Climatological analysis of 71 years of extreme daily precipitation in Arizona

Brandi[1,2], A., Balling[1,2], R., Georgescu[1,2,3], M. – abrandi@asu.edu

[1]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ; [2]Urban Climate Research Center, Arizona State University, Tempe, AZ; [3]Global Institute of Sustainability, Arizona State University, Tempe, AZ.

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Introduction and motivation

Due to its location along the Subtropical high-pressure belt (Figure 2), Arizona is characterized by a dry climate and an arid landscape. Precipitation in Arizona is strongly influenced by two transport processes that bring moisture from the nearby oceans.

The Northern American Monsoon (NAM) brings in moisture from the Gulfs of Mexico and Baja California during the summer. The interaction between the NAM and the local orography produces discontinuous and spotty intense precipitation throughout the months of July, August and September.

During wintertime, Atmospheric Rivers blowing moisture from the Pacific Ocean result in longer precipitation events that help replenish the state water reservoirs. This bi-modal precipitation pattern (Figure 1), combined with the lack of vegetation, results in frequent extreme precipitation events that often produce dangerous flash flooding.

In this research we analyze trends in daily precipitation records and their impact on extreme precipitation events.

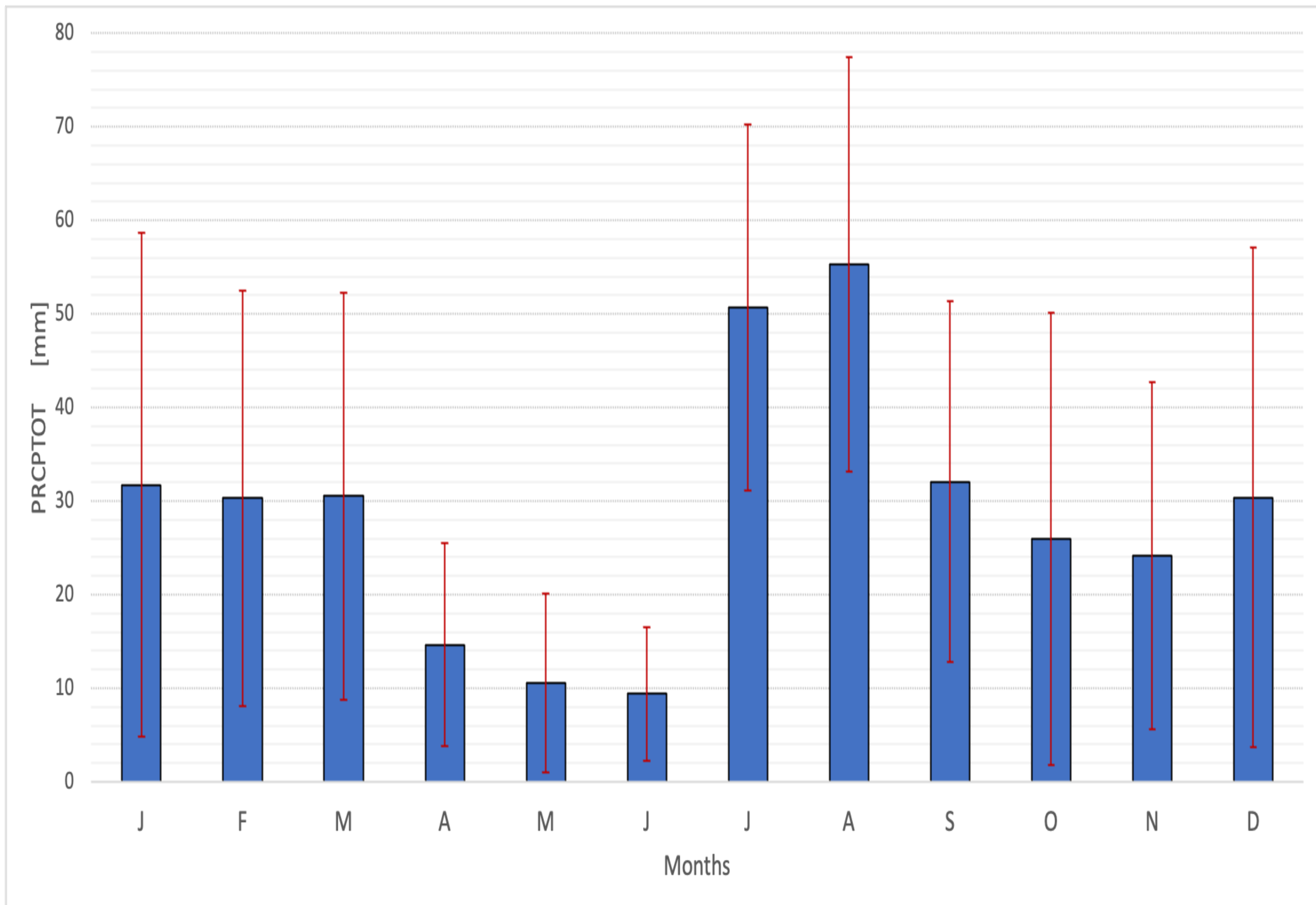

Figure 1 Monthly average of total precipitation records for the 43 GHCND weather stations used in this study, 1950-2020. Error bars represent 1 standard deviation (1 σ).

Data and methods

We use daily precipitation records from a suite of **43 weather stations** from the Global Historical Climatological Network daily (**GHCND**) database.

We defined the time period for the analysis as ranging **from 1950 to 2020**. Accordingly we selected all the stations that collected data in this time frame and that had a **completeness of the record equal or greater than 80%.**

We used a nearest neighbor analysis to check for unwanted clustering in the distribution of stations across Arizona The nearest neighbor statistic for our network of stations is 1.11, indicating a **random distribution** across Arizona (Figure 2).

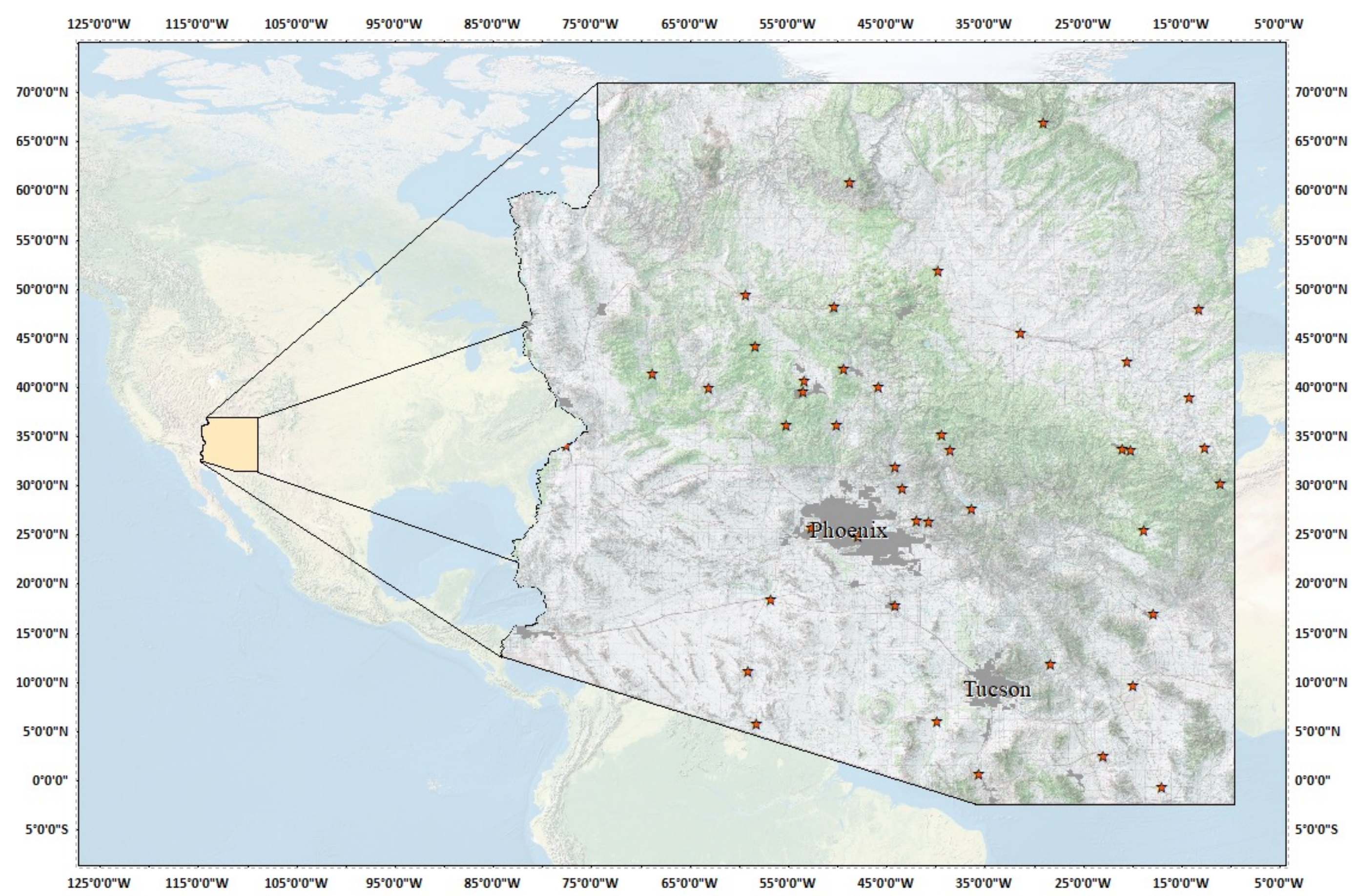

Figure 2 Inset map of the state of Arizona. Red stars represent the 43 GHCND weather stations used in this study.

We use **10 precipitation indexes** recommended by the Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) to classify Arizona daily precipitation according to **Intensity**, **Frequency** and **Duration** (Table 1).

We calculated each of the 10 indexes for all the 43 GHCND stations and across the 71 years of the analysis period (1950-2020), both on an annual and a monthly time scale.

Next, we calculated the **linear correlation** of the precipitation indexes with time for all the stations to produce annual and monthly analysis of precipitation extremes. In this study we only use statistically significant correlation coefficients ($p < 0.05$).

To ensure that the assumption of uniform distribution underlying the standard linear correlation had no effect on our analysis we also calculated Spearman correlation coefficients for all stations and across the whole analysis period. We didn't find any significant difference between results obtained with the two statistical analysis methods.

Table 1. Extreme precipitation indexes used in this study

	ID	Indicator name	Indicator definition	Units
Intensity	**RX1day**	Max 1d precipitation amount	Maximum 1d precipitation	mm
	RX5day	Max 5d precipitation amount	Maximum consecutive 5d precipitation	mm
	SDII	Simple daily intensity index	The ratio of total precipitation to the number of wet days (>= 1 mm)	mm/day
	R95p	Very wet days	Total precipitation from days > 95th percentile	mm
	R99p	Extremely wet days	Total precipitation from days > 99th percentile	mm
	PRCPTOT	Total wet-day precipitation	Total precipitation from days >= 1 mm	mm
Frequency	**R10mm**	Number of heavy precipitation days	Count when precipitation >= 10 mm	days
	R20mm	Number of heavy precipitation days	Count when precipitation >= 20 mm	days
Duration	**CDD**	Consecutive dry days	Maximum number of consecutive days when precipitation < 1 mm	days
	CWD	Consecutive wet days	Maximum number of consecutive days when precipitation > 1 mm	days

Standardize set of extreme precipitation indexes recommended by the Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). The full list of all recommended indexes and precise definitions is given at http://etccdi.pacificclimate.org.

Results

Annual analysis

- Most of significative trends affect stations located south or around the 34 N parallel, where the Mogollon Rim extends along a NW-SE axis (Figure 3).
- The most strongly changing indexes are the the Simple Daily Intensity Index (**SDII**, 7 stations) and the Extremely Wet Days (**R99p**, 13 stations). Increases for both indexes signal an **increase in extreme precipitation** across Arizona during the analysis period.
- A **decrease** in the number of Consecutive Wet Days (**CWD**, 8 stations, not shown in the figure) also supports the hypothesis of an increase of extreme precipitation events, as the same or a greater amount of water is concentrated in shorter precipitation events.
- All other indexes show both positive and negative statistically significant coefficients for a small number of stations and with no clear geographical clustering.

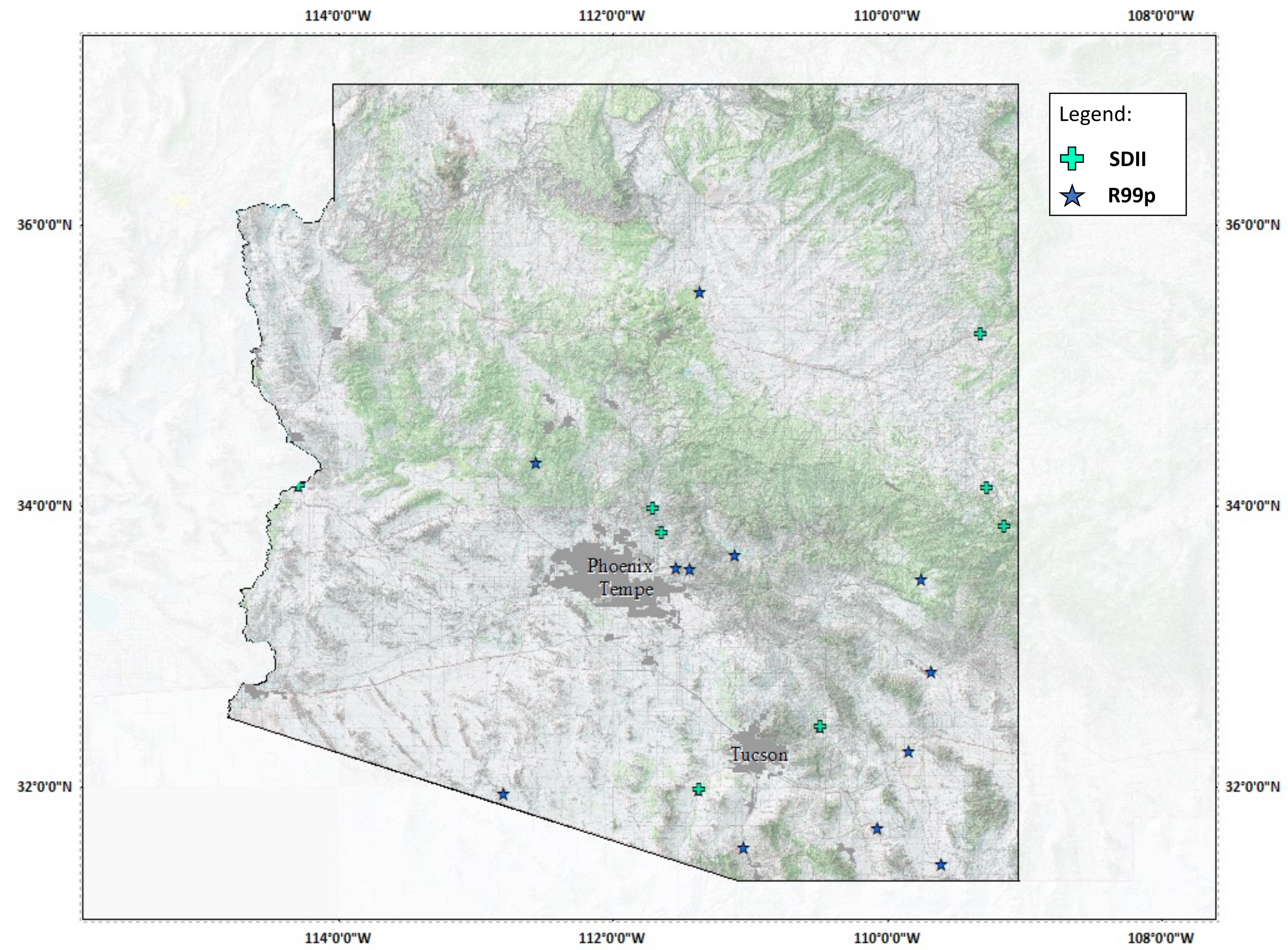

Figure 3 Location of the stations showing positive correlation coefficients for the SDII (green crosses) and R99p (blue stars) indexes

Monthly analysis

The monthly analysis of precipitation indexes against time produced less geographically extended results for most indexes and stations.

- The most notable exception is represented by the month of June (as well as July, to a lesser extent), where an extensive reduction of almost all indexes is found for the northernmost and central stations (Table 2).
- A few stations in the north of the state (Bright Angel, Seligman and Williams) show an increase in total (PRCPTOT) and extreme precipitation (RX1day, SDII and R10mm) indexes.
- 6 stations in Central Arizona display a positive correlation coefficient for the 95th and 99th percentile precipitation indexes

Table 2. Monthly Correlation Coefficients - June

	RX1day	RX5day	SDII	R95p	R99p	PRCPTOT	R10mm	R20mm	CDD	CWD
Betatakin	**-0.34**	-0.17	**-0.34**	**-0.35**	**-0.34**	**-0.29**	**-0.29**	-0.12	**0.28**	**-0.28**
Bright Angel RS	-0.22	0.14	**-0.32**	**-0.28**	**-0.29**	**-0.27**	-0.16	-0.10	-0.05	**-0.27**
Wupatki	**-0.31**	0.17	**-0.35**	**-0.29**	**-0.31**	**-0.27**	-0.15	**-0.27**	0.18	-0.16
Seligman	**-0.29**	-0.08	**-0.34**	-0.18	-0.13	**-0.27**	**-0.33**	-0.15	0.18	-0.12
Williams	-0.21	-0.11	**-0.26**	0.44	0.44	-0.13	-0.03	-0.08	0.16	-0.03
Sanders	-0.18		-0.13	-0.23	-0.25	-0.15	-0.15	-0.19	**0.57**	-0.15
Winslow Airport	-0.20	-0.06	-0.19	-0.20	-0.20	-0.17	-0.13	-0.18	0.13	-0.12
Walnut Creek	**-0.25**	-0.15	**-0.27**	**-0.26**	**-0.25**	**-0.26**	-0.20	-0.15	-0.02	-0.23
Petrified Forest NP	-0.21	-0.08	-0.20	-0.20	-0.21	-0.15	-0.09	**-0.29**	0.06	-0.06
Jerome	-0.11	0.09	-0.14	**0.34**	**0.28**	-0.13	-0.09	-0.14	-0.06	-0.09
Wikieup	-0.21		-0.22	-0.30	-0.30	-0.20	-0.19	-0.19	0.20	-0.06
Prescott Love Field	-0.02		-0.12	-0.07	-0.02	-0.08	-0.07	-0.04	0.10	-0.14
Montezuma Castle	-0.20		-0.15	-0.18	-0.20	-0.17	-0.11	-0.11	**0.33**	-0.15
Bagdad	-0.19	-0.08	-0.20	-0.27	-0.27	-0.16	-0.14	-0.18	0.04	-0.03
Prescott	**-0.33**	-0.01	**-0.37**	**-0.29**	**-0.33**	**-0.28**	-0.19	**-0.30**	0.15	-0.14
Douglas Bisbee Intnl. Airport	-0.14	0.15	-0.21	-0.08	-0.14	-0.05	0.04	-0.08	-0.14	-0.06
Cordes	**-0.25**		-0.19	**-0.26**	**-0.25**	**-0.25**	**-0.24**	-0.17	0.05	-0.06
Payson	-0.24	-0.08	-0.23	**-0.25**	**-0.24**	-0.22	-0.22	-0.17	0.12	-0.14
Parker	-0.09		-0.07	0.22	0.22	-0.08			**-0.27**	-0.15
Springerville	-0.03	0.04	0.04	-0.07	-0.03	-0.08	-0.03	0.03	-0.20	-0.03
Gisela	-0.20		**-0.25**			-0.17	-0.09	-0.15	-0.20	
Pinetop 2 E	-0.07	0.09	-0.07	-0.05	-0.07	-0.06	-0.13	0.04	-0.16	-0.02
Mc Nary 2 N	**-0.24**	-0.06	**-0.28**	-0.19	**-0.24**	-0.15	-0.16	-0.19	0.08	-0.09
Walnut Grove	-0.06	**0.28**	-0.22	**-0.46**	**-0.39**	0.13	0.14	0.06	**-0.27**	**0.34**
Horseshoe Dam	**-0.29**		**-0.34**	-0.20	-0.20	**-0.29**	**-0.27**	-0.19	**-0.38**	**-0.28**
Alpine	-0.04	-0.01	-0.17	-0.03	-0.04	0.02	-0.02	-0.04	0.06	0.04
Bartlett Dam	**-0.25**		**-0.29**	-0.23	**-0.25**	-0.20	-0.22	-0.08	**-0.28**	**-0.25**
Roosevelt 1 S	**-0.28**	0.17	**-0.32**	-0.06	-0.06	-0.22	-0.15	**-0.25**	**-0.27**	-0.13
Stewart Mtn Dam	-0.14		-0.12	-0.17	-0.16	-0.15	-0.01	-0.08	**-0.27**	-0.14
Mormon Flat	**-0.25**		-0.21	-0.26	-0.25	**-0.27**	-0.08	-0.17	**-0.36**	**-0.32**
Lichtfield Park	-0.18		-0.16	0.02	-0.06	-0.19	-0.10		-0.21	-0.16
Black River Pumps	-0.14	-0.07	**-0.24**	0.17	0.15	-0.10	-0.18	-0.10	**-0.37**	-0.09
Phoenix Airport	**-0.25**		**-0.30**	**-0.24**	**-0.25**	-0.23	-0.22	-0.22	**0.24**	-0.20
Gila Bend 2 SE	**-0.25**		**-0.27**	0.10	0.15	-0.22	-0.08		**-0.37**	**-0.26**
Casa Grande	**-0.32**		**-0.33**	-0.05	-0.11	**-0.30**	-0.21	**-0.27**	**-0.51**	**-0.32**
Saffor Agr. Center	-0.01	0.08	-0.02	0.00	-0.01	0.02	0.00	0.08	-0.01	-0.08
Redington	0.05	-0.03	0.03	**0.35**	0.26	0.02	0.03	0.12	-0.07	-0.04
Ajo	-0.13	0.12	-0.18	-0.12	-0.13	-0.10	-0.16		-0.20	-0.08
Willcox	-0.10	0.14	-0.09	-0.23	-0.23	-0.07	-0.05	-0.08	-0.02	0.02
Anvil Ranch	-0.08	0.03	-0.06	-0.06	-0.08	-0.05	0.07	-0.05	-0.11	-0.08
Organ Pipe Cactus NM	0.00		0.00	0.02	0.00	-0.04			**-0.39**	-0.13
Tombstone	0.02	0.08	0.04	0.07	0.10	0.09	0.13	-0.07	0.07	0.13
TumacacoriS	-0.05	0.17	-0.05	-0.05	-0.05	0.00	0.07	-0.08	0.09	-0.07

June monthly correlation coefficients for all 10 precipitation indexes and all 43 weather stations, calculated across the whole analysis period (1950-2020). Bold font indicates statistically significant values ($p < 0.05$). Negative coefficients highlighted in red.

Conclusions

- Extreme precipitation events in southern Arizona have increased in intensity and decreased in duration during the 1950-2020 time period
- The summer months of June and July have been affected by a broad reduction of precipitation intensity in the northern and central part of Arizona during the 1950-2020 time period
- In the northern part of the state a few stations recorded an increase in precipitation intensity and frequency