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CLIMATE ANOMALIES IN SOUTHEASTERN UTAH: MODERN VARIATION FROM 30 YEARS OF TEMPERATURE AND PRECIPITATION TRENDS

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ABSTRACT

The arid desert of southeastern Utah has been changing in response to a warming climate within recent years. The extent to how these changes affect this environment remains unclear. This research analyzed trends in daily temperature and precipitation data from six weather stations between 1981-2010. Using these trends, a baseline was established to compare to more modern climate (2011-2019) to see how maximum and minimum temperatures have changed, and how precipitation, specifically monsoonal rain events, have shifted in intensity, frequency, and seasonality. With few exceptions, this project found increases in minimum and maximum daily temperatures, a decreasing number of precipitation events, and decreasing precipitation totals for water years and monsoon seasons. Both maximum and minimum temperatures showed statistically significant trends in anomalies, while precipitation was less predictable for both modern and historical anomalies. The data used in this research was provided by the National Oceanic and Atmospheric Administration (NOAA) using weather stations across Arches National Park, Canyonlands National Park, Hovenweep National Monument, and Natural Bridges National Monument in the southeastern region of Utah, USA. This project, in partnership with National Park Service (NPS), intends to use these climate change projections to direct land management and adaptation strategies for the NPS.

INTRODUCTION

Extensive research has been done to measure the impacts of climate change around the world. This research focuses on the southeastern corner of Utah, which is part of the greater regional climate of the Colorado Plateau. The climate of southeastern Utah varies greatly with seasonality and is influenced by a few important factors. The primary source of precipitation for the area is the North American Monsoon (NAM). The monsoon season typically lasts from July through September and contributes 30-50% of the annual precipitation. Additionally, temperature and aridity have the greatest roles during May and early June for influencing the onset of the NAM. (Leavitt et al., 2011).

Precipitation in this area often does not exceed 250 mm in a year, yet that is heavily dependent on the El Niño-Southern Oscillation. (Wise, 2012). These factors have created a high variability for climate in southeastern Utah and may fluctuate with future climate change. Although the definitive impacts of climate change in this area remain uncertain, previous research has shown arid and semi-arid deserts similar to southeastern Utah are predicted to receive more precipitation than normal due to abnormal fluctuations in monsoonal circulation and rising temperatures (Lioubimtseva & Adams, 2004). In contrast, circulation models have predicted that this area has previously experienced severe and prolonged drought in the past, which should be factored into climate models for the 21st century. (Cook, Ault, and Smerdon, 2015; Wise, 2012)

The data used this research was collected at weather stations within national parks or national monuments. According to Schwinning et al. (2008), over 15,000 km^2 of the Colorado Plateau are federally designated as national parks. It is important to note that these protected and actively managed landscapes may respond differently to climate change. Previous research on precipitation and temperature changes specifically in national parks has found that national parks specifically are experiencing hotter temperatures, less precipitation, and greater vulnerability to climate change compared to the rest of the United States (Gonzalez et al., 2018). This would exacerbate the previous predictions of climate change of this particular region. However, the trends within all national parks may not by applicable to the scale of southeastern Utah, given its unique location and features. While this area is likely responding to climate change similarly to other studied areas, there are many unique aspects of Southeastern Utah that may be impacted disproportionately, which is why it is important to analyze this area independently. Moreover, studying the historic climate records of this area and its federally protected lands will hopefully bring more insight for management practices within national parks and monuments in Utah and beyond.

METHODS

This research used historical data from NOAA's Global Historical Climatology Network (GHCN) that was analyzed through RStudio software and code. The variables of interests are maximum daily temperature, minimum daily temperature, daily precipitation in millimeters, and the number of precipitation days, primarily because these were the most consistently recorded across the reference period. However, some values were not recorded, and any missing values have been removed.

Temperature

Several variables were added to the temperature dataset before analysis. Initially, the dataset contained daily values of maximum and minimum temperature, which had an assigned month, year, and water year. I averaged daily values across each water year and each month, creating two separate averages for both maximum temperatures and minimum temperatures. Since the data from the GCHN ranged from 1957 to 2020 at some stations, it was filtered to only contain 1981-2010 to create a reference period for climate change. That dataset was then split that into two sets for maximum temperatures and minimum temperatures.

Using the monthly averages for temperatures, I determined the 30-year average and standard deviations for each station (Table 1). The 30-year average was then used as a reference point for departures from the average, which created the annual anomalies. After annual anomalies were analyzed and plotted (Figure 1 and 2), a linear model was applied to each station to depict the general trend. While the linear models did not fit the data strongly, indicated by low r2 values, the vast majority of linear relationships were statistically significance. All but three of the linear relationships were statically significant at $p < .001$.

Modern temperature data were filtered form the original GCHN dataset for the water years 2011 through 2019. I again used averages from the water year and monthly levels to create average from the 9 years after the reference period, which I labeled as “modern” in Table 2. Using the baseline averages from the reference period (Table 1), simple subtraction was used to compare modern and historical averages for maximum and minimum temperatures.

<u>Precipitation</u>

The precipitation data downloaded from the GHCN also contained daily precipitation values that were outside of the reference period, so the data were initially filtered to include 1981 through 2010. Then, I summarized the daily observed precipitation to aggregated values for each month and water year. These totals were averaged at the monthly and water year level to determine the 30-year averages. Water year averages and standard deviations are displayed in Table 3. I then used the reference period average to determine the annual and monthly precipitation anomalies.

Analysis began with linear models of observed water year precipitation (Figure 3). Similar to temperature trends, the linear model outputs show some statistically significant relationships, but low R-squared values (Table 3). The monsoon season was then separated to focus on the seasonal cycles of precipitation. The North American Monsoon heavily impacts the amount of precipitation in this area of Utah, and most precipitation from these patterns occurs between the months of July and September (Leavitt et al., 2011). Therefore, these months should be the most indicative of changes in the seasonality and intensity of precipitation events. After filtering the data for the summer season, a loess model was applied to the plots of seasonal precipitation (Figure 4), due to the poor fit of previous linear models in the water year precipitation. Another important variable that I defined was precipitation days which was created using a summary of all days with any precipitation greater than 0 mm. Using precipitation days negates any outliers for observed precipitation and equalizes all days with any precipitation within each monsoon season. In attempt to portray any seasonality shifts, I categorized the number of days with precipitation by month (Figure 5). For example, if the early season (July) precipitation days were decreasing, and later season (September) days were increasing, this could potentially indicate a shift in monsoon season to later in the year. After looking at the trends of Figure 6, I ran two linear models for each month within the monsoon season: one for precipitation days and another for precipitation amounts.

The modern precipitation data was derived from the original dataset downloaded from GCHN and filtered for the water years 2011- 2019. Similar to the reference period, I summarized the daily precipitation values into monthly totals and water year totals of observe precipitation amounts. Using the observed amounts, I averaged these values to create comparisons to the reference period (Table 5). An additional graph was made to plot the modern precipitation trends and observed values that can visualize modern precipitation in comparison to historic precipitation

RESULTS

Temperature

Linear models show a positive increase in both maximum and minimum temperature anomalies with only one statistically significant exception. The station at Arches National Park (ARCH) is the only station to show any decreasing trend in departures over the 30-year period. The trend showed a statistically significant decrease of approximately .022724 degrees Fahrenheit per year. This could potentially be influenced by several years of positive (warmer) departures at the very beginning of the time series, in addition to the anomalous negative departures observed towards the end. ARCH also had the largest standard deviation in both minimum and maximum temperatures, which could have influenced the overall accuracy and fit of the linear model. The station at Natural Bridges National Monument (NABR) showed a small, but not statistically decreasing trend in maximum temperatures. This could potentially be explained by the fact that the station's warmest maximum temperature departure, which was almost 4 degrees Fahrenheit above the 30-year average, came at the very beginning of the time series in 1981.

Figure 1:

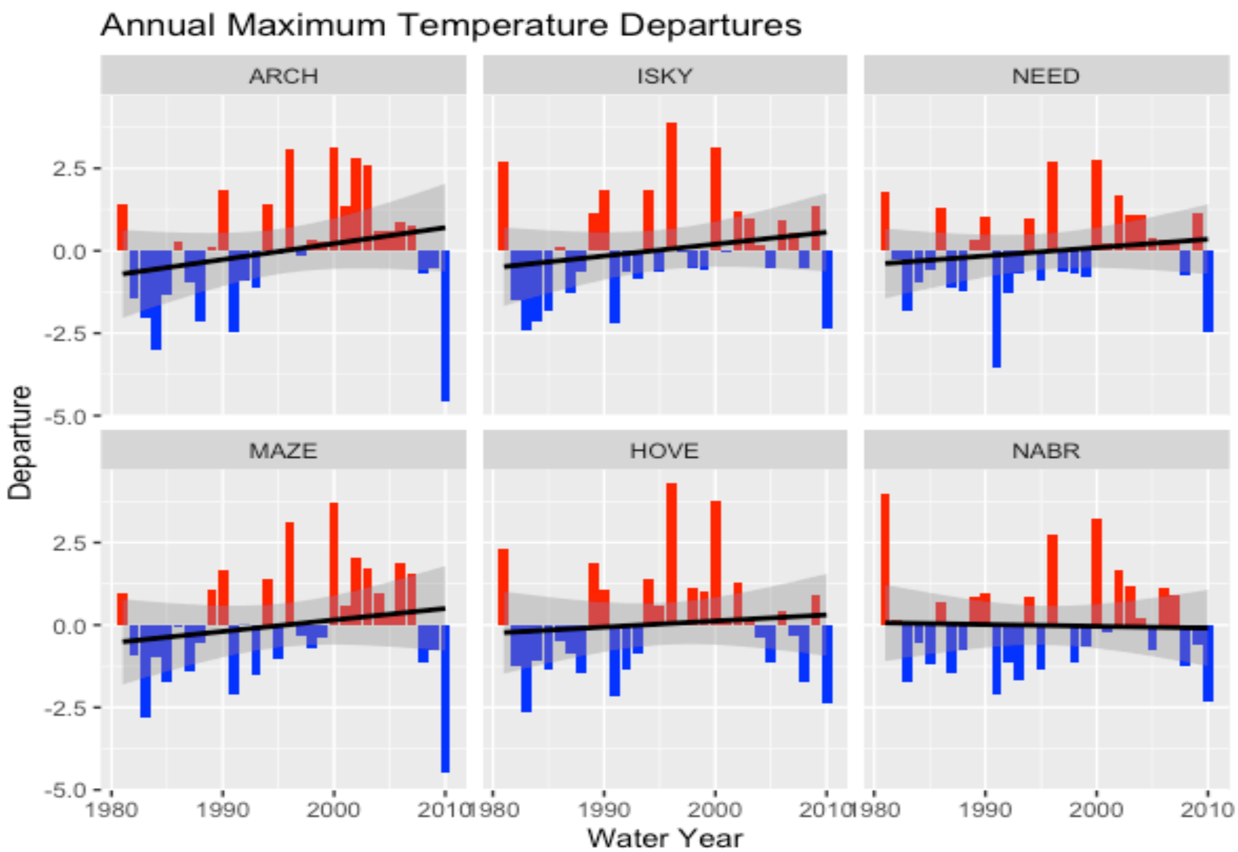
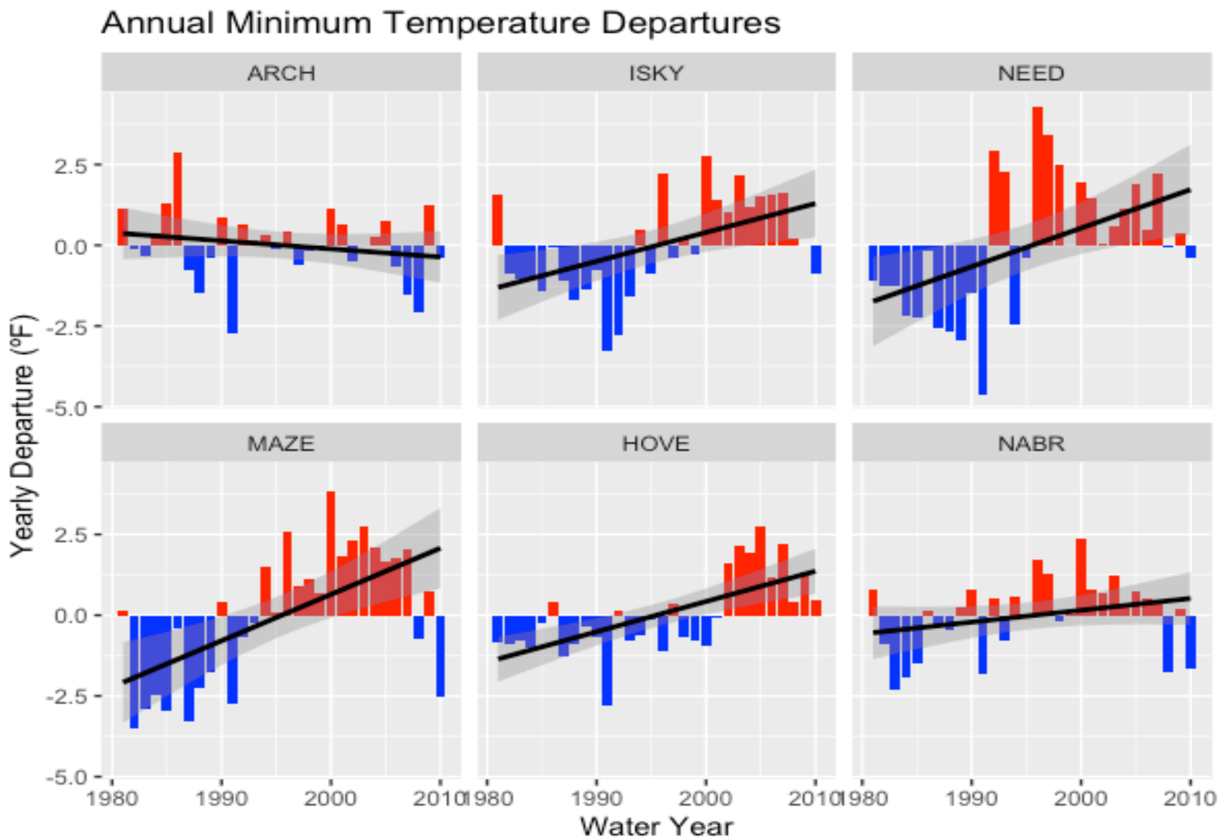


Figure 2:



All other linear relationships were statistically significant (Table 1), showing a general increase in maximum and minimum temperatures across all remaining stations: the Needles District (NEED) in Canyonlands National Park, the Maze District (MAZE) in Canyonlands NP, and Island in the Sky District of Canyonlands NP (ISKY) , and Hovenweep National Monument (HOVE). ARCH experienced the highest rate of increase in maximum temperatures, and the highest rate of minimum temperature increase was at MAZE. These rates were 0.04899ºF per year and .14553ºF per year, respectively.

Table 1: Average temperatures and trends across stations (ºF)

	Average Maximum Temperature	**Max. Temp. Linear Trend**	**Average Minimum Temperature**	**Min. Temp. Linear Trend**
Arches	71.10578	0.04899***	42.95477	-.022724***
Canyonlands-Island in the Sky	63.26792	0.035432***	42.59136	0.009213***
Canyonlands-The Needles	68.71988	0.032045***	39.27037	.11373***
Canyonlands-The Maze	61.41396	0.03404**	41.85146	.14553***
Hovenweep	68.48667	0.02241*	35.80203	.009568***
Natural Bridges	63.07989	-0.003895	38.22128	0.038199***

***: Significance at p <.001
**: Significance at p =.001
*: Significance at p = .01

Table 2: 2011- 2019 Temperatures anomalies (ºF)

	Modern Maximum Temp.	Maximum Temp. Anomaly	Modern Minimum Temp.	Minimum Temp. Anomaly
Arches	70.88111	-.22467	45.58778	+2.63301
Canyonlands- Island in the Sky	64.03367	+.076575	44.60556	+2.0142
Canyonlands- The Needles	69.04378	+.03239	39.75122	+.48085
Canyonlands-The Maze	60.61533	-.79863	42.39156	+.5401
Hovenweep	69.89367	+1.407	38.53200	+2.72997
Natural Bridges	63.46533	+.38544	38.75711	+.57305

As mentioned previously regarding the Arches station, a recent downward spike in temperature departures is apparent and consistent across most stations, primarily with maximum temperatures. All maximum temperature departures for the end of the time series in 2010 were more than 2ºF lower than the 30-year average (Figure 1). 2010 also showed the lowest maximum temperatures at ARCH, MAZE, and NABR stations, and the second lowest departures on record for HOVE and NEED stations.

The minimum temperature departures were similarly affected at most stations, but less noticeably. The 2010 minimum departure values were negative for every station except HOVE, which was 0.4906 ºF above average. However, the lowest recorded minimum temperature anomalies at all stations occurred within the earlier stages of the time series between 1982-1991, which may indicate gradually rising minimum temperatures.

It is important to note that the timing of the transition from positive to negative departures is not consistent across stations, nor do many of the stations stay above positive for long periods. Global temperature trends have much more consecutive increases, less fluctuation, and have been increasing consistently since the late 1970's (NOAA 2020). While these temperatures may not match up to more recent global temperature trends, the modern temperature anomalies exhibited unique trends compared to the reference period.

Maximum temperatures between the 2011 and 2019 water years changed predictably based on the reference period models. The steep decline in maximum temperatures at the end of the reference period that was most prominent at ARCH and MAZE was reflected in an overall decrease in average maximum temperatures at these two stations. All other stations experienced slight increases between modern and historic averages for maximum temperatures. HOVE was a potential outlier with a 1.41ºF average increase between the two periods. This increase is greater than any other stations by more than one degree Fahrenheit.

Minimum temperatures increased much more dramatically and consistently, yet they were not as aligned with the reference period models. The temperature increase ranged between 0.48 and 2.73 degrees Fahrenheit (Table 2). Three out of the six stations- ARCH, ISKY, and HOVE- all increased more than 2 degrees. This does not correspond with the trends of the reference period linear models, especially since ARCH actually had slightly decreasing minimum temperatures during the reference period. The reference period linear models with the strongest relationships, such as the Needles and the Maze, had the least significant increases in minimum temperatures.

<u>Precipitation</u>

Precipitation across water years was much less predictable using linear models. The stations that showed statistically significant decreases in water year precipitation were ARCH (-1.6097 mm/yr.), ISKY (-1.1163 mm/yr.), NEED (-.98 mm/yr.), and HOVE (-3.5589 mm/yr.). Although these decreases are statistically significant, they are much more subtle than the temperature anomalies, and the R-squared values indicate that linear models may not be the best fit for these data (Table 3).

Table 3: Water Year Precipitation Totals

	30 year Average (mm)	**30-year Std. Deviation**	**Linear Model R^2 value**
Arches	220.0784	64.53117	0.04356
Canyonlands- Island in the Sky	234.8916	55.75475	0.02722
Canyonlands- The Maze	249.2547	69.07311	-0.0011
Canyonlands- The Needles	212.359	57.70241	0.01897
Hovenweep	264.1736	89.751	0.1172
Natural Bridges	313.2399	78.1724	0.04354

In order to lower the influence of any outliers in precipitation amounts, seasonality was assigned to each month, with an initial focus on summer monsoon season. As stated earlier, the NAM brings heavy precipitation during the summer months of July, August, and September, so these months were selected to get a precipitation totals for the monsoon seasons of each water year (Figure 4). The general trends in precipitation, both at the water year and summer season level are outlined in Table 3. Another important variable used to observe changes in monsoonal precipitation is the number days with precipitation events. Using the days with precipitation eliminates any disproportionate significance of days with heavy precipitation accumulation as opposed to days with smaller events.

Linear models were used to show trends in total water year precipitation, total summer precipitation, and the total days of precipitation within the summer season. Decreases across all three variables were consistent throughout, although some results were not statistically significant enough to be considered conclusive (Table 4). Strong negative water year trends with less predominant decreases in summer precipitation, like at ARCH and ISKY, may indicate more severe changes in winter precipitation than summer.

Figure 3:

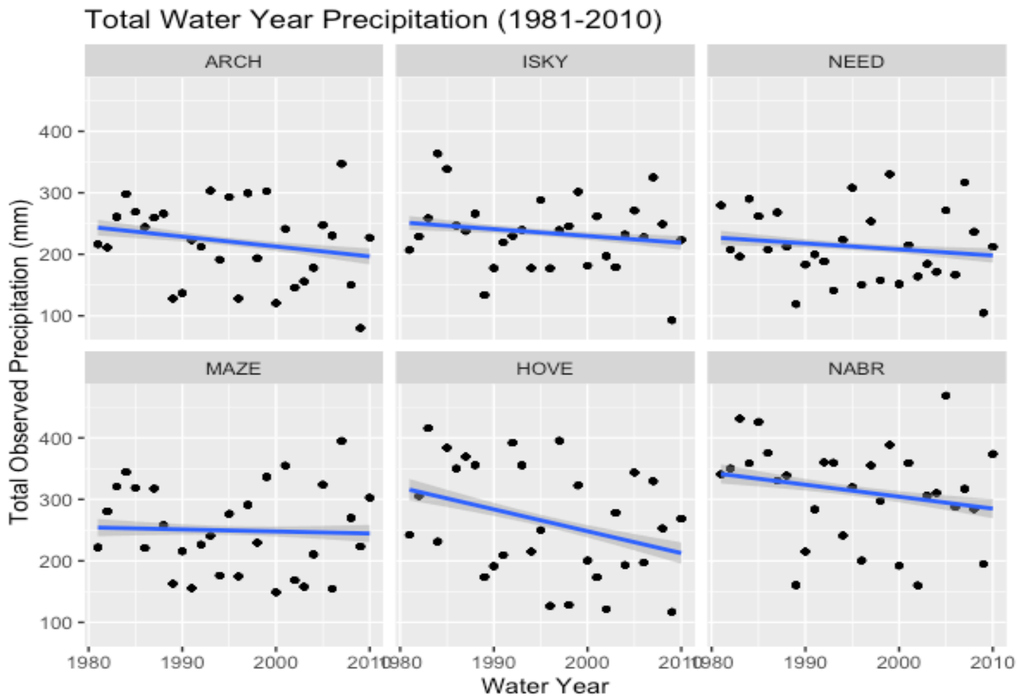


Table 4: Trends in Precipitation Linear Models

	Water Year Precipitation (mm)	**Summer Precipitation (mm)**	**Summer Days of Precipitation**
Arches	-1.6097***	-0.3528	-0.20750**
Canyonlands-Island in the Sky	-1.1163**	-0.6126	-0.16528*
Canyonlands-The Maze	-0.3287	-1.0479 **	-0.03312
Canyonlands-The Needles	-0.9835**	-0.7221*	-0.31964***
Hovenweep	-3.5589***	-1.2169**	-0.08100
Natural Bridges	-1.9459 ***	-1.1235 **	-0.02864

***: Significance at p <.001
**: Significance at p =.001
*: Significance at p = .01

To expand on summer precipitation and seasonality of monsoonal precipitation, I separated the monsoonal precipitation totals and days by month (Figure 5 and 6). July precipitation days outnumbered other months initially but had a steep drop around 1993 and never fully recovered. After that point, August dominated most years, but the amounts of precipitation for all months had much more inconsistency and variation than previously. These results correspond with the months' linear models, in which July had the only statistically significant relationship decrease in both precipitation amount, which was approximately -5.639 mm/year, and precipitation days, which was approximately one full day every 10 years. The strength of the July trends is more pronounced in Figure 6. Decreasing July precipitation could be explained by a seasonal shift in monsoonal rainfall, but that cannot be determined without of any significant linear relationships in the months of August and September.

Figure 4:

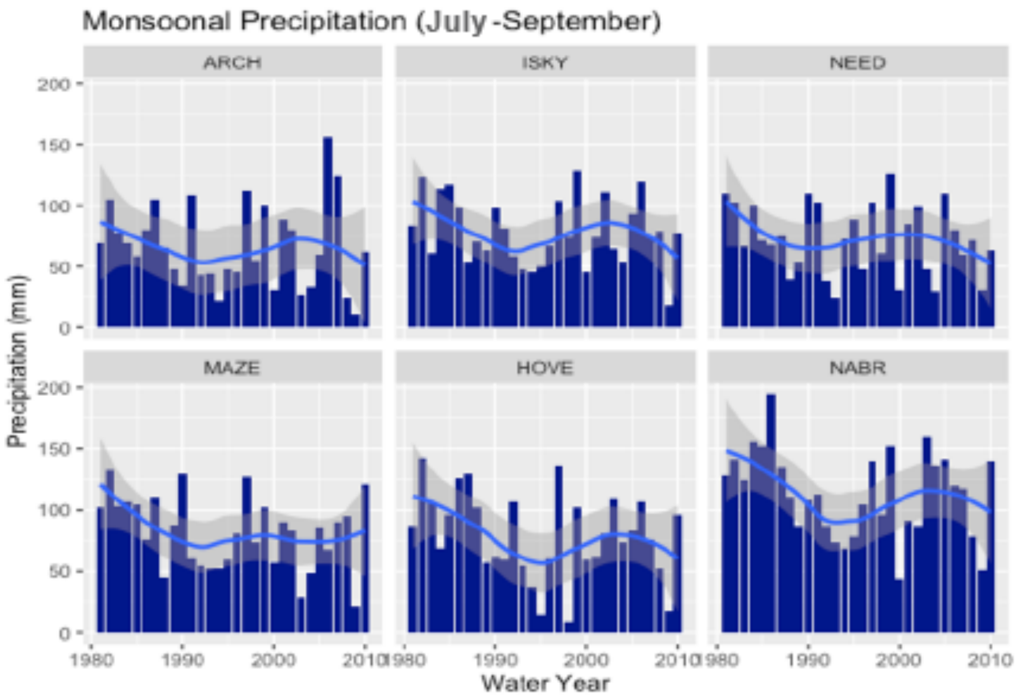


Figure 5:

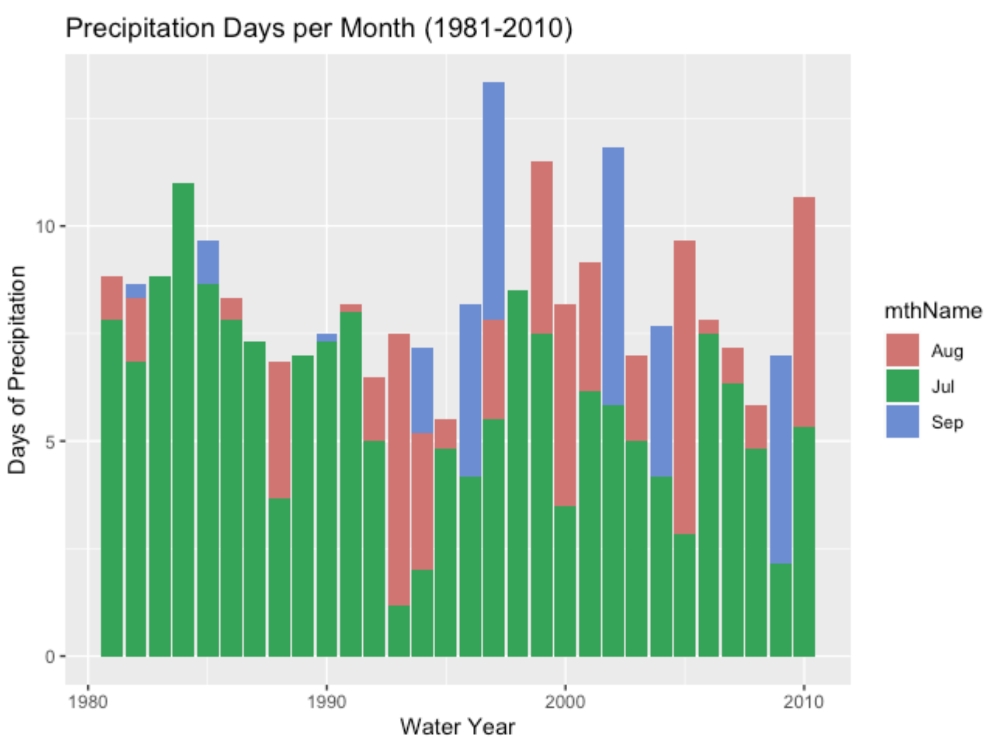
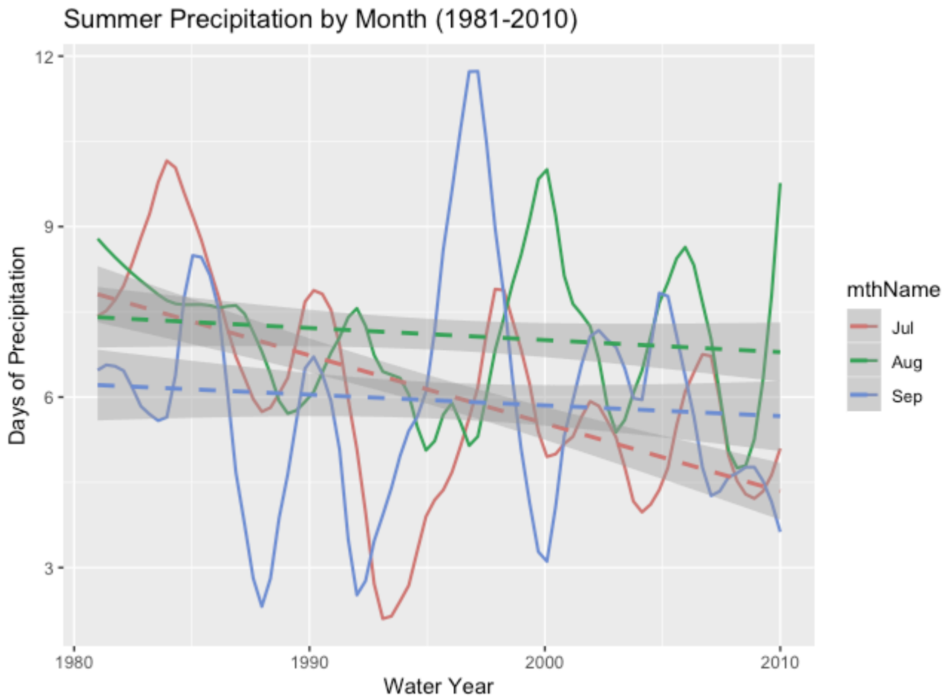


Figure 6:

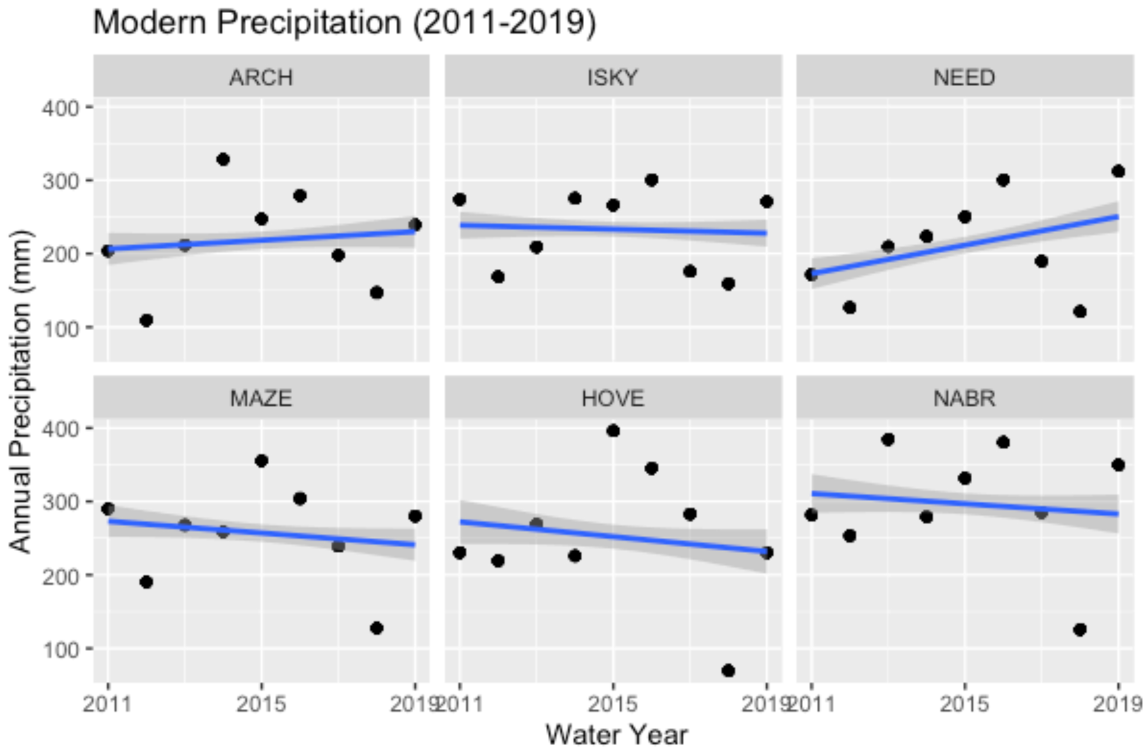


Modern precipitation corresponded with most of the historic trends from the reference period. In the comparison of averages, the stations with the most predominant decreases had the largest anomaly between the modern and historic precipitation averages. HOVE and NABR, which had the two highest decreasing historic trends, also had the greatest negative anomalies at -12.0514 and -16.3843 millimeters (Table 4 and Table 5). MAZE was the only station to record any increase in precipitation observed in the modern period, which had no statistical significance for any decreasing or increasing trends in overall water year totals. While this modern anomaly may seem to be significant, it is improbable due the lack of trends within the data.

Table 5: Modern precipitation departures

	30 year Average (mm)	Modern Average (mm)	Anomaly
Arches	220.0784	218.3000	-1.7784
Canyonlands-Island in the Sky	234.8916	233.3333	-1.5583
Canyonlands-The Maze	249.2547	257.0778	+7.8231
Canyonlands-The Needles	212.359	211.6889	-.06701
Hovenweep	264.1736	252.1222	-12.0514
Natural Bridges	313.2399	296.8556	-16.3843

Figure 7:



DISCUSSION

This research provides insights on the variation of maximum and minimum temperatures, and the quantity and seasonality of monsoonal precipitation in southeastern Utah. An additional factor that should be researched in more detail is the onset and duration of precipitation from the North American Monsoon (NAM). The scale of this project and the size of this dataset was intended to be more of an overview analysis of historic temperature and precipitation trends of the region compared to more recent climate. While I did a smaller scale analysis on precipitation amounts and precipitation days during the monsoon season, this does not account for how the monsoon season may be changing in length and onset. Further research could define more specific criteria for monsoonal events to focus on the onset of summer monsoons every year.

In conjunction, some stations showed decreases in water year precipitation totals without any changes in monsoonal precipitation. This suggests that there could be anomalies within other seasons that could be researched additionally. The complications with this, however, would be the component of rain versus snow events, which is not uncommon for this area during the winter season.

Supplementary research of long-term patterns like the El Niño-Southern Oscillation (ENSO) would also be beneficial to this research and the greater understanding of climate change of the area. I was able to see some cyclic fluctuations in summer precipitation (Figure 6), which could be influenced by the periodicity of ENSO events. However, I did not compare the trends from my data to any timescale of ENSO events. Using data from the stations that extend further back than 1980 may assist in any further analysis on ENSO and its relationship to monsoonal precipitation in southeastern Utah.

Spatial analysis of this area could provide more resolution to help determine any difference between federal lands and other lands, both protected and unprotected by any designations. The boundaries of the national parks and monuments mentioned in this study are likely arbitrary, yet the management capabilities across borders may influence how southeastern Utah and its ecosystems respond to climate change.

CONCLUSION

A global baseline for climate change can be pieced together through localized analyses such as this research. The most significant findings from this project are the increases in minimum temperatures, decrease number of precipitation events and that the overall precipitation totals have been slightly decreasing across water years and monsoon seasons. Both maximum and minimum temperatures showed statistically significant trends in anomalies, while precipitation was less predictable for both modern and historical anomalies. The number of days with rain is also decreasing and potentially shifting seasonally, given the significant decrease of precipitation days in July. While some exceptions apply, southeastern Utah is experiencing climate change in ways that resemble many other areas around the world. With precipitation decreasing and temperatures getting warmer, this region will likely become more arid, creating a positive feedback loop between moisture and temperature. Consequentially, southeastern Utah and the greater Colorado Plateau region will likely see potential impacts to the ecosystems and resources protected within national parks like Arches, Natural Bridges, Hovenweep, Canyonlands, and beyond.

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