Assessing Future Extreme Precipitation Risks in Northern Mexico and Southwestern US

Center for Applied Hydroclimate Sciences

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1. Extreme Precipitation in a Changing Climate in the Monsoon Region

Motivation: The intensifying effects of climate change highlight the importance of understanding its impacts on regional extreme weather events. For Mexico, Global Climate Models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC) project more prolonged and hotter droughts, more intense precipitation, and stronger tropical cyclones (IPCC, 2021)

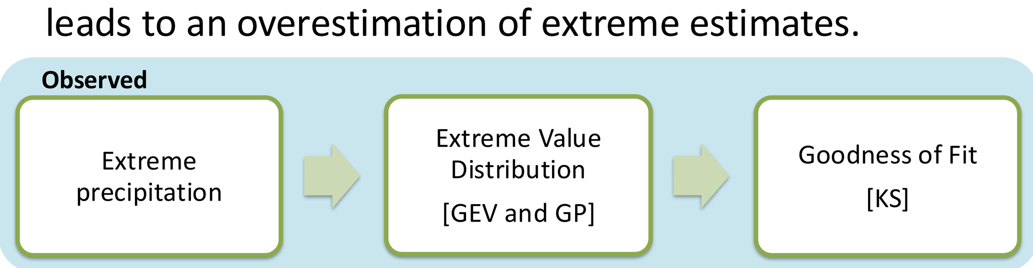
Global Climate Models (GCMs) still have limited capability to resolve localized convection systems in areas with complex topography, such as in the North American Monsoon (NAM) region in Mexico. In this work, we address these limitations by using dynamically downscaled climate projections through Regional Climate Models (RCMs).

Public and private sectors have urgent needs to incorporate climate impact assessments for operations and for financial disclosures. Understanding the impacts of extreme events is critical for this transition. To support these efforts, we estimate return period curves to analyze shifts in extreme precipitation patterns, including changes in intensity, frequency, and associated risks.

Objective: Provide regionalized insights into extreme precipitation trends by evaluating historical and future changes in magnitude, frequency of occurrence and and spatial patterns across the North American Monsoon (NAM) region. This analysis supports region-specific climate assessments to identify hydrometeorological risks.

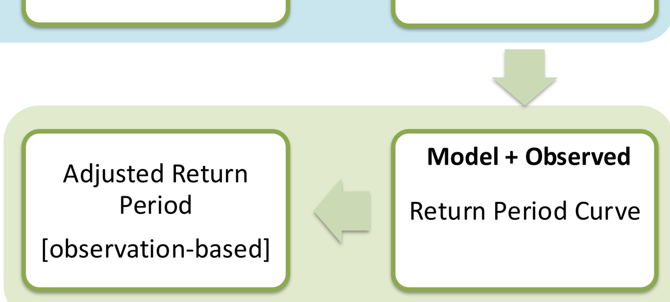
2. From Observations to Model based Climate Projections

- Study period: Historical (1980-2005), future (2020-2099).
- Station-based daily precipitation: Comisión Nacional de Agua (CONAGUA) and the Global Historical Climatology Network-Daily (GHCN) database (Menne et al., 2012).
- Observation-based gridded precipitation: Daily Surface Weather Data (Daymet) database (Thornton et al., 2021).
- Climate projections: North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX), specifically WRF-MPI for the high-emissions RCP8.5 global warming scenario (Mearns et al., 2017).
- Statistical Analysis Methods: 1) Return period curve requires fitting precipitation data to statistical distributions: Generalized Extreme Value (GEV) and Generalized Pareto (GP) (Coles, 2001; Shamir et al., 2013). 2) Kolmogorov-Smirnov (KS) test: goodness of fit test between empirical and model extreme distributions for return period curves (Table 1; Santos et al. 2015; Shamir et al., 2013).
- Observed-based adjustments are applied to correct the wet bias in NA-CORDEX precipitation, which otherwise leads to an overestimation of extreme estimates.



(KS) test		
	GP	GEV
Site	D_n	D_n
1	0.77	0.19
7	0.78	0.15
5	0.8	0.15
6	0.82	0.23

Table 1. KS test results evaluating the fit quality of GEV and GP distributions to observed extreme precipitation data. D_n measures the difference between the observed and theoretical values.



3. Historic and Projected Changes in Precipitation: Mean and Annual Maxima

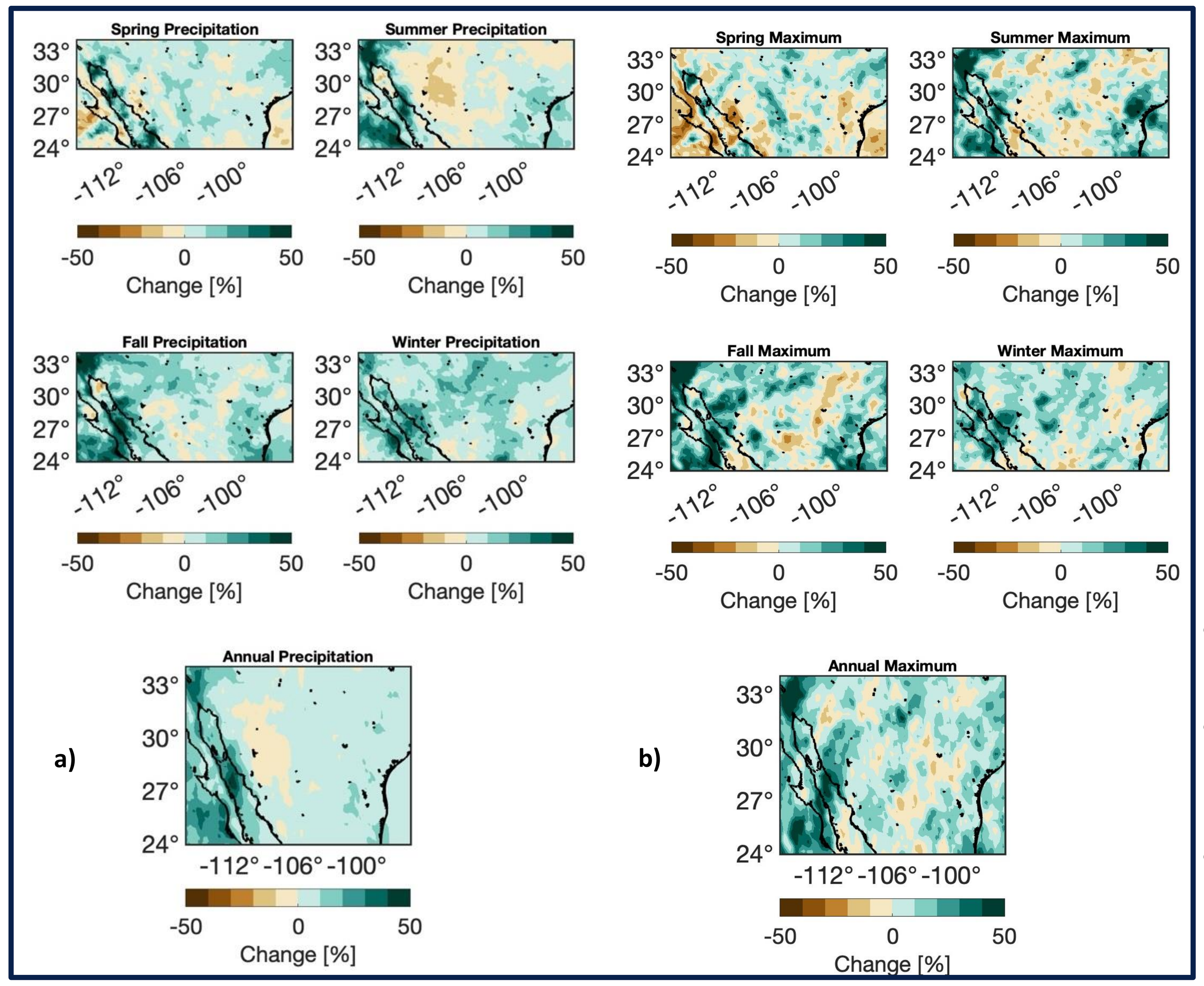


Figure 1. Projected Changes in Mean and Annual Maximum Precipitation. WRF-MPI projections for future (2020–2099) changes in mean precipitation (left) and annual maximum precipitation (right) under the RCP8.5 scenario, relative to the historic period (1980–2005).

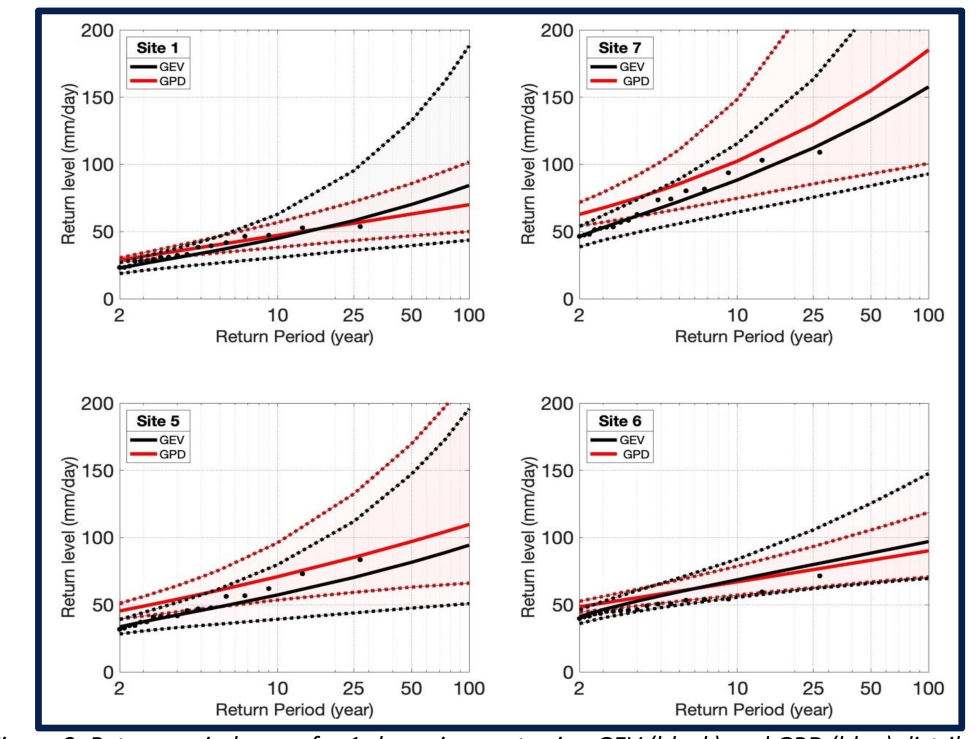


Figure 2. Return period curve for 1-day rain event using GEV (black) and GPD (blue) distribution fit of the 1980-2014 observed maxima series for locations across different regions in Mexico.

- Projected changes in mean precipitation: Projected reductions of 10% to 20% are expected in northern and central Mexico, with significant changes over higher elevation regions during summer (Figure 1a).
- Projected changes in annual maximum precipitation: Greater spatial granularity than mean precipitation. Seasonal trends in spring, fall, and winter align with overall intensification of mean changes. Summer shows opposite trend in parts of NAM region (Figure 1b).
- Identifying suitable extreme distribution method for probability of occurrence: Individual KS test results for all study stations indicate GEV provides a better fit for historical extremes than GP, with smaller D_n values reflecting a closer match to observed data (Table 1). Despite site variability, GEV shows lower uncertainty (narrower confidence intervals), suggesting a more reliable representation of extreme precipitation events (Figure 2).

4. Future Changes in Extreme Precipitation Likelihood

Sites	1.5	2	3	4	5	10	25	50	75	100
1	-0.7	3	6.1	7.4	8.1	9.1	-7	-8.6	-9.6	-11.2
9	-0.7	3	6.1	7.4	8.1	9.1	-7	-8.6	-9.6	-11.2
10	-0.7	3	6.1	7.4	8.1	9.1	-7	-8.6	-9.6	-11.2
2	-19.6	-19.4	-17.7	-16	-14.3	-7.6	-15.7	-7.4	-0.9	2.8
3	1.9	5.5	11.5	16.5	20.7	36.4	27.4	46.4	61.3	70.5
7	10.7	9.8	6.8	4.1	1.9	-5.4	-21.5	-28.1	-31.7	-34.5
4	13.3	15.3	17	17.8	18.1	18.2	-7.4	-10.8	-12.6	-15.2
5	0.4	-2	-4.7	-6.3	-7.6	-11	-23	-26.2	-27.8	-29.4
8	22.7	26.7	27.2	26.3	25.4	21.8	5.6	3.1	1.7	0.2
11	0.4	-2	-4.7	-6.3	-7.6	-11	-23	-26.2	-27.8	-29.4
12	0.4	-2	-4.7	-6.3	-7.6	-11	-23	-26.2	-27.8	-29.4
6	-11.7	-11.1	-11.7	-12.6	-13.4	-15.9	-24.5	-26.6	-27.7	-28.8

Return Period (years); Change [%]

Table 2. WRF-MPI projected changes in 1-day annual maximum precipitation for different return periods at twelve locations across Mexico. The analysis compares historical (1980–2005) and future (2020–2099) climate simulations. The selected sites represent four distinct climate regions based on the updated Köppen-Geiger classification (Peel et al., 2007) and different precipitation regimes: arid-desert region: 1, 9, and 10; desert region: sites 2, 3, and 7; Temperate-Dry Winter-Hot Summer: sites 4, 5, 11, 12, and 8 are classified as arid; and site 6 is characterized by a semi-arid monsoon climate."

- Future extremes region variability (Table 2): Consistent increase in precipitation for region 2 (site 3;2-70%). Consistent increase (2-36%) in lower return periods for Region 2 (site 7), and Region 3 (sites 4, 8). Consistent decrease in precipitation for Region 4 (site 6), parts of Region 3 (sites 5, 11, 12), and Region 2 (site 2).
- Future spatial changes of extremes: Gridded climate data enables extreme precipitation assessments that capture spatial variability, while station-based analysis meets specific project needs. Our assessment focuses on spatial distribution, making it applicable for further research applications. Extreme precipitation events with a 10-year return period are projected to increase in magnitude by 10%–40% across most regions (Figure 4c). For 100-year return period events, the magnitude of change is even greater, exceeding 50% (Figure 4f), indicating more intense but less frequent extreme events.

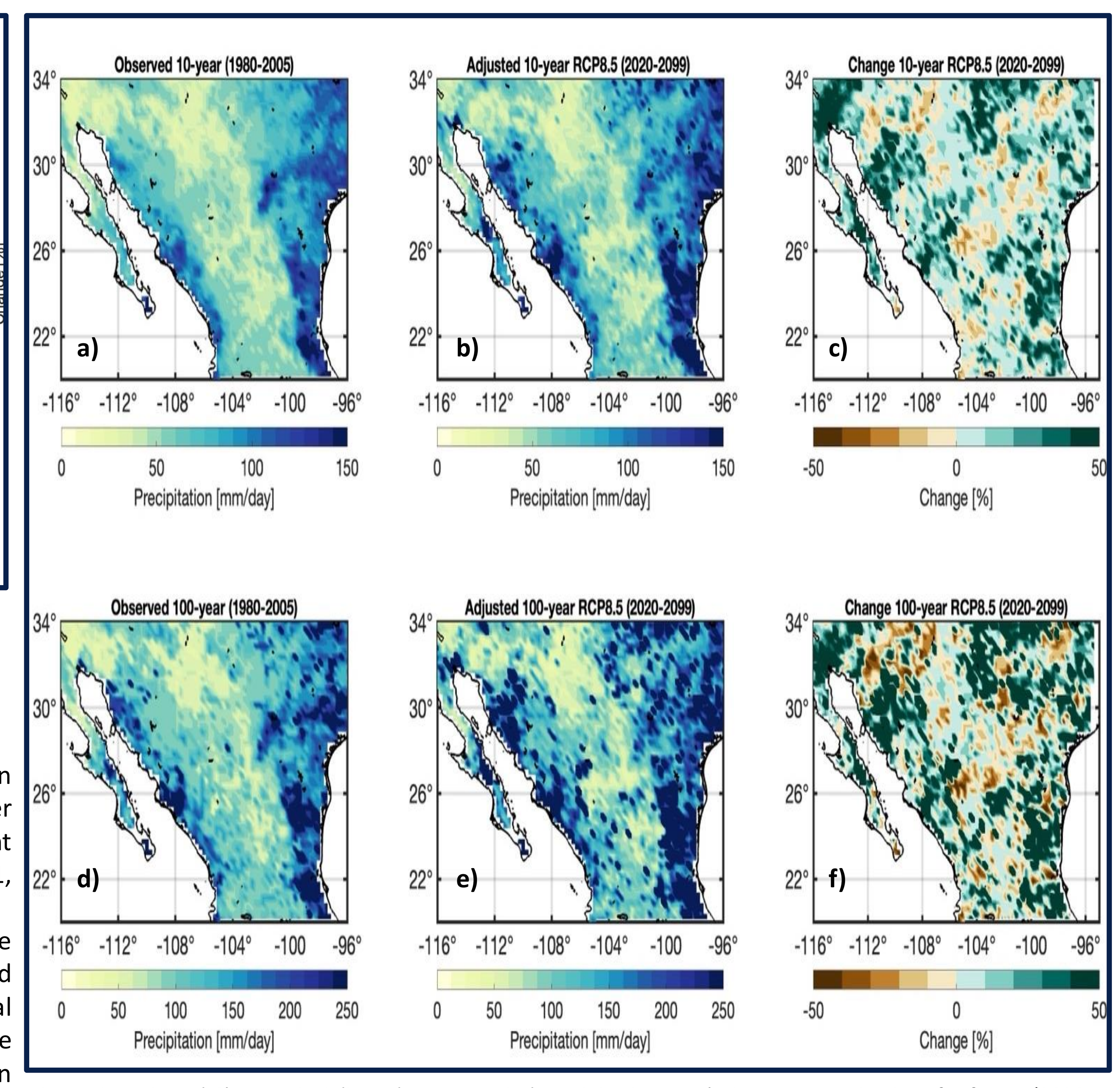


Figure 4. Projected Changes in Adjusted Return Period Precipitation Levels. WRF-MPI projections for future (2020–2099) changes in adjusted 10-year (top) and 100-year (bottom) return period precipitation levels, relative to the historic period (1980–2005).

5. Study case in Tucson: August 8TH, 2021

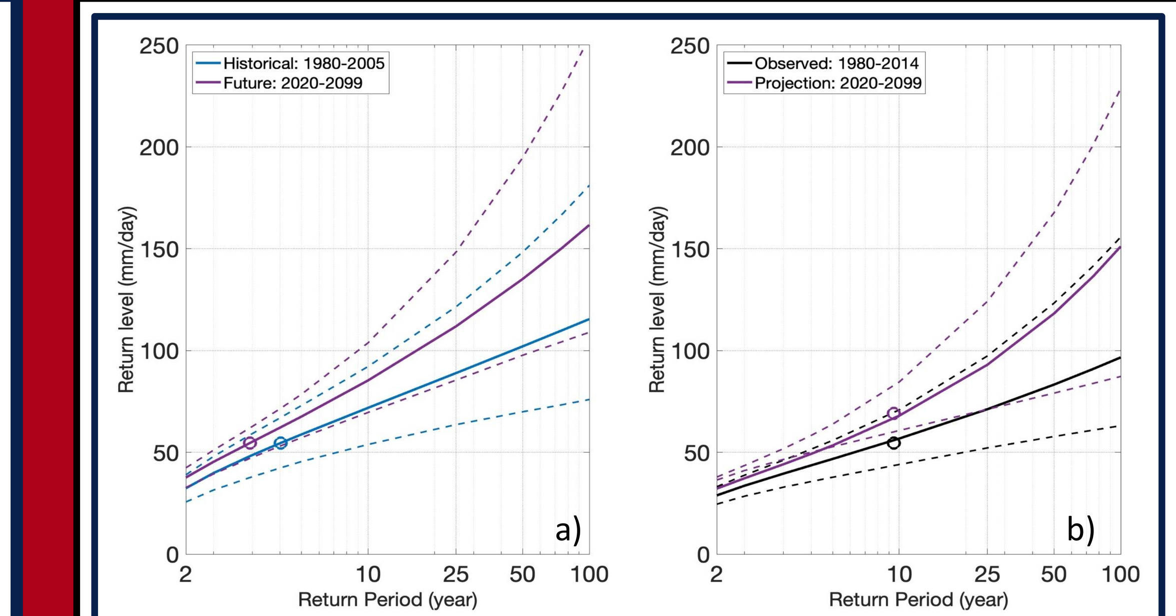


Figure 5. Frequency of the 2021 extreme precipitation event based on return period analysis. (a) Modeled historical estimates (1980–2005) compared to future projections (2020–2099). (Right) (b) Observed return period estimates (1980–2014) compared to adjusted model projections (2020–2099) calibrated with observational data . Dashed lines represent confidence intervals.

- Is the historic extreme event still considered as extreme in the future?
- August 8th, 2021, measured total precipitation of 55 mm (black line) corresponding to a 9-year return year in historic period (Figure 5b). Future projection analysis indicate that this event will become a a 3-year return period, indicating that these type of events will become more frequent in the future (Fig. 5a).
- Future Intensification of Extreme Precipitation: he historical 9-year return period event of 55 mm/day is projected to intensify to 70 mm/day while maintaining the same return period frequency (Figure 5b).

6. Conclusion

- Annual average precipitation is expected to decrease (10%–20%) in higher-elevation regions, while extreme event intensity is projected to rise (shift toward less frequent but more intense precipitation extremes; Figure 1a, 1b).
- Seasonal average precipitation shows a greater spatial and magnitude variability, with projected increases in spring, fall, and winter, except for summer. Maximum precipitation follows this trend but with greater intensification (Figure 1a, 1b).
- The Generalized Extreme Value distribution is more suitable for capturing general trends of extremes (Table 1, Figure 2).
- Frequency of the extremes: Extreme precipitation events across Mexico are projected to intensify, with notable regional variability. In the NAM region, projections indicate a shift toward more intense but less frequent extreme events (Fig. 4).
- Return periods help in quantifying extreme precipitation risks, by creating a scaling factor for risk assessment, enabling additional applications.

Future research

- Expand analysis to include climate datasets with different emission scenarios and different downscaling methods.
- The climate assessment workflow can be tailored to broader public and private sector needs (utilities, disaster management).
- Manuscript in preparation "Downscaled Climate Projections for Extreme Precipitation: A Regional Climate Assessment for Mexico and Southwestern US" by M. del R. Lourdes Mendoza Fierro, et al. (2025) for the Journal of Geophysical Research.

7. Acknowledgments

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