PEAK OVER THRESHOLD ANALYSIS OF HEAVY PRECIPITATION IN TEXAS

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1. INTRODUCTION

Heavy and extreme precipitation is a particular problem in Central Texas along the I-35 corridor in what is known as Flash Flood Alley. Both the geography and meteorology of the region provide a unique set of conditions which lead to dangerous flash flooding. Limestone bedrock close to the surface limits infiltration of rainwater, which promotes runoff into narrow, deep incised streams, which can rise rapidly. The Gulf of Mexico provides a rich source of moisture for showers and thunderstorms for much of the central and eastern parts of the state. The Balcones Escarpment, a feature which bisects the state into the Coastal Plain and the Hill Country, runs in a north-south line between San Antonio and Dallas, and may promote orographic lift. This lift serves as a focusing mechanism for heavy and extreme precipitation (Nielsen and Schumacher, 2016). One anticipated impact of climate change in Texas is an enhancement of the drought-flood cycle, which will have important consequences for both the agricultural sector and the safety of the population living along the heavily populated Flash Flood Alley. This analysis will explore temporal and geographic variation in heavy and extreme precipitation in Texas over the last century.

2. BACKGROUND

Because of the significant threat to public safety posed by flash floods and the importance of precipitation to agriculture, numerous studies have been undertaken to better understand the precipitation climate in Texas, using both archived data and model projections. A statistical study by Shen et al. (2014) led to the division of the past century into two regimes, an earlier "dry" regime (1895-1970) and a later "wet" regime (1971-2010). While the trend is true for the contiguous United States, data for Texas indicate a wetter climate in the later period only in the central and eastern parts of the state, with mixed results for the western half of the state. In a modeling study performed by Venkataraman et al. (2016), a decreasing trend in annual precipitation was found for much of the state of Texas during the 21st Century. Venkataraman emphasized the importance of evaluating Texas's precipitation climate on a region-by-region, rather than a statewide, basis. Ten climate regimes were identified for the state. CMIP5 projections indicate a decreasing trend in annual precipitation for semi-arid parts of the state during the 21st Century. Zhao et al. (2016) found that the total annual precipitation totals do not vary with a changing climate, but that the distribution of precipitation within the year does change, with precipitation occurs in the autumn months than the summer months. Making projections for Texas's precipitation climate is made more complicated by the large number of influences that affect the precipitation climate across the state, for example orographic effects (Nielsen and Schumacher, 2016) and tropical cyclones (Furl et al., 2015; Villarini and Smith, 2013; Bosart et al., 2012) in addition to synoptic scale influences.

3. METHODS

Daily precipitation totals were collected using the online interface of the National Center for Environmental Information (NCEI) website. Data with a record greater than fifty years in length was selected from fourteen Texas cities. Nine of those records were of sufficient length for two independent evaluation periods, an "early" period beginning around 1900, and a "late" period beginning near 1950. In this way, it was possible to evaluate temporal dependencies in addition to spatial ones. Each dataset was divided into seasons and examined for a long term trend using a linear regression. Second, a Weibull Distribution was fit to all precipitation days in each dataset. When possible, the Weibull distributions for the early and late periods were compared. The remainder of the analysis focused on a peak over threshold analysis and the generation of return period curves.

3.1 Peak Over Threshold Technique

This analysis employed the peak over threshold technique based on the work of Acero (2010). In contrast to traditional extreme value theory, in which the peak value from each year of a dataset is selected as the extreme, the peak over threshold technique includes each datapoint which exceeds a given threshold. In this way, multiple extreme events per year can be counted. It is not unusual in Texas for there to be more than one extreme precipitation event in a given location during a given year, so this method is most appropriate for the evaluation of extremes in this region. The ninety-fifth percentile of all data (including days with zero precipitation) was chosen as the threshold for each dataset. Days with precipitation totals greater than the threshold were extracted from the dataset for further analysis. Extreme precipitation events in Texas are often due to multi-day frontal or upper-level low pressure systems. Such systems often lead to multiple successive days of high precipitation totals. To ensure independence of each event in the database, these clusters were treated as single events, with the peak day in the event representing the entire event. The extremal index (θ, Equation 1) was used to estimate the portion of data which existed outside of these clusters and then to scale the resulting return period curve based upon this amount.

Table 1. Stations and periods of study

Station	Period(s) of Study
Abilene	28 Dec 1949-31 Dec 2017
Alpine	29 Sep 1911 - 1 Oct 1960
	5 Oct 1965 - 28 Sep 2014
Amarillo	28 Dec 1949 - 31 Dec 2017
Austin	5 Oct 1904 - 28 Sep 1953
	28 Dec 1949 - 31 Dec 2017
Blanco	6 Oct 1900 - 29 Sep 1949
	5 Oct 1965 - 28 Sep 2014
Brownsville	6 Oct 1900 - 29 Sep 1949
	5 Oct 1965 0 28 Sep 2014
College Station	1 Oct 1901 - 29 Sep 1949
	5 Oct 1965 0 28 Sep 2014
El Paso	28 Dec 1949 - 31 Dec 2017
Houston	6 Oct 1921 - 28 Sep 1972
	28 Dec 1949 - 1 Dec 2017
Kingsville	6 Oct 1902 - 29 Sep 1951
	5 Oct 1965 - 28 Sep 2014
Lubbock	28 Dec 1949 - 31 Dec 2017
San Antonio	5 Sep 1946 - 1 Jan 2016
San Marcos	6 Oct 1902 - 29 Sep 1949
	5 Oct 1965 - 28 Sep 2014
Texarkana	6 Oct 1900 - 29 Sep 1949
	5 Oct 1965 - 28 Sep 2014

$$\theta(u) = \frac{2[\sum_{i=1}^{N-1}(T_i - 1)]^2}{(N-1)\sum_{i=1}^{N-1}(T_i - 1)(T_i - 2)} \quad (1)$$

Next, a Generalized Pareto Distribution (GPD) was fit to the exceedance data. The shape (σ) and scale (ξ) parameters from the GPD fit, along with θ, were used to compute the return period curve for N = 1 to 100 years using Equation 2.

$$x_N = u(t) + \frac{\sigma(t)}{\xi}\left[(Nn\zeta_u\theta)^{\xi} - 1\right] \quad (2)$$

4. RESULTS AND DISCUSSION

When linear regressions were fit to the raw daily precipitation data for each season at each station, trend in the magnitude, but not the frequency, of extreme precipitation could be evaluated. Over the course of the study period, nine stations saw an increase in the magnitude of extreme precipitation events during the winter months. College Station was the only station to see a decline in the magnitude of extreme events during the winter, with San Antonio, Austin, and Brownsville reporting no change in extreme precipitation. Seven of thirteen stations reported an increase during the autumn months with no regional dependence evident. Spring and summer were variable with regard to extreme precipitation trend and also exhibit no regional dependence.

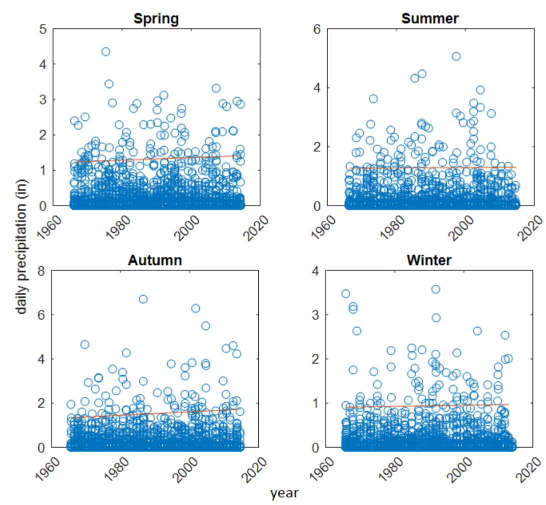

Figure 1. Raw data divided into four seasons for the Blanco station

Fitting a Weibull distribution to the whole dataset (all seasons, including days with no precipitation) enabled comparison of the frequency of extreme events between the early and late datasets for stations with sufficiently long records. Weibull distribution fits to the whole precipitation dataset for each site indicated a change in the 1-day precipitation dataset at the heavy to extreme end of the distribution between the early and late periods (Figures 2-6). Weibull fits indicate a higher number of heavy and extreme precipitation events for later data compared with earlier data for five stations: Austin, Elgin, Lockhart, and San Marcos. Of the remaining stations, three (Brownsville, Kingsville, and Texarkana) repored fewer extreme precipitation events based on the Weibull fits. College Station's early and late data Weibull fits did not indicate a trend between the early and late periods.

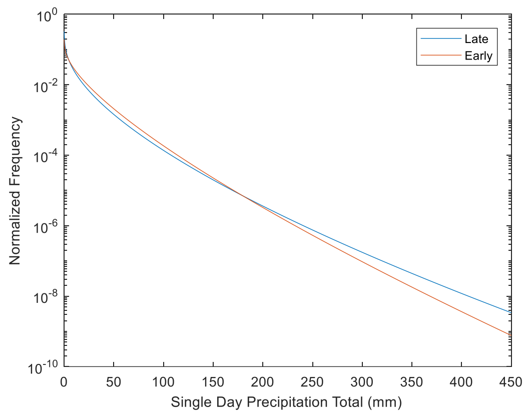

Figure 2. Weibull fits for the early and late periods for the Austin data.

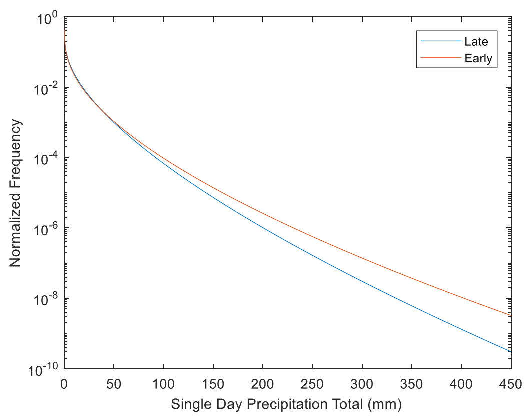

Figure 3. Weibull fits for the early and late periods for the Brownsville data.

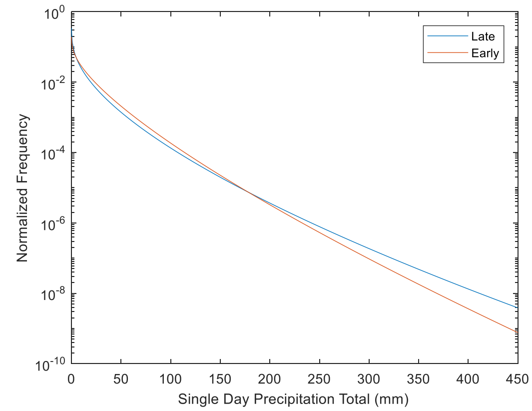

Figure 4. Weibull fits for the early and late periods for the Houston data.

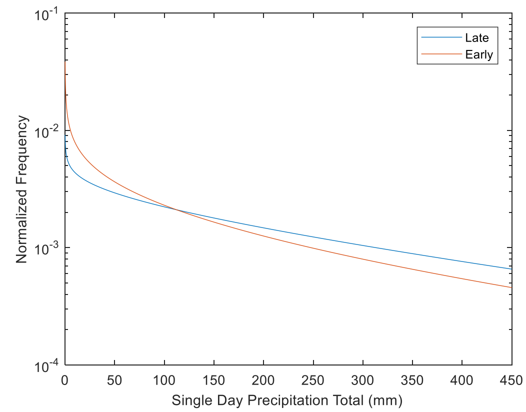

Figure 5. Weibull fits for the early and late periods for the San Marcos data.

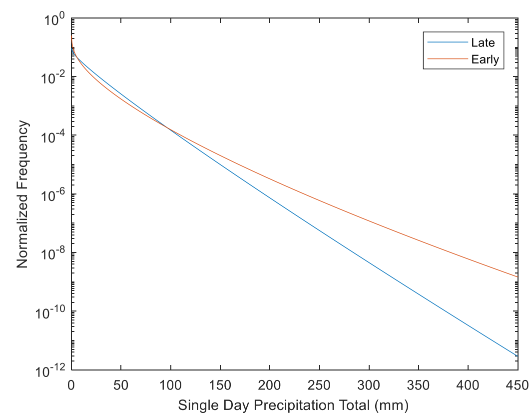

Figure 6. Weibull fits for the early and late periods for the Texarkana data.

Tabular recurrence interval data in Table 2, which were generated using the peak over threshold method, reflect a regional dependence for the daily precipitation totals for each station. This result was expected given the diverse range of precipitation climates in Texas. Lower values were found in the arid and semi-arid locations in the western and northwestern parts of the state, with 20-year return period single day totals of 2.5 in, 3.8 in, 2.0 in, and 3.9 in for Alpine, Amarillo, El Paso, and Lubbock, respectively. Larger totals were found for more temperate environments on the eastern side of the state (6.8 in and 7.1 in for College Station and Houston). The highest return period total in the dataset occurred in San Marcos, with single day precipitation totals of 6.8 in, 7.6 in, and 9.3 in for the 10-, 20-, and 100-year recurrence intervals.

Table 3 lists daily precipitation totals for three recurrence intervals for the early and late periods. The magnitudes of daily precipitation values at the 10-, 20-, and 100-year levels for the Austin, Blanco, and Texarkana stations decrease between the early and late period. Brownsville, Houston, and San Marcos each had an increase in daily precipitation totals at the 10-, 20-, and 100-year return periods.

Table 2. Return period values (10, 20, and 100-year) in inches for the late time period for each site.

City	10-year	20-year	100-year
Abilene	4.5	4.9	5.8
Alpine	2.1	2.5	3.1
Amarillo	3.5	3.8	4.4
Blanco	5.2	5.5	6.2
Brownsville	4.3	5.0	6.7
College Station	5.7	6.8	9.3
El Paso	1.8	2.0	2.3
Houston	6.3	7.1	8.5
Kingsville	4.0	4.6	6.0
Lubbock	3.6	3.9	4.7
San Marcos	6.8	7.6	9.3
Texarkana	5.2	5.9	7.3

Table 3. Return period values (10, 20, and 100-year) in inches for the early and late time periods

	10-year		20-year		100-year	
	Early	Late	Early	Late	Early	Late
Austin	7.0	5.5	7.8	5.9	9.5	6.7
Blanco	5.3	5.2	5.7	5.5	6.5	6.2
Brownsville	2.4	4.3	3.0	5.0	4.4	6.7
Houston	5.5	6.3	6.0	7.1	7.0	8.5
San Marcos	6.4	6.8	7.1	7.6	8.5	9.3
Texarkana	5.8	5.2	6.4	5.9	7.6	7.3

Return period curves for the early and late periods (Figures 7-13) also indicate a temporal trend in daily precipitation values at a given recurrence interval. For Brownsville, College Station, Houston, and San Marcos, daily precipitation totals at a given recurrence interval increased between the early and late period. For Austin, Blanco, and Texarkana, the daily precipitation total for a given recurrence interval decreased between the early and late period. In several cases, this trend is opposite what was observed for the Weibull fits. For example, Weibull fit data for both Austin and Blanco indicates an increase in the frequency of events at the heavy and extreme end of the daily precipitation spectrum, but return period curves for the same stations indicate a decrease in daily precipitation totals for given recurrence intervals over the same period. In other words, for these stations, the number of extreme events has increased between the early and late period, but the total precipitation occurring during each of those events has declined. Other stations experienced an increasing trend in both frequency of extreme events and the daily precipitation total associated with a given recurrence interval. College Station, whose Weibull fits for the early and late periods indicated no temporal trend in extreme event frequency, experienced an increase in daily precipitation total at a given recurrence interval. Brownsville's Weibull fit data indicated a decrease in the number of extreme events while return period curves indicated an increase in daily precipitation totals associated with a given recurrence interval.

Some preliminary regional dependencies begin to appear in this analysis. The three Central Texas stations, Blanco, Austin, and San Marcos, all experienced an increase in the frequency of extreme events between the early and late periods. San Marcos, which has seen numerous notable flash flooding events in the past decade, has experienced an increase in both frequency and quantity of extreme precipitation. Houston and College Station, both situated in East Texas, both experienced an increase in return period values between the early and the late period. Texarkana was the only station to report a decrease in both frequency and quantity of extreme precipitation. Historical data from stations in the western and northern parts of the state would allow for further evaluation of regional trends in extreme precipitation.

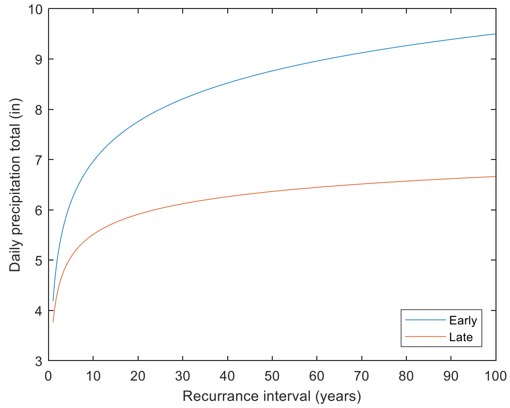

Figure 7. Return period curves for early and late Austin data

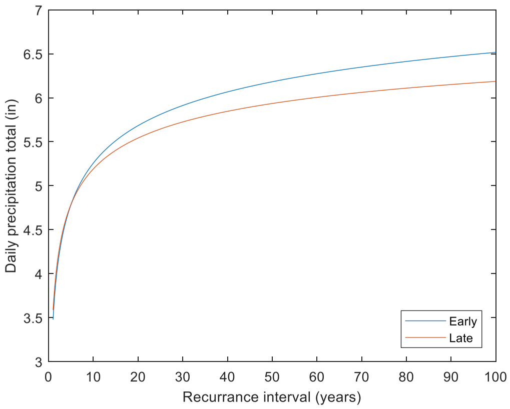

Figure 8. Return Period curves for the early and late Blanco data

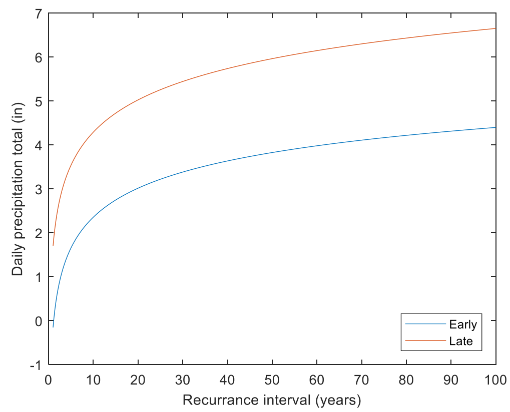

Figure 9. Return period curves for the early and late Brownsville data

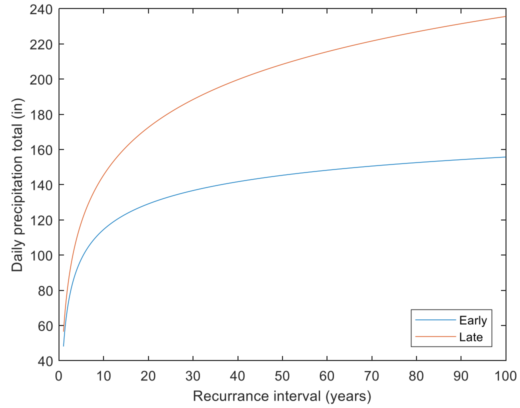

Figure 10. Return period curves for early and late College Station data

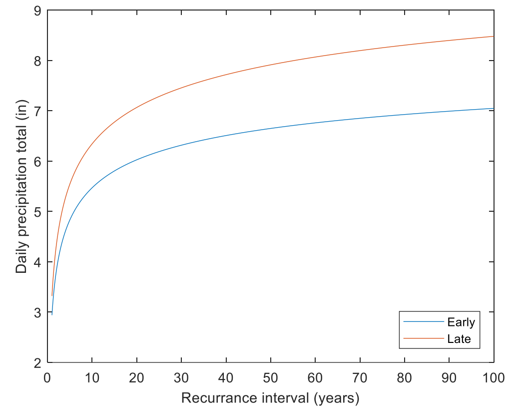

Figure 11. Return period curves for early and late Houston data

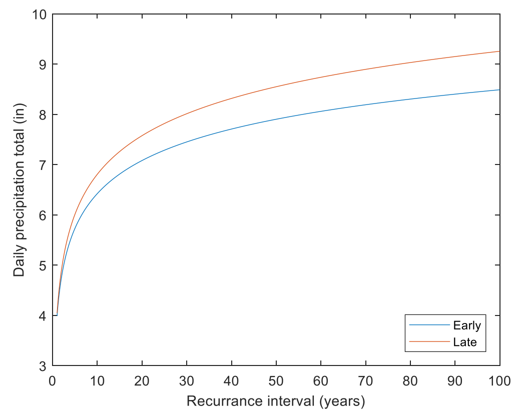

Figure 12. Return period curves for early and late San Marcos data

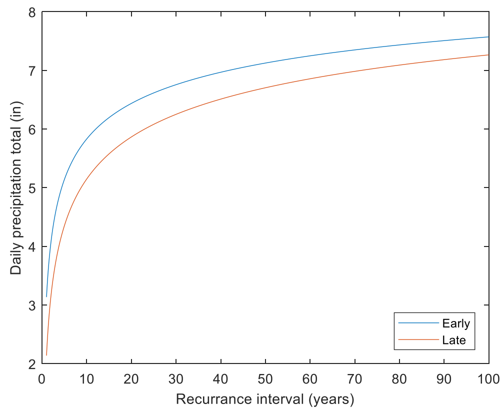

Figure 13. Return period curves for early and late Texarkana data.

5. CONCLUSIONS

Fourteen precipitation records varying in length from fifty to one-hundred years from cities across the state of Texas were evaluated for temporal and regional dependences using the peak over threshold method for generating return period curves. As expected, some regional dependence was apparent, including higher single-day precipitation totals for the 10-, 20-, and 100-year recurrence intervals for stations located in the central and eastern portions of the state. The largest single day precipitation totals were found in the central part of the state (San Marcos). For those stations whose records were long enough to evaluate both an early and a late period, temporal changes in single-day precipitation total distribution were identified in comparisons of both Weibull fits and return period curves. Blanco, Austin, San Marcos, and Houston all experienced an increase in frequency of extreme precipitation events between the two periods. Trends in the return period curves for those stations were not as straightforward, with decrease in values at a given recurrence interval reported for Blanco and Austin. Texarkana and Brownsville both reported a decrease in the frequency of extreme events, with Texarkana also reporting a decrease in recurrence interval values and Brownsville reporting an increase. Notably, Houston and San Marcos, cities which have experienced multiple noteworthy flooding events in the past decade, both reported an increase in both the frequency and the return period values over the past century.

6. FUTURE WORK

This study will benefit from a denser network of historical precipitation observations as well as more data from the western and northern portions of the state. Enhancing the resolution of the data network will facilitate evaluation of regional trends and allow for more detailed analysis of trends in frequency and daily precipitation totals.

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