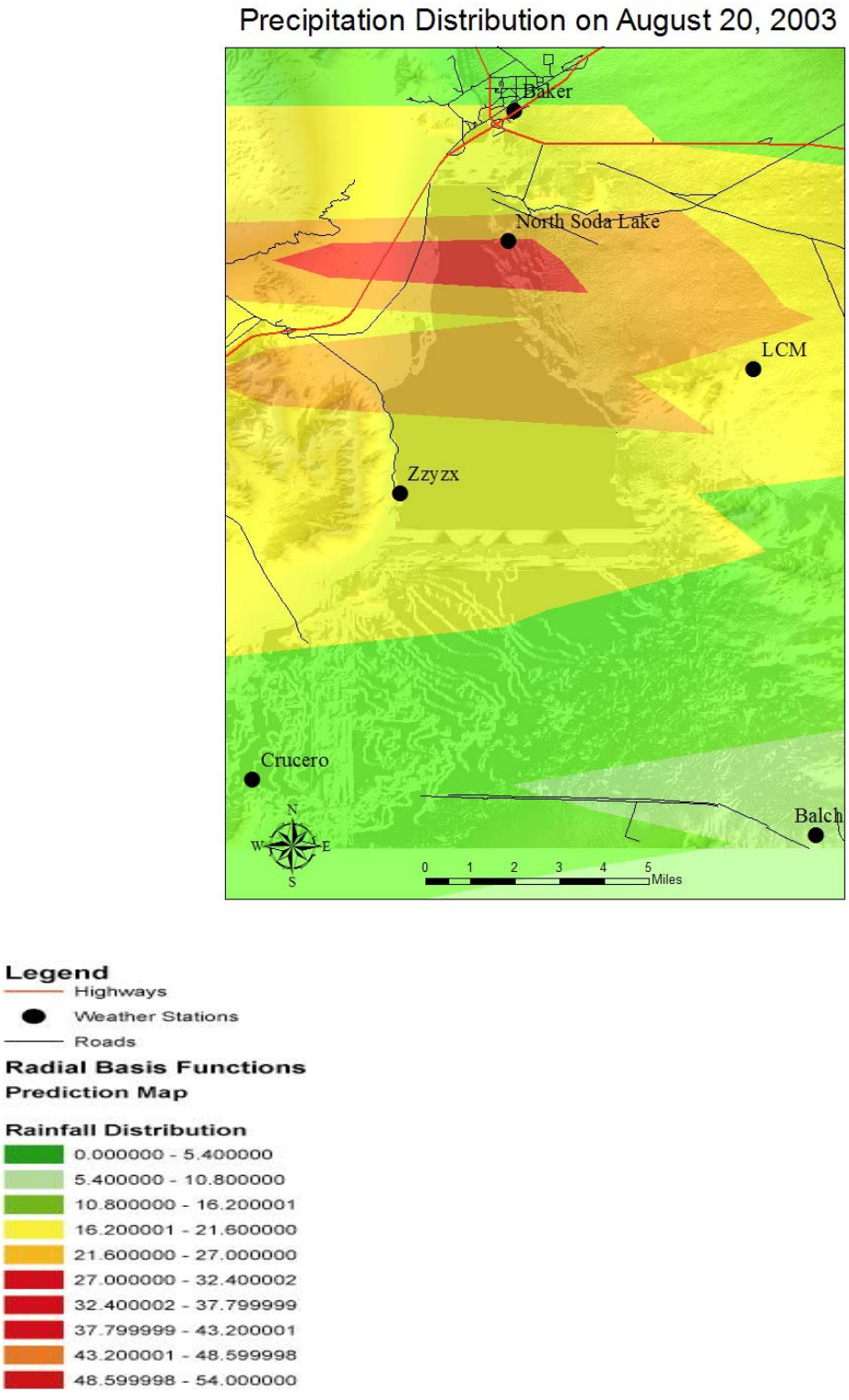
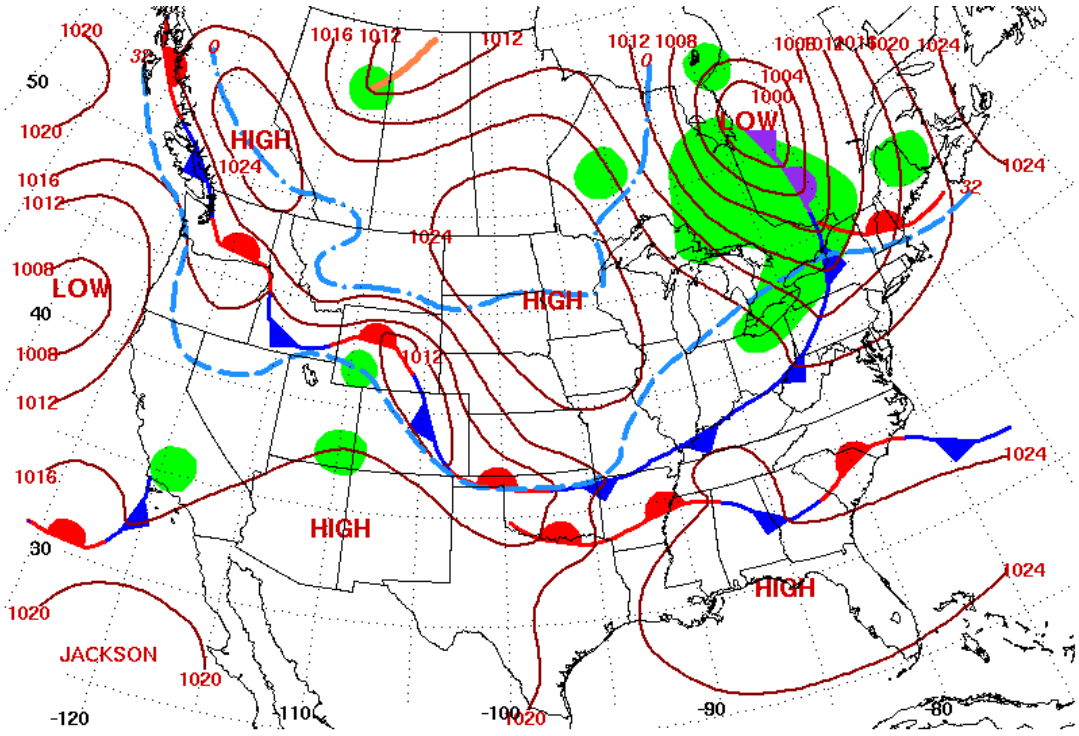
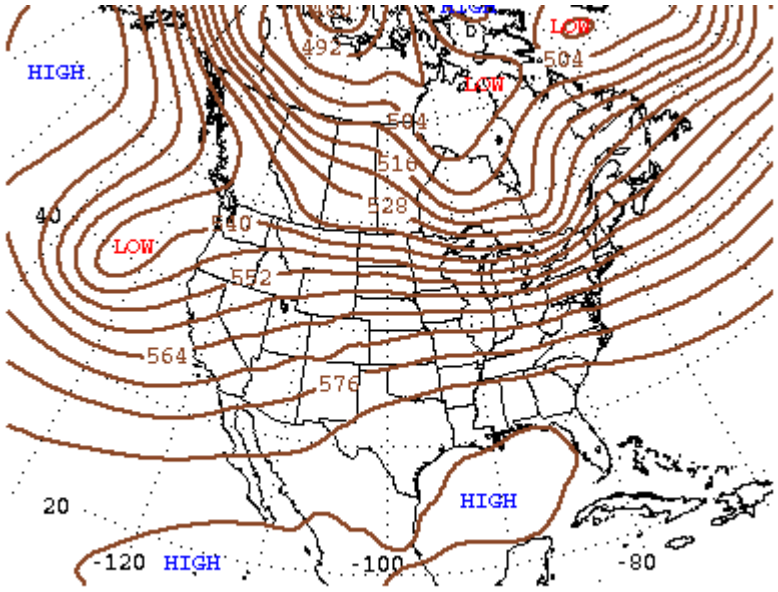


Figure 20. *Prediction map showing total rainfall for August 20, 2003 in the Baker area.*

January 10, 2005 (Winter)



Surface Weather Map at 7:00 A.M. E.S.T.



500-Millibar Height Contour at 7:00 A.M. E.S.T.

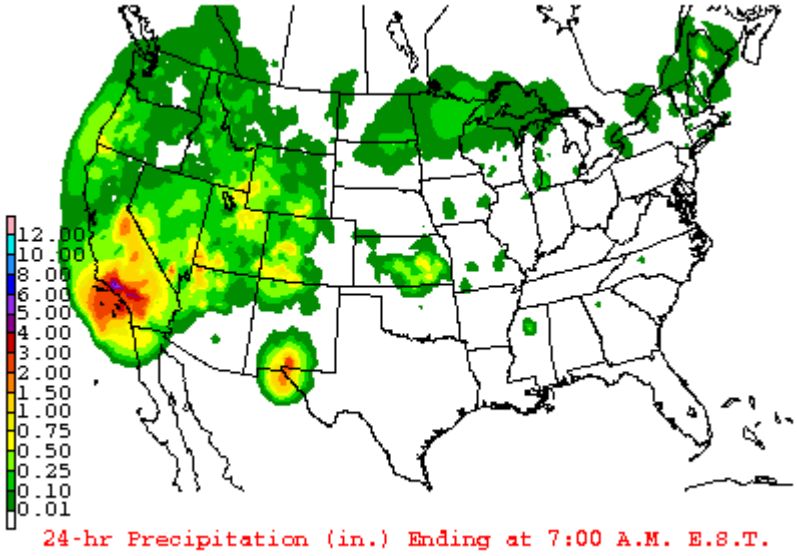


Figure 21. *Combined pressure and precipitation map (top), pressure map (middle), and rainfall map (bottom) for rain event on January 10, 2005. (Climate Prediction Center, U.S. Department of Commerce)*

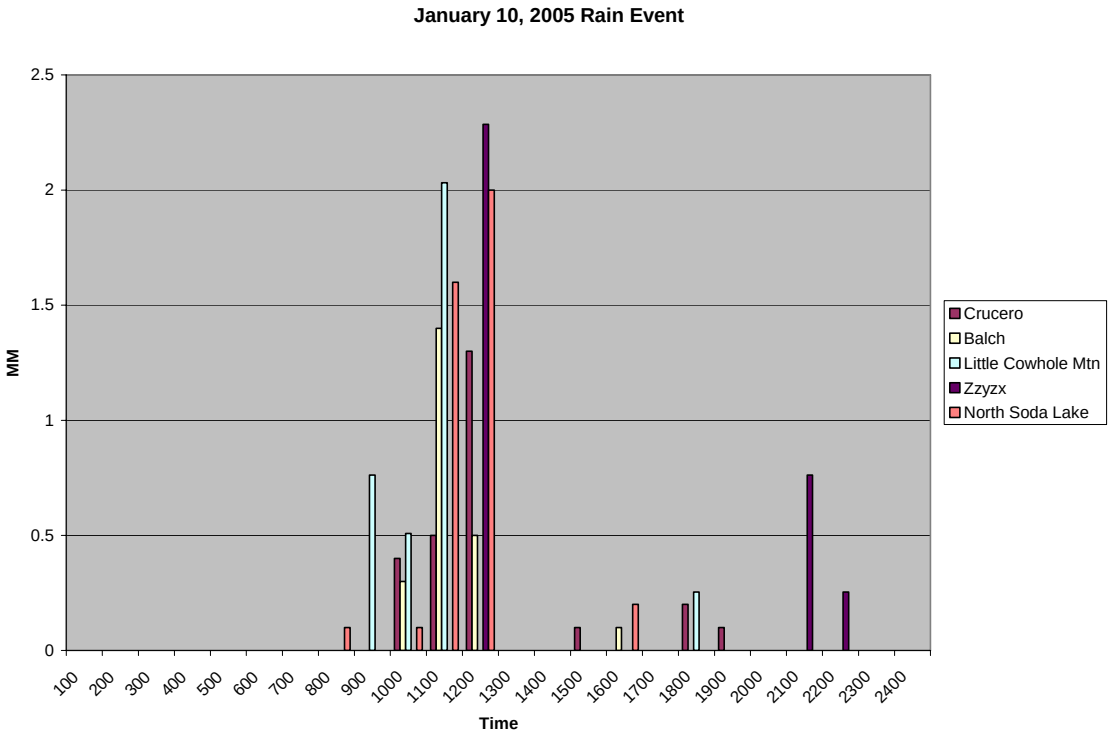


Figure 22. *Rainfall totals for each station per hour for January 10, 2005 rain event.*

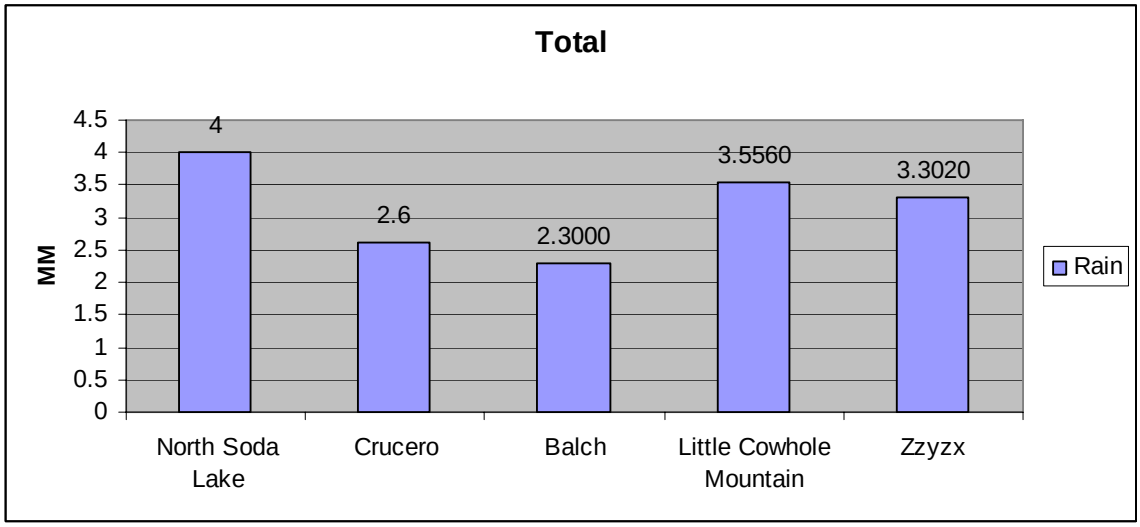


Figure 23. *Total rainfall for each station on January 10, 2005 rain event.*

The winter of 2004/2005 featured many El Nino-like storms. Scientists predicted another powerful El Nino building in 2003/2004 (Climate Prediction Center) before conditions started to calm in the winter of 2004/2005, though patchy storms resembling that of an El Nino year cycled through the United States. One such event was on January 10, 2005. The western half of the United States experienced unusually heavy rainfall throughout (figure 21), including the Mojave Desert.

The storm brought a considerable amount of rain to all five Baker Valley stations. The storm began with rainfall on the North Soda Lake and Little Cowhole Mountain stations in the 800 hour. By 1200 and 1300, the storm had reached its peak, dropping heavy amounts of rain on all five stations. The showers ceased by 1300 and picked up again at 1500 with sporadic showers until the 2300 hour. The variability between the stations recording the highest and lowest values was only 57.5%, considerably lower than the value derived from the monsoonal event. The map in figure 24 shows the day's rainfall totals in the Baker Valley area for this event.

The graph of the rain event on January 10, 2005 resembles that of a summer rain event with a steep increase in totals and a short period of relatively more intense rainfall. The temporal behavior of this storm is likely one factor that classified this rain event as El Nino-like. Typical frontal systems display light steady rains over longer periods, whereas convective events exhibit shorter periods of intense rainfall.

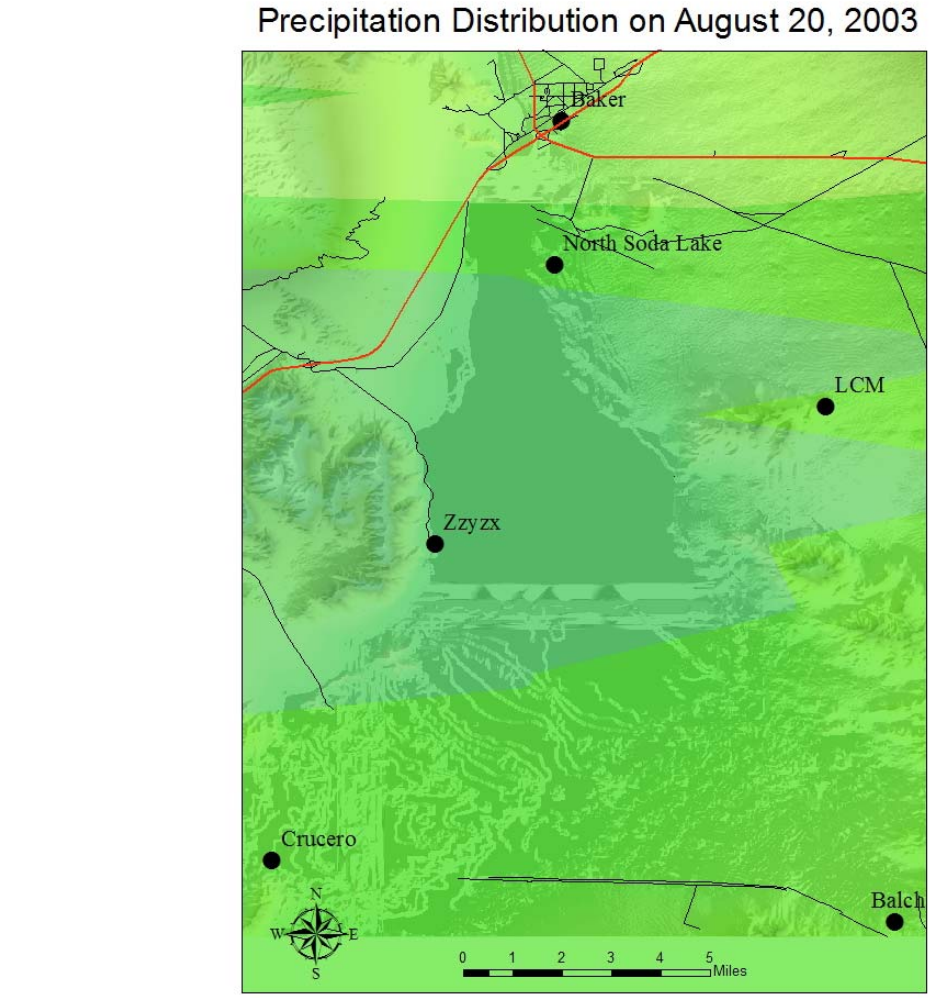


Figure 24. *Prediction map showing total rainfall for January 10, 2005 in the Baker area.*

Conclusion

The Mojave Desert has lacked an extensive study of precipitation patterns and variability. The study of Yoho (1999) using two stations in the Baker area was not published. The results of this study indicate that precipitation in the eastern Mojave Desert displays great variability over time and space, even in a relatively small area.

Frontal precipitation in the winter months brings lower daily and hourly averages than summer convective precipitation events. Higher annual totals are present in the winter time than in the summer. Spatial variability exists throughout the winter months, within a range of monthly means between 0.35 mm and 0.58 mm. Zzyzx, sheltered by the Soda Mountains, experiences significantly less winter rainfall. During the summer months, Zzzyx experiences the highest seasonal totals. Variability increases enormously between the nine stations due to the spottier nature of convective precipitation.

There is a noticeable but somewhat weak association between temperature and precipitation. Temperatures during winter events most commonly occur when temperatures are close to 10º C, whereas summer rainfall temperatures range from 22º C to 36º C depending on the dominant diurnal precipitation time, which ranges from 200 to 2000. The dependence of time on summer rainfall events is important in feeding the instability of the air mass in creation of a local convective event. Frontal storms are not time dependant owing to their latent moisture content.

Lower wind speeds during winter events allow for more accurate rainfall measurements. The skew in the wind data on figure 14 indicates that higher wind speeds result in lower precipitation values, suggesting the effects of the wind on angling the rain and causing data error.

Results presented here reinforce the work of Yoho for the Little Cowhole Mountain and Zzyzx stations. Evaluations of seasonal and monthly averages yield similar results. Analysis of the effects of temperature and time on precipitation reinforces the findings in his report as well.

Future Work

This study took into account a small area of the Mojave Desert over a span of seven years. No inference can be made about surrounding areas or other deserts without further study. Many questions have been answered through this study, yet many more have presented themselves through the course of analysis. Time was the most limiting factor, hindering any possible further analysis. With more time, further analysis could have added data and expanded the area of study. This expanded study would allow for more accurate results, possibly reaffirming the findings from this study. Incorporating another area in the Mojave Desert such as Death Valley and making a comparison to Baker Valley could better establish a climatic regime for the Mojave Desert, and possibly solidify the concept of the existence of microclimates. Taking more stations into account would also help to better understand the relationship between rainfall and elevation.

Other future work could compare this study to other deserts in order to establish how similar the climates are at each site. The Mojave is a temperate desert. Comparisons with cold and hot deserts would seemingly yield many differences. As to what differences and what extent, can only be answered with additional analysis.

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