BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS

STATE OF KANSAS

IN THE MATTER OF

THE APPLICATION OF THE CITIES OF HAYS, KANSAS AND RUSSELL, KANSAS FOR APPROVAL TO TRANSFER WATER FROM EDWARDS COUNTY, KANSAS PURSUANT TO THE KANSAS WATER TRANSFER ACT.	))) OAH NO. 23AG0003 AG))))

Pursuant to K.S.A. Chapter 77.

DIRECT TESTIMONY OF JEFF BASARA, Ph.D.

ON BEHALF OF

THE CITIES OF HAYS AND RUSSELL, KANSAS

RELATING TO

DROUGHT IMPACTS AND RISK TO

WATER RESOURCES IN

THE SMOKY HILL WATERSHED

1

1   **I.   INTRODUCTION AND SUMMARY**

2   **Q.   Please state your name and present position.**

3   A.   My name is Dr. Jeffrey Basara. I am an Associate Professor at the University of

4   Oklahoma with a joint appointment between the School of Meteorology (SoM) and the School of

5   Civil Engineering and Environmental Science (CEES). I also serve as the Executive Associate

6   Director for the Hydrology and Water Security (HWS) Program at the University of Oklahoma.

7   **Q.   On whose behalf are you submitting testimony?**

8   A.   The City of Hays, Kansas and the City of Russell, Kansas (the "Cities").

9   **Q.   Please describe your educational background, employment experience, and**

10   **duties and responsibilities of your current position.**

11   A.   I received a B.S. degree in Atmospheric Science from Purdue University in 1994

12   and M.S. and Ph.D. degrees in Meteorology from the University of Oklahoma in 1998 and 2001,

13   respectively. I joined the Oklahoma Climatological Survey (OCS) as a Research Scientist in 2001

14   and served as the Director of Research from 2002-2018. I served as adjunct faculty in the School

15   of Meteorology (SoM) at the University of Oklahoma from 2010-2011 before joining as regular

16   faculty in the SoM in 2012 and CEES in 2018.

17   I have served as lead or co-author on over 100 peer-reviewed articles related to weather,

18   climate, water, and ecosystems that have been cited over 5,800 times. Over my two decades of

19   service to the scientific community, I have served on numerous panels and committees focused on

20   weather and climate. Currently, I serve on the international Global Energy and Water Exchanges

21   (GEWEX) Regional Hydroclimate Project (RPH) Affinity Group for North America (2021-

22   present) and the COMET (https://www.comet.ucar.edu/) Advisory Panel (2011-present). I have

23   also served as an expert reviewer for many peer-reviewed publications and have served as a

24   technical reviewer and panelist for NASA, NOAA, and the National Science Foundation. In 2021,

25   I testified before the United States House of Representatives - House Subcommittee on the

1   Environment. I also have extensive experience working with community stakeholders across the

2   Southern Great Plains. Overall, I have over 20 years of professional experience working on

3   weather-climate research and education.

4   **Q.   Has this direct testimony been prepared by you or under your direct**

5   **supervision?**

6   A.   Yes, it has.

7   **Q.   Have you previously testified before the Kansas Department of Agriculture–**

8   **Division of Water Resources or any other regulatory agency?**

9   A.   No, I have not.

10   **Q.   Have you testified in any litigation in the prior four years?**

11   A.   Yes: *Enterprise Products Operating LLC v. CPS Energy*, CAUSE NO. MDL

12   2022CI02879, in the District Court, 407th Judicial District, Bexar County, TX.

13   **Q.   Are you sponsoring any exhibits with your direct testimony?**

14   A.   Yes. I Sponsor Exhibit JBB-01, which is my expert report titled "Drought Impacts

15   and Risk to Water Resources in the Smoky Hill Watershed," and which is incorporated into my

16   testimony as if set forth in full.

17   **Q.   What is the purpose of your direct testimony?**

18   A.   My opinions are set forth in detail in my expert report, but in general, my testimony

19   relates to the impact that drought is an ever-present risk in the Smoky Hill Watershed and climate

20   change has had and will continue to have on the hydroclimate of the Great Plains and especially

21   in the Smoky Hill Watershed ("SHW") and, in particular, (1) the likelihood of increased drought

22   conditions over the next 25 to 100 years for the Cities, and (2) the associated impacts to water

23   sources that supply those areas.

1   **Q.   In summary, what did you conclude, and what should public water suppliers**

2   **who lack a drought-resistant water source—like Hays and Russell—do to account for the**

3   **increased likelihood of future drought?**

4   A.   The climatological record demonstrates consistent, regular, and recent high-impact

5   and multiyear drought events for the area including droughts in the 1930s, 1950s, and 2011-2012.

6   Perhaps more importantly, the state of the science demonstrates that the risk of multiyear (i.e.,

7   two-year, five-year, decadal or multi-decadal droughts) will increase significantly for the area over

8   the next 25 to 100 years. More specifically, the evolution of the hydroclimate into the future poses

9   a significant risk to water resources across the SHW domain, and for the citizens of Hays and

10   Russell, KS.

11   As set forth in detail in my expert report, future risk assessments of water resources for the

12   SHW should incorporate the following baselines and outcomes:

13   •   Drought occurrence at multiple temporal scales will continue within the

14   hydroclimate of the SHW region including multidecadal "megadroughts," decadal,

15   annual, subseasonal to seasonal, and flash droughts. All scales of drought should

16   be planned for.

17   •   An increase in seasonal, annual, and interannual drought intensities with a 4–8

18   mm/month (0.16-0.32 inches/month) reduction in precipitation and an 8–16%

19   increase in consecutive dry days from mid-century through 2100. Such increased

20   precipitation deficits will yield an additional water loss of approximately 6.8–13.6

21   billion gallons per month across the SHW during drought events. In addition, an 8–

22   16% increase in consecutive dry days from mid-century through 2100 is projected

23   to occur with increased precipitation deficits of 1–3 inches of rainfall during the

24   summer and reduced water input of approximately 42–126 billion gallons across

25   the SHW. Such water losses represent a total (input) water loss from the system

that cannot be gained back until sufficient, excessive precipitation occurs. As a result, such reductions of precipitation will have both direct and indirect impacts on the municipalities of Hays and Russell.

- A significant increase in decadal and multi-decadal drought risk of 35–60% and 60–85%, respectively. Using the Dust Bowl as a proxy, a decadal drought in the future would lead to water loss from the SHW of approximately 2 trillion gallons, and if the intensity were more consistent with the drought of the 1950's, a decadal drought could yield water losses in excess of 3 trillion gallons. Further, given the increased risk of multidecadal megadrought in the region. It is likely, that by 2100, a megadrought in the Great Plains could yield water loss values in the SHW ranging between 5–10 trillion gallons or more with associated historic and devastating impacts to water resources.

- The timing of subseasonal to seasonal drought is critically important. Flash drought events are more likely in an environment with increased evaporative stress (i.e., warmer temperatures and reduced soil moisture). As evidenced by the 1980 and 2012 events, seasonal events that occur during the climatological peak of precipitation can yield significant water losses (300 billion gallons or more across the SHW) and impacts to water resources due to intensity and timing.

- Scenarios that incorporate the eastward shift of the precipitation/aridity boundary along and adjacent to the 100th Meridian. This should include planning for potential decreases in total annual precipitation of 10% or more, which corresponds to 2.4 inches for Hays, KS and 2.6 inches for Russell, KS. Such deficits in annual precipitation at 10% will yield a reduction of approximately 175 billion gallons of water annually across the combined SHW and SHW Headwaters per year.

- An extension of the growing season by 2-4 weeks. This extended period will drive increased water stress due to increased temperatures and evaporation over a larger annual window. In addition, due to temperature moderation during winter periods, crop diseases and pests will be more likely, thereby increasing the potential incidents of insect damage to crops and insect-borne diseases in humans and animals.

- Reduced soil moisture from the current climatology (e.g., 10-20%). Increased aridity and reduced precipitation will contribute to reductions of soil moisture on an annual scale and periods of enhanced and prolonged soil dryness especially at subseasonal to seasonal periods.

- A reduction of average monthly streamflow of 0-60%. At the annual scale, total streamflow reductions will decrease to approximately 50% by 2100 with individual years reaching 100% reductions during drought periods. The impacts of input water loss at all temporal scales and intensities of drought noted in this report, combined with changing environmental conditions due to climate change in the region, will strongly and negatively impact streamflow. As such, it is likely that overall streamflow will decrease throughout the SHW with extended periods at or below historic minimum values. At the same time, because the variability of precipitation is increasing, excessive precipitation will likely occur at shorter temporal scales causing significant runoff and enhanced erosion when the events occur. Thus, while low streamflow should be expected, short-term periods of high streamflow are also likely, and the enhanced variability of streamflow should also be incorporated.

- Elevated temperatures across the region due to drought and increasing aridity will increase evaporation and transpiration and decrease soil moisture. This will not only impact the SHW but also upstream regions, including the Cedar Bluff

1 Reservoir. As such, less available water in the SHW will occur due to these impacts

2 and should be planned for accordingly.

3 • The socioeconomic impacts of (A) drought, (B) increasing aridity, and (C) the

4 combined effects of A-B will extend to the communities of Hays, KS, Russell, KS,

5 and across the SHW. As such, local businesses reliant on available water, including

6 agriculture and recreation, will be significantly impacted in the absence of

7 mitigation efforts.

8 **Q.   Please describe how you arrived at your conclusions.**

9 A.   As explained in more detail in Section four of my report, I first identified the area

10 of focus as the SHW, which includes the Cities of Hays and Russell, Kansas, as well as the area

11 upstream of the Cities, referred to in my report as the SHW Headwaters. I explain that the Cities'

12 existing water sources are dependent on surface water flow in the Smoky Hill River and Big Creek,

13 in the portion of the SHW downstream from the Cedar Bluff Reservoir.

14 In Sections 4.2 and 4.3, I discuss historical drought occurrence in the focus area and

15 evaluate the impacts of such droughts based on a survey of published studies in the scientific field

16 quantifying drought impacts in both the SHW and in the SHW Headwaters (which serves as critical

17 upstream control of streamflow in the area of the Cities). My evaluation includes the estimated

18 water loss due to precipitation deficits that have occurred in both regions as a result of those

19 historical droughts and analyzes the factors affecting water loss, including how warm temperatures

20 and timing of precipitation can cause intense subseasonal to seasonal-scale "flash" droughts, which

21 develop rapidly compared to most drought events and are more likely to occur in the SHW as

22 compared to other areas in the United States.

23 In Section 4.4, I address the drivers of drought, beginning from the fundamental

24 atmospheric conditions causing a lack of precipitation over an extended period due to "blocking

25 high" pressure areas, which, coupled with elevated temperatures and clear sky conditions result in

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increased evaporation, all of which are generally linked to drought development. I then address how atmospheric conditions in other areas, called "teleconnections," play critical roles in increasing drought duration and intensity in the focus area, including anomalous sea surface temperatures and changes in atmospheric circulation. I then address how interactions between the earth's land surface and the atmosphere, referred to as "land-atmosphere coupling," such as soil moisture, dry surface temperatures, and reduced vegetation also drive drought and associated impacts.

In Section 4.5 and 4.6, I address future drought projection based on the reported results of the Coupled Model Intercomparison Project (CMIP) climate simulation model as well as observed increasing precipitation variability and a changing hydroclimate in the historical record. As I explain, numerous studies have utilized CMIP to simulate the increased risk of drought development, intensification and maintenance, and the attendant impacts—all of which are consistent with generally accepted scientific methodologies and presented within a reasonable degree of professional certainty. My conclusions relating to the risks posed by the evolving hydroclimate in and around the SHW and its headwaters align with the results of those studies.

Q.   Does that conclude your direct testimony?

A.   Yes, it does.

VERIFICATION

STATE OF _____)
)
COUNTY OF _____)

      I Jeffrey B. Basara, being duly sworn, on oath state that I have read the foregoing and know the contents thereof, and that the facts set forth therein are true and correct to the best of my knowledge and belief.

By: _____
                Jeffrey B. Basara, Ph.D.

      The foregoing was subscribed and sworn to before me this _25_ day of _May_,
2023.

_____
Notary Public

My Commission Expires:

_7/24/26_

MISTY WILSON
NOTARY
14006467
EXP. 07/24/26
PUBLIC
STATE OF OKLAHOMA

Drought Impacts and Risk to Water Resources in the Smoky Hill Watershed

Prepared by: Dr. Jeffrey Basara

Jeffrey Basara

11 May 2023

1 - Expert Qualifications

I am an Associate Professor at the University of Oklahoma with a joint appointment between the School of Meteorology (SoM) and the School of Civil Engineering and Environmental Science (CEES). I also serve as the Executive Associate Director for the Hydrology and Water Security (HWS) Program at the University of Oklahoma.

My research focuses on improving fundamental knowledge of the environmental processes driving weather-climate extremes, which yield significant impacts to the natural system and society. In particular, I have (1) worked for over two decades on understanding, monitoring, and improving the prediction of drought from local to global scales with a primary focus on the Great Plains of the United States and (2) worked with various stakeholder groups including agricultural producers, local communities, tribal entities, and state and federal agencies to improve awareness and response to extreme environmental events and associated impacts.

I received a B.S. degree in Atmospheric Science from Purdue University in 1994 and M.S. and Ph.D. degrees in Meteorology from the University of Oklahoma in 1998 and 2001 respectively. I joined the Oklahoma Climatological Survey (OCS) as a Research Scientist in 2001 and served as the Director of Research from 2002-2018. In addition, I served as adjunct faculty in the School of Meteorology at the University of Oklahoma from 2010-2011 before joining as regular faculty in the SoM in 2012 and CEES in 2018.

I have served as a lead or co-author on over 100 peer-reviewed articles related to weather, climate, water, and ecosystems that have been cited over 5,800 times. Over my two decades of service to the scientific community, I have served on numerous panels and committees focused on weather and climate. Currently, I serve on the international Global Energy and Water Exchanges (GEWEX) Regional Hydroclimate Project (RPH) Affinity Group for North America (2021-present) and the COMET (https://www.comet.ucar.edu/) Advisory Panel (2011-present).

In 2021, I testified before the United States House of Representatives - House Subcommittee on the Environment concerning "Working Towards Climate Equity: the Case for a Federal Climate Service." I have also served as an expert reviewer for peer-reviewed publications including the Journal of Climate, Journal of Hydrometeorology, Journal of Geophysical Research-Atmospheres, Water Resources Research, Journal of Hydrology, Nature Communications, Nature Climate Change, Nature Climate and Atmospheric Science, Weather and Forecasting, Remote Sensing, Environmental Research Letters, Geophysical Research Letters, Journal of Applied Meteorology and Climatology, Agriculture and Forest Meteorology. Further, I have served as a technical reviewer and panelist for NASA, NOAA, and the National Science Foundation. Finally, due in part to my positions in OCS and HWS, I have extensive experience working with community

stakeholders across the Southern Great Plains. Overall, I have over 20 years of professional experience working on weather-climate research and education.

Rate: I am being compensated at a rate of $180 per hour.

Previous Cases: Enterprise Products Operating LLC v. CPS Energy, CAUSE NO. MDL 2022CI02879, In the District Court, 407th Judicial District, Bexar County, TX

Curriculum Vitae: My full CV is included in Appendix E of this Report.

2 - Summary of Opinions

Water resources and water availability in the Smoky Hill Watershed (SHW) are impacted by several critical and simultaneous environmental challenges that directly impact the hydroclimate of the region. Specifically related to drought, these challenges include:

- **Drought occurrence will continue** - In the SHW region, drought will continue to occur placing considerable stress on available water resources during and after drought events. This applies to drought at the timescales spanning subseasonal to seasonal (S2S), to annual, to interannual, to decadal, and multidecadal. In addition, there is strong evidence that the intensity of drought events will increase into the future. Uncertainty exists concerning the timing and occurrence of future decadal to multidecadal-length drought periods similar to the 1930's Dust Bowl. Even so, given recent megadrought conditions across the western United States, the history of drought in the Great Plains region, and the projection of future megadroughts, *long-term (decadal to multidecadal) drought is a likely outcome* for the SHW and the municipalities of Hays, KS and Russell, KS by the end of the century. Such an event would remove billions to trillions gallons of water from the SHW and upstream regions and drastically impact available water for the municipalities of Hays, KS and Russell, KS.

- **Precipitation variability in the Great Plains is increasing** - At multiple spatial and temporal scales the *variability* in the magnitude, timing, intensity, and duration of precipitation events is increasing. In particular, the seasonality of precipitation is becoming more variable. The increased variability will increase and exacerbate drought occurrence in the SHW region into the future.

- **The growing season is increasing** - While overall trends in summer temperature conditions have yielded minor increases over the past century, the cool season is significantly warming thereby lengthening the growing season and increasing (a) water loss to the atmosphere via evaporation and (b) water use (transpiration) by vegetation. Thus, even if total annual precipitation remains consistent into the future (e.g., annual totals), the extended growing season will yield an overall reduction in available water from the Smoky Hill River, Big Creek and their alluvia compared to past and current conditions. The extended growing season and increased demand for water resources will increase the risk of drought occurrence and associated impacts in the SHW region into the future.

- **The climate is becoming increasingly arid** - Climate change is producing an overall more arid environment across the SHW region. In a practical sense, this is noted by the eastward shift of the boundary between the humid east and arid west (and associated impacts) that has traditionally been located along the 100th meridian first noted by John Wesley Powell over a century ago. Combined with the increased warming (especially during the cool season) the current climate (and the associated hydroclimate) will become more consistent with that currently associated with locations to the south and west (e.g., Dodge City, KS). The increased aridity will increase drought risk in the SHW region into the future at all temporal scales.

3 - Introduction

As an expert in meteorology and climatology, specifically for the Great Plains of the United States, I have been asked to provide my opinion on (1) the likelihood of increased drought conditions over the next 25 to 100 years for Hays and Russell, Kansas, and (2) the associated impacts to water sources that supply those areas. First, the climatological record demonstrates consistent, regular, and recent high-impact and multiyear drought events for the area including the 1930s, 1950s, and 2011-2012. Perhaps more importantly, the state of the science demonstrates that the risk of multiyear (i.e., two-year, five-year, decadal or multi-decadal droughts) will increase significantly for the Smoky Hill Watershed and adjacent areas over the next 25 to 100 years. All of my opinions on these matters are presented within a reasonable degree of scientific and professional certainty.

The Great Plains (GP) of North America reside in a transition zone between the humid east and the arid west and extend from south Texas to northern Alberta in Western Canada. For this report, specific reference of the Great Plains will primarily focus on those regions within the contiguous United States (US). Further, the Southern Great Plains (SGP) will refer to the region noted by Christian et al. (2015) that includes the states of Kansas, Oklahoma, and Texas.

John Wesley Powell (1890) noted that the 100th meridian[1] serves as a reference barrier between the general climate regions of the humid east and arid west, and has long been established in common lore as a critical feature of the region whereby lives and livelihoods depend on water resources to thrive. In fact, Powell noted that a science-based approach was needed to develop the land along and to the west of the 100th Meridian in a sustainable way to preserve agriculture and water resources. However, living along and adjacent to the 100th meridian poses challenges, especially as related to water resources. This is due to the significant change in annual precipitation from east to west across the region (Fig. 1), particularly in the Southern Great Plains where, across Kansas (Fig. 2), the annual value of precipitation decreases from values in excess of 44 inches across the eastern portions of the state to under 16 inches along the western border. With such a significant natural gradient defining the regional climate, even subtle shifts in the local to global state of the atmosphere can decrease (or increase) local rainfall across the region at various spatial and temporal scales. As such, drought is an ever-present threat to water resources in the region along and adjacent to the 100th meridian.

Willhite and Glantz (1985) noted that drought can be typically divided into four main categories:

1. **Meteorological Drought**, which is defined as an extended precipitation deficit from a climatological mean value.

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[1]The meridian 100° west longitude of the Prime Meridian, Greenwich, England, is the geographic reference line on the earth that extends from the North Pole to the South Pole. The border between the Texas panhandle and Oklahoma is along the 100th Meridian which runs through Clark, Ford, Hodgeman, Ness, Trego, Graham, and Norton Counties in Kansas.

2. **Agricultural Drought**, whereby sufficient drying will reduce soil moisture and lead to drying of the land surface, failure of crops, and overall desiccation.
3. **Hydrologic Drought** in which, after prolonged precipitation deficits and desiccation, impacts to surface and groundwater resources will occur. Streamflow becomes reduced, water-levels drop in surface water storage (ponds, lakes, reservoirs, etc.), and groundwater depletion increases.
4. **Socioeconomic Drought**, which is defined as the threshold whereby the economic demand exceeds supply as a result of a weather-related deficit in water supply. The impacts include reduced water consumption by residences and industry, reduced and limited transportation using surface waterways, and loss of water resources for recreation.

These definitions of drought are well-established and consistent across the scientific community and stakeholders dependent on water resources. More recently, minor modifications to drought definitions have been proposed including by Mishra and Singh (2010), who noted that Groundwater Drought could be treated separately from other components of Hydrologic Drought (e.g., surface water, streamflow, etc.). Additionally, rapid intensification of drought during the growing season has been labeled "flash drought" (Otkin et al. 2018, Lisonbee et al. 2021) and tends to overlap with Meteorological Drought and Agricultural Drought. Depending on the timing and severity of flash drought, such events can have direct impacts on water availability and water resources thereby accelerating the onset of hydrological drought.

Figure 1 – Annual mean total precipitation across the contiguous United States. (Source – NOAA)
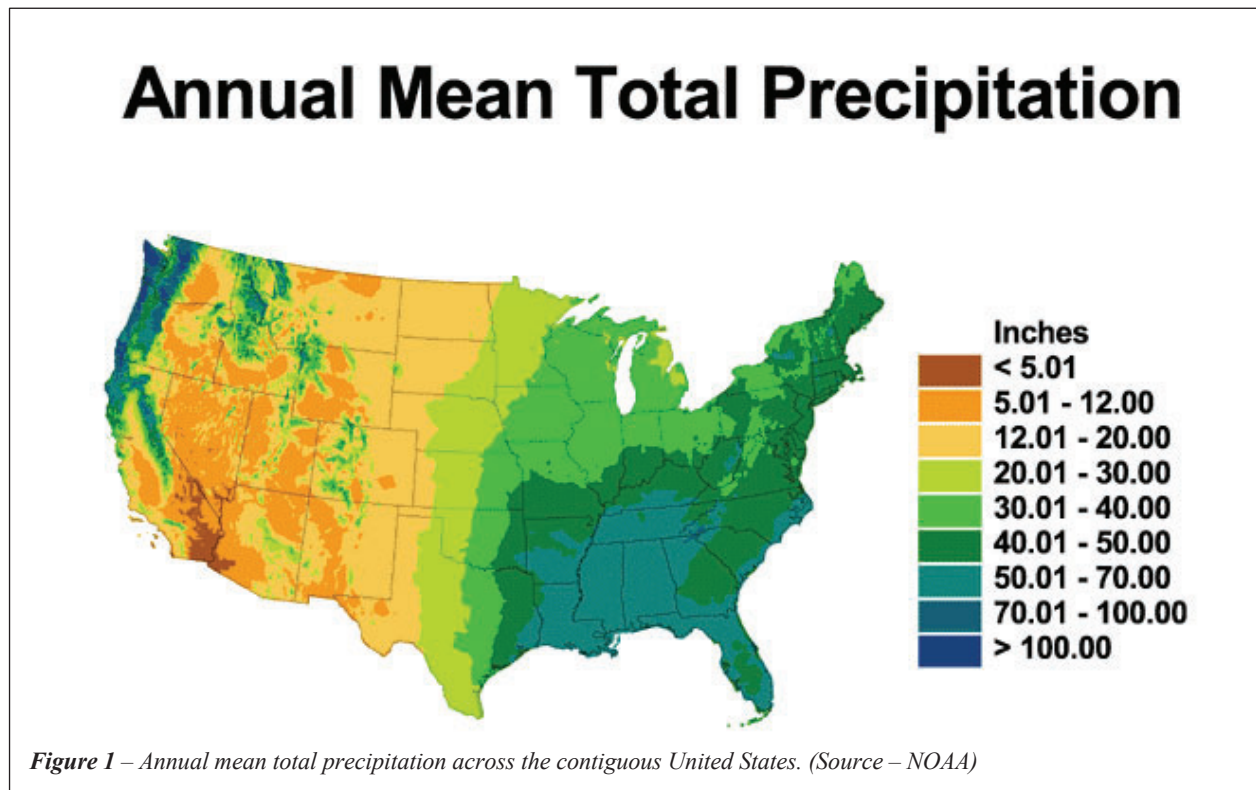
4 – Methodology and Background

4.1 Focus Area

Hays, KS, located at 38.8792° N and 99.3268° W, lies within the Smoky Hill Watershed (SHW), is located in Ellis County, and resides just east and immediately adjacent to the 100th meridian. The average annual precipitation for Hays is 24.4 inches (via the National Oceanic and Atmospheric Administration - NOAA) and Hays, KS is located in the northwest corner of Kansas Climate Division 5. (Fig. 4.)

Russell, KS, located at 38.8953° N and 98.8598° W also lies within the SHW, is located in Russell County (which is just east of Ellis County) and 1.14° east of the 100th meridian. The average annual precipitation for Russell is 26.3 inches (via the National Oceanic and Atmospheric Administration - NOAA) and Russell is also located in Kansas Climate Division 5.

Current municipal water supplies for both Hays and Russell are dependent on the surface water in the portion of the SHW downstream from the Cedar Bluff Reservoir in Trego County and Big Creek, which stretches over 150 miles across portions of northwest and central Kansas with the headwaters to the west of the 100th meridian and the output of the basin to the east (Fig. 3.) As such, precipitation accumulation in both Kansas Climate Division 4 and 5 are critical to the streamflow, surface water storage, and water availability for the municipalities of Hays and

Figure 2 – *Annual mean total precipitation across Kansas. (Source – Kansas State Climate Office)*
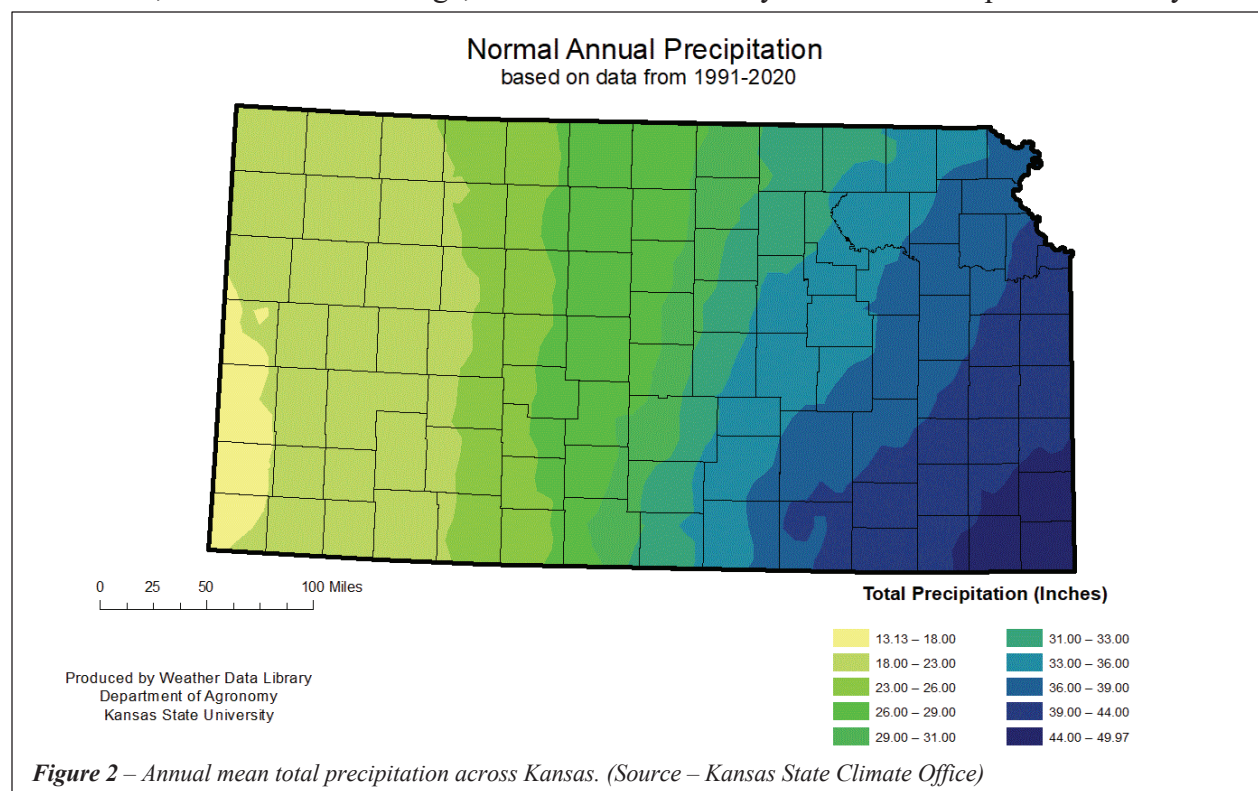
Russell. Hays is near the midpoint of the Watershed as shown in Figure 3 and Russell is approximately 25 miles east of Hays. Not only does the SHW straddle the 100th meridian, but portions of the basin are located in three of the nine Climate Divisions in Kansas established by the NOAA for the state (northwest-1, west-central-4, and central-5; Fig. 4).

4.2 Drought Occurrence

The expansive region encompassed by the Great Plains has experienced drought conditions at multiple spatial and temporal scales. The most infamous drought was the Dust Bowl of the 1930s because of its intensity, duration, devastating economic impacts, iconic dust storm images, and significant social migration (Burnette and Stahle 2013, Cook et al. 2011). The SHW region is located near the epicenter of the Dust Bowl and experienced some of the harshest environmental and water resource conditions during the duration of the event (Table 1).

In addition, during the decade of the 1950s, extreme drought conditions existed across portions of the Southern Great Plains (Cook et al. 2011). However, due to mitigation strategies such as sustainable farming practices focused on preventing soil erosion, the overall societal impacts of drought were significantly less during the 1950s than they were during the Dust Bowl. Even so, persistent drought with severe impacts occurred across the SHW during the 1950s, and the 5-year period spanning 1952-1956 included dramatic precipitation reductions (Table 1).

Table 1. Estimated Water Loss Due to Precipitation Deficits During Droughts of Record[+] in the SHW Domain

Drought Period	Total Precipitation Deficit (inches)	Average Precipitation Deficit per Year	Percentage Change From Annual Average	Water Loss for 1 square mile (gal/mi^2)	Water Loss for 1 square mile per year (gal/mi^2/yr)	Total Water Loss for SHW (gal) – 2439 mi^2	Total Water Loss for SHW (gal) per year – 2439 mi^2
1930-1940 (11 yrs)	-56.86	-5.17	-19.0	988.0 M	89.8 M	2.409 T	219 B
1952-1956 (5 yrs)	-42.11	-8.42	-30.9	731.8 M	146.3 M	1.784 T	357 B
1988-1989 (2 yrs)	-14.33	-7.17	-26.3	249.0 M	124.5 M	607 B	304 B
2011-2012 (2 yrs)	-11.99	-6.00	-22.1	208.4 M	104.2 M	508 B	254 B
1936	-10.25	-10.25	-37.6	178.1 M	178.1 M	434 B	434 B
1956	-12.61	-12.61	-46.3	219.1 M	219.1 M	534 B	534 B
1988	-10.42	-10.42	-38.3	181.1 M	181.1 M	442 B	442 B
2012	-8.76	-8.76	-32.2	152.2 M	152.2 M	371 B	371 B
1980 (Apr-Jul)*	-8.62	NA	NA	149.8 M	NA	365 B	NA
2012 (May-Jul)**	-6.93	NA	NA	120.4 M	NA	294 B	NA

Note: M = Million, B = Billion, T = Trillion
[+]Data represents events that occurred within Kansas Climate Division 5 (KS-CD5)

Both decadal-length drought periods are displayed in Figures 5 and 6 (the annual precipitation and temperature) for Kansas Climate Division 5 (For statewide plots as well as Kansas Climate Divisions 1 and 4, see Appendices A-D). In both cases, significant precipitation deficits coincided with warm temperature anomalies.
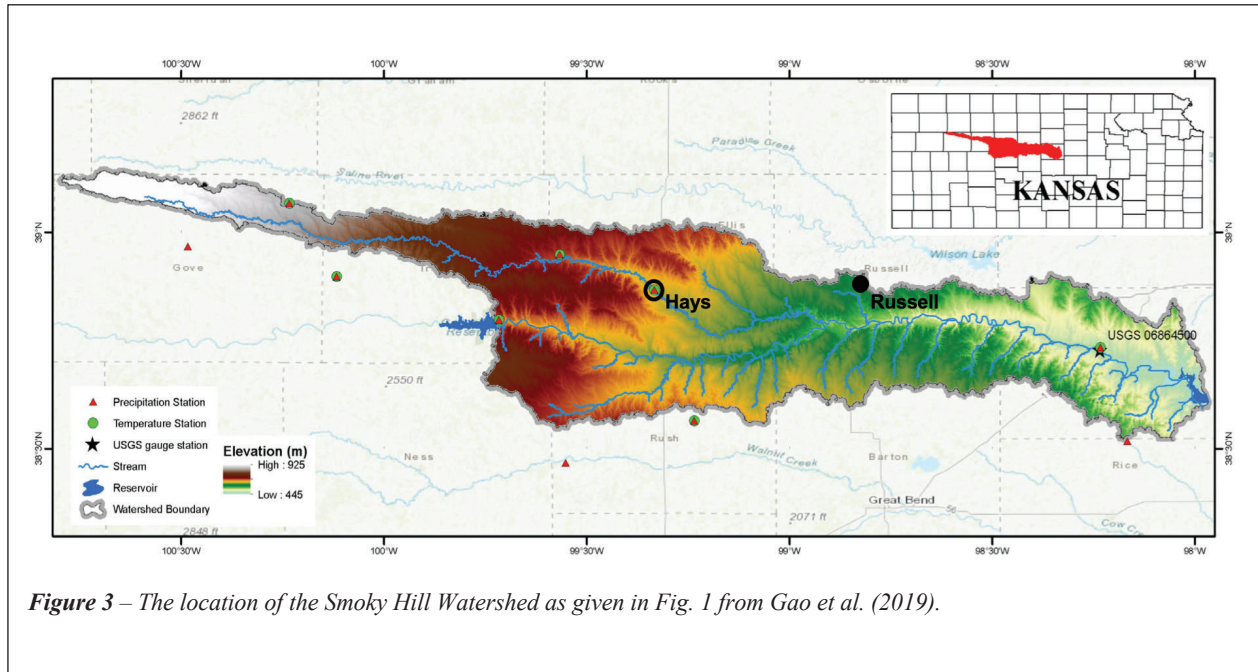
Figure 3 – *The location of the Smoky Hill Watershed as given in Fig. 1 from Gao et al. (2019).*
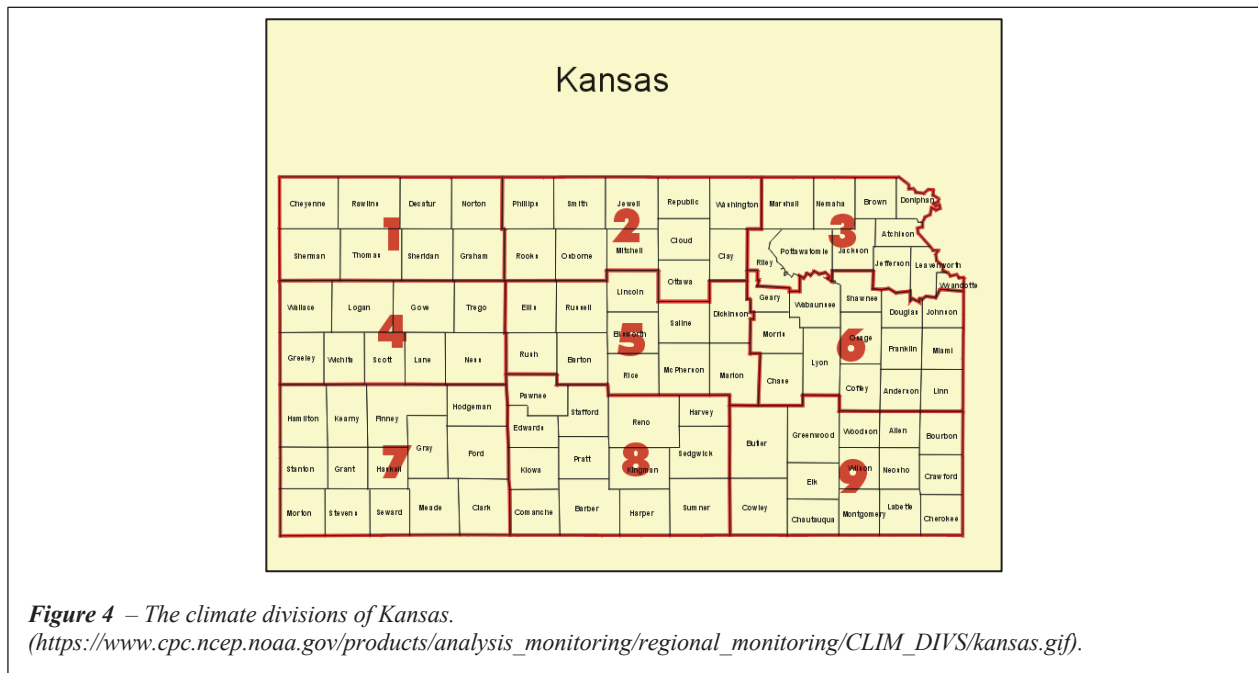

Figure 4 – *The climate divisions of Kansas.*
(https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/CLIM_DIVS/kansas.gif).

Since the 1950's, central Kansas and the region of the SHW have not experienced a decadal-drought event. However, several events spanning 1-2 years have been particularly intense and yielded significant drought impacts including those that occurred in 1966, 1980, 1988-1989, 1994, and 2011-2012 (Skaggs 1978, Karl and Quayle 1981, Trenberth et al. 1988, Woodhouse and Overpeck 1998, Hoerling et al. 2014, Yuan and Quiring 2014, Figs. 5-6). In all events, severe

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drought impacts occurred in the SHW with depleted water resources and significant socioeconomic impacts.

Additional challenges with drought in the Great Plains are events that occur at subseasonal to seasonal scales (S2S). For example, drought developed rapidly during the Fall of 2017 across portions of the Southern Great Plains and reached peak intensity in early 2018. Because precipitation both prior to and immediately after this approximately 6-8 month period of drought was above normal, the annual values for precipitation were near normal during 2017-2018. Nevertheless, portions of the SHW reached severe/extreme drought conditions as defined by the United States Drought Monitor during the Spring of 2018.
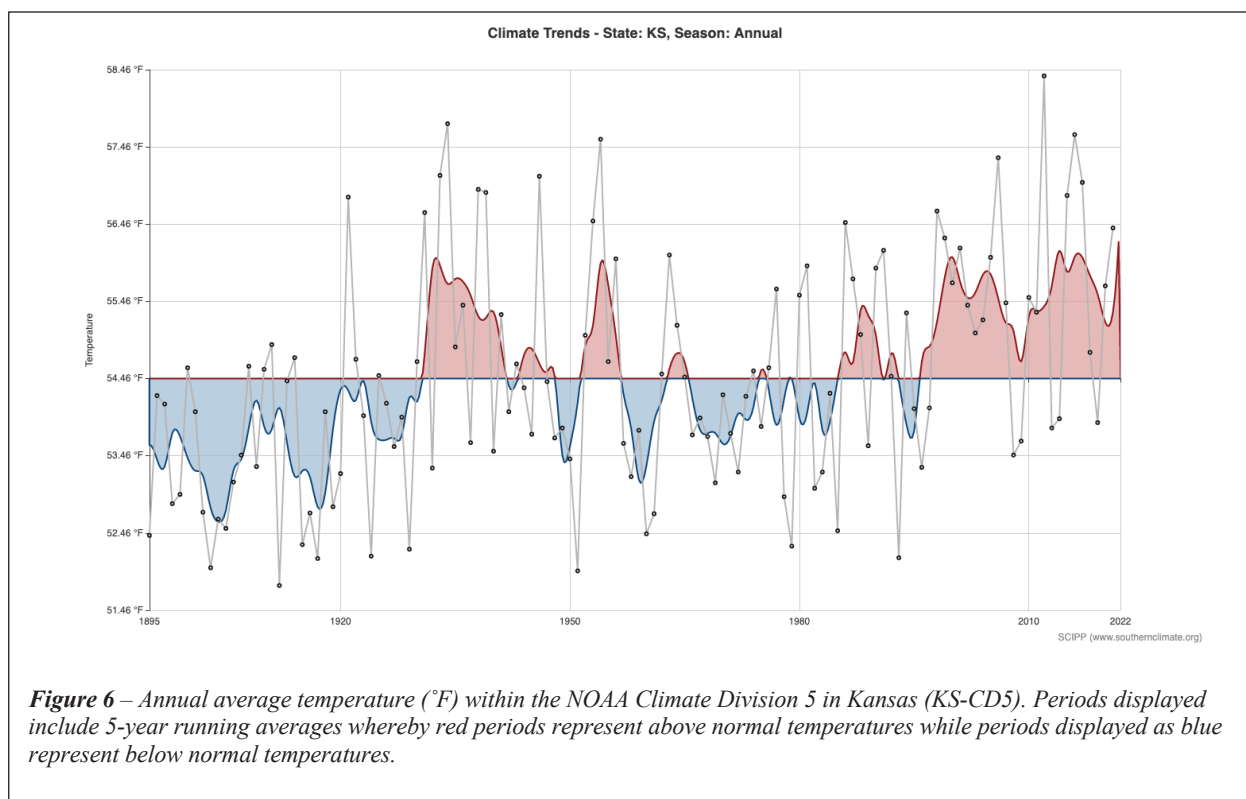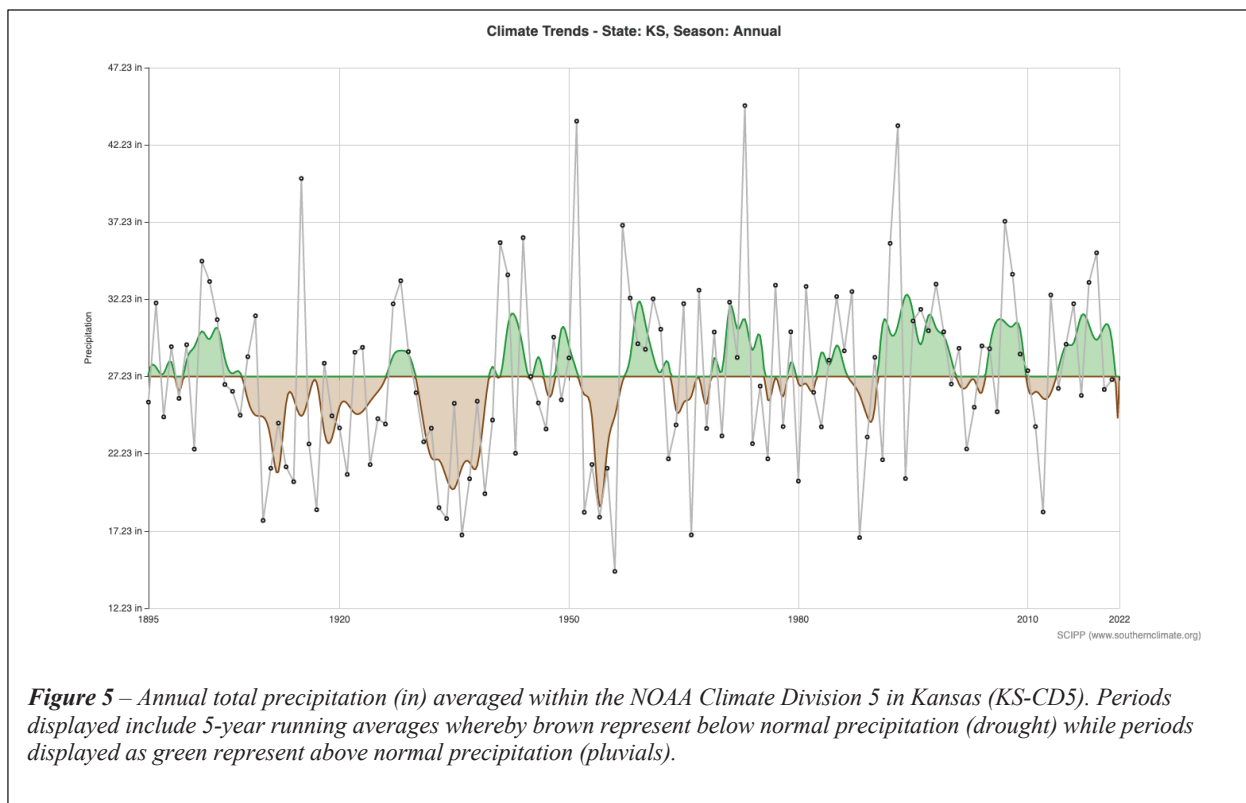
Another event that illustrates S2S drought evolution across the SHW occurred during 2012. In that case, a "flash drought" occurred whereby conditions across central Kansas during late Spring rapidly deteriorated as drought spread across much of the central United States (Basara et al. 2019). Flash droughts are events that develop extremely rapidly (several weeks; Otkin et al. 2018) when compared to most drought (several months). At its peak in 2012, drought conditions reached exceptional drought across the SHW (D4) as defined by the US Drought Monitor - the most intense drought conditions represented by a 2 percentile of occurrence. Further, the 2012 flash drought occurred across the SHW during the climatological peak in precipitation (May – July) yielding significant precipitation deficits in a short temporal window (Table 1). Recent studies that examined the occurrence of flash drought have noted that the Great Plains and all areas within and adjacent to the SHW are embedded within a climatological hotspot of flash drought occurrence (Fig. 7; Christian et al. 2019a,b, Christian et al. 2021). A such, flash drought events are more likely to occur and produce water resource-related impacts in the SHW region than other locations in the United States outside of the Great Plains and the timing of these events can yield similar water resource impacts observed with longer-term drought events.
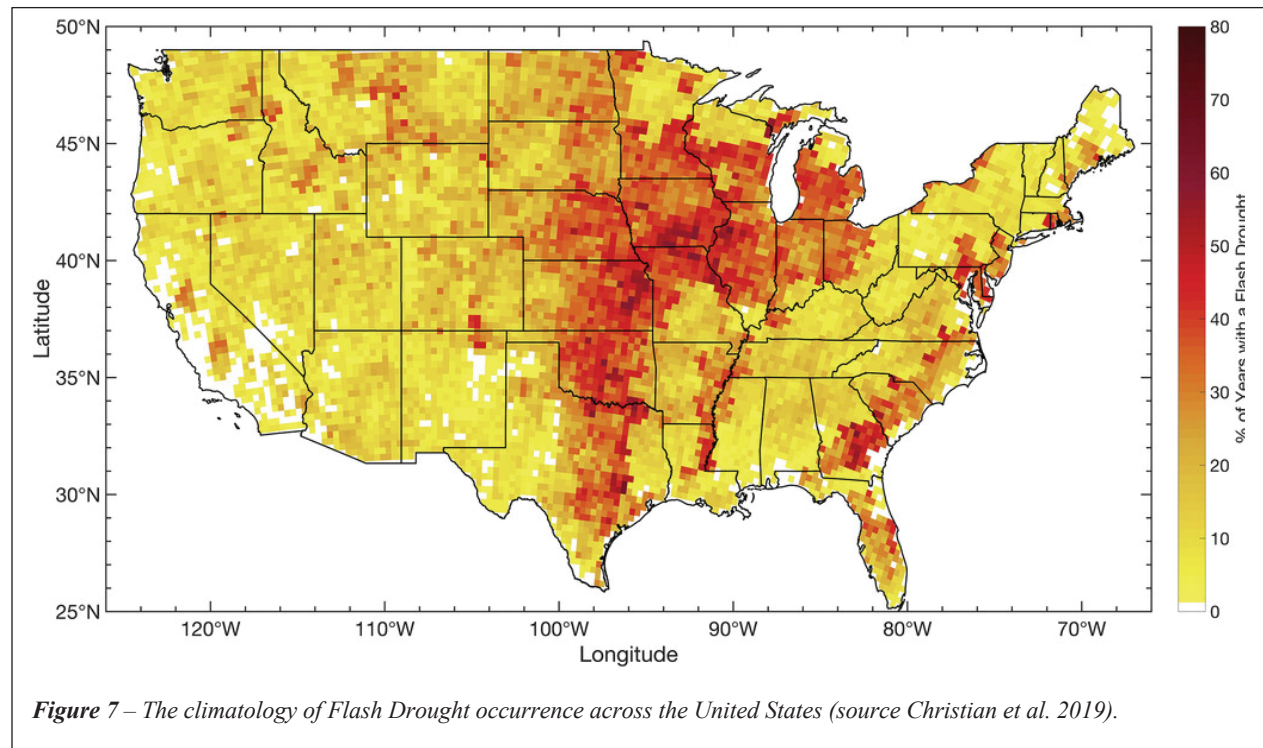
4.3 Water Loss due to Drought in the SHW

The impact of past (historic) drought events on precipitation accumulation in the SHW is displayed in Table 1. The precipitation includes mean values observed in Kansas Climate Division 5 (Fig. 4) applied across the SHW (KS-CD5 encompasses the majority of the SHW in Fig. 3 as well as the municipalities of Hays, KS and Russell, KS). The drought events were selected based on historical impact and relevance to this report.

The Dust Bowl period was a decadal drought with persistent precipitation deficits (from the historical average) that occurred continuously from 1930-1940. During that 11-year period, the accumulated deficit exceeded 56 inches, which, when applied over the 2,439 mi^2 area of the SHW, led to a total water loss (solely due to precipitation) of approximately 2.4 trillion gallons into the basin at a mean rate of approximately 219 billion gallons per year. [2]

[2]One inch or rainfall accumulated over a square mile aggregates to a volume of 17,378,743 gallons.

Figure 5 – *Annual total precipitation (in) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*

Figure 6 – *Annual average temperature (°F) within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

The historic drought of the 1950's lasted from 1952-1956 but included a total reduction of annual precipitation of over 30% for the period, and an average total deficit of over 42 inches during the 5-year drought episode. As a result, the total water loss for the basin due to reduced precipitation was approximately 1.78 trillion gallons of water with a mean rate of approximately 357 billion gallons per year.

Figure 7 – The climatology of Flash Drought occurrence across the United States (source Christian et al. 2019).

While shorter in overall length, the 2-year drought periods spanning 1988-1989 and 2011-2012 both produced total water losses of over 500 billion gallons, while individual years of 1936, 1956, 1988, and 2012 ranged from approximately 371 to 534 billion of gallons of water lost (in a single year) due to the reduction of precipitation during drought across the SHW.

Finally, to illustrate that timing is critical in drought occurrence, the period of May-July 2012 yielded exceptional precipitation deficits due to a flash drought. As such, during the three months that typically yield the greatest annual accumulation of precipitation (i.e., May-July), the deficit of nearly 7 inches resulted in water loss across the SHW of nearly 300 billion gallons of water. A similar event in 1980 that spanned April-July yielded a water loss of approximately 365 billion gallons of water. Thus, even short-term flash drought events can have significant impacts on water resources depending on the timing of the event.

To quantify drought impacts upstream of the SHW, a similar analysis was performed for the Upper Smoky Hill (USH; 1,477.7 mi^2) and Smoky Hill Headwaters (SHH; 721.4 mi^2) watersheds in Climate Region 4; the results for droughts of record for the USH/SHH regions are displayed in Table 2. The combined areal extent of these two Hydrological Units spans approximately 2,199 mi^2, includes the Cedar Bluff Reservoir on the eastern border, and extends west to the border between Kansas and Colorado. Because this region serves as the critical upstream control of streamflow into the SHW, impacts to this area will have direct impacts on the SHW, and as such, are relevant to this report. The precipitation data used in this analysis correspond to Kansas Climate Division 4 (Fig. 4) given the region resides within the west-central region. Further, while the Dust Bowl and 1950's drought periods are consistent between Tables 1 and 2, minor differences in the shorter-term droughts of record are reflected in the analyses.

Table 2. Estimated Water Loss Due to Precipitation Deficits During Droughts of Record[++] in the SHW Headwaters

Drought Period	Total Precipitation Deficit (inches)	Average Precipitation Deficit per Year	Percentage Change From Annual Average	Water Loss for 1 square mile (gal/mi^2)	Water Loss for 1 square mile per year (gal/mi^2/yr)	Total Water Loss for SHW Headwaters (gal) – 2199 mi^2	Total Water Loss for SHW Headwaters (gal) per year – 2199 mi^2
1930-1940 (11 yrs)	-37.04	-3.36	-17.4	643.7 M	58.5 M	1.415 T	129 B
1952-1956 (5 yrs)	-30.25	-6.05	-31.3	525.7 M	105.1 M	1.156 T	231 B
1988-1989 (2 yrs)	-5.53	-2.77	-14.4	96.1 M	48.1 M	211 B	106 B
2010-2013 (4 yrs)	-11.82	-2.96	-15.3	205.4 M	51.4 M	452 B	113 B
1934	-8.41	-8.41	-43.6	146.1 M	146.1 M	321 B	321 B
1956	-9.62	-9.62	-49.8	167.2 M	167.2 M	368 B	368 B
1988	-4.26	-4.26	-22.1	70.0 M	70.0 M	153 B	153 B
2012	-7.40	-7.40	-38.3	128.6 M	128.6 M	283 B	283 B
2012 (May-Jul)**	-6.42	NA	NA	111.6 M	NA	294 B	NA

Note: M = Million, B = Billion, T = Trillion
[++]Data represents events that occurred within Kansas Climate Division 4 (KS-CD4)

Overall, the impacts of the droughts of record spanning the Dust Bowl, the 1950's, and shorter-term periods displayed in Table 2 are consistent with the SHW analysis in Table 1. As such, when these events occur, billions of gallons of water are lost (on an annual basis) from the region immediately upstream of the SHW. Further, when aggregated to the sub-decadal and decadal droughts of the 1950's and the Dust Bowl era of the 1930's, ***total water losses extend beyond a trillion gallons***.

4.4 Drivers of Drought

Overall, the development, intensification, evolution, and termination of drought is complex and involves multiple environmental processes. The primary aspect of drought is a lack of precipitation. Sinking air through the atmospheric column reduces cloud cover and precipitation and is perhaps the simplest cause of drought. A key feature that yields large-scale dynamic subsidence is a pronounced mid-tropospheric ridge and near-surface anticyclone (surface high

pressure). During drought, these features persist for extended periods (often referred to "blocking highs" or "blocks" given that they remain in place for long periods) and inhibit the formation of precipitation while enhanced elevated temperatures and clear-sky conditions increase evaporative demand and water loss from the surface. Such features have been linked to drought development at S2S, annual, interannual, and decadal scales across the Great Plains (Basara et al. 2019, Cook et al. 2014, Jong et al. 2022, Wang et al. 2015).

In addition, multiple factors often play critical roles in reducing precipitation for extended durations suitable for the development, intensification, and persistence of drought. "Teleconnections" is a term used to describe how environmental factors in one area or region on the planet, can impact processes in another. In the case of drought, multiple teleconnections lead to subsidence (sinking air) and a reduction of precipitation in the Great Plains and SHW. However, uncertainty remains as to what specific teleconnections play the greatest role in drought development in the region. Sea surface temperature (SST) anomalies (i.e., warmer or colder than "normal" conditions) can impact the overlying atmosphere and alter the overall atmospheric circulation. Through teleconnections such as the El Niño-Southern Oscillation (ENSO), changes to the atmospheric circulation can drive drought in the SHW region (Seager et al. 2005, Schubert et al. 2004). In general, within the Great Plains there is a tendency for drought when the tropical SSTs are colder than normal (La Niña)[3]. In particular, when negative (cold) SST anomalies exist in the Pacific, the subtropical jet and intertropical convergence zone (ITCZ) are shifted north, and subsidence develops in the midlatitudes (and in SHW region) suppressing precipitation. In addition, the Hadley cell which is a global feature that produces rising air near the equator and sinking air at approximately 30ºN latitude[4] (and south), is strengthened during negative SSTs anomalies. Thus, sinking air yields increased descent over the Gulf of Mexico and the southeast US. As a result, water vapor transport from the Gulf of Mexico by the low-level jet stream to the Great Plains is reduced, which limits precipitation and prolongs drought conditions (Seager et al. 2005, Mo et al. 1997). This is illustrated by a study led by White et al. (2008) who noted that La Niña conditions are correlated with April-August drought in the region. More recently, Hoerling et al. (2012) noted that La Niña conditions likely played a critical role in extreme drought conditions that formed during the summer of 2011 over the Southern Great Plains.

Another teleconnection relevant to drought in the Great Plains is associated with the Pacific Decadal Oscillation (PDO) which consists of SST anomalies primarily in the north Pacific Ocean that vary much more slowly than ENSO. Both phases of the PDO (i.e., warmer and colder than normal) are factors causing drought in the Great Plains: under positive PDO, drought tends to be associated with lower sea level pressure (SLP) and hotter than normal temperatures over the continent, while under negative PDO, drought tends to be associated with higher SLP and nearly normal temperatures, especially early in the warm season (Engelhart and Douglas 2003).

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[3]Ongoing exceptional (D4) drought (as of 1 May 2023) was preceded by La Niña conditions.

[4]30ºN is the approximate latitude of New Orleans (29.95ºN) and Houston (29.76ºN).

A critical challenge in understanding how teleconnections cause or impact drought conditions is the strength and the magnitude of the processes and impacts on the associated atmospheric circulation. In some cases (e.g., 1988, 2012, etc.), forcings from teleconnections (ENSO and PDO) can "phase" and create a favorable environment for drought formation and persistence. However, in other cases, teleconnections may counteract each other and yield limited drought impacts.

Just as drought can be affected by SSTs and the resulting atmospheric circulations, drought is often enhanced by land-atmosphere coupling (i.e., interactions between the earth's land surface and the atmosphere). Climate transition zones, where strong gradients of temperature and precipitation exist over a relatively small distance, are particularly prone to strong feedbacks between the land surface and the atmosphere (Seneviratne et al. 2006). Such conditions exist in the Great Plains, and numerous studies have demonstrated that strong coupling occurs at various spatial and temporal scales during the warm season (Koster et al. 2004, Livneh and Hoerling 2016, Basara and Christian 2018, Wakefield et al. 2019).

Soil moisture is the main variable that drives land-atmosphere coupling related to drought. Soil that is already dry can enhance a drought by several methods: the dry soil contributes to warming surface temperatures, reduced vegetation (and evapotranspiration), and decreased precipitation (Trenberth et al. 1988, Koster et al. 2004, Hong and Kalnay 2000). These mechanisms create positive feedback loops, making drought self-perpetuating (Trenberth et al. 1988).

Soil moisture was at an extreme minimum during the Dust Bowl of the 1930s, and Cook et al. (2008) noted that the amount of dust emission in 1935 further reduced evaporation rates and precipitation. Additional recent studies by Basara and Christian (2018), and Wakefield et al. (2019), demonstrated that very strong feedback processes between the land surface and the atmosphere strengthened and perpetuated drought during most of the recent events in the Southern Great Plains that occurred during the growing season including 1980, 1988, 2006, 2011, and 2012.

On the whole, land-atmosphere coupling is a significant process that drives drought in the Great Plains, particularly in its perpetuation. Further, land-atmosphere coupling often plays a significant role at a more local area and on smaller time scales, while teleconnection and synoptic causes (i.e., features that produce blocking ridges and strong surface high pressure) tend to be the major forcings of drought at a larger area and on longer time scales (Schubert et al. 2004, Koster et al. 2004). Perhaps most importantly, droughts that may be initially caused by teleconnections can be maintained through the growing season by land-atmosphere feedbacks such as desiccated soils (Trenberth et al. 1988, Hong and Kalnay 2000).

Precipitation changes within the hydroclimate of the SHW region and adjacent areas further impact the occurrence and intensity of drought. For example, Dai (2011) noted that dry patches in the Great Plains have been increasing and Zambreski et al. (2018) found that overall drought

variability in the region has been increasing. Thus, changes in the distribution and timing of precipitation will impact drought occurrence and intensity.

4.5 Future Drought

To understand future drought development, occurrence, and intensity, climate simulations are utilized. The Coupled Model Intercomparison Project (CMIP) includes a suite of climate models developed by research centers and government agencies around the world to simulate future scenarios that capture key feedbacks between the atmosphere, oceans, and land. The two most recent ensembles of climate simulations, CMIP5 (Taylor et al. 2012) and CMIP6 (Eyring et al. 2016), offer key insights into drought within the SHW domain. To provide standardized and consistent reference points where the different CMIP model simulations can be compared, "Representative Concentration Pathways" were selected. The Representative Concentration Pathways (RCP's) represent multiple scenarios by which the climate may evolve depending on greenhouse gas emissions and associated radiative impacts to the earth climate system, often in reference to values early in the century (e.g., 2000) compared with periods in the future (e.g., 2100). The RCP's are numbered (2.6, 4.5, 6.0, and 8.5) based on composite radiative increases in watts per square meter (W/m^2) within the earth climate system. Thus, 2.6 represents minor increases of energy input into the global climate system while 8.5 includes significant greenhouse emissions and the greatest impacts and warming to the climate system. In terms of which of these scenarios currently and most closely aligns with the current climate system, Schwalm et al. (2020) noted that RCP8.5 is the most representative of the current pathway that the climate is evolving on (i.e., versus 2.6, 4.5, 6.0).

Ukkola et al. (2020) examined drought occurrence and intensity using CMIP5 and CMIP6 simulations. The results noted that the simulations represent the historical analysis well (demonstrating that the models have been properly calibrated), and as such, represent drought in the Great Plains and the SHW. In addition, the analyses demonstrated increased drought intensity and precipitation reductions on the order of 4-8 mm/month (0.16-0.32 inches/month) during future drought events.
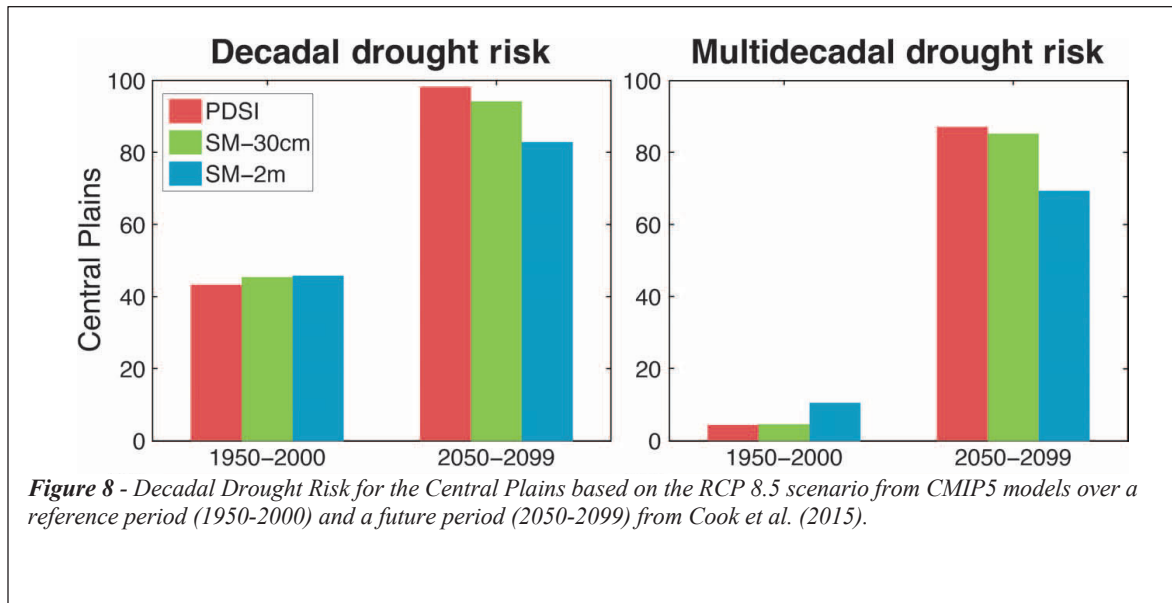
Drought is accentuated or mitigated by the frequency of precipitation. As such, increased duration between precipitation events will increase the risk of drought development, intensification, and maintenance. Akinsanola et al. (2020) utilized 12 CMIP6 models and RCP8.5 to analyze drought across the U.S. during the climatological summer months (June, July, August). The results indicate that the SHW domain will see an increase of 8-16 percent in consecutive dry days during the summer period as the climate progresses into the latter half of the century (i.e., 2051-2100). Such increases in dry days (alone) would (1) lead to increased precipitation deficits of 1-3 inches of rainfall during the summer, (2) reduce water input of approximately 42 – 126 billion gallons across the SHW, and (3) increase the risk and intensity of drought.

Additionally, Cook et al. (2022) examined the critical feature of "blocking highs" over the Central Plains using 6 members of the CMIP6[5] model suite and found an increase in the occurrence of ridging events associated with precipitation deficits and significant growing season soil moisture desiccation. Such events are critical to the development of S2S, flash drought, and annual drought events.

While precipitation deficits represent the first-order occurrence and impacts of drought (i.e., meteorological drought), soil moisture and runoff are critical variables associated with the evolution and impacts of drought throughout the water cycle. Cook et al. (2020) utilized CMIP6 simulations to demonstrate that precipitation-related drought was maximized (with increased risk) across the western US and extending into the Great Plains. More importantly, the results demonstrated greater relative decreases in warm-season soil moisture and runoff and a higher proficiency of robust drying that impacts the whole range of water resources in the SHW domain. These results are consistent with Gao et al. (2019) who used six models from the CMIP5 suite and a range of RCPs to examine future streamflow in the SHW. The results noted that for both near-future (2041-2060) and distant-future (2081-2100) periods, all RCPs consistently show a reduction in streamflow with a consistent reduction of approximately 50% total streamflow by 2100 despite the results showing some periods at monthly scales with increased streamflow due to variability in precipitation. Further, the range of outcomes varies between models and RCPs. However, for the periods spanning 2041-2060 and 2081-2100 the models are in near unanimous agreement, namely that within both periods, annual streamflow will decrease by over 90% in particularly dry periods (i.e., drought) with numerous cases of 100% streamflow reduction. Further, Granco et al. (2020) found annual streamflow would decrease by more than 50% (compared to baseline) approximately twice per decade during significant drought events for the period spanning mid-century (2041-2060) with the potential for such events yielding nearly 80% reductions. By the end-of-century (2081-2100), the magnitude of the streamflow reduction during drought significantly increases with several drought events exceeding 90% annual reduction in streamflow across the SHW while the frequency increases to approximately 2.5 drought events per decade with at least 50% annual reduction in streamflow.

Finally, because long-term drought is a fundamental and critical risk to the central United States, Cook et al. (2015) examined decadal and multidecadal drought risk in the Central Plains. Overall, the study concluded that the climatological, baseline risk associated with decadal drought in the Central Plains is approximately 40% over a 50-year period while multidecadal drought risk is less than 10%. However, projections of future climate calibrated to past climatology (1950-2000) and utilizing CMIP5 models with the RCP8.5 pathway, concluded that (1) there is a 35-60% increase in decadal drought risk to values that exceed 80% and (2) a 60–85% increase in multidecadal drought risk for the last half of the century (i.e., 2050-2099) to values that exceed 70% for the SHW domain (Fig. 8.).

[5]To address uncertainty and calibration with global climate models, the standard practice is to utilize simulations from several climate models and compare results for consistency and robustness.

Figure 8 *- Decadal Drought Risk for the Central Plains based on the RCP 8.5 scenario from CMIP5 models over a reference period (1950-2000) and a future period (2050-2099) from Cook et al. (2015).*

4.6 Precipitation Variability and a Changing Hydroclimate

The Hydroclimate of the Great Plains is changing, especially at sub-annual scales. Numerous studies based on past observations have highlighted that, over the past 100 years, multiple changes have been occurring in the intensity and timing of precipitation in the region, and specifically the GP, SGP, and SHW domains. For example, Weaver et al. (2016) found that since the 1950's the overall precipitation variability in the SGP has been steadily increasing. Similarly, Christian et al. (2015) found that strong whiplash events can occur between drought and pluvial (excessive precipitation) events on an annual basis whereby a drought year is immediately followed by a pluvial year due to excessive precipitation of a similar magnitude. Perhaps more importantly, the study determined that the frequency of drought to pluvial transitions has been steadily increasing whereby the interval of an event that may have occurred roughly every 20 years has decreased to once every 9 years since 1960.

There is also increasing evidence that the seasonality of precipitation in the Great Plains is also becoming more variable both as observed in the historical record (Flanagan et al. 2018) and via CMIP6 simulations (Marvel et al. 2021). Further, thunderstorms during the warm-season are critical contributors to the precipitation accumulation in the Great Plains and the SHW region (Haberlie and Ashley 2019) and recent CMIP6 simulations project an overall decrease in thunderstorms over the SHW and surrounding area of the Great Plains through the latter half of the century (Haberlie et al. 2022).

It is also important to note, that while <u>overall trends</u> in summer temperature conditions have changed little over the past half-century in the region encompassing and adjacent to the SHW,

discernable and consistent warming has been observed during the Spring, Autumn, and Winter seasons (i.e., statewide, CD1, CD4, and CD5 – See Appendices A-D). The net effect is not only a warming climate in general, but an extension of the growing season across the SHW domain. Perhaps most alarming, Seager et al (2018a,b) found that the boundary that has been traditionally identified as the dividing line of North America between the humid east and arid west (i.e., the 100th Meridian), is slowly migrating to the east. The results, determined via observational analysis (Seager et al. 2018a) and CMIP6 simulations (Seager et al 2018b), illustrate that the SHW is slowly becoming more arid over time. Further, CMIP5 simulations of future climate for SGP and SHW show a consistent drying trend through both the mid-century (2036-2065) and late century (2070-2099) when compared to the baseline of 2005 (Figs. 9-10; Dixon et al. 2020). Depending on the RCP, this includes annual reductions approaching 10% in the RCP8.5 simulations across the SHW and adjacent regions.

5 – Conclusions

The evolution of the hydroclimate into the future poses ***a significant risk*** to water resources across the SHW domain, and for the citizens of Hays and Russell, KS. Further, each of the aforementioned challenges individually increases the risk to water resources in the SHW domain. Moreover, in the current and evolving hydroclimate, the combination of these features can lead to compound and cascading events that significantly stress the availability of water. Based on the current scientific understanding and the studies noted, future risk assessments of water resources for the SHW should incorporate the following baselines and outcomes:

1. Drought occurrence at multiple temporal scales will continue within the hydroclimate of the SHW region including megadrought, decadal, annual, S2S, and flash drought. All scales of drought should be planned for.
2. An increase in seasonal, annual, and interannual drought intensities with a 4-8 mm/month (0.16-0.32 inches/month) reduction in precipitation and an 8-16% increase in consecutive dry days from mid-century through 2100. Such increased precipitation deficits will yield an additional water loss of approximately 6.8 – 13.6 billion gallons per month across the SHW during drought events. In addition, an 8-16% increase in consecutive dry days from mid-century through 2100 is projected to occur with increased precipitation deficits of 1-3 inches of rainfall during the summer and reduced water input of approximately 42 – 126 billion gallons across the SHW. Further, such water losses represent a total (input) water loss from the system that cannot be gained back until sufficient, excessive precipitation occurs. As a result, such reductions of precipitation will have both direct and indirect impacts on the municipalities of Hays and Russell, KS.
3. A significant increase in decadal and multi-decadal drought risk of 35-60% and 60-85% respectively. Using the Dust Bowl as a proxy, a decadal drought in the future would lead to water loss from the SHW of approximately 2 trillion gallons, and if the intensity were more consistent with the drought of the 1950's, ***a decadal drought could yield water losses***

in excess of 3 trillion gallons. Further, given the increased risk of multidecadal megadrought in the region it is likely that, by 2100, a megadrought in the Great Plains could yield water loss values in the SHW ranging between ***5-10 trillion gallons or more*** with associated historic and devastating impacts to water resources.

4. The timing of subseasonal to seasonal drought is critically important. Flash drought events are more likely in an environment with increased evaporative stress (i.e., warmer temperatures and reduced soil moisture). As evidenced by the 1980 and 2012 events, seasonal events that occur during the climatological peak of precipitation can yield significant water losses (300 billion gallons or more across the SHW) and impacts to water resources due to *intensity and timing*.

5. Scenarios that incorporate the eastward shift of the precipitation/aridity boundary along and adjacent to the 100th Meridian. This should include planning for potential decreases in total annual precipitation of 10% or more, which corresponds to 2.4 inches for Hays, KS and 2.6 inches for Russell, KS. Such deficits in annual precipitation at 10% will yield a reduction of approximately 175 billion gallons of water annually across the combined SHW and SHW Headwaters per year.

6. An extension of the growing season by 2-4 weeks. This extended period will drive increased water stress due to increased temperatures and evaporation over a larger annual window. In addition, due to temperature moderation during winter periods, crop diseases and pests will be more likely, thereby increasing the potential incidents of insect damage to crops and insect-borne diseases in humans and animals.

7. Reduced soil moisture from the current climatology by at least 10-20%. Increased aridity and reduced precipitation will contribute to reductions of soil moisture on an annual scale and periods of enhanced and prolonged soil dryness especially at S2S periods.

8. A reduction of average monthly streamflow of 0-60%. At the annual scale, total streamflow reductions will decrease to approximately 50% by 2100 with ***individual years reaching 100% reductions during drought periods***. The impacts of input water loss at all temporal scales and intensities of drought noted in this report, combined with changing environmental conditions due to climate change in the region, will strongly and negatively impact streamflow. As such, it is likely that overall streamflow will decrease throughout the SHW with extended periods at or below historic minimum values. At the same time, because the variability of precipitation is increasing, excessive precipitation will likely occur at shorter temporal scales causing significant runoff and enhanced erosion when the events occur. Thus, while low streamflow should be expected, short-term periods of high streamflow are also likely and the enhanced variability of streamflow should also be incorporated.

9. Elevated temperatures across the region due to drought and increasing aridity will increase evaporation and transpiration and decrease soil moisture. This will not only impact the SHW but also regions immediately upstream in the USH and SHH and including the Cedar

Bluff Reservoir. As such, less available water in the SHW will occur due to these impacts and should be planned for accordingly.

10. The socioeconomic impacts of (A) drought, (B) increasing aridity, and (C) the combined effects of A-B will extend to the communities of Hays, KS, Russell, KS, and across the SHW. As such, local residents businesses reliant on available water, including agriculture and recreation, will be significantly impacted in the absence of mitigation efforts to preserve the water resources of the region.
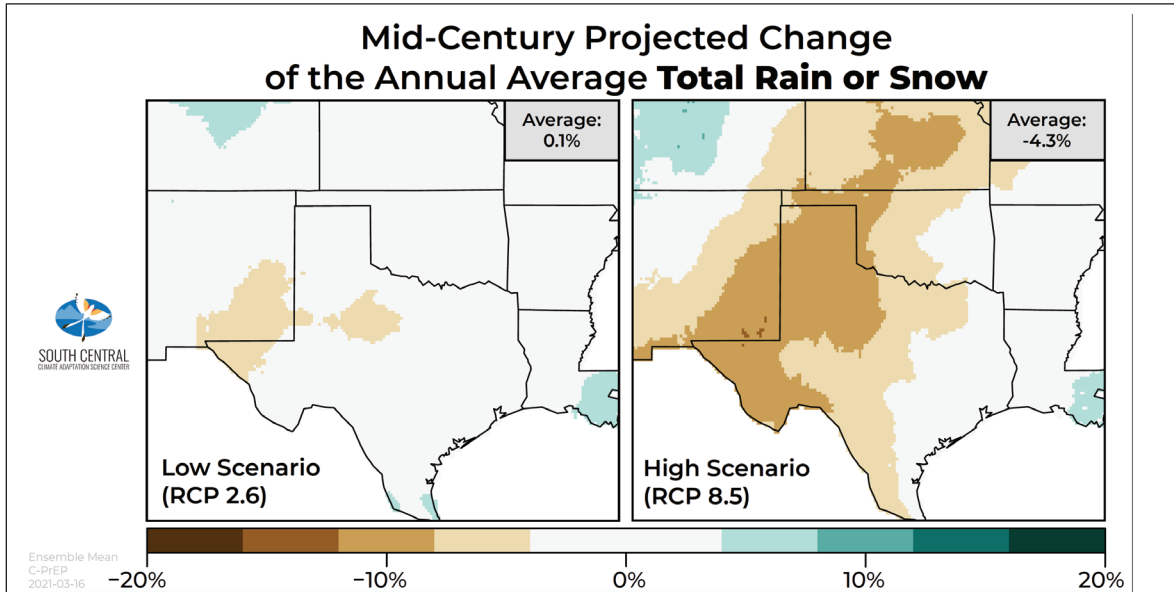

Figure 9 *– Change in annual precipitation for the Southern Great Plains determined from the ensemble mean of 81 projections from CMIP5 models. The reference period spans 1981-2005 and the Mid-Century future period spans*
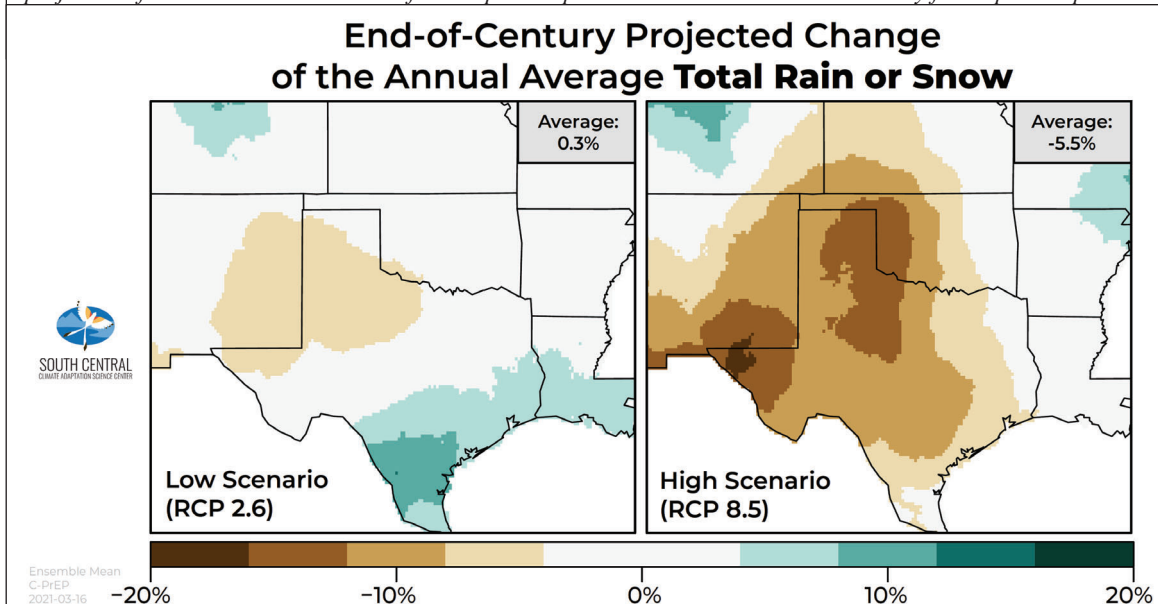

Figure 10 *– Change in annual precipitation for the Southern Great Plains determined from the ensemble mean of 81 projections from CMIP5 models. The reference period spans 1981-2005 and the End-Of-Century future period spans 2070-2099. (Source – South Central Climate Adaptation Science Center)*

References

Akinsanola, A. A., G. J. Kooperman, K. A. Reed, A. G. Pendergrass, and W. M. Hannah, 2020: Projected changes in seasonal precipitation extremes over the United States in CMIP6 simulations. *Environ. Res. Lett.*, **15**, doi:10.1088/1748-9326/abb397.

Basara, J. B., and J. I. Christian, 2018: Seasonal and interannual variability of land–atmosphere coupling across the Southern Great Plains of North America using the North American regional reanalysis. *International Journal of Climatology*, **38**, 964–978.10.1002/joc.5223.

Basara, J. B., Christian, J., Wakefield, R., Otkin, J., Hunt, E., and D. Brown, 2019: The evolution, propagation, and spread of flash drought in the Central United States during 2012. *Environmental Research Letters,* **14,** 084025. https://doi.org/10.1088/1748-9326/ab2cc0

Burnette, D., and D. Stahle, 2013: Historical Perspective on the Dust Bowl Drought in the Central United States. *Climatic Change*, **116**, 479-494.

Christian, J., K. Christian, and J. B. Basara, 2015: Drought and Pluvial Dipole Events within the Great Plains of the United States. *J. Appl. Meteor. Climatol.*, **54**, 1886–1898.

Christian, J., Basara, J. B., Otkin, J., Hunt, E., Wakefield, R., Flanagan, P., Xiao, X., 2019: A Methodology for Flash Drought Identification: Application of Flash Drought Frequency Across the United States. *Journal of Hydrometeorology,* **20**, 833–846. https://doi.org/10.1175/JHM-D-18-0198.1.

Christian, J., Basara, J. B., Otkin, J., Hunt, E, 2019: Regional characteristics of flash droughts across the United States. *Environmental Research Communications,* **1,** 12, doi: 10.1088/2515-7620/ab50ca.

Christian, J., Basara, J. B., Hunt, E., Otkin, J., Furtado, J., Xiao, X. and R. Randall, 2021: Global Distribution, Trends, and Drivers of Flash Drought Occurrence. *Nature Comms.,* **12,** 6330 (2021).

Cook, B. I., R. L. Miller, and R. Seager, 2008: Dust and Sea Surface Temperature Forcing of the 1930s 'Dust Bowl' Drought. *Geophysical Research Letters*, **35**, No. 8.

Cook, B., R. Seager and R. Miller, 2011: Atmospheric Circulation Anomalies during Two Persistent North American Droughts: 1932-1939 and 1948-1957. *Climate Dynamics*, **36**, 2339-2355.

Cook, B. I., R. Seager, J.E. Smerdon, 2014: The worst North American drought year of the last millennium: 1934. *Geophysical Research Letters*, **41**, 7298–7305.

Cook, B. I., T. R. Ault, and J. E. Smerdon, 2015: Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Sci. Adv.*, **1**, e1400082.

Cook, B. I., J. S. Mankin, K. Marvel, A. P. Williams, J. E. Smerdon, and K. J. Anchukaitis, 2020: Twenty-First Century Drought Projections in the CMIP6 Forcing Scenarios. *Earth's Future*, **8,** e2019EF001461.

Cook, B. I., A. P. Williams, and K. Marvel, 2022: Projected changes in early summer ridging and drought over the Central Plains. *Environmental Research Letters*, in review.

Dai, A., 2011: Characteristics and trends in various forms of the Palmer Drought Severity Index

during 1900–2008. *Journal of Geophysical Research: Atmospheres*, **116**.

Dixon K.W., A.M. Wootten, M.J. Nath, J. Lanzante, D.J. Adams-Smith, C.E. Whitlock, C.F. Gaitán, R.A. McPherson, 2020: South Central Climate Projections Evaluation Project (C-PrEP), South Central Climate Adaptation Science Center, Norman, Oklahoma, USA. DOI: **https://doi.org/10.21429/12gk-dh47**

Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor, 2016: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geosci. Model Dev.*, **9**, 1937–1958, doi:10.5194/gmd-9-1937-2016. http://www.geosci-model-dev.net/9/1937/2016/ (Accessed March 6, 2018).

Englehart, P. J., and A. V. Douglas, 2003: Assessing Warm Season Drought Episodes in the Central United States. *Journal of Climate*, **16**, 1831-1842.

Flanagan, P., **J. Basara**, J. Furtado, and X. Xiao, 2018: Primary Atmospheric Drivers of Pluvial Years in the United States Great Plains. *J. Hydrometeor., 19, 643–658, https://doi.org/10.1175/JHM-D-17-0148.1*

Gao, J., A. Y. Sheshukov, H. Yen, K. R. Douglas-Mankin, M. J. White, and J. G. Arnold, 2019: Uncertainty of hydrologic processes caused by bias-corrected CMIP5 climate change projections with alternative historical data sources. Journal of Hydrology, 568, 551-561.

Granco, G., and Coauthors, 2019: Evaluating environmental change and behavioral decision-making for sustainability policy using an agent-based model: A case study for the Smoky Hill River Watershed, Kansas. Science of The Total Environment, 695, 133769.

Hong, S. Y., and E. Kalnay, 2000: Role of Sea Surface Temperature and Soil-Moisture Feedback in the 1998 Oklahoma-Texas Drought. *Nature*, **408**, 842-844.

Jong, B.-T., M. Newman, and A. Hoell, 2022: Subseasonal Meteorological Drought Development over the Central United States during Spring. *Journal of Climate*, **35,** 2525-2547.

Koster, R. D., P. A. Dirmeyer, Z. Guo, G. Bonan, E. Chan, P. Cox, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C.-H. Lu, S. Malyshev, B. McAvaney, K. E. Mitchell, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. C. Sud, C. M. Taylor, D. Verseghy, R. Vasic, Y. Xue and T. Yamada, 2001: Regions of Strong Coupling between Soil Moisture and Precipitation. *Science*, **305**, 1138-1140.

Haberlie, A. M., & Ashley, W. S. (2019). A Radar-Based Climatology of Mesoscale Convective Systems in the United States, Journal of Climate, 32, 1591-1606.

Haberlie, A. M., W. S. Ashley, C. M. Battisto, and V. A. Gensini, 2022: Thunderstorm Activity Under Intermediate and Extreme Climate Change Scenarios. *Geophysical Research Letters*, **49,** e2022GL098779.

Hoerling, M., A. Kumar, R. Dole, J. W. Nielsen-Gammon, J. Eischeid, J. Perlwitz, X.-W. Quan, T. Zhang, P. Pegion and M. Chen, 2012: Anatomy of an Extreme Event. *Journal of Climate*, **26**, 2811-2832.

Hoerling, M., Eischeid, J., Kumar, A., Leung, R., Mariotti, A., Mo, K., Schubert, S., and Seager, R., 2014: Causes and predictability of the 2012 Great Plains drought. *Bulletin of the American Meteorological Society*, **95**, 269-282.

Lisonbee, J., M. Wolosyzn, M. Schmanisch, 2021: Making sense of flash drought: efinitions, indicators, and where we go from here. Journal of Applied and Service Climatology, Volume 2021, Issue 001, DOI: doi.org/10.46275/JOASC.2021.02.001.

Livneh, B., and M. P. Hoerling, 2016: The Physics of Drought in the U.S. Central Great Plains. *J. Clim.*, **29**, 6783–6804, doi:10.1175/JCLI-D-15-0697.1

Marvel, K., B. I. Cook, C. Bonfils, J. E. Smerdon, A. P. Williams, and H. Liu, 2021: Projected Changes to Hydroclimate Seasonality in the Continental United States. *Earth's Future*, **9,** e2021EF002019.

Mishra, A. K., and V. P. Singh, 2010: A review of drought concepts. *J. Hydrol.*, **391**, 202–216, doi:10.1016/j.jhydrol.2010.07.012.

Mo, K. C., J. N. Paegle and R. W. Higgins, 1997: Atmospheric Processes Associated with Summer Floods and Droughts in the Central United States. *Journal of Climate*, **10**, 3028-3046.

Powell, J. W., 1890: The irrigable lands of the arid region. *Cent. Mag.*, **39**, 766–776.

Otkin, J.A., M. Svoboda, E.D. Hunt, T.W. Ford, M.C. Anderson, C. Hain, and J.B. Basara, 2018: Flash Droughts: A Review and Assessment of the Challenges Imposed by Rapid Onset Droughts in the United States. *Bulletin of the American Meteorological Society*, **99**, 911–919.

Schubert, S. D., M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister, 2004: Causes of Long-Term Drought in the U.S. Great Plains. *Journal of Climate*, **17**, 485-503.

Schwalm, C. R., S. Glendon, and P. B. Duffy, 2020: RCP8.5 tracks cumulative CO_2 emissions. *Proc. Natl. Acad. Sci. U. S. A.*, **117**, 19656–19657, doi:10.1073/PNAS.2007117117.

Seager, R., Y. Kushnir, C. Herweijer, N. Naik and J. Velez, 2005: Modeling of Tropical Forcing of Persistent Droughts and Pluvials over Western North America: 1856-2000. *Journal of Climate*, **18**, 4065-4088.

Seager, R., and Coauthors, 2018: Whither the 100th Meridian? The Once and Future Physical and Human Geography of America's Arid–Humid Divide. Part I: The Story So Far. *Earth Interactions*, **22,** 1-22.

Seager, R., and Coauthors, 2018: Whither the 100th Meridian? The Once and Future Physical and Human Geography of America's Arid–Humid Divide. Part II: The Meridian Moves East. *Earth Interactions*, **22,** 1-24.

Seneviratne, S. I., D. Lüthi, M. Litschi and C. Schär, 2006: Land Atmosphere Coupling and Climate Change in Europe. *Nature*, **443**, 205-209.

Skaggs, R.H., 1978: Climatic Change and Persistence in Western Kansas. *Annals of the Association of American Geographers*, **68**, 73-80.

Svoboda, M., and Coauthors, 2002: The drought monitor. *Bull. Am. Meteorol. Soc.*, **83**, 1181–1190.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl, 2012: An Overview of CMIP5 and the Experiment Design. *Bull. Am. Meteorol. Soc.*, **93**, 485–498, doi:10.1175/BAMS-D-11-00094.1. http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-11-00094.1 (Accessed July 9, 2014).

Trenberth, K. E., G. W. Branstator, and P. A. Arkin, 1988: Origins of the 1988 North American Drought. *Science*, **242,** 1640-1645.

Ukkola, A. M., M. G. De Kauwe, M. L. Roderick, G. Abramowitz, and A. J. Pitman, 2020: Robust Future Changes in Meteorological Drought in CMIP6 Projections Despite Uncertainty in Precipitation. *Geophys. Res. Lett.*, **47**, 1–9, doi:10.1029/2020GL087820.

Wakefield, R.A., J.B. Basara, J.C. Furtado, B.G. Illston, C.R. Ferguson, and P.M. Klein, 2019: A Modified Framework for Quantifying Land-Atmosphere Covariability during Hydrometeorological and Soil Wetness Extremes in Oklahoma. *J. Appl. Meteor. Climatol.,* **58**, 1465–1483, https://doi.org/10.1175/JAMC-D-18-0230.1

Wang, S.-Y. S., Santanello, J., Wang, H., Barandiaran, D., Pinker, R. T., Schubert, S., Gillies, R. R., Oglesby, R., Hilburn, K., Kilic, A., et al., 2015: An intensified seasonal transition in the Central U.S. that enhances summer drought, *J. Geophys. Res. Atmos.*, **120**, 8804– 8816

Weaver, S. J., S. Baxter, and K. Harnos, 2016: Regional Changes in the Interannual Variability of U.S. Warm Season Precipitation. *Journal of Climate*, **29,** 5157-5173.

Wilhite, D. A., and M. H. Glantz, 1985: Understanding: the Drought Phenomenon: The Role of Definitions. *Water International*, **10**, 111-120.

White, B., A. Gershunov, and J. Annis, 2008: Climatic Influences on Midwest Drought during the Twentieth Century. *Journal of Climate,* **21**, 517- 531.

Woodhouse, C. A., and J. T. Overpeck, 1998): 2000 Years of Drought Variability in the Central United States. *Bulletin of the American Meteorological Society*, **79**, 2693-2714.

Yuan, S., and Quiring, S. M., 2014: Drought in the U.S. Great Plains (1980–2012): A sensitivity study using different methods for estimating potential evapotranspiration in the Palmer Drought Severity Index, *J. Geophys. Res. Atmos.*, **119**, 10,996– 11,01

Zachary, T. Z., L. Xiaomao, M. A. Robert, J. K. Gerard, and A. Roger, 2018: Identification of hydroclimate subregions for seasonal drought monitoring in the U.S. Great Plains. *Journal of Hydrology*, **567,** 370-381.

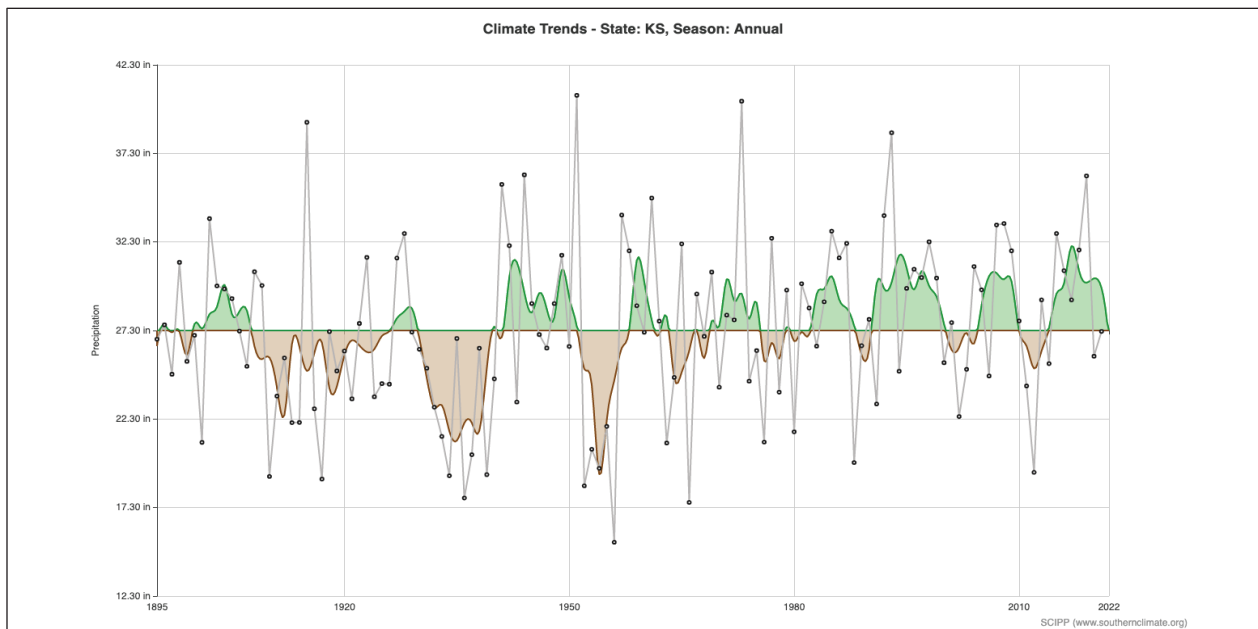# Appendix A – Statewide Climate Timeseries Plots for Kansas

Figure A.1 *– Annual total precipitation (in) averaged across Kansas. Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*

Figure A.2 *– Annual average temperature (°F) averaged across Kansas. Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure A.3 *– Spring total precipitation (in) averaged across Kansas. Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
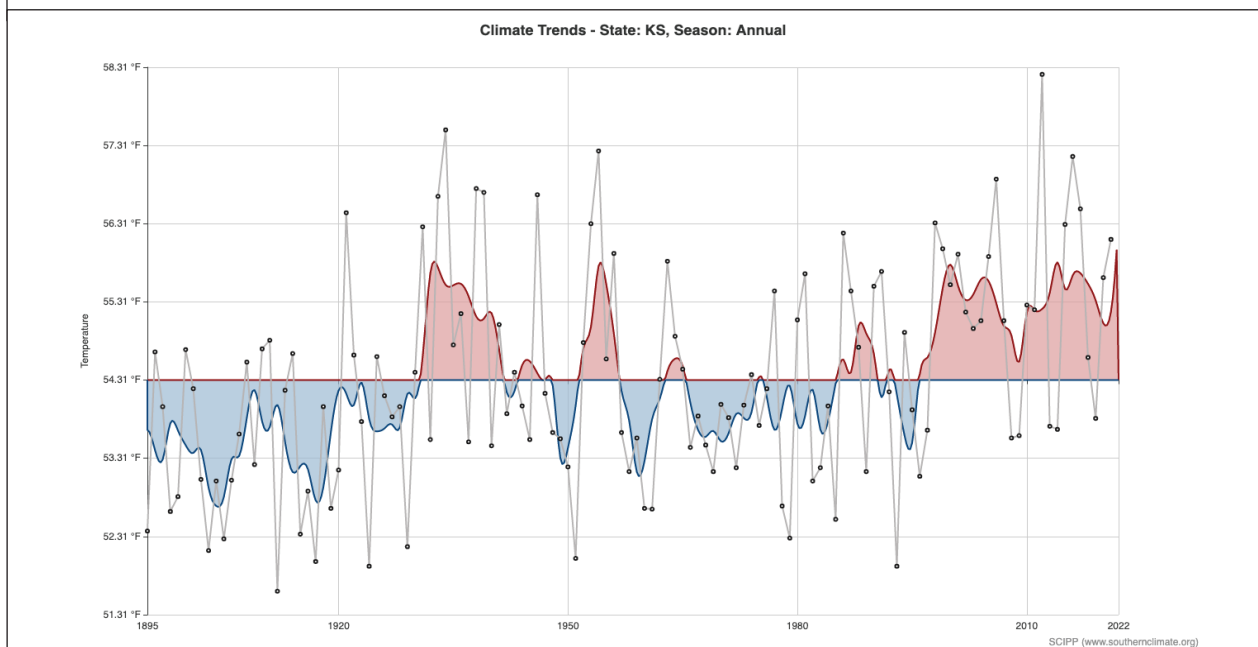

Figure A.4 *– Spring average temperature (˚F) averaged across Kansas. Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
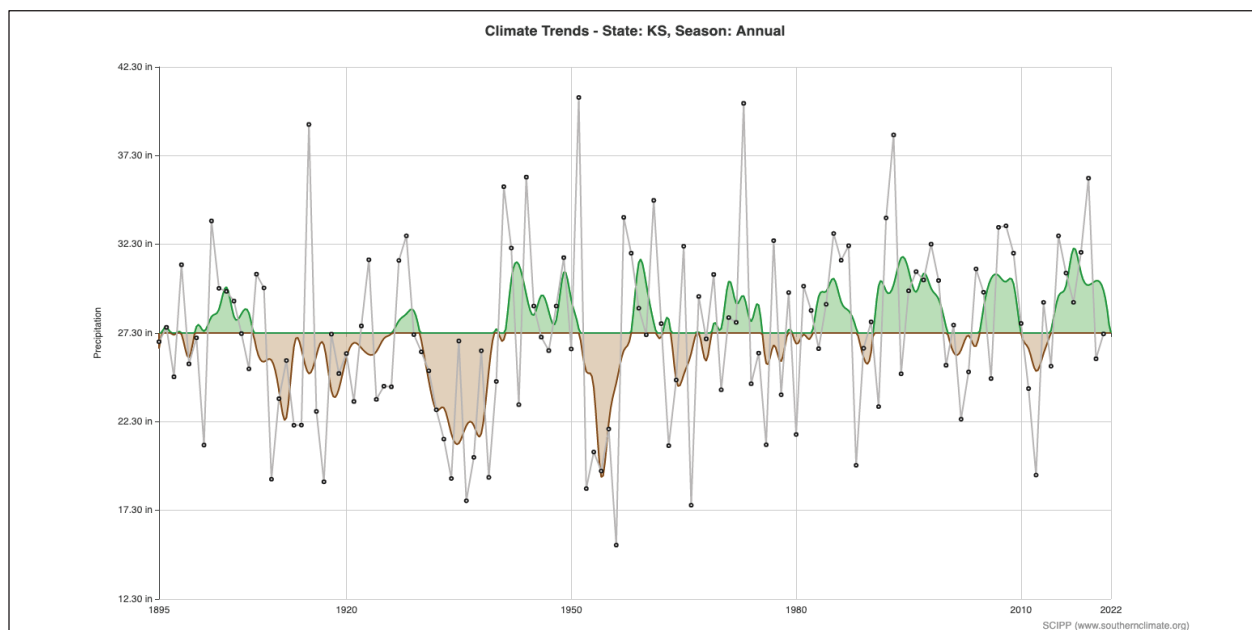
Figure A.5 *– Summer total precipitation (in) averaged across Kansas. Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
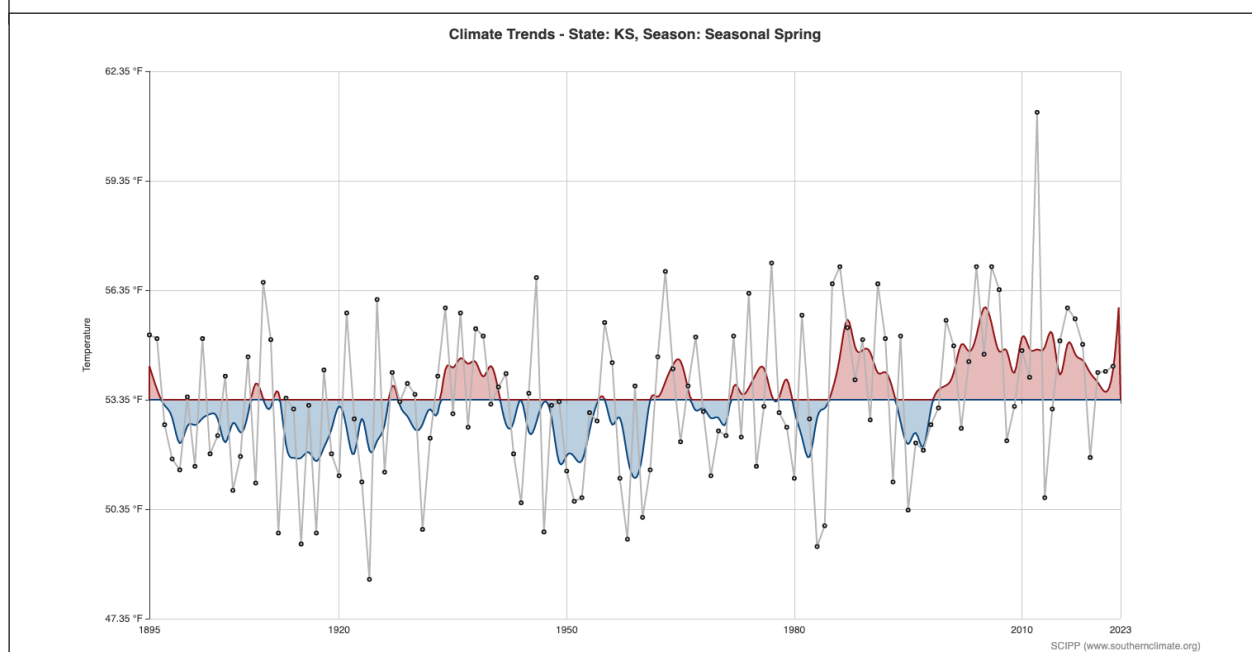

Figure A.6 *– Summer average temperature (˚F) averaged across Kansas. Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
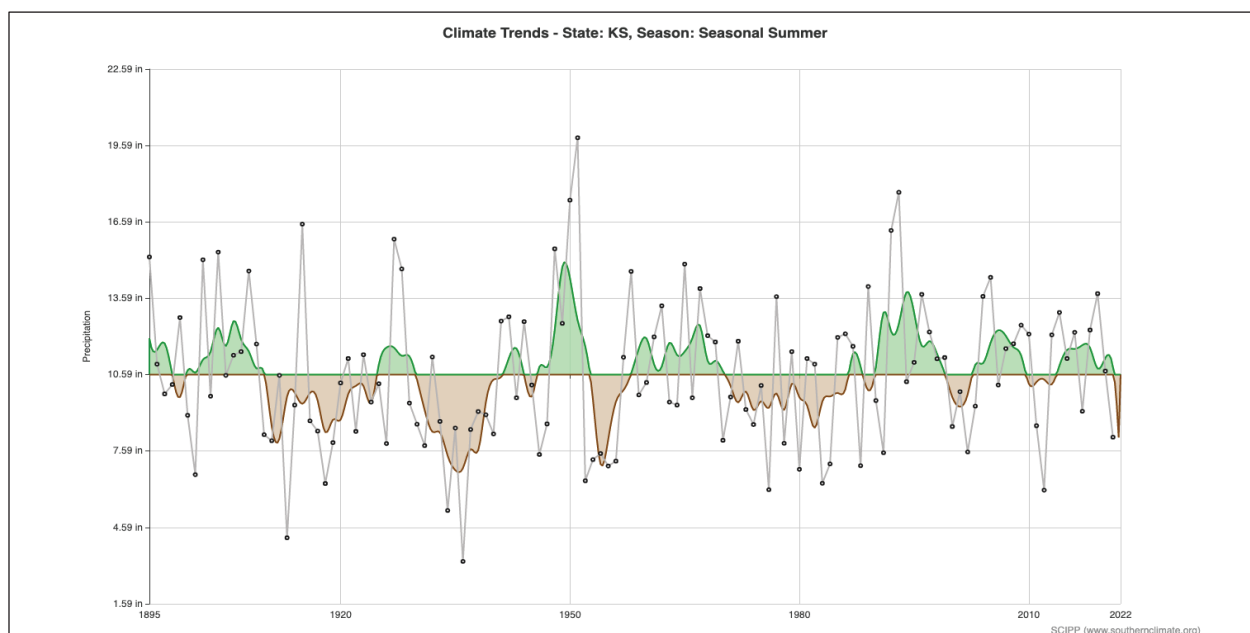
Figure A.7 – *Autumn total precipitation (in) averaged across Kansas. Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*

Figure A.8 – *Autumn average temperature (°F) averaged across Kansas. Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure A.9 *– Winter total precipitation (in) averaged across Kansas. Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
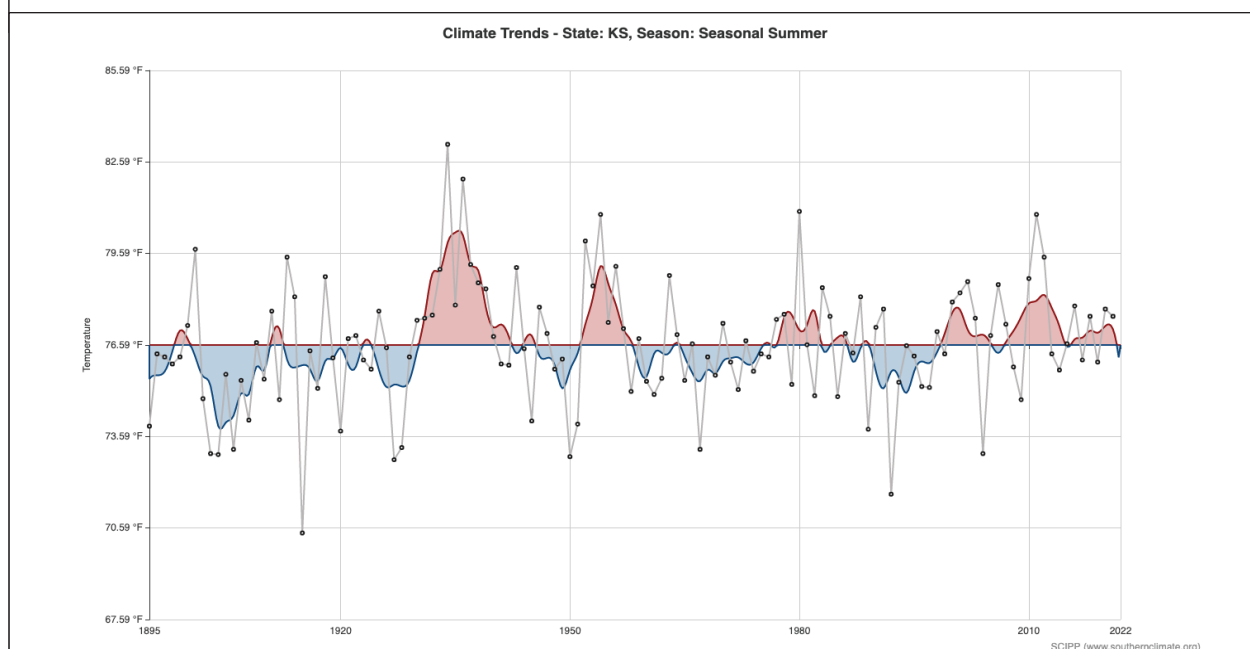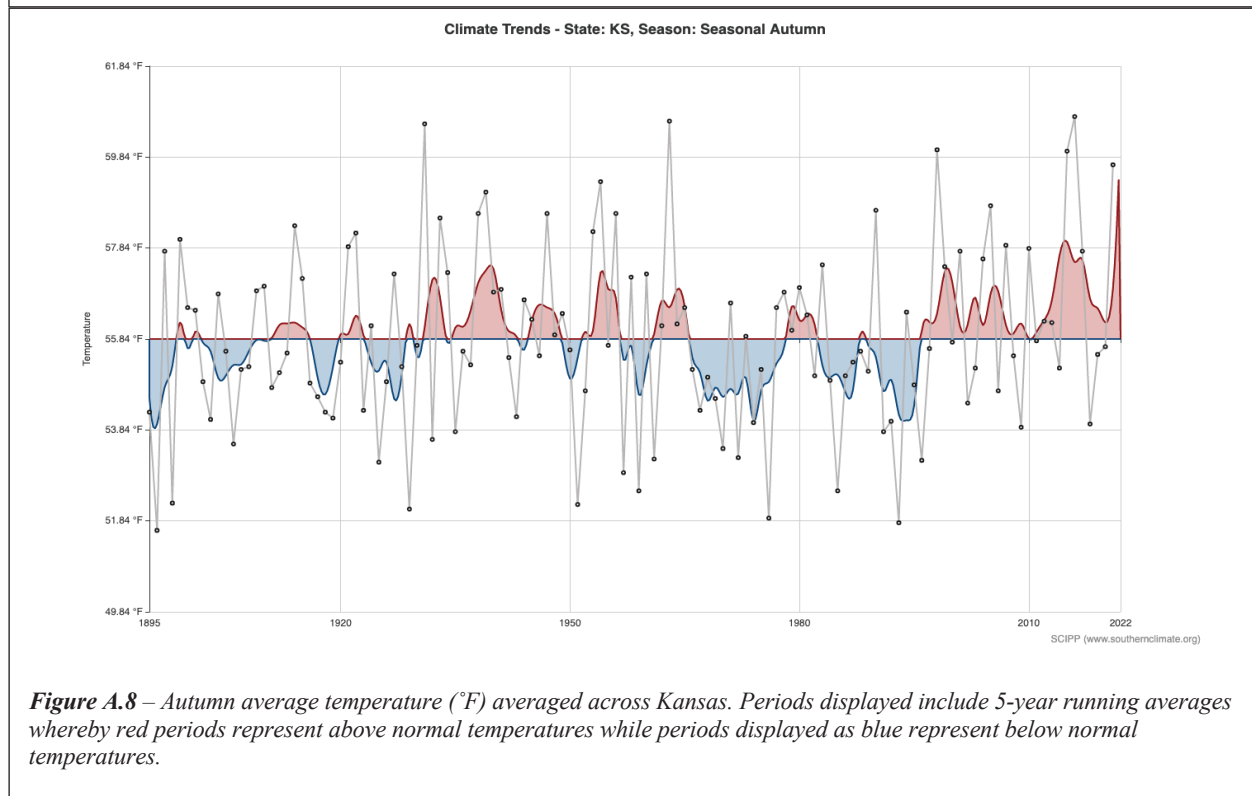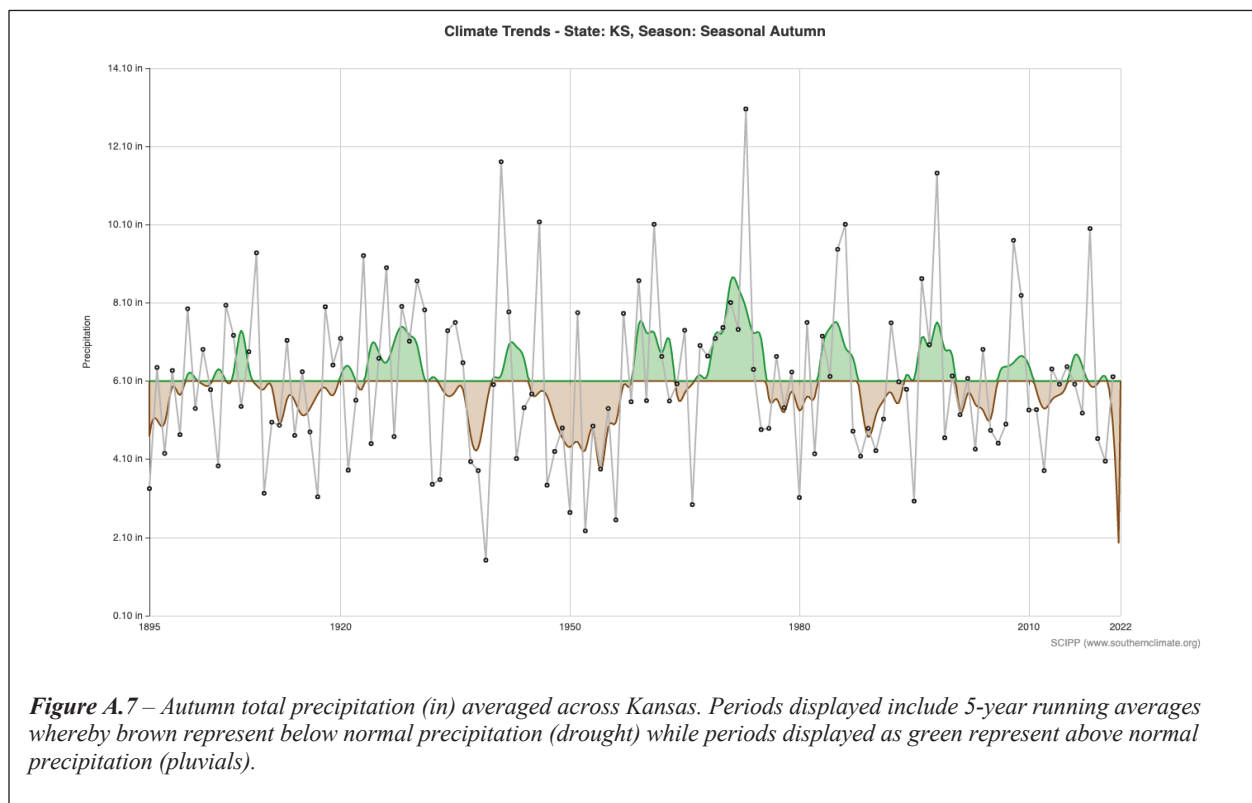

Figure A.10 *– Winter average temperature (˚F) averaged across Kansas. Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Appendix B – Climate Timeseries Plots for Kansas Climate Division 01

Figure B.1 *– Annual total precipitation (in) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
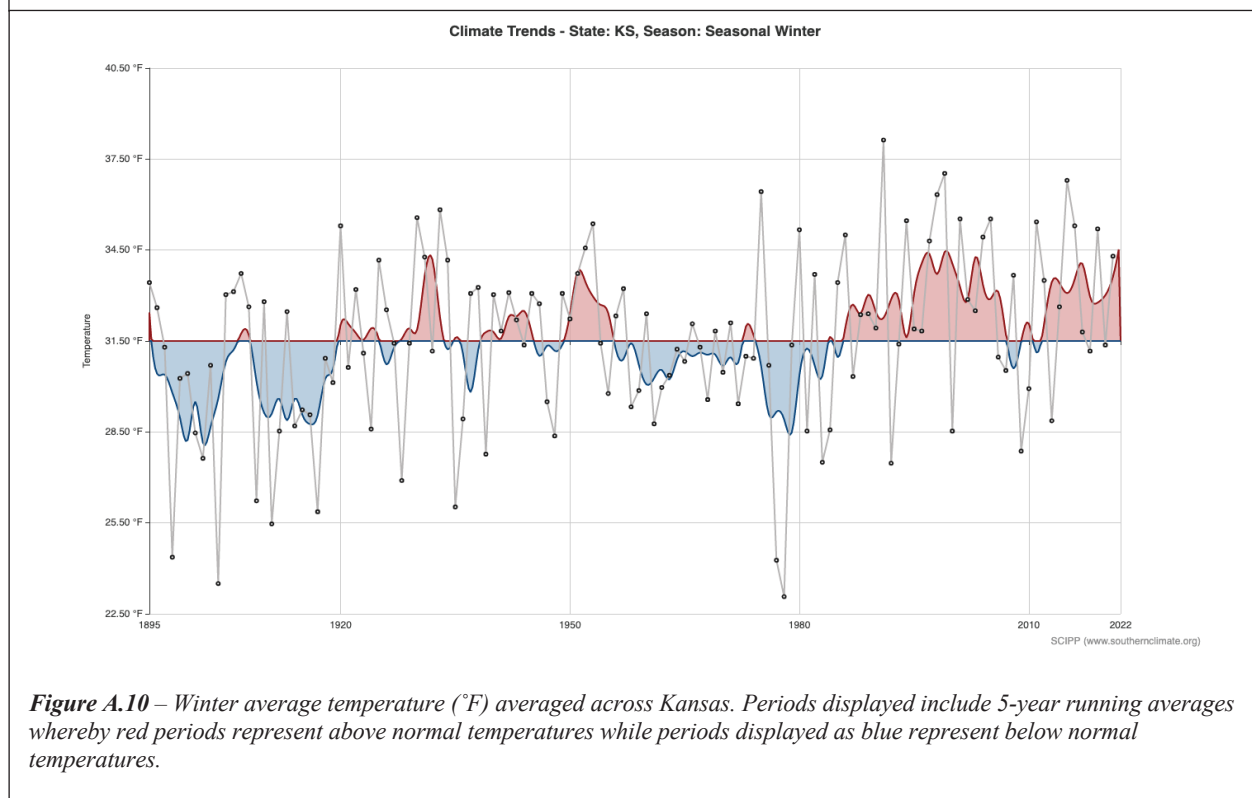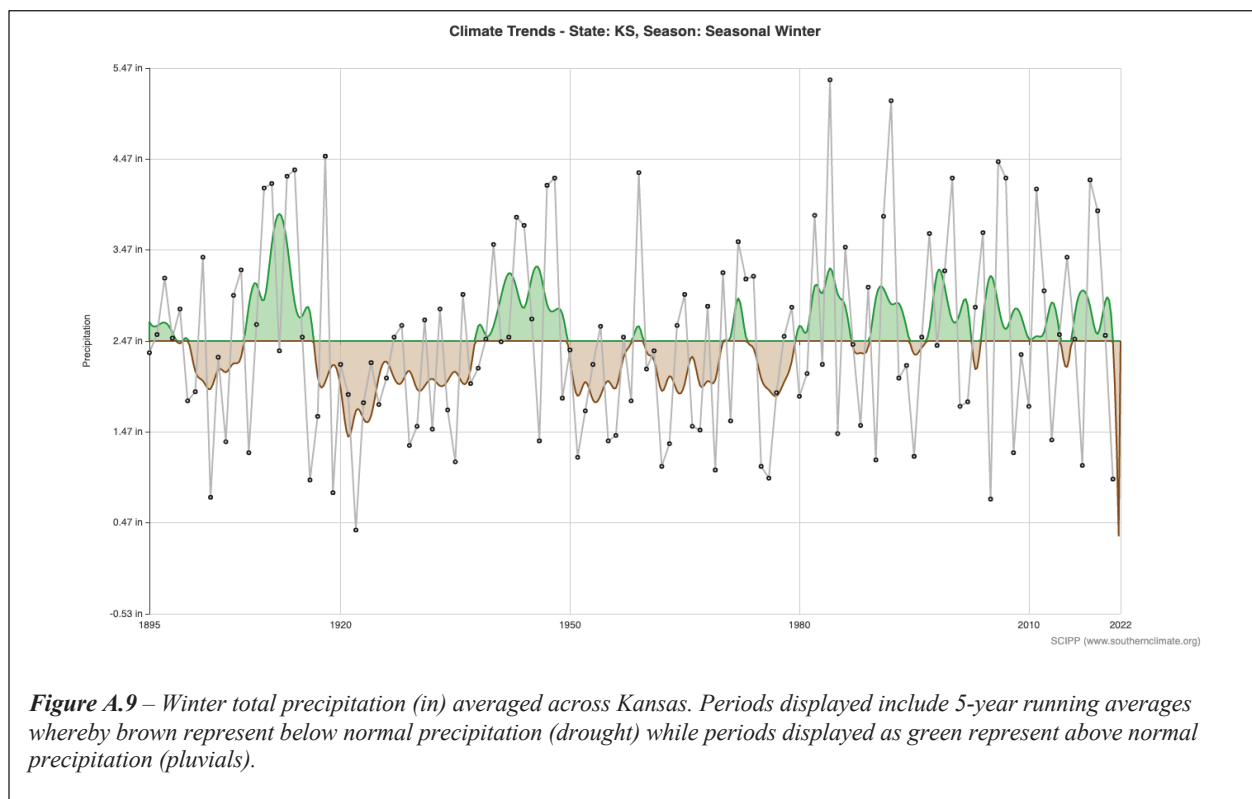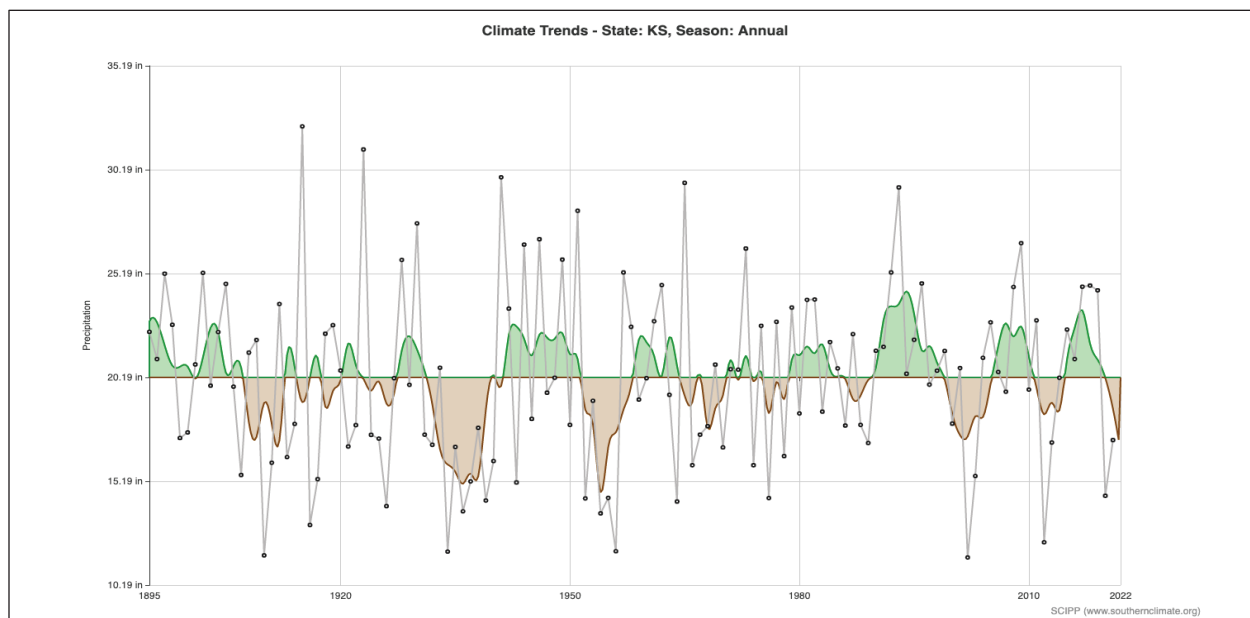

Figure B.2 *– Annual average temperature (˚F) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure B.3 *– Spring total precipitation (in) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
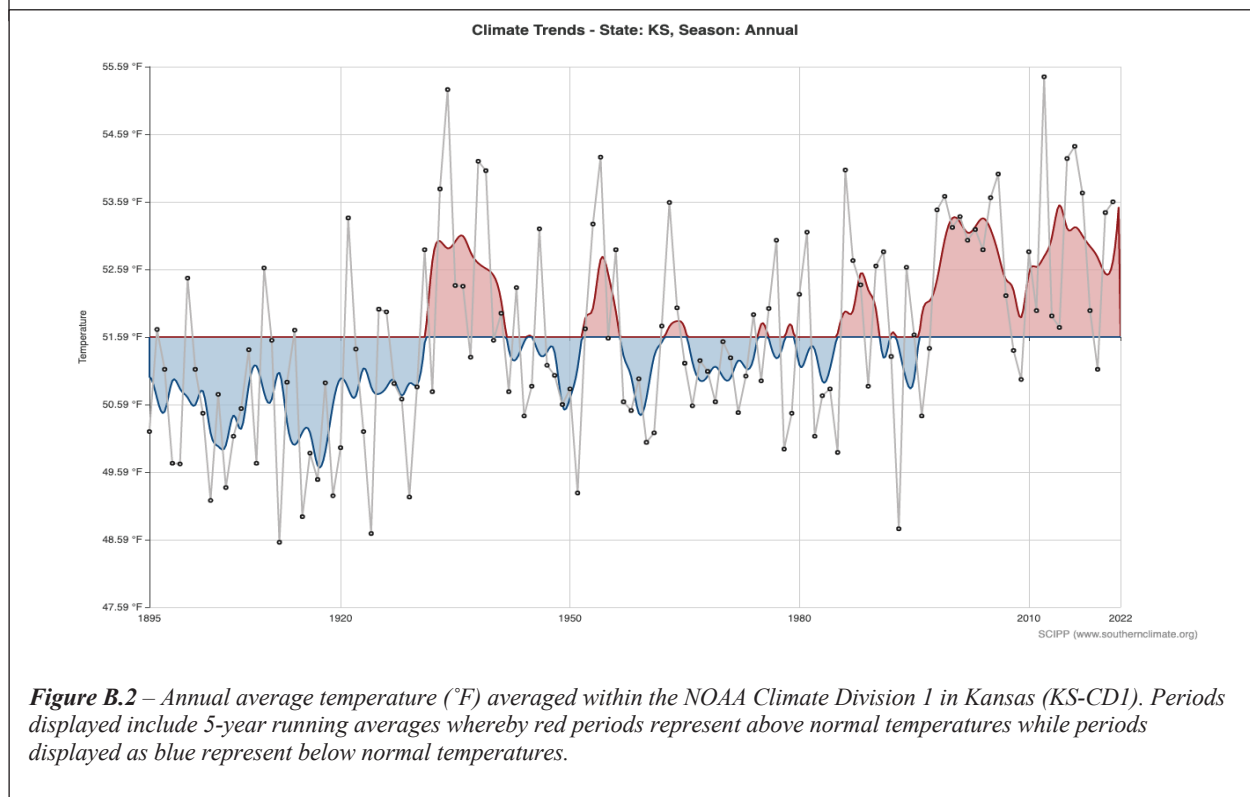

Figure B.4 *– Spring average temperature (˚F) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure B.5 – *Summer total precipitation (in) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*

Figure B.6 – *Summer average temperature (˚F) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
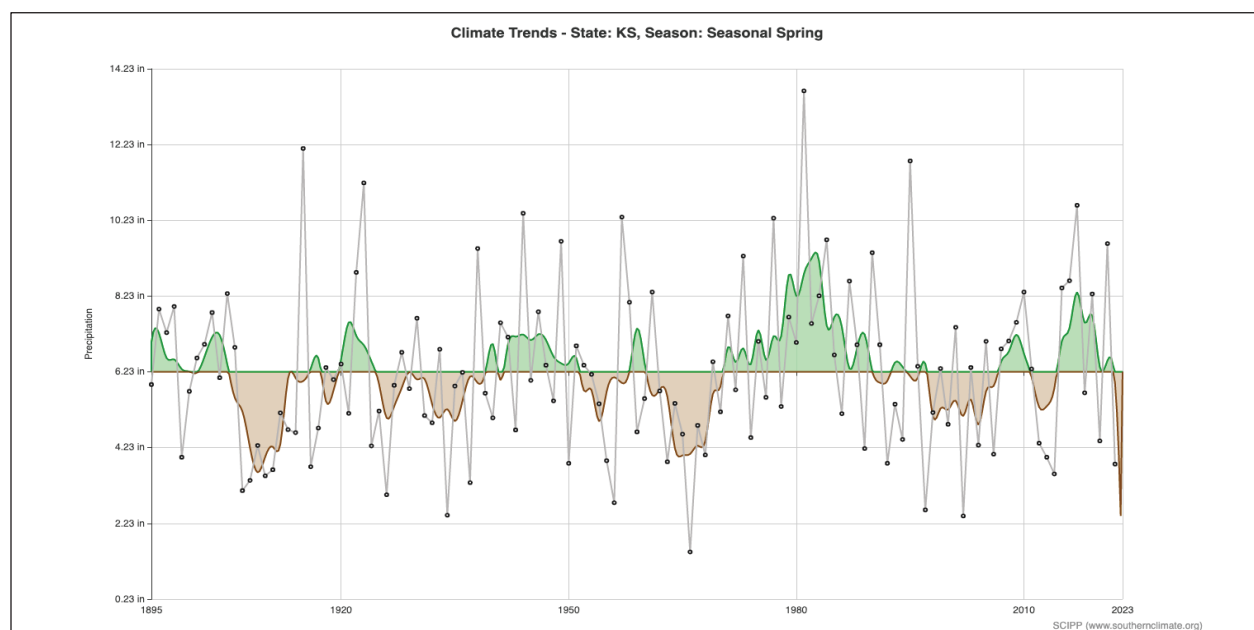
Figure B.7 *– Autumn total precipitation (in) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
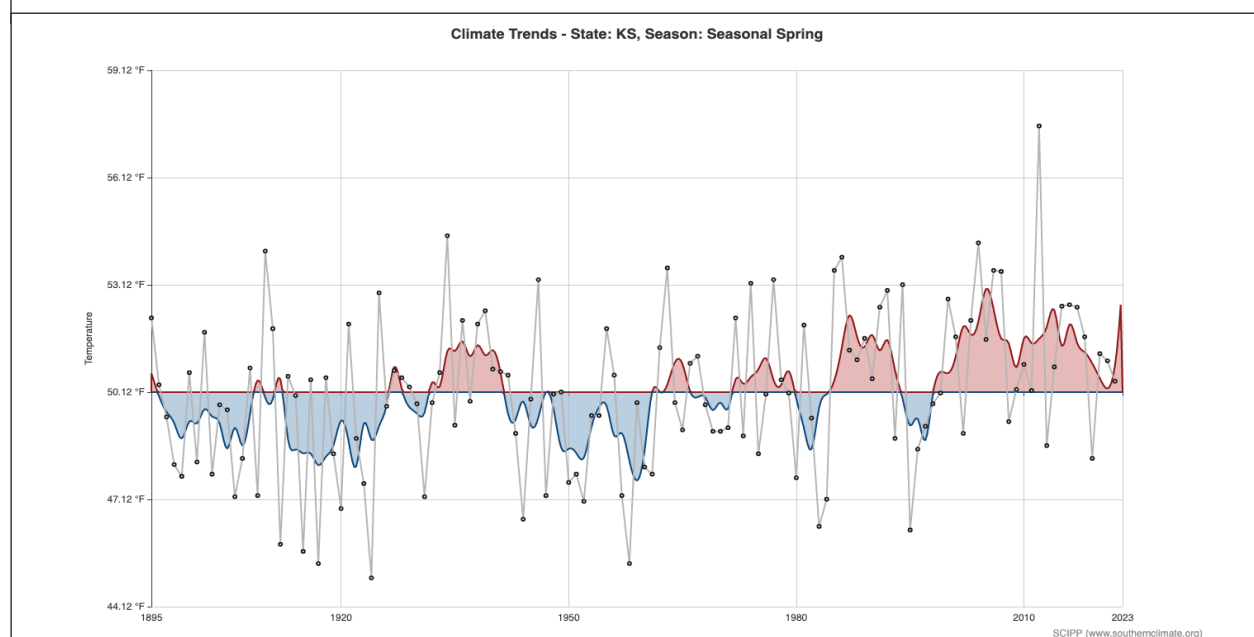

Figure B.8 *– Autumn average temperature (˚F) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
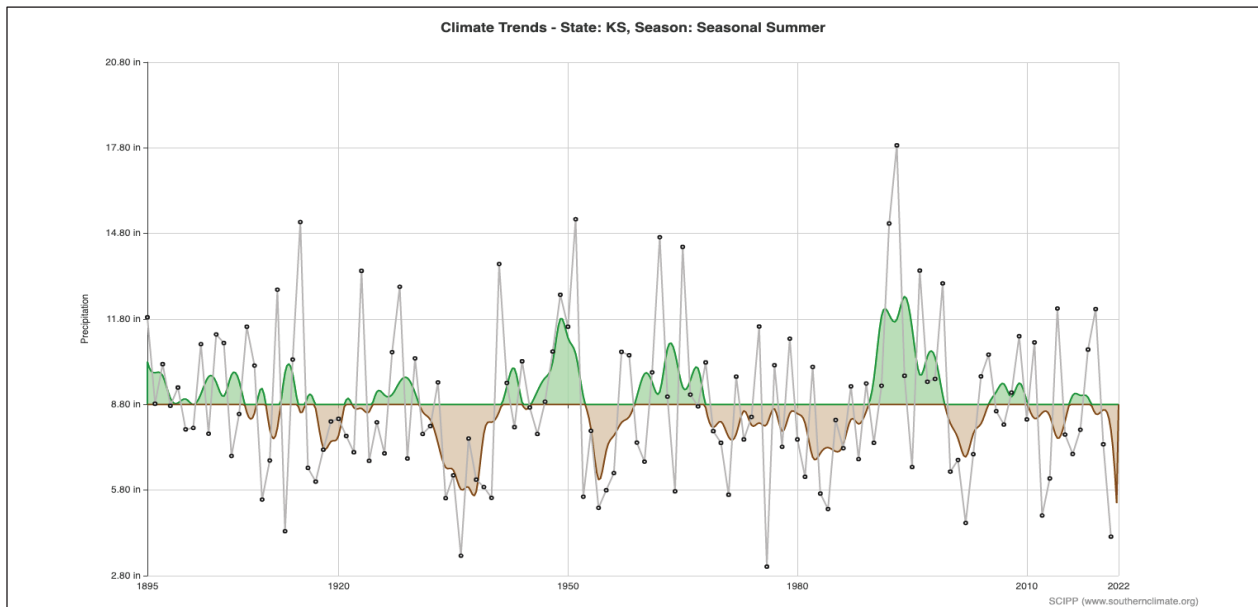
34

Figure B.9 – *Winter total precipitation (in) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
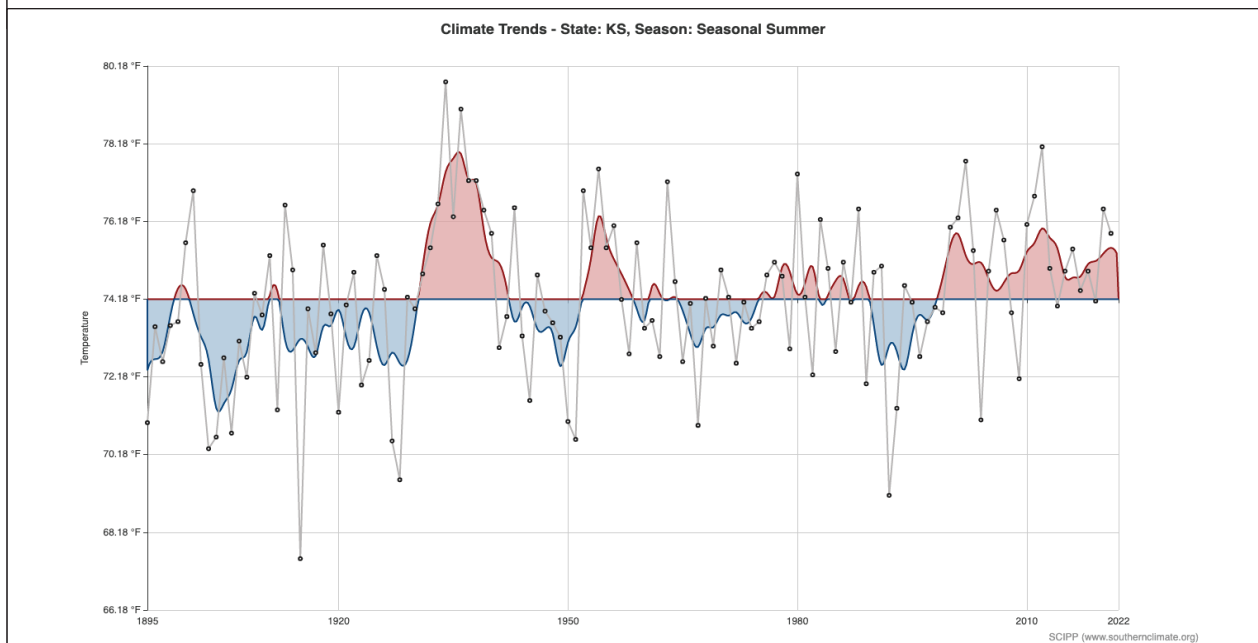

Figure B.10 – *Winter average temperature (˚F) averaged within the NOAA Climate Division 1 in Kansas (KS-CD1). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Appendix C – Climate Timeseries Plots for Kansas Climate Division 04

Figure C.1 – *Annual total precipitation (in) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
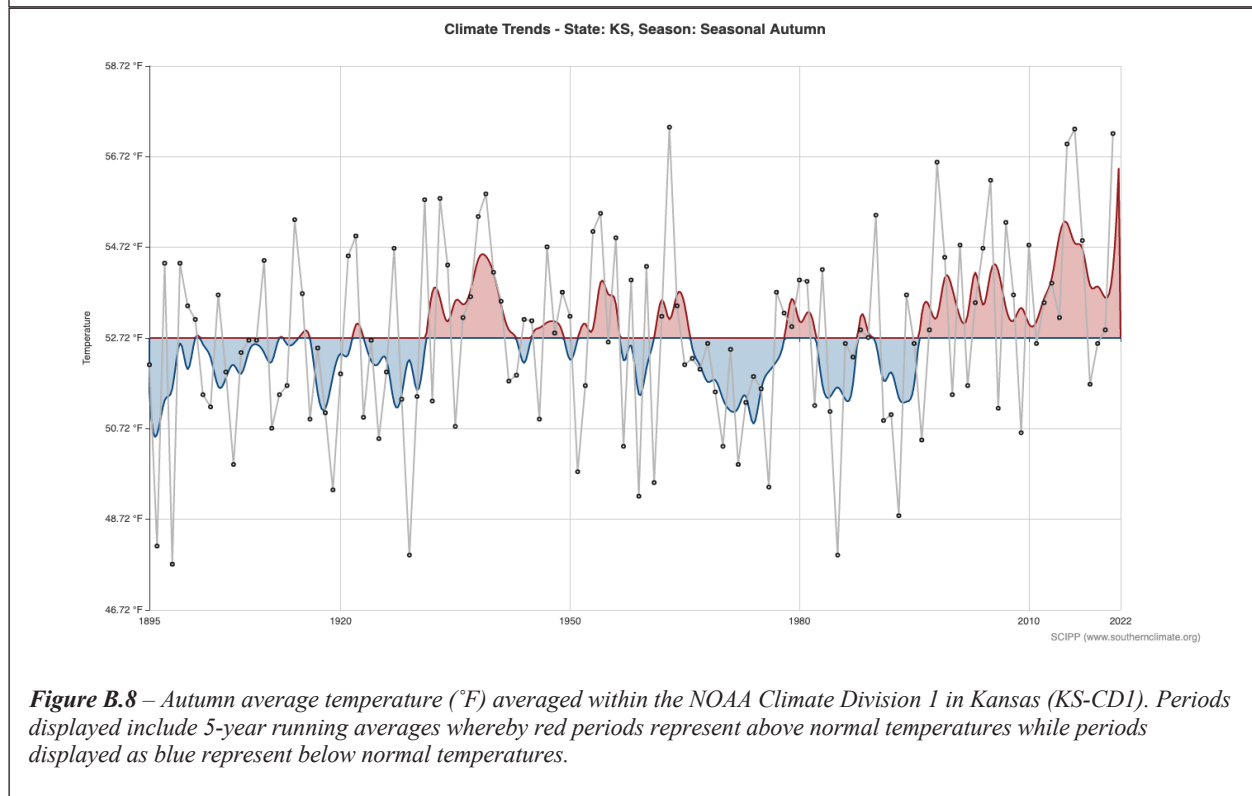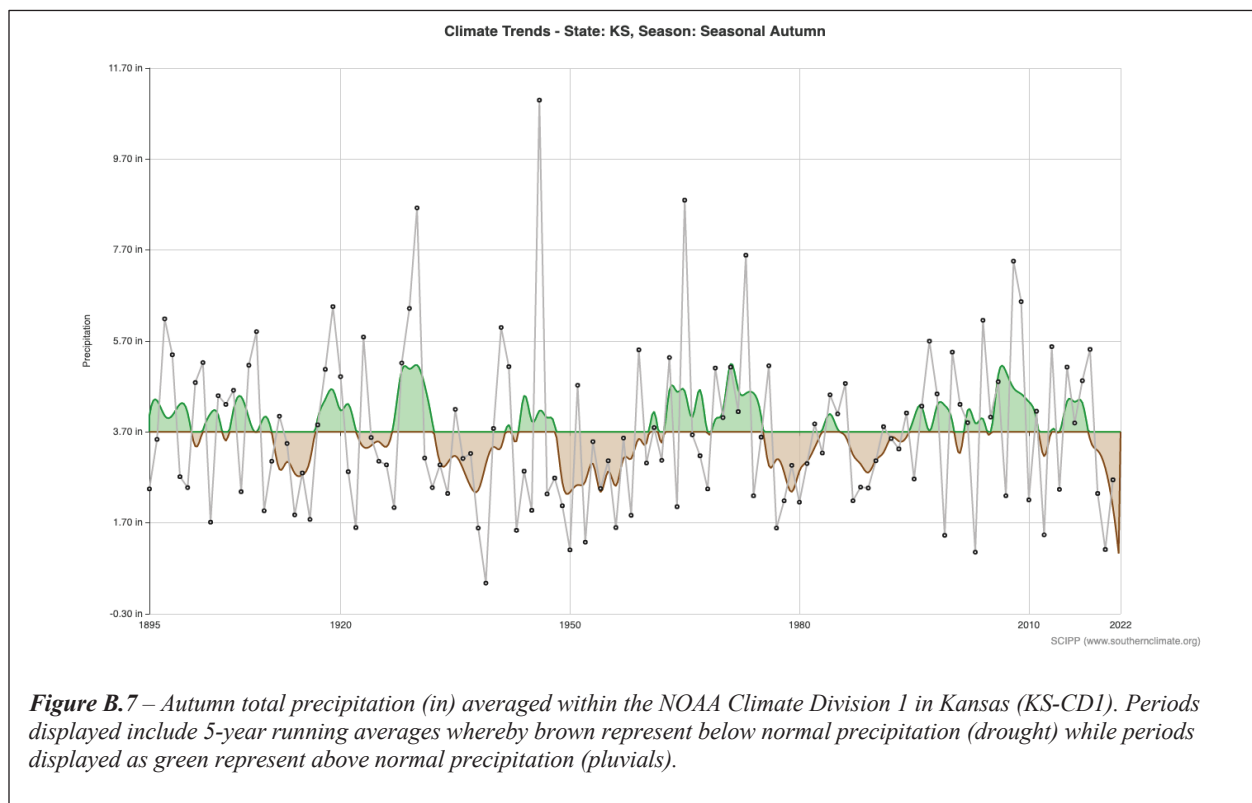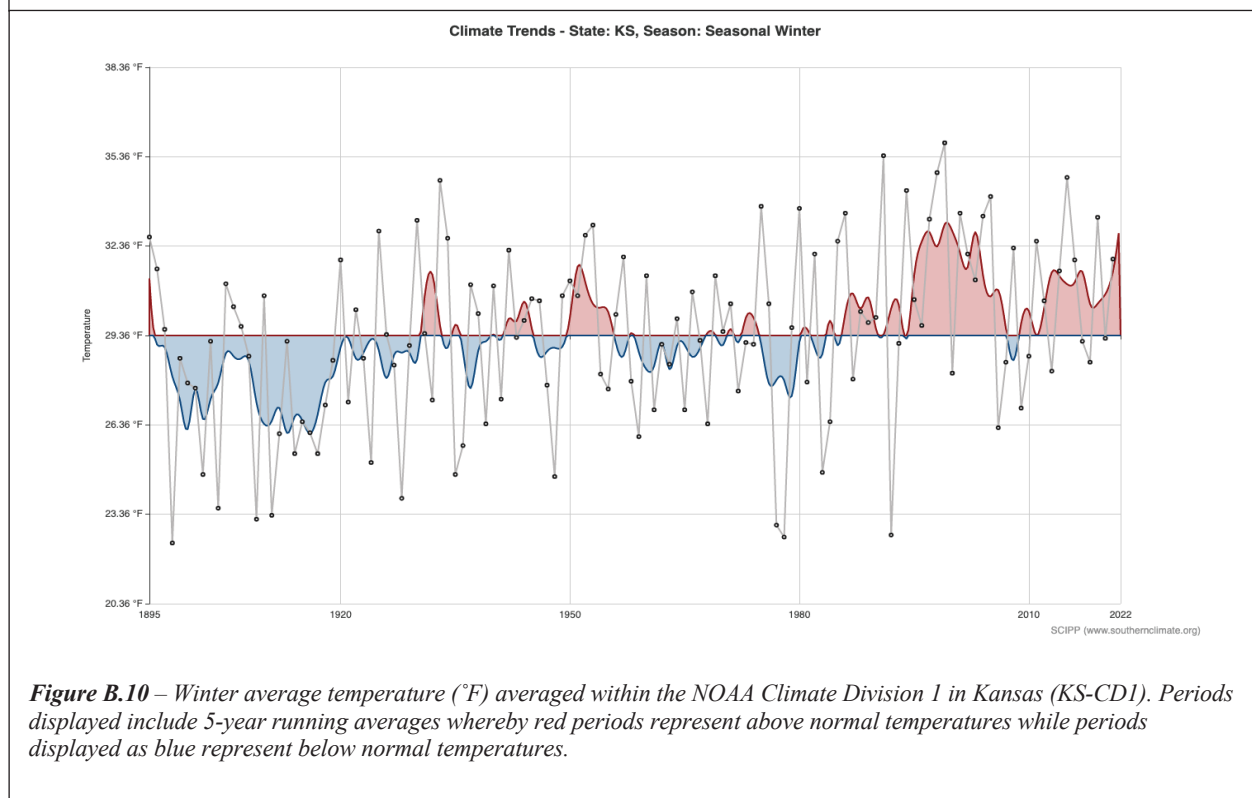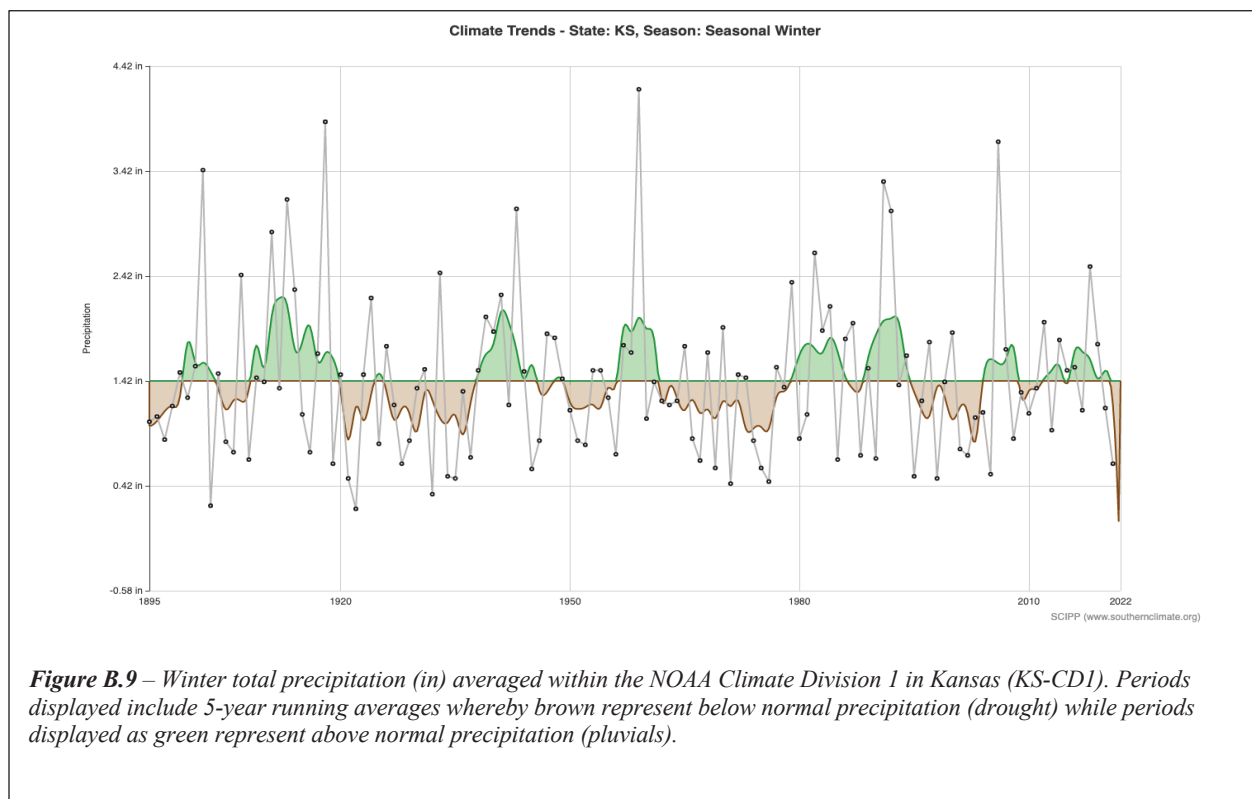

Figure C.2 – *Annual average temperature (°F) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure C.3 *– Spring total precipitation (in) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*

Figure C.4 *– Spring average temperature (˚F) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

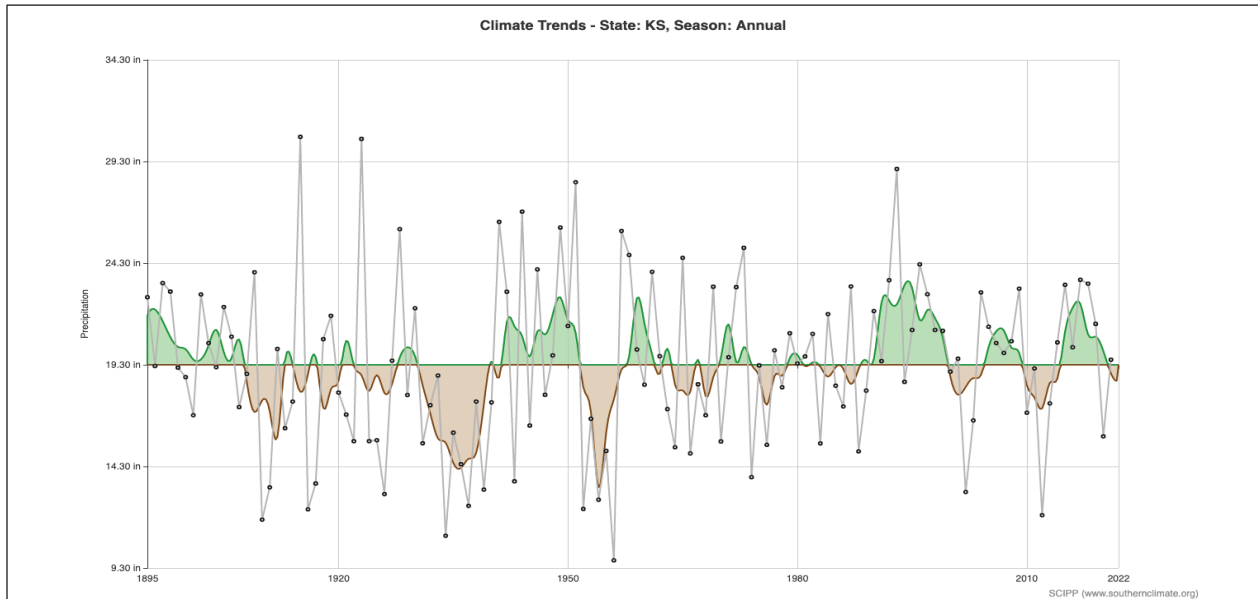**Climate Trends - State: KS, Season: Seasonal Summer**

Figure C.5 – Summer total precipitation (in) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).
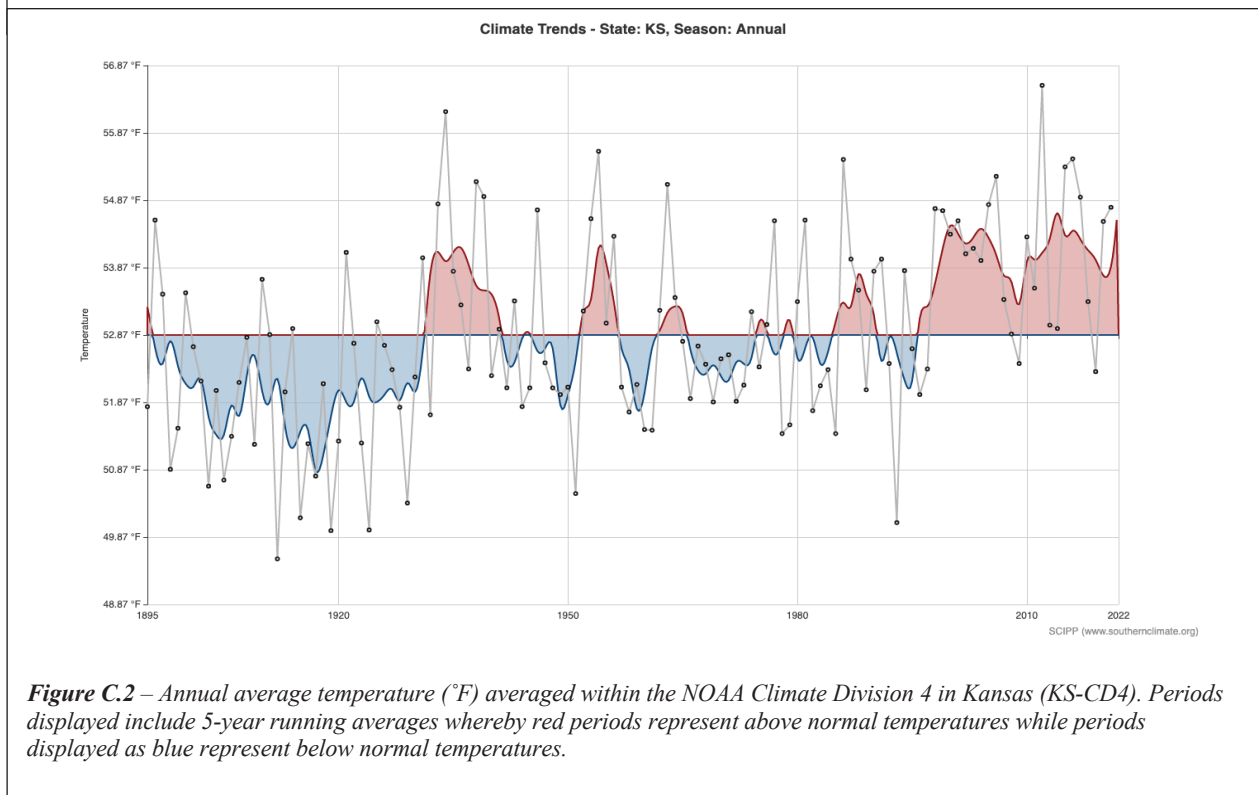
Climate Trends - State: KS, Season: Seasonal Summer

Figure C.6 – Summer average temperature (°F) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.
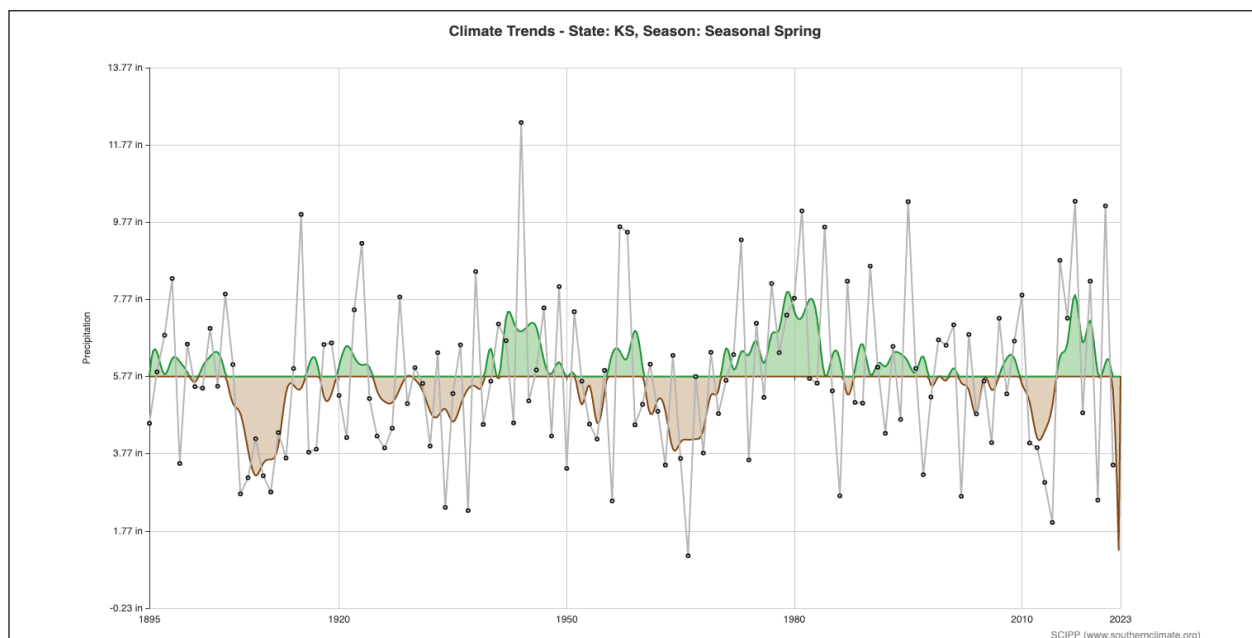
Figure C.7 – *Autumn total precipitation (in) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*

Figure C.8 – *Autumn average temperature (˚F) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure C.9 *– Winter total precipitation (in) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
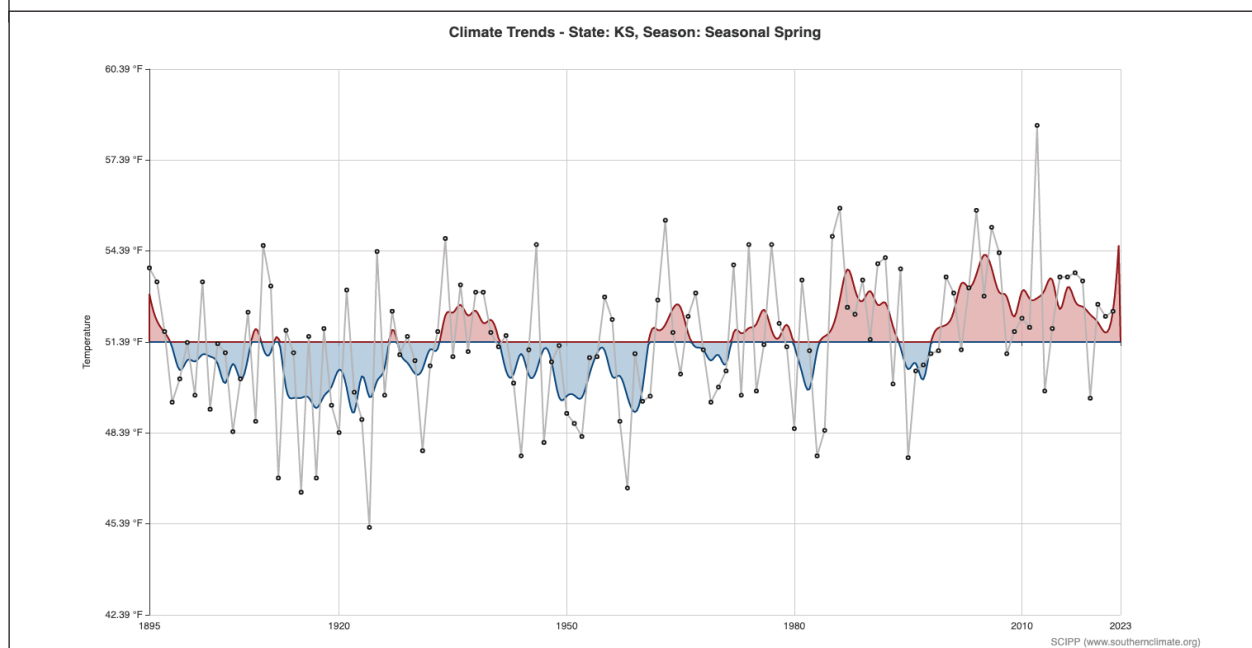

Figure C.10 *– Winter average temperature (˚F) averaged within the NOAA Climate Division 4 in Kansas (KS-CD4). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
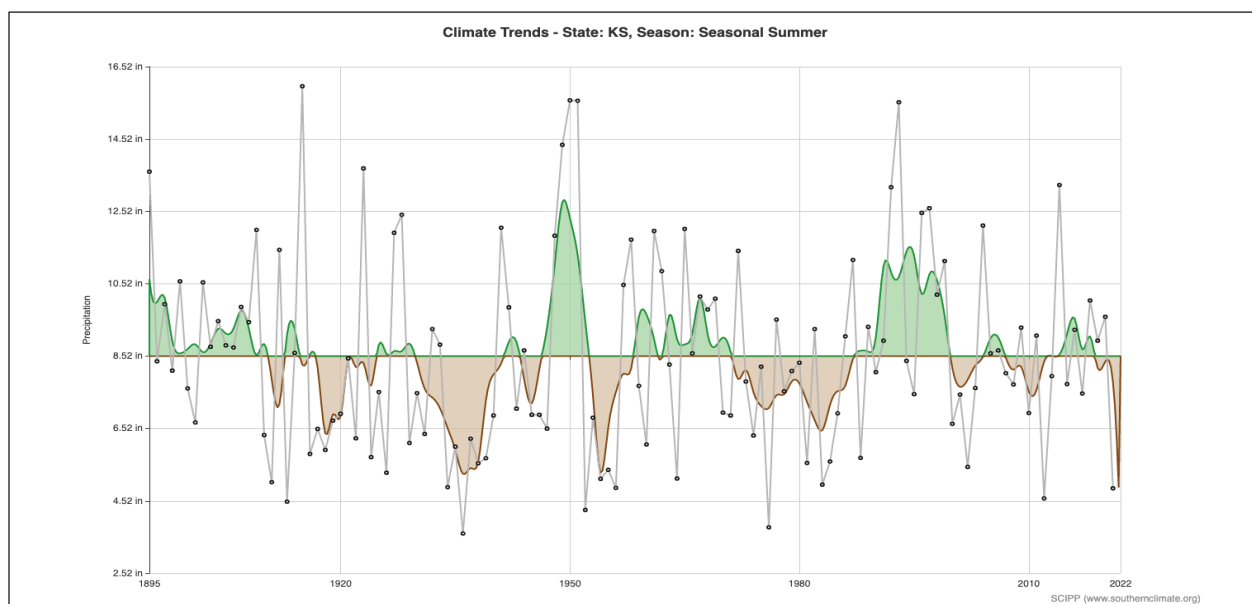
Appendix D – Climate Timeseries Plots for Kansas Climate Division 05

Figure D.1 *– Annual total precipitation (in) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
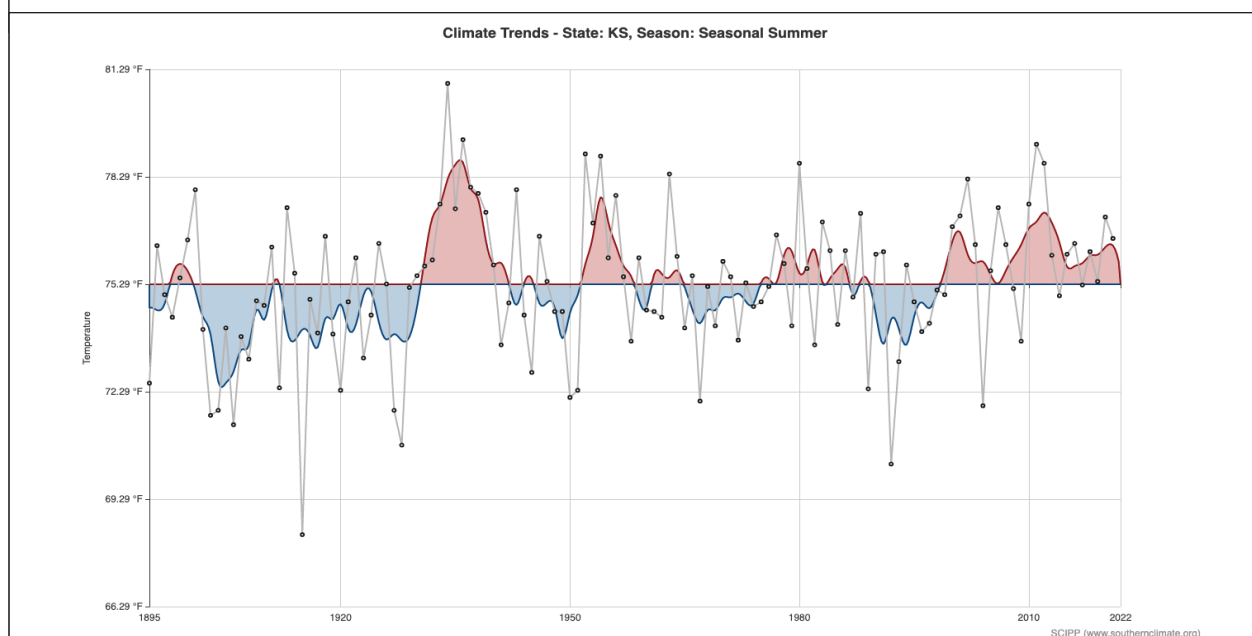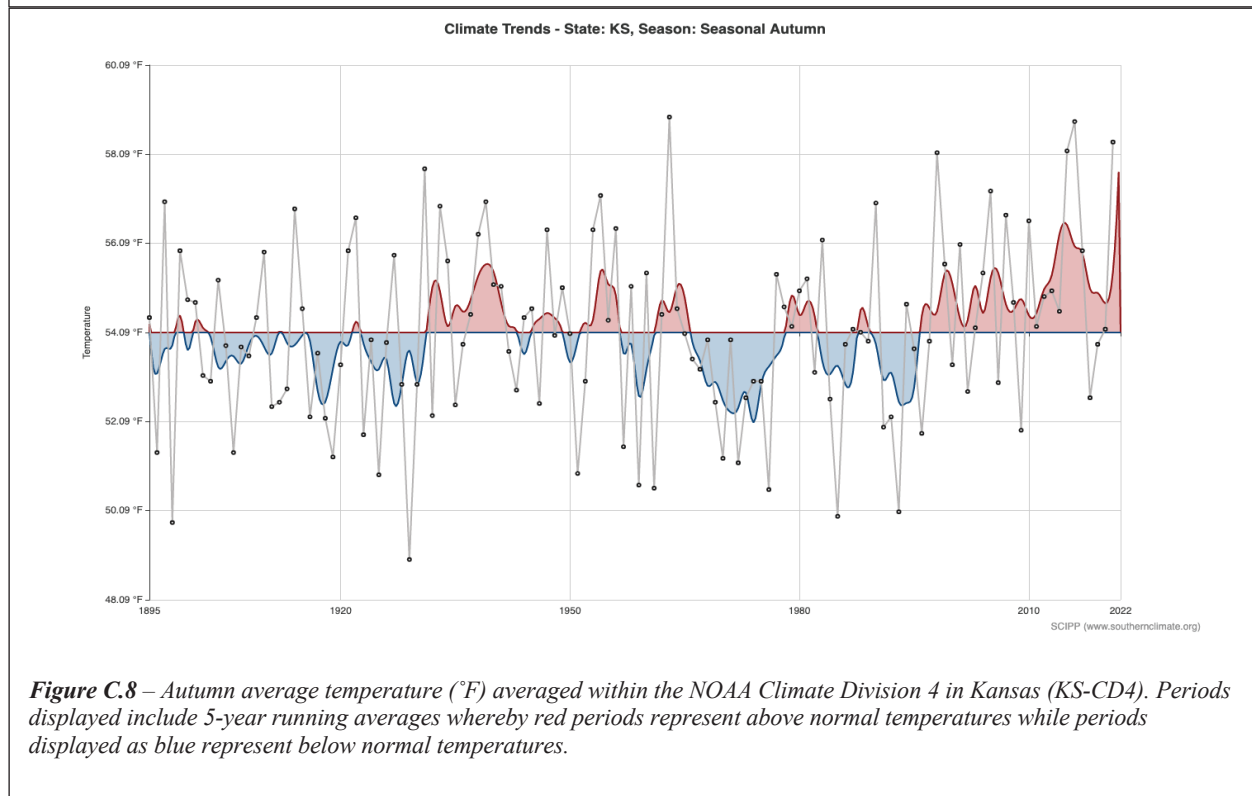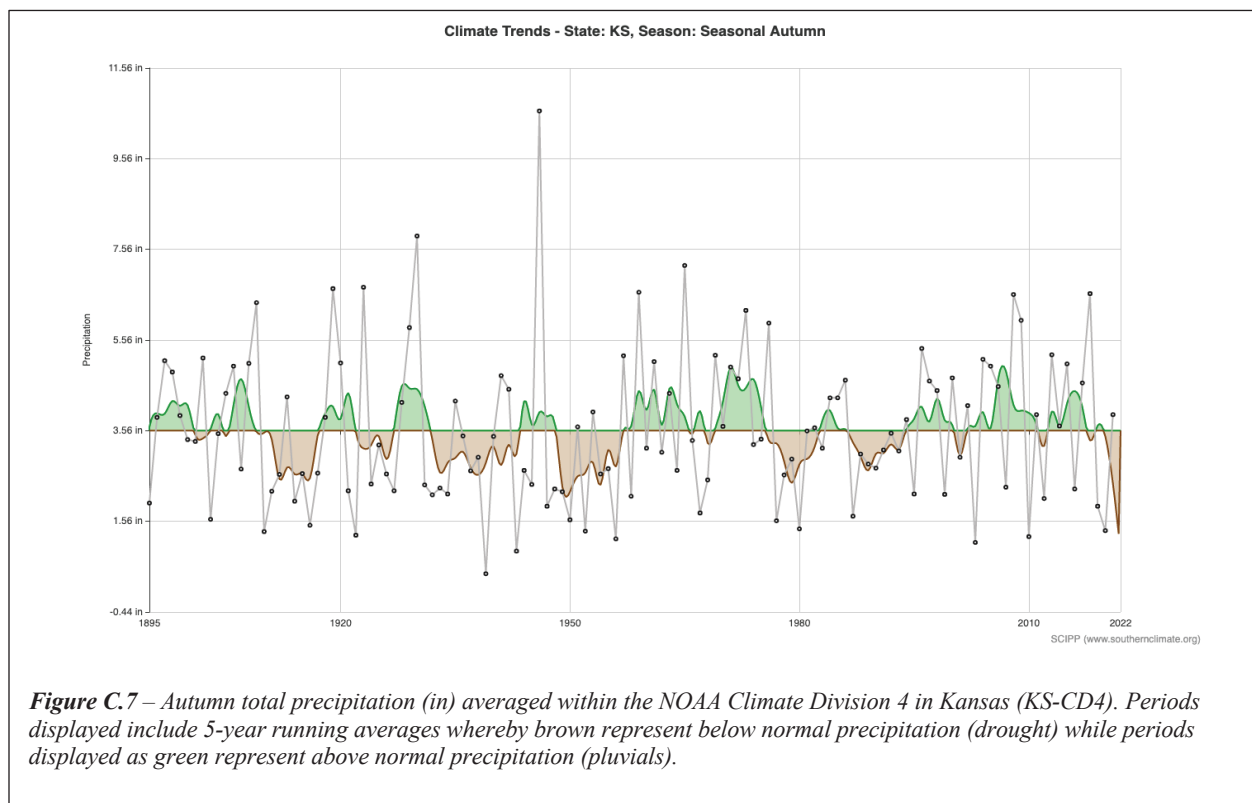

Figure D.2 *– Annual average temperature (°F) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure D.3 *– Spring total precipitation (in) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
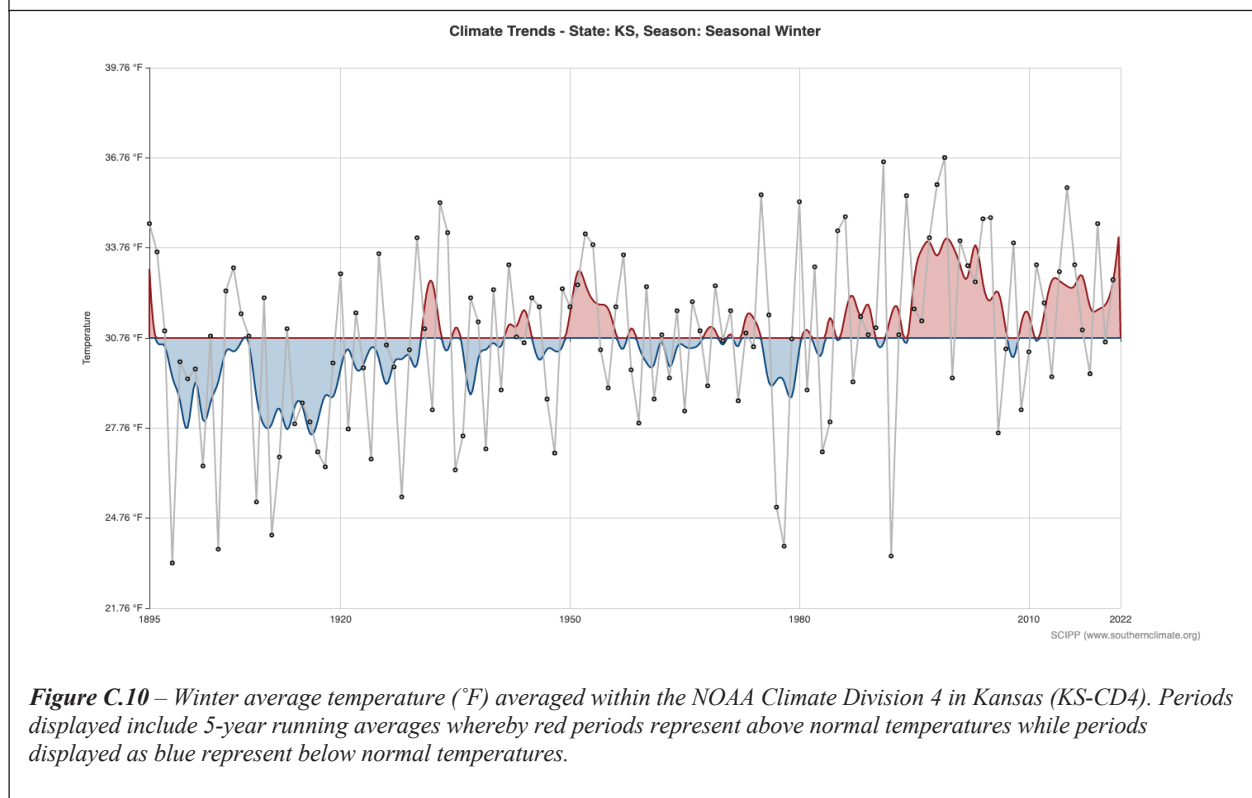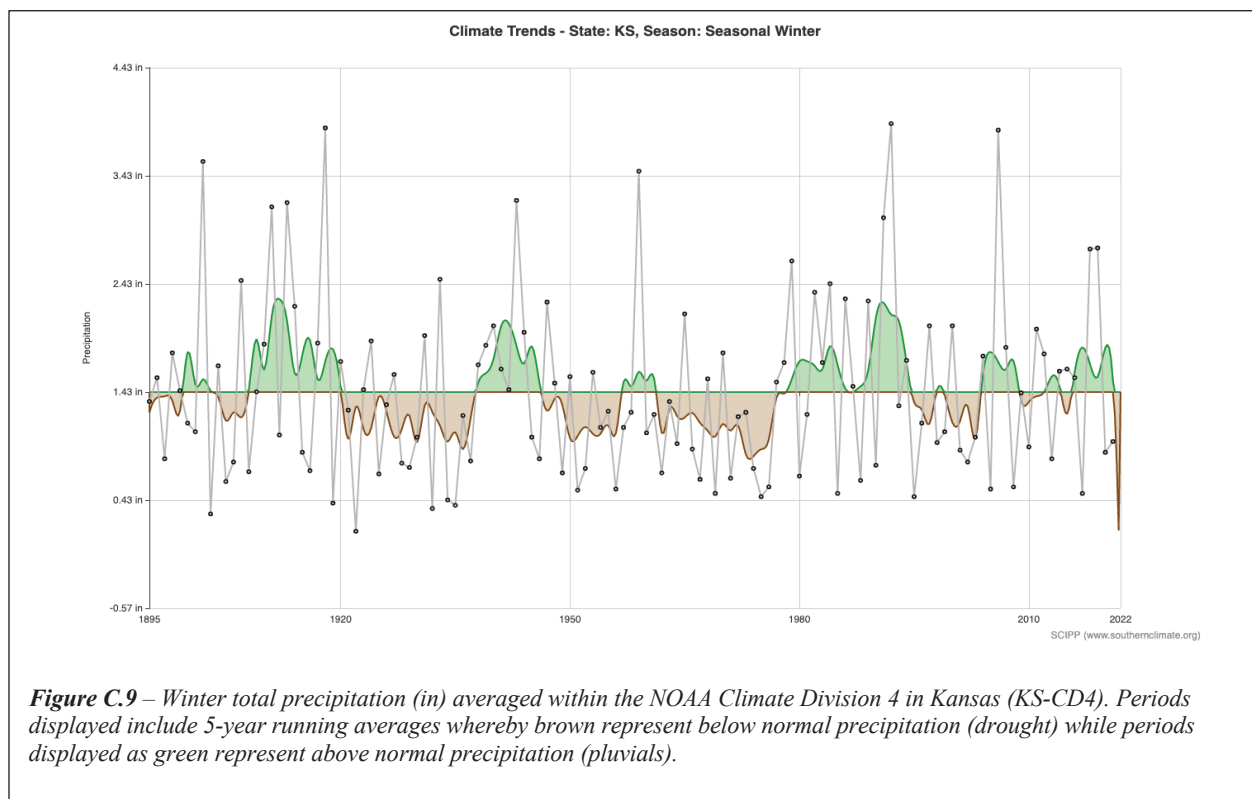

Figure D.4 *– Spring average temperature (°F) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
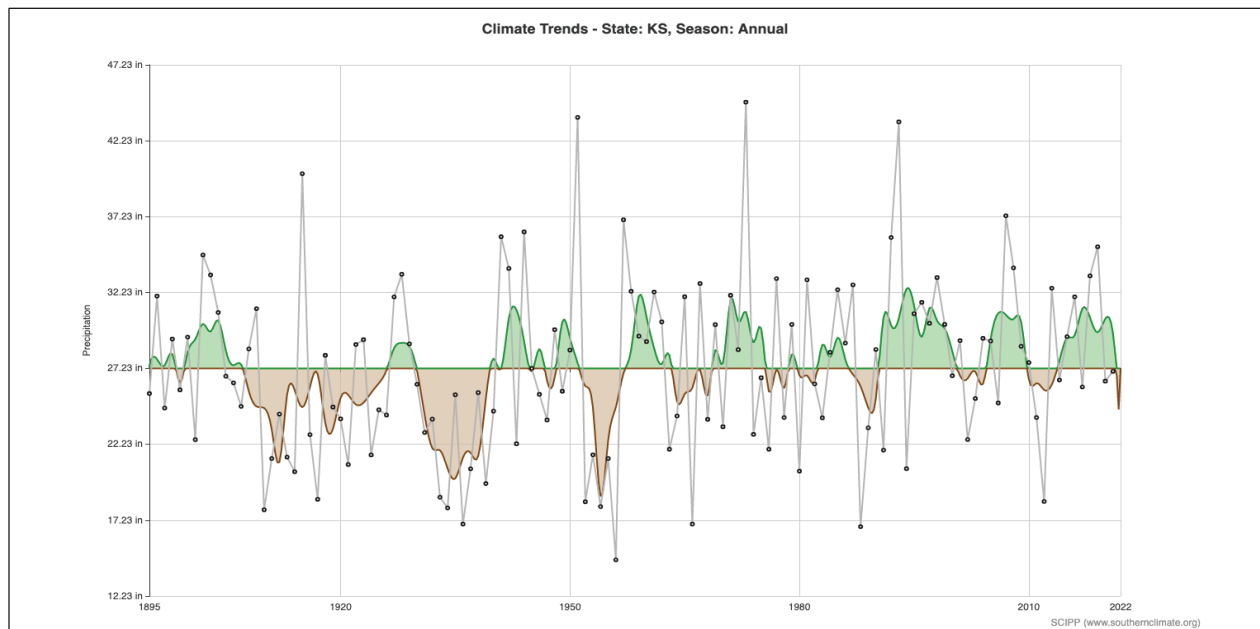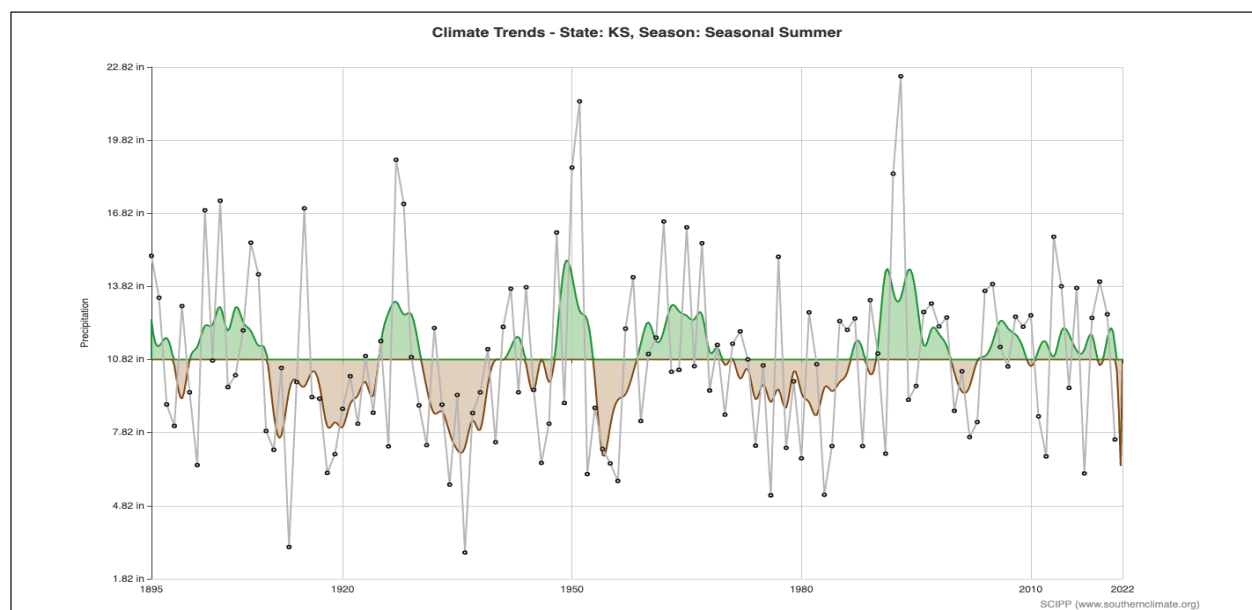
Figure D.5 *– Summer total precipitation (in) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
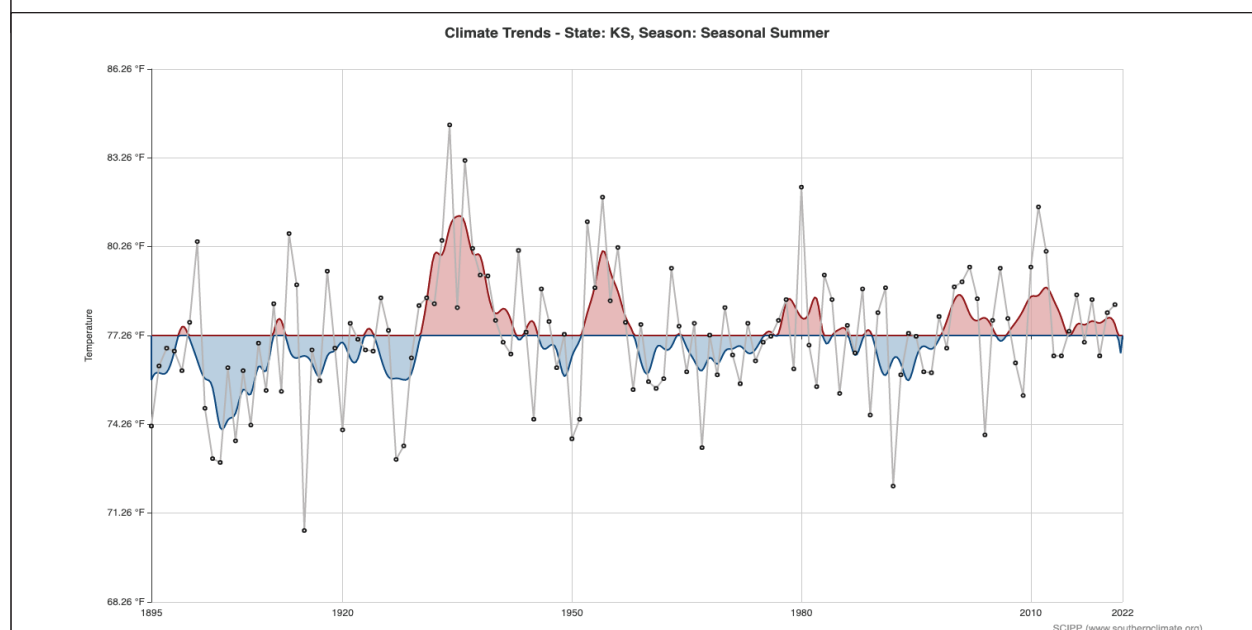
Figure D.6 *– Summer average temperature (˚F) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*

Figure D.7 – *Autumn total precipitation (in) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
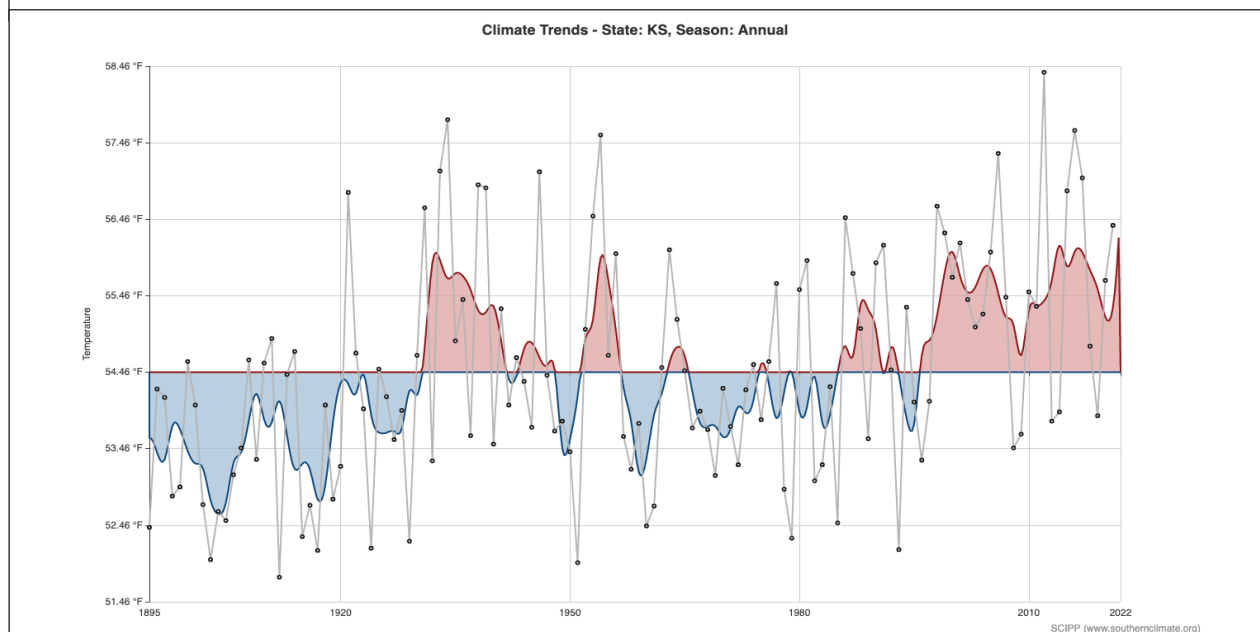

Figure D.8 – *Autumn average temperature (˚F) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
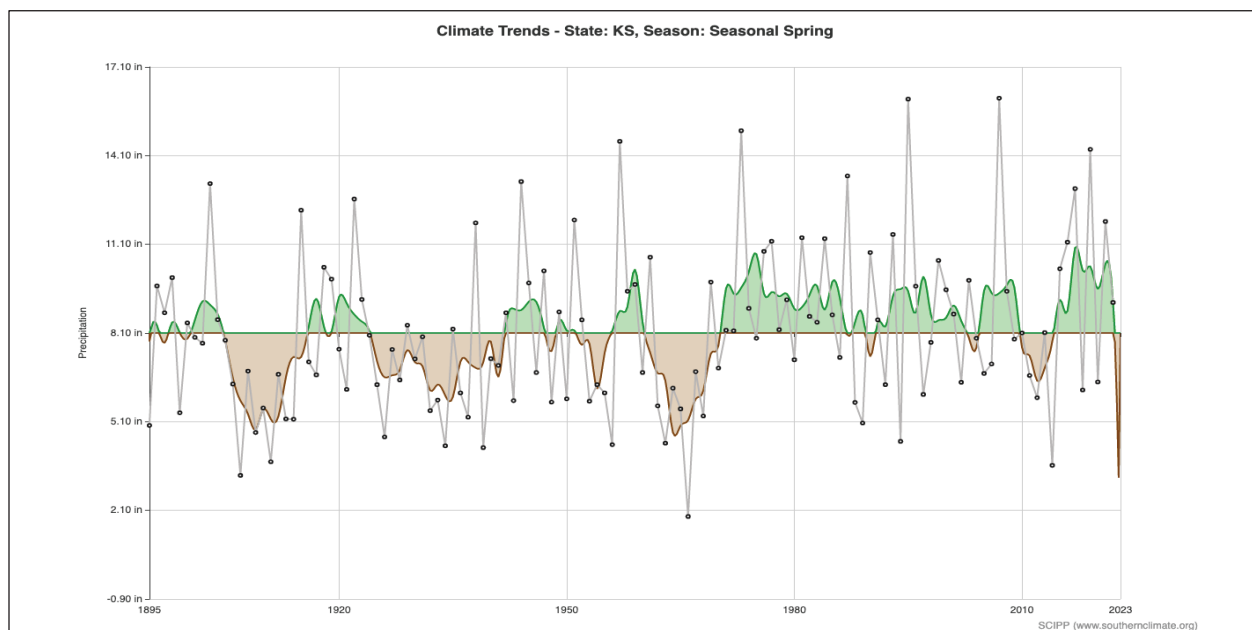
Figure D.9 *– Winter total precipitation (in) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby brown represent below normal precipitation (drought) while periods displayed as green represent above normal precipitation (pluvials).*
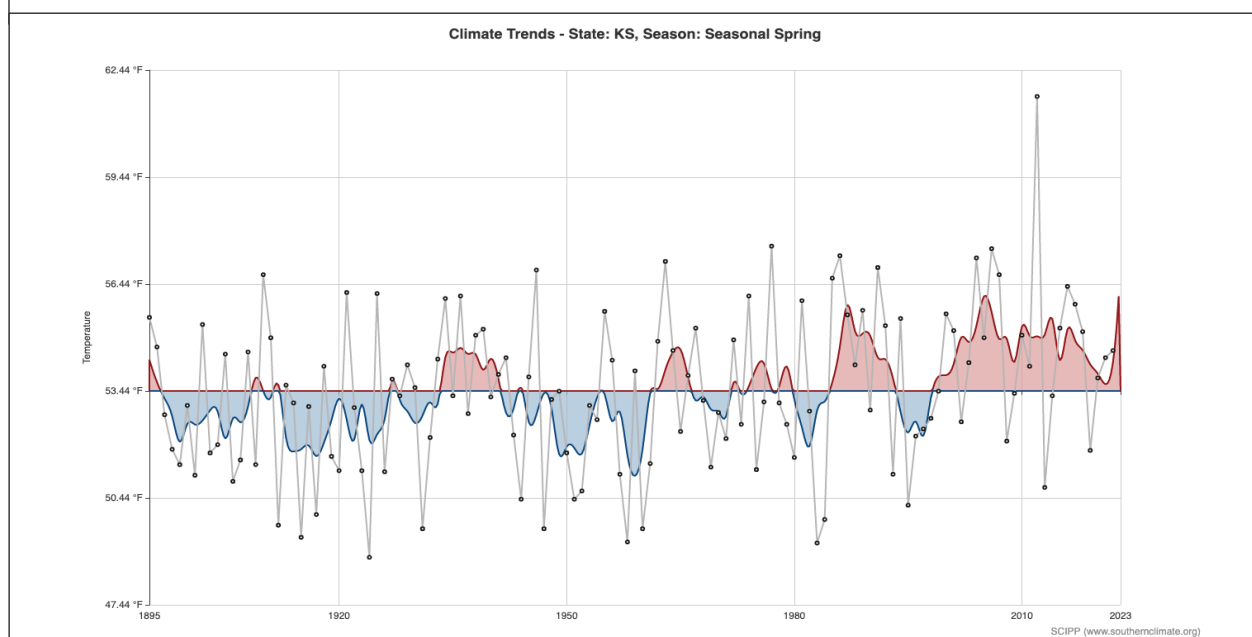

Figure D.10 *– Winter average temperature (˚F) averaged within the NOAA Climate Division 5 in Kansas (KS-CD5). Periods displayed include 5-year running averages whereby red periods represent above normal temperatures while periods displayed as blue represent below normal temperatures.*
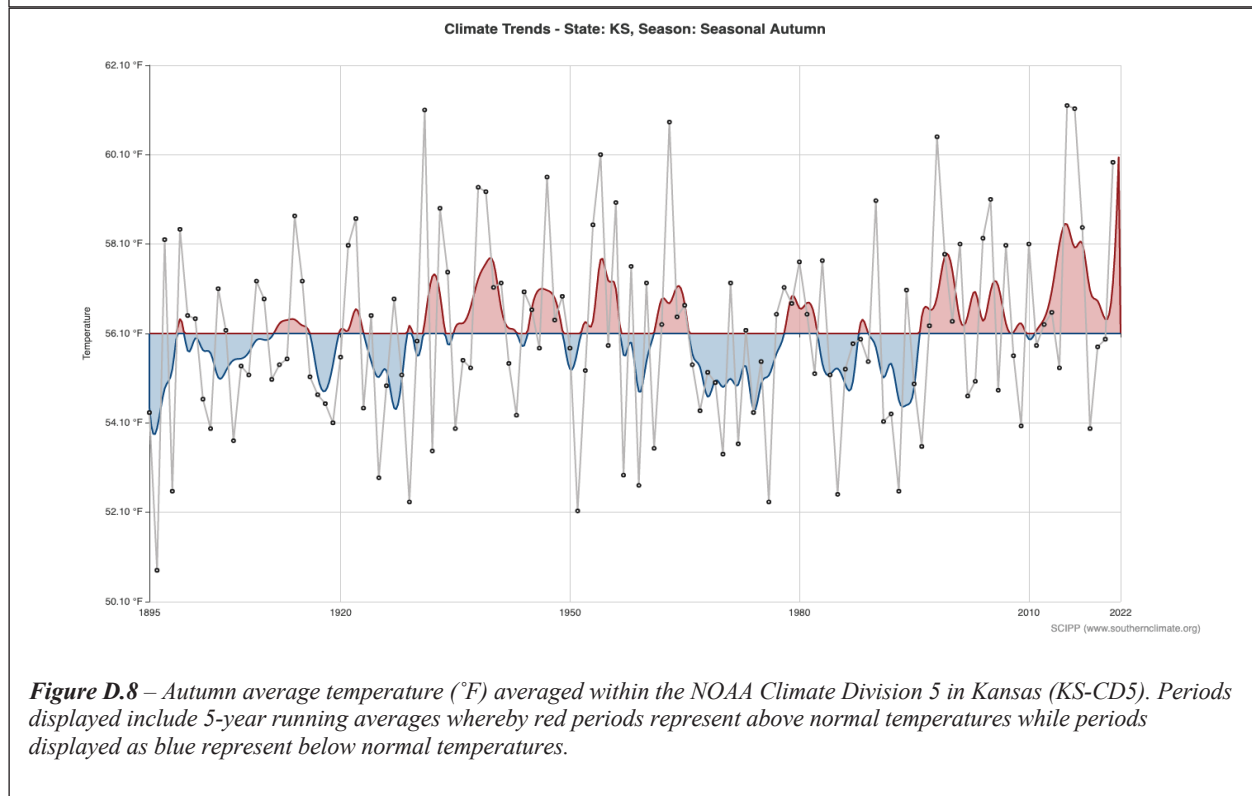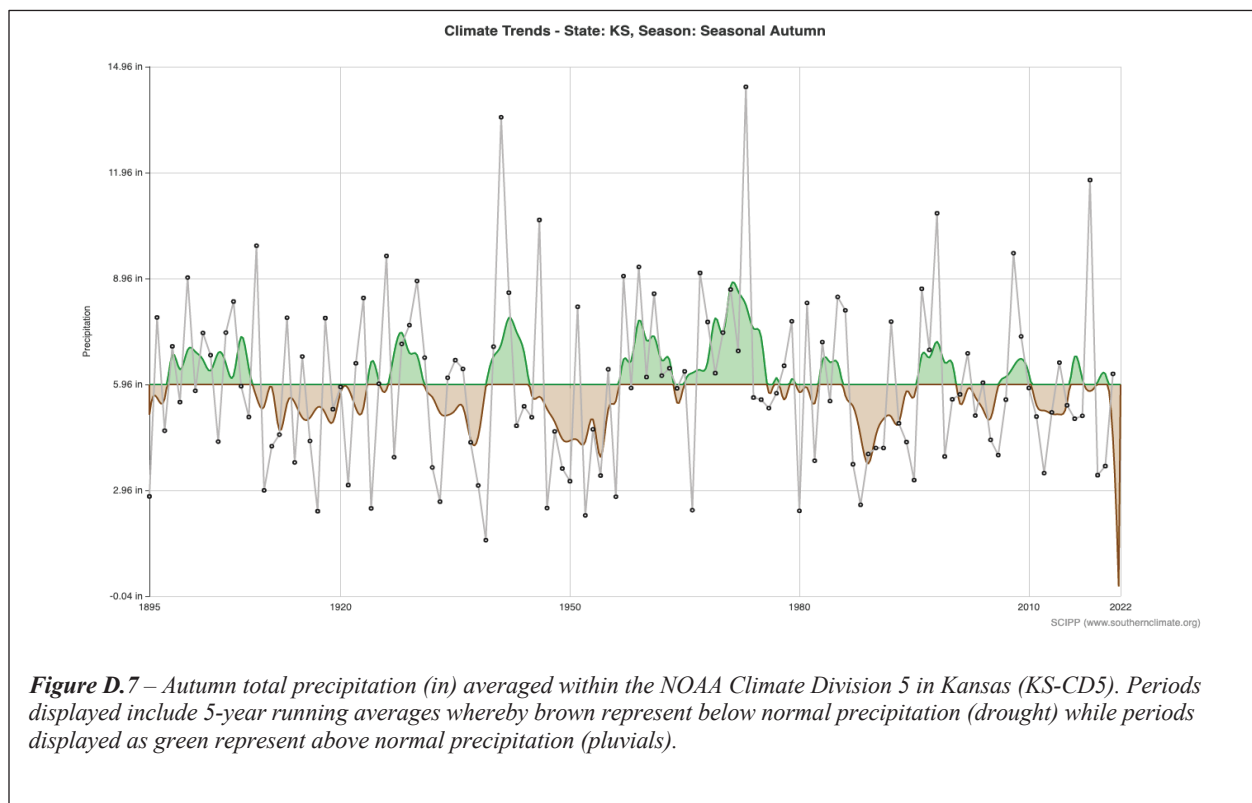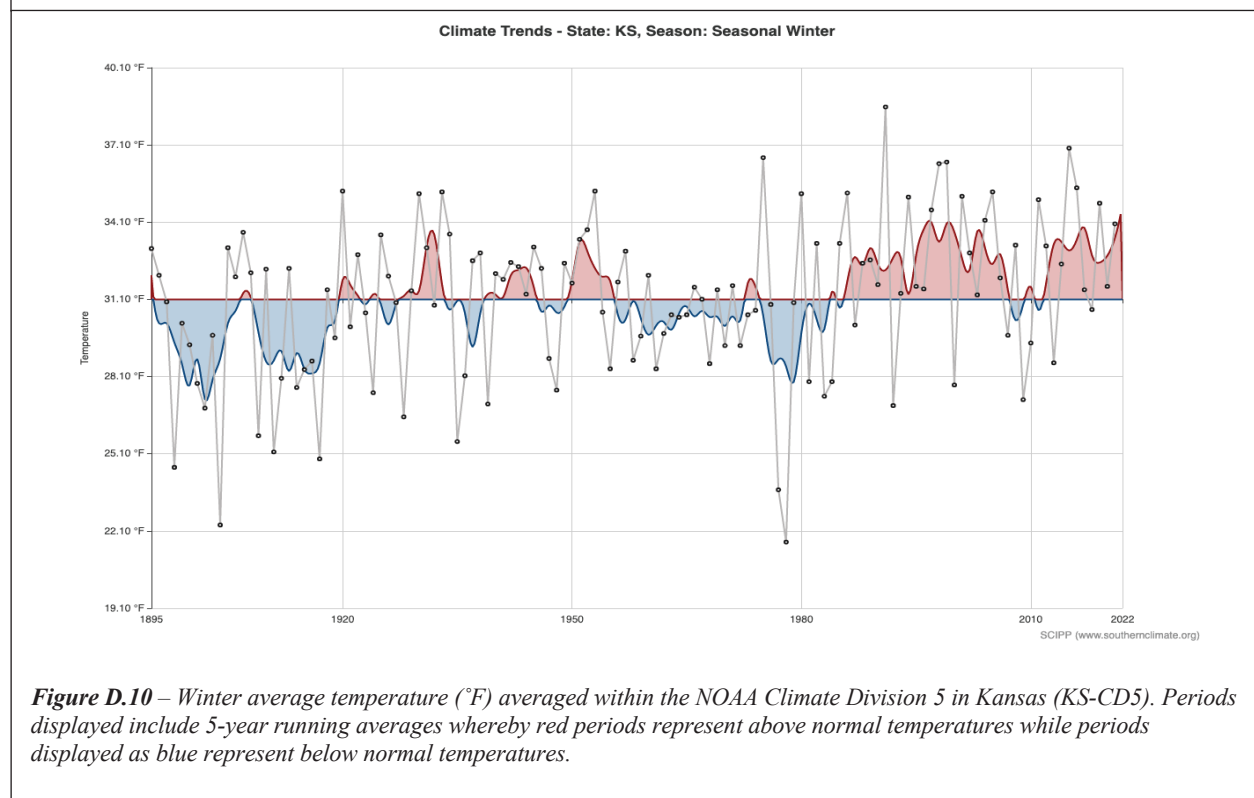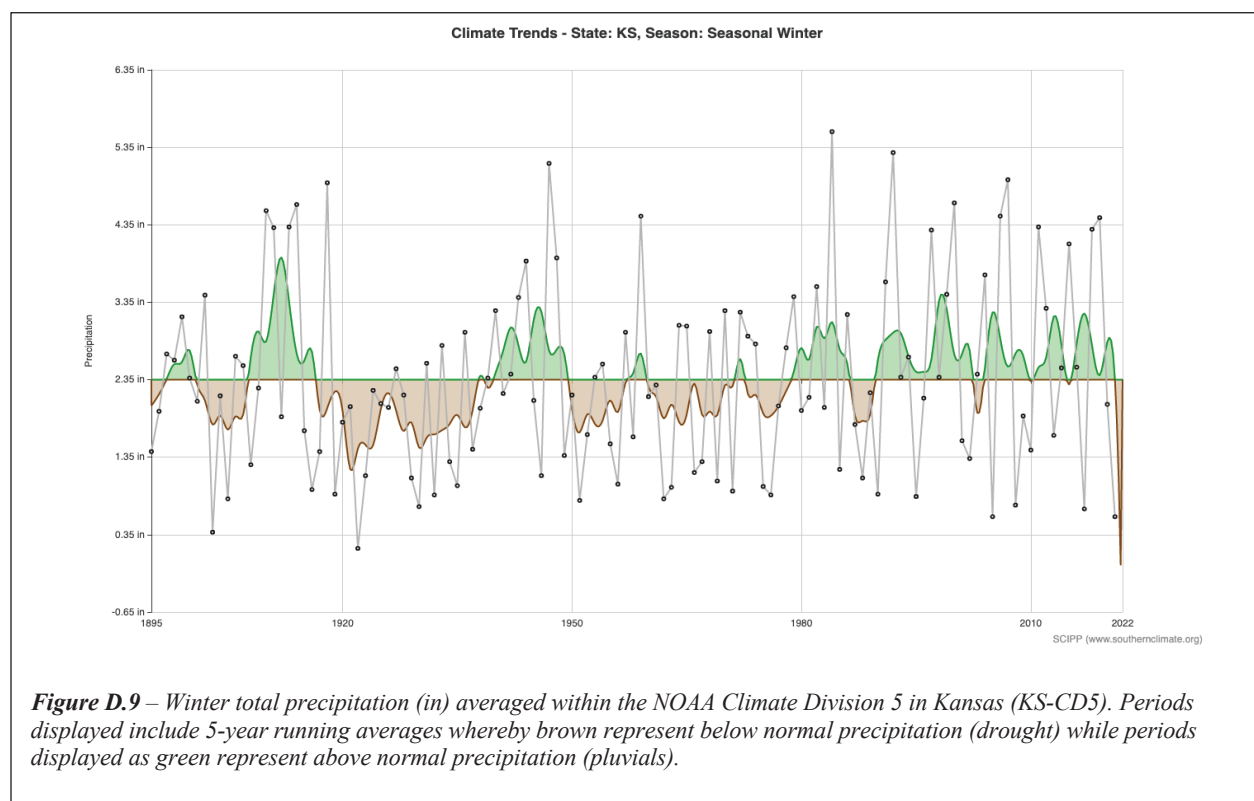
Appendix E – Curriculum Vitae for Jeffrey B. Basara

JEFFREY B. BASARA
Associate Professor, School of Meteorology
Associate Professor, School of Civil Engineering and Environmental Science
Executive Associate Director, Hydrology and Water Security Program
120 David L. Boren Blvd, Suite 5900, Norman, OK 73072
Phone: (405) 325-1760, E-mail: jbasara@ou.edu

PROFESSIONAL PREPARATION

University of Oklahoma, Norman, OK	Meteorology	Ph.D.	2001
University of Oklahoma, Norman, OK	Meteorology	M.S.	1998
Purdue University, West Lafayette, IN	Atmospheric Science	B.S.	1994

PROFESSIONAL APPOINTMENTS

2012-present	Associate Professor, School of Meteorology, University of Oklahoma
2018-present	Associate Professor, School of Civil Engineering and Environmental Science, University of Oklahoma
2018-present	Executive Associate Director, Hydrology and Water Security Program, University of Oklahoma
2017-2018	Associate Director for the Graduate Program, School of Meteorology, University of Oklahoma
2014-2020	Director, Kessler Atmospheric and Ecological Field Station
2002-2018	Director of Research, Oklahoma Climatological Survey, University of Oklahoma
2007-2012	Adjunct Associate Professor, School of Meteorology, University of Oklahoma
2001-2007	Adjunct Assistant Professor, School of Meteorology, University of Oklahoma
2001-2002	Research Scientist, Oklahoma Climatological Survey, University of Oklahoma

Dr. Basara leads the Climate, Hydrology, Ecosystems, Weather (CHEWe) research group at the University of Oklahoma. His current work includes interdisciplinary research focused on precipitation extremes, land-atmosphere interactions, and developing observational and modeling strategies that (1) increase the overall understanding of the complex interactions within the environmental column and (2) meet the needs of critical stakeholders. http://hydrometeorology.oucreate.com

SIGNIFICANT HONORS AND AWARDS

2023	Vice President for Research and Partnerships Annual Award for Excellence in Research Grants
2022	College of Atmospheric and Geographic Sciences Award for Excellence in Research
2021	Awarded Tenure at the University of Oklahoma
2021	Vice President for Research and Partnerships Annual Award for Excellence in Research Grants

2019	College of Atmospheric and Geographic Sciences Dean's Award for Excellence in Teaching
2019	USDA Research Education Economics (REE) Under Secretary's Award
2019	USDA-NIFA Multistate Partnership Award
2014	Named a Kavli Fellow of the United States National Academy of Sciences.
2010	Special Award from the American Meteorological Society for "*A new paradigm for the nation's weather forecasting enterprise based on a voluntary grass-roots effort, with impressive national impact through its use in curricula at scores of universities*."
2004	Named a Fellow of the Cooperative Institute for Mesoscale Meteorological Studies.
2001	School of Meteorology Douglas Lilly Award for the best Ph. D. Manuscript
2001	School of Meteorology Outstanding Teaching Assistant Award
2000	The David James Schellberg Memorial Scholarship Award
1998-2001	NASA Earth System Science *Ph.D. Fellowship*
1996-1998	NASA Space Grant Consortium *Graduate Student Fellowship*
1992-1994	Citizens Scholarship Foundation of America Award

1. Teaching data

a. Statement of Teaching

The core foundation of any academic institution, organization, or department is the quality of instruction and preparation of the students. While this statement applies broadly, it is manifest in numerous capacities in today's academic system throughout undergraduate and graduate student education including traditional classroom-style instruction and mentored research at local campuses (graduate and undergraduate students) to new paradigms including online instruction that reach a global population. This places increasing challenges on faculty to pursue excellence in teaching across a changing landscape of instruction. Further, the complexity of instruction will likely increase into the foreseeable future (especially given the response to Covid-19 and its impacts) and the ultimate success of academic institutions will be dependent upon identifying strengths within current and future faculty to meet the needs of students in the changing educational environment.

I have a passion for teaching. This passion has been borne out in many ways, but all within one overarching goal – to provide excellent instruction that meets the needs of current students to be difference makers across the environmental sciences. To that end, I attempt to utilize every available asset that can increase learning capacity from traditional lecture-based approaches, to experimental and experiential techniques (i.e., "hands-on" approach), to discussion-based formats that foster collaborative efforts (e.g., the flipped classroom approach), and the incorporation of enhanced digital learning via online instruction.

Summary of Teaching History and Accomplishments

To date, my teaching activities have included multiple components from in-person to online to direct mentorship and include those accomplishments below:

- I have always pursued experience in teaching, and while a graduate student at the University of Oklahoma, I served as a teaching assistant for multiple courses. However, while on a NASA fellowship as a Ph.D. student, I volunteered to instruct the primary non-major undergraduate course which included 100 students from a variety of backgrounds and disciplines. While it was the first course I developed and instructed on my own, it was a tremendous experience and solidified my vision for one-day becoming a professor. Further, due to my efforts in the classroom, I was awarded the 2001 Outstanding Teaching Assistant Award from the School of Meteorology at the University of Oklahoma.

- After becoming an adjunct faculty member in 2002 and until I transitioned to regular faculty in 2012 (ranked renewable term; RRT), I continued teaching approximately one course per year and instructed students at both the undergraduate and graduate levels. This included the opportunity to specifically engage those who were enrolled in the Honors sections of introductory courses within the Meteorology major and provide targeted instruction.

- After participating in the Oklahoma Weather Center Research Experiences for Undergraduates program (OWC REU; now NWC REU) early in my career, I developed a summer internship program at the Oklahoma Climatological Survey (OCS) to specifically provide research opportunities specifically for School of Meteorology undergraduates; the program was funded from 2004-2007. Of note is that, of the eight undergraduates who participated in the OCS Summer Research Internship Program, three obtained Ph.D. degrees later in their academic careers (Eric Hunt, University of Nebraska; Amanda Schroeder, University of Georgia; Tommy Winning, University of Texas A&M Corpus Christi). Additionally, from 2004-2009 I also developed a partnership with the Université de Limoges and supervised undergraduate students from France during the summer.

- In 2012, I transitioned to a regular faculty position in the School of Meteorology and, in 2018, I assumed a joint appointment with the School of Civil Engineering and Environmental Science. I was awarded tenure in 2021. My primary in-person, classroom instruction since becoming regular (RRT and now tenured) faculty has been focused on two courses: (1) METR 4424 Synoptic Meteorology Laboratory; a four-credit, five-contact hour core course for undergraduate majors and (2) METR 4633/5633 Hydrometeorology; a three-credit elective course offered to upper-division undergraduate students and graduate students. I have also instructed the graduate advanced synoptic meteorology course – METR 5413 – a three-credit core course to "fill-in" for an instructor on sabbatical.

- As part of an interdisciplinary education activity, I teamed with Dr. Phil Gibson of Biology and we developed a 3-4 week intercession/summer course that brings students from a wide range of backgrounds to the Kessler Atmospheric and Ecological Field Station and provides them with on-site experience and instruction focused on environmental sampling strategies across vegetation, soil, water, and atmospheric techniques. First offered during the summer of 2016, the course is led by Dr. Gibson and now regularly offered as students can receive both undergraduate and graduate credit.

- To meet the growing online needs of students timed with the launch of the Hydrology and Water Security (HWS) Program, I converted/developed my Hydrometeorology course to an online version during the Fall of 2018. This adaptation of the Hydrometeorology course required enhanced design to facilitate an online course that could be rigorous in technical merit and apply broadly across the environmental sciences.

- During 2019, I developed a second, but in this case previously untaught, online course at the graduate level for the HWS program: Hydroclimatology. Because this was a new course, it was

specifically and strategically designed to maximize learning in an online environment via targeted content, recorded lectures, and rigorous assignments designed to connect students to practical applications. The course has received excellent reviews and, at some point in the future I anticipate converting the online Hydroclimatology course to a full, on-ground course.

While course design, development and instruction are critical to academia at the university level, the concept of "teaching" applies more broadly. In particular, engaging students at all levels with mentored research provides new opportunities to expand their intellectual and applied capabilities within both discipline and interdisciplinary sciences. As such I fully support the development of students through research and have served as the academic chair for **27** graduate students who have obtained advanced degrees (21 M.S. and 6 Ph.D.) and am currently chair or co-chair for **8** others (8 Ph.D.). Additionally, I have served on the graduate committees of **43** past and current students. In all cases, I work with the students on end-to-end research which includes not only developing a scientific idea, plan, and analysis, but also the communication of the research to broader audiences (scientific and stakeholder-oriented) in the form of poster and oral presentations as well as peer-reviewed publications. In recent years and as the CHEWe group has matured with a distribution of students spanning second-year undergraduates to Ph.D. candidates, the environment has developed into a collaboratory whereby the exchange of ideas is no longer solely top-down driven by my influence, but also amongst the students themselves. This has led to an explosion of productivity from the group which has been evident not only in the graduation rates, but also in the number of student-led, first-authored publications (and co-publications) as well as numerous departmental, university, and national awards (**30** undergraduate and graduate awards, fellowships, and internships).

In addition, I routinely mentor undergraduate students with focused research projects embedded within research experiences for undergraduates (REU), senior capstone projects, and sponsored research. While it is not uncommon for graduate students to serve as (lead) authors on manuscripts, it is far less common for undergraduate students to serve in such a capacity. However, undergraduates I have mentored have served as the lead author on four publications since 2015 and in the 10 years that the McCasland Award for Outstanding Undergraduate Research has been presented by the School of Meteorology, student teams I have mentored have won the award three times.

b. Courses Taught and Enrollments

Course	Course Title	Semester Taught	Enrollment
METR 5413	Advanced Synoptic Meteorology	Spring 2023	28
METR 4424	Synoptic Meteorology Laboratory	Fall 2022	49
METR 5633	Hydrometeorology	Fall 2022	33
METR 5633	Hydrometeorology	Summer 2022	19
METR 5733 CEES 5733	Hydroclimatology	Summer 2022	68
METR 4424	Synoptic Meteorology Laboratory	Fall 2021	54
METR 5633	Hydrometeorology	Fall 2021	51
METR 5633	Hydrometeorology	Summer 2021	37
METR 5733 CEES 5733	Hydroclimatology	Summer 2021	50
METR 5633	Hydrometeorology	Fall 2020	82
METR 4424	Synoptic Meteorology Laboratory	Fall 2020	48
METR 5803 CEES 5020	Hydroclimatology	Summer 2020	65
METR 4633 METR 5633	Hydrometeorology	Spring 2020	15 1
METR 4424	Synoptic Meteorology Laboratory	Fall 2019	38
METR 5633	Hydrometeorology	Fall 2019	63
METR 5803 CEES 5020	Hydroclimatology	Summer 2019	45
METR 4970/5970 MBIO/PBIO 4970/5970	Environmental Sampling Techniques*	Spring 2019	1 4
METR 4633 METR 5633	Hydrometeorology	Spring 2019	21 2
METR 4424	Synoptic Meteorology Laboratory	Fall 2018	40
METR 5633	Hydrometeorology	Fall 2018	21
METR 4970/5970	Environmental Sampling Techniques*		8 1
METR 4633 METR 5633	Hydrometeorology	Spring 2018	10 1
METR 4424	Synoptic Meteorology Laboratory	Fall 2017	39
METR 4970/5970 PBIO 4970/5970	Environmental Sampling Techniques*	Spring 2017	4 5
METR 4633 METR 5633	Hydrometeorology	Spring 2017	20 -
METR 4424	Synoptic Meteorology Laboratory	Fall 2016	49
METR 5413	Advanced Synoptic Meteorology	Spring 2016	16
METR 4424	Synoptic Meteorology Laboratory	Fall 2015	43
METR 4633 METR 5633	Hydrometeorology	Spring 2015	14 -
METR 4424	Synoptic Meteorology Laboratory	Fall 2014	52

METR 4633	Hydrometeorology	Spring 2014	30
METR 5633			-
METR 4424	Synoptic Meteorology Laboratory	Fall 2013	48
METR 4633	Hydrometeorology	Spring 2013	15
METR 5633			-
METR 4491	Weather Briefing	Fall 2012	5
METR 5491			1
METR 2013	Introduction to Meteorology (Honors Section)	Fall 2011	8
METR 2013	Introduction to Meteorology	Spring 2011	6
METR 2013	Introduction to Meteorology (Honors Section)	Fall 2010	16
METR 4633	Hydrometeorology	Spring 2010	22
METR 5633			-
METR 2013	Introduction to Meteorology (Honors Section)	Fall 2009	5
METR 5803	Climate Issues	Spring 2007	16
METR 4424	Synoptic Meteorology Laboratory	Fall 2004	54
METR 4424	Synoptic Meteorology Laboratory	Fall 2003	41
METR 4424	Synoptic Meteorology Laboratory	Fall 2002	37
METR 4803	Forecasting**	Spring 2002	9
METR 2413	Introduction to Synoptic Meteorology	Spring 2002	71
METR 1014	Introduction to Meteorology	Fall 2000	100

* **Served as a Co-instructor - Lead Instructor was Dr. Phil Gibson**
** **Served as a Co-instructor - Lead Instructor was Dr. Fred Carr**

c. Individual Work with Students

Due to my position(s) within the University of Oklahoma, and because of the support provided by internal and external funding, I have had the privilege to advise, supervise, and mentor individual students from a variety of backgrounds and at multiple academic levels (i.e., both graduate and undergraduate). This is and has been one of the most fulfilling aspects of my role as an academic.

Graduate Advisees

Student	Thesis/Dissertation Title	Degree	Graduation Year
Kodi L. Nemunaitis	Validation of the North American Land Data Assimilation System (NLDAS) Using Data from Oklahoma Mesonet OASIS Sites	M.S.	2003
Donald J. Giuliano	Using the B-W Fuzzy Logic Technique to Estimate CBL Depth from 915 MHZ Wind Profiler Data	M.S.P.M.	2004

Christy Carlson	A Spatial and Temporal Climatology of 1% Temperatures and Coincident Dew Point Temperature for the Continental United States	M.S.P.M.	2004
Peter K. Hall	The Urban Environment of Oklahoma City: Spatial and Temporal Analysis of the Meteorological Conditions	M.S.	2004
Daniel R. Cheresnick	An Analysis of Severe Hail Swaths in the Southern Plains of the United States	M.S.	2005
James Hocker	A Geographic Information Based Analysis of Supercell and Squall Line Storms Swaths Across Oklahoma	M.S.	2006
Justin W. Monroe	Evaluating NARR surface Reanalysis Variables and NLDAS Using Oklahoma Mesonet Observations	M.S.	2007
Amanda Schroeder	A Quantitative Description of the Oklahoma City Urban Heat Island	M.S.	2010
Lindsay Tardif	Quantifying the Spatial and Temporal Variability of the Surface Energy Budget Across Oklahoma During a Period of Historic Precipitation	M.S.	2011
Aaron Gleason	Evolution of National Weather Service Forecast Products Using In Situ Observations in Oklahoma	M.S.	2011
Kodi L. Nemunaitis*	Observational and Model Analyses of the Oklahoma City Urban Heat Island	Ph.D.*	2014
Jing Liu	Quantitative Analysis of Evapotranspiration Climatology and Variation at Oklahoma Mesonet Sites during Drought Period	M.S.	2015
Paul Flanagan	The Dryline, Convective Initiation, and Rapid Evolution of Drought in Oklahoma During 2011	M.S.	2015
Hayden Mahan	In-Situ Measurements and Remotely Sensed Estimations of Surface Fluxes over the Southern Great Plains of the United States	M.S.	2016
Bradley G. Illston	Near Surface Atmopsheric Impacts Resulting from a Developing Metropolitan Area	Ph.D.	2016
Ryann Wakefield	A 16-Year Observational Analysis of Land-Atmosphere Coupling in Oklahoma Using Mesonet and North American Regional Reanalysis Data	M.S.	2018

Paul Flanagan	The Changing Hydroclimate of the United States Great Plains: Meteorological and Climatological Impacts on Water Resources	Ph.D.	2018
Noah Brauer	Quantifying Precipitation Efficiency and Drivers of Excessive Precipitation in Post-Landfall Hurricane Harvey	M.S.	2019
Sarah Wugofski	Synoptic and Mesoscale Analysis of the 2015 Southern Great Plains Flash Pluvial	M.S.	2019
Stuart Edris	Evaluation of Flash Drought Criteria Components	M.S.	2020
Jordan Christian	Flash Droughts: A Local to Global Analysis of Rapid Drought Intensification and their Associated Impacts	Ph.D.	2020
Ryann Wakefield	Disentangling the relative contribution of land-atmosphere coupling toward the evolution of extreme events	Ph.D.	2021
Taylor Grace	An Applied Heat Wave Definition across the Southern Great Plains	M.S.	2021
Bryony Puxley**	Precipitation Whiplash Events Across the Southern Great Plains of the United States	M.S.	2021
Noah Brauer***	Satellite and Radar Remote Sensing of Tropical Cyclones to Quantify Microphysical and Precipitation Processes	Ph.D.	2022
Alyssa Woodward	A Multidimensional Analysis of an Anomalous, High-Impact, Early-Season Ice Storm in Oklahoma	M.S.	2022
Ben Fellman	Abrupt Agricultural Flash Drought: An Investigation of Rapid Drought Development across Vital Agricultural Zones of the United States	M.S.	2023
Devon Woods***		Ph.D.	Current Student – Expected 2023
Stuart Edris		Ph.D.	Current Student – Expected 2023
Daniel Mesheske		Ph.D.	Current Student – Expected 2023
Taylor Grace		Ph.D.	Current Student – Expected 2024

Austin Dixon		Ph.D.	Current Student – Expected 2024
Bryony Puxley**		Ph.D.	Current Student – Expected 2024
Stephen Foskey		Ph.D.	Current Student – Expected 2025
Henry Olayiwola		Ph.D.	Current Student – Expected 2025

*   Co-Advised with Dr. Petra Klein
**   Co-Advised with Dr. Elinor Martin
***   Co-Advised with Dr. Pierre Kirstetter

Graduate Student Committees Served On

Student	**Degree**	**Graduation Year**	**Department**
Brad Illston	M.S.	2002	Meteorology
John Ensworth	Ph.D.	Withdrew in 2004	Meteorology
Michael James	M.S.	2006	Meteorology
Carlos Yanez-Uribe	M.S.	2008	Geography
Mang Lueck Cheuk	M.S.	2009	Geography
Shanon Connelly	M.S.	2010	Environmental Science, Policy, and Geography, University of South Florida
Diana Vanegas	M.S.	2011	Microbiology and Plant Biology
Jill Hardy	M.S.	2014	Meteorology
Reed Timmer	Ph.D.	2015	Meteorology
Amanda Schroeder	Ph.D.	2015	Department of Geography, University of Georgia
Zac Flamig	Ph.D.	2016	Meteorology
David Gagne	Ph.D.	2016	Meteorology
Cui Jin	Ph.D.	2016	Microbiology and Plant Biology
Race Clark	Ph.D.	2016	Meteorology
Rajen Bajgain	Ph.D.	2017	Microbiology and Plant Biology
Yuting Zhao	Ph.D.	2017	Microbiology and Plant Biology
Yao Zhang	Ph.D.	2017	Microbiology and Plant Biology
Jessica Erlingis	Ph.D.	2017	Meteorology
Bill Dower	Ph.D.	2017	Electrical Engineering
Manabendra Saharia	Ph.D.	2017	Microbiology and Plant Biology
Uvirkaa Akumagaa	Ph.D.	2018	Geography
Jay McDaniel	Ph.D.	2018	Electrical Engineering
Greg Blumberg	Ph.D.	2018	Meteorology
David Harrison	M.S.	2018	Meteorology
Russell Caldwell	Ph.D.	2019	Microbiology and Plant Biology
Greg Jennrich	M.S.	2019	Meteorology

Zhenhua Zou	Ph.D.	2019	Microbiology and Plant Biology
Jie Wang	Ph.D.	2019	Microbiology and Plant Biology
Ryan Lagerquist	Ph.D.	2020	Meteorology
Tri Pham	M.S.	2020	Environmental Science
Walter Chandler	M.S.	2020	Environmental Science
Xiaocui Wu	Ph.D.	2020	Microbiology and Plant Biology
Ryan Bunker	M.S.	2020	Meteorology
Anna Wanless	M.S.	2021	Meteorology
Stephen Foskey	M.S.	2022	Meteorology
Maresa Searls	M.S.	2022	Meteorology
Brian Sun	Ph.D.	2022	Electrical Engineering
David Harrison	Ph.D.	2022	Meteorology
Qing Chang	Ph.D.	Current Student	Microbiology and Plant Biology
Qingyu Wang	Ph.D.	Current Student	Meteorology
Jorge Celis	Ph.D.	Current Student	Microbiology and Plant Biology
Chenchen Zhang	Ph.D.	Current Student	Microbiology and Plant Biology
Ben Davis	Ph.D.	Current Student	Meteorology

Undergraduate Senior Capstone Mentorship

- Collin Caldwell, Steve Bodnar, Michael James, Grant Stewart, and Shane Young, 2003
- Chad Ringley, Michael Grogan, Beth Minter, Justin Monroe, Kelly Sugden, and Dianne Laird, 2004
- Eric Hunt and Cindy Morgan, 2004-2005
- Josh Benefield, Michael Morris, Scott Stevens, Chad Ganeau, Melissa Moon, and Amanda Schroeder, 2005-2006
- Megan Ferris, 2006-2007
- Kenneth Jackson, Ben Walnick, Jonathan Whitehead, Eric Hollingshead, Kyle Davis, Tommy Winning, Trevor Grout, Lauren Bodenhamer, 2008-2009.
- Landon Harrison, Mason Rowell, and Chase Thomason, 2009-2010.
- Lamont Bain, Brittany Benson, 2010-2011.
- Kyle Pennington, James Glenn, Kyle Thiem, Jessica Voveris, Emma Kuster, Wava Denito, Daniela Spade, 2012-2013
- Jordan Ferguson, Lauren Wigley, Jordan Christian, Katy Christian, 2013-2014
- Taylor McCorckle, Skylar Williams, Tim Pfieffer, 2014-2015
- Brett Borchardt, Andrew Moore, Kevin Biehl, Rachel Gaal, David King, 2015-2016
- Mathew Bray, Kristine Chen, Stephen Foskey, 2019-2020
- Virgil Enos, Mark McCoy, Jack Miller, 2020-2021
- Brett Scott, Emilie McReynolds, Matthew Rada, Haylee Glass, Hunter Martinez-Buehrer, Danya Meadows, Reed Drapela, Xander Teets, 2021-2022

Undergraduate Research Mentorship

Student	Support/Activity	Period
Andrew Philpott	OWC REU Program	Summer 2002
Justin Monroe	OCS Undergraduate Research Assistant	2003-2005
Dutin Rapp	OWC REU Program	Summer 2002
Collin Caldwell, Steve Bodnar	SMEX03 Field Sampling; Grant Funded via USDA	Summer 2003
Michael James, Grant Stewart, Michael Morris, Kristen Poole	Joint Urban 2003 Field Campagian; Grant Funded via DoD	Summer 2003
Jim Southard, Eric Hunt	OCS Undergraduate Summer Internship Program	Summer 2004
Scott Stevens, Amanda Schroeder	OCS Undergraduate Summer Internship Program	Summer 2005
Sophie Denis, Adrien Dalhun	Undergraduate Research Exchange Program with the Université de Limoges	Summer 2005
Heather Campbell, Tommy Winning	OCS Undergraduate Summer Internship Program	Summer 2006
Emilie Delanoue, François Bélingard	Undergraduate Research Exchange Program with the Université de Limoges	Summer 2006
Tommy Winning	OCS Undergraduate Research Assistant	2006-2009
John Barr, Aaron Gleason	OCS Undergraduate Summer Internship Program	Summer 2007
Nicolas Ducleroir, Jonathan Dautrement	Undergraduate Research Exchange Program with the Université de Limoges	Summer 2007
Maxime Renoux, Arnaud Rival	Undergraduate Research Exchange Program with the Université de Limoges	Summer 2008
Pierre-Antione Dutheil	Undergraduate Research Exchange Program with the Université de Limoges	Summer 2009
Megan Conway	KAEFS Undergraduate Research Assistant	2014-2015
Nicholas Balderas	KAEFS Undergraduate Research Assistant	2015-2018
Morgan Clark	NWC REU Program	Summer 2018
Raquel Dominguez	NWC REU Program	Summer 2019
Emily West	Undergraduate Research Assistant	2020 - 2021
Mac Syrett	Undergraduate Research Assistant	2021 - 2022

Undergraduate Student Awards

- **Eric Hunt** and **Cindy Morgan** (Jeffrey Basara, Student Mentor) - David Shellberg Memorial Scholarship, University of Oklahoma. Served as the mentor and co-author of the research project entitled *Significant Inversions and Rapid In-Situ Cooling at a Well-Sited Oklahoma Mesonet Station* and published in the Journal of Applied Meteorology. (April 2005).

- **Joanna N. Maybourn, Casey M. Peirano, Jennifer E. Tate, Parker J. Brown, Jake D. Hoey, Brandon R. Smith** (Jeffrey Basara, Student Mentor) - <u>McCasland Award for Outstanding Undergraduate Research</u>, School of Meteorology. Served as the mentor and co-author of the research project entitled *Drought and associated impacts in the Great Plains of the United States - A review* and published in the International Journal of Geosciences. (April 2014).
- **Taylor McCorckle, Skylar Williams, Tim Pfieffer** (Jeffrey Basara, Student Mentor) <u>McCasland Award for Outstanding Undergraduate Research</u>, School of Meteorology. Served as the mentor and co-author of the research project entitled *Atmospheric Contributors to Heavy Rainfall Events in the Arkansas-Red River Basin* and published in Advances in Meteorology. (April 2016).
- **Ben Toms** (Jeffrey Basara, Student Mentor) - <u>McCasland Award for Outstanding Undergraduate Research</u>, School of Meteorology. Served as the mentor and co-author of the research project entitled *Usage of Existing Meteorological Data Networks for Parameterized Road Ice Formation Modeling* published in the Journal of Applied Meteorology and Climatology. (April 2017).

<u>Graduate Student Awards, Fellowships, and Internships</u>

- **Paul Flanagan** (Jeffrey Basara Ph.D. Student Advisor) - David Shellberg Memorial Scholarship, University of Oklahoma. (April 2016).
- **Jordan Christian** (Jeffrey Basara Ph.D. Student Advisor) - <u>1st Place Student Oral Presentation Award, The American Meteorological Society 32nd Conference on Hydrology</u>. "The Evaporative Stress Index as an Indicator for Flash Drought Across the United States Using Reanalysis Datasets". (2018)
- **Ryann Wakefield** (Jeffrey Basara M.S. Student Advisor) - <u>2nd Place Poster Presentation</u>, 2018 Student Research and Creativity Day - Engineering/Science A Category. (February 2018).
- **Ryann Wakefield** (Jeffrey Basara M.S. Student Advisor) – <u>Outstanding Teaching Assistant Award</u>, School of Meteorology. (2018).
- **Paul Flanagan** (Jeffrey Basara Ph.D. Student Advisor) - <u>Outstanding Performance as a Graduate Student</u>, School of Meteorology. (2018).
- **Ryann Wakefield** (Jeffrey Basara Ph.D. Student Advisor) - <u>David Shellberg Memorial Scholarship</u>, University of Oklahoma. (2019).
- **Ryann Wakefield** (Jeffrey Basara Ph.D. Student Advisor) - <u>Provost's Certificate of Distinction in Teaching</u>, University of Oklahoma. (2019).
- **Ryann Wakefield** (Jeffrey Basara Ph.D. Student Advisor) - <u>Future Investigators in NASA Earth and Space Science and Technology (FINESST) Fellowship Recipient</u>. (2019).
- **Noah Brauer** (Jeffrey Basara Ph.D. Student Advisor) - **James Bruce Morehead Award**, University of Oklahoma. (2019).
- **Jordan Christian** (Jeffrey Basara Ph.D. Student Advisor) - <u>David Shellberg Memorial Scholarship</u>, Graduate College, University of Oklahoma (2020).
- **Jordan Christian** (Jeffrey Basara Ph.D. Student Advisor) - <u>Bullard Dissertation Completion Fellowship</u>, University of Oklahoma (2020).
- **Jordan Christian** (Jeffrey Basara Ph.D. Student Advisor) - <u>Provost's Graduate Teaching Assistant Award,</u> University of Oklahoma (2020).

- **Ryann Wakefield** (Jeffrey Basara Ph.D. Student Advisor) – <u>Yoshi Sasaki Award for best M.S. Publication</u>, School of Meteorology, University of Oklahoma (2020).
- **Noah Brauer** (Jeffrey Basara Ph.D. Student Co-Advisor) - <u>Outstanding Teaching Assistant Award</u>, School of Meteorology, University of Oklahoma (2020).
- **Jordan Christian** (Jeffrey Basara Ph.D. Student Advisor) - <u>Outstanding Performance as a Graduate Student</u>, School of Meteorology, University of Oklahoma (2020).
- **Bryony Puxley (Jeffrey Basara M.S. Student Co-Advisor)** – <u>Douglas K. Lilly Scholarship in Climate Science</u>, School of Meteorology, University of Oklahoma (2020).
- **Noah Brauer** (Jeffrey Basara Ph.D. Student Co-Advisor) - Student Journal Paper Award, ARRC, University of Oklahoma (2021).
- **Noah Brauer** (Jeffrey Basara Ph.D. Student Co-Advisor) - <u>Tommy C. Craighead Award for Best Paper in Radar Meteorology</u>, School of Meteorology, University of Oklahoma (2021).
- **Jordan Christian** (Jeffrey Basara Ph.D. Student Advisor) – <u>Edwin Adlerman Award for Graduate Student Research,</u> School of Meteorology, University of Oklahoma (2021).
- **Noah Brauer** (Jeffrey Basara Ph.D. Student Co-Advisor) - <u>Future Investigators in NASA Earth and Space Science and Technology (FINESST) Fellowship Recipient</u>. (2021).
- **Taylor Grace** (Jeffrey Basara Ph.D. Student Advisor) – <u>2nd Place Student Oral Presentation Award, The American Meteorological Society 35th Conference on Climate Variability and Change</u>. "A Heat Wave Definition Trend Analysis from 1979 through 2019 in the Southern Great Plains" (2022).
- **Benjamin Fellman** (Jeffrey Basara M.S. Student Advisor) **–** NCAR Earth System Science Internship. (2022).
- **Taylor Grace** (Jeffrey Basara Ph.D. Student Advisor) – <u>Outstanding Poster Presentation Award, The American Meteorological Society 36th Conference on Climate Variability and Change</u>. "A Statistical Analysis Toward the Development of a Heat Wave Definition in the Contiguous United States" (2023).
- **Taylor Grace** (Jeffrey Basara Ph.D. Student Advisor) – <u>Outstanding Teaching Assistant Award</u>, School of Meteorology. (2023).
- **Bryony Puxley (Jeffrey Basara Ph.D. Student Co-Advisor**) – <u>Outstanding Service to the Department,</u> School of Meteorology. (2023).
- **Benjamin Fellman** (Jeffrey Basara M.S. Student Advisor) **–** <u>Outstanding Student Oral Presentation Award,</u> Oklahoma EPSCOR State Conference. (2023).

2. Research/Creative Activity Data

a. Statement of Research/Creative Activities

My research interests have focused on the integration of increased understanding across weather, climate, water, and ecosystems, with specific research activities that include the physical processes which impact the development of the planetary boundary layer, surface-atmosphere exchange, urban meteorology, severe weather, in situ instrumentation, precipitation extremes (droughts, flash droughts, flash floods, and pluvial periods) the development, validation, and improvement of land surface models used in numerical weather prediction, and the validation and application of remotely sensed soil moisture, skin temperature, and vegetation conditions from satellite mounted

instruments. Because of the nature of past research positions affiliated with the Oklahoma Climatological Survey, a primary focus of my research has been on the Great Plains of North America. However, in more recent years and in concert with leading the CHEWe Research Group, the work has taken on a broader perspective: local to global with specific focus on how surface-atmosphere coupling drives hydrometeorological and hydroclimatological extremes. Many of these research projects <u>require collaboration</u> with a range of colleagues and scientists and true <u>interdisciplinary partnerships</u>.

<u>Summary of Research/Creative Activities Accomplishments</u>

- I served as the Director of Research for the Oklahoma Climatological Survey (OCS) for 17 years. In this capacity, I was tasked with developing and maintaining the research activities within OCS utilizing State of Oklahoma budgeted resources augmented with external funding. During this period, I led numerous staff and students in expanding the fundamental knowledge of weather and climate processes across the Great Plains of the United States and worked to communicate critical results to stakeholders across a variety of sectors spanning agriculture, to water resources, to emergency management. Key components of the work also included (1) utilizing and expanding the capacities of the Oklahoma Mesonet, a statewide network of environmental observing sites that collects critical weather and climate observations and (2) associated applied research that addressed the needs of local stakeholders while improving our fundamental knowledge of high-impact environmental processes in the region (drought, floods, severe weather, etc.).

- As an early career scientist, I served as a PI of the Joint Urban 2003 field experiment in Oklahoma City, led the logistics and operations center during the 35-day campaign, and served as the primary liaison between the project and the City of Oklahoma City prior to, during, and following the field campaign.

- I served as the lead scientist for the Oklahoma City Micronet project (OKCNET). The OKCNET project was a 5-year effort to deploy a network of 40 atmospheric monitoring stations deployed across Oklahoma City as a collaborative effort between the Oklahoma Mesonet and the City of Oklahoma City. The network was designed to provide critical weather information for the daily operations of the City of Oklahoma City, to spur new scientific research focused on urban meteorology, and to serve as a resource for the citizens of Oklahoma.

- As regular faculty at the University of Oklahoma (since 2012), I have maintained a research-active presence on the campus and lead the Climate, Hydrology, Ecology, Weather (CHEWe) Research Group (http://hydrometeorology.oucreate.com). With funding provided by external agencies including, but not limited to, the NSF, USDA, NASA, and NOAA, this interdisciplinary group of colleagues and students examines critical aspects of hydrometeorological and hydroclimatological extremes, their impact on environmental processes, and associated surface-atmosphere coupling and feedbacks from local to global scales. The work also includes the design and deployment of in situ sensing systems (surface flux towers, unmanned aerial systems, etc.) across various landscapes including at the Kessler Atmospheric and Ecological Field Station (KAEFS), at the USDA

Grazinglands Research Laboratory (USDA-GRL) in El, Reno Oklahoma, and the Marena, Oklahoma In Situ Sensor Testbed (MOISST).

- I served as the Director of the Kessler Atmospheric and Ecological Field Station (2014-2020) and worked closely with scientists across multiple disciplines both within and beyond the University of Oklahoma to increase the overall understanding of the complex interactions within the environmental column and the promotion of interdisciplinary research across the environmental sciences.

- Overall, I have served as PI, Co-PI, or Senior Personnel on external funding awards exceeding $40M (over $30M since joining the regular faculty within a RRT appointment in 2012). In addition, I have served as the lead or co-author on over 100 peer-reviewed articles and currently have the following H-Index values: Google Scholar = 41, Web of Science = 36, and Research Gate = 38.

- I firmly believe that a critical aspect of research involves communication across all scales, and in particular, to relevant stakeholders and the general public. As such, due to funding supported by the USDA, a key aspect of my recent research has been focused on the impacts of hydrometeorological and hydroclimatological processes/extremes on agriculture in the Great Plains. While this has led to several key scientific publications, a critical component of the work has been interacting with a host of interdisciplinary researchers from multiple institutions (e.g., USDA-GRL, Oklahoma State University, Kansas State University, Tarleton State University, University of Nebraska, the Noble Foundation, etc.) and through direct engagement of with agriculture extension across the Southern Great Plains via invited presentations at regional workshops with agricultural producers. As an example and as part of the USDA Sponsored Grazing Cap project, my efforts on climate variability and agriculture in the Great Plains were featured as part of video series:

  - https://www.youtube.com/watch?v=Q9tri6xa7rI

- In recent years, I have expanded our CHEWe research from local to regional and global at varying temporal scales to address critical hydrometeorological and hydroclimatological processes/extremes (i.e., too much and too little precipitation). In particular, I have led specific efforts to advance our understanding of rapid onset of drought (otherwise referred to as flash drought) and excessive precipitation at the subseasonal to seasonal scales (S2S). The fruit of these efforts has resulted in critical results published across the peer-reviewed literature and S2S was included as a key focus area (FA) of the recently awarded $20M NSF Track-1 project (I serve as the PI of the S2S FA).

b. Publications

As of April 2023, my h-index ranges from **36** to **41** via peer-reviewed or edited publications throughout the environmental sciences. The overall metrics of scholarly impact are dependent on the information source, including those at the links below:

Publications Accepted or In Press:
1. Christian, J., E. Martin, **Basara, J. B.**, Furtado, J., Otkin, J., L. Lowman, Hunt, E., V. Mishra, Xiao, X., 2022: Global Projections of Flash Drought in a Warming Climate, *Nature Communications Earth & Environment,* Accepted.
2. Celis, J., Xiao, X., **Basara, J. B.,** Wagle, P., McCarthy, H., 2023. Simple and innovative methods to estimate gross primary production and transpiration of crops: a review. *Digital Ecosystem for Innovation in Agriculture*. In Press.

Publications In Final Form (Reverse Chronological Order):

1. Edris, S. E., J**. B. Basara**; J. I. Christian; E. D. Hunt; J. A. Otkin; S. T. Salesky; B. G. Illston, 2023: Decomposing the Critical Components of Flash Drought Using the Standardized Evaporative Stress Ratio. *Agriculture and Forest Meteorology*, **330,** 109288.
2. Paudel, S. N. Gomez-Casanovas, E. H. Boughton, S. D. Chamberlain, P. Wagle, B. L Peterson, R. Bajgain, P. J Starks, **J. B. Basara**, C. J Bernacchi, E. H. DeLucia, L. E Goodman, P. H. Gowda, R. Reuter, J. P. Sparks, H. M Swain, X. Xiao, and J. L Steiner, 2023: Intensification differentially affects the delivery of multiple ecosystem services in subtropical and temperate grasslands. *Agriculture, Ecology & Environment*, 108398.
3. Woods, D., P.-E. Kirstetter, H. Vergara, J. A. Duarte, and **J. Basara**, 2023: Hydrologic evaluation of the Global Precipitation Measurement Mission over the U.S.: flood peak discharge and duration. *Journal of Hydrology***,** 129124.
4. Brauer, N. S., A. A. Alford, S. M. Waugh, M. I. Biggerstaff, G. D. Carrie, P. E. Kirstetter, **J. B. Basara**, D. T Dawson, K. L. Elmore, J. Stevenson, and R. W. Moore, 2022: Hurricane Laura (2020): A comparison of drop size distribution moments using numerous ground and radar remote sensing retrievals methods. *Journal of Geophysical Research: Atmospheres*, **127**, e2021JD035845.
5. Christian J. I., **J. B. Basara**, L.E.L. Lowman, X. Xiao, D. Mesheske, and Y. Zhou, 2022: Flash Drought Identification from Satellite-Based Land Surface Water Index. *Remote Sensing Applications: Society and Environment,* **26**, 100770.
6. Millin, O. T., J. C. Furtado, **J. B. Basara**, 2022: Characteristics, Evolution, and Formation of Cold Air Outbreaks in the Great Plains of the United States. *J. Climate*. **35**, 4585-4602. https://doi.org/10.1175/JCLI-D-21-0772.1
7. Christian, J., **Basara, J. B.**, Hunt, E., Otkin, J., Furtado, J., Xiao, X. and R. Randall, 2021: Global Distribution, Trends, and Drivers of Flash Drought Occurrence. *Nature Comms.,* **12,** 6330 (2021). https://doi.org/10.1038/s41467-021-26692-z.
8. Deng, J., S. Frolking, R. Bajgain, C. R. Cornell, P. Wagle, X. Xiao, J. Zhou, **J. Basara**, J. Steiner, C. Li, 2021: Improving a Biogeochemical Model to Simulate Microbial-mediated Carbon Dynamics in Agroecosystems. Journal of Advances in Modeling Earth Systems, 13, e2021MS002752, https://doi.org/10.1029/2021MS002752.
9. Wakefield, R. A., **J. B. Basara**, N. S. Brauer , J. Furtado, J. M. Shepherd, J. Santanello, 2021: The Inland Maintenance and Re-intensification of Tropical Storm Bill (2015) Part

1: Contributions of the Brown Ocean Effect. *Journal of Hydrometeorology*. **22,** 2675-2693. https://doi.org/10.1175/JHM-D-20-0150.1.

10. Brauer, N. S., **J. B. Basara**, R. A. Wakefield, P. Kirstetter, C. R. Homeyer, J. M. Shepherd, J. Santanello, 2021: The Inland Maintenance and Re-intensification of Tropical Storm Bill (2015) Part 2: Precipitation Microphysics. *Journal of Hydrometeorology*. **22**, 2695-2711. https://doi.org/10.1175/JHM-D-20-0151.1.

11. Hunt, E., F. Femia, C. Werrell, J. Christian, J. Otkin, **J. Basara**, M. Anderson, T. White, R. Randall, C. Hain, K. McGaughey, 2021: Agricultural and Food Security Impacts from the 2010 Russia flash drought. *Weather and Climate Extremes*, **34,** 100383, https://doi.org/10.1016/j.wace.2021.100383.

12. Wakefield, R. A., D. Turner, **J. B. Basara**, 2021: Evaluation of a land-atmosphere coupling metric computed from a ground-based infrared interferometer. *Journal of Hydrometeorology*. **22**, 2073-2087. https://doi.org/10.1175/JHM-D-20-0303.1

13. Krueger, E., T. E. Ochsner, M. R. Levi, **J. B. Basara**, 2021: Grassland Productivity Estimates Informed by soil moisture measurements: statistical and mechanistic approaches. *Agronomy Journal*. **113**, 3498-3517, **DOI:**10.1002/agj2.20709.

14. Wang, J., X. Xiao, **J. Basara**, X. Wu, R. Bajgain, Y. Qin, R. B Doughty, B. Moore, 2021: Impacts of juniper woody plant encroachment into grasslands on local climate. *Agricultural and Forest Meteorology,* **307**, 108508, https://doi.org/10.1016/j.agrformet.2021.108508

15. Otkin, J., Y. Zhong, E. Hunt, J. Christian, **J. Basara,** H. Nguyen, M. Wheeler, T. Ford, A. Hoell, M. Svoboda, M. Anderson, 2021: Development of a Flash Drought Intensity Index. *Atmosphere,* **12**, 741, https://doi.org/10.3390/atmos12060741.

16. Chen, W, R. T. Pinker, Y. Ma, G. Hulley, E. Borbas, T. Islam, K.-A. Cawse-Nicholson, S. Hook, C. Hain, **J. Basara**, 2021: Land Surface Temperature from GOES-East and GOES-West, *J. of Atmos. and Oceanic Tech.*, **38**, 843-858.

17. Shepherd, J.M., A. Thomas, J. Santanello, P. Lawston, **J. Basara,** 2021: Evidence of Warm Core Structure Maintenance Over Land: A Case Study Analysis of Cyclone Kelvin. *Environmental Research Communications*, **3** 045004, https://doi.org/10.1088/2515-7620/abf39a

18. Celis, J., H. Moreno, **J. Basara**, R. McPherson, M. Cosh, T. Ochsner, X. Xiao, 2021, From Standard Weather Stations to Virtual Micro-meteorological Towers: Real-time Modeling Tool for Surface Energy Fluxes, Evapotranspiration, Soil Temperature and Soil Moisture Estimations. *Remotes Sensing*, *13*, 1271, https://doi.org/10.3390/rs13071271.

19. Homeyer, C. R., A. O. Fierro, B. A. Schenkel, A. C. Didlake, G. M. McFarquar, J. Hu, A. Ryzhkov, **J. B. Basara**, A. Murphy, J. Zawislak, 2021: Polarmetric signatures in landfalling tropical cyclones. *Monthly Weather Review*. **149**, 131-154. https://doi.org/10.1175/MWR-D-20-0111.1

20. Bajgain, R. X. Xiao, P. Wagle, Y. Zhou, J. S. Kimball, C. Brust, **J. B Basara**, P. Gowda, P. Starks, J. P. S. Neel, 2021: Comparing Evapotranspiration Products of Different Temporal and Spatial Scales in Native and Managed Prairie Pastures. *Remote Sensing, 13*, 82. https://doi.org/10.1016/j.agrformet.2020.108137

21. Christian, J., **Basara, J. B.**, Hunt, E., Otkin, J., and X. Xiao, 2020: Flash drought development and cascading impacts associated with the 2010 Russian Heatwave. *Environmental Research Letters,* **15,** 9. https://doi.org/10.1088/1748-

9326/ab9faf

22. Bajgain, R. X. Xiao, **J. B Basara**, R. Doughty, X. Wu, P. Wagle, Y. Zhou, P. Gowda, J. Steiner, 2020: Differential responses of native and managed prairie pastures to environmental variability and management practices. *Agricultural and Forest Meteorology,* **294**, 108137, https://doi.org/10.1016/j.agrformet.2020.108137

23. Hunt, E. D., **J. I. Christian, J. B. Basara**, L. Lowman, J. A Otkin, J. Bell, K. Jarecke, **R. A. Wakefield,** R. M. Randall, 2020: The Flash Drought of 1936. *Journal of Applied and Service Climatology, 4.* doi.org/10.46275/JOASC.2020.11.001.

24. Brauer, N., **Basara, J. B.,** Homeyer, C. R., McFarquhar, G., Kirstetter, P.-E. (2020). Quantifying Precipitation Efficiency and Drivers of Excessive Precipitation in Post-Landfall Hurricane Harvey. *Journal of Hydrometeorology* ,**21**, 433–452.

25. Jennrich, G.C., J.C. Furtado, **J.B. Basara**, and E.R. Martin, (2020). Synoptic Characteristics of 14-Day Extreme Precipitation Events Across the United States. *J. Climate,* **33** (15): 6423–6440 ,https://doi.org/10.1175/JCLI-D-19-0563.1

26. Niraula, R., Saleh, A., Bhattarai, N., Bajgain, R., Kannan, N., Osei, E., Gowda, P., Neel, J., Xiao, X., **Basara, J. B.** (2020). Understanding the effects of pasture type and stocking rate on the hydrology of the Southern Great Plains. *Science of The Total Environment, 708*, 134873. https://doi.org/10.1016/j.scitotenv.2019.134873.

27. **Basara, J. B.**, Christian, J., Wakefield, R., Otkin, J., Hunt, E., and D. Brown, 2019: The evolution, propagation, and spread of flash drought in the Central United States during 2012. *Environmental Research Letters,* **14,** 084025. https://doi.org/10.1088/1748-9326/ab2cc0

28. Blumberg, W.G., D.D. Turner, S.M. Cavallo, J. Gao, **J. Basara**, and A. Shapiro, 2019: An Analysis of the Processes Affecting Rapid Near-Surface Water Vapor Increases during the Afternoon to Evening Transition in Oklahoma. *J. Appl. Meteor. Climatol.*, **58**, 2217–2234. https://doi.org/10.1175/JAMC-D-19-0062.1

29. Christian, J., **Basara, J. B.**, Otkin, J., Hunt, E., Wakefield, R., Flanagan, P., Xiao, X., 2019: A Methodology for Flash Drought Identification: Application of Flash Drought Frequency Across the United States. *Journal of Hydrometeorology, 20, 833–846.* https://doi.org/10.1175/JHM-D-18-0198.1.

30. Christian, J., **Basara, J. B.,** Otkin, J., Hunt, E, 2019: Regional characteristics of flash droughts across the United States. *Environmental Research Communications,* **1,** 12, doi: 10.1088/2515-7620/ab50ca.

31. Erlingis, J.M., J.J. Gourley, and **J.B. Basara**, 2019: Diagnosing Moisture Sources for Flash Floods in the United States Part I: Kinematic Trajectories. *J. Hydrometeor.*, **20**,1495–1509. https://doi.org/10.1175/JHM-D-18-0119.1

32. Erlingis, J.M., J.J. Gourley, and **J.B. Basara**, 2019: Diagnosing Moisture Sources for Flash Floods in the United States Part II: Terrestrial and Oceanic Sources of Moisture.. *J. Hydrometeor.*, **20**, 1511–1531. https://doi.org/10.1175/JHM-D-18-0120.1

33. Flanagan, P.X., **J.B. Basara**, J.C. Furtado, E.R. Martin, and X. Xiao, 2019: Role of Sea Surface Temperatures in Forcing Circulation Anomalies Driving United States Great Plains Pluvial Years. *J. Climate,* **32**, 7081–7100. https://doi.org/10.1175/JCLI-D-18-0726.1

34. Otkin, J.A., Y. Zhong, E.D. Hunt, **J. Basara**, M. Svoboda, M.C. Anderson, and C. Hain, 2019: Assessing The Evolution Of Soil Moisture And Vegetation Conditions During A Flash Drought – Flash Recovery Sequence Over The South-Central United States.

Journal of Hydrometeorology, **20**, 549–562. https://doi.org/10.1175/JHM-D-18-0171.1

35. Pinker, R., Y. Ma, W. Chen, G. Hulley, E. Borbas, T. Islam, C. Hain, K.-A. Cawse Nicholson, S. Hook, **J. Basara**, 2019: Towards a Unified and Coherent Land Surface Temperature Earth System Data Record from Geostationary Satellites. *Remote Sens.* **11**, 1399; https://doi.org/10.3390/rs11121399

36. Wakefield, R.A., **J.B. Basara**, J.C. Furtado, B.G. Illston, C.R. Ferguson, and P.M. Klein, 2019: A Modified Framework for Quantifying Land-Atmosphere Covariability during Hydrometeorological and Soil Wetness Extremes in Oklahoma. *J. Appl. Meteor. Climatol.,* **58**, 1465–1483, https://doi.org/10.1175/JAMC-D-18-0230.1

37. Bajgain, R., Xiao, X., **Basara, J. B.**, Wagle, P., Zhou, Y., Mahan, H., Gowda, P., McCarthy, H. R., Northrup, B., Neel, J., Steiner, J. (2018). Carbon dioxide and water vapor fluxes in winter wheat and tallgrass prairie in central Oklahoma. *Science of the Total Environment,* **644**, 1511-1524

38. **Basara, J. B.**, and J. I. Christian, 2018: Seasonal and interannual variability of land–atmosphere coupling across the Southern Great Plains of North America using the North American regional reanalysis. *International Journal of Climatology*, **38**, 964–978.10.1002/joc.5223.

39. Doughty, R., Xiao, X., Wu, X., Zhang, Y., Bajgain, R., Zhou, Y., Qin, Y., Zhou, Z., McCarthy, H. R., Friedman, J. R., Wagle, P., **Basara, J. B.**, Stiener, J., 2018: Responses of gross primary production of grasslands and croplands to drought and pluvial events and irrigation during 2010-2016, Oklahoma, USA., *Agricultural Water Management*, **204**, 47-59

40. Flanagan, P., **J. Basara**, J. Furtado, and X. Xiao, 2018: Primary Atmospheric Drivers of Pluvial Years in the United States Great Plains. *J. Hydrometeor., 19, 643–658, https://doi.org/10.1175/JHM-D-17-0148.1*

41. Otkin, J.A., M. Svoboda, E.D. Hunt, T.W. Ford, M.C. Anderson, C. Hain, and **J.B. Basara**, 2018: Flash Droughts: A Review and Assessment of the Challenges Imposed by Rapid Onset Droughts in the United States. *Bulletin of the American Meteorological Society*, **99**, 911–919.

42. Bajgain, R., X. Xiao, **J. Basara**, P. Wagle, Y. Zhou, Y. Zhang, and H. Mahan, 2017: Assessing agricultural drought in summer over Oklahoma Mesonet sites using the water-related vegetation index from MODIS. *International Journal of Biometeorology*, 61 (2), 377-390. 1-14. doi:10.1007/s00484-016-1218-8

43. Cheng, Y., C. Sayde, Q. Li, **J. Basara**, J. Selker, E. Tanner, and P. Gentine, 2017: Failure of Taylor's hypothesis in the atmospheric surface layer and its correction for eddy-covariance measurements. *Geophys. Res. Lett.*, **44**, 4287–4295, doi:10.1002/2017GL073499.

44. Flanagan, P. X., **J. B. Basara**, and X. Xiao, 2017: Long-term analysis of the asynchronicity between temperature and precipitation maxima in the United States Great Plains. *International Journal of Climatology*, **37,** 3919-3933. dos:10.1002/joc.4966.

45. Flanagan, P. X., **J. B. Basara**, J. Otkin, and B. G. Illston, 2017: The Effect of the Dryline and Convective Initiation on Drought Evolution Over Oklahoma During the 2011 Drought. *Advances in Meteorology*, doi:10.1155/2017/8430743.

46. Nemunaitis-Berry, K. L., P. M. Klein, **J. B. Basara**, and E. Fedorovich, 2017: Sensitivity of Predictions of the Urban Surface Energy Balance and Heat Island to Variations of Urban Canopy Parameters in Simulations with the WRF Model. *Journal of Applied*

Meteorology and Climatology, 10.1175/jamc-d-16-0157.1.

47. Toms, B. A., **J. B. Basara**, and Y. Hong, 2017: Usage of Existing Meteorological Data Networks for Parameterized Road Ice Formation Modeling. *Journal of Applied Meteorology and Climatology,* **56**, 1959–1976, 10.1175/JAMC-D-16-0199.1.

48. Wagle, P., X. Xiao, P. Gowda, **J. Basara**, N. Brunsell, J. Steiner, and A. K.C, 2017: Analysis and estimation of tallgrass prairie evapotranspiration in the central United States. *Agricultural and Forest Meteorology*, **232,** 35-47.

49. Zhou, Y., X. Xiao, P. Wagle, R. Bajgain, H. Mahan, **J. B. Basara**, J. Dong, Y. Qin, G. Zhang, Y. Luo, P. H. Gowda, J. P. S. Neel, P. J. Starks, and J. L. Steiner, 2017: Examining the short-term impacts of diverse management practices on plant phenology and carbon fluxes of Old World bluestems pasture. *Agricultural and Forest Meteorology*, **237–238,** 60-70.

50. Zhou, Y., X. Xiao, G. Zhang, P. Wagle, R. Bajgain, J. Dong, C. Jin, **J. B. Basara**, M. C. Anderson, C. Hain, and J. A. Otkin, 2017: Quantifying agricultural drought in tallgrass prairie region in the U.S. Southern Great Plains through analysis of a water-related vegetation index from MODIS images. *Agricultural and Forest Meteorology,* **246**: 111-122.

51. Cosh, M. H., T. E. Ochsner, L. McKee, J. Dong, **J. B. Basara**, S. R. Evett, C. E. Hatch, E. E. Small, S. C. Steele-Dunne, M. Zreda, and C. Sayde, 2016: The Soil Moisture Active Passive Marena, Oklahoma, In Situ Sensor Testbed (SMAP-MOISST): Testbed Design and Evaluation of In Situ Sensors. *Vadose Zone Journal*, **15**.

52. Degelia, S. K., J. I. Christian, **J. B. Basara**, T. J. Mitchell, D. F. Gardner, S. E. Jackson, S. E., J. C. Ragland, J. C. and H. R. Mahan, 2016: An overview of ice storms and their impact in the United States. *Int. J. Climatol.*. doi:10.1002/joc.4525

53. Hu, X.-M., M. Xue, P. M. Klein, **B. G. Illston**, and S. Chen, 2016: Analysis of Urban Effects in Oklahoma City using a Dense Surface Observing Network. *Journal of Applied Meteorology and Climatology*, **55,** 723-741.

54. McCorkle, T. A., S. S. Williams, T. A. Pfeiffer, and **J. B. Basara**, 2016: Atmospheric Contributors to Heavy Rainfall Events in the Arkansas-Red River Basin. Advances in Meteorology, doi:10.1155/2016/4597912.

55. Schroeder, A., **J. B. Basara**, J. M. Shepherd, and S. Nelson, 2016: Insights into Atmospheric Contributors to Urban Flash Flooding across the United States Using an Analysis of Rawinsonde Data and Associated Calculated Parameters. *Journal of Applied Meteorology and Climatology***,** 313-323.

56. Bajgain, R., X. Xiao, P. Wagle, **J. Basara**, and Y. Zhou, 2015: Sensitivity analysis of vegetation indices to drought over two tallgrass prairie sites. *ISPRS Journal of Photogrammetry and Remote Sensing*, **108,** 151-160.

57. Christian, J., K. Christian, and **J. B. Basara**, 2015: Drought and Pluvial Dipole Events within the Great Plains of the United States. *J. Appl. Meteor. Climatol.*, **54**, 1886–1898.

58. McGovern, A., D. J. Gagne, **J. Basara**, T. M. Hamill, and D. Margolin, 2015: Solar Energy Prediction: An International Contest to Initiate Interdisciplinary Research on Compelling Meteorological Problems. *Bulletin of the American Meteorological Society*, **96,** 1388-1395.

59. Otkin, J. A. M. Shafer, M. Svoboda, B. Wardlow, M. C. Anderson, C. Hain, and **J. Basara**, 2015: Facilitating the Use of Drought Early Warning Information through Interactions with Agricultural Stakeholders. *Bull. Amer. Meteor. Soc.*, **96**, 1073–1078.

60. Wagle, P., X.Xiao, R. L. Scott, T. E. Kolb, D. R. Cook, N. Brunsell, D. D. Baldocchi, **J. Basara**, R. Matamala, Y. Zhou, R. Bajgain, 2015: Biophysical controls on carbon and water vapor fluxes across a grassland climatic gradient in the United States. *Agricultural and Forest Meteorology*, **214–215,** 293-305.

61. Xinyi, S., H. Yang, Q. Qiming, **J. B. Basara**, M. Kebiao, and D. Wang, 2015: A Semiphysical Microwave Surface Emission Model for Soil Moisture Retrieval. *Geoscience and Remote Sensing, IEEE Transactions on*, **53,** 4079-4090.

62. McGovern, A., D. Gagne, II, J. Williams, R. Brown, and **J. Basara**, 2014: Enhancing understanding and improving prediction of severe weather through spatiotemporal relational learning. *Mach Learn*, 95, 27-50, DOI 10.1007/s10994-013-5343-x

63. Steiner, J. L., D. M. Engle, X. Xiao, A. Saleh, P. Tomlinson, C. W. Rice, N. A. Cole, S. W. Coleman, E. Osei, **J. Basara**, G. Middendorf, P. Gowda, R.Todd, C. Moffet, A. Anandhi, P.J Starks, T. Ocshner, R. Reuter, D. Devlin, 2014: Knowledge and tools to enhance resilience of beef grazing systems for sustainable animal protein production, Annals of the New York Academy of Sciences, 1328, 10-17.

64. **Basara, J. B.**, J. N. Maybourn, C. M. Peirano, J. E. Tate, P. J. Brown, J. D. Hoey, and B. R. Smith, 2013: Drought and associated impacts in the Great Plains of the United States – A review. *International Journal of Geosciences*, 4, 72-81.

65. Dong, J., J. Liu, G. Zhang, **J. B. Basara**, S. Greene, and X. Xiao, 2013: Climate change affecting temperature and aridity zones: a case study in Eastern Inner Mongolia, China from 1960-2008. *Theoretical and Applied Climatology*, 113, 561-572.

66. Fang, B., V. Lakshmi, R. Bindlish, T. J. Jackson, M. Cosh, and **J. B. Basara**, 2013: Passive Microwave Soil Moisture Downscaling Using Vegetation Index and Skin Surface Temperature. *Vadose Zone*, 12, doi:10.2136/vzj2013.05.0089.

67. Holmes, T., W. T. Crow, M. T. Yilmaz, T. Jackson, **J. B. Basara**, 2013: Enhancing model-based land surface temperature estimates using multi-platform microwave observations. *Journal of Geophysical Research,* 118, DOI: 10.1002/jgrd.50113.

68. Illston, B. G., C. A. Fiebrich, D. L. Grimsley, and **J. B. Basara**, 2013: Evaluation of a Heat Dissipation Sensor for In Situ Measurement of Soil Temperature. *Soil Sci. Soc. Am. J.*, **77,** 741-747.

69. Otkin, J. A., M. C. Anderson, C. Hain, I. E. Mladenova, **J. B. Basara**, and M. Svoboda, 2013: Examining Rapid Onset Drought Development Using the Thermal Infrared-Based Evaporative Stress Index. *Journal of Hydrometeorology*, **14,** 1057-1074.

70. Scott, B. L., T. E. Ochsner, B. G. Illston, C. A. Fiebrich, **J. B. Basara**, and A. J. Sutherland, 2013: New Soil Property Database Improves Oklahoma Mesonet Soil Moisture Estimates. *Journal of Atmospheric and Oceanic Technology*, **30,** 2585-2595.

71. Illston, B. G., **J. B. Basara**, C. Weiss, M. Voss, 2012: The WxChallenge: Forecasting Competition, Educational Tool, and Social Medium. *Bulletin of the American Meteorological Society*, **94,** 1501-1506.

72. Alfieri, J.G., W.P. Kustas, J.H. Prueger, L.E. Hipps, S.R. Evett, **J. B. Basara**, C.M.U. Neale, A.N. French, P. Colaizzi, N. Agam, M.H. Cosh, J. L. Chavez, and T. A. Howell, 2012: On the discrepancy between eddy covariance and lysimetry-based surface flux measurements under strongly advective conditions. *Advances in Water Resources*. 50, 62-78.

73. **Basara, J. B.**, and M. Rowell, 2012: Mesoscale Observations of an Extended Heat Burst and Associated Wind Storm in Central Oklahoma. *Meteorological Applications,* **19**, 91-

110.

74. Bindlish, R., T. J. Jackson, Y. Wang, J. C. Shi, and **J. B. Basara**, 2012: Regional and temporal patterns of soil moisture during CLASIC using passive microwave satellite observations. *Remote Sensing and Hydrology* (Proceedings of a symposium held at Jackson Hole, Wyoming, USA, September 2010), IAHS 352, 371-374.

75. Collow, T. W., A. Robock, **J. B. Basara**, B. G. Illston, 2012: Evaluation of SMOS Retrievals of Soil Moisture over the Central United States with Currently Available In Situ Observations. *Journal of Geophysical Research*, **117**, doi:10.1029/2011JD017095.

76. Gagne, D. J. II, McGovern, **J. B. Basara**, R. A. Brown, 2012: Tornadic supercell analysis from surface and proximity sounding observations: a spatiotemporal relationship data mining approach. *Journal of Applied Meteorology and Climatology,* 51, 2203-2217.

77. Holmes, T., T. Jackson, R. Reichle, **J. B. Basara**, 2012: An Assessment of Surface Soil Temperature Products from Numerical Weather Prediction Models Using Ground-based Measurements, *Water Resources Research,* 48, doi:10.1029/2011WR010538.

78. Grout, T., Y. Hong, **J. B. Basara**, B. Balasundaram, S. Bukkapatnam, and Z. Hong, 2012: Significant winter weather events and associated socioeconmomic impacts across Oklahoma: 2000 – 2010. *Wea. Climate Soc.*, 4, 48–58.

79. **Basara, J. B.**, B. G. Illston, C. A. Fiebrich, P. Browder, C. Morgan, J. P. Bostic, A. McCombs, R. A. McPherson, A. J. Schroeder, and K. C. Crawford, 2011: The Oklahoma City Micronet. *Meteorological Applications*, 18, 252-261.

80. McGovern, A., D. J. Gagne II, N. Troutman, R. A. Brown, **J. B. Basara**, J. Williams, 2011: Using spatiotemporal relational random forests to improve our understanding severe weather processes. *Statistical Analysis and Data Mining,* 4, 407-429.

81. **Basara, J. B.**, H. G. Basara, B. G. Illston, and K. C. Crawford, 2010: The Impact of the Urban Heat Island During an Intense Heat Wave in Oklahoma City. *Advances in Meteorology*, DOI:10.1155/2010/230365.

82. McGovern, A., T. Supinie, D. J. Gagne II, N. Troutman, M. Collier, R. A. Brown, **J. B. Basara**, J. Williams, 2010: Understanding severe weather processes through spatiotemporal relational random forests. *Proceedings of the NASA Conference on Intelligent Data Understanding: CIDU 2010*.

83. Schroeder, A. J., **J. B. Basara**, B. G. Illston, 2010: Challenges Associated with Classifying Urban Meteorological Stations: The Oklahoma City Micronet Example. *The Open Atmospheric Science Journal*, **4**, 88-100.

84. Arndt, D. S., **J. B. Basara**, R. A. McPherson, B. G. Illston, G. D. McManus, and D. B. Demko, 2009: The overland reintensification of Tropical Storm Erin (2007). *Bull. Amer. Meteor. Soc.*, **90**, 1079-1093.

85. **Basara, J. B.**, B. G. Illston, T. E. Winning, and C. A Fiebrich, 2009: Evaluation of Rainfall Measurements from the WXT510 Sensor for use in the Oklahoma City Micronet. *The Open Atmospheric Science Journal*, **3**, 39-45.

86. Pathe, C., W. Wagner, D. Sabel, M. Doubkova, **J. B. Basara**, 2009: Using ENVISAT ASAR Global Model Data for Surface Soil Moisture Retrieval over Oklahoma. *IEEE Transactions on Geoscience and Remote Sensing*, **47**, 468-480.

87. Pinker, R.T., D. Sun, M.P. Hung, C. Li, and **J. B. Basara**, 2009: Evaluation of Satellite Estimates of Land Surface Temperature from GOES over the United States. *J. Appl. Meteor. Climatol.*, **48**, 167–180.

88. Arndt, D. S., **J. B. Basara**, R. A. McPherson, B. G. Illston, G. D. McManus, and D. B.

Demko, 2009: The overland reintensification of Tropical Storm Erin (2007). *Bull. Amer. Meteor. Soc.*, **90**, 1079-1093.

89. **Basara, J. B.**, P. K. Hall, A. Schroeder, B. G. Illston, and K. L. Nemunaitis, 2008: The diurnal cycle of the urban heat island in Oklahoma City. *J. Geophys. Res.*, **113**, D20109, doi:10.1029/2008JD010311.

90. Gu, Y., E. Hunt, B. Wardlow, **J. B. Basara**, J. F. Brown, and J. P. Verdin, 2008: Evaluation and validation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data. *Geophys. Res. Lett.*, **35**, L22401, doi:10.1029/2008GL035772.

91. Hocker, J. E., and **J. B. Basara**, 2008: A ten year spatial climatology of squall line storms across Oklahoma. *Int. J. Climatol.,* **28**, 765-775.

92. Hocker, J. E., and **J. B. Basara**, 2008: A geographic information systems based analysis of supercells across Oklahoma. *J. Appl. Meteor. and Climatol.,* **47**, 1518-1538.

93. Illston, B. G., **J. B. Basara**, D. K Fisher, C. Fiebrich, K. Humes, R. Elliott, K. C. Crawford, E. Hunt, 2008: Mesoscale monitoring of soil moisture across a statewide network. *J. of Atmos. and Oceanic Tech.,* **25**, 167-182.

94. Swenson, S., J. Famiglietti, **J. Basara**, and J. Wahr, 2008: Estimating Profile Soil Moisture and Groundwater Storage Variations in the Southern Great Plains Using GRACE Satellite Gravimetric and Oklahoma Mesonet Soil Moisture Data. *Water Resources Research*. **44**, W01413, doi:10.1029/2007WR006057.

95. **Basara, J. B.**, D. R. Cheresnick, D. Mitchell, and B. G. Illston, 2007: An analysis of Severe Hail Swaths in the Southern Plains of the United States. *Trans. in GIS*, **11**, 531-554.

96. Chen, F., K. W. Manning, M. A. LeMone, S. B. Trier, J. G. Alfieri, R. Roberts, J. Wilson, M. Tewari, D. Niyogi, T. W. Horst, S. P. Oncley, **J. B. Basara** , and P. D. Blanken, 2007: Evaluation of the Characteristics of the NCAR High-Resolution Land Data Assimilation System During IHOP-02. *J. Appl. Meteor.*, **46**, 694-713.

97. Hunt, E., **J. B. Basara**, C. Morgan, 2007: Significant Inversions and Rapid In-Situ Cooling at a Well-Sited Oklahoma Mesonet Station. *J. Appl. Meteor.*, **46**, 353-367.

98. McPherson, R.A., C.A. Fiebrich, K.C. Crawford, R.L. Elliott, J.R. Kilby, D.L. Grimsley, J.E. Martinez, **J.B. Basara**, B.G. Illston, D.A. Morris, K.A. Kloesel, S.J. Stadler, A.D. Melvin, A.J. Sutherland, H. Shrivastava, J.D. Carlson, J.M. Wolfinbarger, J.P. Bostic, and D.B. Demko, 2007: Statewide Monitoring of the Mesoscale Environment: A Technical Update on the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.*, **24**, 301–321.

99. Liu, Y., F. Chen, T. Warner, and **J. B. Basara**, 2006: Verification of a Mesoscale Data-Assimilation and Forecasting System for the Oklahoma City Area During the Joint Urban 2003 Field Project. *J. Appl. Meteor.*, **45**, 912-929.

100. Niyogi, D., T. Holt, S. Zhong, P. C. Pyle, and **J. B. Basara,** 2006: Urban and Land Surface Effects on the 30 July 2003 MCS Event Observed in the Southern Great Plains, *J. Geophys. Res.*, **111**, D19107, doi:10.1029/2005JD006746.

101. Cheresnick, D.R., and **J. B. Basara**, 2005: The Impact of Land-Atmosphere Interactions on the Benson, MN Tornado of 11 June 2001. *Bull. Amer. Meteor. Soc.*, **86**, 637-642.

102. Anderson, M. C., J. R. Mecikalski, R. D. Torn, J. M. Norman, W. L. Kustas, and **J. B. Basara, 2004**: Disaggregation of Regional Flux Estimates using Landsat Thermal and Visible Band Imagery. *J. Hydromet.*, **5**, 343-363.

103. Sun, D., R. Pinker, and **J. B. Basara,** 2004: Land surface temperature estimation from

the next generation Geostationary Operational Environmental Satellite GOES M-Q. *J. Applied Meteor.*, **43**, 363-372.

104. Fiebrich, C. A., J E. Martinez, J. A. Brotzge, and **J. B. Basara**, 2003: The Oklahoma Mesonet's skin temperature network. *J. Atmos. Oceanic Tech.*, **29**, 1496-1504.

105. Illston, B. G. and **J. B. Basara**, 2003: Analysis of short term droughts in Oklahoma. EOS, Trans., AGU, Vol. 84, No. 17, p.157, 161.

106. Robock, A., L. Luo, E. F. Wood, F. Wen, K. E. Mitchell, P. R. Houser, J. C. Schaake, D. Lohmann, B. Cosgrove, J. Sheffield, Q. Duan, R. W. Higgins, R. T. Pinker, J. D. Tarpley, **J. B. Basara**, K. C. Crawford, 2003: Evaluation of the North American Land Data Assimilation System over the southern Great Plains during the warm season, *J. Geophys. Res.*, 108, 8846, doi:10.1029/2002JD003245, D22.

107. **Basara, J. B.**, and K. C. Crawford, 2002: Linear relationships between root-zone soil moisture and atmospheric processes in the planetary boundary layer. *J. Geophys. Res.*, **107**, (ACL 10) 1-18.

108. **Basara, J. B.**, 2001: Soil Moisture Observations for Flash Flood Research and Prediction. In: E. Gruntfest and J. Handmer, eds., Coping with flash floods, Kluwer Academic Publishers, Dordrect, 231-241.

109. **Basara, J. B.**, and T. M. Crawford, 2000: Improved installation procedures for deep layer soil moisture measurements. *J. of Atmos. and Oceanic Tech.*, **17**, 879-884.

Publications In Preparation:

1. Bajgain, R., X. Xiao, **J. B Basara**, R. Doughty, X. Wu, 2023: Divergent responses of soil greenhouse gas effluxes to nitrogen addition and rainfall events measured using high frequency automated chambers. *Journal of Environmental Quality*. In review.

2. Brauer, N. S., P. E. Kirstetter, **J. B. Basara**, S. Hristova-Veleva, S. Tanelli, 2023: Precipitation Microphysics in Tropical Cyclones: A Global Perspective, *Journal of Geophysical Research: Atmospheres*, In review.

3. Wakefield, R.A., D.D. Turner, T. Rosenbeger, T. Heus, T.J. Wagner, J. Santanello, and **J.B. Basara**, 2023: A Methodology for Estimating the Energy and Moisture Budget of the Convective Boundary Layer Using Continuous Ground-based Infrared Spectrometer Observations. *JGR-Atmospheres,* in review.

4. Zhang, Y., X. Xiao, X. Yang, M. Migliavacca, **J. Basara,** S. Zhou, Y. Deng, M. Cai, 2023: Immediate and lagged vegetation responses to dry spells revealed by continuous solar-induced chlorophyll fluorescence observations. *Remote Sensing of Environment*, in review.

c. **External and Internal Funding**

In Reverse Chronological Order

1. *PIPP Phase I: International Center for Avian Influenza Pandemic Prediction and Prevention*, NSF, Co-PI; Project Total = $999,999, 2022-2023, 0.5 months of support.

2. *OU-ARS Cooperative Agreement.* USDA ARS, PI, Total funds awarded: $75,000, 2021-2023, 0 months of support.

3. *Enhancing Communities Preparedness and Resilience to Post-Wildfire Hydrology in Mountainous Areas* NSF, Co-PI; Project Total = $41,287, 2021, 0 months of support.

4. *RII Track-1:* **Socially Sustainable Solutions for Water, Carbon, and Infrastructure Resilience in Oklahoma**, NSF EPSCOR, Project Co-PI; Project Total = $20M; PI, S2S Focus Area - Total = $2.35M. 2020-2025, 3 months of support.

5. *OU-ARS Cooperative Agreement.* USDA ARS, PI, Total funds awarded: $161,765, 2020-2023, 0.5 months of support.

6. *Enhancing National Security Decision-making Process for Regions Vulnerable to the Impacts of Flash Droughts Through Greater Use of NASA Resources*, Project Co-PI; OU PI, NASA, Project total = $400,000, 2019-2021, 1 month of support.

7. *OU-ARS Cooperative Agreement.* USDA ARS, PI, Total funds awarded: $156,000, 2019-2020, 0 months of support.

8. *RII Track-2 FEC: Marshalling Diverse Big Data Streams to Understand Complexity of Tick-borne Diseases in the Southern Great Plains*, NSF, KU is the Lead Institution (~$4M Total), OU Total = $883,8468, Co-PI, 2019-2023, PI- X. Xiao, 1.75 months of support.

9. *Evaluating the Contributions of Local and Non-Local Land-Atmosphere Coupling to Flash Drought Evolution and Prediction*, PI, NASA, $135,000, 0 months of support.

10. *OU-ARS Cooperative Agreement.* USDA ARS, PI, $75,000, 2018-2019, 0 months of support.

11. *Modernization of Mesonet Long Term Averages.* Earth Networks / NOAA, Co-PI, Total funds awarded: $200,000, 2018-2019. PI – B. Moore, 0 months of support.

12. *Space-borne Antennas and Circuits for Condensed Radars and STEM.* NASA, Co-PI, Total funds awarded: $889,761, 2018-2020, PI – H. Sigmarsson, 0.75 months of support.

13. *PREEVENTS Track 2: Collaborative Research: Developing a Framework for Seamless Prediction of Sub-Seasonal to Seasonal Extreme Precipitation Events in the United States.* NSF, Senior Personnel, Total funds awarded: $1,842,562, 2017-2022, PI – E. Martin, 3 months of support.

14. *Multi-scale analysis of microbe-climate interactions in greenhouse gas emissions from grasslands and croplands with livestock and manure use.* USDA, Co-PI, Total funds awarded: $3M, 2016-2021, PI – X. Xiao, 3 months of support.

15. *Central Oklahoma Rural Partnership for Science (CORPS).* State of Oklahoma, Department of Education, Co-PI, Total funds awarded: $2,072,087, 2016-2020. PI – L. Atkinson, 1 month of support.

16. *Evaluating the Impacts of Sensor Return Interval on Remote Estimates of Evapotranspiration at Field Scales.* USDA, PI, Total funds awarded: $36,890, 2013-2015, 0 months of support.

17. *Facilitating adaptive management under conditions of rapid drought onset using the GOES-based evaporative stress index.* NOAA, PI, Total funds awarded: $149,350, 2013-2015, 3 months of support.

18. *Resilience and vulnerability of beef cattle production in the Southern Great Plains under changing climate, land use and markets.* USDA, Total funds awarded: ~$10M, OSU/KSU were lead agencies, Co-PI, 2013-2018, 5 months of support.

19. *Black Ice Detection and Road Closure and Warning Control System for Oklahoma.* Oklahoma Department of Transportation, Co-PI, Total funds awarded: $230,544, 2012-2014, PI - Y. Hong, 0 months of support.

NOTE: *Prior to 2012, position did not require summer salary due to 12-month appointment.*

20. *A Mobile Intelligent Transportation System (ITS) Platform*. Oklahoma State University, Co-PI, Total funds awarded: $341,352, Y. Hong, 0 months of support.

21. *Drought Monitoring: A System for Tracking Plant Available Soil Moisture Based on the Oklahoma Mesonet.* Oklahoma Water Resource Research Institute, Co-PI, Total funds awarded: $50,000, T. Ochsner (OSU), 0 months of support.

22. *Evaluation of Downscaled High-Resolution WRF Simulations For Use in Operational Forecasting*. Cooperative Program for Operational Meteorology, Education and Training (COMET) Outreach Program, PI, Total funds awarded: $76,849, 2009-2010, 0 months of support.

23. *Quantifying Evaporation and Effective Precipitation Across Varying Seasonal and Within-Season Climatic Signals Across Oklahoma*. Oklahoma Water Resources Board, PI, Total funds awarded: $118,902, 2009-2012, 0 months of support.

24. *Support of CLASIC field activities*, USDA, PI, $40,000, 2007, 0 months of support.

25. As the lead scientist for the project, awarded $333,715 from the Office of the Vice President for Research at the University of Oklahoma to implement the Oklahoma City Micronet, PI, 2006, 0 months of support.

26. Develop an implementation plan for meteorological monitoring and air quality stations within the SHENAIR project. James Madison University Awarded, PI, $24,862, 2006, 0 months of support, PI – B. Nairn, 0 months of support.

27. *Remediation and Restoration Monitoring at the Tar Creek Superfund Site*. USGS, Co-PI, Co-PI Total funds award = $76,273, 2005.

28. *Development of an urban micronet in Oklahoma City*. Oklahoma Regents for Higher Education, PI, $250,000, 2005, 0 months of support.

29. *Quantifying the Structure of the Planetary Boundary Layer In and Around Oklahoma City*. NASA New Investigator Award, PI, Total funds awarded: $274,433, 2004-2008, 0 months of support.

30. *Remediation and Restoration Monitoring at the Tar Creek Superfund Site*. USGS, Co-PI, The total award from the USGS of $888,570 included $154,718 for OCS research activities, 2004, PI – B. Nairn, 0 months of support.

31. *Evaluating NARR and LDAS Data Using the Oklahoma Mesonet.* NASA, PI, $25,000, 2004, 0 months of support.

32. *Research Activities at the University of Oklahoma in Support of the Joint Urban 2003 Field Experiment (FY03-FY04)*. The Department of Defense (DoD) Defense Threat Reduction Agency (DTRA) through the H. E. Cramer Company, PI, Total funds awarded: $252,999, 2003-2007, 0 months of support.

33. The Department of Transportation (VOLPE) awarded a contract in the amount of $9,731. PI, 2003, 0 months of support.

34. ITT Industries awarded a contract in the amount of $2,949. PI, 2003, 0 months of support.

35. *Support the SMEX03 Field Experiment*, USDA, PI, $11,000, 2003, 0 months of support.

36. *Scientific Evaluation of Weather Modification in Oklahoma*. Oklahoma Water Resources Board, PI, Total funds awarded: $61,748, 2003-2005, 0 months of support.

37. Awarded a NASA EPSCoR a Research Initiation Grant in the amount of $19,047. PI, 2002, 0 months of support.

38. *Land-Atmosphere Memory Quantified Using Observations from the Oklahoma Mesonet and the NOAH Land Surface Model*. NOAA, PI, Total funds awarded: $336,592, 2002-2006, 0 months of support.

39. *Research Activities at the University of Oklahoma in Support of the 2003 Oklahoma City Field Experiment (FY02)*. The Department of Defense (DoD) Defense Threat Reduction Agency (DTRA) through the H. E. Cramer Company, PI, Total funds awarded: $53,980, 2002-2003, 0 months of support.

3. Service Data

a. Statement of Service

During the formative years of my development, I was fortunate to be exposed to coaches and mentors that helped me to develop a worldview whereby leadership and responsibility were not simply important concepts, but were expected. Through those encounters I have valued the position of the servant-leader who was repeatedly modeled to me by great men and women throughout my life. I watched and admired how individuals grounded in honesty, integrity, and a dedicated work ethic could lead many and accomplish more than the individuals, or parts, alone. To me, service and leadership are entirely synonymous and intricately connected. In that vein, I have intentionally chosen a path by which to continuously gain experience and wisdom in effective leadership to serve others, accomplish more, and to pass on what I have learned.

During my time at the University of Oklahoma I have never shied away from taking on leadership responsibilities within my professional career. In fact, from the onset of my first professional appointment in 2001 until present, and through multiple academic and administrative positions, I have continuously built my capacity for leadership and engagement to strengthen my service to all levels of the University of Oklahoma and enhance our academic, scholarship, and research missions.

Summary of Service Accomplishments at OU

- I served as the Director of Research for the Oklahoma Climatological Survey (OCS) for 17 years. In this capacity, I was tasked with developing and maintaining the research activities within OCS utilizing State of Oklahoma budgeted resources augmented with external funding. During this period, I led numerous staff and students in expanding the fundamental knowledge of weather and climate processes across the Great Plains of the United States and worked to communicate critical results to stakeholders across a variety of sectors spanning agriculture, to water resources, to emergency management. A key component of the work also included utilizing and expanding the capacities of the Oklahoma Mesonet, a statewide network of environmental observing sites that collects critical weather and climate observations.

- Since 2002 I have been involved in the academic enterprise of the University of Oklahoma, first as an adjunct faculty member, and since 2012, as a member of the regular faculty with appointments in the School of Meteorology and the School of Civil Engineering and Environmental Sciences (beginning in 2018).

- After serving on the executive committee for nearly a decade, in 2014, I was named the Director of the Kessler Atmospheric and Ecological Field Station (KAEFS) at the University of Oklahoma. During the period of that appointment through 2020, I was actively engaged with faculty, staff, and students across the university to sustain and grow the footprint of KAEFS within the university system. As a result, (interdisciplinary) research activities at the site have more than doubled, undergrad and graduate student educational activities (courses, mentored research, etc.) have more than tripled, and

facilities have been modernized utilizing multi-level partnerships including those between the university and the private sector (e.g., delivering high-bandwidth connectivity to KAEFS through a partnership with Pioneer Telephone Cooperative).

- In more recent years, my administrate responsibilities within the University of Oklahoma have increased. From 2017-2018 I served as the Associate Director of the Graduate Program for the School of Meteorology (SoM) while in a RRT appointment. In this position, I led the graduate student enterprise of the SoM which included assessment of our graduate program and nearly 100 graduate students, recruiting and admissions of new graduate students into the SoM, oversight concerning inclusiveness and increased diversity, curriculum revisions at the graduate-level, teaching assistant assignments, course scheduling for the SoM, oversight of the academic performance review for the SoM which occurred in 2017-2018, and mentorship of junior faculty. While I transitioned to another administrative role in the HWS Program 2018 (see next bullet), I continued to serve the SoM in a number of capacities including as the Graduate Liaison, the chair of the Graduate Admissions Committee, and as a member of the Graduate Studies Committee.

- Beginning in 2016, I was tasked, along with a committee of colleagues, to draft a vision for a Hydrology and Water Security (HWS) initiative at the University of Oklahoma. In 2017, the draft vision was presented to and accepted by the administration of the University of Oklahoma which led to the launch of the HWS Program. In 2018, I was named the Executive Associate Director of the HWS Program and assumed a joint faculty position within the School of Civil Engineering and Environmental Science. In this capacity, I have joint responsibility for launching, maintaining, and expanding the HWS program which incorporates faculty from four departments and three colleges and students from diverse backgrounds through:

  o The development of curriculum for online M.S. tracks in both Hydrology and Water Security.
  o Mentoring two junior faculty hired into the HWS program.
  o Development of a HWS academic minor for undergraduate students.
  o Engaging the talented faculty across the University of Oklahoma to enhance existing and pursue new research activities.
  o Serving on the Graduate Admissions Committee for the HWS Program.

b. List of Service

Academic Service

2018-present   Executive Associate Director, Hydrology and Water Security Program, University of Oklahoma

2018-present   Committee Member, Graduate Admission Committee, Hydrology and Water Security Program

2018	Evaluation Committee for the Dean of the College of Atmospheric and Geographic Sciences
2017-2022	Chair, Graduate Admission Committee, School of Meteorology, University of Oklahoma
2017-2022	Graduate Liaison, School of Meteorology, University of Oklahoma
2017-2021	Committee Member, Provost's Advisory Committee for General Education Oversight, University of Oklahoma
2017-2018	Faculty Search Committee, Hydrology and Water Security Program, University of Oklahoma
2017-2018	Associate Director of the Graduate Program, School of Meteorology, University of Oklahoma
2016-present	Graduate Admissions Committee, School, School of Meteorology, University of Oklahoma
2014-2020	Director, Kessler Atmospheric and Ecological Field Station
2013-present	Member, Graduate Studies Committee, School of Meteorology, University of Oklahoma
2012	College of Atmospheric and Geographic Sciences Faculty Marshall, University of Oklahoma
2010-2011	Search Committee Member, Climate Ecologist faculty position, University of Oklahoma
2010	Strategic Weather Enterprise Committee member, University of Oklahoma
2010	College of Atmospheric and Geographic Sciences Faculty Marshall, University of Oklahoma
2009-2012	Advisory Board member for the Atmospheric Radar Research Center at the University of Oklahoma
2008	Strategic Planning Committee member for the School of Meteorology, University of Oklahoma
2006-2011	Co-convenor of the Boundary-Layer, Urban, and Land Atmosphere Interactions Specialty Seminar Series

2005-2006	Transition Committee member for the College of Atmospheric and Geographic Sciences
2004-2014	Executive Committee member for the Kessler Farm Field Laboratory (Kessler Atmospheric and Ecological Field Station), University of Oklahoma

Professional Service and Instruction

2022-present	Lead, GEWEX US-RHP Impactful Extremes Working Group
2022-present	Member, Committee on Hydrology, American Meteorological Society.
2021-present	Member, GEWEX US-RHP Affinity Group
2021	Expert Testimony - United States House of Representatives - House Subcommittee on the Environment, Washington D.C.
2020-2021	COMET Instructor for the Chinese Meteorological Administration and the forecast team for the 2022 Beijing Winter Olympics.
2020	Reviewer-Panelist, NASA Science Utilization of the Soil Moisture Active-Passive Mission solicitation.
2020	Co-Chair, Improvements to the Analysis and Prediction of Flash Drought and Long-Term Drought, American Meteorological Society Annual Meeting, Boston, MA.
2019	Co-Chair, Integrating Water and Energy Cycle Pathways to Better Understand Weather and Climate Extremes, American Meteorological Society Annual Meeting, Phoenix, AZ.
2018	Co-Chair, Variability of Regional Hydroclimate, American Meteorological Society Annual Meeting, Austin, TX.
2016	Reviewer-Panelist, NASA Science Utilization of the Soil Moisture Active-Passive Mission solicitation.
2015	US Chair, Sixth Indo-American Symposium, United States National Academy of Sciences, Kavli Frontiers of Science. Irvine, CA, August.
2015	Reviewer-Panelist, National Science Foundation East Asia Pacific Summer Institute Graduate Fellowship Program.
2014-2022	WxChallenge National Manager

2015   US Representative and Presenter, 16th Chinese-American Symposium, United States National Academy of Sciences, Kavli Frontiers of Science. Beijing, China, October.

2014   Reviewer-Panelist, National Science Foundation East Asia Pacific Summer Institute Graduate Fellowship Program.

2011-present   COMET Advisory Panel member

2010-2016   American Meteorological Society Committee member on Artificial Intelligence Applications to Environmental Science.

2010   Lead Instructor for the Seventh COMET Symposium on Processes in the PBL in Boulder, CO in September.

2009-2011   Named to the National Science Foundation Facilities Assessment Editorial Board and Represented the In-Situ Surface and Surface-Atmosphere Exchange Area.

2009   Reviewer-Panelist, National Science Foundation East Asia Pacific Summer Institute Graduate Fellowship Program.

2008   Lead Instructor for the Sixth COMET Symposium on Processes in the PBL in Boulder, CO in September.

2008   Served as a member of the science team which conducted the BEAREX field experiment in Bushland, TX.

2007   Lead Instructor for the Fifth COMET Symposium on Processes in the PBL in Boulder, CO in August.

2006-2014   WxChallenge Advisory Board Member

2006   Lead Instructor for the Fourth COMET Symposium on Processes in the PBL in Boulder, CO in September.

2006   Reviewer-Panelist, National Science Foundation East Asia Pacific Summer Institute Graduate Fellowship Program.

2004   Lead Instructor for the Second and Third COMET Symposia on Processes in the PBL in Boulder, CO in June and August.

2004   NASA Earth System Science Scholars Network Organizing Committee member.

2003   Invited lecturer at First COMET Symposium on Processes in the PBL in Boulder, CO in September. Provided two lectures entitled "The Impact of Soil Moisture on

Processes within the PBL" and "The Impact of Vegetation on Atmospheric Processes within the PBL"

2002   Invited participant at a planning workshop for the national ecological observing network (NEON) infrastructure. Served as a working group leader for automated observing networks.

Professional Stakeholder Engagement

Direct engagement with stakeholders and the transmission of critical scientific findings is a <u>critical act of service</u> to our communities. A summary of recent, **<u>invited</u>** presentations at stakeholder workshops and conferences are provided below:

- Kansas State University Cattleman's Day (2022), Manhattan, KS
- OSU Winter Crops School (2022), Stillwater, OK
- Ag Educator – Mesonet In-Service (2022), Norman, OK
- Southern Plains DEWS Partners Meeting (2022), Norman, OK
- Oklahoma Governor's Water Conference (2021), Oklahoma City, OK
- Citizen Science and Drought Monitoring (2021), Stillwater, OK
- Oklahoma Irrigation Conference (2020), Altus OK
- 21st Annual Crop Production Clinic (2020), Goodwell, OK
- Ag Education – Mesonet (2019), Norman, OK
- CPOF 2019 Western Region Conference (2019), Oakley, KS
- KRC Farm and Food Conference (2019), Wichita, KS
- USDA-ARS Range Research Field Day (2019), Woodward, OK
- KS Extension Roundup (2019), Hays, KS
- K-State Research and Extension (2018), Garden City, KS
- Adapting Grazing Management for Future Needs Conference (2018), Shawnee OK
- K-State Research and Extension (2018), Hays, KS
- Cover Your Acres Winter Conference (2018), Oberlin, KS