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Abstract

Recent studies have examined hydroclimate precipitation reversals, but because it is a newly defined concept, there is minimal research available on how reversals are changing, and it has not been widely investigated. Precipitation reversal is the rapid switch between wet and dry periods or "precipitation extremes and the opposite" (McKay, 2018), based on precipitation measurements in this case. A single reversal is the immediate transition from a wet to a dry period or from a dry to a wet period. Changes in reversals have not been thoroughly reported and this gap in research creates a risk of unpredictable conditions that will negatively impact human activity. This research will serve to report precipitation reversals and how they may change over the state of Arkansas using observational data from Climate.gov and the National Center for Environmental Information (NCEI). Both inter-annual and seasonal and inter-annual precipitation reversal events were examined and compared between past and current periods. For seasonal data, using one standard deviation of the baseline period from 1900 to 1950, there was a total of seven reversals for 1900-1950 and 17 reversals for 1951-2021. For inter-annual calculations, there was an increase for both wet-to-dry and dry-to-wet reversals using deviations of one half, one, one and a half, and two. Both annual and seasonal averages showed an overall increase in precipitation reversals in recent years. Anthropogenic practices are heavily tied to precipitation for agriculture, safety, and recreation purposes, so any changes in amounts will have an effect.

Introduction

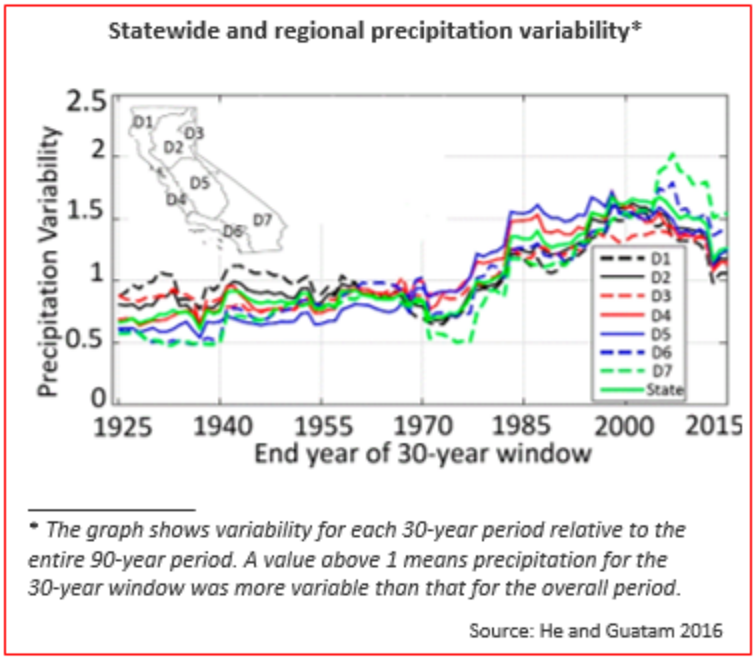
Background and Motivation

Precipitation reversal refers to the cycle/transitions between extreme and mild precipitation and lack of precipitation (McKay, 2018). Heavy periods of rain, sleet, snow, or other forms of precipitation are followed by drought situations despite these weather patterns existing on opposite sides of the spectrum—or occurring in reverse order- wet-to-dry or dry-to-wet transitions (measured annually and seasonally). These reversals do not always need to be extreme and include relatively low-intensity dry-to-wet or wet-to-dry periods, which more closely resembles the conditions for this research. For this study, delineation of wet/dry events was based on different standard deviations of precipitation anomalies which were derived relative to a baseline period. A reversal will be documented when an anomaly year/season of precipitation is followed by the opposite transition (wet vs. dry). The years/seasons that fall above a certain standard deviation are considered as a wet period and fall below as a dry period. Precipitation, for the purposes of this research, can be defined as any liquid or frozen water that forms in the atmosphere and falls to the earth, which is a major component of the water cycle and circulation (National Geographic Society, 2019). Drought conditions are defined as a period of prolonged dryness that can cause damage or inhibit growth (Merriam-Webster, 2022).

On the opposite end, floods can be defined as an overflow of water (temporarily) that covers land that is typically dry, ranging in depth and severity (Earth Networks, 2021). There are three general types of floods—coastal, fluvial, and pluvial. Arkansas' landscape and location make it most susceptible to fluvial flooding, where excessive rainfall causes the river to exceed its capacity (Maddox, 2014). But, because this study is focused on precipitation and not river overflow, pluvial will be of the greatest relevance. Fluvial flooding will be assessed by evaluating runoff rather than precipitation which can be involved using the same research method. Pluvial flooding is caused by extreme rainfall that causes flooding independent of a water body (Maddox, 2014). Pluvial flooding is divided into two categories- flash floods and surface water floods. Flash floods are the result of high velocity caused by torrential rainfall in a short amount of time or from a sudden release of water from a dam (Maddox, 2014). Surface water floods occur when urban drainage systems overflow, usually happening gradually and are of little depth. The two main elements of floods are duration and intensity, though these elements are not covered in depth for the purposes of this research. The National Weather Service measures floods by calculating how much water has risen above gauges placed in key locations across the country during times of flooding (Reference.com, 2022)

There is not a singular definition for drought, but one way drought conditions are classified is distinct levels based on the Palmer Drought Index, ranging from “abnormally dry” to, at its most severe, “exceptional drought” (NCEI, 2021). The National Drought Mitigation Center used a combination of soil moisture percentiles, weekly streamflow measures, the standardized precipitation index, and short- and long-term drought indicator blends to create a comprehensive look at the category of drought with which they are dealing. Drought is categorized and defined as hydrological, agricultural, socioeconomic, or meteorological/climatological. This data collection will be using the meteorological definition of drought based on the collected precipitation numbers from the NCEI and Climate.gov. Meteorological drought is measured using the magnitude and duration of precipitation, determination of drought is specific to the region (American Meteorological Society, 2022). Having established guidelines for determining if drought or flood has taken place, the conditions can then be used to compare how the timelines and locations for these extremes have changed and will change. In order to compare how extremes have changed, past (1900-1950) and current (1951-2021) precipitation data were compared to calculate reversal frequency changes. Research on the specific topic of drought and floods as a part of precipitation reversal is limited and appears to only have become of interest recently.

Most research on precipitation reversals and the increase in drought cycles is primarily from California, the location with the most noticeable and extreme reversal events occurring as shown in Figure 1. The climate in California typically experiences a range of wet and dry seasons every year, but with changes in drought cycle occurrence, it is predicted that the time periods between the wet and dry seasons will be narrower and the events themselves will be potentially more hazardous (Johnson, 2021). Daniel Swain from UCLA's Institute of the Environment and Sustainability Center for Climate Science stated that, when reversal events were compared for past and hypothetical future, there was a considerable increase in events with human influence (McKay, 2018, p. 12). In another study on reversals in California, researchers projected that, at the end of the 20th century, the transitions will double in Southern California and increase by 25% in Northern California (Robbins, 2019).


Statewide and regional precipitation variability*

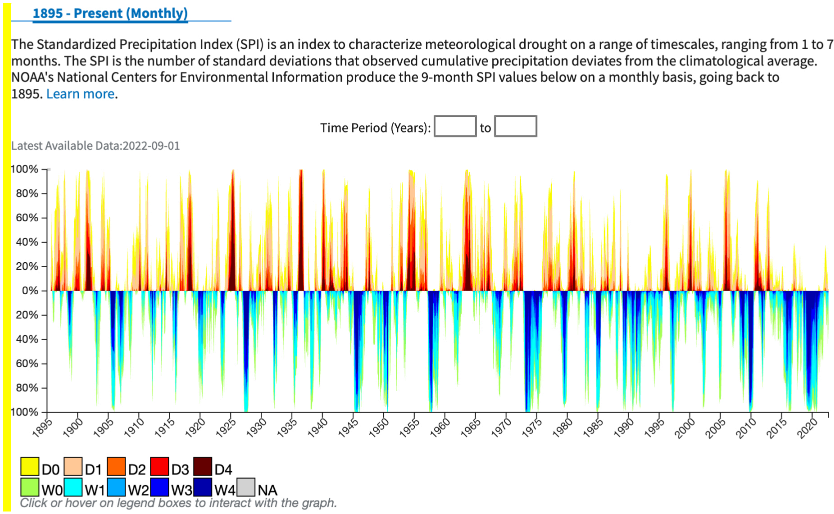
* The graph shows variability for each 30-year period relative to the entire 90-year period. A value above 1 means precipitation for the 30-year window was more variable than that for the overall period.

Source: He and Guatam 2016

Figure 1. California's precipitation variability in the last 30 years. Image source: He and Guatam 2016

https://oehha.ca.gov/epic/changes-climate/precipitation

Limited research has also been conducted in the southern Great Plains of the United States, an area that receives an abundance of precipitation compared to California. While current changing reversal conditions are not well studied, Puxley (2021) conducted a study from 1981 to 2018 that showed one major event per year during the period. Although precipitation reversal is not a new concept and is a part of normal climate fluctuations, anthropogenic interference and global warming have caused a shift in the events that call for examination. Extreme weather events are not new, and Arkansas is no exception. Notable flooding events in the state's history include, the Great Flood of 1915, the Great Flood of 1927, The Ohio-Mississippi Valley Flood of 1937, the April 1945 flood, and the most recent the Albert Pike Flooding on June 11, 2010 (US Department of Commerce, N.O.A.A, 2020). On the opposite end of extremes, Arkansas has seen major drought events as well, shown in Figure 2, but that have been less well documented in research than flood events.



1895 - Present (Monthly)

The Standardized Precipitation Index (SPI) is an index to characterize meteorological drought on a range of timescales, ranging from 1 to 72 months. The SPI is the number of standard deviations that observed cumulative precipitation deviates from the climatological average. NOAA's National Centers for Environmental Information produce the 9-month SPI values below on a monthly basis, going back to 1895. Learn more.

Time Period (Years): ☐ to ☐

Latest Available Data:2022-09-01

Click or hover on legend boxes to interact with the graph.

Figure 2. Historical droughts in Arkansas from 1895-2020 using the Standardized Precipitation index. Image source: https://www.drought.gov/states/Arkansas#historical-conditions

Even though the state is subject to both droughts and floods, Arkansas' climate is majority humid subtropical, which is classified by hot and humid summers, with cold to moderate winter seasons, with an even distribution of precipitation throughout the year (UC Davis, 2018). Knowing the climate and weather patterns it can be assumed there will be about even distribution for the yearly calculations. There is no research specifically investigating the changing weather patterns in Arkansas. This research aims to fill the gap in the lack of knowledge of how changes in climate have affected Arkansas and the length and extremity of precipitation reversals.

Problem Statement

One of the issues associated with the increase in precipitation reversals is its unpredictability and how the reversals will affect human life and natural resources. In the case of agricultural practices, both ends of the reversal's present issues, especially if there are increased precipitation reversals in a shorter timeframe. Elevated levels of precipitation do not allow for soils to absorb the moisture, resulting in increased runoff and soil erosion. Many crops are sensitive to flooded conditions. In more extreme weather events, like floods, humans are directly at risk. The compounded effects of both the dry and wet period of reversal are potentially severe. Reaping the effects of not only one end of the spectrum, but the opposite within a shorter period, will leave little room for environmental recovery for soils, plants, etc. Seasons will become more variable and harder to predict, making it difficult for planning and agricultural practices to survive. According to Henson (2022), wet-to-dry reversals make the environment prone to wildfires due to production of thicker shrubs and grasses in the wet period, while the dry periods are fire-inducing. Adaptions for wet and dry periods are opposite and focusing on one over the other could lead to maladaptation.

Drought is costly in that the crops do not get the necessary water without supplementing them with irrigation, which depletes the groundwater aquifers. Drought can trigger wildfires that damage health from inhalation, affect communities and destroy their homes (Iberdrola, 2022). Both floods and drought may lead to a decrease in food production.

Climate refugees are also a possible consequence of randomly occurring harmful precipitation events. By delving further into the causes and patterns of precipitation reversals, modeling may be able to predict when and where future events will occur, preventing loss and harmful impacts to humans (health, economics, stability). Although there is not a professional association assigned with researching and handling precipitation reversals, paleoclimatologists are the most involved in furthering what is known about changing transitions in precipitation and droughts (NCEI, 2021). Therefore, at this current time, it is essential for precipitation reversals to be researched and more developed as a topic, because increased changes in climate have been detected due to anthropogenic influence and will continue to have impacts in the future. The issue with precipitation reversals and the increasing variability is that its unpredictability could be costly to ecosystems and human infrastructure. Work and research in the state of Arkansas is relevant because the economy does rely on agriculture largely for its success. According to AR Agriculture (2019), for the year 2016, Arkansas was among the top 25 states for production of several agricultural products, providing 1/6 of the total jobs with labor income producing 17.6 percent of the state's total. Any change in typical weather patterns could negatively affect the agriculture sector and in turn, the economy.

Purpose Statement

The purpose of this study was to identify if Arkansas is experiencing changes in precipitation reversal at different spatiotemporal scales as compared to historical reversals.

Research Objectives

The following objectives guided this research. The first objective is to examine precipitation trends in the state. The next was to find the degree to which precipitation reversals have shifted in Arkansas relative to time and space by using data extracted from Climate.gov and NCEI (National Center for Environmental Information), government websites that contain datasets and services for climate-related subjects. The datasets include both inter-annual and seasonal precipitation values (from 1900 to 2021), with a monthly temporal resolution calculated from a land-based station. This research aims to provide examinations of reversals for Arkansas stations (for the annual data) and the entire state of Arkansas (for the seasonal data), which have been affected by changing patterns of precipitation reversal.

Predictions

- There will be a change in precipitation reversals at different spatiotemporal scales because shifts in precipitation patterns over many regions are expected as a consequence of climate change.
- Precipitation data will indicate more extremes than those in the past.

Literature Review

Precipitation reversals are a measure of the cycles between dry and wet periods, measured on different temporal scales. Different climates possess differing baseline patterns for these cycles. Recent research into precipitation reversal has indicated that the frequency and intensity of cycles is changing (Robbins, 2019). The impacts of the changes happening have not been comprehensively researched, but current knowledge shows disproportionate effects on certain areas over others and the systems they have in place. Evaluated literature included in this research attributes increasing reversals to factors such as: atmospheric circulation, extratropical cyclone patterns, global warming, seasonally varying solar radiations, monsoon season timing, etc. The following literature review explores precipitation reversal impacts with their increase due to climate change in the past century.

Variability and Increased Intensity in the Hydroclimate

Documented changes show how natural water systems and their stages have been altered during typical cycling of wet and dry seasons. A case study by Johnson (2021) investigated paleoclimate records to determine hydroclimate values. The records show the baseline for typical variability to help formulate a comparison to today's variability patterns. Precipitation reversal in this case is defined as large swings between wet and dry conditions (Johnson, 2021). Johnson (2021) reported that California will see significant impacts on their ecosystem, economy, and water resources with changes in hydroclimate extremes. Johnson concluded that, even without the hypothesized effects of climate change on reversal patterns, there is already more extreme variability taking place than in the past due to human-caused climate warming. A study by Ma and Zhu (2020), evaluated Northern China's atmospheric circulation system to measure how events have changed, considering reversals to be rapid transitions between warm and freezing conditions or wet and dry conditions. Between a combination of a wave-activity flux equation, a temperature budget diagnosis, and a two-tailed t-test on temperature reversal events, Ma and Zhu documented drastic temperature shifts during the winter season. Events in the wintertime in Northern China were correlated with southern propagation temperature anomalies in the lower and middle troposphere (Ma and Zhu, 2020). This research highlighted how anthropogenic activity directly correlated to the change in intensity of winter temperature events. In another instance of documented variabilities, Puxley (2021) focused on spatial and temporal precipitation patterns. Parameter-Elevation Regressions on Independent Slopes Model (PRISM) datasets defined pluvial drought conditions, when conditions are wetter or drier than some threshold (UH News, 2022), along with defined reversals- precipitation extremes on the sub-seasonal-to-seasonal scale that show the climatology of transitions and characteristics from 1981 to 2018, with a focus on the time from 2017 to 2018. The findings from the Puxley (2021) study were similar to Johnson (2021) and Ma and Zhu's (2020) work, in that researchers identified an increase in precipitation events in the areas, but the Puxley (2021) study on the southern Great Plains differed in that the study disproved the effectiveness of taking data monthly for precipitation events because it does not give the big picture of hydroclimate changes. In a study investigating anthropogenic influence on variability using a CMIP5 model from 1950-2005, Konapala et. al (2017) compared simulations of natural and anthropogenic forcings. The variability and intensity were measured at global, continental, and sub-continental scales, getting 10,000 spatially averaged coefficients. The results indicated that there was higher temporal variability from "anthropogenic contributions" (Konapala, et.al 2017). Additionally, the anthropogenic forcings showed an increase in non-uniformity, meaning that there was more unevenness and disparity over the time period examined. Konapala et. al (2017) found that temporal precipitation intensity was more impacted by anthropogenic influence than the actual precipitation amount. Change in temporal variability of precipitation requires implementation of adaptation management practices that will prevent global damages. Each of these cases indicated there are hydroclimate intensity spikes, which are extreme random changes in typical hydroclimate conditions, but it does not provide evidence that this is a new global pattern. Based on variable cycles of precipitation reversals, any changes can have an impact, especially on already vulnerable regions.

The Impacts of Precipitation Reversals in a Warming Climate on Specific Regions

Delving further into data from locations in the United States and Asia shows how different regions face various consequences of global warming. Dai and Cheng (2022) created a model for carbon emissions and their relevance to the skewed monsoon cycles in east Asia. Dai and Cheng (2022) created the projected changes for emissions based on current and mitigated levels with precipitation, extremes, and compound events from six separate locations based on a historical run (1971-2005) to determine probable future scenarios (2006-2100) using simulations from Coupled Model Intercomparison Project (CMIP5). Results of the study predicted a late retreat that causes larger mid-summer stages of monsoons, with a longer rainy season and later winter stages-- from Spring to Mid-Summer, there will be about 14-20 more heavy precipitation days (Dai and Cheng, 2022). For this study, Dai and Cheng (2022) refer to reversals as prolonged dry periods and “intensified” precipitation due to human activity. For such a densely populated part of the world, the projected changes would impact on a large number of people and the way they live. Changes in the timing of when events occur will leave populations at greater risk due to a lack of preparation and warning.

The American Meteorological Society conducted a study to determine trends of greenhouse-gas-induced global warming (in part due to human activities) using the hydroclimatic intensity index to calculate average intensity during wet and dry periods (Lee, 2021). Precipitation reversals were defined as “rapidly changing” weather events (Lee, 2021) Results showed that daily and weekly data showed global increases in variability for all seasons, with no significant decreases statistically, except for boreal autumn (Lee, 2021). Researchers for this model emphasized that changes in the hydrologic cycle are crucial to study because humans are so dependent on water systems and natural systems for survival (Lee, 2021). The results of this model showed that the hypothesis was supported in predicting increased intensity for hydroclimate which puts sensitive systems at risk for wet and dry extremes (Giorgi et al., 2011).

Bevacqua, E, et al (2019), looked at compounded hydroclimate effects due to anthropogenic influence. The research does not necessarily define reversal but focuses on the wet period (flooding events). The study claimed that high sea levels together will produce compound flooding that will cause fatalities and severe damage. Using a simulator to simulate maxima storm surges and waves (D-FLOW) and CMIP5 models for present and future climate, results showed that the highest compounded flood probability was near the Mediterranean Sea. The calculated statistical dependence showed the relationship between sea level and precipitation enhances likelihood of CF occurring (along European coasts) (Bevacqua, E, et al, 2019). In relation to anthropogenic influence, there is a projected increase (3% to 11%) for lower return periods-- time in between events-- for compounded floods (Bevacqua, E, et al, 2019). The predicted driver of increased compounded flooding is a warmer atmosphere (in part due to anthropogenic factors) that can carry more moisture, increasing the amount of precipitation. A driver of more extreme reversal (or individual events- flooding) can be attributed to climate warming. In another case study from Oliver (2019), Rocky Mountain Junipers (*Juniperus scopoulorum*) in New Mexico were used as indicators for drought records. The Rocky Mountain Junipers are particularly porous and therefore sensitive to moisture levels. Using the Palmer Drought Severity Index on the trees aided in producing results for the CAN-hydroclimate (Candeleria site) relationship (Oliver, 2019). There was an overall stable CAN-hydroclimate relationship, but seven hydroclimatic flips/reversals-- extreme wet to dry and vice versa-- indicating more extreme droughts in the last two centuries (Oliver, 2019). Just in the United States and Asia alone, there are several studies that document findings of disruptions in natural hydrological systems (Francis, 2021; Ma and Zhu, 2020). These findings do not include how all different climate regions have seen changes, but they do show that climate warming has and will continue to change natural systems at the rate it is going. A reoccurring observed pattern in climatological studies is the amplified intensity of already existing conditions. For example, Chou et. al (2013) looks at how water vapor increase in the atmosphere has strengthened the hydrological cycle. As a result, wet regions are only getting more wet, and dry regions have been getting dryer. Both sides of extremes have created a larger range in precipitation. These variations in seasonal precipitation can change the frequency of droughts and floods. The model does not specify a particular region resulting extremes will apply to, but like Lee's (2021) findings, human alterations of the hydrological cycle can have devastating results, because humans are so reliant on water systems.

Measured Precipitation Reversals and How it is Affecting Human Systems

Changes in precipitation reversal patterns are impacting human processes, such as recreational activity and agricultural practices. Casson et al. (2019) used a series of case studies to highlight impacts of extreme reversal from sets of weather data—the shifts between opposite weather conditions (Casson et al, 2019). Researchers used four different case studies to represent several types of reversal events under the categories: “snow-on-leaf", “cold-on-leaf", “winter heat waves,” and a “rain-on-snow" event (Casson et. Al, 2019). As a whole, the data showed an increase in the average winter temperatures, earlier spring, and an increase in the distribution of winter weather events (WWEs) (Casson et. Al, 2019). Casson et al. (2019) stated the increase in events disrupts daily activities, agriculture, and ecosystems and gave a specific example stating that fruit farmers were impacted by killing freezes in April, with crops blooming too early in the season that then were damaged by a cold spell. The Earth and Space Open Archive created an innovative approach for measuring events based on their transitions and atmospheric circulation patterns (Francis et. al, 2021). The Self-Organizing Maps algorithm examined atmospheric trends over North America and the Pacific Ocean and showed that winter weather events are likely to shift from high latitude nodes to more meridional nodes, meaning there will be more extreme cold in the middle latitudes (Francis et al., 2021). Francis et. al (2021) concluded that this methodology could give shifts in precipitation and temperature with WWEs in each of the nodes. As Casson et al. (2019) explained, the decline in agricultural conditions and colder temperatures towards the equator will have devastating effects.

Lee (2021) studies the variability of air temperatures to determine spatial and seasonal trends through diurnal, daily, and weekly ranges (reversals have been previously defined for this study). Over the 280 seasons studied, there was no global trend detected, but the last 35 years showed numeric increase in air temperature (Lee, 2021). Geographically, there was variability, mostly in the southern hemisphere, a region that already experiences elevated temperatures (Lee, 2021). A slight increase in air temperature could disrupt human as well as other species' health in the south. This research will not cover temperature reversals, but it is still crucial for measuring comprehensive weather reversals.

As for agricultural regions, biogeochemistry research was conducted by Loecke et al. (2017) in the midwestern United States. They used the Applied Climate Information System to collect data on nitrogen levels in soil with nitrate flux and discharge rates (Loecke et al., 2017). The original hypothesis that droughts store nitrogen was supported by record levels of large discharge when precipitation flushed the active nitrogen into the water sources. Results of the information system showed near-record breaking dissolved N fluxes and high cumulative discharge values, supporting the idea that reactive N stored during droughts in flushed during floods and rain events (Loecke et. al, 2017). Loecke et. al (2017) claimed that, as climate change impacts weather reversals, the abrupt change in drought conditions to wet and the opposite, there will be an increase in nitrate concentration in rivers that will increase the probability of surface water exceeding the drinking water standard maximum (10 mg L^{-1}) set by the U.S Environmental Protection Agency (U.S.E.P.A). Exceeding the drinking water standard has a direct impact on human safety due to reversal events and a changing climate.

The current research in precipitation reversals is limited because of its newness in the science world, but the studies examined in the literature review create a framework of how natural processes are changing, likely because of global climate change. The hydroclimate has shifted in how often extreme weather events occur and their intensity when they do. The impacts of these shifts will not have equal consequences everywhere and certain regions will experience the effects of anthropogenic climate reversal more than others. Human systems are at risk with unpredictable weather events and air temperatures and the danger is predicted to only increase in the future (Iberbola, 2022). Future studies are needed to provide a comprehensive look at how patterns are changing on a global scale and what this means for humanity.

The purpose of this study was to identify if Arkansas is experiencing changes at different spatiotemporal scales regarding precipitation reversal or dramatic shifts in weather conditions. The hypothesis being tested is to see if there is an increase in precipitation patterns over the examined time period. A quantitative study will be conducted to evaluate patterns in documented and published climate data in Arkansas. Due to the nature of the content being researched, the design will be classified under correlational and ex-post-facto requirements. The process will consist of obtaining measured data from Climate.gov to formulate conclusions based on the compared results.

Methods and Materials

Research Design

The quantitative study will require extracting Arkansas data from Climate.gov and the National Center for Environmental Information (NCEI). This study will utilize a non-experimental design method because the design will be examining the relationship between two preexisting groups: past (1900-1950) and current (1951-2021) climate data in Arkansas. More specifically, the non-experimental design will be comparative due to the intent to evaluate any pattern in precipitation reversal likelihood in different Climate.gov stations in Arkansas. The study is considered ex-post-facto, which is a design where the research occurs after the fact and with no interference from the researcher (Salkind, 2010). The ex-post-facto nature of this study is due to using historic data from 1900 to 2021, thus the data being used are from after-the-fact observations. Monthly and seasonal data are collected with a monthly temporal resolution for the selected stations from Climate.gov and the NCEI. Each station and season averages annually will have a graph with linear regression for time and precipitation. Another set of graphs will be created to represent anomalies for seasonal averages, with the frequency of wet-to-dry and dry-to-wet reversals.

Rigor

To prevent potential issues with data validity and reliability, purposeful measures have been implemented. External validity may be compromised by the accuracy of the climate data extracted from government sources. The website does not indicate whether the precipitation measurements were recorded at the same time of day, which could skew the accuracy of changing climate patterns. In addition, climate data does not go back to before 1810 and is limited until 1900, and some counties have missing data. To account for the validity of the study including the missing data, the time period used for the study is over 100 years using only stations that have over 50% of the data for the time period. By using results with a significant amount of data, and a longer time scale, there will be less impact of missing data. The secondary data calculated from the U.S. Climate Divisional Database using 344 climate divisions with measurements from weather stations in the Global Historical Climatology Network-Daily provide reliable information to analyze precipitation reversals in the designated stations, mostly separated by county (Climate.gov, 2022). Though there are possible discrepancies in the completeness of the data due to missing data, the lengthy time period and reliability of the source providing the data makes the study reliable and accurate. The data source for the seasonal averages had more substantial and consistent data and was therefore more reliable for making reversal assumptions, so a wider range of sensitivities was used to determine reversals for seasonal annual data instead of the annual data. Objectivity is the idea that there should not be influence of specific viewpoints on scientific methods, results, and claims. This is also key to the results, and because of the scientific nature of the data collection, objectivity and reliability of the analyses is also met (Irwin, 2022).

Data Collection

The population for this study consists of regions of Arkansas. There are 344 stations in Arkansas from Climate.gov's database. In order to conduct this research, climate data consisting of annual precipitation and seasonal averages annually were extracted from Climate.gov and the National Center for Environmental Information (NCEI) for every year between 1900 and 2021. Extracting climate data from every station and season helps ensure that the results can be better generalized for the entire state, and no area is excluded from the conclusions for precipitation reversal patterns. Because the size of the data set is extensive, there should be little chance of standard error, which is when the population mean differs from the sample mean (Bhandari, 2020). The large data set size used in this study will better represent the total area's precipitation numbers. Data was recorded in an Excel spreadsheet (Version 16.64, Microsoft, Fayetteville, Arkansas). The files received from the NCEI consisted of weekly updated data for the Global Summaries of The Year (in inches) and seasonal averages taken from monthly calculations (in inches), where blank spaces signified no measurement flag was used and no data was collected. For each station and season, a graph was created for the climate variable (annual precipitation) to graphically represent the data patterns over time so precipitation reversal changes in Arkansas can be evaluated. These will be evaluated by performing a linear regression, determining if the value is negative or positive, and finding the averages to get upper and lower deviation numbers for calculating wet and dry periods. For the inter-annual and seasonal data, a baseline graph will be created for 1900-1950 precipitation anomalies to represent "pre-climate change" conditions to compare with the 1951-2021 "active climate change" anomalies. Once the two anomaly graphs for each season and year have been established, standard deviations of .5,1,1.5, and 2 will be used to tell when a dry or wet period occurs. Anomalies were taken from the seasonal data by subtracting the average of the time period (1900-1950 or 1951-2021) from the year's precipitation value. These numbers were plotted on a line graph and chosen standard deviations were applied. Any year above the indicated positive deviation was counted as a wet year, and any year below the negative standard deviation was a dry year. A reversal occurred when a wet year was directly followed by a dry year or vice versa based on the chosen deviation/intensity. By this definition, some reversals will be counted for a certain deviation, that are not see at a different value, including variability that is not as critical as a “reversal”. The chosen deviations used were 0.5, 1, 1.5, and 2.

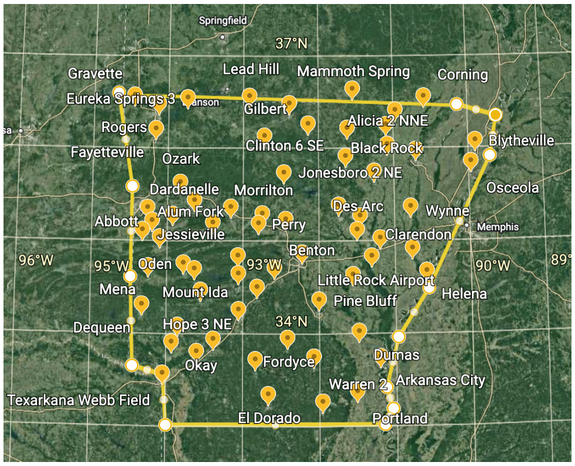


Figure 3. Distribution of observational stations with greater than 50% of data collected from Climate.gov.

Data Analyses

The 66 sites were evaluated on the basis that they had over 50% of data collected from 1900 through 2021. Climate.gov and the National Center for Environmental Information provided 344 stations to draw precipitation data from, but only 66 of the total number provided enough data to use for this study’s purposes. The seasonal averages also used collected data from the entire region of Arkansas. Each seasonal and stational set of data was used to formulate a linear graph showing regression. There were three categories or patterns of precipitation trends over time: increasing (i.e., positive slope), decreasing (i.e., negative slope), or no change (slope of zero). Linear regression an equation using an independent (year) and dependent variable (precipitation in inches). Regression can be used to identify trends and effects and determine if a relationship existed between the dependent and independent variables (Statology, 2022). The sign of the slope determines if the relationship is positive or negative.

Before determining the patterns of precipitation over time, the data will be sorted into categories based on how much data is present—any stations with less than the desired 50% of data will be eliminated before performing a regression. That leaves 66 stations of a total of 344 and their locations have been marked in Figure 3. To perform a test of the hypothesis, a linear regression will be performed for each of the 66 stations, and the averages for all four seasons in the state of Arkansas provided they have a substantial amount of data for analysis. Because the stations have been selected based on the amount of data provided, there is little emphasis on site distribution. In formulating the representative graphs, the independent variable will be the time in years (ex: 1900), while the dependent factor is the yearly precipitation value (in inches). Plotting these numbers and finding the slope or "b" value with regression will determine if precipitation is either increasing or decreasing over time and the strength of the relationship. A positive slope value in the regression will represent a positive increase between time and precipitation, while a negative slope will demonstrate there is decrease in precipitation values over time. It was projected for this study that the majority (over 50%) of sites will have a positive relationship over a negative one, due to more documented precipitation events globally (Ma and Zhu, 2020; Puxley, 2021; Johnson, 2021). Precipitation anomalies are first derived with respect to the climatology of 1900-1950. Based on the anomalies one reversal is counted when there is a dry period following a wet period or vice versa. For the actual reversals-- the historical reversal baseline will be established by creating a graph for precipitation from 1900-1950- which will represent the reversals before climate change. A graph for "during" climate change was also created from 1951 to 2021 so the two can be compared to see if there has been an increase or decrease in reversals since climate change. Reversals will be found by calculating anomalies (subtracting the average from the precipitation for the year), creating a line graph, and computing standard deviation (using values of .5, 1, 1.5, 2). Years/seasons that fall above the positive standard deviation are a wet period, and years that fall below the negative standard deviation on the graph are a dry period. The resulting reversals are more intense for higher deviations (1.5 and 2) and less intense when they are present at lower deviations (.5 and 1). Two connected years, either a wet year followed directly by a dry year, or a dry year followed by a wet year will be equivalent to one reversal.

Analysis of the data collected will serve to either support or disprove our hypothesis that reversals have increased in the current period in comparison to a period without distinguishable climate change. The aforementioned methods and analyses in place will be used to give resulting alternating periods (wet and dry) and what this could mean for the effected stations in Arkansas.

Results

Precipitation trend analysis at Stations

As hypothesized, there was a larger percentage of sites that had a positive calculated slope in comparison to sites with a negative slope, indicating an overall increase in precipitation over time (Figure 4). Figure 4 summarizes stations having increasing trend (in green) and deceasing trend (in red). The sites with decreasing annual precipitation were Arkansas City, Dumas, Wynne, Eureka Springs 3 (Figure 5), Helena, Brinkley, Stuttgart, Georgetown, and Alicia 2 NNE. These sites made up 13.6% of the total. As for the positive regression group from the annual data, 57 sites showed an increasing annual precipitation trend over time, making up 86.4% of the total [Gravette, Mena (Figure 6, Hot Springs 1 NNE, Clarendon, Des Arc, Crossett 2 SSE, Abbott, Searcy, Malvern, Jessieville, Greenwood, Hope 3 NE, Marianna 2 S, El Dorado, Little Rock Airport, Clinton 6 SE, Perry, Calico Rock WSW, Okay, Texarkana Webb Field, Blytheville, Mammoth Spring, Pocahontas 1, Gilbert, Alum Fork, Corning, Glenwood 4 NNE, Mount Ida, Fayetteville, Lead Hill, Subiaco, Mountain Home 1, Conway, Ozark, Portland, Newport, Waldron, Dequeen, Morrilton, Prescott 2 NNW, Jonesboro 2 NE, Danville, Black Rock, Camden 1, Rogers, Oden, Pine Bluff, Benton, Batesville Lock and Dam 1, Arkadelphia, Evening Shade 1, Nashville, Osceola, Fordyce, Warren 2, Dardanelle, and Booneville].

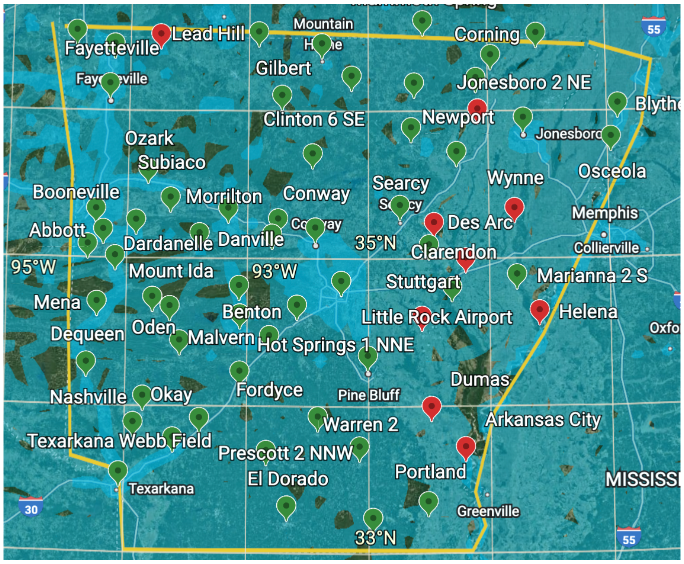
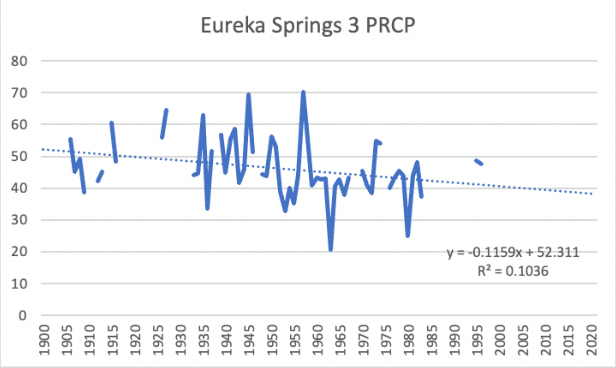


Figure 4. Positive and negative linear regression at observed stations with greater than 50% of total data. The red locations had a negative regression (13.6%), and the green locations had a positive regression (86.4%).



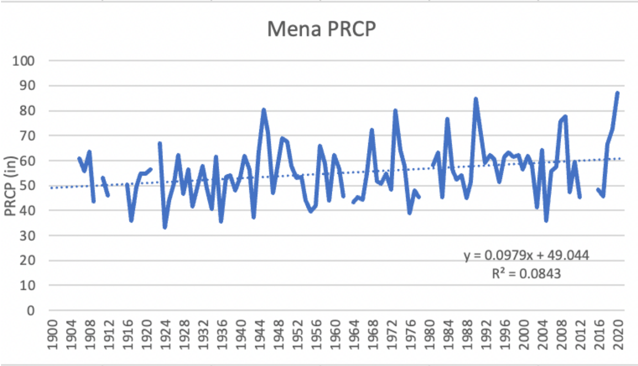


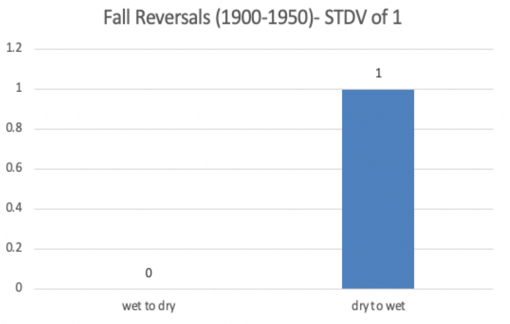
Figure 5. (left) Eureka Springs 3 observed station annual precipitations from 1900-2021. Linear regression resulting in a negative slope (in inches).

Figure 6. (right)) Mena observed station annual precipitations from 1900-2021. Linear regression performed resulting in a positive slope (in inches).

Seasonal Reversal Events Over the State

The standard deviations 1.5 and 2 showed no reversals, except for one wet-to-dry reversal in spring in the 1900-1950 time period. This indicated that the reversals for the seasonal data were not of a high intensity.

Using a standard deviation of one for 1900-1950, fall had zero wet-to-dry reversals and one dry-to-wet reversal (Figure 6), winter had one wet-to-dry reversal and two dry-to-wet reversals (Figure 7), spring had two wet-to-dry reversals and zero dry-to-wet reversals (Figure 8), and summer had one wet-to-dry reversal and zero dry-to-wet reversals (Figure 9). With a deviation of one, the past time period showed seven total reversals.



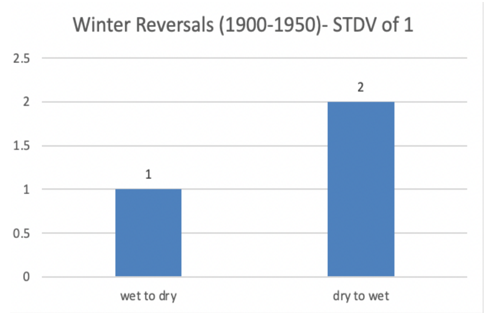
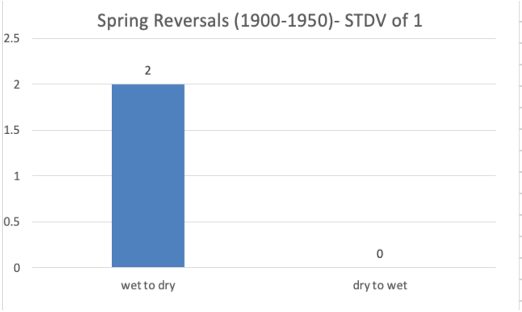


Figure 6. (left) Fall wet-to-dry (0) and dry-to-wet (1) reversals from 1900-1950 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).

Figure 7. (right) Winter wet-to-dry (1) and dry-to-wet (2) reversals from 1900-1950 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).



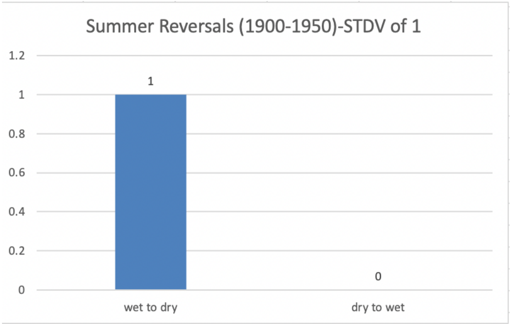
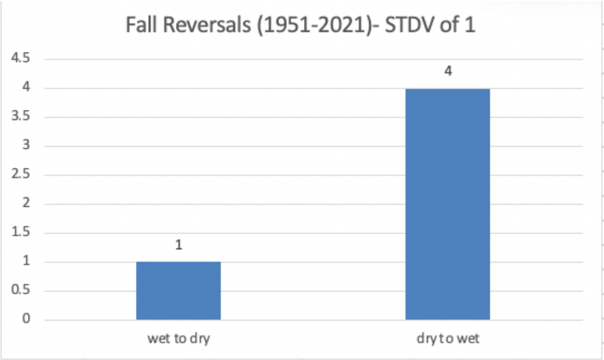


Figure 8. (left) Spring wet-to-dry (2) and dry-to-wet (0) reversals from 1900-1950 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).

Figure 9. (right) Summer wet-to-dry (1) and dry-to-wet (0) reversals from 1900-1950 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).

The next relevant evaluation was using a standard deviation of one in the current time period, 1951 to 2021. In fall, there was one wet-to-dry reversals and four dry-to-wet reversals (Figure 10), in winter there were two wet-to-dry and zero dry-to-wet reversals (Figure 11), in spring there was one wet-to-dry and four dry-to-wet reversals (Figure 12), and in summer there were two wet-to-dry and three dry-to-wet reversals (Figure 13). For this time period, there were 17 total reversals. The results of these analyses indicate there has been an increase in the total number of reversals, from seven to 17, occurring from 1900 to 2021 at a relatively low intensity level.



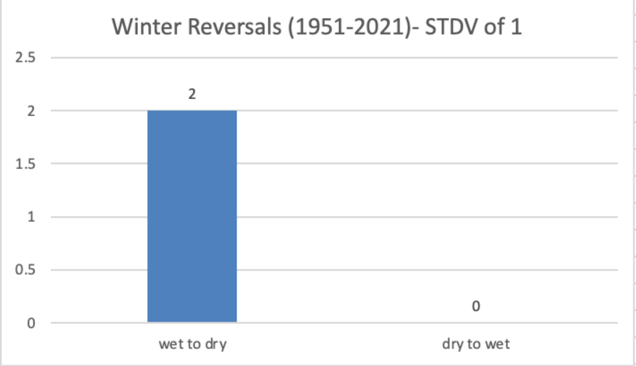
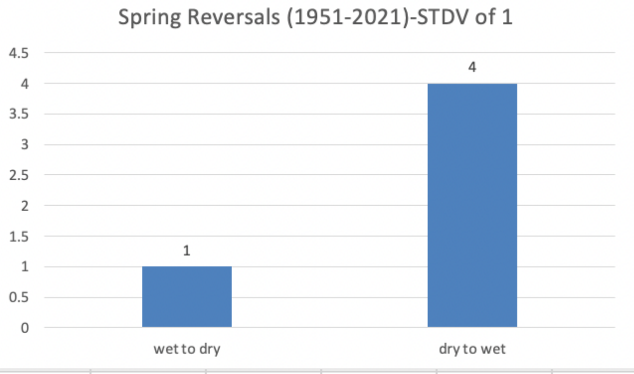


Figure 10. (left) Fall wet-to-dry (1) and dry-to-wet (4) reversals from 1951-2021 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).

Figure 11. (right) Winter wet-to-dry (2) and dry-to-wet (0) reversals from 1951-2021 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).



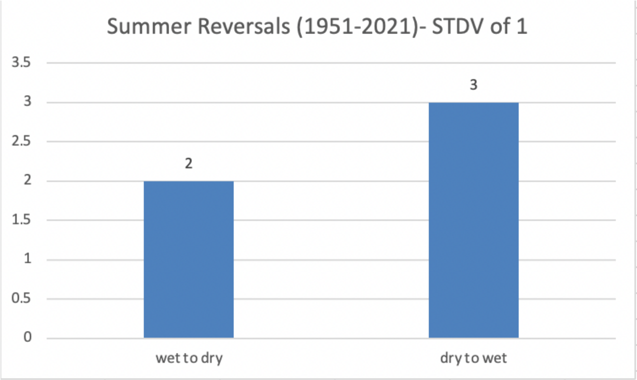
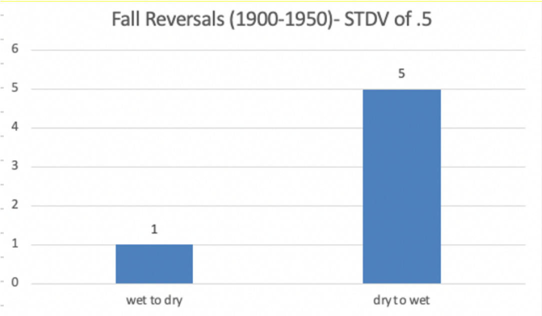
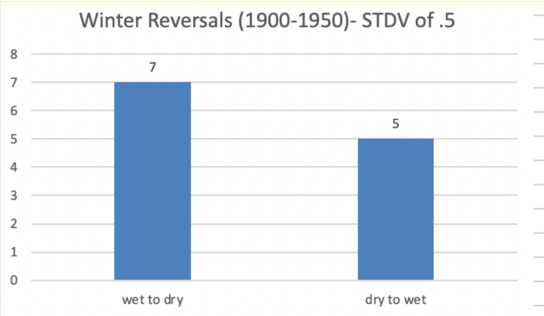


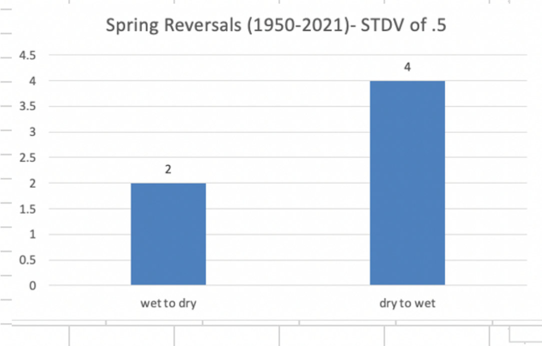
Figure 12. (left) Spring wet-to-dry (1) and dry-to-wet (4) reversals from 1951-2021 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).

Figure 13. (right)Summer wet-to-dry (2) and dry-to-wet (3) reversals from 1951-2021 using a standard deviation of one (relatively low intensity), based on calculated precipitation anomaly linear regressions (in inches).

The next results were for the same time periods and values, but with a standard deviation of one half, representing a lower intensity for the reversals. From 1900-1950, fall had one wet-to-dry reversal and five dry-to-wet reversals (Figure 14), winter had seven wet-to-dry and five dry-to-wet reversals (Figure 15), spring had two wet-to-dry and four dry-to-wet reversals (Figure 16), and summer had four wet-to-dry and five wet-to-dry reversals (Figure 17).







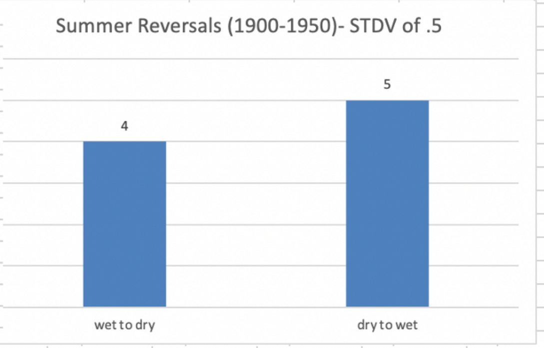


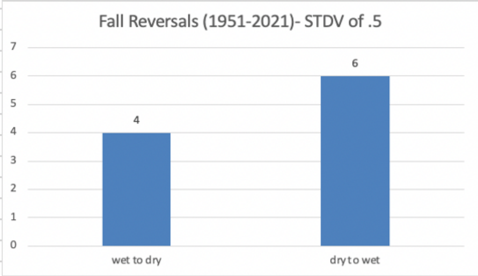
Figure 14. (Top left) Fall wet-to-dry (1) and dry-to-wet (5) reversals from 1900-1950 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions (in inches)

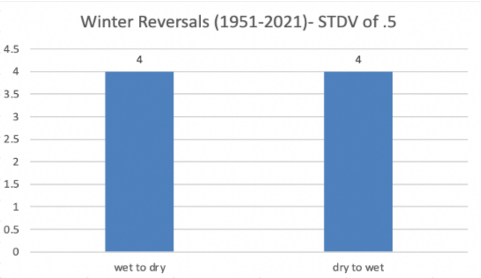
Figure 15. (Top right) Winter wet-to-dry (7) and dry-to-wet (5) reversals from 1900-1950 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions (in inches).

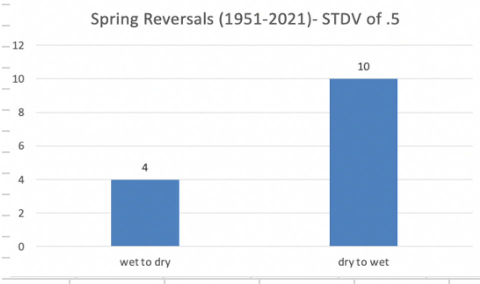
Figure 16. (Bottom left) Spring wet-to-dry (2) and dry-to-wet (4) reversals from 1900-1950 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions.

Figure 17. (Bottom right) Summer wet-to-dry (4) and dry-to-wet (5) reversals from 1900-1950 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions.

Again, for the same deviation reversals were counted during 1950 to 2021. In fall, there were four wet-to-dry and six dry-to-wet reversals (Figure 18), winter had four wet-to-dry and four dry-to-wet reversals (Figure 19), spring had four wet-to-dry and 10 dry-to-wet reversals (Figure 20), and summer had three wet-to-dry and three dry-to-wet reversals (Figure 21). With a standard deviation of one half, there were a total of 33 reversals from 1900-1950 and 38 reversals from 1951-2021. Like with a standard deviation of one, there was also an increase in reversals over time, but there was also a greater number of reversals when a lower deviation was used. This can be attributed to the fact that the deviations are a measure of not only count, but intensity; thus, as intensity increases, reversals will be eliminated from the reversal count. The results show that reversals have increased over time and there is a greater frequency of low-intensity reversals than large-intensity reversals.







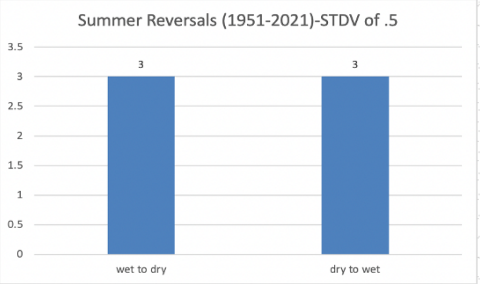


Figure 18. (Top left) Fall wet-to-dry (4) and dry-to-wet (6) reversals from 1951-2021 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions (in inches).

Figure 19. (Top right) Winter wet-to-dry (4) and dry-to-wet (4) reversals from 1951-2021 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions (in inches).

Figure 20. (Bottom left) Spring wet-to-dry (4) and dry-to-wet (10) reversals from 1951-2021 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions (in inches).

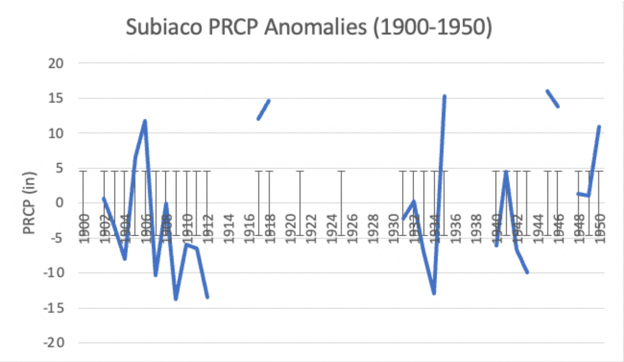
Figure 21. (Bottom right) Summer wet-to-dry (3) and dry-to-wet (3) reversals from 1951-2021 using a standard deviation of .5 (lowest intensity), based on calculated precipitation anomaly linear regressions (in inches).

Inter-annual Reversal Events at the Stations

The same process completed for seasonal reversals was repeated for inter-annual anomalies at the 66 stations with substantial climate data. Standard deviations of 0.5, 1, 1.5, and 2 were used to present differing reversal intensities, with 0.5 being the lowest and 2 being the most intense. Using a standard deviation of 0.5, past and current time periods were compared and divided into dry-to-wet and wet-to-dry reversals. For a standard deviation of 0.5, there was an increase in dry-to-wet reversals from 1900-1950 to 1951-2021 for 56 out of 66 (84.8%) stations.

The total increased from 117 reversal events to 303. Using the same deviation, calculating wet-to-dry reversals, there was an increase for the same number of stations, 56 of 66. The total increased from 100 to 285 from 1900-1950 to 1951-2021.

For the next deviation calculation, the same process was conducted, but documented reversals with a slightly greater intensity (STDV = 1). There was an increase in dry-to-wet reversals for 27 out of 66 stations (40.9%), where the rest of the stations did not exhibit any reversals either, did not change for both time periods, and decreased. For 1900-1950, there were 31 dry-to-wet reversals with a deviation of 1, and for 1951-2021, there were 60 reversals. Then looking at wet-to-dry reversals, there was an increase in 32 of the stations (48.5%). There were 29 wet-to-dry reversals for 1900-1950, and 66 reversals from 1951-2021 with a standard deviation of 1. The station with the greatest change in number of total reversals, and the greatest change in reversals over time was Subiaco (Figures 22 and 23).



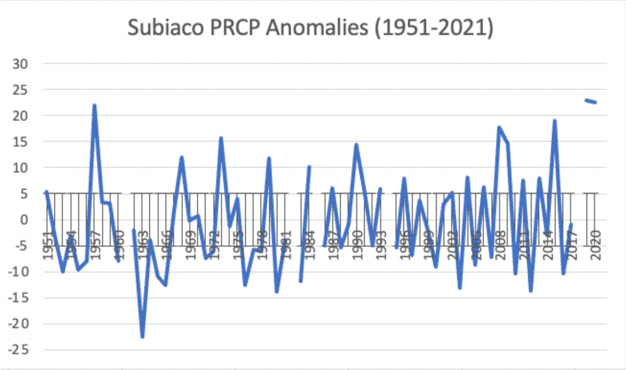


Figure 22. (left) The station with the greatest number of reversals-- Subiaco-- precipitation reversals for 1900-1950 with a standard deviation of .5 measured in inches.

Figure 23. (right) The station with the greatest number of reversals-- Subiaco-- precipitation reversals for 1951-2021 with a standard deviation of .5 measured in inches.

For the large-intensity deviations during 1900-1950, there were 10 reversals using a deviation of 1.5 (Gravette, Hope 3 NE, Eureka Springs 3, Clinton 6 SE, Ozark, Camden 1, Warren 2, Wynne, Perry, and Booneville), and zero reversals with deviation of 2. From 1951-2021, with a deviation of 1.5 there were 14 reversals (Dumas, Hope 3 NE, Calico Rock 2 WSW, Okay, Blytheville, Brinkley, Dequeen, Camden 1, Pine Bluff, Arkadelphia, Nashville, Fordyce, and Warren 2). Figure 24 below shows the station with the greatest frequency of large-intensity reversals at a deviation of 1.5. Overall, there was an increase in the frequency of large intensity reversals from 1900-1950 to 1951-2021.

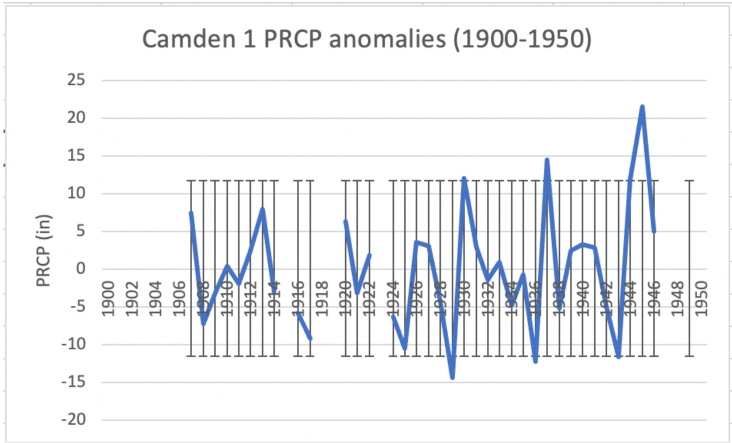
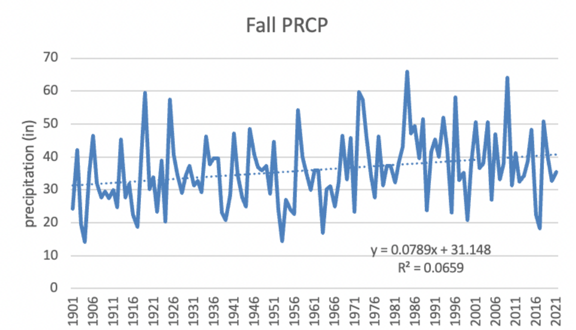


Figure 24. Camden 1 (1900-1950) had the highest number of high intensity reversals (2 total) of all the observed stations (Standard deviation of 1.5, measured in inches).

In all four seasons, precipitation trends were positive, with largest to lowest “m” values as follows- fall (Figure 25), spring (Figure 27), winter (Figure 26), summer (Figure 28). Results from both groups of data showed there was an overall increase in precipitation from 1900 to 2021, and seasonal and inter-annual analyses showed an increase in reversal events.



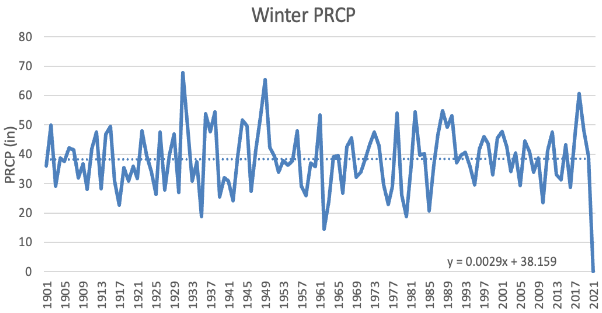
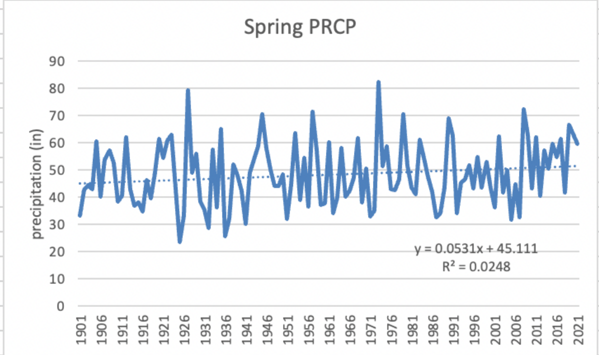


Figure 25. (Left) Fall annual precipitation from 1900-2021 plotted with a linear regression (in inches).

Figure 26. (Right) Winter annual precipitation from 1900-2021 plotted with a linear regression (in inches).



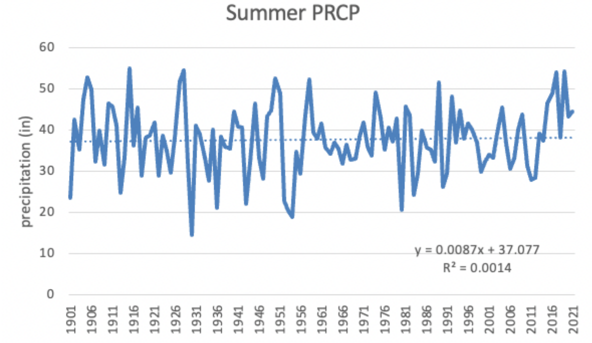


Figure 27. (Left) Spring annual precipitation from 1900-2021 plotted with a linear regression (in inches).

Figure 28. (Right) Summer annual precipitation from 1900-2021plotted with a linear regression (in inches).

Discussion

Results can be better understood in the context of other studies, Bevacqua et. Al (2018), Eley (2021), Johnson (2021), Joshi (2021), Henson (2022), Giorgi (2011), all of which illustrated increased frequency of reversal events and many claiming climate change and a warming climate are to blame. The results showed increasing inter-annual precipitation and more extreme weather events. Increases in frequency were present and compared to related research on precipitation. This study focused on reversal conditions for available stations and seasons and did not fully encapsulate reversal patterns. Due to missing data, certain stations had to be excluded from this research, and therefore patterns in specific regions in Arkansas have not been accounted for. The portion of selected data for research purposes has a significant amount of missing data and therefore not a representation of reversal patterns across the state. Missing data can skew the results and impair the accuracy of reversal identification by potentially leaving out years that make up reversals. The ex-facto inconsistent data provided by Climate.gov and the National Center for Environmental Information call for additional focus on reversals in not only the state of Arkansas, but globally. Other limitations of this type of research are the temporal and spatial scales used (time period- short-term, long-term, future prediction models, and location- regional, national, or global) and the data available to complete this research. Determining the scale to use is important for trend analyses and what the researcher wants to accomplish with the results. Biases on predisposed notions on climate change can lead researchers to look for findings that show increased reversals, though this may not be the case globally.

As climate change continues to show its impacts, research will continue to be necessary to predict and explain natural phenomena and patterns. The results of this study align with findings from Ma and Zhu (2020), Johnson (2021), and Puxley (2021), which all reported increased precipitation over time. The limitations of this research include, but are not limited to, the scale of the data, which was limited to Arkansas and does not cover all the weather stations, the values used to determine a wet or dry period are not a set calculation and depend on the researcher's specified values, and the timeframe only goes back to 1900 and does not predict future trends in precipitation. Floods and droughts are typically identified by their intensity and duration, and research should be conducted on how reversals are attributed to different intensities and durations. For future Arkansas studies, fluvial flooding is more relevant, and a better assessment of this type of flooding would be to evaluate runoff patterns instead of precipitation amount. Runoff can be measured by several methods: rational method, curve number method, and station frequency analysis. One example to calculate is the rational method that uses the runoff, the runoff coefficient, rainfall intensity, and the drainage area (Roseke, 2013). There are multiple indexes that can be used based on the preferred method and available information to perform flood and drought analyses to get the same or similar results.

Because the indication of a reversal is dependent on the deviation values used, it is difficult to determine when they have occurred, and a set value could be determined to prevent discrepancy in reversal frequencies. Arkansas has a humid-subtropical climate, with consistent, large amounts of rainfall throughout the year. With a humid-subtropical climate, there is little variance in yearly precipitation reversals because there is consistent rainfall throughout the year (UC Davis, 2018). The climate may explain why more intense reversals were not identified based on more extreme standard deviations. Research on reversals should be adapted to the region's climate to ensure greater levels of accuracy (i.e., changing standard deviation values, threshold values, etc.). A key point is to establish the climate of the area being studied, determine which deviation would best represent any reversals, and find differences from baseline periods based.

Future reversal research should be done for other states and on a global scale to determine reversal changes more adequately. Another extension of research could be completed with different deviation values to get different dry and wet periods. Because there are multiple ways to measure reversals, drought and flood indices can be implemented as well. Drought.gov (2016) provides a handbook of drought indicators and indices including meteorology, soil moisture, hydrology, remote sensing, and composite or model based. An example of each type of indices is the Standardized Precipitation Index (SPI), Soil Moisture Anomaly (SMA), Palmer Hydrological Drought Severity Index (PHDI), Enhanced Vegetation Index (EHI), or the

Combined Drought Indicator (CDI) (Drought.gov, 2016). Floods have fewer indices for measurement and are based on measurements of rain gauges during a flood or rain event, determining duration and intensity. Climate model simulations would be useful to provide more comprehensive imagery of where reversals are occurring and how extreme the reversals are. Another use for climate models is to estimate future risks of precipitation reversals and implement predicted trends. Using previously calculated data, future predictions can be made and encourage planning and adaptation based on the results.

Research of this kind and this study included will impact the public and have environmental impacts. With increasing levels of carbon dioxide in the atmosphere and other greenhouse gases, there will be more intense hydrologic extremes (Climate.gov, 2022). As glacial ice melts due to a warmed atmosphere, there is greater flooding and disruptions to the hydrologic cycle. Increased precipitation impacts agriculture, and those involved in agricultural practices. With the limited results of this study, further research will need to be conducted with more data to better determine reversal patterns in the last century.

Conclusions

This study analyzed the change in precipitation reversals in the state of Arkansas via Climate.gov stations starting with the year 1900 to 2021. Results indicated that there has been an increase in reversals from 1900-1950 to 1951-2021 using a standard deviation of either 1 or 0.5, and there has been an overall increase in precipitation based on the linear regressions for the stations in Arkansas and the entire state. The predicted increase in reversals over time was seen for the majority of stations (using several deviations) and for all four seasons. Seasonally and annually, the majority of stations, and for all four seasons, had an increase in annual precipitation. Increased precipitation presents issues economically, environmentally, and socially if it is not addressed or adapted to. Greater precipitation means a greater likelihood of flood, with less time for recovery and oversaturated soils and farmlands. Results from other states and globally have already shown reversal intensity increases and changes need to be looked at further. Reversals are a natural part of weather cycles, but their intensity and frequency have changed and therefore more research needs to examine how changes in reversal patterns will affect human systems. Implications of the research findings call for further evaluation of how anthropogenic inputs might be interfering with the natural environment.

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