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Spatial Patterns of Precipitation Trends in the Continental United States, 1950-2016

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SPATIAL PATTERNS OF PRECIPITATION TRENDS IN THE CONTINENTAL UNITED STATES, 1950–2016

being

A Thesis Presented to the Graduate Faculty

of the Fort Hays State University

in Partial Fulfillment of the Requirements for

the Degree of Master of Science

by

Shayne R. O’Brien

B.A., Southern Connecticut State University

Date_______________________ Approved___________________________

Major Professor

Approved___________________________

Chair Graduate Council

This thesis for

the Master of Science Degree

By

Shayne R. O'Brien

has been approved

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Dr. P. Grady Dixon, Committee Chair

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Dr. Keith Bremer, Committee Member

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Chair, Department of Geosciences

ABSTRACT

Identifying trends in aspects of meteorology is becoming increasingly important to understanding how climate can be expected to change, and how those affected may plan contingencies. Analyzing spatial patterns of precipitation trends allows for associations to be discovered to better understand regional climatology. For this study, daily precipitation data were collected from The National Oceanic and Atmospheric Administration (NOAA) Global Historical Climate Network (GHCN) at stations across the continental United States, with selection based on distance from each other within a state, as well as percent completeness of observation data. Two stations per state were selected, with some exceptions for smaller states. The data were organized by year, and six different variables were examined for each station. Mean annual precipitation per event, annual standard deviation, frequency of days with more than 0.5 inches of precipitation, frequency of days with more than 1.0 in. of precipitation, annual 90th percentile value, and frequency of days with precipitation amount greater than the 90th percentile value for the entire period were tested for trends with a Mann-Kendall trend test. The stations were then mapped to identify the regions where trends were identified. Over 546 trend tests, there were 122 positive trends and 11 negative trends detected. Hot spots in both positive and negative trends were detected, and there were statistically hot spots in each of the six variables.

ACKNOWLEDGMENTS

To my Advisor, Dr. Grady Dixon thank you for your patience and encouragement in guiding me from curiosity to understanding of atmospheric science, as well as your interest in helping me achieve my goals.

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To my Grandparents, Ann, Grace, and Ron, without your constant stream of letters, my first experience away from home would not have been the same. Thank you.

To my Colleagues and my Hays Family, thank you for making the hardest two years of my life, also the absolute best.

To Elizabeth Schumann, thank you for the love and support you give to me daily. You never fail to put a smile on my face.

Finally, to my brother Garrett. You inspire me every day to be my very best. You are my hero.

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INTRODUCTION

Meteorological and climatic trends have been well studied and are documented in their occurrence that has led scientists to the conclusion that anthropogenic climate change has manifested itself in almost every aspect of the Earth's health. Precipitation trends have been studied as a symptom of climate change (Gleason et. al., 2008). The increased potential for precipitation extremes that can be produced by increased humidity creates a potential hazard for populations in areas prone to increased humidity and temperature (O'Gorman and Schneider, 2008). The objective of this study is to use trend statistics to gain a better understanding of the types of precipitation trends that are present in the United States and compare them spatially to identify regions with significant trends in precipitation. The U.S Climate Extremes Index (CEI) was developed in 1996, to present data on climate extremes to policy makers and the public to understand the implications of global climate change (Gleason et. al., 2008). However, the index was not developed to track the causes of change; it simply records observations and leaves causes up for interpretation. The most recent iteration of the CEI was released in 2008 (Easterling, 2008). The CEI was designed to examine precipitation change from a number of perspectives, namely monthly mean maximum and minimum temperature, extreme 1-day precipitation, days with/without precipitation and the Palmer Drought Severity Index (Gleason et. al, 2008). The CEI helped identify any precipitation greater than the 90th percentile for a period as a "precipitation extreme" (Gleason et. al, 2008). This precedent was used in this study to look at precipitation extreme thresholds from a different perspective. By studying change in the 90th percentile, the goal is to learn if an event is considered extreme in one year versus another?

There has been a global average increase of 2.3% precipitation change per degree Celsius of temperature change (Adler et. al., 2008). While trends are linear in the tropics, trends at the mid-latitudes are less so due to the El Niño Southern Oscillation (Adler et. al., 2008). This means that due to the ENSO, some years may have higher or lower individual precipitation totals, while still having an overall positive or negative trend. In the tropics, the trends are more even and predictable. The previously unpredictable relationship between precipitation and temperature is interesting as it has been shown that in the context of a rising global temperature, precipitation everywhere is experiencing either a positive or negative trend, but these trends are not as evenly distributed spatially as temperature trends (Alexander and Arblaster, 2009). Precipitation total per event is the most instrumental criterion in this study for understanding the behavior of the precipitation over the entire annual distribution (Karl and Knight, 1998). The widening or narrowing of the distribution of precipitation event totals over time is further summarized by the inclusion of standard deviation (Legates and Wilmott, 1990).

For this study, it was determined that using daily precipitation totals was most effective (Beniston, 2004). Hourly precipitation is too inaccurate due to instrumentation and staffing, and monthly and annual totals do not provide the desired resolution for this study. Climate models need to be ground-truthed with weather stations because precipitation simulations are too inaccurate to be sufficient (Dulière et. al., 2011). For this reason, the spatial patterns of trend are determined by ground stations. This is further supported by the underestimated precipitation totals predicted by climate models. The Coupled Model Intercomparison Project (CMIP3) underestimated potential precipitation totals when compared to the actual recorded precipitation totals from the ground (Allan and Soden, 2008; DeAngelis et. al., 2013). This discrepancy is due to a greater potential humidity in warm air than previously observed, with observed humidity measured at much higher values than predictions (Lenderink and Meijgaard, 2008) (O'Gorman and Schneider, 2009).

METHODS

Data Selection

The data used in the study were collected from the National Oceanic and Atmospheric Administration (NOAA) Climate Data Online (CDO) Global Historical Climate Network (GHCN). The "Daily Summaries" dataset was selected, as it is complete with daily precipitation totals. The precipitation data from each day from January 1st, 1950 through December 31st, 2016 were available in standard measurements (inches). Days with trace precipitation are marked with a "T" in an adjacent column, and the precipitation amount from that day is recorded as zero. Zero values, trace precipitation days, and days entered as an error (-9999) were removed from the data used, as the study was focused on trends in days with recorded precipitation only.

Station Selection

For this study, 93 weather stations were selected in the continental United States. Two stations per state were selected with a few exceptions. There is no station selected for Delaware, as nearby stations in New Jersey and Maryland would have made an additional station in such a compact area unnecessary. There is only one station selected for Rhode Island, as the station selections from Connecticut and Massachusetts would also have caused some redundancy. (Figure 1)

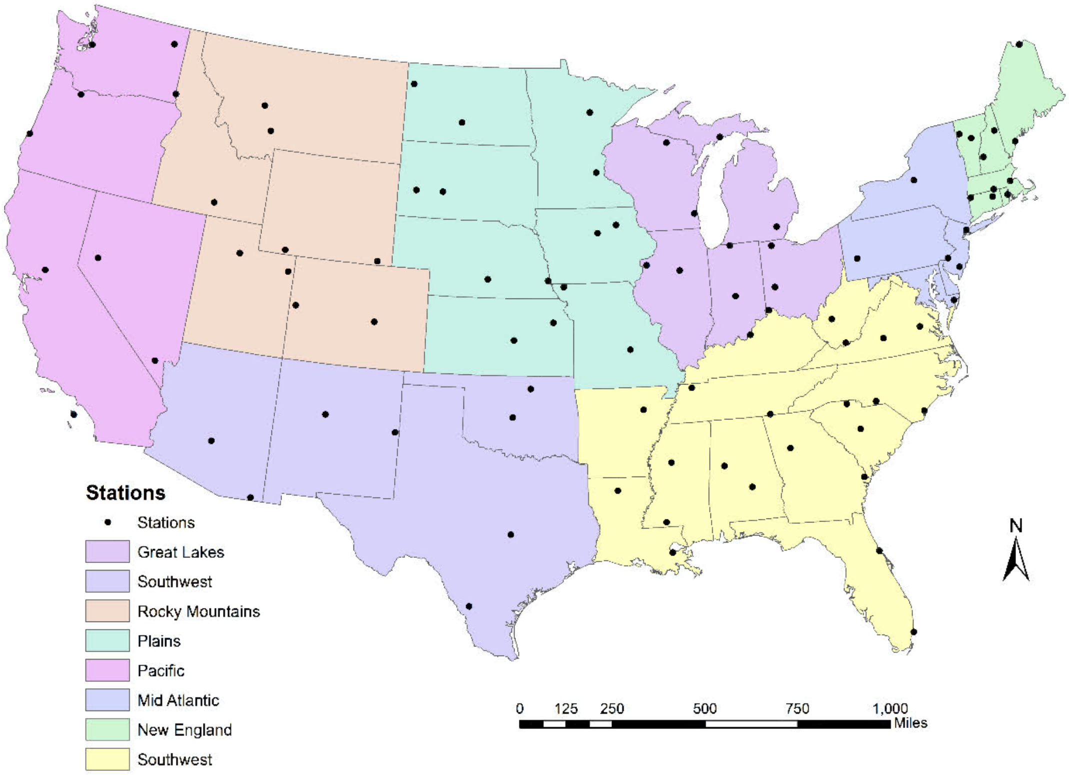

Figure 1 Map of Regions and Selected Weather Stations.

A completion percentage of the data were calculated by dividing the number of data recordings for each station by the number of days that occurred between January 1st, 1950, and December 31st, 2016.

Variables

The daily precipitation totals were organized to produce six different products, listed as follows:

1. *Mean Annual Precipitation per Event*

This product was calculated by dividing the annual sum of precipitation by the number of recorded rain days in the same year.

2. *Annual Standard Deviation of Daily Precipitation Values*

This value was calculated for each year, to show if there are significant changes over the study period.

3. *Value of Annual 90th Percentile Value*

The 90th percentile value is important because it is used as the threshold between an extreme precipitation day and a non-extreme precipitation day. By calculating the 90th percentile value in each year, a trend can be established in the definition of an extreme.

4. *Frequency of Events > 90th Percentile Value for the Entire Period*

This value extracts the 90th percentile value of precipitation amounts from the entire period, and then compares the annual frequency of precipitation events that occur in amounts greater than the 90th percentile for the entire period. The purpose of this measure is to identify trends in heavy precipitation.

5. *Frequency of Events with Precipitation > 0.5 inches.*
6. *Frequency of Events with Precipitation > 1.0 inch.*

When used in conjunction, these six variables can be used to generally understand the trends in precipitation over the course of the study.

Temporal Analysis Methods

Trends were tested by using the Mann-Kendall trend test (Mann, 1945; Kendall, 1975). This test is ideal for identifying precipitation trends as it is an effective test for non-normally distributed data (Yue et. al., 2002) The non-parametric test is used to detect significant monotonic trends in linear, temporal data (Moore, 2017). The Mann-Kendall test produces a Kendall's Tau and a p-value. The Kendall's Tau statistic is represented as a number between -1 for a negative trend, and 1 for a positive trend. (Sen, 1968). This test is resistant to outliers and is preferred for use in non-autocorrelated data (Moore, 2017). In the case of data with serial autocorrelation, a modified Mann-Kendall test can be performed, which decreases the likelihood a type-1 error (Hamed and Rao, 1998).

Spatial Analysis Methods

Spatially, the data are tested using a Getis-Ord Gi Statistic (Hot Spot Analysis) which tests spatial correlation. This was achieved using the Hot Spot analysis tool on ArcMap 10.6. This test uses areas with high Kendall's Tau and low Kendall's Tau and identifies statistically significant clusters of each, resulting in a new feature class with a z-score and p-value for each block in the map (Ord and Getis, 1995). A feature with clustering of high values results in a high z-score and a low p-value, while a feature with clustering of low values will result in a low p-value and a low (negative) z-score (Ord and Getis, 1995) For this study, the Kendall's Tau Statistic is used for a value, with a non-trend being represented by zeros. This allows for spatial correlations between stations with similar trends to be identified. The hot and dry spots are color coded by confidence level. Higher confidence levels indicate more statistically significant areas.

TEMPORAL RESULTS

The following results are summaries of the significant trends detected at each station. For a full list all stations involved in the study, refer to Table 1.

Table 1 List of Selected Stations. %= Completion Percentage of Data

St	Station	Station ID	Lat	Long	Elev.	%
AL	Montgomery Airport	USW00013895	32.2997	-86.4075	61.6 m	100%
AL	Tuscaloosa Municipal Airport	USW00093806	33.2119	-87.6161	45.7 m	92%
AR	Damascus	USC00031829	33.2119	-87.6161	207.3 m	94%
AR	Newport	USC00035186	35.6042	-91.2744	69.5 m	99%
AZ	Douglas Bisbee Inl Airport	USW00093026	31.4583	-109.606	1251.2 m	99%
AZ	Mesa	USC00025467	33.4114	-111.818	376.4 m	99%
CA	Los Angeles International Airport	USW00023174	33.3394	-118.389	29.5 m	100%
CA	Sacramento Executive Airport	USW00023232	38.5069	-121.495	4.6 m	100%
CO	Colorado National Monument	USC00051772	39.1013	-108.734	1762 m	97%
CO	Colorado Springs Municipal Airport	USW00093037	38.81	-104.688	1884 m	100%
CT	Falls Village	US00062658	41.95	-73.3667	167.6 m	95%
CT	Storrs	USC00068138	41.7951	-72.2285	202.9 m	97%
FL	Daytona Beach International	USW00012834	29.1828	-81.0483	9.4 m	100%
FL	Miami Beach	USW00092811	25.8063	-80.1334	2.4 m	96%
GA	Atlanta Hartsfield International Airport	USW00013874	33.6301	-84.4418	307.8 m	100%
GA	Savannah International Airport	USW00003822	32.1313	-81.2024	14m	100%
IA	Iowa Falls	USC00134142	42.5188	-93.2536	321.6 m	96%
IA	Tripoli	USC00138339	42.8125	-92.2574	292.6 m	95%
ID	Burley Municipal Airport	USW00024133	42.5416	-113.766	1266.1 m	100%

ID	Lewiston Nez Perce Co Airport	USW00024149	46.3747	-117.016	437.7 m	100%
IL	Aledo	USC00110072	41.1977	-90.7447	222.5 m	99%
IL	Minonk	USW00115712	40.9126	-89.034	228.6 m	97%
IN	Indianapolis International Airport	USCW00093819	39.7252	-86.2817	241.1 m	100%
IN	South Bend Airport	USW00014848	41.7072	-86.3163	235.6 m	99%
KS	McPherson	USC00145152	38.3772	-97.6097	463.3 m	100%
KS	Topeka Municipal Airport	US00013996	39.0725	-95.6261	267 m	100%
KY	Cincinnati/ Northern Kentucky Int’l Airport	USW00093814	39.0444	-84.6724	269.1 m	100%
KY	Louisville International Airport	USW00093821	38.1811	-85.7391	148.7m	100%
LA	New Orleans Airport	USW00012916	29.9969	-90.2775	1.2 m	100%
LA	Louisiana Tech University (Ruston)	USW00168067	32.5099	-92.6504	89.9 m	98%
MA	Blue Hill	USC00190736	42.2123	-71.1137	190.5 m	99%
MA	Southbridge 3 SW	USC00197627	42.0583	-72.0725	208.8 m	99%
MD	Snow Hill 4 N	USC00188380	38.2364	-75.3789	9.1 m	98%
ME	Portland Jetport	USW00014764	43.6422	-70.3044	13.7 m	100%
ME	Fort Kent	USC00172878	47.2386	-68.612	185.9 m	95%
MI	Ann Arbor Municipal Airport	USW00094889	42.2228	-83.7444	255.7 m	99%
MI	Manistique WWTP	USC00205073	45.9512	-86.2513	182.9 m	86%
MN	Itasca University of Minn	USC00214106	47.2436	-93.4975	399.3 m	99%
MN	Minneapolis St. Paul International Airport	USW00014922	44.8831	-93.2289	265 m	100%
MO	Rolla Missouri S and T	USC00237263	37.9567	-91.7762	357.5 m	96%
MO	Burlington Junction	USC00231141	40.4525	-95.073	281 m	90%
MS	John E. Lewis Field Airport	USW00093919	31.1827	-90.4708	125.9 m	100%
MS	Greenwood Leflore Airport	USW00013978	33.4963	-90.0866	40.5 m	100$

MT	Helena Airport ASOS	USW00024144	46.6056	-111.964	1166.8 m	100%
MT	Bozeman Montana State University	USC00241044	45.6621	-111.406	1497.5 m	100%
NC	Wilmington International Airport	USW00013748	34.2675	-77.8997	10.1 m	100%
NC	Wadesboro	USC00318964	34.9587	-80.0779	146.3 m	98%
ND	Williston Sloulin Field International Airport	USW00094014	48.1738	-103.637	579.7 m	100%
ND	Bismarck Municipal Airport	USW00024011	46.7825	-100.757	503.2 m	100%
NE	Kearney 4 NE	USC00254335	40.7255	-99.0133	649.2 m	95%
NE	Nebraska City 2 NW	USC00255810	40.6986	-95.8866	321.6 m	96%
NH	Pinkham Notch	USC00276818	44.258	-71.2525	617.2 m	98%
NH	Newport	USC00275868	43.3772	-72.1812	234.7 m	98%
NJ	Mays Landing 1 W	USC00285346	39.4505	-74.7469	8.5 m	94%
NM	Albuquerque International Airport	USW00023050	35.0419	-106.616	1618.5m	100%
NM	Clovis 13 N	USCW00291963	34.5988	-103.216	1351.3 m	97%
NV	Las Vegas McCarran International Airport	USW00023169	36.0719	-115.163	664.5 m	100%
NV	Lahontan Dam	USC00264349	39.4688	-119.064	1270.1 m	86%
NY	NY City Central Park	USW00094728	40.779	-73.9693	42.7 m	100%
NY	Syracuse Hancock International Airport	USW00014771	43.1111	-76.1038	125.9 m	100%
OH	Dayton International Airport	USW00093815	39.9064	-84.2185	305.7 m	100%
OH	Wauseon Water Plant	USC00338822	41.5183	-84.1452	228.6 m	99%
OK	Oklahoma City Will Rodgers World Airport	USW00013967	35.3889	-97.6006	391.7 m	100%
OK	Ralston	USC00347390	36.5044	-96.7438	251.5m	98%
OR	Headworks Portland Water B	USC00353770	45.4486	-122.155	228 m	100%

OR	North Bend Southwest Oregon Regional Airport	USW00024284	43.4133	-124.244	5.2 m	100%
PA	Philadelphia International Airport	USW00013739	39.8733	-75.2268	3 m	100%
PA	Acmetonia Lock 3	USC00360022	40.5361	-79.8152	228 m	100%
RI	Providence	USW00014765	41.7225	-71.4325	16.8 m	100%
SC	Columbia Univ. of SC	USC00381944	33.9915	-81.0241	74.4 m	97%
SC	Ninety-nine Islands	USC00386293	35.0316	-81.4927	152.4 m	98%
SD	Rapid City Regional Airport	USW00024090	44.0433	-103.054	963.2 m	100%
SD	Philip Airport	USW00024242	44.0511	-101.601	672.4 m	92%
TN	Chattanooga Airport	USQ00013882	35.0336	-85.2004	204.2 m	100%
TN	Martin University of TN Experiment Station	USC00405681	36.3444	-88.8636	103.6 m	98%
TX	Encinal	USW00412906	27.9774	-99.3847	166.1 m	91%
TX	Jarrell	USW00414556	30.8294	-97.601	267 m	94%
UT	Jensen	USC00424342	40.361	-109.346	1443.5 m	99%
UT	Salt Lake City	USW00024127	40.7781	-111.969	1287.8 m	100%
VA	Lynchburg International Airport	US00013733	37.3208	-79.2067	286.5 m	100%
VA	Richmond International Airport	USW00013740	37.505	-77.3202	50 m	100%
VT	Barre Montpelier Knapp State Airport	USW00094705	44.2035	-72.5623	342.2 m	97%
VT	Burlington Weather Service Office Airport	USW00014742	44.4683	-73.1499	100.6 m	100%
WA	Seattle Tacoma International Airport	USW0024233	47.4444	-122.314	112.8 m	100%
WA	Chewelah	USC00451395	48.2733	-117.741	509 m	92%
WI	Milwaukee Mount Mary College	USC00475474	43.0719	-88.0294	221.3 m	100%
WI	Eagle River	USC00472314	45.9169	-89.2563	494.7 m	97%

WV	Charleston Yeager Airport	USW00013866	38.3794	-81.59	277.4 m	100%
WV	Princeton	USC00467207	37.3842	-81.0822	722.4 m	99%
WY	Cheyenne WSFO Airport	USW00024018	41.1578	-104.807	1863.2 m	100%
WY	Dubois	USC00482715	41.1783	-78.8989	2119.9 m	92%

NEW ENGLAND

Statistically significant trends in New England occurred most frequently in the northern portion of the region with all 19 significant trends occurring in Maine, Vermont and New Hampshire. All but one significant trend in this region was positive (Figures 2–20). There is at least one instance of a statistically significant positive trend in each of the six variables in the study.

Maine

Fort Kent

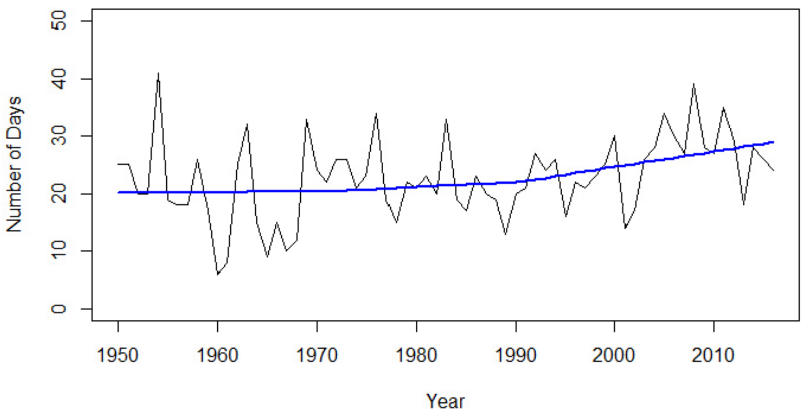

Figure 2 Frequency of Days with Precipitation Greater than 0.5 in.. Fort Kent, ME

Portland Jetport

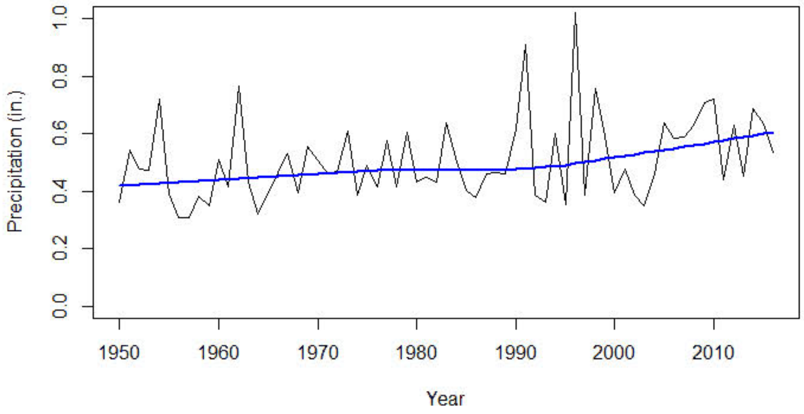

Figure 3 Annual Standard Deviation. Portland Jetport, ME

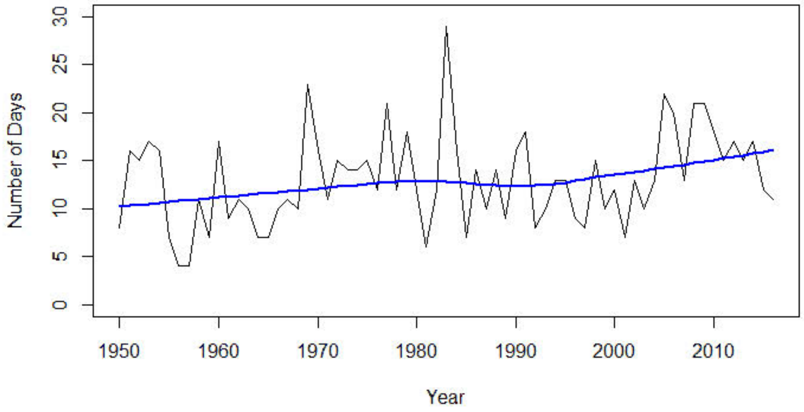

Figure 4 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which was 0.81 in. Portland Jetport, ME

New Hampshire

Newport

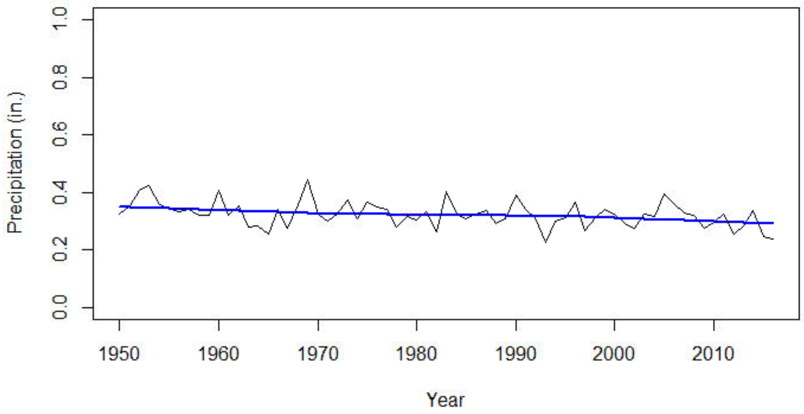

Figure 5 Mean Annual Precipitation per Event, Newport, NH

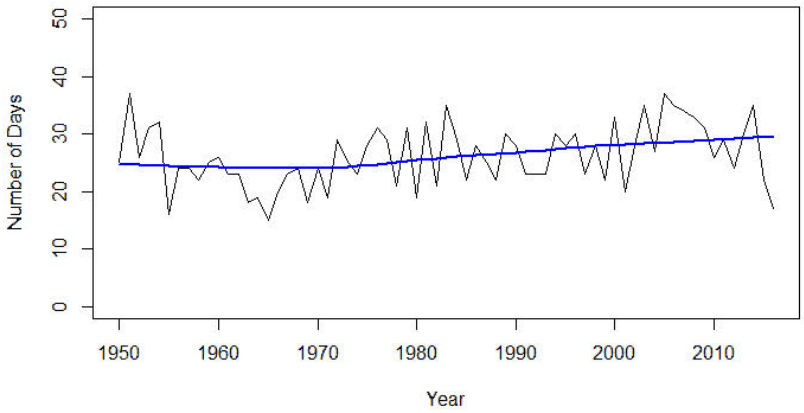

Figure 6 Frequency of Days with Precipitation Greater than 0.5 inches. Newport, NH

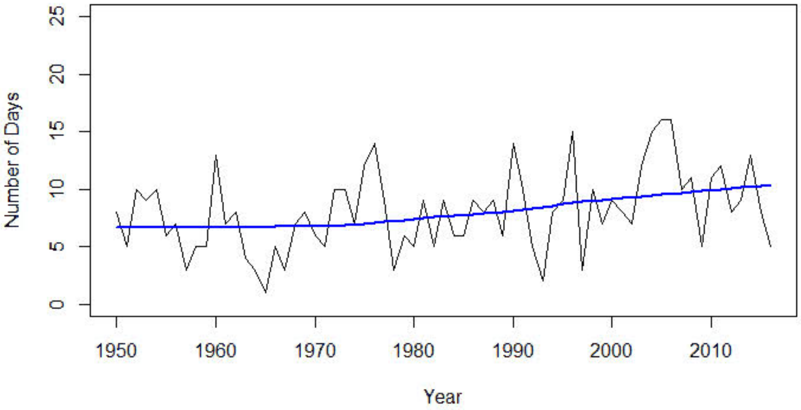

Figure 7 Frequency of Days with Greater than 1.0 inch of Precipitation. Newport, NH

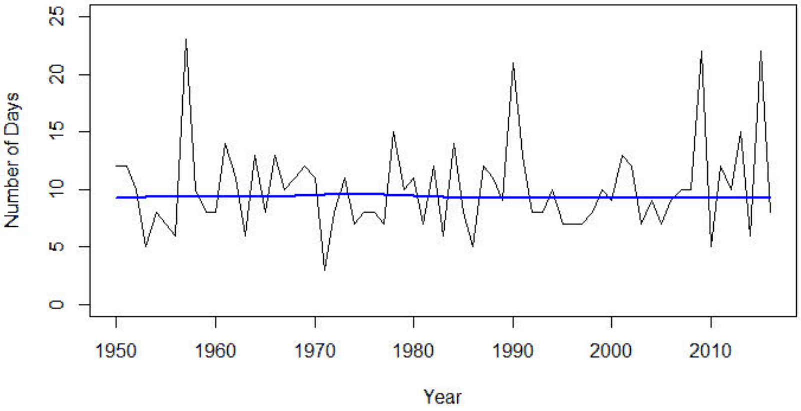

Figure 8 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.954 inches. Newport, NH

Pinkham Notch

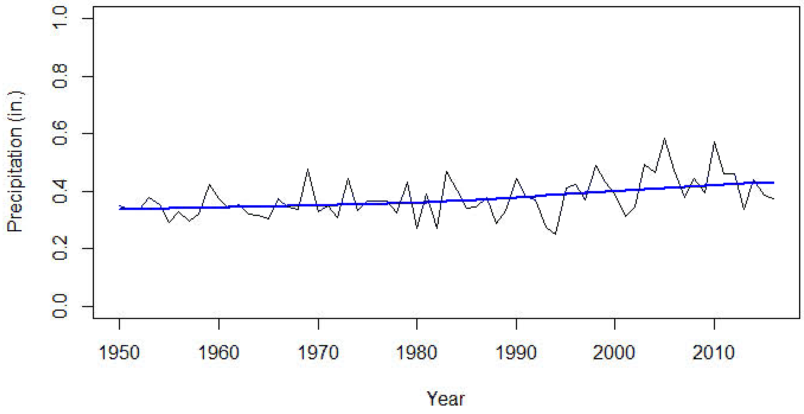

Figure 9 Mean Annual Precipitation per Event. Pinkham Notch, NH

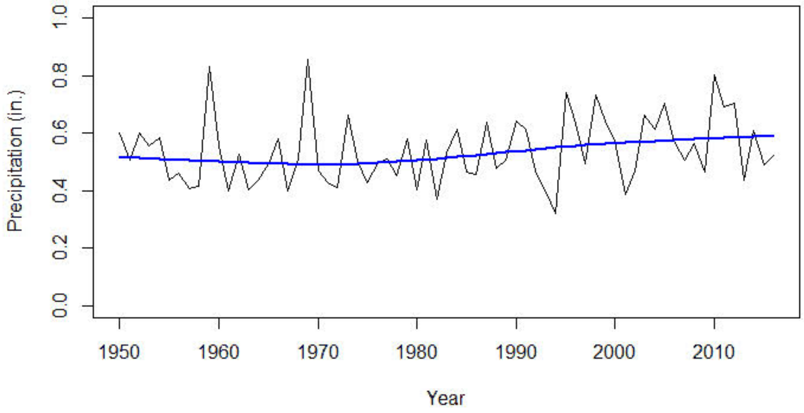

Figure 10 Annual Standard Deviation. Pinkham Notch, NH

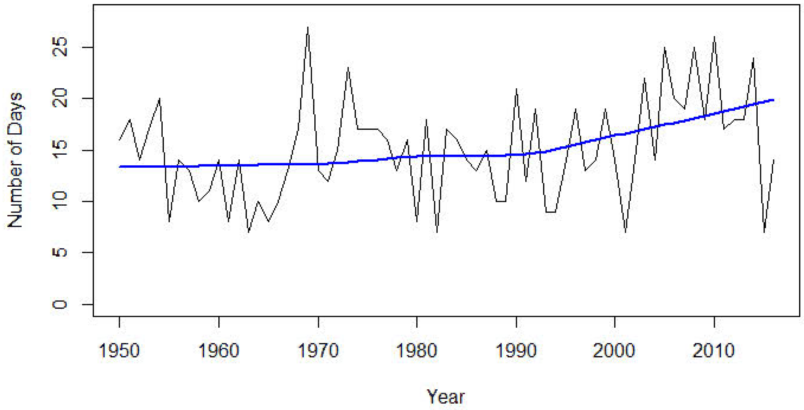

Figure 11 Frequency of Days with Precipitation Greater than 1.0 in. Pinkham Notch, NH

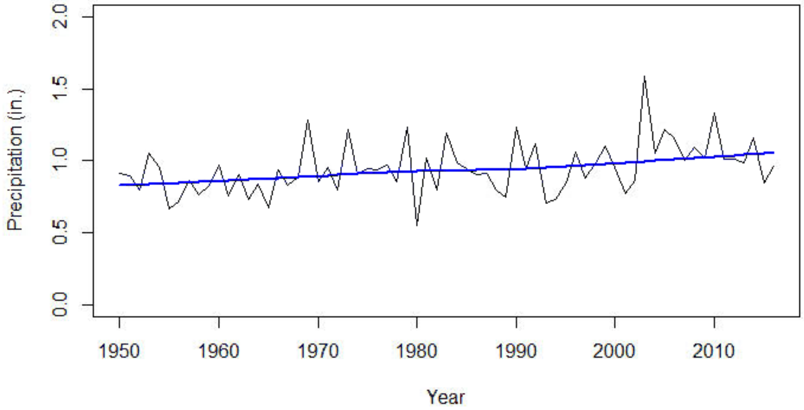

Figure 12 Annual 90th Percentile Value. Pinkham Notch, New Hampshire

Vermont

Barre Montpelier Knapp State Airport

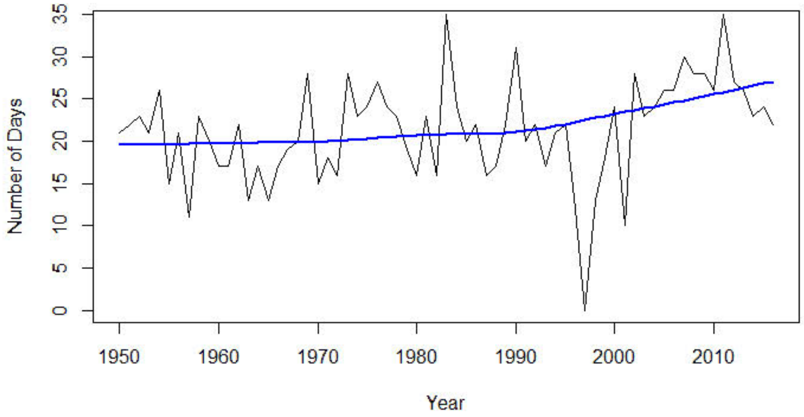

Figure 13 Frequency of Days with Precipitation Greater than 0.5 in.. Barre, VT

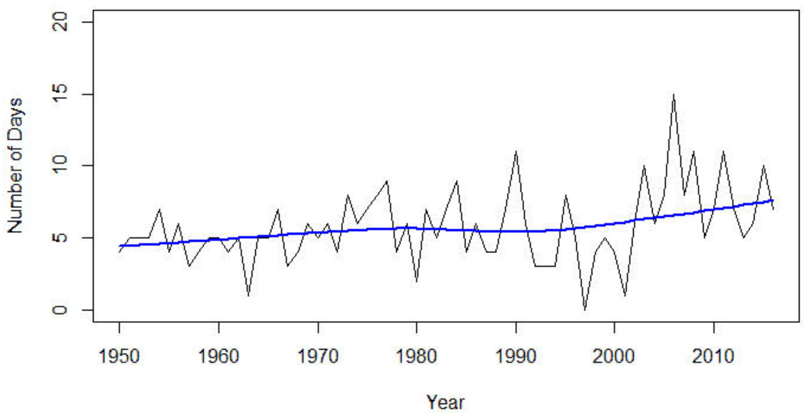

Figure 14 Frequency of Days with Precipitation Greater than 1.0 in. Barre, VT

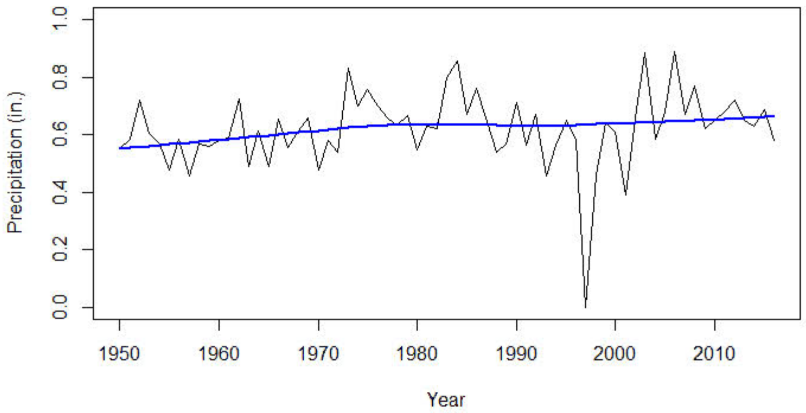

Figure 15 Annual 90th Percentile Value. Barre, VT

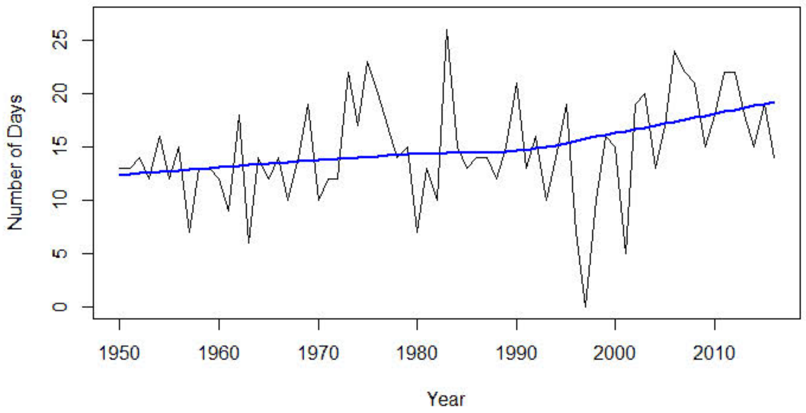

Figure 16 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.83 in. Barre, VT

Burlington Weather Service Office Airport

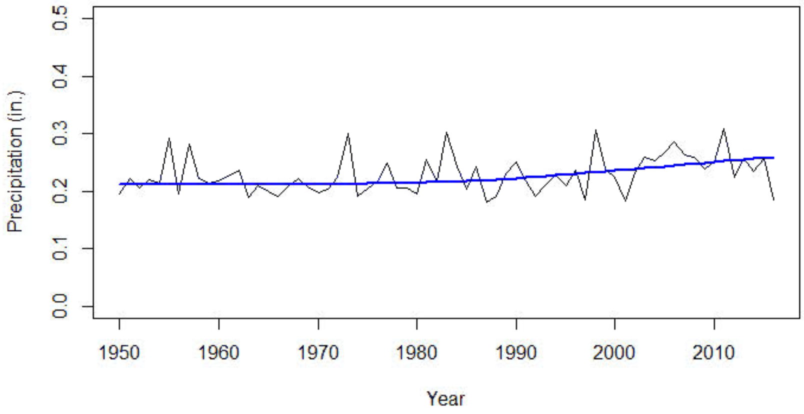

Figure 17 Mean Annual Precipitation per Event. Burlington, NH

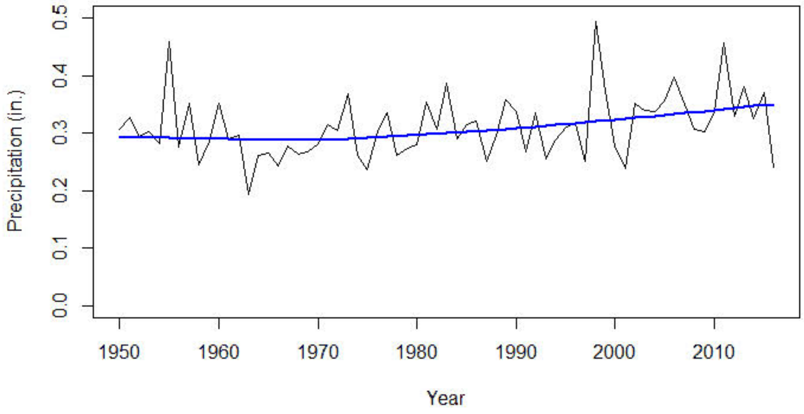

Figure 18 Annual Standard Deviation. Burlington, VT

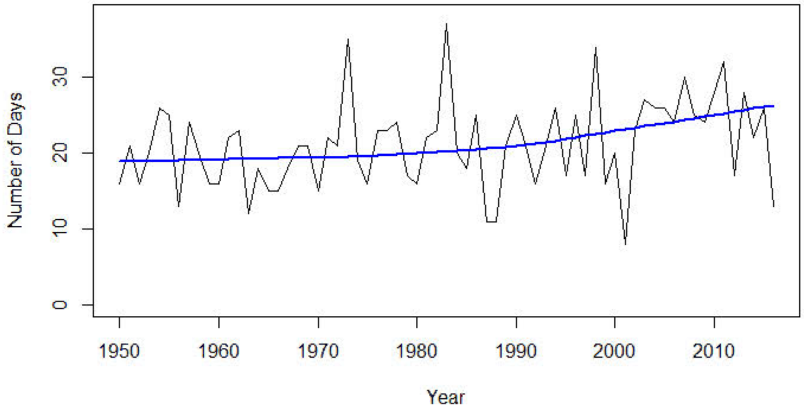

Figure 19 Frequency of Days with Precipitation Greater than 0.5 in. Burlington, VT

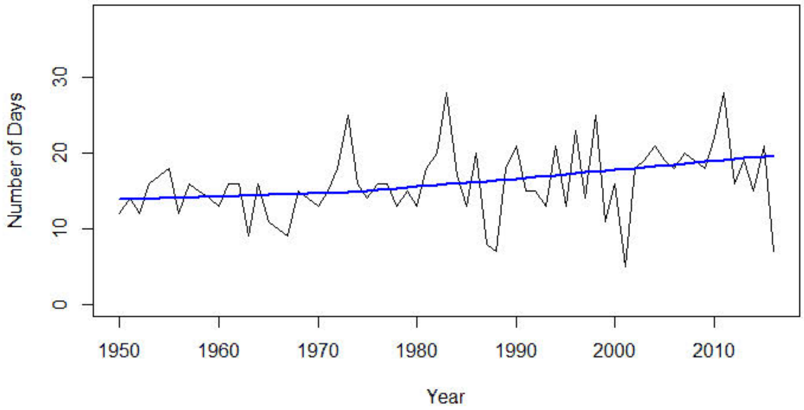

Figure 20 Frequency of Days with Precipitation Greater than 1.0 in. Burlington, VT

MID-ATLANTIC

Statistically significant trends in the Mid-Atlantic are mostly organized around the New York City Metro Area with only three of the nine trends in this region occurring outside of New York City. New York City is one of two stations in the study in which a positive trend was identified in all six of the variables. All significant trends in this region were positive (Figures 21–29).

New Jersey

Mays Landing 1 W

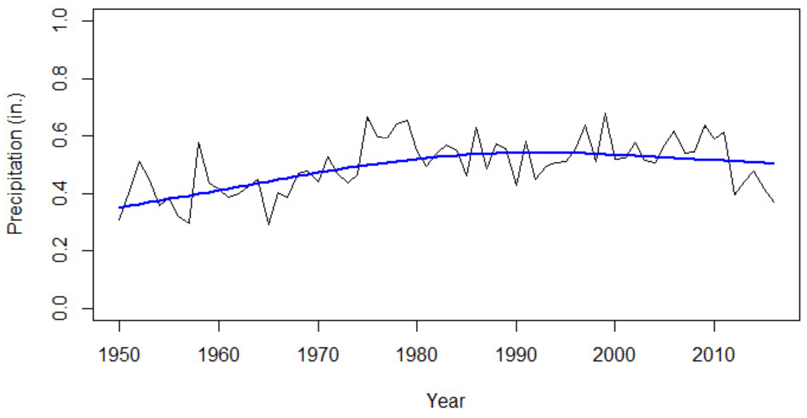

Figure 21 Mean Annual Precipitation per Event. Mays Landing, NJ

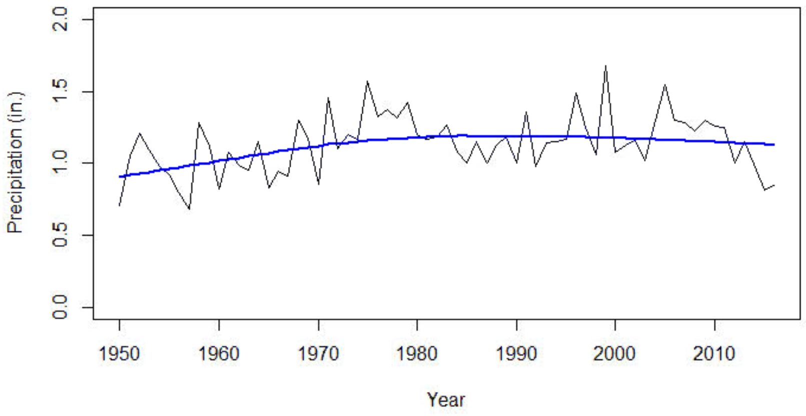

Figure 22 Annual 90th Percentile Value. Mays Landing, NJ

New York

NY City Central Park

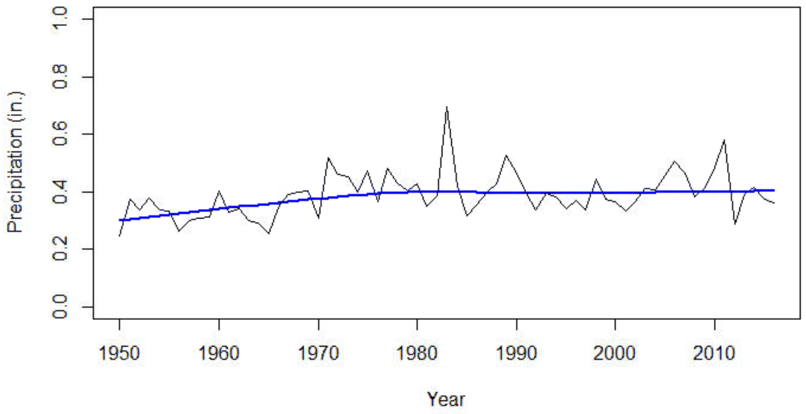

Figure 23 Mean Annual Precipitation per Event. New York, NY

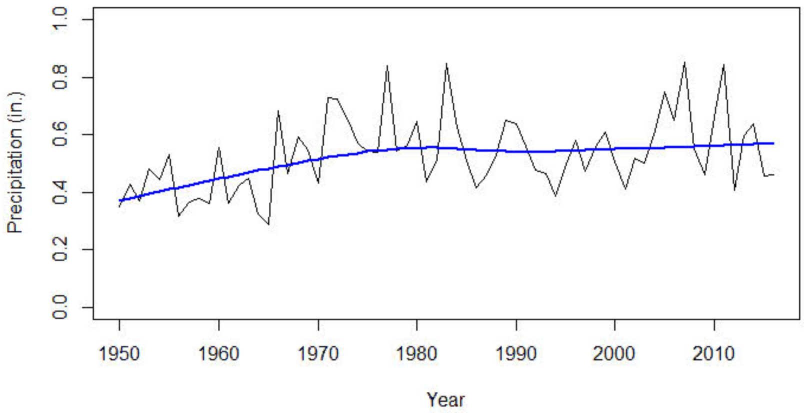

Figure 24 Annual Standard Deviation. New York, NY

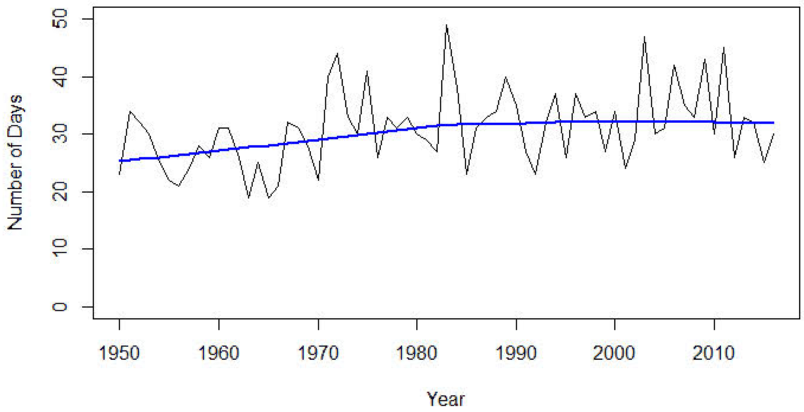

Figure 25 Frequency of Days with Precipitation Greater than 0.5 in. New York, NY

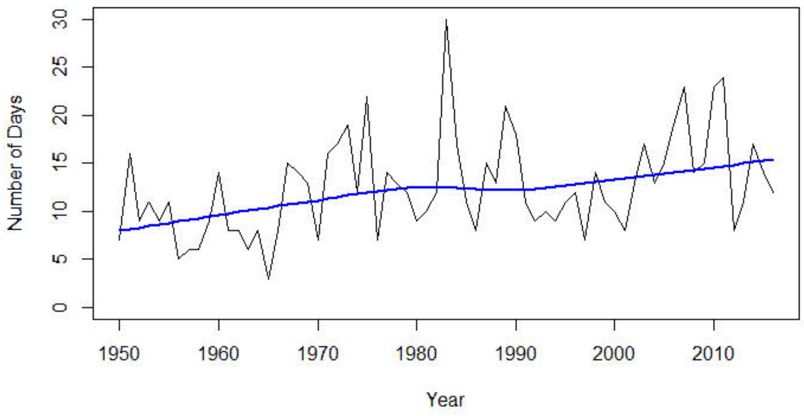

Figure 26 Frequency of Days with Precipitation Greater than 1.0 in. New York, NY

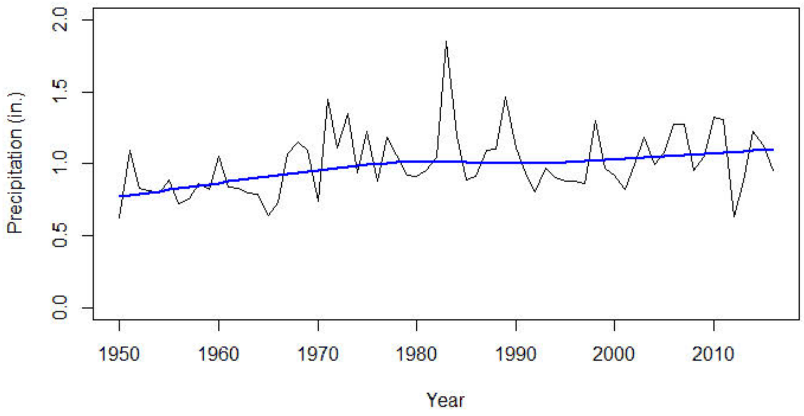

Figure 27 Annual 90th Percentile Value. New York, NY.

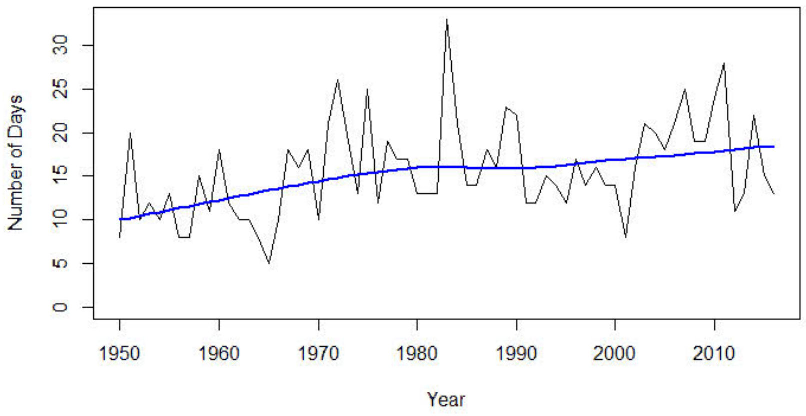

Figure 28 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.86 in. New York, NY

Pennsylvania

Acmetonia Lock 3

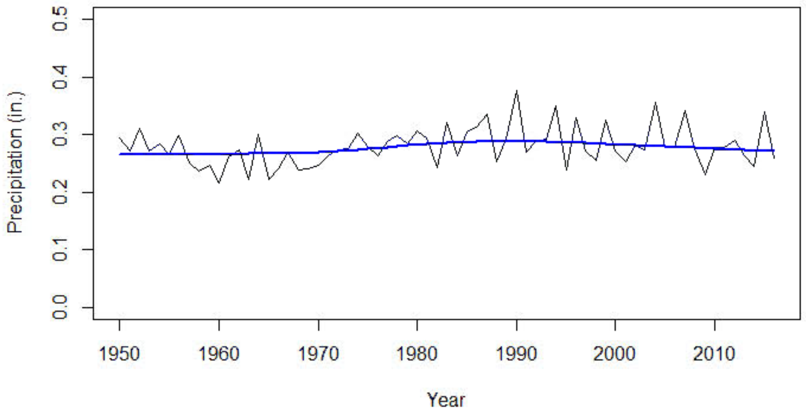

Figure 29 Mean Annual Precipitation per Event. Pittsburgh, PA

SOUTHEAST

Statistically significant trends were scattered in the Southeast region. Only Arkansas and South Carolina displayed no significant trends in any of the 6 variables. Trends in the Annual 90th Percentile Value and Frequency of Days with Precipitation Greater than the 90th Percentile occurred with the greatest frequency. There was only one statistically significant negative trend in the region, out of 30. (Figures 30–59)

Alabama

Montgomery Airport

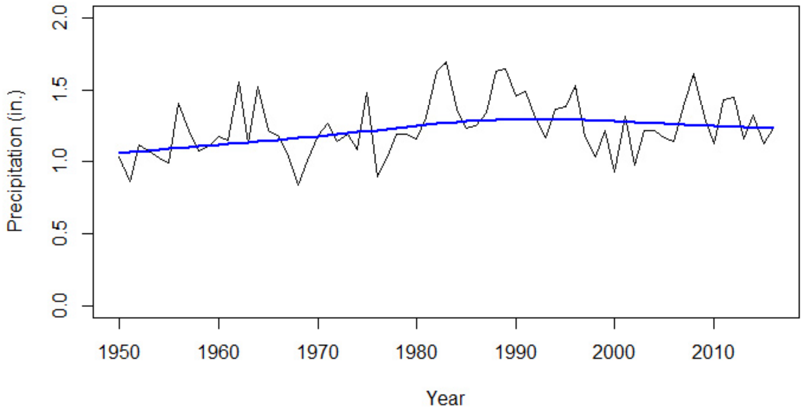

Figure 30 Annual 90th Percentile Value. Montgomery, AL

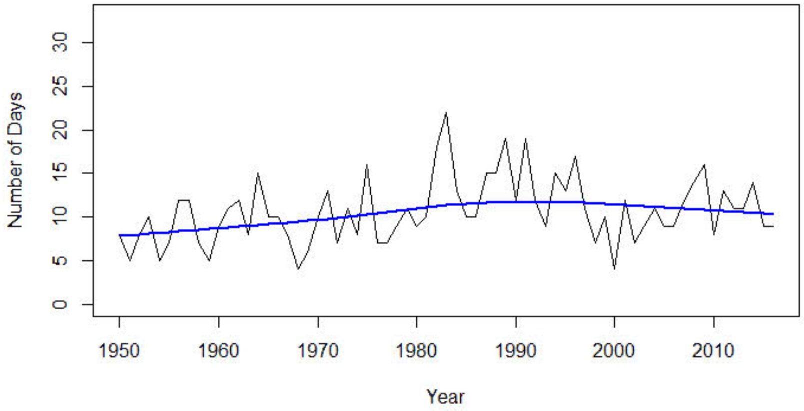

Figure 31 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 1.26 in. Montgomery, AL

Florida

Miami Beach

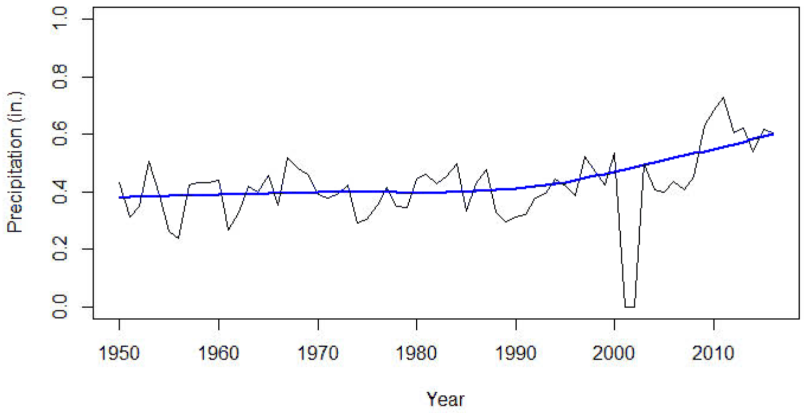

Figure 32 Mean Precipitation per Event. Miami Beach, FL

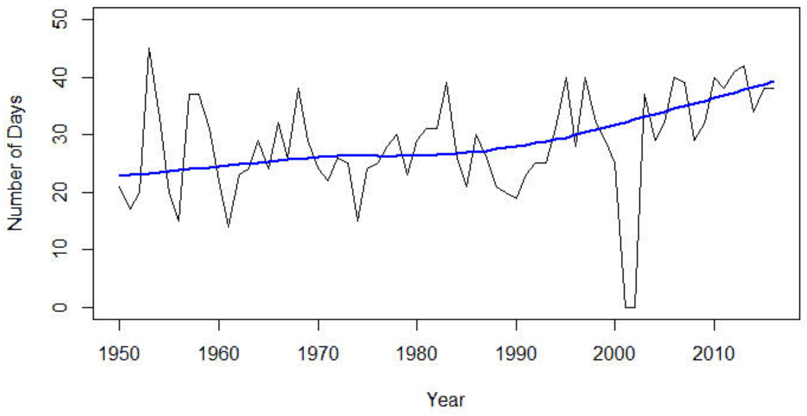

Figure 33 Frequency of Days with Precipitation Greater than 0.5 in. Miami Beach, FL

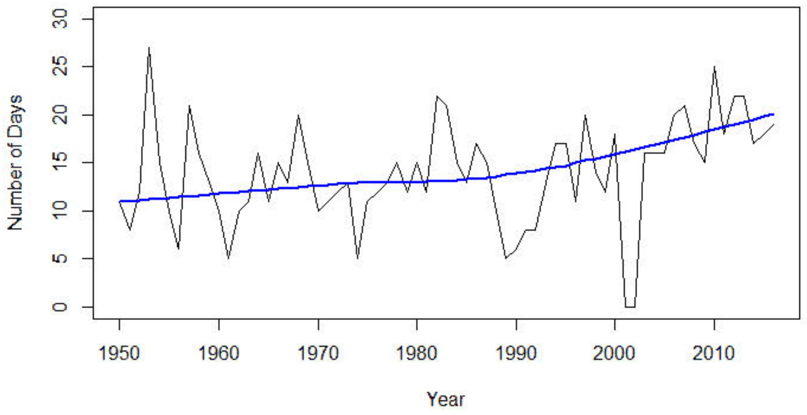

Figure 34 Frequency of Days with Precipitation over 1.0 in. Miami Beach, FL

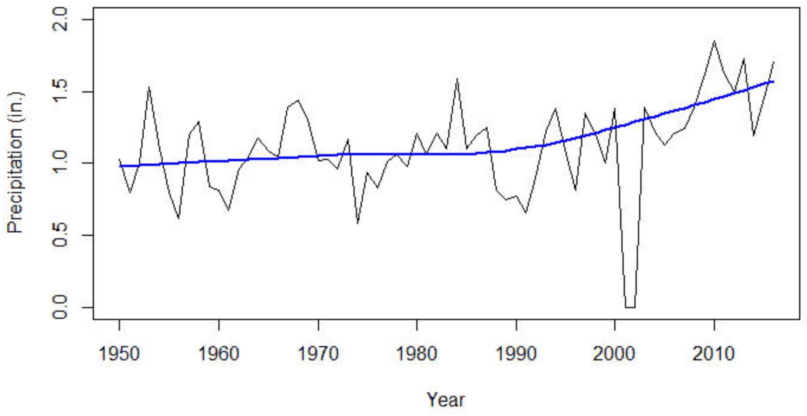

Figure 35 Annual 90th Percentile Value. Miami Beach, FL

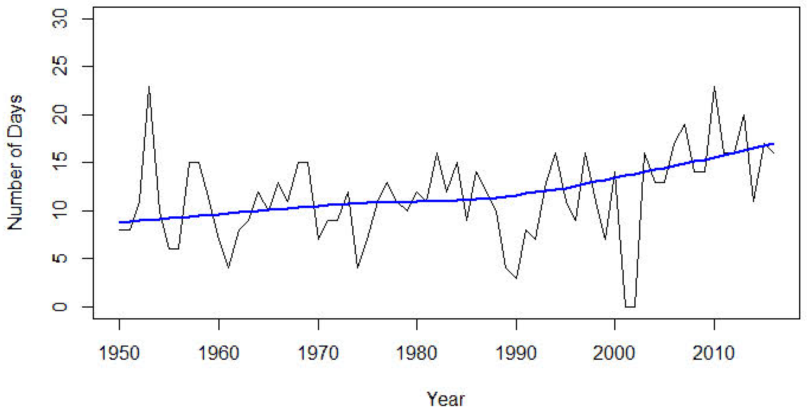

Figure 36 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, 1.17in. Miami Beach, FL

Kentucky

Cincinnati/Northern Kentucky International Airport (Hebron, KY)

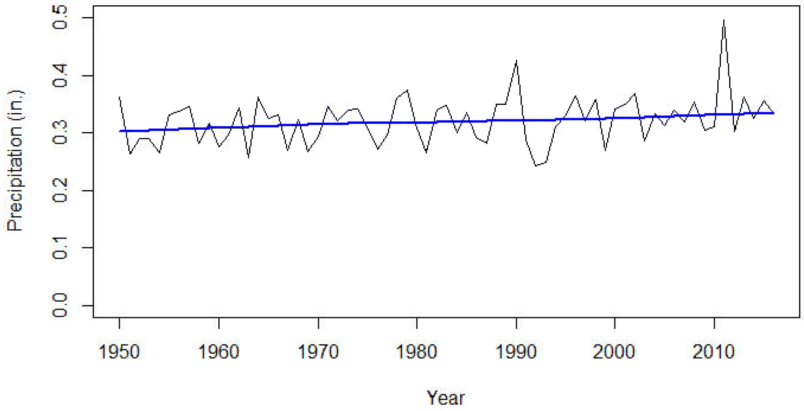

Figure 37 Mean Annual Precipitation per Event. Hebron, KY

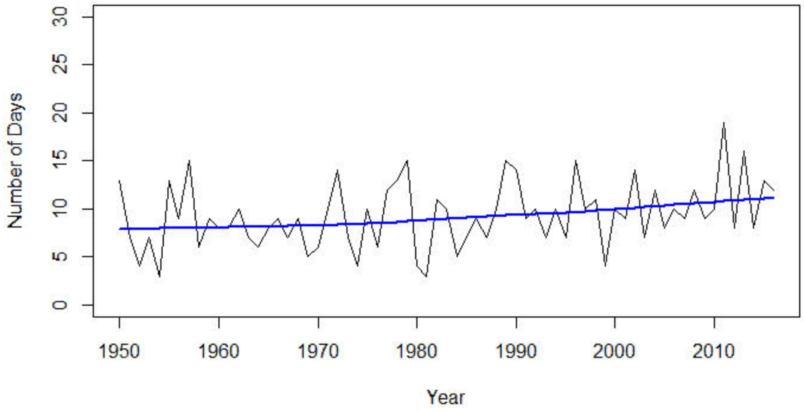

Figure 38 Frequency of Days with Precipitation Greater than 0.5in. Hebron, KY

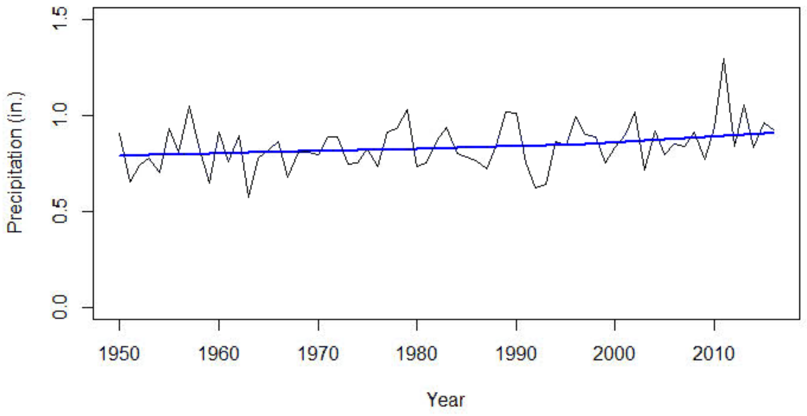

Figure 39 Annual 90th Percentile Value. Hebron, KY

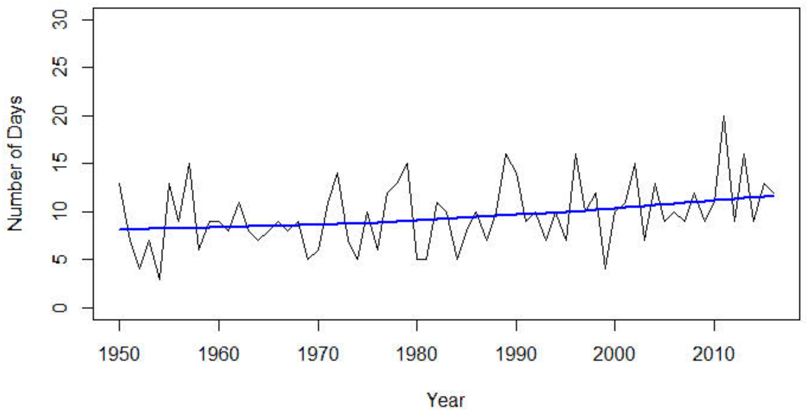

Figure 40 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.84 in. Hebron, KY

<u>Louisville International Airport</u>

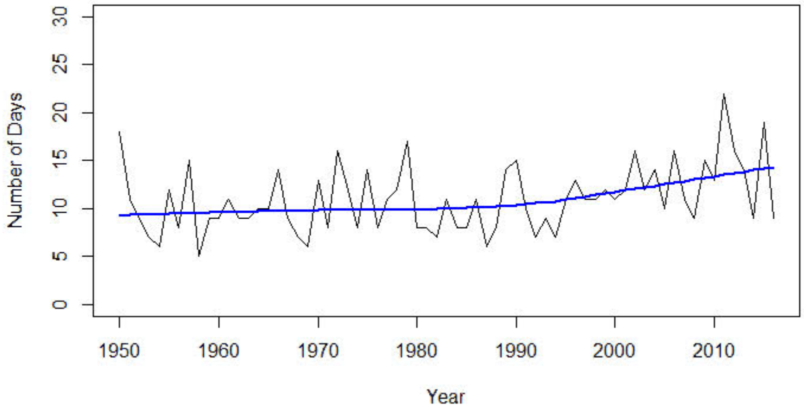

Figure 41 Frequency of Days with Precipitation Greater than 1.0 in. Louisville, KY

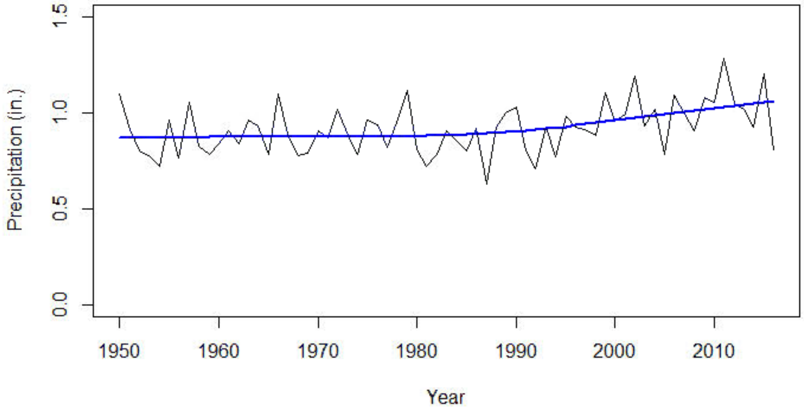

Figure 42 Annual 90th Percentile Value. Louisville, KY

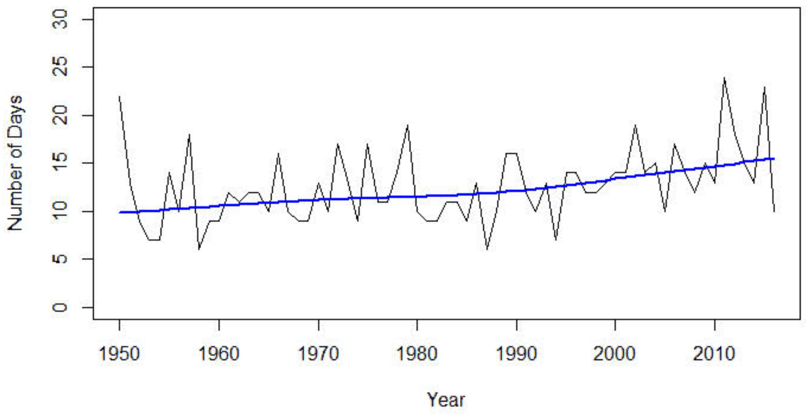

Figure 43 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 0.93. Louisville, KY

Louisiana

<u>New Orleans Airport</u>

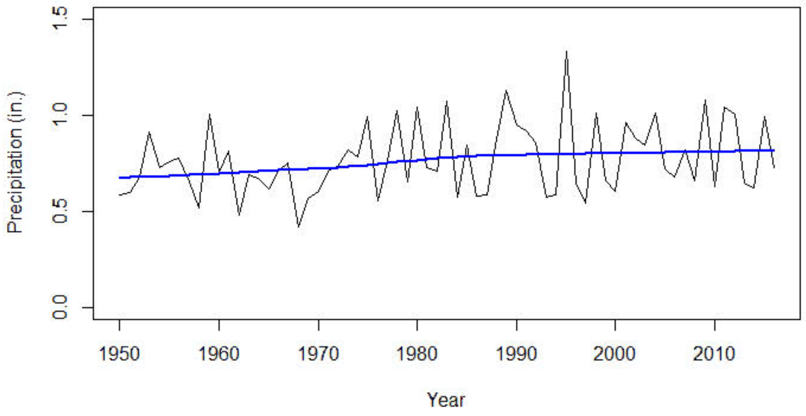

Figure 44 Annual Standard Deviation. New Orleans, LA

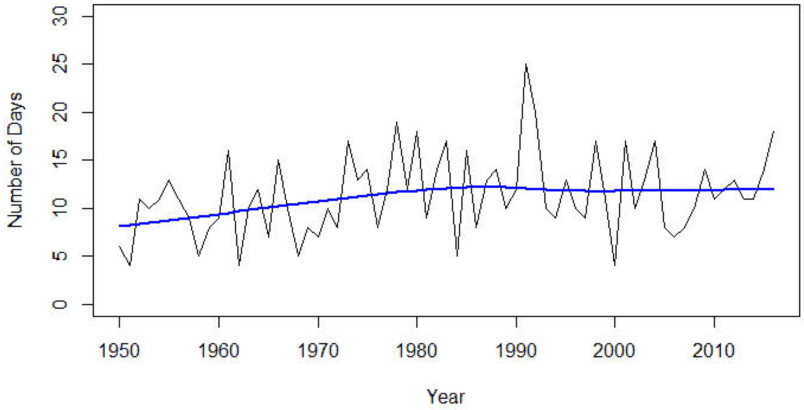

Figure 45 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 1.43 inches. New Orleans, LA

Louisiana Tech University (Ruston)

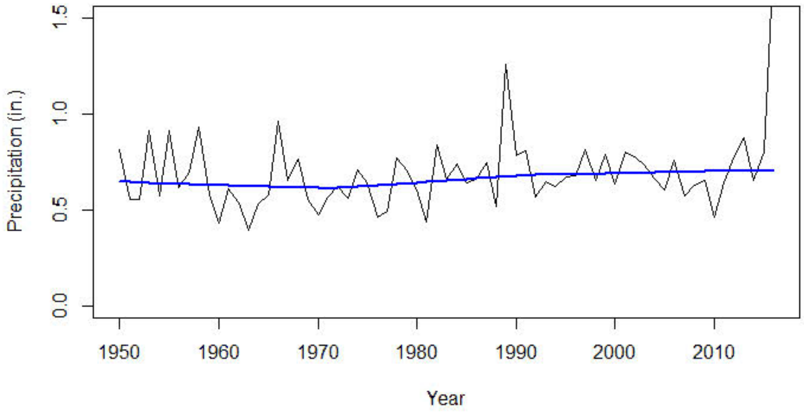

Figure 46 Annual Standard Deviation. Ruston, LA

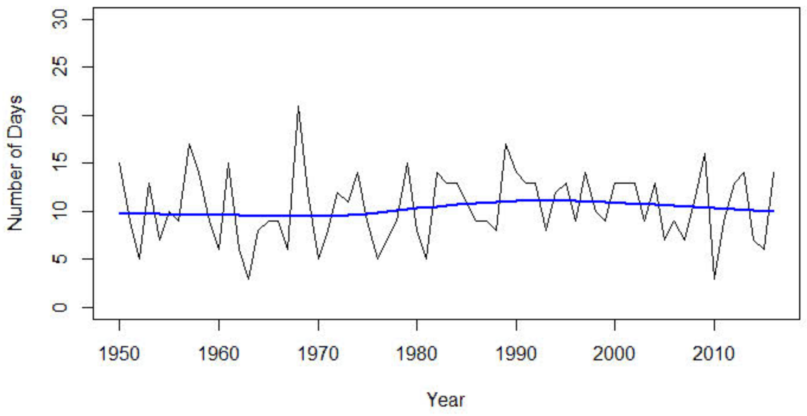

Figure 47 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 1.39 inches. Ruston, LA

North Carolina

Wadesboro

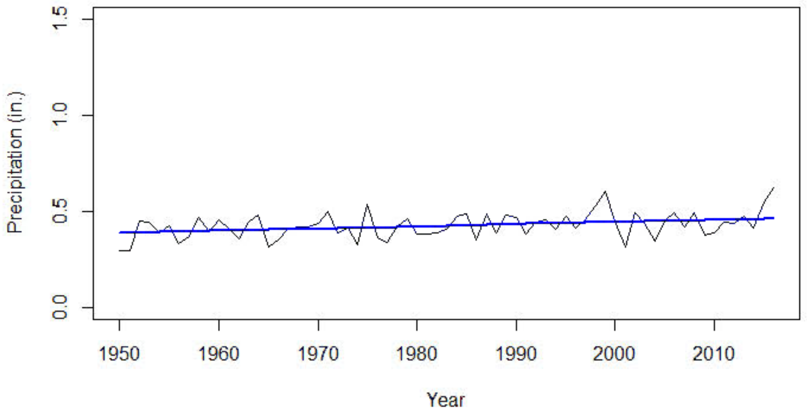

Figure 48 Mean Annual Precipitation per Event. Wadesboro, NC

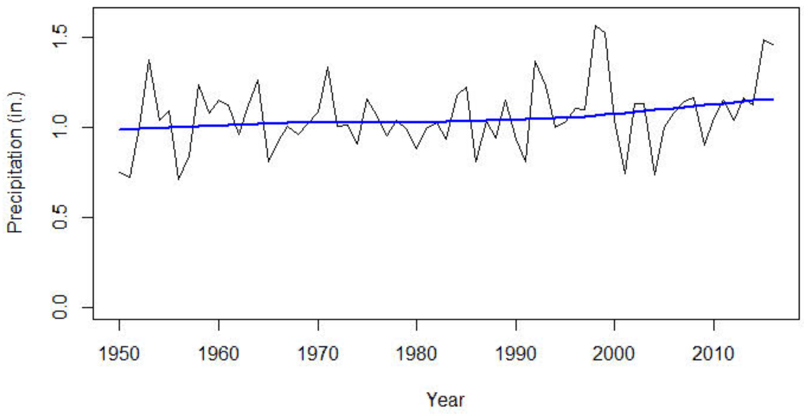

Figure 49 Annual 90th Percentile Value. Wadesboro, NC

Tennessee

Chattanooga Airport

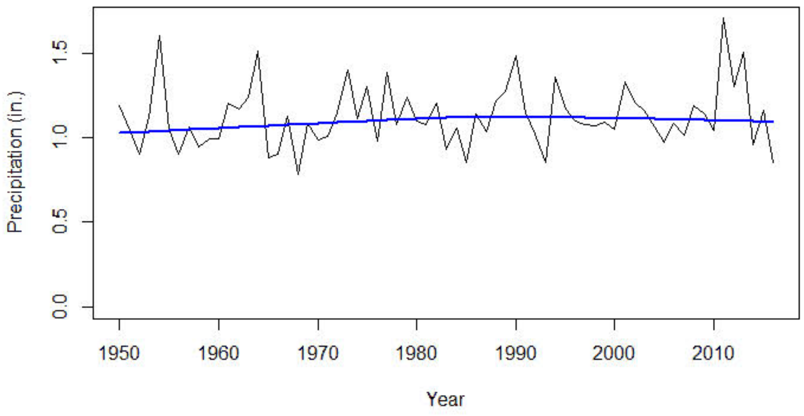

Figure 50 Annual 90th Percentile Value. Chattanooga, TN

Martin University of TN Experiment Station

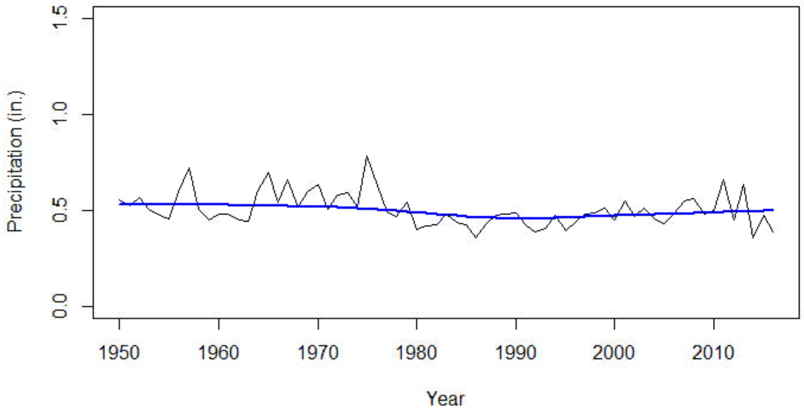

Figure 51 Mean Annual Precipitation per Event. Martin, TN

Virginia

Lynchburg International Airport

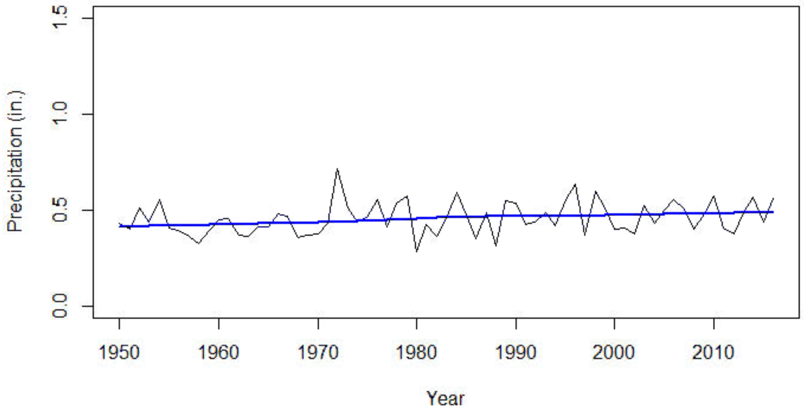

Figure 52 Annual Standard Deviation. Lynchburg, VA

West Virginia

Charleston Yeager Airport

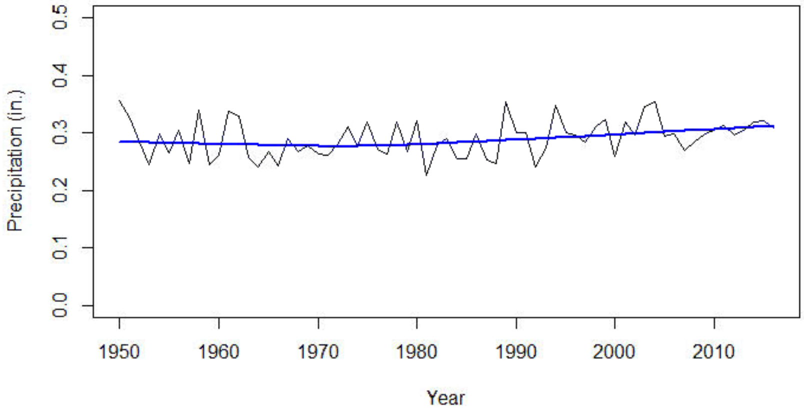

Figure 53 Mean Annual Precipitation per Event. Charleston, WV

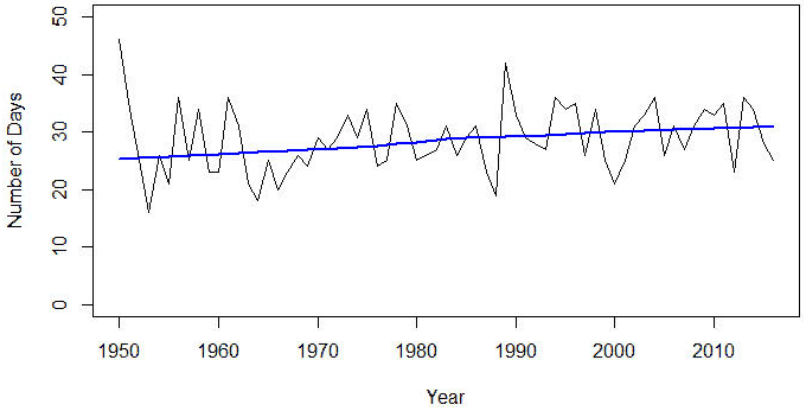

Figure 54 Frequency of Days with Precipitation Greater than 0.5 in. Charleston, WV

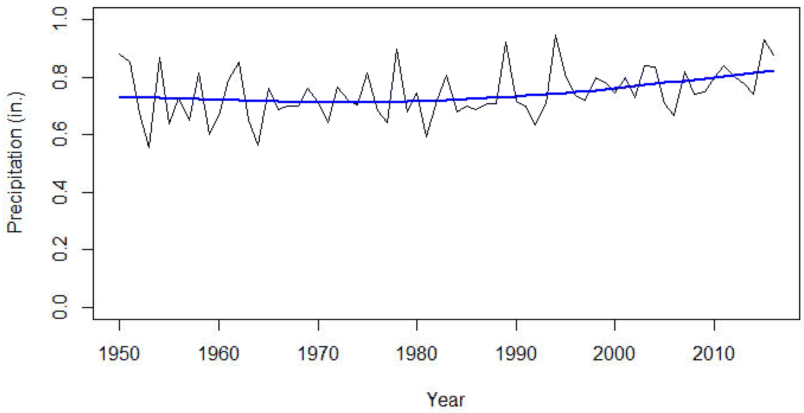

Figure 55 Annual 90th Percentile Value. Charleston, WV

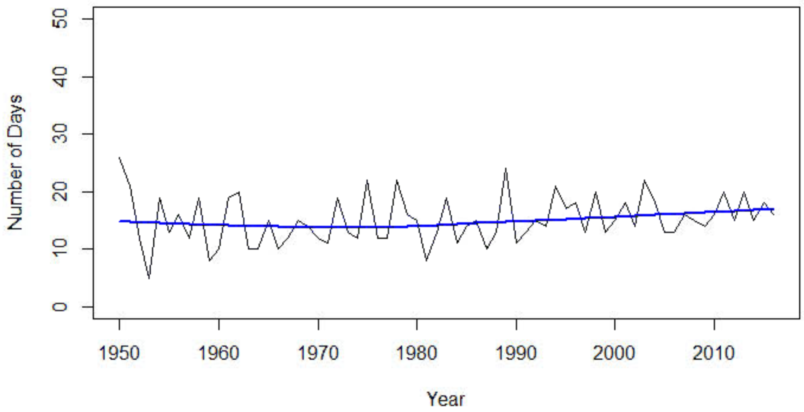

Figure 56 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.76 inches, Charleston, WV

Princeton

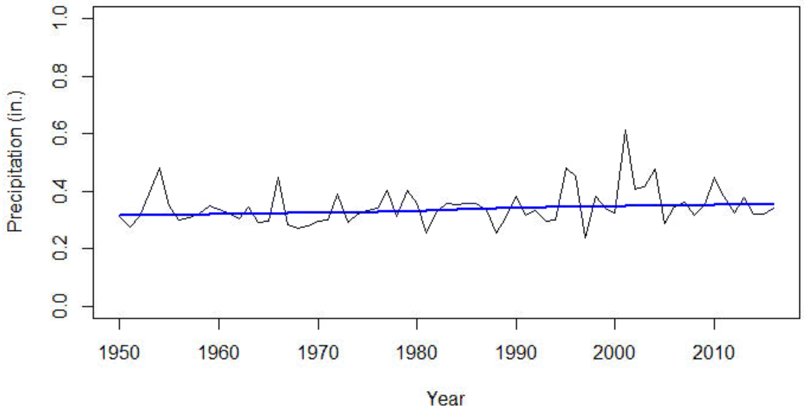

Figure 57 Annual Standard Deviation. Princeton, WV

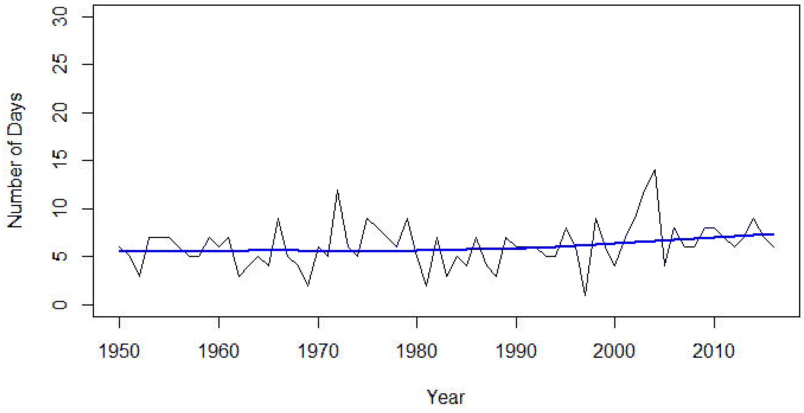

Figure 58 Frequency of Days with Greater than 1.0 in. of Precipitation. Princeton, WV

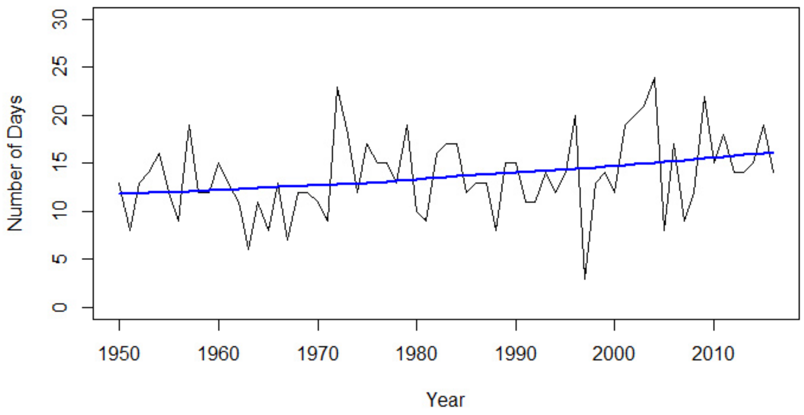

Figure 59 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.71 inches. Princeton, KY

GREAT LAKES

Statistically significant trends in the Great Lakes region occur in every state in the region. Negative trends were concentrated in the northern part of the region with all three negative trends occurring in northern Wisconsin and Michigan. The remaning 18 statistically significant trends were positive. All of the variables in the study have statistically significant trends in this region (Figure 60–81).

Illinois

Aledo

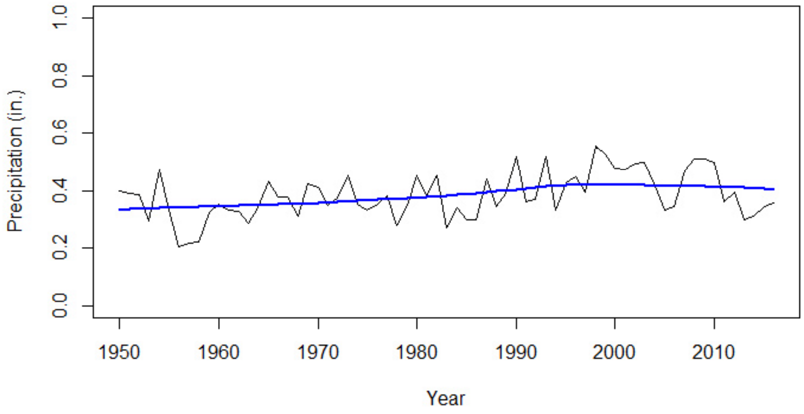

Figure 60 Mean Annual Precipitation per Event. Aledo, IL

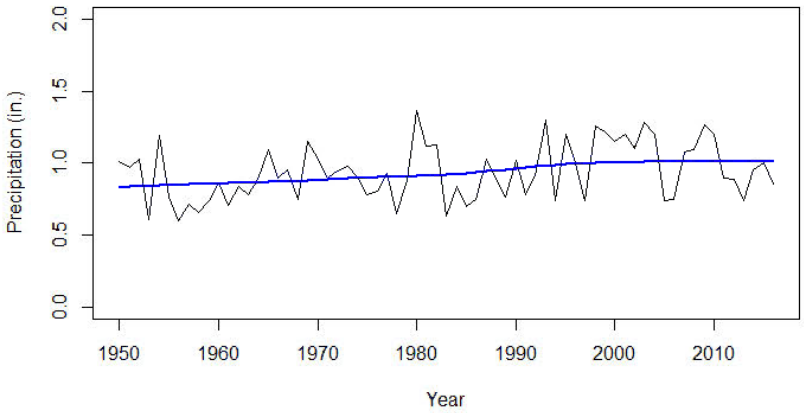

Figure 61 Annual 90th Percentile Value. Aledo, IL

Indiana

Indianapolis International Airport

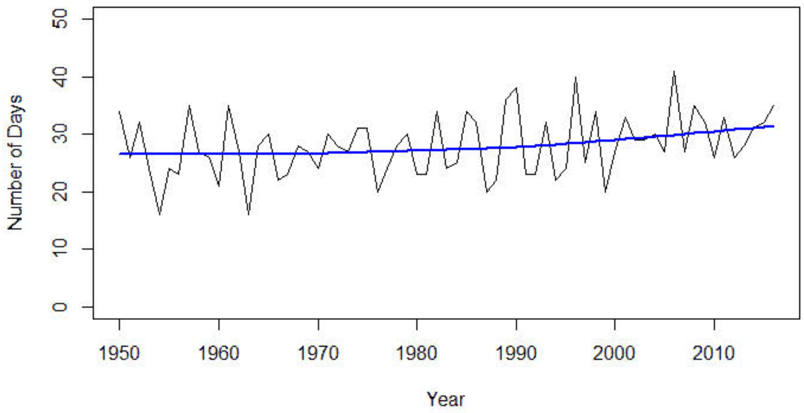

Figure 62 Frequency of Days with Precipitation Greater than 0.5 in. Indianapolis, Indiana.

Michigan

Ann Arbor Municipal Airport

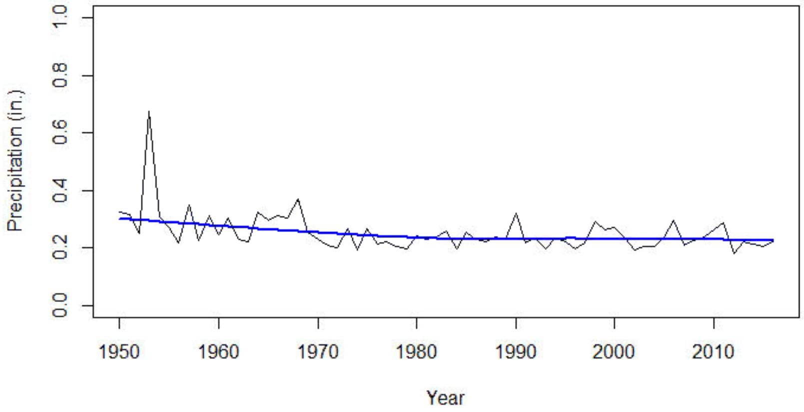

Figure 63 Mean Annual Precipitation per Event. Ann Arbor, MI

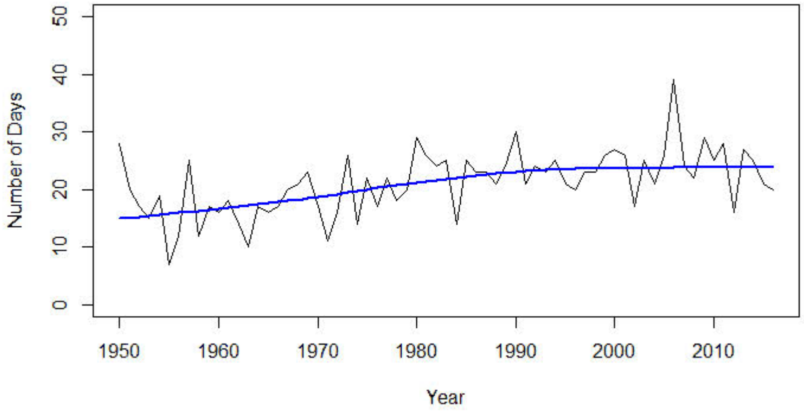

Figure 64 Frequency of Days with Precipitation Greater than 0.5 in.(Figure 63)

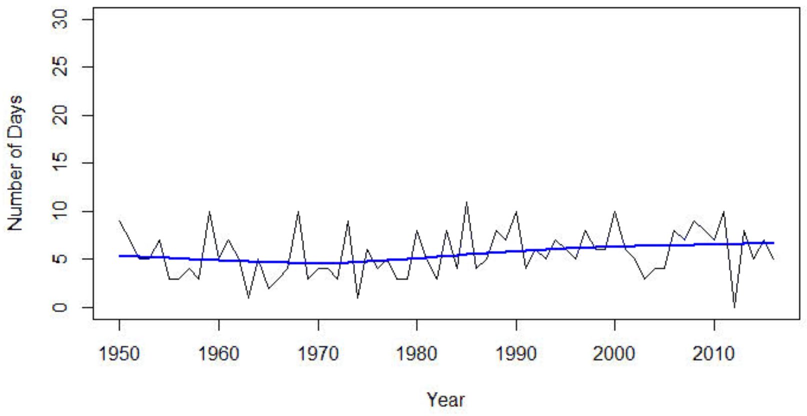

Figure 65 Frequency of Days with Precipitation Greater than 1.0 in. Ann Arbor, MI

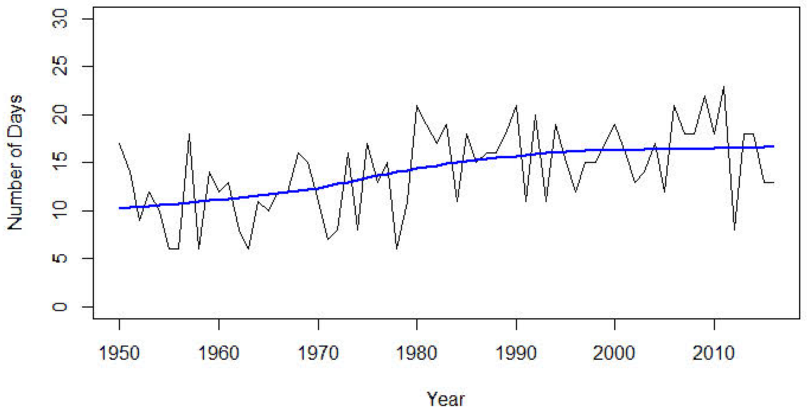

Figure 66 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 0.64. Ann Arbor, MI

Manistique WWTP

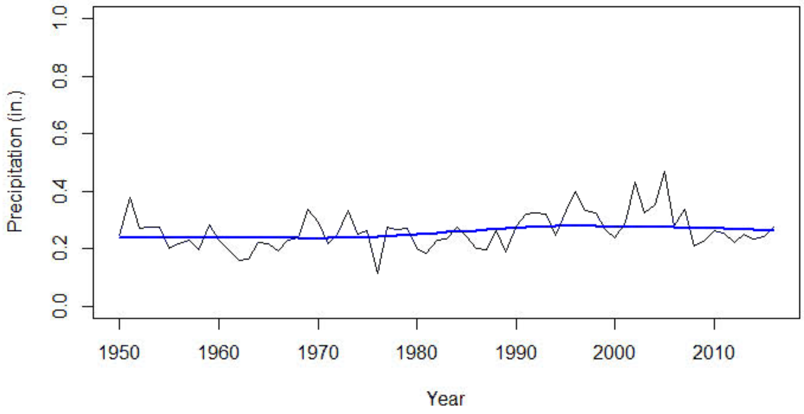

Figure 67 Mean Annual Precipitation per Event. Manistique, MI

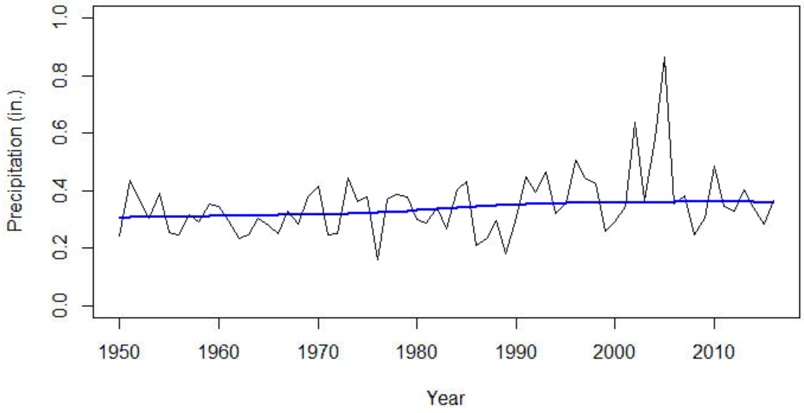

Figure 68 Annual Standard Deviation. Manistique, MI

Ohio

Dayton International Airport

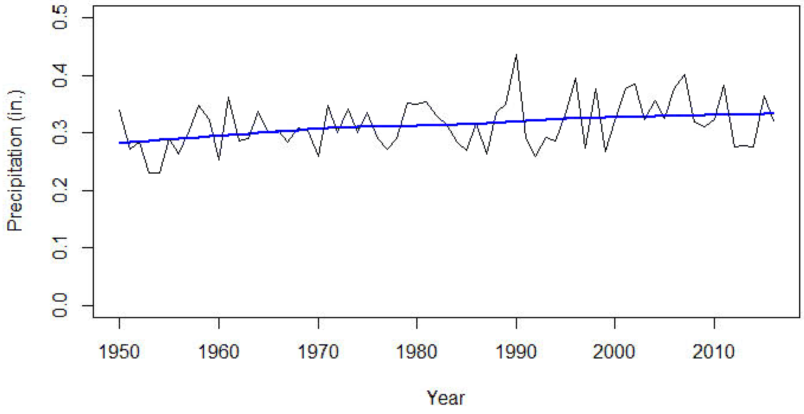

Figure 69 Mean Annual Precipitation per Event. Dayton, OH

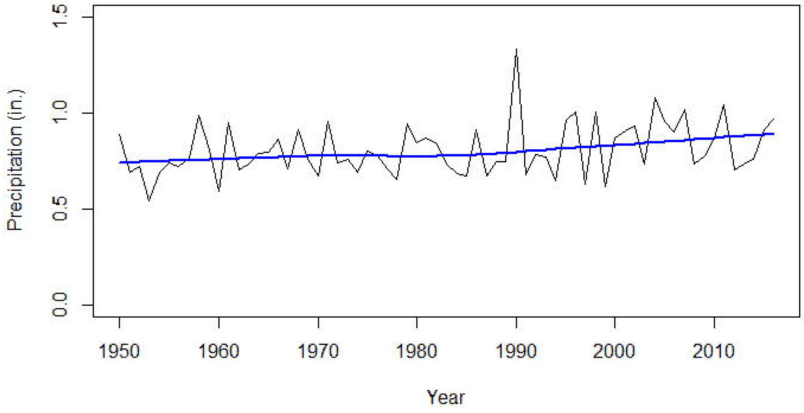

Figure 70 Annual 90th Percentile Value Dayton, OH

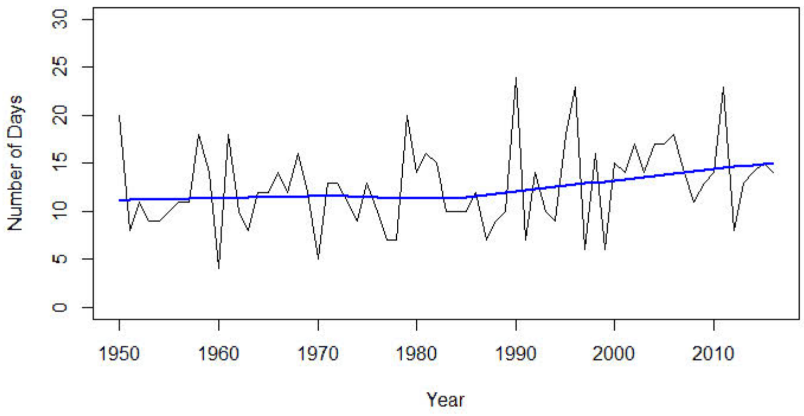

Figure 71 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.81 Dayton, OH

Wauseon Water Plant

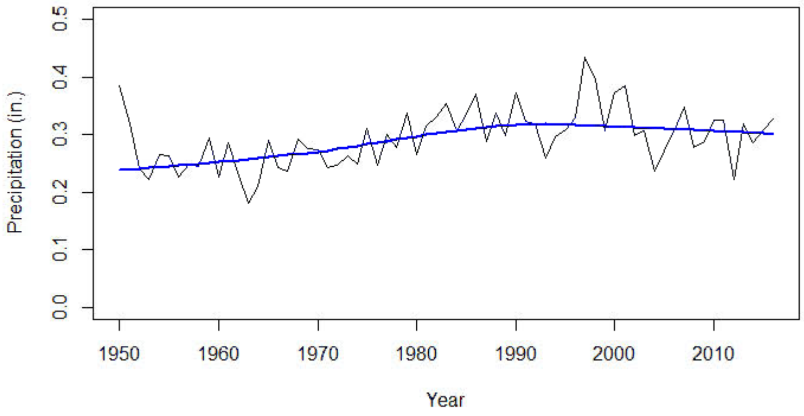

Figure 72 Mean Annual Precipitation per Event Wauseon, OH

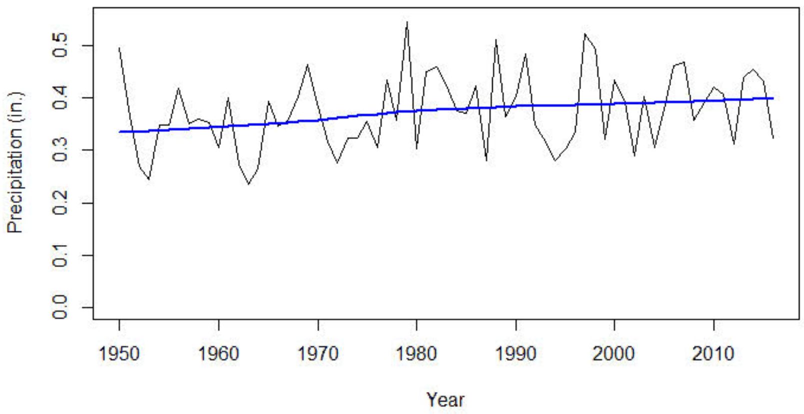

Figure 73 Annual Standard Deviation Wauseon, OH

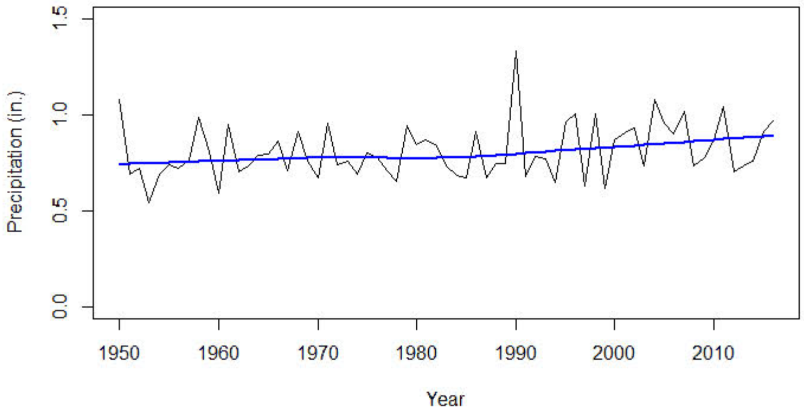

Figure 74 Annual 90th Percentile Value. Wauseon, OH

Wisconsin

Eagle River

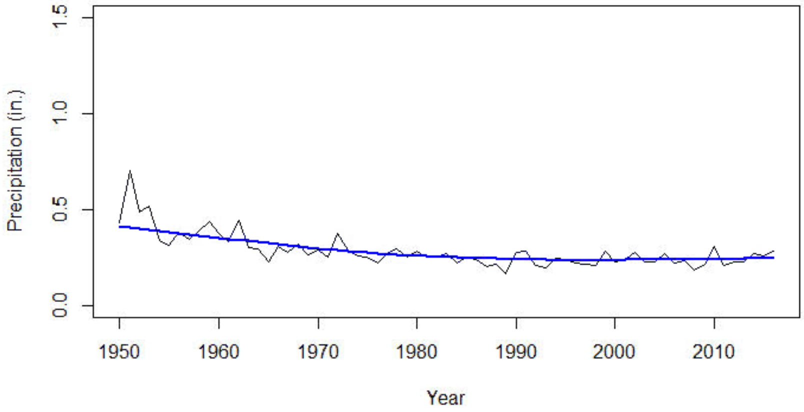

Figure 75 Mean Annual Precipitation per Event Eagle River, WI

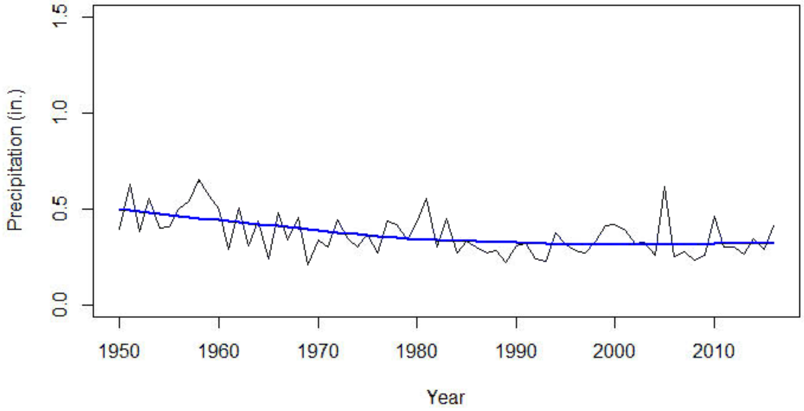

Figure 76 Annual Standard Deviation Eagle River, WI

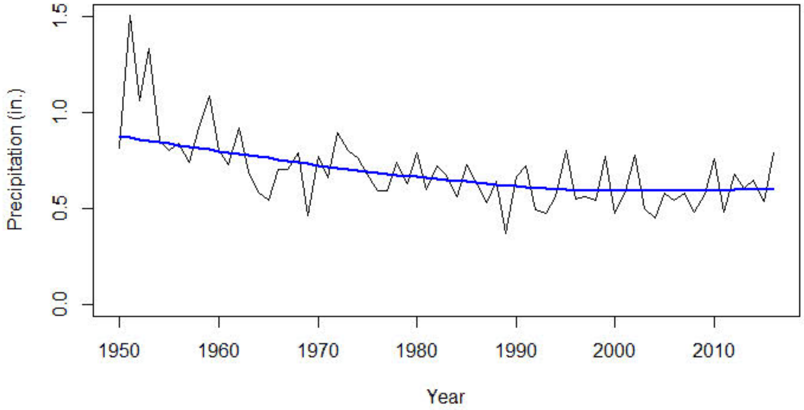

Figure 77 Annual 90th Percentile Value. Eagle River, WI

Milwaukee Mount Mary College

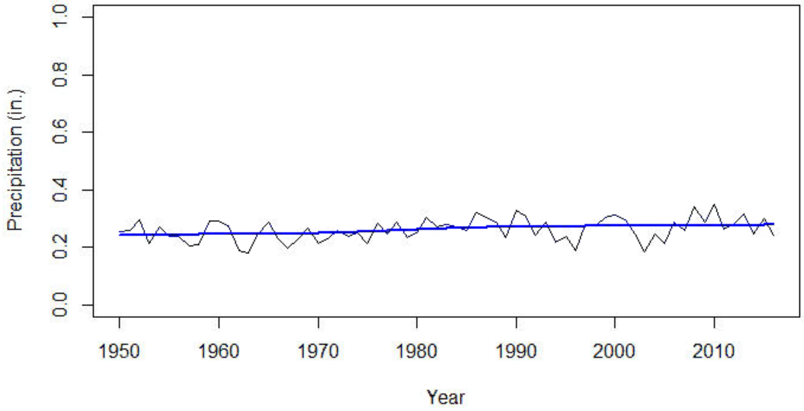

Figure 78 Mean Annual Precipitation per Event. Milwaukee, WI

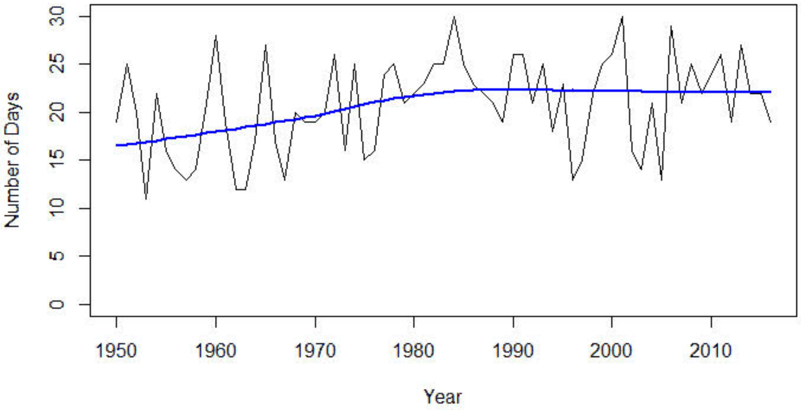

Figure 79 Frequency of Days with Precipitation Greater than 0.5 in.. Milwaukee, WI

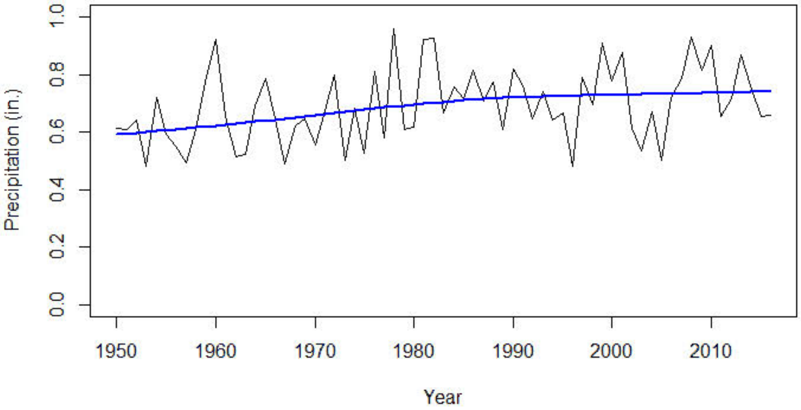

Figure 80 Annual 90th Percentile Value. Milwaukee, WI

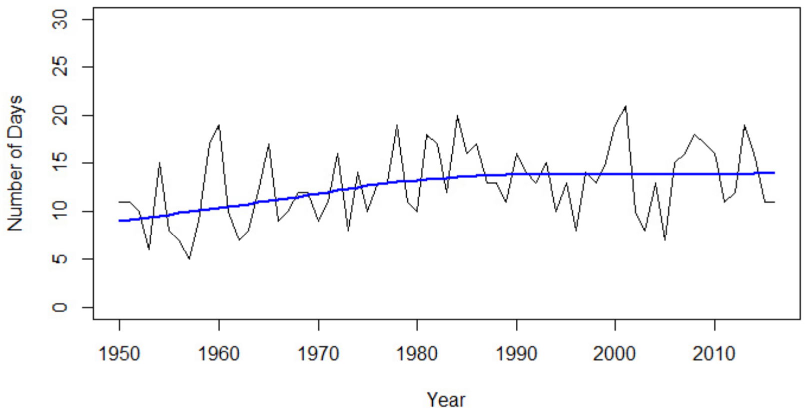

Figure 81	Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which was 0.7 inches. Milwaukee, WI

PLAINS

Statistically Significant trends in the Plains region were identified in every state apart from South Dakota, with Nebraska and North Dakota displaying significant trends on only one of their two stations. There are significant trends in each of the six variables with only two of the 28 present significant trends being negative. This region contains Minneapolis, one of two stations in the study with statistically significant positive trends in each of the six variables. (Figures 82–109)

Iowa

Iowa Falls

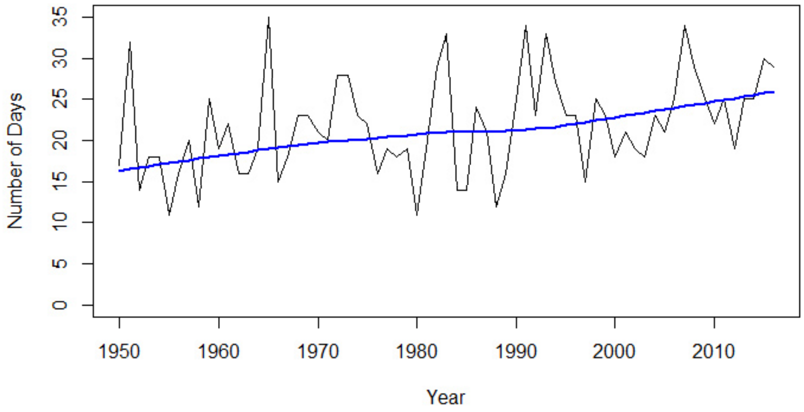

Figure 82 Frequency of Days with Precipitation Greater than 0.5 in.. Iowa Falls, IA

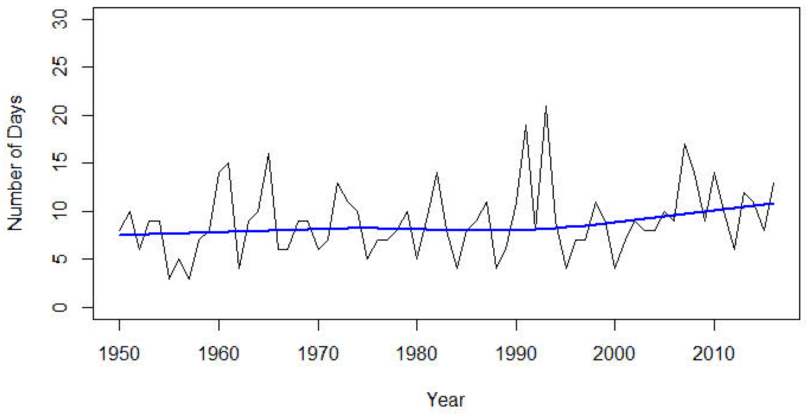

Figure 83 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.9 inches. Iowa Falls, IA

Tripoli

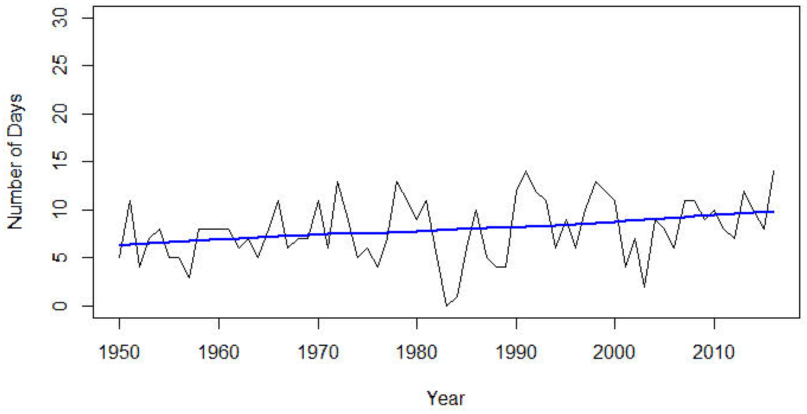

Figure 84 Frequency of Days with Precipitation Greater than 1.0 in. Iowa Falls, IA.

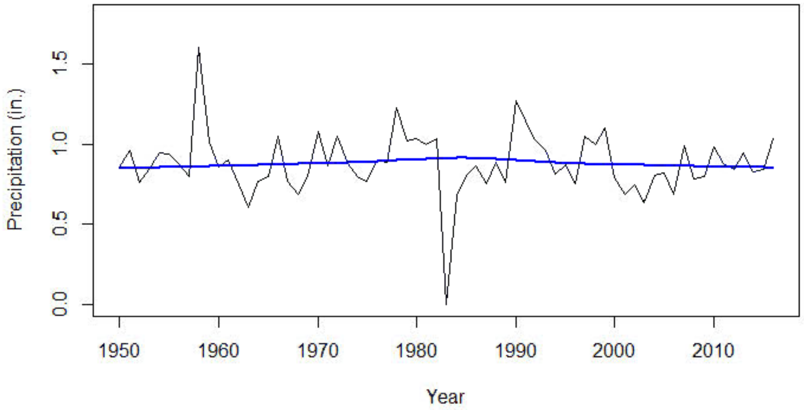

Figure 85 Annual 90th Percentile Value. Iowa Falls, IA.

Kansas

McPherson

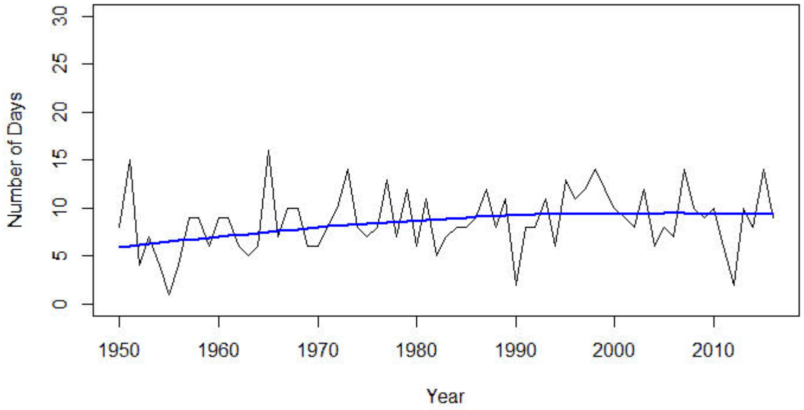

Figure 86 Frequency of Days with Precipitation Greater than 1.0 in. McPherson, KS

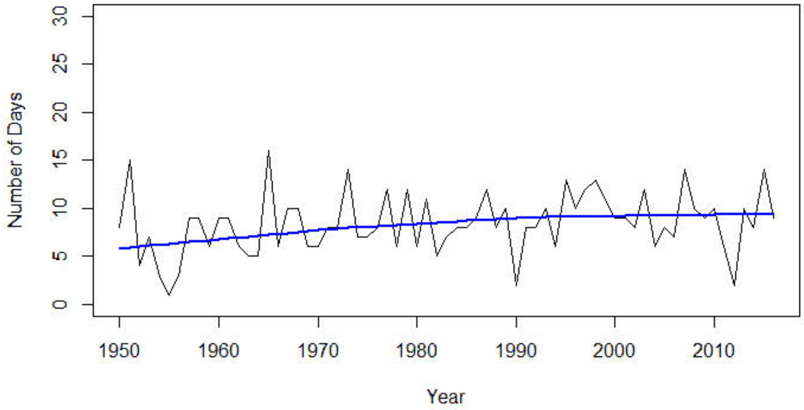

Figure 87 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 1.02 in. McPherson, KS

Topeka Municipal Airport

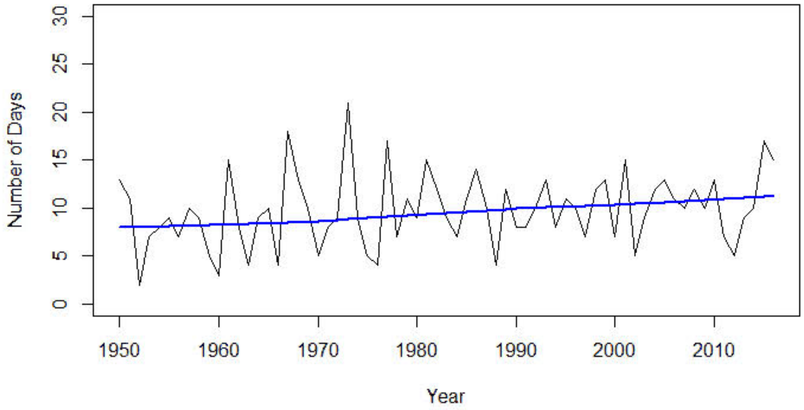

Figure 88 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.99 in. Topeka, KS

Minnesota

Itasca University of Minn

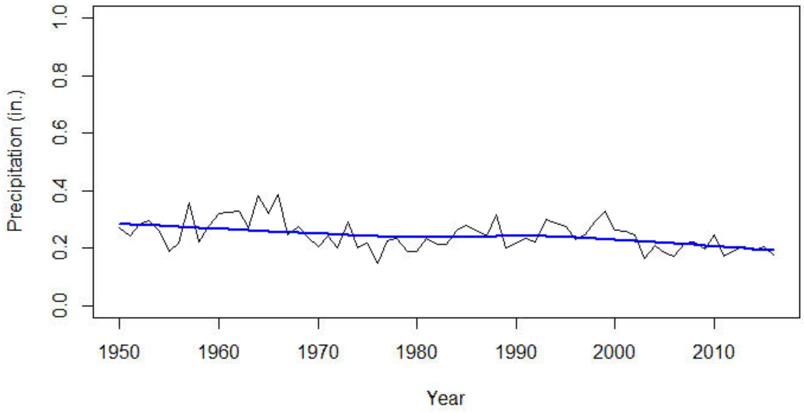

Figure 89 Mean Annual Precipitation per Event. Itasca, MN

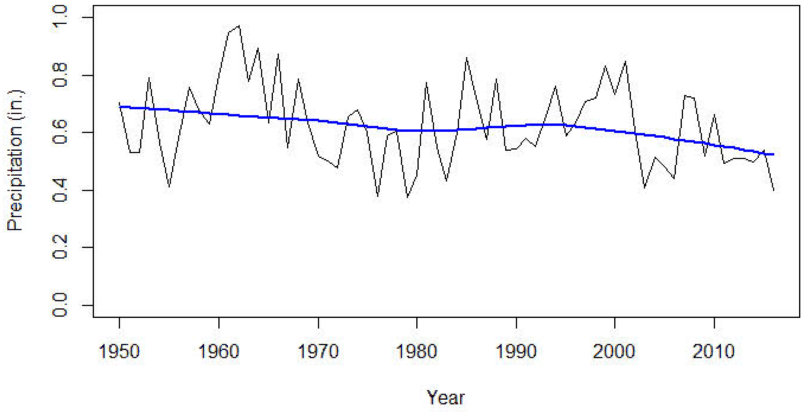

Figure 90 Annual 90th Percentile Value. Itasca, MN

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Minneapolis St. Paul International Airport

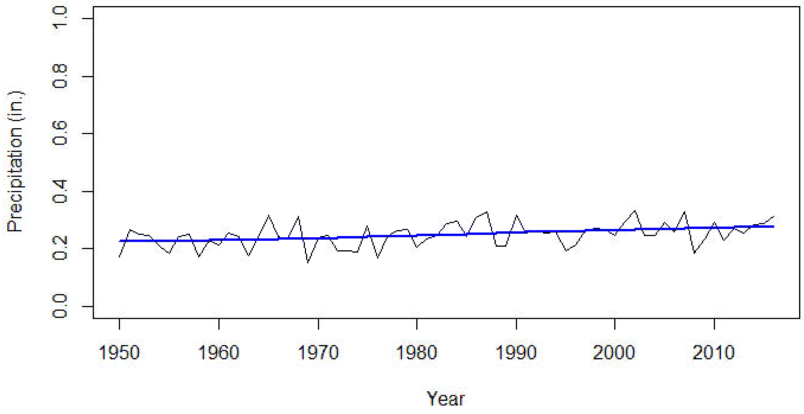

Figure 91 Mean Annual Precipitation per Event. Minneapolis, MN

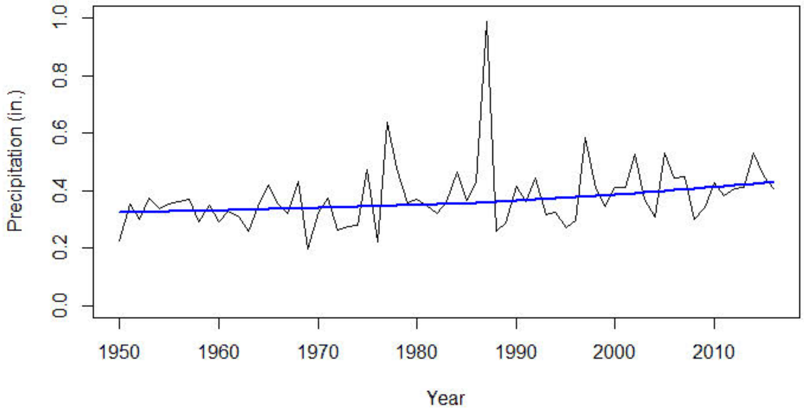

Figure 92 Annual Standard Deviation. Minneapolis, MN`

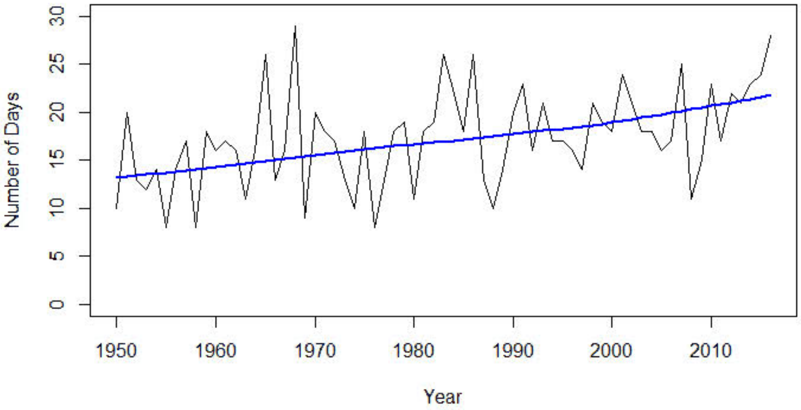

Figure 93 Frequency of Days with Precipitation Greater than 0.5 in. Minneapolis, MN

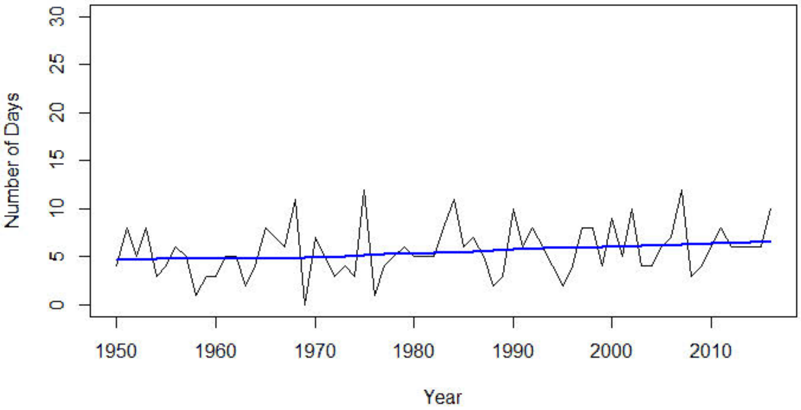

Figure 94 Frequency of Days with Precipitation Greater than 1.0 in. Minneapolis, MN

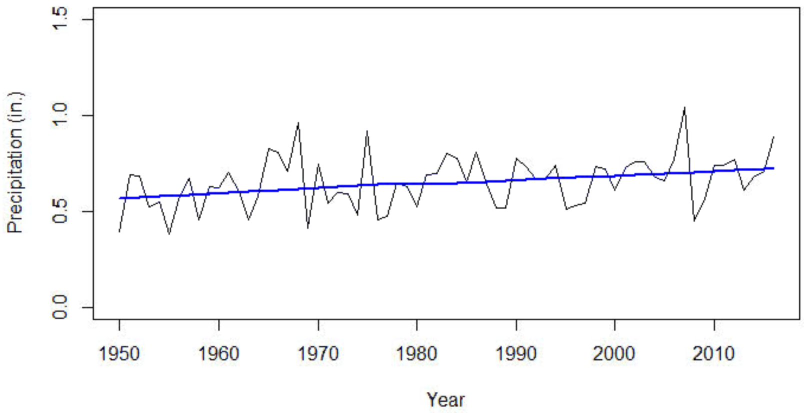

Figure 95 Annual 90th Percentile Value, Minneapolis MN

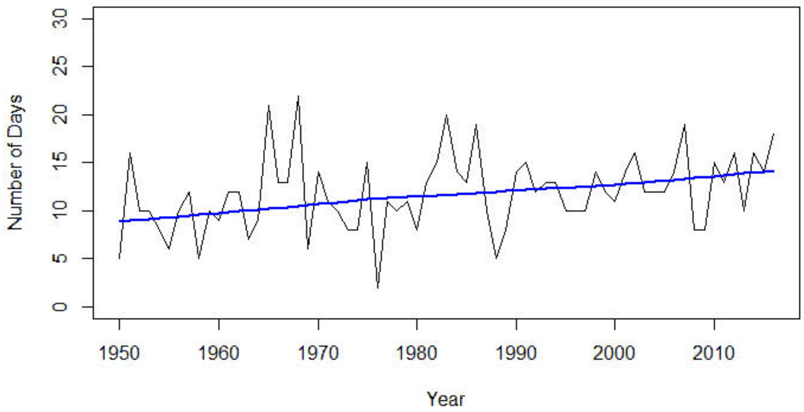

Figure 96 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.67 inches. Minneapolis, MN

Missouri

Burlington Junction

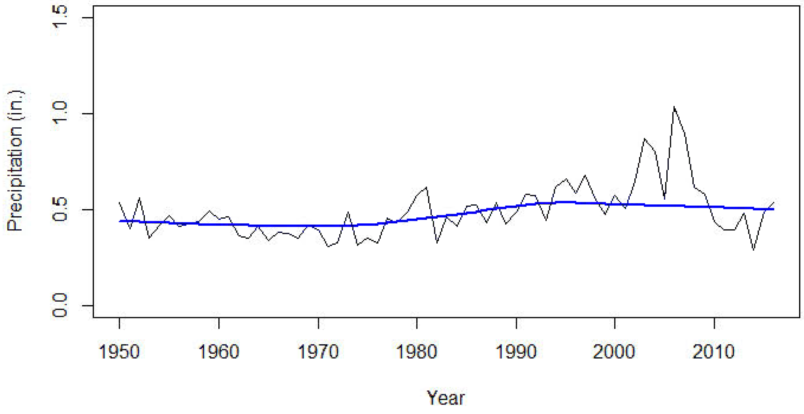

Figure 97 Mean Annual Precipitation per Event. Burlington Junction, MO

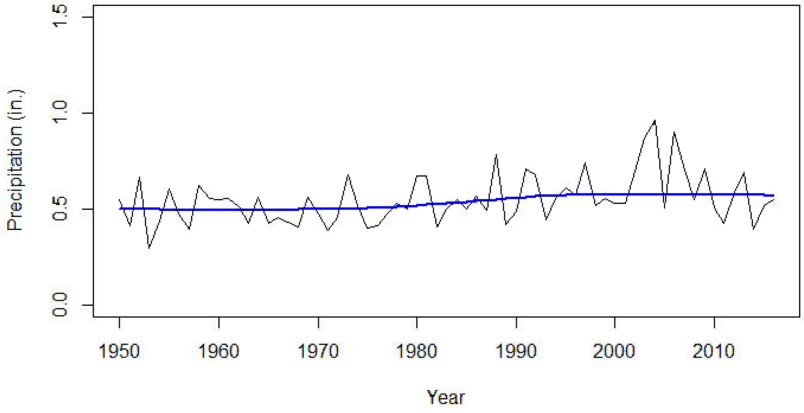

Figure 98 Annual Standard Deviation. Burlington Junction, MO

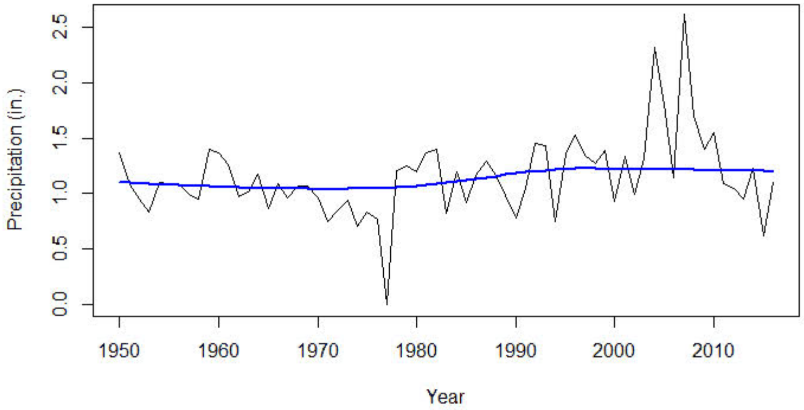

Figure 99 Annual 90th Percentile Value. Burlington Junction, MO

Rolla Missouri S and T

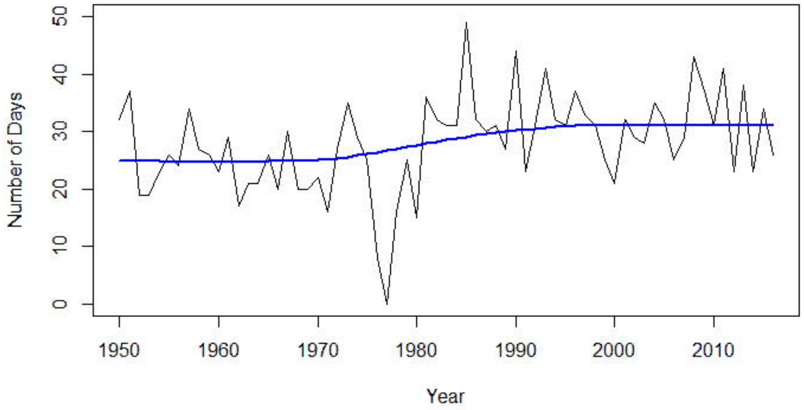

Figure 100 Frequency of Days with Precipitation Greater than 0.5 in. Rolla, MO

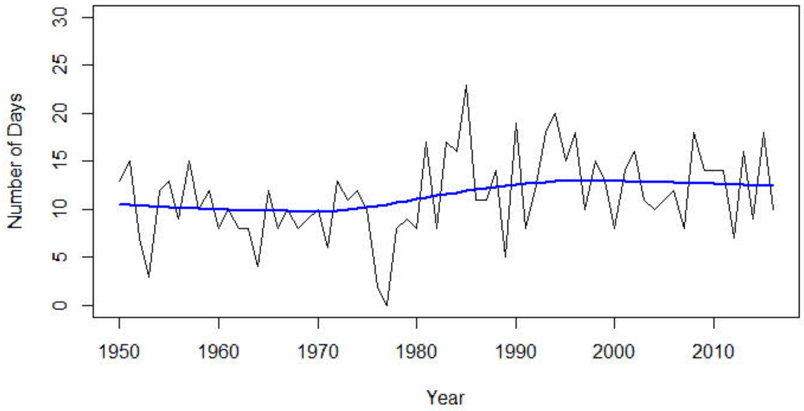

Figure 101 Frequency of Days with Precipitation Greater than 1.0 in. Rolla, MO

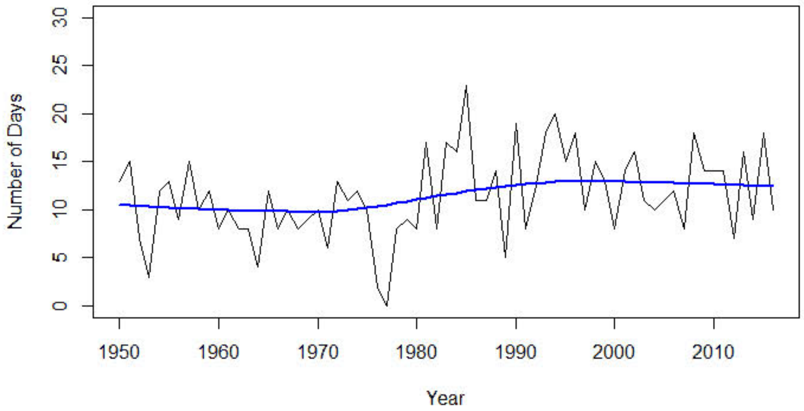

Figure 102 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 1.07. Rolla, MO

Nebraska

Nebraska City 2 NW

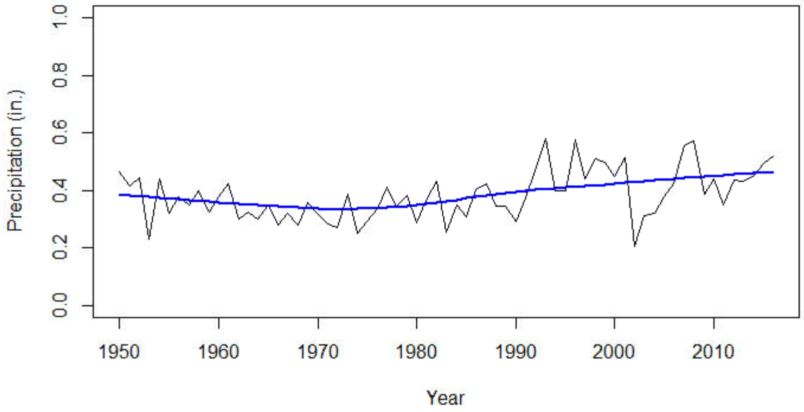

Figure 103 Mean Annual Precipitation per Event. Nebraska City, NE

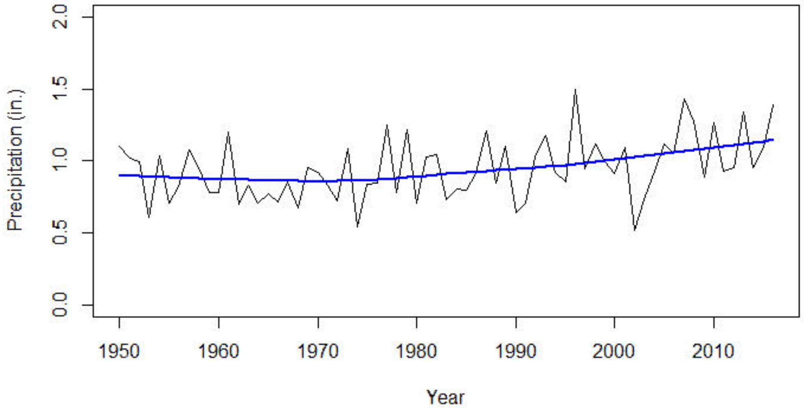

Figure 104 Annual 90th Percentile Value. Nebraska City, NE

North Dakota

Bismarck Municipal Airport

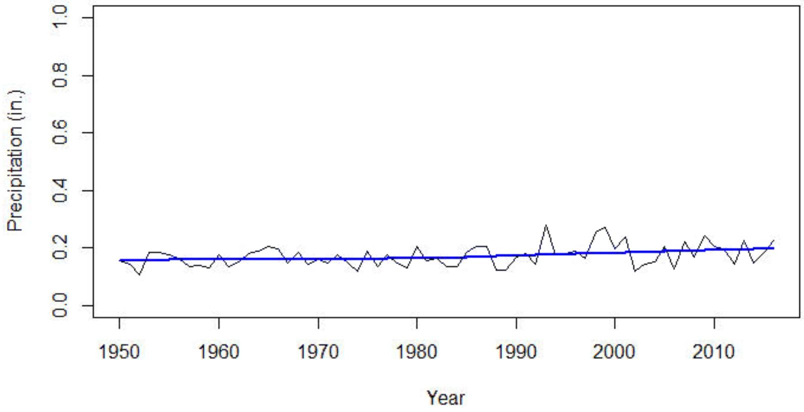

Figure 105 Mean Annual Precipitation per Event. Bismarck, ND

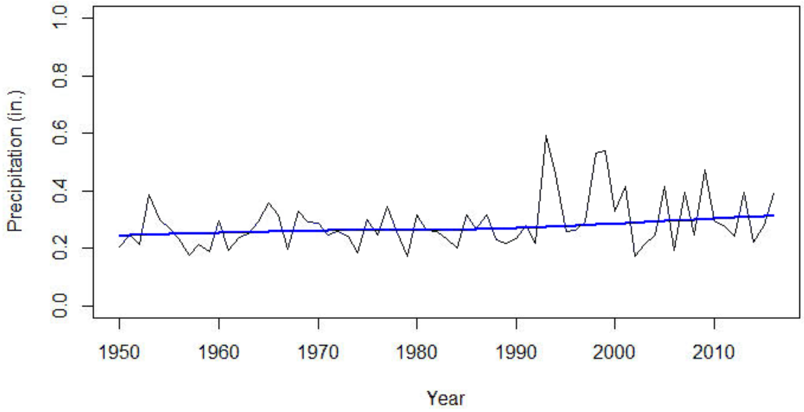

Figure 106 Annual Standard Deviation. Bismarck, ND

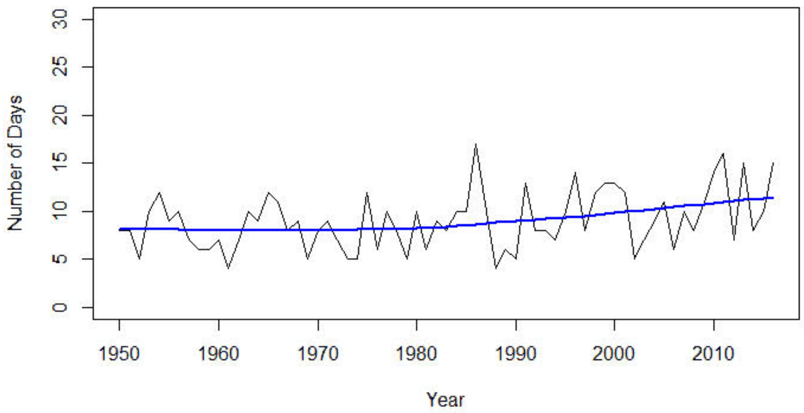

Figure 107 Frequency of Days with Precipitation Greater than 0.5 in.. Bismarck, ND

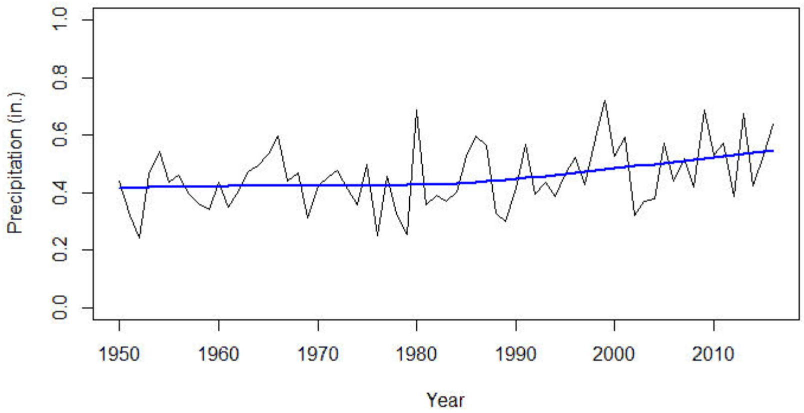

Figure 108 Annual 90th Percentile Value. Bismarck, ND

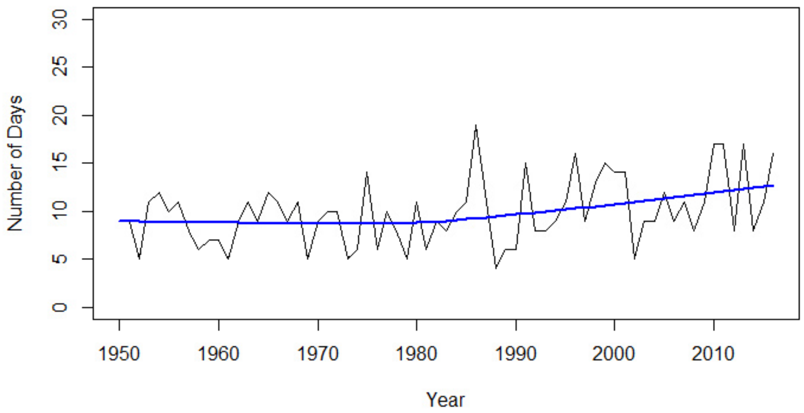

Figure 109 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 0.47. Bismarck, ND

SOUTHWEST

Statistically significant trends in the Southwest region were detected in each state, with Texas, Arizona and New Mexico displaying significant trends in only one of their two stations. A statistically significant trend has been identified in each of the six variables in this region. All of the statistically significant trends in the region were positive. (Figures 110–129).

Arizona

Mesa

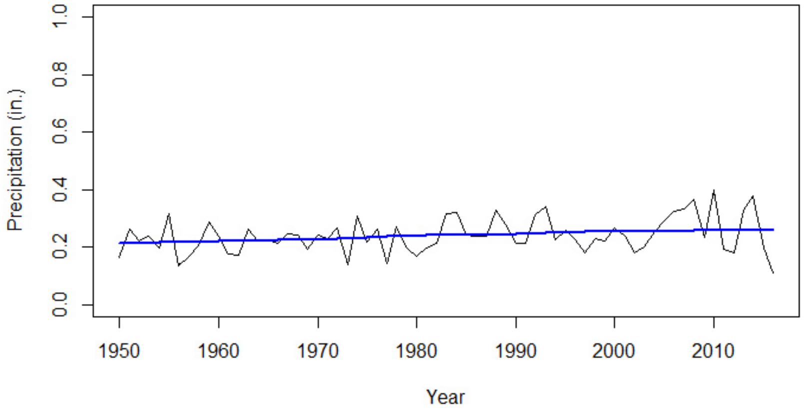

Figure 110	Mean Annual Precipitation per Event. Mesa, AZ

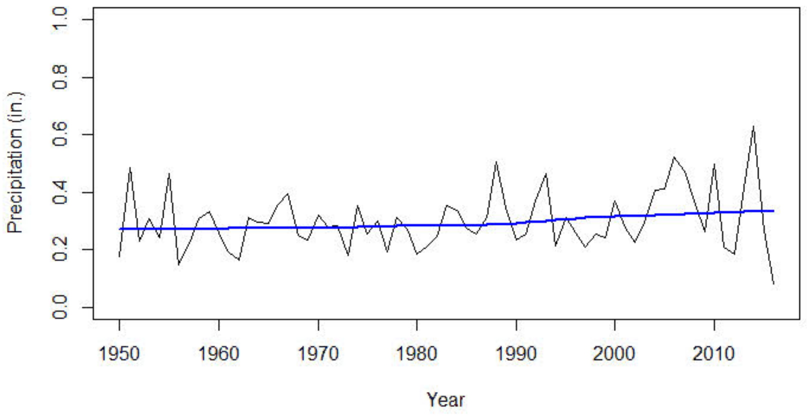

Figure 111 Annual Standard Deviation. Mesa, AZ

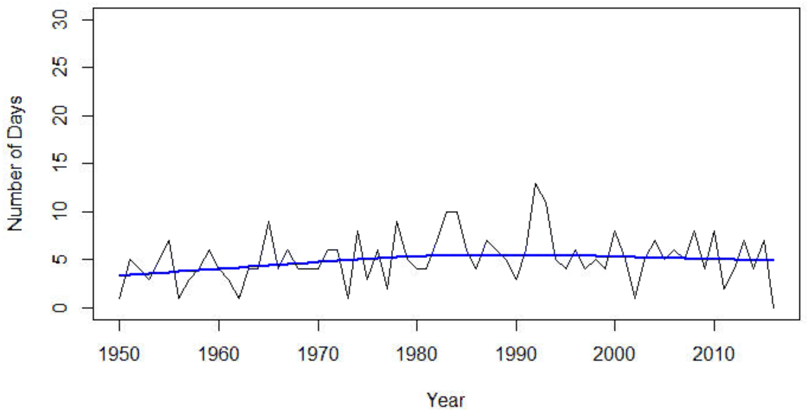

Figure 112 Frequency of Days with Precipitation Greater than 0.5 in. Mesa, AZ

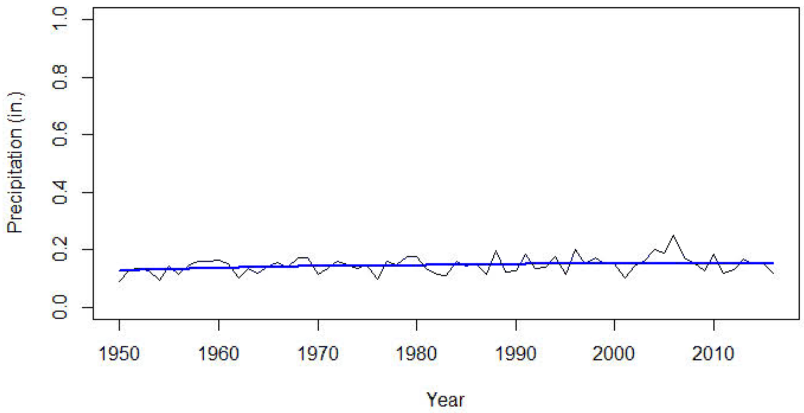

Figure 113 Annual 90th Percentile Value. Mesa, AZ

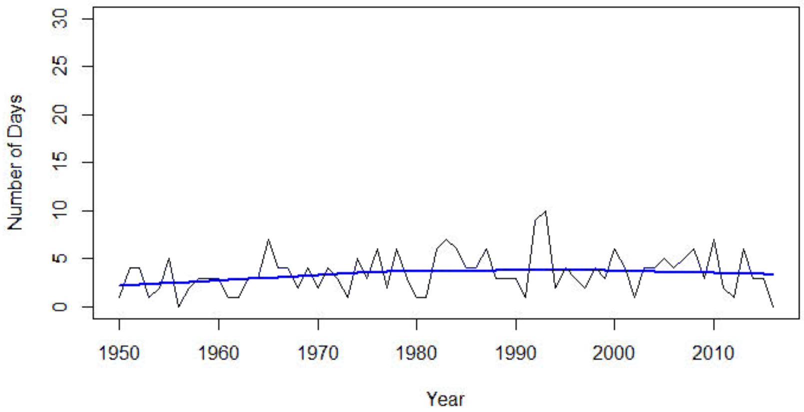

Figure 114 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, which is 0.63 inches. Mesa, AZ

New Mexico

Albuquerque International Airport

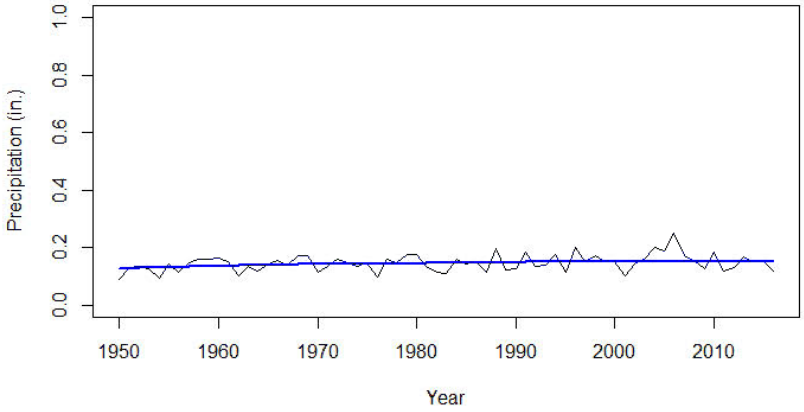

Figure 115 Mean Annual Precipitation per Event. Albuquerque, NM

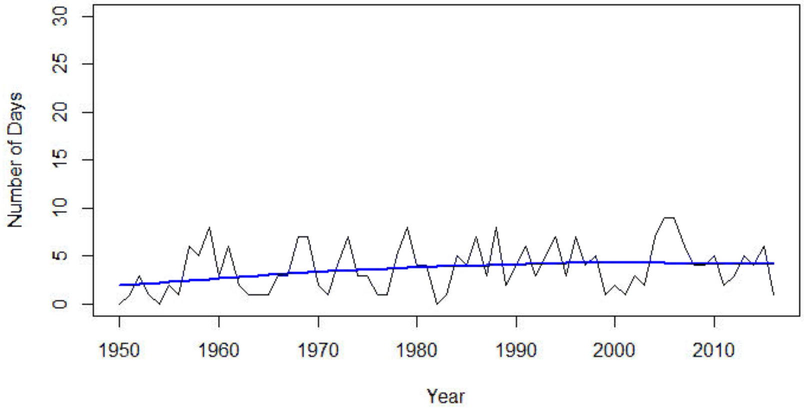

Figure 116 Frequency of Days with Precipitation Greater than 0.5 in. Albuquerque, NM

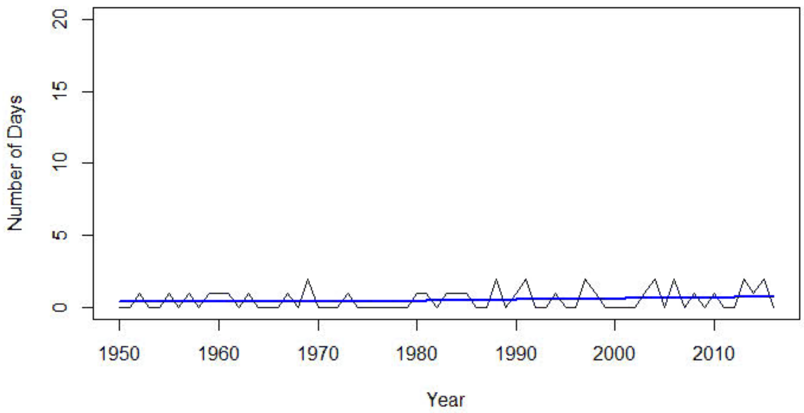

Figure 117 Frequency of Days with Precipitation Greater than 1.0 in. Albuquerque, NM

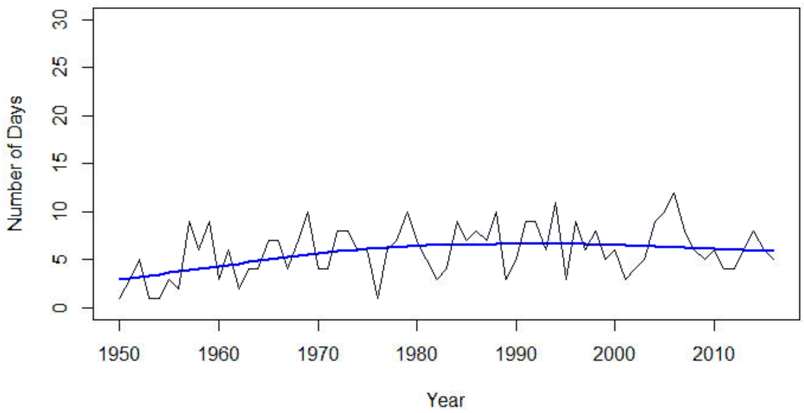

Figure 118 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 0.38 in. Albuquerque, NM

Oklahoma

<u>Oklahoma City Will Rodgers World Airport</u>

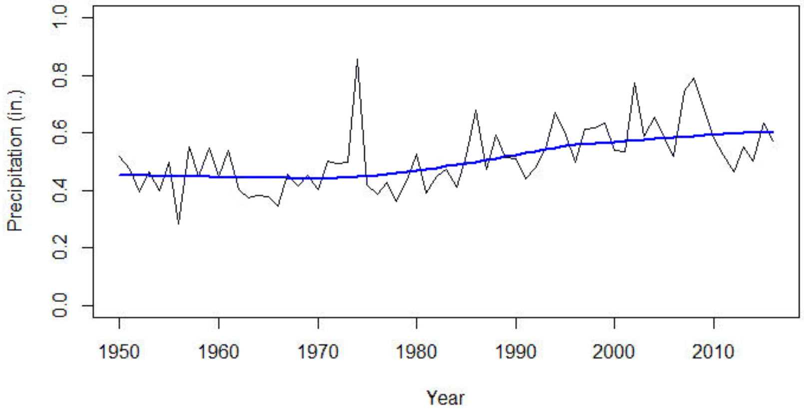

Figure 119 Mean Annual Precipitation per Event. Oklahoma City, OK

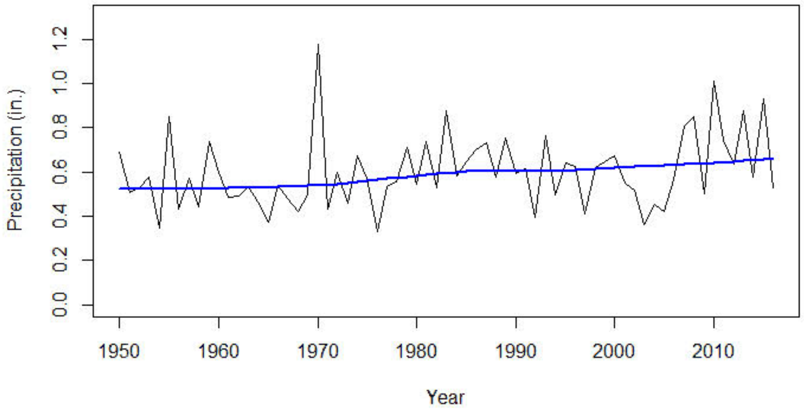

Figure 120 Annual Standard Deviation. Oklahoma City, OK

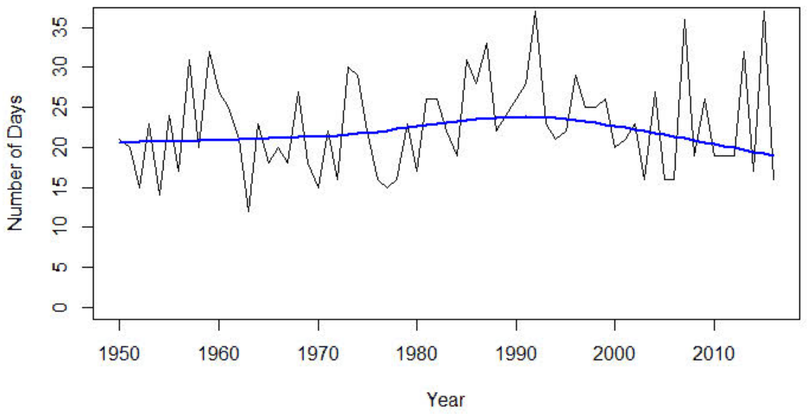

Figure 121 Frequency of Days with Precipitation Greater than 0.5 in.. Oklahoma City, OK

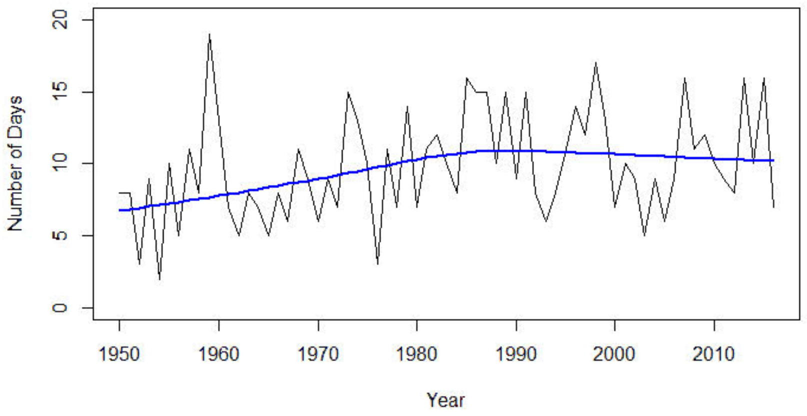

Figure 122 Frequency of Days

with Precipitation Greater than 1.0 in. Oklahoma City, OK

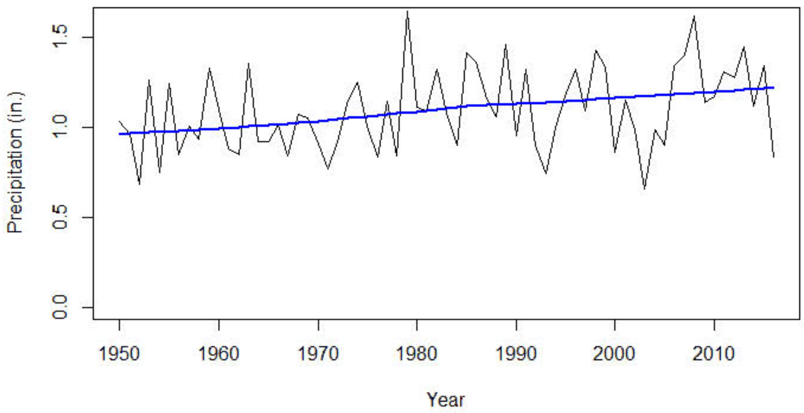

Figure 123 Annual 90th Percentile Value. Oklahoma City, OK

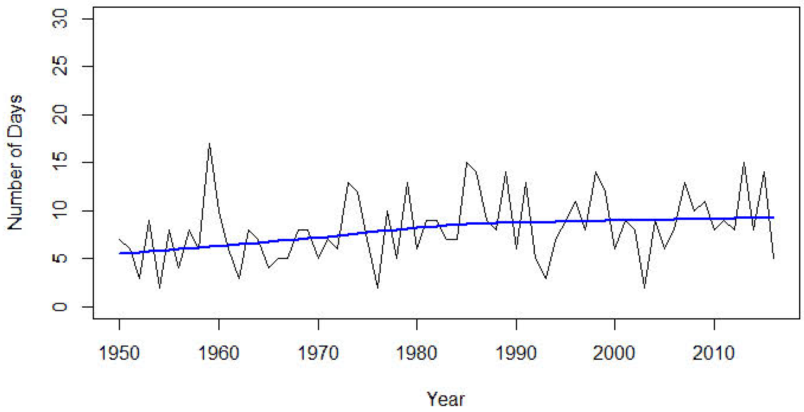

Figure 124 Frequency of Days with Precipitation Greater than 0.5 in.. Oklahoma City, OK

Ralston

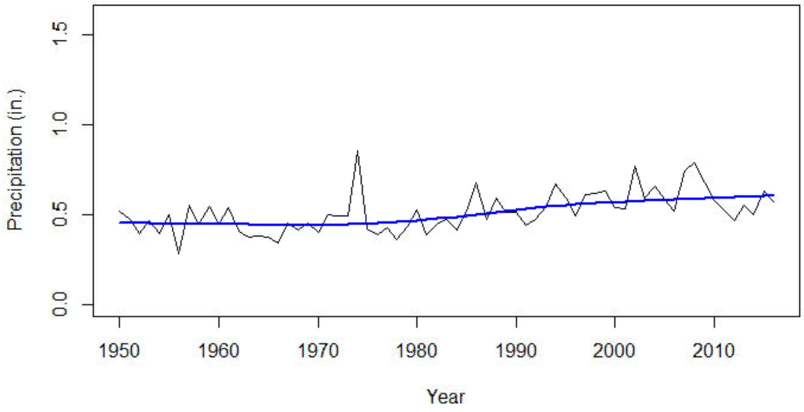

Figure 125 Mean Annual Precipitation per Event. Ralston, OK

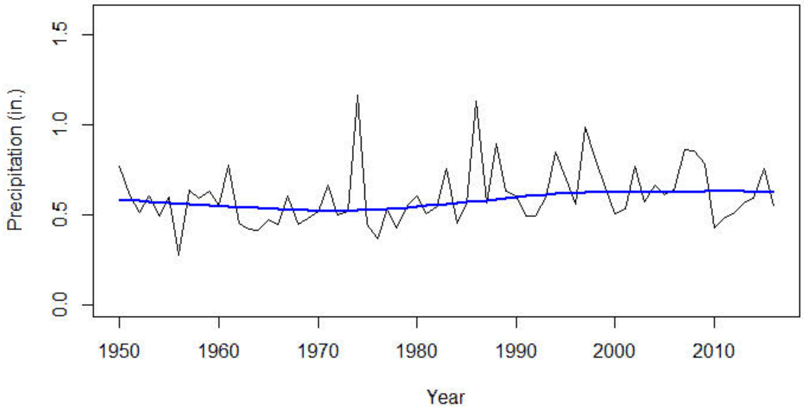

Figure 126 Annual Standard Deviation Ralston, OK

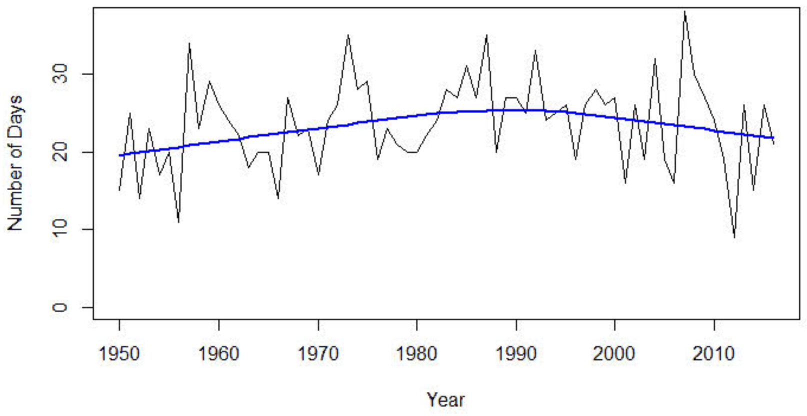

Figure 127 Frequency of Days with Precipitation Greater than 0.5 in., Ralston, OK

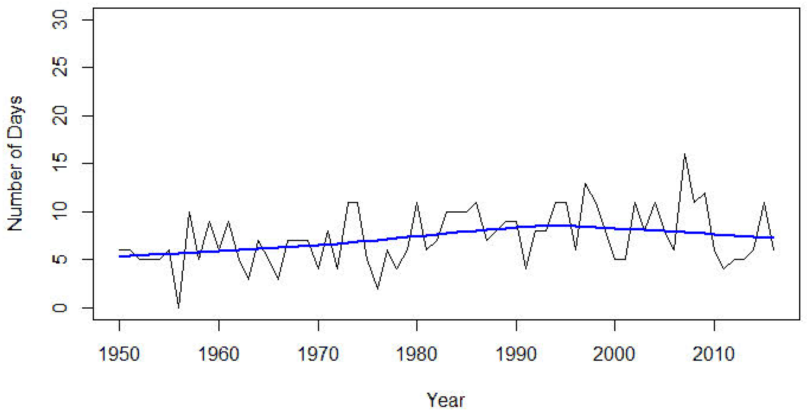

Figure 128 Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period, being 1.25in. Ralston, OK

Texas

Jarrell

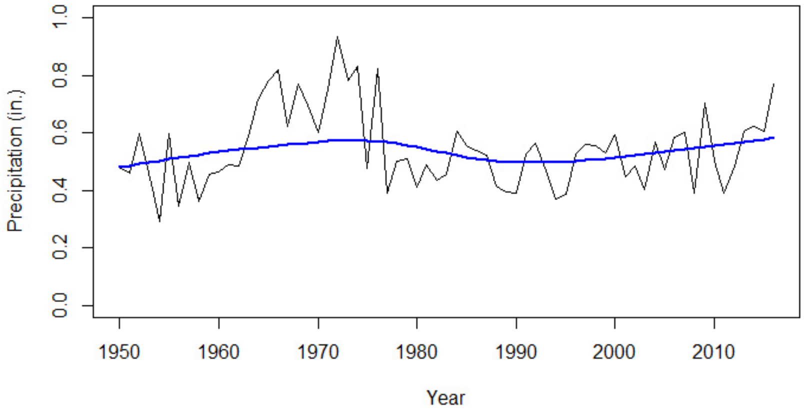

Figure 129 Mean Annual Precipitation per Event. Jarrell, TX

ROCKY MOUNTAIN

There were only three statistically significant trends in the Rocky Mountain region, two of which were negative. These trends occurred in Idaho, Utah and Wyoming (Figures 130–132).

Idaho

Lewiston Nez Perce Co Airport

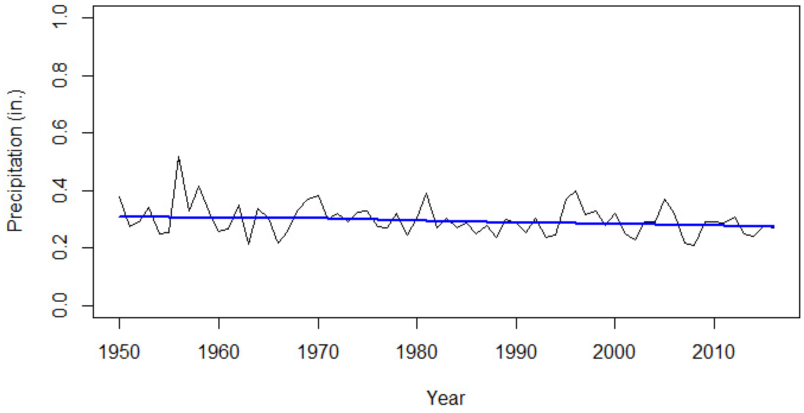

Figure 130	Annual 90th Percentile Value. Lewiston, ID

Utah

Jensen

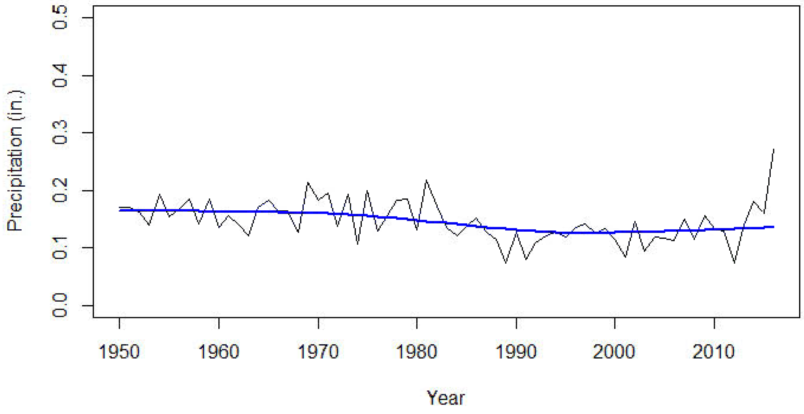

Figure 131 Mean Annual Precipitation per Event. Jensen, UT

Wyoming

Cheyenne WSFO Airport

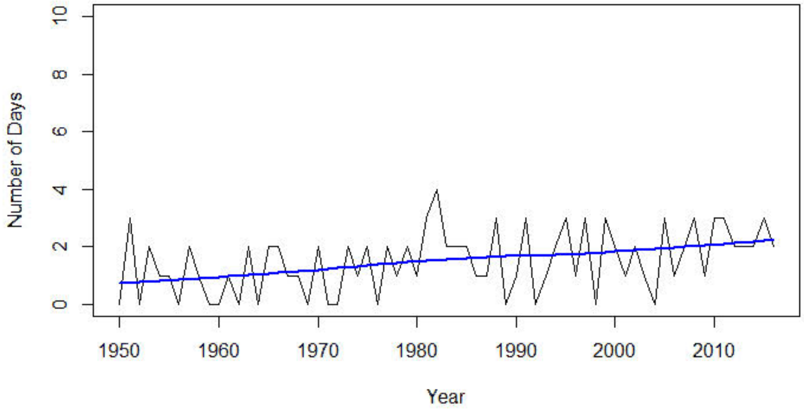

Figure 132 Frequency of Days with Precipitation Greater than 1.0 in. Cheyenne, WY

PACIFIC

There were seven statistically significant trends in this region, three were negative and four were positive, all occurring in the Oregon and Washington (Figures 133–139).

Oregon

Headworks Portland Water B

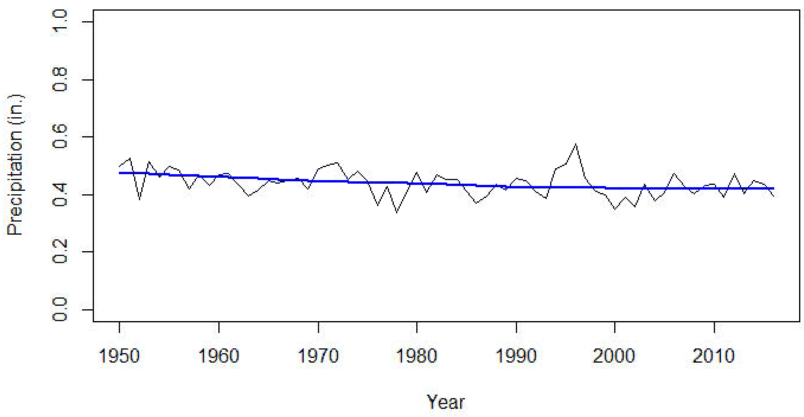

Figure 133 Mean Annual Precipitation per Event. Portland, OR

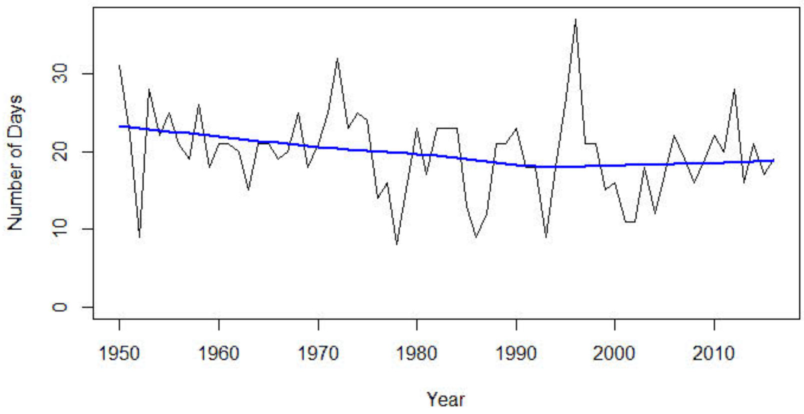

Figure 134 Frequency of Days with Precipitation Greater than 1.0 in. Portland, OR

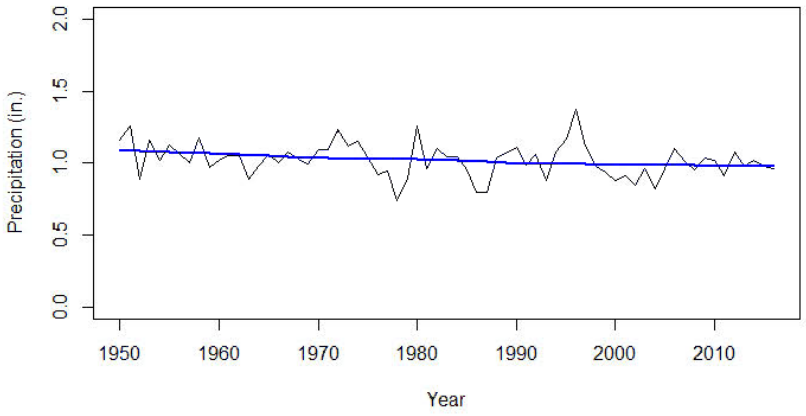

Figure 135	Annual 90th Percentile Value. Portland, OR

Washington

Chewelah

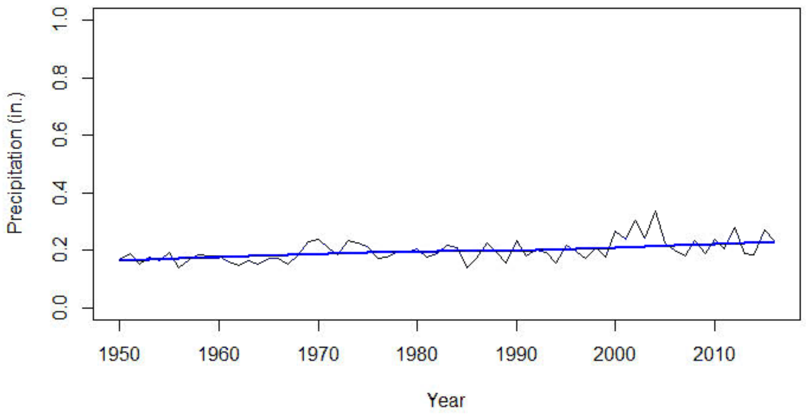

Figure 136	Mean Annual Precipitation per Event. Chewelah, WA

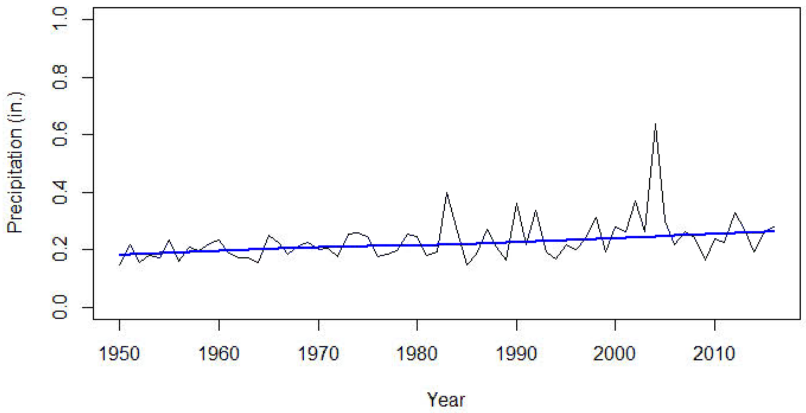

Figure 137 Annual Standard Deviation. Chewelah, WA

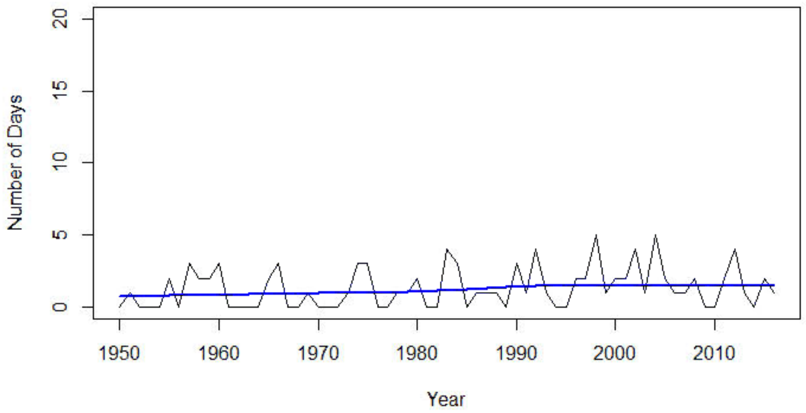

Figure 138 Frequency of days with Precipitation Greater than 1.0 inch. Chewelah, WA

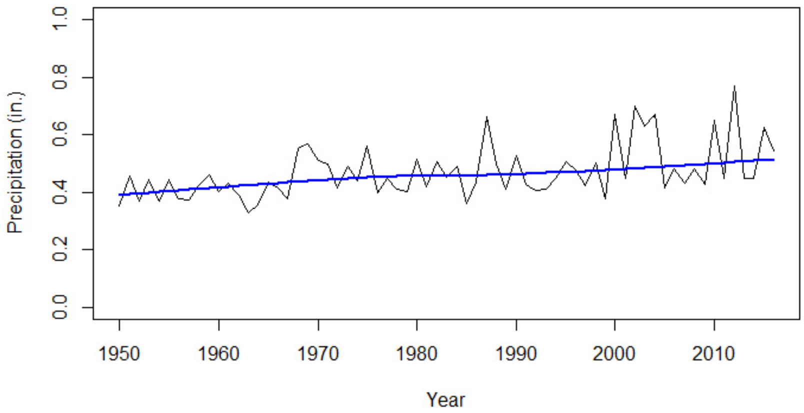

Figure 139	Annual 90th Percentile Value. Chewelah, WA

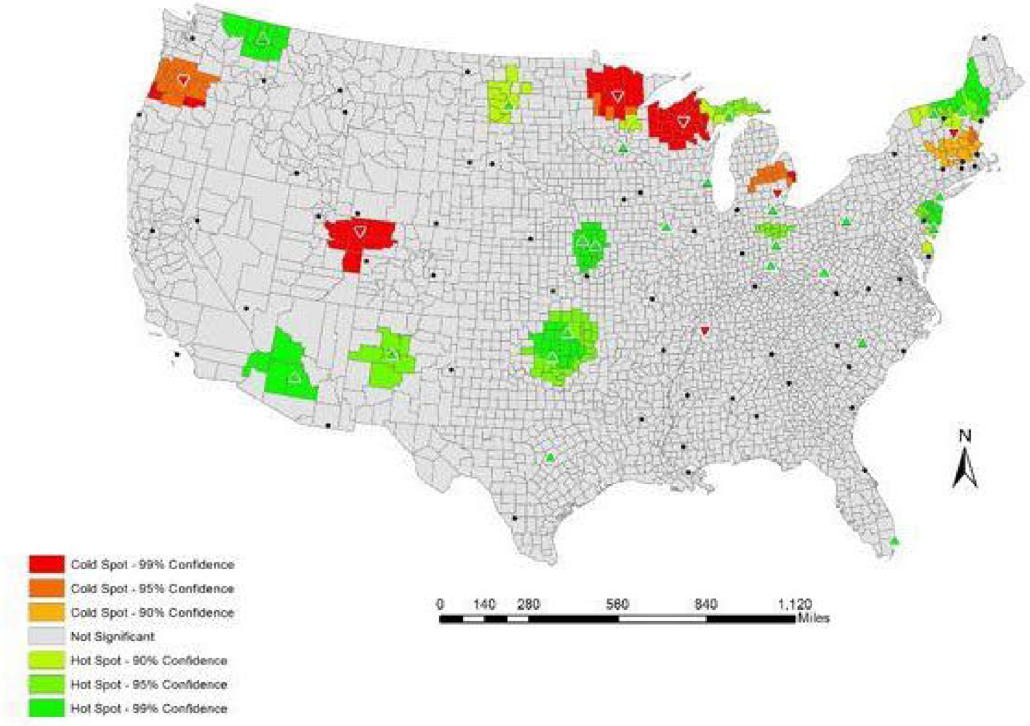

Figure 140 Hot Spot Analysis of Mean Annual Precipitation per Event.

In the hot spot analysis of comparable Kendall’s Tau values at stations with significant trends in mean annual precipitation per event, there are several significant pockets of comparable trends.

There are both hot spots (a pocket of like-valued *positive* areas, hereafter referred to as a wet spot) and cold spots (a pocket of like-valued *negative* areas, hereafter referred to as a dry spot). There is a 90–95% confidence wet spot in northern New England, adjacent to a 90–95% confidence dry spot in southern New England (Figure 140). There is a 90–99% wet spot in the area south of New York City, extending in to southern Delaware. There is a 95% confidence wet spot in central Indiana. There are large 99% confidence wet spots near Omaha, northeast Washington, and western Arizona. There is a 90–95% confidence wet spot on Michigan’s Upper Peninsula, adjacent to two 99%

confidence dry spots in northern Wisconsin and northern Minnesota, respectively. There is a 90% confidence wet spot in central North Dakota, as well as a 95–99% confidence wet spot in Oklahoma/southern Kansas. There is a 95% confidence wet spot in central New Mexico. There is a 99% confidence wet spot on the northern border of Colorado and Utah, as well as a 90–99% dry spot in western Oregon.(Figure 140).

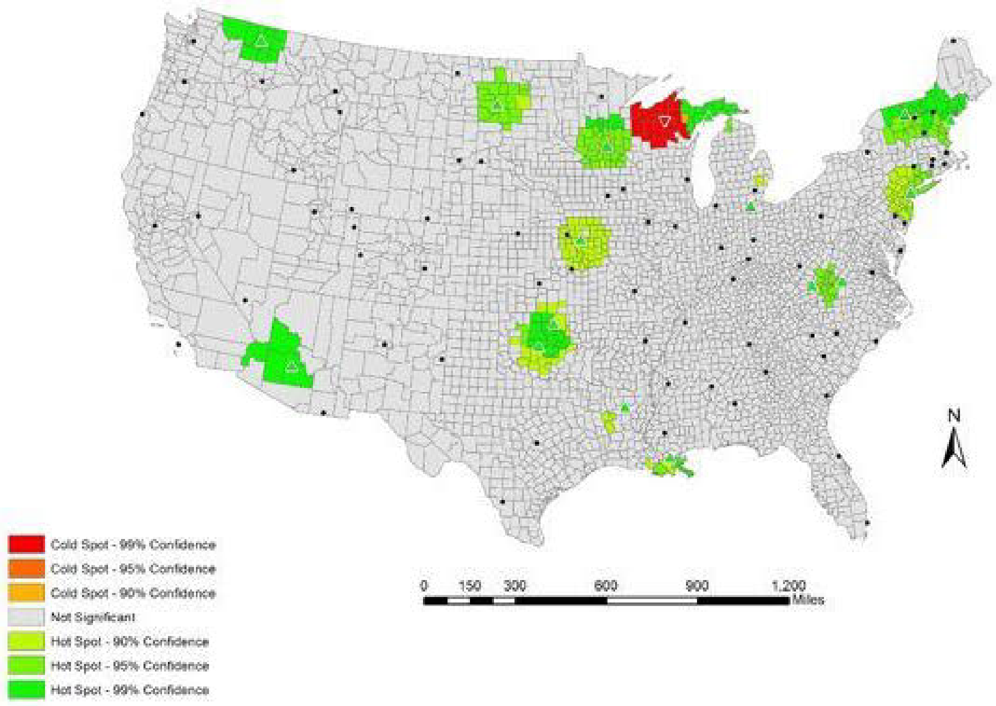

Figure 141 Hot Spot Analysis of Mean Annual Standard Deviation.

In the hot spot analysis of comparable Kendall's Tau values at stations with significant trends in annual standard deviation, there are several significant pockets of comparable trends.

There is a large wet spot in northern New England, between 99% and 95% confidence. There is also a 90–95% confidence wet spot surrounding New York City that includes parts of Western Connecticut, and all of New Jersey. There is a 95% confidence wet spot in Western Virginia (Figure 141). There is another 90–99% confidence wet spot in southern Louisiana as well as a small 90% confidence wet spot in northwest Louisiana. There is a large 99% confidence wet spot in Central Oklahoma, surrounded by some 90% confidence areas. There is a 90% confidence wet spot near Omaha. In the north, there is a 95% confidence wet spot on Michigan's upper peninsula, bordered directly by a 99% confidence dry spot (a pocket of like valued *negative* areas that share a similar trend) in

Northern Wisconsin. There is a 95% confidence wet spot in the central Dakotas, and a 95–99% confidence wet spot in Southern Minnesota. Finally, there are two large 99% confidence wet spots in Western Arizona, and Northeast Washington, respectively (Figure 141).

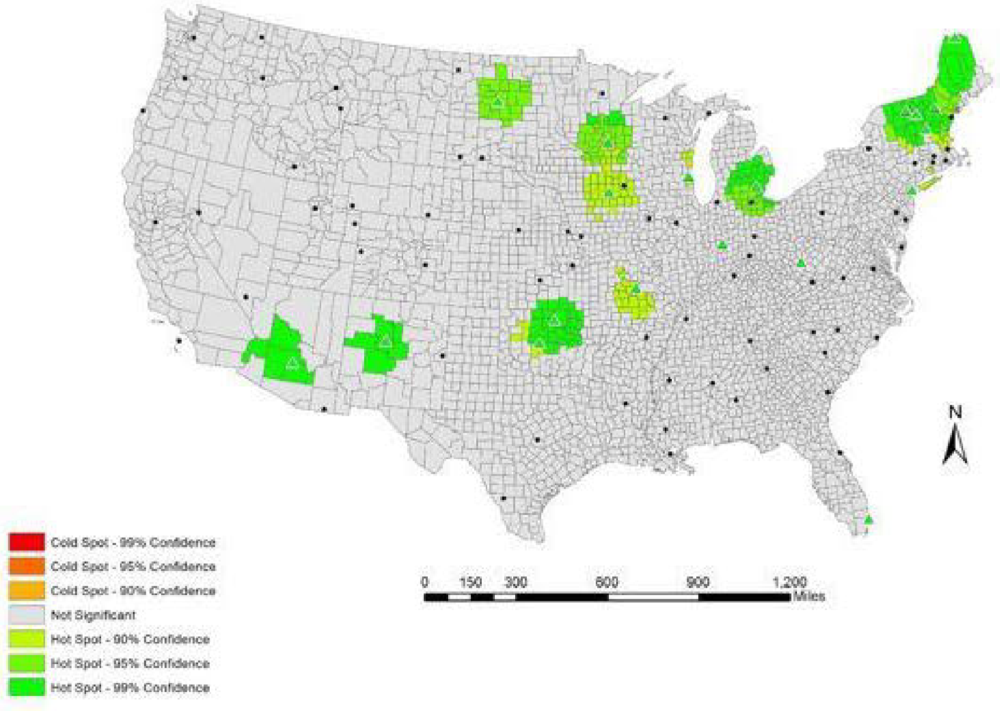

Figure 142 Hot Spot Analysis of Frequency of Days with Greater than 0.5in. of Precipitation

In the hot spot analysis of comparable Kendall's Tau values at stations with significant trends in frequency of days with greater than 0.5 in of precipitation, there are several significant pockets of comparable trends, all of which were positive (wet spots).

There is a large 95–90% confidence wet spot in northern New England, surrounded by some 90% confidence counties in southern new England, including Long Island. There is a large 95–90% confidence wet spot in southern Michigan/ northern Ohio, as well as a 90% confidence wet spot on Wisconsin's Lake Superior coast (Figure 142). There is a 95–99% confidence wet spot in southern Minnesota, bordered directly to the south by a 90% confidence wet spot. There is a large 99% confidence wet spot in central Oklahoma, with some 90% confidence extensions to the southwest. There is a

95% confidence wet spot in North Dakota. Finally, there are two large 99% confidence wet spots in Arizona, and New Mexico(Figure 142).

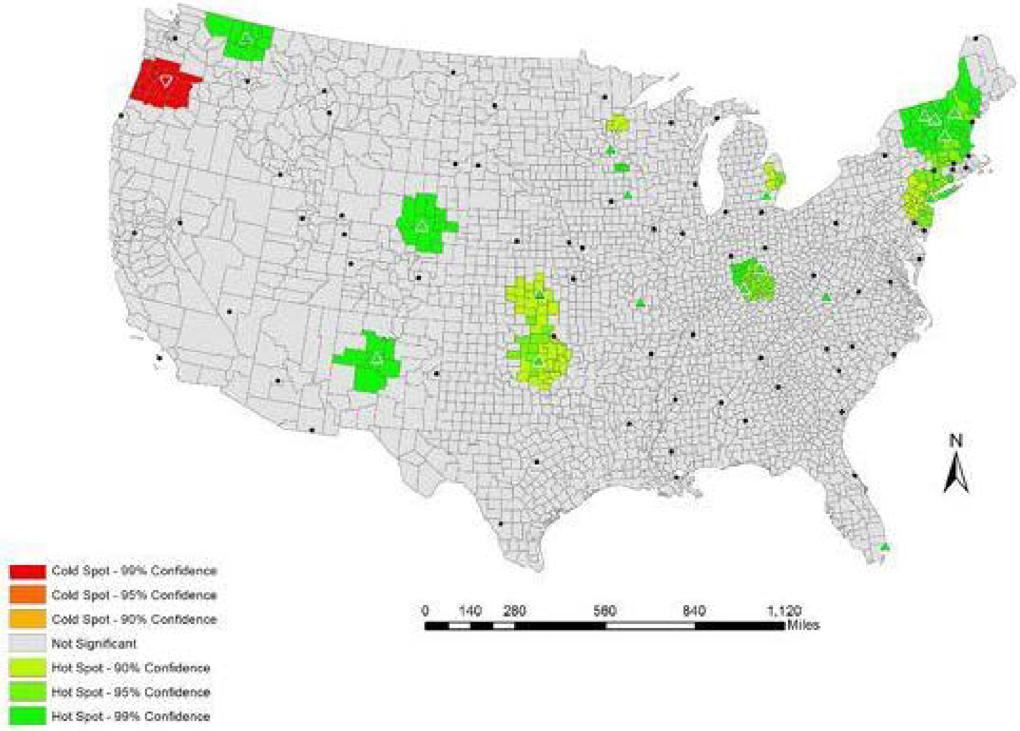

Figure 143 Hot Spot Analysis of Frequency of Days with Greater than 1.0 in.of Precipitation

In the hot spot analysis of comparable Kendall's Tau values at stations with significant trends in annual standard deviation, there are several significant pockets of comparable trends.

There is a very large 90–99% confidence wet spot in New England, which extends through New York City, and into New Jersey. There is a 99–95% wet spot on the Indiana/Kentucky Border. There is a small 90–95%confidence wet spot in eastern Michigan, a small 99% confidence wet spot in southeastern Minnesota, and a small 90% confidence wet spot on the central Minnesota/Wisconsin border. There is a very large 90–95% confidence wet spot in central Oklahoma, continuing north through central Kansas. (Figure 143). There are three large 99% confidence wet spots in central New Mexico, the

Nebraska/Colorado/Wyoming corner, and in northeast Washington. Finally, there is a large dry spot in western Oregon (Figure 143).

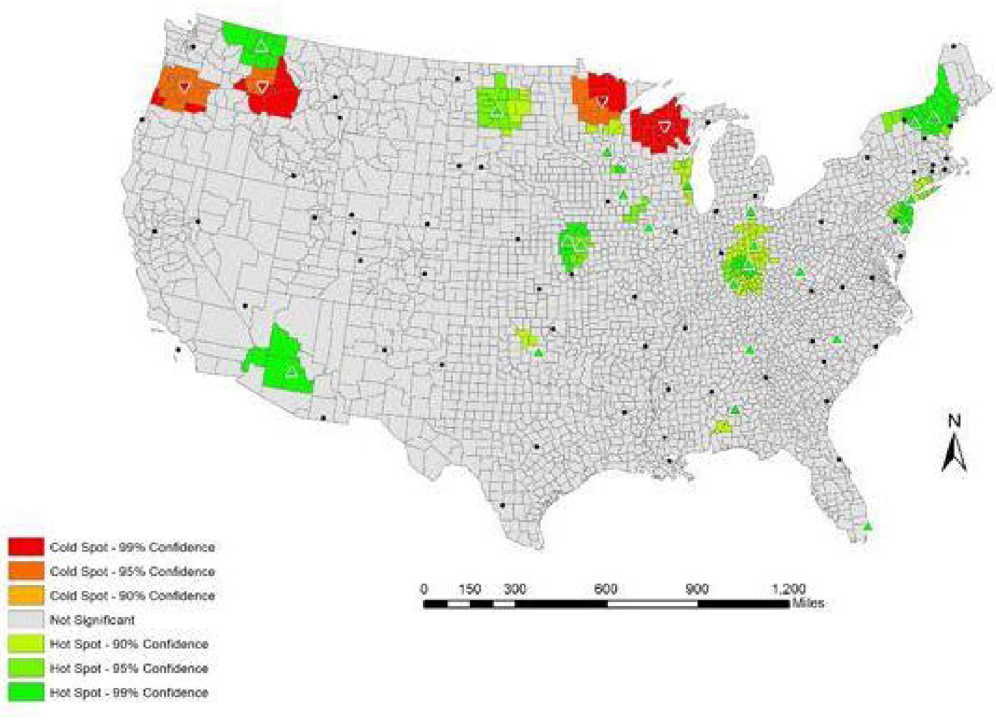

Figure 144 Hot Spot Analysis of Annual 90th Percentile Value

In the hot spot analysis of comparable Kendall's Tau values at stations with significant trends in annual 90th percentile value, there are several significant pockets of like comparable both positively trending (wet spot) and negatively trending (dry spot).

There are four large dry spots. Three 95–99% confidence dry spots in western Oregon, eastern Oregon/Idaho, and northern Minnesota. There is a large 99% dry spot in northern Wisconsin. There is a large 95–99% wet spot in northern New England, and a 90–99% wet spot in the greater New York City area. There is a large 90% confidence wet spot surround a smaller 99% confidence wet spot in the Indiana, Kentucky, Ohio Tri-State area. There is a 95–99% confidence wet spot near Omaha (Figure 144). There is a 90–95% confidence wet spot in the central Dakotas. There are two large 99% confidence wet spots in northern Washington and western Arizona. There are several small 90%

confidence wet spots in southern Alabama, central Oklahoma, central Minnesota, Wisconsin’s Lake Michigan coast. There is a small 95% confidence wet spot in eastern Iowa, and a small 95–99% confidence wet spot in southeast Minnesota (Figure 144).

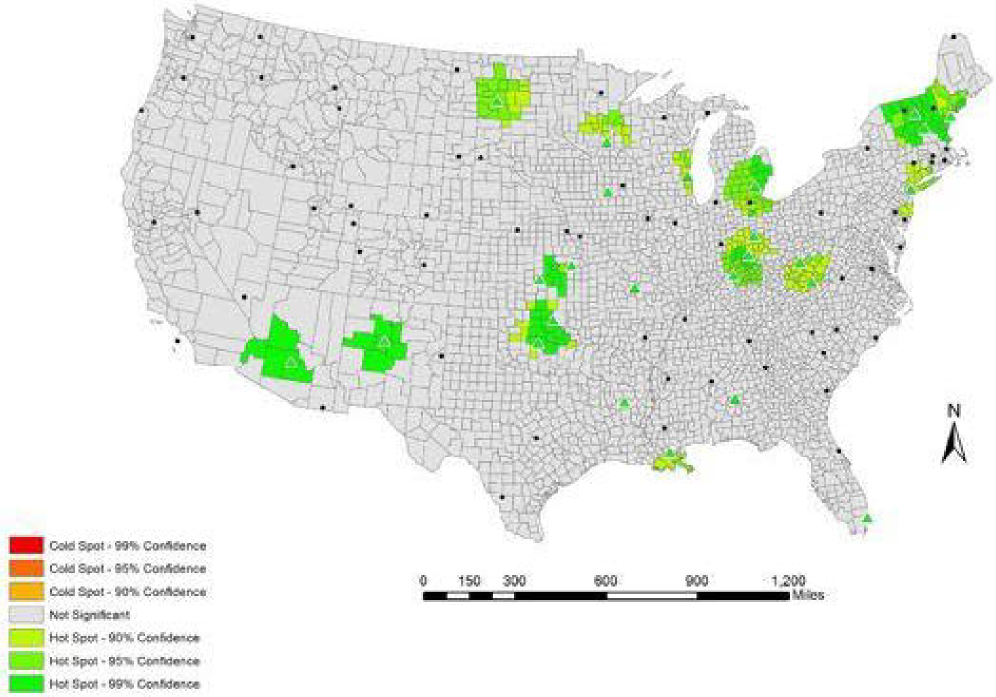

Figure 145 Hot spot analysis of frequency of rain days with greater than the 90th percentile for the entire period.

In the hot spot analysis of comparable Kendall's Tau values at stations with significant trends in frequency of days with precipitation greater than the 90th percentile for the entire period, there are several significant pockets of like-trends, all of which were positive (wet spots).

There is a large 90–99% confidence wet spot in northern New England, and a 90% confidence wet spot in the greater New York City area, including parts of Connecticut, Long Island and New Jersey. There are mid-sized 90–95% confidence wet spots in western Virginia, Wisconsin's Lake Michigan coast, the central Minnesota/Wisconsin border, the central Dakotas, and southern Louisiana (Figure 145). There is a large 90–95% confidence wet spot in southern Michigan/ northern Ohio. There are two 99% confidence wet spots adjacent to each other in Oklahoma/ Eastern Kansas, surrounded by some 90% confidence areas. Finally, there are two large 99% confidence wet spots in western Arizona, and New Mexico respectively (Figure 145).

CONCLUSION

The results that are presented in this study are a collection of complete data at selected weather stations. In a large majority of cases there are positive trends, suggesting that overall, many areas of the continental United States are seeing positive trends in the six precipitation variables examined in this study, as well as frequency of larger magnitude precipitation events than experienced in the past at a rate of 73% positive to 27% negative. This includes all trends both significant and non-significant. Each region showed more positive trends than negative trends. In New England, the 66 variables tested indicated 18 positive trends and one negative trend, mostly centered around northern New England. In the Mid-Atlantic, the 36 tested variables indicated nine positive trends compared to 0 negative trends. The Southeast showed 29 positive trends compared to 1 negative trend out of 144 tested variables. The Great Lakes continued this pattern with 18 positive trends compared to 3 negative trends out of 60 tested variables. In the Plains, 26 positive trends were detected compared to 2 negative trends, out of 84 tested variables. The Southwest, the driest of the regions, showed 18 positive trends and 0 negative trends out of 48 tested variables. The Rocky Mountains is the only region of the study where negative trends outnumber positive trends, with 0 positive trends and 1 negative trend out of 60 tested variables. In the Pacific region, 4 positive trends were detected in comparison to three negative trends out of 48 tested variables. The overall pattern of increasing precipitation nationwide, featuring 122 positive trends, and 11 negative trends out of 546 tested variables, which is in line with previous work on increases in atmospheric moisture capacity with climate change (Adler et. al., 2008;

Alexander and Arblaster, 2009; Lenderink and Meijgaard, 2008; O'Gorman and Schneider, 2009).

Spatially, the results show that most of the wet and dry spots are occurring in the same areas across all of the tested variables, meaning that stations and their surrounding areas with at least one negative trend are are likely to have at least one more in another variable. The Great Lakes and New England are especially noteworthy. It is possible that spatial testing could have different results if more stations were selected or if they were selected in an equidistant manner, which was impossible due to the two stations per state setup of this study. Future studies should attempt to use a greater density of stations. Due to the methods of this limited study, the hot spot analysis was selected as it places more weight on values of polygons, rather than distance to each other. A distance-based test would simply have discovered spatial patterns of trend in the more compact states, with more stations in a smaller area. The results of the hot spot analysis testing should be accepted, for when the test was performed under different spatial ranges, the results remained the same. However, it should be noted that while the scope of this study limited testing to statistically significant trends, non-significant trends are still trends, and if included in this type of study, could yield larger dry and wet spots when coupled with a larger sample size. The results of this study also do not report causes of the identified trends. The results of the study simply identified the trends and tested them spatially. The causes of such trends will be left to future studies.

Potential future work on this subject could include geographic factors, to explain the lack of significant trends in the Rocky Mountains and Pacific. Future work could also differentiate between liquid and frozen precipitation, as well as account for local temperatures at each station, as well as comparison to the El Niño Southern Oscillation. One question that remains from this study that would be ideal for study in the future is why are there few statistically significant trends in precipitation for the traditionally humid gulf-fed southeast regions? Seasonality could play a large role in these patterns as well, as that factor was not taken into account for this study.

The study meets its goal of identifying temporal precipitation trends and using those trends to identify hotspots of areas with statistically significant like values. Within the selected variables, precipitation is trending.

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APPENDIX

Appendix 1 Kendall’s Tau Values for Significant Trends

C1= Mean Annual Precipitaton per Event

C2= Annual Standard Deviation

C3= Frequency of Days with Precipitation Greater than 0.5 inches

C4= Frequency of Days with Precipitation Greater than 1.0 inches

C5= Annual 90th Percentile Value

C6= Frequency of Days with Precipitation Greater than the 90th Percentile for the Entire Period

St	Station	C1	C2	C3	C4	C5	C6
AL	Montgomery Airport	0	0	0	0	0.222	0.207
AZ	Mesa	0.203	0.166	0.198	0	0.292	0.181
FL	Miami Beach	0.271	0	0.3	0.283	0.297	0.278
IA	Iowa Falls	0	0	0.278	0	0	0.171
IA	Tripoli	0	0	0	0.195	0.195	0
ID	Lewiston Nez Perce Co Airport	0	0	0	0	-0.189	0
IL	Aledo	0.239	0	0	0	0.202	0
IN	Indianapolis International Airport	0	0	0.192	0	0	0
KS	McPherson	0	0	0	0.195	0	0.208
KS	Topeka Municipal Airport	0	0	0	0	0	0.173
KY	Cincinnati/Northern Kentucky Int’l Airport	0.169	0	0	0.218	0.209	0.231
KY	Louisville International Airport	0	0	0	0.234	0.254	0.281
LA	New Orleans Airport	0	0.165	0	0	0	0.192
LA	Louisiana Tech University(Ruston)	0	0.18	0	0	0	0.18
ME	Portland Jetport	0	0.211	0	0	0	0.199
ME	Fort Kent	0	0	0.245	0	0	0
MI	Ann Arbor Municipal Airport	-0.291	0	0.382	0.18	0	0.34
MI	Manistique WWTP	0.199	0.199	0	0	0	0
MN	Itasca University of Minn	-0.285	0	0	0	-0.166	0
MN	Minneapolis St. Paul International Airport	0.28	0.261	0.317	0.18	0.227	0.257
MO	Rolla Missouri S and T	0	0	0.258	0.197	0	0.197
MO	Burlington Junction	0.312	0.236	0	0	0.172	0
NC	Wadesboro	0.238	0	0	0	0.178	0
ND	Bismarck Municipal Airport	0.218	0.17	0.218	0	0.209	0.206

NE	Nebraska City 2 NW	0.27	0	0	0	0.256	0
NH	Pinkham Notch	0.318	0	0.211	0.202	0.276	0
NH	Newport	-0.232	0	0.228	0.267	0	0.216
NJ	Mays Landing 1 W	0.314	0	0	0	0.174	0
NM	Albuquerque International Airport	0.19	0	0.221	0.202	0	0.203
NY	NY City Central Park	0.256	0.244	0.238	0.277	0.269	0.288
OH	Dayton International Airport	0.217	0	0	0	0.183	0.172
OH	Wauseon Water Plant	0.322	0.177	0	0	0.167	0
OK	Oklahoma City Will Rodgers World Airport	-0.202	0.196	0.218	0	0.209	0.225
OK	Ralston	0.408	0.18	0.402	0	0	0.233
OR	Headworks Portland Water B	-0.243	0	0	-0.182	-0.182	0
PA	Acmetonia Lock 3	0.17	0	0	0	0	0
TN	Chattanooga Airport	0	0	0	0	0.0806	0
TN	Martin University of TN Experiment Station	-0.189	0	0	0	0	0
TX	Jarrell	0.199	0	0	0	0	0
UT	Jensen	-0.293	0	0	0	0	0
VA	Lynchburg International Airport	0	0.185	0	0	0	0
VT	Barre Montpelier Knapp State Airport	0	0	0.233	0.232	0.188	0.252
VT	Burlington Weather Service Office Airport	0.218	0.216	0.234	0.252	0	0
WA	Chewelah	0.365	0.333	0	0.196	0.316	0
WI	Milwaukee Mount Mary College	0.217	0	0.211	0	0.245	0.247
WI	Eagle River	-0.504	-0.306	0	0	-0.428	0
WV	Charleston Yeager Airport	0.192	0	0.184	0	0.253	0.183
WV	Princeton	0	0.172	0	0.18	0	0.207
WY	Cheyenne WSFO Airport	0	0	0	0.285	0	0