Catastrophe and Climate

Actuarial Weather Extremes Series
Fort Lauderdale Florida Precipitation, April 2023

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Precipitation Impact Summary

On April 12-13, Fort Lauderdale, Florida was hit by a slow-moving storm system that led to prolonged periods of very heavy rainfall. According to the National Weather Service, extremely high rainfall amounts in excess of 20 inches were noted near and around Fort Lauderdale/Hollywood International Airport, and an area of 15-20 inches was also noted from the Hollywood and Dania Beach areas north to Fort Lauderdale [1]. Widespread flash flooding led to damaged personal and public property [2]. Fortunately, no fatalities have been reported.

The subsequent analysis examines the historical context of this record rainfall and attempts to estimate the probability distribution of the annual maximum of daily precipitation observations in Fort Lauderdale, Florida.

Data Sources

This analysis relies exclusively on the Global Historical Climatological Network (GHCN) Daily data available through their web service [3]. Daily precipitation totals are available for the period 11/1/1912 to 4/14/2023; however, there are some days with no recorded observations and six years have fewer than 300 observations.

Detailed analysis data can be found in Source [4] listed at the end of this report.

Methodology

This analysis follows the Extreme Value Theory methodology described in the report “Precipitation Analysis using Extreme Value Theory” published by the SOA Research Institute [5].

We begin by importing the daily precipitation observations into Excel. For each year in the record, we calculate the maximum daily observation, resulting in 112 annual maxima, in Figure 1. After visually inspecting the distribution of the annual maxima in Figure 2, we fit the data to a Generalized Extreme Value (GEV) distribution, using a gradient descent algorithm, shown in Figure 3. Next, we construct 95% confidence intervals for the fitted parameters using two methods: Monte Carlo Simulations and Bootstrap Resampling, shown in Figure 4. Lastly, we evaluate the different distributions and return periods of the best estimate and the four boundaries of the confidence intervals, in Figure 5.

April 26, 2023

Results

Figure 1 below plots the maximum daily precipitation in each year between 1912 and 2023. 2023's value of 17.10 inches is clearly an extreme and is greater than the previous record by 2.5 inches.

Figure 1

ANNUAL MAXIMUM DAILY PRECIPITATION IN FT. LAUDERDALE, FLORIDA

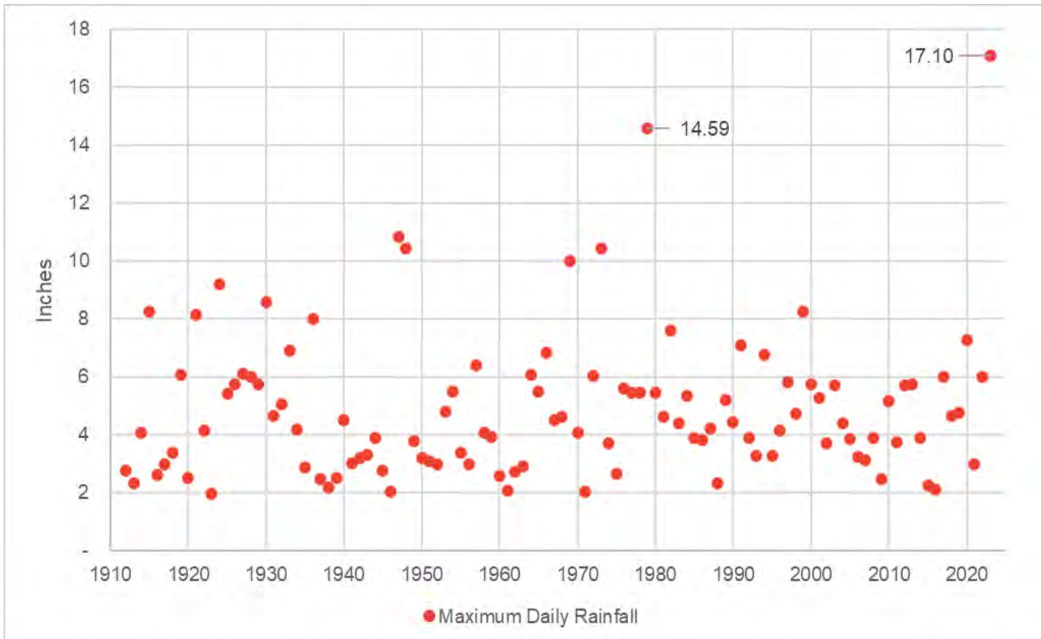
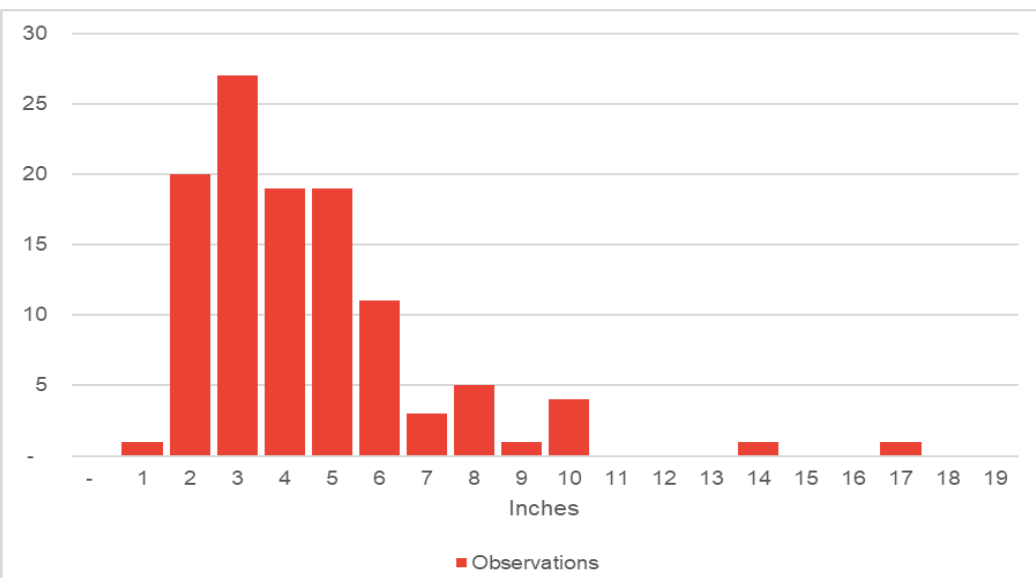


Figure 2 plots a histogram of the annual maxima and also highlights the extreme nature of 2023's value.

Figure 2

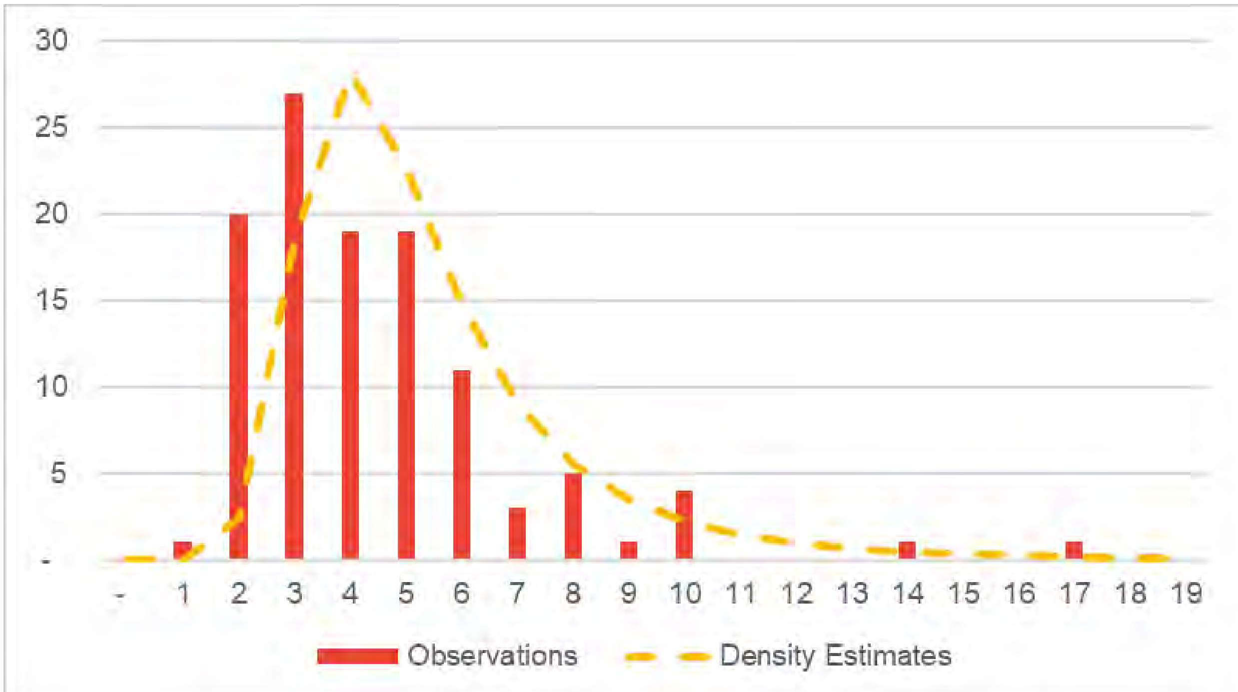
DISTRIBUTION OF ANNUAL MAXIMA OF DAILY PRECIPITATION IN FORT LAUDERDALE



After running the gradient descent algorithm to estimate the GEV parameters from the annual maxima observations, we plot the expected observations against the actuals in Figure 3 below. The resulting parameter estimates are: Location = 3.711, Scale = 1.457, and Shape = 0.210. This parameter set maximizes the log-likelihood function with a value of -232.3091 and is therefore most likely to accurately match the distribution of the underlying observations. The implied probability of observing an annual maximum greater than 17.10 is 0.5953%.

Figure 3

COMPARISON OF ACTUAL OBSERVATIONS TO EXPECTED OBSERVATIONS FROM THE GEV BEST ESTIMATE



After producing simulated data for 1000 Monte Carlo simulations and fitting the data in each simulation to a GEV distribution, we calculated the 2.5th percentile and 97.5th percentile of each distribution. Table 1 shows the resulting parameter estimates. From these percentiles, we can evaluate the uncertainty in our parameter estimation. If we look at the percentiles as a percentage of the Mean, we see that the estimate for the location parameter has the narrowest range and therefore the highest degree of certainty. Conversely, the estimate of the shape parameter has a very wide range and the lowest degree of certainty. Such a high degree of uncertainty is particularly material for this analysis because the shape parameter has the greatest impact on the "fatness" of the tail and the probabilities of extreme observations.

Table 1

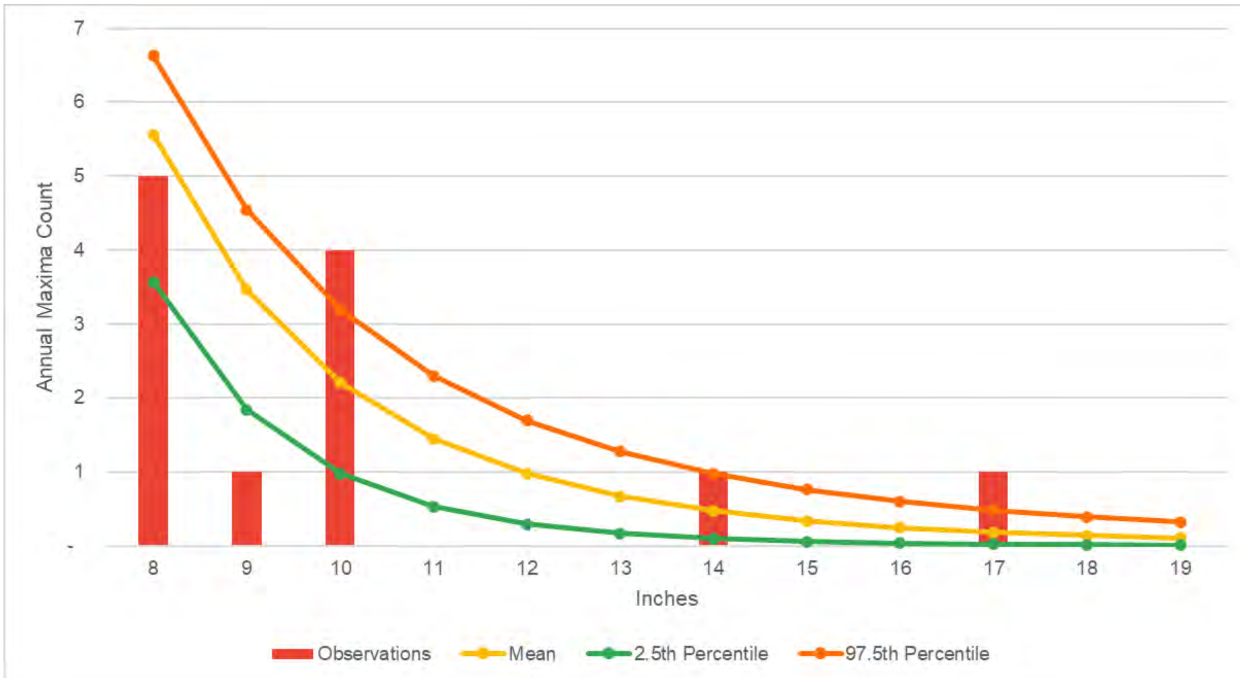
CONFIDENCE INTERVALS FOR GEV PARAMETERS FROM MONTE CARLO SIMULATIONS

Parameter	Best Estimate	Mean	2.5th Percentile	97.5th Percentile	2.5th Percentile % of Mean	97.5th Percentile % of Mean
Location	3.711	3.719	3.4242	4.0184	92.1%	108.0%
Scale	1.457	1.449	1.2040	1.6919	83.1%	116.8%
Shape	0.210	0.209	0.0840	0.3588	40.1%	171.5%

Figure 4 shows the expected observations of three distributions. The estimated frequencies of 17 inches of precipitation are all less than 1 for a 112-year period. That is, we can say with 95% confidence that we would not expect to observe a day with 17 inches of rain in a 112-year period.

Figure 4

COMPARISON OF EXPECTED EXTREMES FROM MONTE CARLO SIMULATIONS



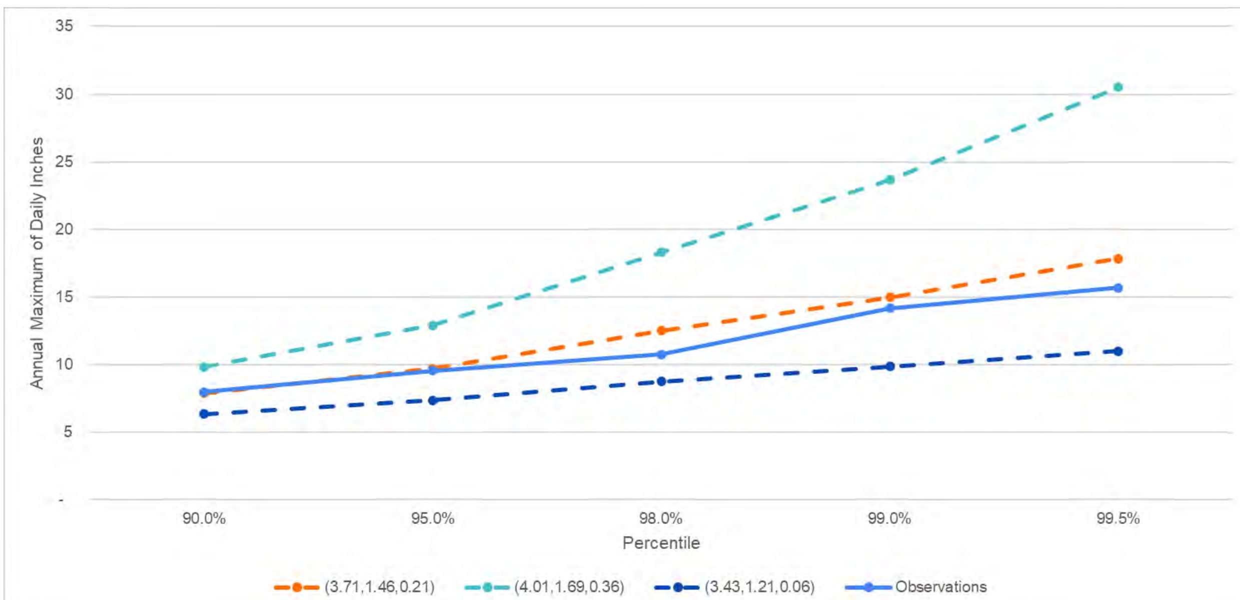
Once we have parameter estimates and confidence intervals for the parameters, we can calculate the corresponding return periods. These return periods correspond to percentiles of the GEV distribution. Table 2 shows the Annual Maximum of Daily Precipitation for each selected Return Period (and Percentile) and Distribution. The three distributions correspond to the Best Estimate, 97.5th Percentile, and 2.5th Percentile, from left to right in the table. The range in the annual maxima for low-probability events illustrates the sensitivity of the return period calculation to small changes in the parameters and the probability value.

Table 2
ESTIMATED ANNUAL MAXIMA BY RETURN PERIOD AND DISTRIBUTION

				(Location, Scale, Shape)		
Percentile	**Annual Probability**	**Return Period**	**Observations**	**(3.71,1.46,0.21)**	**(4.01,1.69,0.36)**	**(3.43,1.21,0.06)**
1.0%	99.0%	1.01	2.041	1.806	2.019	1.671
5.0%	95.0%	1.05	2.229	2.282	2.475	2.148
10.0%	90.0%	1.11	2.503	2.596	2.791	2.447
20.0%	80.0%	1.25	3.000	3.051	3.272	2.861
30.0%	70.0%	1.43	3.352	3.446	3.709	3.203
40.0%	60.0%	1.67	3.902	3.839	4.163	3.532
50.0%	50.0%	2.00	4.415	4.266	4.675	3.873
60.0%	40.0%	2.50	4.955	4.762	5.296	4.253
70.0%	30.0%	3.33	5.583	5.388	6.119	4.710
80.0%	20.0%	5.00	6.029	6.280	7.365	5.323
90.0%	10.0%	10.00	7.978	7.902	9.844	6.341
95.0%	5.0%	20.00	9.560	9.717	12.931	7.365
98.0%	2.0%	50.00	10.762	12.512	18.298	8.761
99.0%	1.0%	100.00	14.179	14.995	23.661	9.862
99.5%	0.5%	200.00	15.707	17.858	30.504	11.009

Figure 5 plots the 90%+ percentiles for the three distributions. Graphically, we see close alignment between the observations (solid blue line) and the Best Estimate (dashed orange line).

Figure 5
ESTIMATED ANNUAL MAXIMA BY PERCENTILE AND PARAMETER SET (LOCATION, SCALE, SHAPE)



For additional context about return periods, we'll examine a scenario. If we were an infrastructure engineer, we could want to construct a drainage system to handle a rainfall event with 0.5% chance of occurring in a given year, i.e., a 200-year return period. If we also want to be 95% sure that the system can handle such an event, we would construct it to handle a daily rainfall between 11 and 30.5 inches of rain. Such a wide range of plausible outcomes for extreme events presents significant challenges to both infrastructure planners and insurers.

Sources

- **[1]** National Weather Service Public Information Statement
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  - Date Published: 4/13/2023
- [2] Fort Lauderdale airport to remain closed
  - CNN
  - https://www.cnn.com/2023/04/12/weather/florida-flash-flood-fort-lauderdale/index.html
  - Date Published: 4/14/2023
- [3] Global Historical Climatological Network (GHCN)
  - https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00083163/detail
  - Date Accessed: 4/22/2023
- [4] Source Data Analysis
  - See Excel spreadsheet published along with this report.
  - Date Created: 4/22/2023
- [5] Precipitation Analysis Using Extreme Value Theory
  - Society of Actuaries
  - https://www.soa.org/49496b/globalassets/assets/files/resources/research-report/2023/2023-precipitation-extreme-value-theory.pdf