



Weather of Shenandoah National Park

Mid-Atlantic Network Summary Report for 2014

Natural Resource Data Series NPS/MIDN/NRDS—2016/1115



ON THE COVER

Shenandoah National Park.
Photographer: Bill Tucker.

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Natural Resource Data Series NPS/MIDN/NRDS—2016/1115

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List of Key Acronyms

ASOS	Automated Surface Observation System
CASTNET	Clean Air Status and Trends Network
COOP	National Weather Service Cooperative Observer Program
CWOP	Citizen Weather Observer Program
FAA	Federal Aviation Administration
IFLOWS	Integrated Flood Observing and Warning System
MIDN	Mid-Atlantic Network
NADP	National Atmospheric Deposition Program
NARR	North American Regional Reanalysis
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NP	National Park
NWS	National Weather Service
PASC	Pennsylvania State Climatologist
PDSI	Palmer Drought Severity Index
POR	Period of Record
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RAWS	Remote Automated Weather Stations
RWIS	Road Weather Information System
SHEN	Shenandoah National Park
USDM	United States Drought Monitor
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Introduction

Weather and climate are widely recognized as key drivers of terrestrial and aquatic ecosystems, affecting biotic as well as abiotic ecosystem characteristics and processes. Global and regional scale climatic patterns, trends, and variations are critical to the cycling of elements, nutrients, and minerals through ecosystems and can deliver pollutants from regional and even global sources (National Assessment Synthesis Team 2001). These variations and trends influence the fundamental properties of ecologic systems such as soil-water relationships and plant-soil processes and their disturbance rates and intensity. Information obtained from meteorological monitoring will be useful to interpreting and understanding changes in species composition, community structure, water and soil chemistry, and related landscape processes (Comiskey and Callahan 2008). A baseline climate summary has been produced for Shenandoah National Park (Gawtry and Stenger 2007).

The purpose of this report is to provide a concise weather and climate summary for January 1 to December 31, 2014, and to place current patterns and trends in an appropriate historical, regional, and global context (Marshall et al. 2012). It is our intention that this report will satisfy an inherent interest in meteorological phenomena and meet the Mid-Atlantic Network (MIDN) Weather and Climate Monitoring objective:

- Document current status and long-term trends in air temperature and precipitation at multiple temporal scales (e.g., daily, monthly, seasonal, annual, and decadal) and spatial scales (e.g., individual stations and aggregated stations such as climate divisions) utilizing existing weather and climate monitoring programs and datasets.

To accomplish this objective, a variety of atmospheric data streams were evaluated for their quality, longevity, and applicability to the MIDN parks. Since no single weather network contains all the pertinent measures of atmospheric phenomena to assess ecosystem health, an objective analysis of the data networks was developed and outlined in the Weather and Climate Monitoring Protocol for the Eastern Rivers and Mountains Network and Mid-Atlantic Network of the National Park Service (Marshall et al. 2012). Through this analysis, a select number of weather/climate observing stations were chosen as representative of each park; these are the primary data sources used in the profile of 2014's climate summary and trends.

In addition to a suite of summary tables, graphs, and narratives, we specifically identify a series of key weather indicators to report status and trends. This report includes a summary of several of these indicators for the period of record of selected stations (ending on December 31, 2013). These key indicators are further described in the protocol (Marshall et al. 2012) and are summarized in the body of this report.

The Climate of the Western Piedmont, Northern Virginia, and the Central Mountain Regions of Virginia

Shenandoah National Park (NP) is located in Virginia Climate Division 3 (Western Piedmont), Virginia Climate Division 4 (Northern Virginia), and Virginia Climate Division 5 (Central Mountain). A climate division is a region that is reasonably homogenous with respect to climatic and hydrologic characteristics and is frequently used for compiling climate statistics

(<http://www.esrl.noaa.gov/psd/data/usclimdivs/data/map.html>). Virginia is divided into six climate divisions. The Shenandoah Valley and Mountains are generally considered to have a humid, continental type of climate, but the varied physiographic features have a marked effect on the weather and climate of the various parts of the park. The prevailing westerly winds carry most of the weather disturbances that affect the region from the interior of the continent, with the Atlantic Ocean having only an occasional influence on the climate of the area (Davey et al. 2006, Gawtry and Stenger 2007). Coastal storms do, at times, affect the day-to-day weather, especially in the winter. Also, storms of tropical origin can have significant effect within this part of Virginia, causing severe floods in some instances. Ice storms along the higher elevations of Shenandoah NP can contribute to significant natural alterations to forest structure.

Temperatures are moderately continental, with the tempering effects due to the higher elevations contributing to cloud production in summer and onshore winds modifying the chill at times during winter (Davey et al. 2006). The lowest readings in winter occur with polar air masses of Canadian origin settling over the Northeast after a fresh snowfall. The highest readings of the summer happen when the sub-tropical fair weather system, the Bermuda high, pushes westward into the Carolinas; its clockwise circulation will direct hot, humid air from the Gulf region into the Shenandoah Valley. Southwest winds gain additional warmth when descending the crest of the Appalachians. The last freeze and first frost typically occur in late April and October, respectively.

Precipitation is fairly evenly distributed throughout the year. Annual amounts generally range between 34–52 in (864–1,321 mm), while the majority of places receive 39–45 in (991–1,143 mm). Greatest amounts usually occur in the late spring and summer months, while February is the driest month, having about 2 in (51 mm) less than the wettest months. Precipitation tends to be somewhat greater in the mountains, due primarily to coastal storms which occasionally frequent the area. For example, the annual average precipitation at Big Meadows is 55 in (1,397 mm), while Luray, to the west and at a much lower elevation, receives an average 41 in (1,041 mm) per year (Gawtry and Stenger 2007). During the warm season, these storms can bring heavy rain; while in winter heavy snow or a mixture of rain and snow may be produced.

Surface winds blow from the west and northwest in the cold season and from the southwest during the warm half of the year. Thunderstorms follow a frequency that matches the solar cycle, occurring between the equinoxes and reaching a peak near the solstice. Hail is relatively infrequent, occurring about once every other year, but flash floods and damaging thunderstorm winds affect parts of the park each summer. On average, tornadoes pass through the area about once every three years. The direct effects of an Atlantic hurricane are uncommon, though remnant rains from hurricanes and trop-

ical storms have contributed to the region's worst floods. Ice storms, which can cause significant disruption, occur at irregular intervals, but are primarily confined to the months between December and March (Kocin and Uccellini 2004).

Observing Stations

A total of nine weather observing stations comprising four weather observing networks were selected as the most representative weather stations around Shenandoah NP in 2014 (Figure 1). Representative stations within a 100-km range of the park were chosen based on several criteria, which include proximity to the park, the representativeness of the station to the park elevation profile, the type and frequency of observations, the period of record of the data, and data availability (Marshall et al. 2012). Moreover, the percentage of time a station reports a particular parameter (e.g., temperature) can influence data inclusion. A total of nine stations were ultimately used for this 2014 report: Luray, Madison, Staunton Water Treatment Plant, Waynesboro Water Treatment Plant, Front Royal, Charlottesville-Albemarle Airport, Headquarters, Sawmill Ridge, and Big Meadows (Figure 1, Table 1).

Two stations, Luray 5 E (1941-current) and Staunton WTP (1894-current), were used for a long-term trend analysis using the period of record for both stations ending December 31, 2013. Graphs of these long-term trends are shown in the Appendix section of this document. For temperatures, long-term means and the standard deviation above and below the long-term mean are computed for each indicator. Because precipitation distributions do not fall on a normal curve like temperature distributions do, standard deviations are not computed for the precipitation indicators.

The following are the climate indicators selected for each of the parks:

- Average Annual Mean Temperature – A measure of the composite mean temperature (averaging the maximum and minimum on a daily basis) for an entire year
- Average Annual Maximum Temperature – A measure of the average of the daily maximum temperature for an entire year
- Highest Annual Maximum Temperature – A measure of the individual highest maximum temperature each year
- Annual Number of Hot Days (maximum temperature equal to or exceeding 90°F (32°C) – A measure of warm season heat using a threshold of days with a 90°F (32°C) maxima
- Average Annual Minimum Temperature – A measure of the average of the daily minimum temperature for an entire year
- Lowest Annual Minimum Temperature – A measure of the individual lowest minimum temperature each year
- Annual Number of Cold Days (maximum temperature less than or equal to 32°F (0°C)) – A measure of cold season chill using a threshold of days with a 32°F (0°C) maxima
- Annual Number of Subfreezing Days (minimum temperature less than or equal to 32°F (0°C)) – A measure of cold season chill using a threshold of days with a 32°F (0°C) minima

- Annual Number of Subzero Days (minimum temperature less than or equal to 0°F (-17.8°C))
– A measure of cold season chill using a threshold of days with a 0°F (-17.8°C) minima
- Growing Season Length (number of days between last freeze in spring and first freeze in fall)
– A measure of the local growing season as tallied by the total number of days between the last 32°F (0°C) in the spring and the first 32°F (0°C) in the fall
- Annual Precipitation – A measure of total liquid (and its equivalent melted snow) for all days
- Autumn Precipitation (October 1 – December 31) - The three month total precipitation including rain and melted snow
- Annual Number of Heavy Precipitation Days (liquid equal to or greater than 1.0 in (25mm)) – A measure of the frequency of heavy precipitation events during each year
- Annual Number of Extreme Precipitation Days (liquid equal to or greater than 2.0 in (50mm)) – A measure of frequency of extreme precipitation events during each year
- Annual Number of Micro-droughts – A measure of micro-droughts for the year as the number of periods of 7+ days without rain
- Annual Snowfall – A measure of total solid precipitation (includes sleet and hail; does not include freezing rain)
- Annual Number of Measureable Snow Days – A measure of the severity of winter precipitation as the number of days receiving more than or equal to 0.1 in (0.3 cm) of solid precipitation (includes sleet and hail; does not include freezing rain)
- Annual Number of Moderate Snow Days– A measure of the severity of winter precipitation as the number of days receiving more than or equal to 3 in (7.6 cm) of solid precipitation (includes sleet and hail; does not include freezing rain)
- Annual Number of Heavy Snow Days– A measure of the severity of winter precipitation as the number of days receiving more than or equal to 5 in (12.7 cm) of solid precipitation (includes sleet and hail; does not include freezing rain)

The average value of a climate element over 30 years is defined as a climatological normal, which is calculated and established by NOAA's National Climatic Data Center (NCDC). Every ten years, NCDC computes new thirty-year climate normals for selected temperature and precipitation elements for a large number of U.S. climate and weather stations. The current (as of 2014) normals cover the period 1981–2010. In this report, the 30-year normals established by NCDC are used as the baseline for comparisons (e.g., departures from normal). In cases where data for the 30-year normal period are not available, we use alternative comparisons such as the new pseudo-normals from NCDC or a recent 10-year period. In some cases, sufficient data may simply not be available to calculate normals. For metrics that NCDC may not routinely calculate a normal, such as the number of days with more

than 2 in (55 mm) of rain or liquid equivalent, normals are calculated using the same time period (e.g., 1981–2010) as the current NCDC standard. Throughout the report, descriptions of a station's values as compared to the normals are described as a difference from the “average”, “mean”, “typical”, “long-term value”, as well as “normal”, to improve the readability of the document. However, all of these terms are comparing a value from one year at that station to that station's normal, whether it is the 30-year normal or the pseudo-normal calculated on a shorter time frame

Of the nine stations, three (Luray, Staunton, and Charlottesville-Albemarle) have a Period of Record (POR) sufficiently long for a 30-year normal (normal calculated from years 1981–2010). However, Charlottesville-Albemarle has a low percentage of time reporting temperature and precipitation over its POR and is therefore not used for the corresponding indicator tables. Madison was also excluded from the monthly deviations from normal for temperature due to gaps in reporting over its POR.

In addition to the summary information available in this report, a near real-time data stream has been made available to the MIDN through a Web interface for the weather observing stations along with monthly, seasonal, and annual summaries. The Web interface is accessible through the following link: <http://climate.met.psu.edu/NPS/interface.php>.

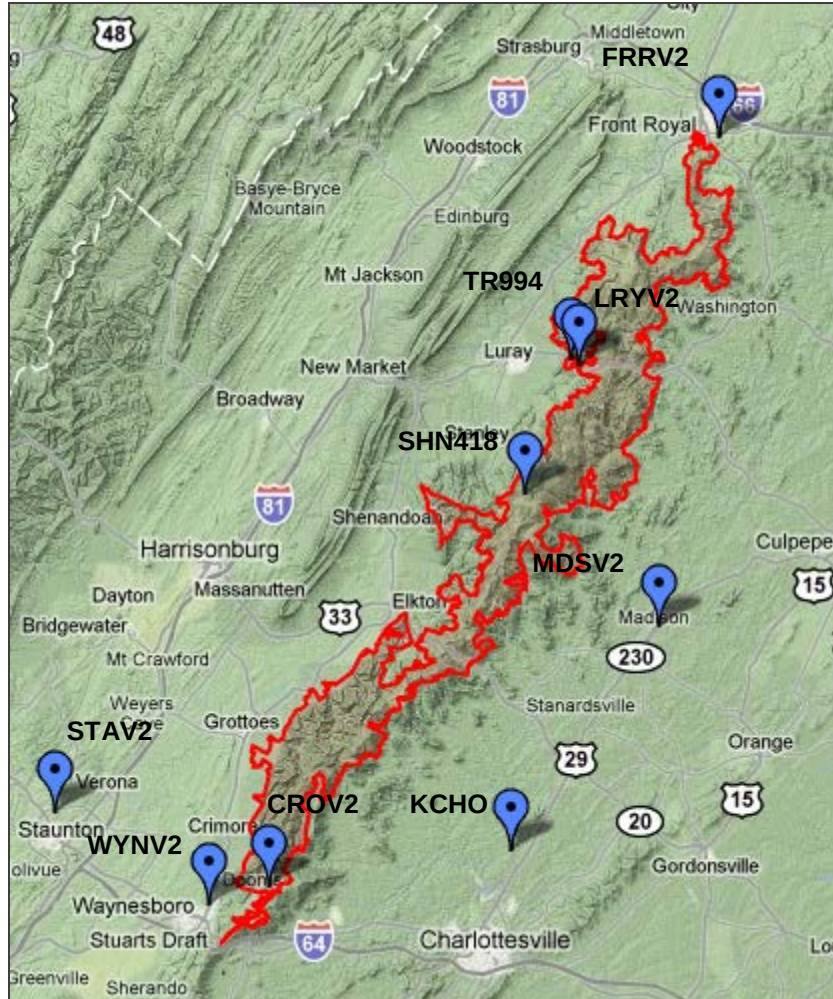


Figure 1. Location of weather observing stations around Shenandoah National Park selected as most representative of the park in 2014. See Table 1 for station names.

Table 1. List of weather observing stations around Shenandoah National Park selected as most representative of the park in 2014.

Station	Observing Network ¹	Name	Period of Record (POR)		Percentage of time reporting temperature for 2014	Percentage of time reporting precipitation for 2014	Percentage of time reporting temperature for entire POR	Percentage of time reporting precipitation for entire POR
LRYV2	COOP	Luray 5 E	03/01/1941	Present	100.0	100.0	92.6	96.9
MDSV2	COOP	Madison	01/01/1996	Present	70.7	64.4	65.7	65.9
STAV2	COOP	Staunton WTP ²	01/01/1893	Present	100.0	100.0	95.8	91.8
WYNV2	COOP	Waynesboro WTP ²	10/01/2000	Present	99.7	99.7	94.9	94.2
FRRV2	COOP	Front Royal	12/01/1995	Present	98.6	97.8	99.7	98.9
KCHO	ASOS	Charlottesville-Albemarle Airport	01/07/1973	Present	100.0	100.0	40.6	33.5
SHN418	CASTNET	Big Meadows	07/01/1988	Present	98.6	95.2	98.5	98.2
TR994	RAWS	Headquarters	11/15/2006	Present	100.0	100.0	97.5	97.5
CROV2	RAWS	Sawmill Ridge	11/15/2006	Present	100.0	100.0	89.6	89.6

¹ Observing networks are: COOP — National Weather Service Cooperative Observer Program, ASOS — Automated Surface Observation System, CASTNET — Clean Air Status and Trends Network, and RAWS — Remote Automated Weather Stations.

² WTP — Water Treatment Plant

Temperature Summary

Temperatures for 2014 were below average for the area around Shenandoah NP with departures varying from 1.1°F (0.6°C) to 2.4°F (1.4°C) below normal (Table 2). January was very cold, averaging between 5.1°F to 7.1°F (2.8°C to 3.9°C) below normal across Shenandoah NP (Tables 3 and 4). Below average temperatures continued into February (Figures 2 and 3) which led to negative departures between -0.9°F to -3.1°F (-0.5°C to -1.7°C) (Table 4). March was another cold month across Shenandoah NP with readings ranging from 3.8°F (-2.1°C) below normal at Big Meadows to 7.7°F (-4.3°C) below normal at Luray (Table 4). The average of the winter months (January through March) ranged from the 13th coolest since records began in 1895 across the Western Piedmont and Northern Virginia to 12th coolest in the Central Mountains (Tables 5, 6 and 7) division. The number of cold days was above normal (17 compared with 10 at Luray, and 19 compared with 14 at Staunton; Table 2).

Temperatures during the month of April averaged near to slightly below normal at most stations. May and June were slightly milder, with temperature departures as high as 3.6°F (2.0°C) above normal during May at Big Meadows (Table 4). This resulted in the three climate divisions having spring ranked as the 20th to 27th warmest in 120 years (Tables 5, 6 and 7). The growing season was much longer than normal, by almost 30 days (over four weeks) at both Luray and Staunton (Table 2).

The summer of 2014 started off rather cool for July and August but returned to near seasonal condition by September. Staunton, Front Royal, and Luray averaged more than 2.0°F (1.1°C) below normal in both July and August (Table 4). The number of days in which the maximum temperature exceeded 90°F (32.2°C) was less than half of the normal at both Stanton and Luray, and the highest readings of the year were several degrees below the usual values (Table 2). In fact, the summer of 2014 ranked as the 17th coolest since 1895 in the Central Mountains Climate Division (Table 7). During September, readings ranged from as much as 2.2°F (1.2°C) above normal in Charlottesville to 0.4°F (0.2°C) below normal at Luray (Table 4).

The year concluded with chill in November and rather mild conditions in October and December. November temperatures averaged 40.8°F (4.9°C) at Luray, which is 6.1°F (3.4°C) below its normal values for the month (Tables 3 and 4). Overall, autumn 2014 varied from the 31st to the 53rd warmest for the three climate divisions encompassing Shenandoah NP (Tables 5, 6, and 7).

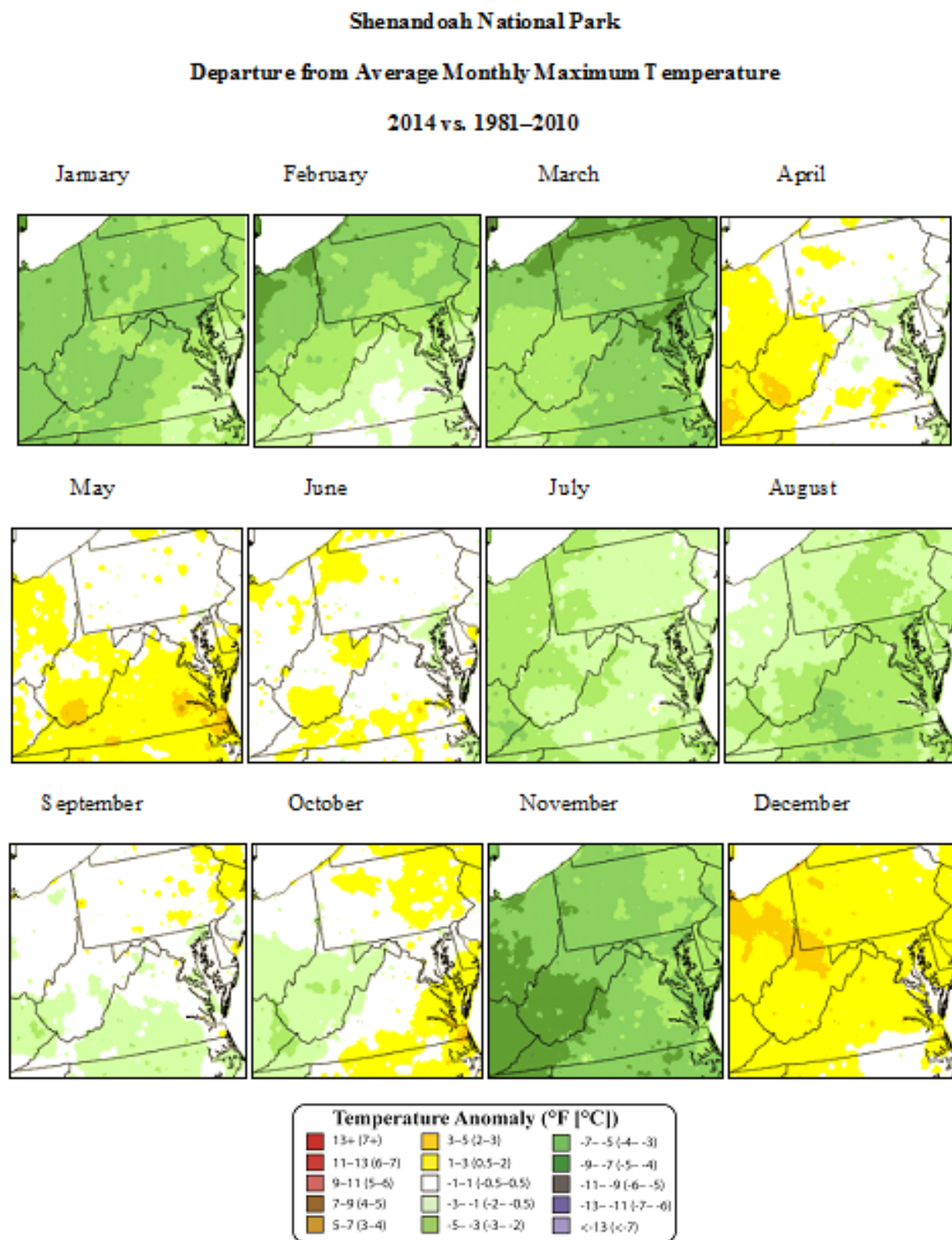


Figure 2. Maps showing departure from average monthly maximum temperature in 2014 compared to the 30-year normal (1981–2010).

Shenandoah National Park

Departure from Average Monthly Minimum Temperature

2014 vs. 1981–2010

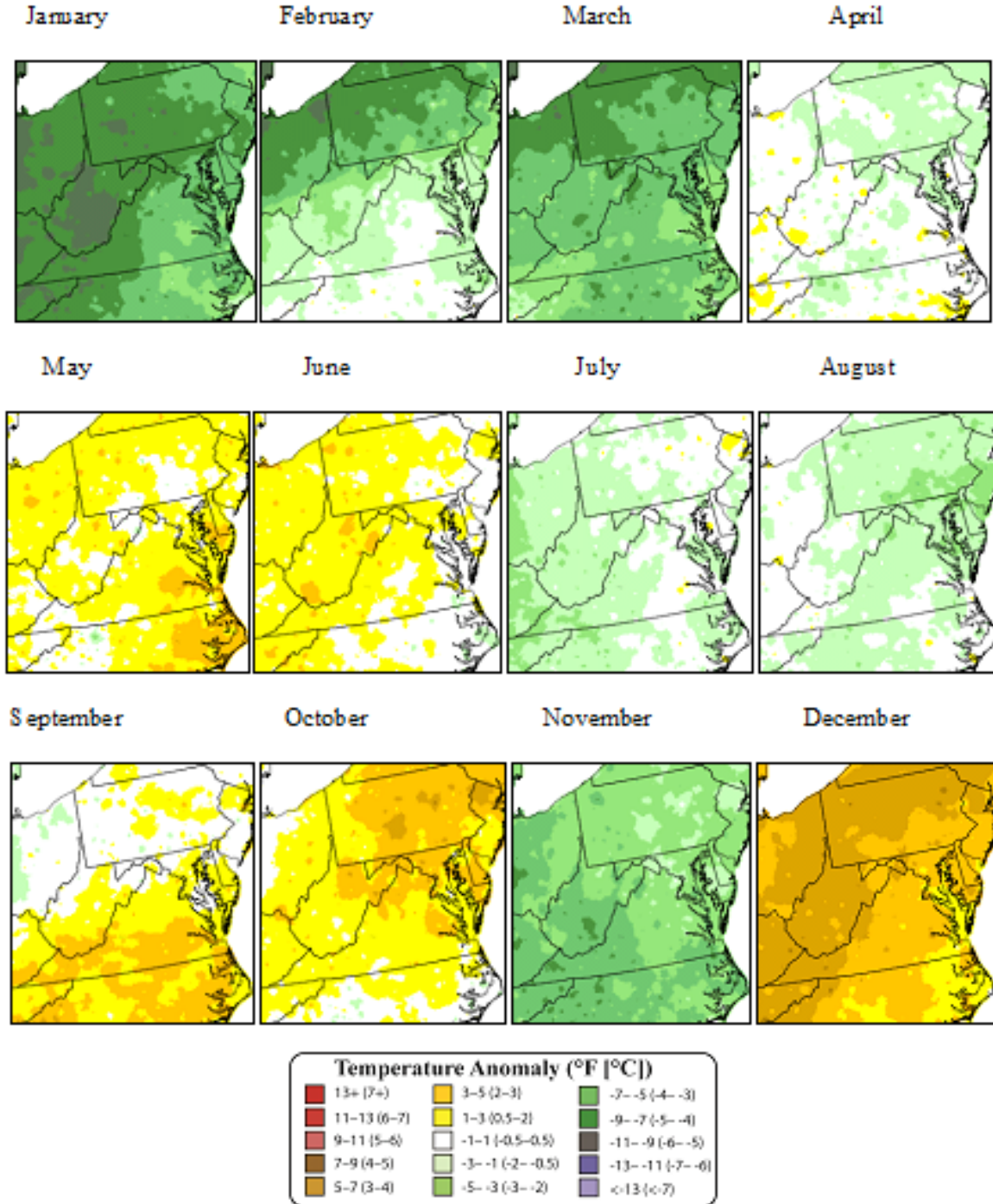


Figure 3. Maps showing departure from average monthly minimum temperature in 2014 compared to the 30-year normal (1981–2010).

Table 2. Status of 2014 temperature indicators compared to the 30-year normal (1981–2010) and the station period of record at the Luray 5 E (LRYV2) and Staunton WTP (STAV2) weather observing stations.

Temperature Indicator	Luray 5 E 2014	Luray 5 E 1981–2010	Luray 5 E 1941-2013 Mean (±1 SD)	Staunton WTP 2014	Staunton WTP 1981–2010	Staunton WTP 1983-2013 Mean (±1 SD)
Average Annual Temperature	52.3°F 11.3°C	54.7°F 12.7°C	53.6 (52.0 – 55.3) °F 12.0 (11.1 – 13.0) °C	52.5°F 11.4°C	53.6°F 12.0°C	54.0(52.4 – 55.6) °F 12.2 (11.3 – 13.1) °C
Average Annual Maximum Temperature	63.8°F 17.7°C	67.2°F 19.6°C	NA	62.8°F 17.1°C	64.0°F 17.8°C	NA
Maximum Temperature	93.0°F 33.8°C	97.4°F 36.3°C	96.5 (93.4 – 99.5) °F 35.8 (34.1 – 37.5) °C	92.0°F 33.3°C	94.7°F 34.8°C	95.6 (92.2 – 98.9) °F 35.3 (33.4 – 37.2) °C
Hot Days (days with Tmax≥90°F/32°C)	12	25	26 (12 –40)	4	10	18(6 – 30)
Average Annual Minimum Temperature	40.8°F 4.9°C	42.3°F 5.7°C	NA	42.1°F 5.6°C	43.1°F 6.2°C	NA
Minimum Temperature	-2.0°F -18.9°C	-1.9°F -18.8°C	-1.3 (-6.9 to 4.3) °F -18.5 (-15.4 to -21.6) °C	-3.0°F -19.4°C	-1.8°F -18.8°C	1.5 (-5.3 to 8.3) °F -17.0 (-13.2 to -20.7) °C
Cold Days (days with Tmax≤32°F/0°C)	17	10	NA	19	14	NA
Sub-freezing Days (days with Tmin≤32°F/0°C)	125	111	120 (104 – 137)	115	105	108 (91 – 126)
Sub-zero Days (days with Tmin≤0°F/-17.8°C)	5	2	NA	3	1	NA
Growing Season Length (days between last spring Tmin 32°F/0°C and first fall Tmin 32°F/0°C)	189	160	157 (139 – 175)	203	174	175 (155 – 194)

Table 3. Summary of monthly average temperatures for 2014 for the selected station

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	27.2°F	33.9°F	36.6°F	53.5°F	62.9°F	70.7°F	71.9°F	69.2°F	66.1°F	56.0°F	40.8°F	38.5 °F	52.3°F
		-2.7°C	1.1°C	2.6°C	11.9°C	17.2°C	21.5°C	22.2°C	20.7°C	18.9°C	13.3°C	4.9°C	3.6°C	11.3°C
Madison	MDSV2	M	M	M	M	65.8°F	72.9°F	74.0°F	71.1°F	68.1°F	M	44.8°F	42.3°F	62.7°F
		M	M	M	M	18.8°C	22.7°C	23.3°C	21.7°C	20.1°C	M	7.1°C	5.7°C	17.1°C
Staunton WTP	STAV2	26.6°F	34.5°F	37.0°F	53.1°F	63.9°F	71.7°F	71.6°F	69.5°F	66.5°F	56.4°F	40.2°F	38.6°F	52.5°F
		-3.0°C	1.4°C	2.8°C	11.7°C	17.7°C	22.1°C	22.0°C	20.8°C	19.2°C	13.6°C	4.6°C	3.7°C	11.4°C
Waynesboro WTP	WYNV2	27.5°F	33.8°F	36.6°F	52.5°F	62.5°F	71.3°F	72.0°F	69.5°F	66.3°F	55.7°F	39.7°F	38.5°F	52.2°F
		-2.5°C	1.0°C	2.6°C	11.4°C	16.9°C	21.8°C	22.2°C	20.8°C	19.1°C	13.2°C	4.3°C	3.6°C	11.2°C
Front Royal	FRRV2	25.8°F	33.1°F	36.6°F	52.9°F	63.4°F	71.6°F	72.8°F	70.0°F	66.3°F	57.1°F	41.2°F	38.7°F	52.5°F
		-3.4°C	0.6°C	2.6°C	11.6°C	17.4°C	22.0°C	22.7°C	21.1°C	19.1°C	13.9°C	5.1°C	3.7°C	11.4°C
Charlottesville-Albemarle Airport	KCHO	30.1°F	37.3°F	41.3°F	55.2°F	66.3°F	73.7°F	74.5°F	72.3°F	69.0°F	58.6°F	43.9°F	41.3°F	55.3°F
		-1.1°C	2.9°C	5.2°C	12.9°C	19.1°C	23.2°C	23.6°C	22.4°C	20.6°C	14.8°C	6.6°C	5.2°C	12.9°C
Big Meadows	SHN418	21.6°F	26.8°F	32.0°F	46.0°F	56.8°F	62.9°F	63.1°F	61.4°F	57.5°F	49.1°F	35.5°F	33.63°F	45.6°F
		-5.8°C	-2.9°C	0.0°C	8.1°C	13.8°C	17.2°C	17.3°C	16.3°C	14.2°C	9.5°C	1.9°C	0.9°C	7.54°C
Headquarters	TR994	27.0°F	32.8°F	38.0°F	53.7°F	63.4°F	71.0°F	71.2°F	69.0°F	65.0°F	55.2°F	40.2°F	37.0 °F	52.0°F
		-2.6°C	0.5°C	3.3°C	12.1°C	17.4°C	21.7°C	21.7°C	20.6°C	18.4°C	12.9°C	4.6°C	2.8°C	11.1°C
Sawmill Ridge	CROV2	28.4°F	33.9°F	38.8°F	54.0°F	64.5°F	71.2°F	71.3°F	69.1°F	65.4°F	56.0°F	41.2°F	38.4°F	52.7°F
		-1.9°C	1.0°C	3.8°C	12.2°C	18.0°C	21.8°C	21.8°C	20.6°C	18.5°C	13.3°C	5.1°C	3.5°C	11.5°C

M = missing data (monthly statistics are reported as 'M' if greater than 4 days of data are missing).

Table 4. Summary of 2014 departure from normal temperature based on 30-year normal (1981–2010) for the selected stations.

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	-5.7°F	-2.6°F	-7.7°F	-1.1°F	0.1°F	-0.2°F	-2.6°F	-3.9°F	-0.4°F	-0.5°F	-6.1°F	1.6°F	-2.4°F
		-3.2°C	-1.4°C	-4.3°C	-0.6°C	0.0°C	-0.1°C	-1.4°C	-2.2°C	-0.2°C	-0.3°C	-3.4°C	0.9°C	-1.3°C
Staunton WTP	STAV2	-6.0°F	-1.1°F	-6.2°F	0.2°F	2.4°F	1.7°F	-2.0°F	-2.8°F	1.3°F	2.2°F	-5.0°F	2.8°F	-1.0°F
		-3.3°C	-0.6°C	-3.4°C	0.1°C	1.3°C	0.9°C	-1.1°C	-1.6°C	0.7°C	1.2°C	-2.8°C	1.6°C	-0.6°C
Front Royal*	FRRV2	-7.1°F	-3.1°F	-6.6°F	-1.4°F	1.0°F	0.4°F	-2.2°F	-3.9°F	-0.3°F	1.0°F	-5.2°F	2.4°F	-2.0°F
		-3.9°C	-1.7°C	-3.7°C	-0.8°C	0.6°C	0.2°C	-1.2°C	-2.2°C	-0.2°C	0.6°C	-2.9°C	1.3°C	-1.1°C
Charlottesville-Albemarle Airport*	KCHO	-5.1°F	-0.9°F	-4.6°F	-0.1°F	3.1°F	1.8°F	-0.9°F	-1.7°F	2.2°F	2.6°F	-3.0°F	3.5°F	-0.2°F
		-2.8°C	-0.5°C	-2.6°C	0.0°C	1.7°C	1.0°C	-0.5°C	-0.9°C	1.2°C	1.4°C	-1.7°C	1.9°C	-0.1°C
Big Meadows*	SHN418	-6.3°F	-2.1°F	-3.8°F	0.0°F	3.6°F	3.0°F	1.9°F	-0.1°F	1.7°F	1.4°F	-3.7°F	2.7°F	-1.0°F
		-3.5°C	-1.2°C	-2.1°C	0.0°C	2.0°C	1.7°C	1.1°C	-0.1°C	1.0°C	0.8°C	-2.1°C	1.5°C	-0.6°C

* Indicates a station's Period of Record does not cover the period of 1981-2010 but is ten or more years. In these cases, the departure-from-normal values were calculated with normals derived from data spanning the length of the station's Period of Record. Madison and Waynesboro WTP were not included due to a low percentage of time reporting temperature for the entire Period of Record. Stations with a Period of Record of less than 5 years were not included in this table.

Table 5. Seasonal and annual temperature and precipitation rankings for 2014 over 120 years for the Western Piedmont (NOAA 2015).

Climate Division 3 Rankings Western Piedmont	Jan–Feb–Mar WINTER	Apr–May–Jun SPRING	Jul–Aug–Sep SUMMER	Oct–Nov–Dec AUTUMN	Jan–Dec YEAR
Temperature-2014	108-T	20-T	90	47-T	89-T
Precipitation-2014	63-T	49	66-T	49	61

1 = warmest/wettest year and 120 = coldest/driest year. T = Tie between multiple years.

Table 6. Seasonal and annual temperature and precipitation rankings for 2014 over 120 years for Northern Virginia (NOAA 2014).

Climate Division 4 Rankings Northern Virginia	Jan–Feb–Mar WINTER	Apr–May–Jun SPRING	Jul–Aug–Sep SUMMER	Oct–Nov–Dec AUTUMN	Jan–Dec YEAR
Temperature-2014	108	27-T	82-T	31-T	81-T
Precipitation-2014	42	12	95	43	36

1 = warmest/wettest year and 120 = coldest/driest year. T = Tie between multiple years.

Table 7. Seasonal and annual temperature and precipitation rankings for 2014 over 120 years for the Central Mountains (NOAA 2014).

Climate Division 5 Rankings Central Mountains	Jan–Feb–Mar WINTER	Apr–May–Jun SPRING	Jul–Aug–Sep SUMMER	Oct–Nov–Dec AUTUMN	Jan–Dec YEAR
Temperature-2014	109	20-T	104-T	53-T	92-T
Precipitation-2014	54-T	44	102	35	63

1 = warmest/wettest year and 120 = coldest/driest year. T = Tie between multiple years.

Precipitation Summary

Precipitation totals in 2014 averaged near to slightly below normal throughout Shenandoah NP (Table 11). Wet days were particularly notable in May and February while dry spells were most pronounced in September and late February (Table 9). Overall, reporting stations in the region tallied annual precipitation between 89 to 109 percent of normal values (Table 10 and 11).

The year began rather dry during January (Figure 4). A quick turnaround to very wet conditions ensued for February, with precipitation amounts ranging from 104 to 200 percent of normal (Table 11). March totals were highly variable, with as little as 1.7 in. (44 mm) tallied at Front Royal and as much as 4.0 in. (100 mm) at Staunton (Table 10). All three-climate divisions in which the park resides (Western Piedmont, Northern Mountains, and Central Mountains) reported winter precipitation totals between the 42nd to 63rd wettest winters since 1895 (Tables 5, 6, and 7; 60 is the mid-point). Snowfall was well above normal throughout Shenandoah NP (Table 8) due in part to a snowstorm that brought over a foot (30 cm) of snow to most of the region on February 12th and 13th.

The spring months of 2014 had above average precipitation, particularly in the months of April and May. In the three climate divisions in which the park resides, that three-month period in 2014 was the 12th to the 49th wettest since 1895 in the Northern and Central Mountains climate division. Rainfall during April averaged between 101-166 percent of normal and all but one station (Big Meadows) reported above average precipitation during May (Table 11). In fact, the wettest day of the year occurred on May 16th, with 3.14 in. recorded (Table 9).

The summer months in Shenandoah NP had below normal, but varied rainfall (Figure 4), with the Central Mountains ranking as the 19th driest and the Western Piedmont ranking the 55th driest since 1895 (Tables 5, 6 and 7). The season ended below normal due in large part to a very dry September (Figure 4, Table 9). Precipitation totals ranged from just 17 to 38 percent of normal across Shenandoah NP during September (Table 11). The longest dry spell also occurred during this time, with an 11-day period stretching from Sept. 15-25 (Table 9). As in 2013, there were no direct effects of tropical storms in Shenandoah NP during the summer of 2014.

Autumn began wet across Shenandoah NP with precipitation averaging 200 percent of normal at Big Meadows during the month of October (Table 11). The wet weather did not last long, however, as a dry November ensued with totals as low as 28 percent of normal at Madison (Table 11). December amounts were near normal, resulting in totals for the season near to slightly above normal (Table 8). The number of days with heavy rain was slightly below normal at both Staunton and Luray, but the frequency of micro-droughts was also below the average (Table 8). Snowy days were well above normal in Shenandoah NP, with 15 compared to the normal of 6 at Luray and 15 compared to the normal of 9 at Staunton (Table 8).

Table 8. Status of 2014 precipitation indicators compared to the 30-year normal (1981–2010) and the station period of record at the Luray 5 E (LRYV2) and Staunton WTP (STAV2) weather observing stations.

Precipitation Indicator	Luray 5 E 2014	Luray 5 E 1981–2010	Luray 5 E 1941-2013 Mean (min – max)	Staunton WTP 2014	Staunton WTP 1981–2010	Staunton WTP 1894-2013 Mean (min – max)
Annual Precipitation	37.9 in 962 mm	42.3 in 1,074 mm	40.4 (27.3 – 65.9) in 1,026 (693 – 1,674) mm	37.0 in 939 mm	39.1 in 993 mm	37.2 (15.5 – 61.5) in 945 (394 – 1,562) mm
Autumn (Oct, Nov, Dec) Pre- cipitation	10.2 in 259 mm	9.7 in 246 mm	9.3 (2.1 – 19.4) in 236 (53 – 493) mm	8.9 in 226 mm	8.8 in 224 mm	8.1 (2.7 – 17.1) in 206 (69 – 434) mm
Heavy Precipitation Days (days with ≥1.0 in [25 mm] rain)	7	11	NA	8	9	NA
Extreme Precipitation Days (days with ≥2.0 in [51 mm] rain)	1	2	2 (0 – 6)	1	2	1 (0 – 6)
Micro-drought (periods of 7+ days without rain)	6	10	NA	7	9	NA
Annual Snowfall	43.6 in 110.7 cm	17.9 in 45.5 cm	17.2 (0 – 53.0) in 43.7 (0 – 134.6) cm	34.8 in 88.4 cm	22.7 in 57.7 cm	21.8 (1.3 – 60.0) in 55.4 (3.3 – 152.4) cm
Measurable Snow Days (days with ≥0.1 in [0.3 cm] snow)	15	6	NA	15	9	NA
Moderate Snow Days (days with ≥3.0 in [7.6 cm] snow)	5	3	NA	4	3	NA
Heavy Snow Days (days with ≥5.0 in [12.7 cm] snow)	4	1	NA	2	1	NA

Table 9. Top five wettest days and top five dry spells (consecutive days with a trace or less of liquid precipitation) during 2014 from weather observing stations at Luray 5 E (LRYV2) and Staunton WTP (STAV2).

Wettest Days in 2014	Dry Spells in 2014
May 16: 3.14 in (80 mm)	Sept. 15-25
Feb. 14: 1.83 in (46 mm)	Feb 20 – March 2
Feb. 3: 1.81 in (46 mm)	May 18-27
Oct. 15: 1.59 in (40 mm)	April. 17- 25
Jun. 21: 1.50 in (38 mm)	Nov. 8-16

Table 10. Summary of 2014 monthly total precipitation for selected stations.

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	1.7 in	4.2 in	2.9 in	3.6 in	4.6 in	4.4 in	2.7 in	2.6 in	0.97 in	5.1 in	2.3 in	2.7 in	37.9 in
		44 mm	108 mm	73 mm	91 mm	117 mm	113 mm	68 mm	66 mm	25 mm	130 mm	59 mm	70 mm	962 mm
Madison	MDSV2	M	M	M	4.9 in	6.9 in	2.5 in	4.7 in	2.9 in	1.3 in	M	1.1 in	2.7 in	M
		M	M	M	125 mm	175 mm	64 mm	119 mm	73 mm	33 mm	M	28 mm	69 mm	M
Staunton WTP	STAV2	1.7 in	3.7 in	4.0 in	4.2 in	4.9 in	4.0 in	2.1 in	2.4 in	0.9 in	4.1 in	2.6 in	2.4 in	36.9 in
		43 mm	95 mm	100 mm	107 mm	125 mm	101 mm	53 mm	60 mm	22 mm	105 mm	66 mm	61 mm	939 mm
Waynesboro WTP	WYNV2	1.9 in	4.3 in	3.5 in	4.2 in	4.0 in	4.1 in	3.4 in	2.4 in	0.9 in	4.9 in	3.3 in	2.8 in	39.6 in
		48 mm	110 mm	90 mm	107 mm	100 mm	105 mm	85 mm	61 mm	23 mm	123 mm	83 mm	70 mm	1007 mm
Front Royal	FRRV2	1.2 in	3.2 in	1.7 in	3.3 in	5.5 in	5.1 in	2.4 in	4.2 in	1.7 in	5.2 in	1.8 in	3.0 in	38.6 in
		31 mm	82 mm	44 mm	85 mm	139 mm	131 mm	61 mm	107 mm	43 mm	131 mm	46 mm	77 mm	979 mm
Charlottesville-Albemarle Airport	KCHO	2.2 in	2.8 in	2.5 in	5.8 in	4.9 in	2.9 in	3.1 in	4.1 in	0.9 in	3.7 in	2.8 in	2.8 in	38.4 in
		56 mm	71 mm	64 mm	147 mm	124 mm	74 mm	79 mm	104 mm	23 mm	94 mm	71 mm	71 mm	975 mm
Big Meadows	SHN418	2.5 in	4.0 in	3.1 in	5.3 in	4.1 in	10.2 in	3.8 in	4.1 in	1.0 in	7.3 in	3.1 in	2.9 in	51.3 in
		64 mm	100 mm	80 mm	135 mm	103 mm	260 mm	96 mm	103 mm	24 mm	185 mm	79 mm	73 mm	1303 mm
Headquarters	TR994	0.52 in	2.9 in	2.9 in	3.6 in	4.3 in	3.8 in	2.6 in	2.9 in	1.0 in	4.8 in	2.5 in	2.8 in	34.7 in
		13 mm	74 mm	74 mm	91 mm	109 mm	96 mm	67 mm	74 mm	25 mm	122 mm	62 mm	72 mm	880 mm
Sawmill Ridge	CROV2	2.0 in	2.6 in	3.8 in	4.6 in	4.3 in	6.8 in	2.6 in	1.8 in	0.6 in	5.0 in	3.2 in	2.5 in	40.0 in
		51 mm	67 mm	97 mm	117 mm	109 mm	174 mm	67 mm	45 mm	16 mm	127 mm	82 mm	65 mm	1016 mm

M = missing data (monthly statistics are reported as 'M' if more than 4 days of data are missing).

Table 11. Summary of 2014 percent of normal total precipitation based on 30-year normal (1981–2010) for selected stations.

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	63	158	75	105	115	111	66	78	21	168	64	89	90
Madison*	MDSV2	M	M	M	149	154	57	112	80	30	M	28	77	M
Staunton WTP	STAV2	64	145	123	133	131	111	54	66	24	138	84	88	94
Front Royal*	FRRV2	49	121	45	101	131	127	72	137	38	165	48	106	94
Charlottesville-Albemarle Airport*	KCHO	79	104	68	166	123	76	72	134	20	119	74	88	89
Big Meadows*	SHN418	78	200	78	133	90	219	98	111	17	200	74	91	109

* Indicates a station's Period of Record does not cover the period of 1981-2010 but is more than 10 years. In these cases the departure from normal values were calculated with normals derived from data spanning the length of the station's Period of Record. Waynesboro was not included due to a low percentage of time reporting precipitation for the entire Period of Record. Stations with a Period of Record of less than 5 years were not included in this table.

M = missing data (monthly statistics are reported as 'M' if more than 4 days of data are missing).

Shenandoah National Park
Percent of Average Monthly Precipitation
2014 vs. 1981–2010

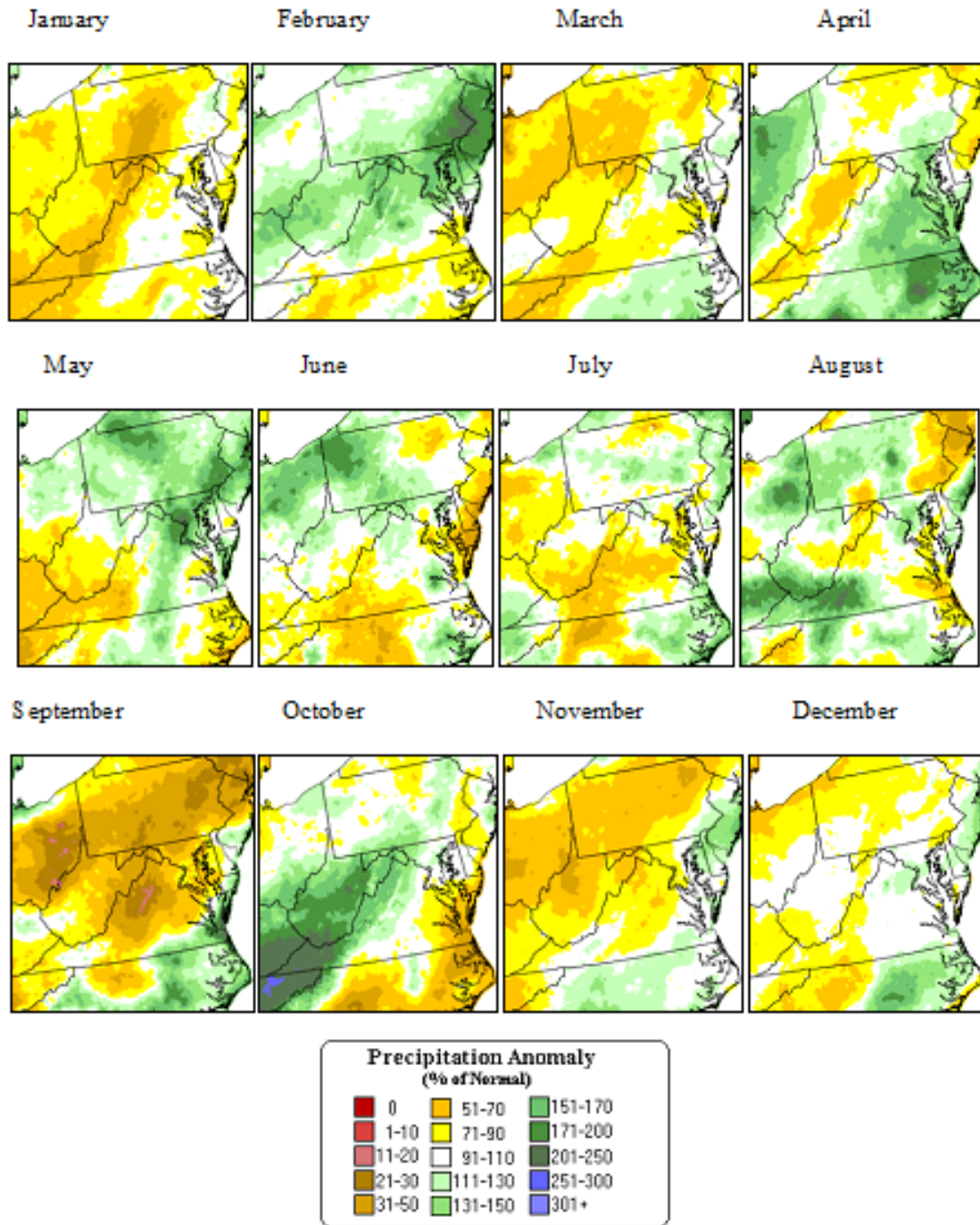


Figure 4. Maps showing percent of average monthly precipitation in 2014 compared to the 30-year normal (1981–2010).

Drought Status

There are a number of drought indices used to estimate the severity of drought in an area using algorithms that incorporate recent temperatures, rainfall, soil moisture, and other information (<http://www.drought.gov>). The main indices we report are the Palmer Drought Severity Index (PDSI) and the United States Drought Monitor (DM) – Drought Intensity Index. While both indices provide excellent summary information on broad-scale conditions, local conditions (such as at the park scale) may vary.

The PDSI is a soil moisture algorithm calibrated for relatively homogeneous regions and is calculated on a monthly basis using precipitation and temperature data, as well as the water content of the soil. The values vary between extremely moist (>4.0) and extreme drought (<-4.0) with “normal” values ranging between -1.9 and 1.9 . The long-term average is “zero”. Monthly PDSI values for Northern Virginia in 2014 are shown in Figure 5.

According to the PDSI, moist conditions persisted in the Western Piedmont through the spring but then dropped to near normal for the rest of the year (Figure 5). When compared to the previous two years, 2013 was more consistently moist throughout the year and was very moist during the summer months. In contrast, 2012 was a drier year than 2013 or 2014. PDSI values remained below 0 for the duration of 2012 and entered into moderate drought conditions during the autumn.

The DM – Drought Intensity Index is a synthesis of multiple indices (including the PDSI) and impacts, which represents a consensus of federal and academic scientists (NIDIS 2014). The DM produces a summary map of drought intensity for the nation and all states each week. It is on a scale ranging from abnormally dry (D0) to exceptional drought (D4). Mid-month (i.e., the second or third week) values for Virginia (Figure 6) and the Southeast (Figure 7) are shown for 2014. Other than for a few dry spells, no drought conditions were evident during the growing season.

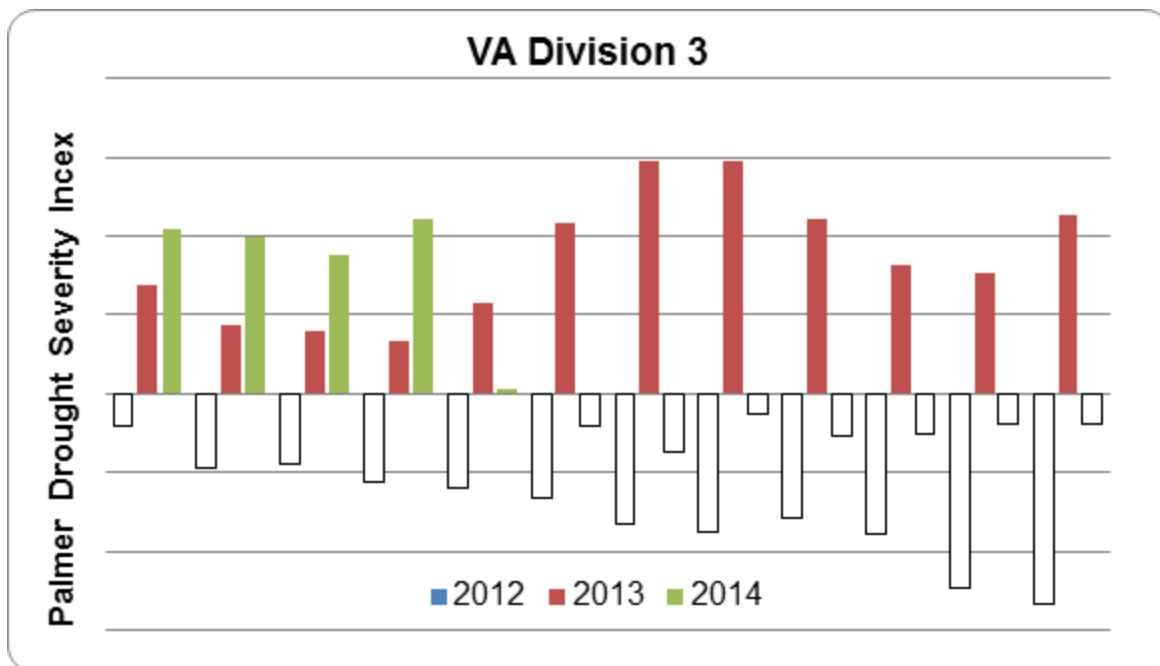


Figure 5. Palmer Drought Severity Index (PDSI) for Western Piedmont, 2012–2014.

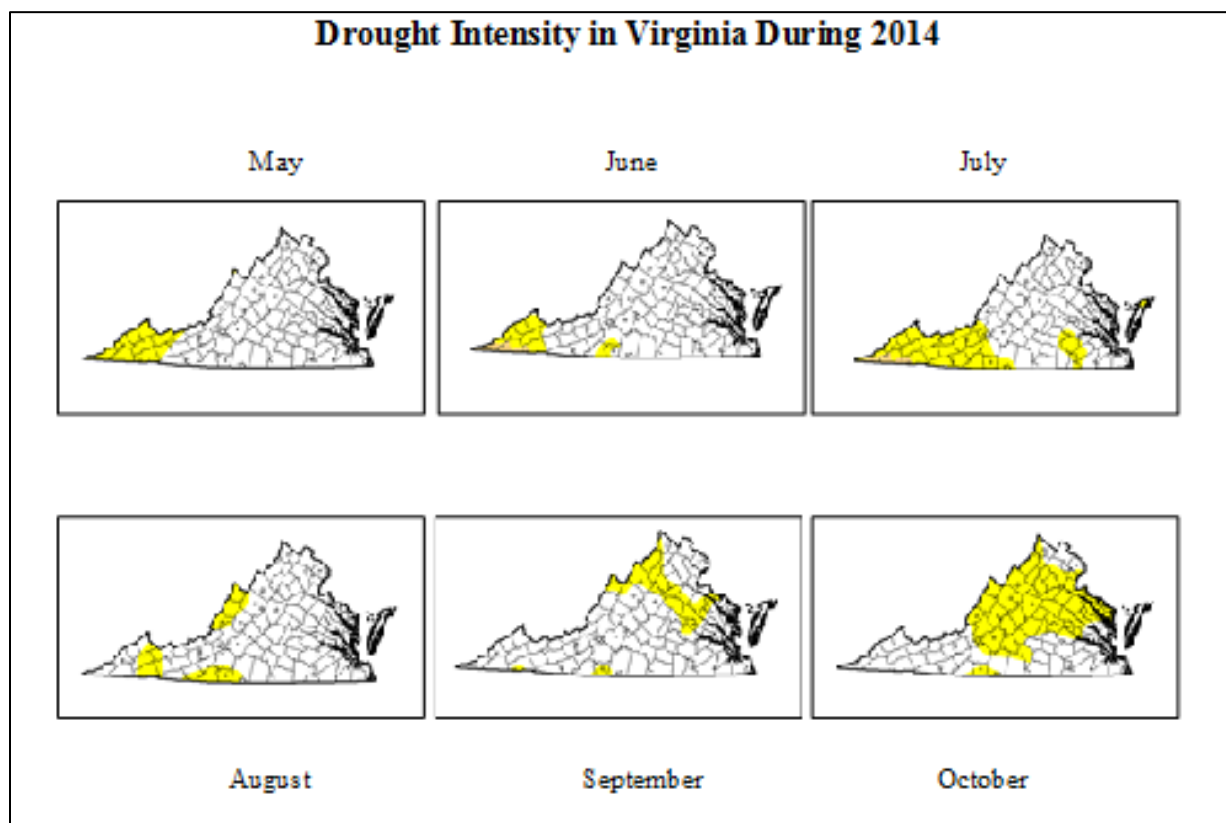


Figure 6. Mid-month values of the United States Drought Monitor (DM) - Drought Intensity Index for Virginia in 2014.

Drought Intensity for the Southeast during 2014

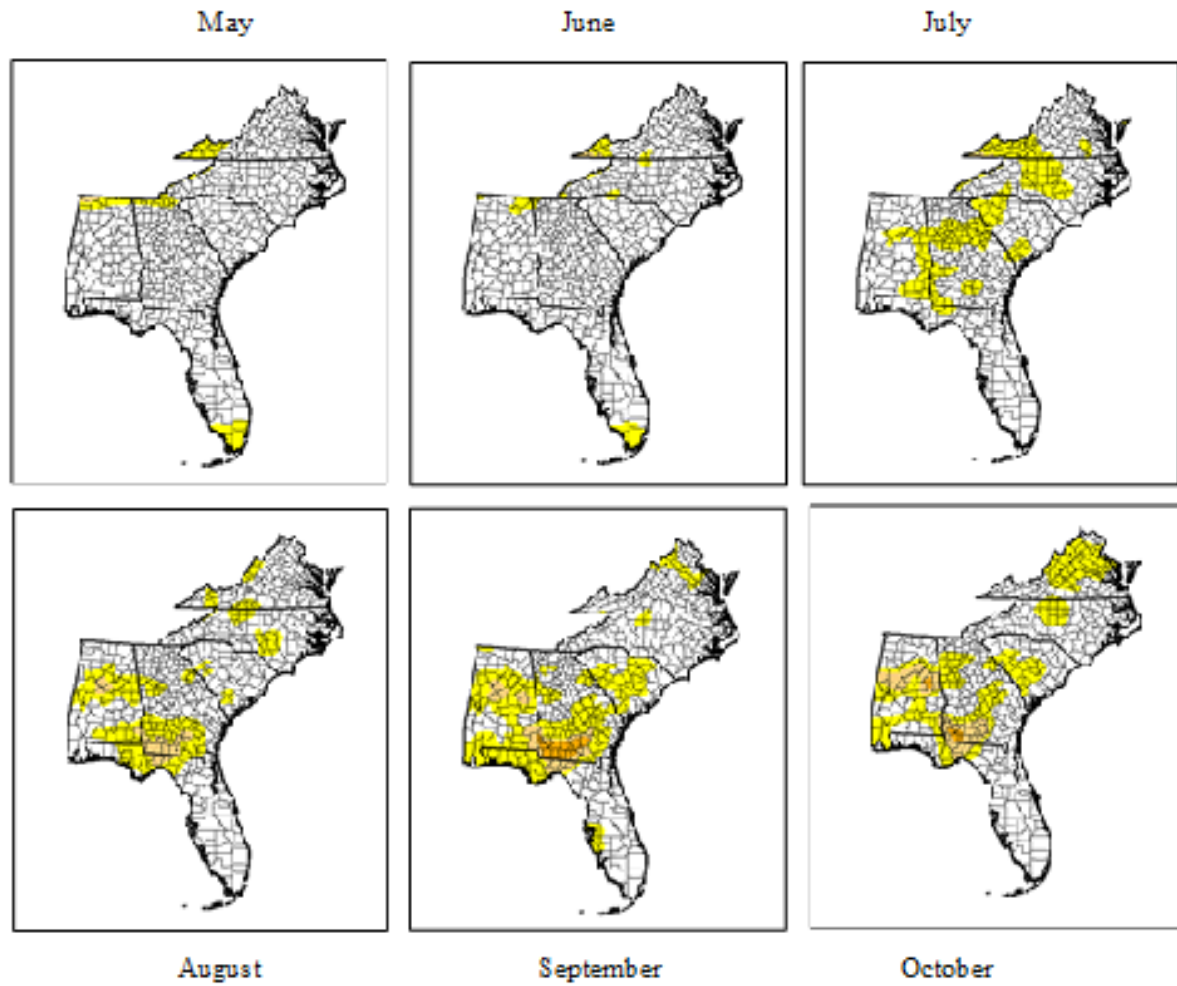


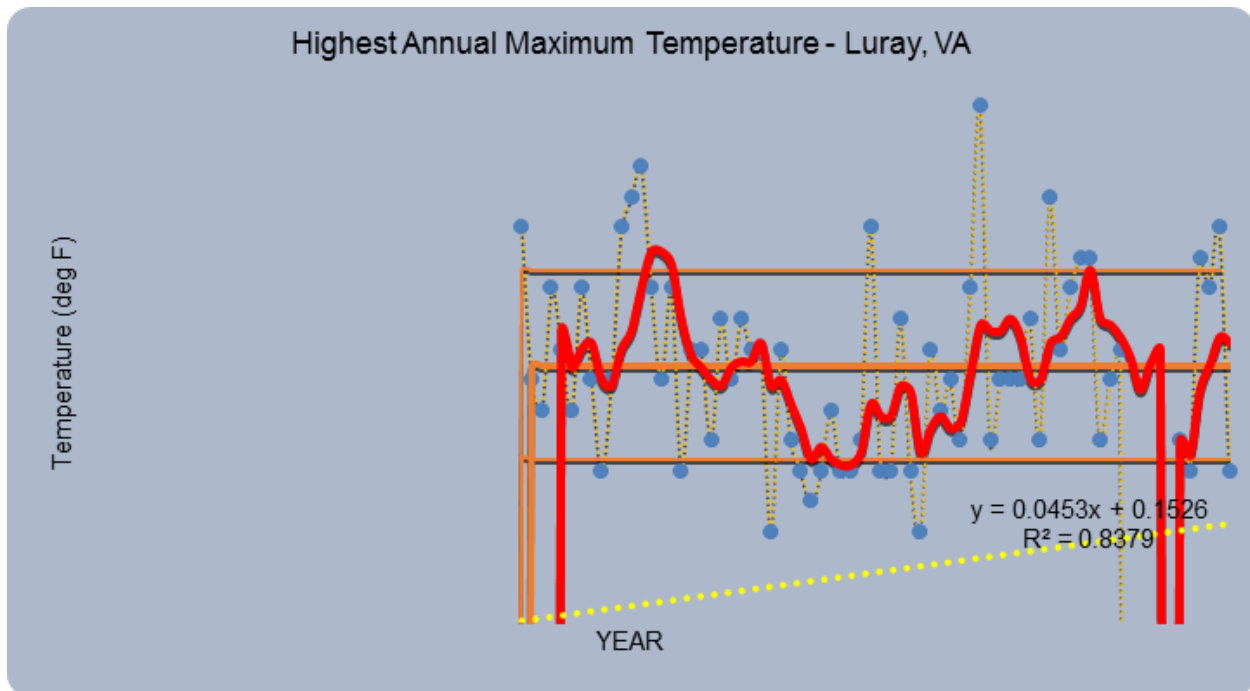
Figure 7. Mid-month values of the United States Drought Monitor (DM) - Drought Intensity Index for the Southeast in 2014.

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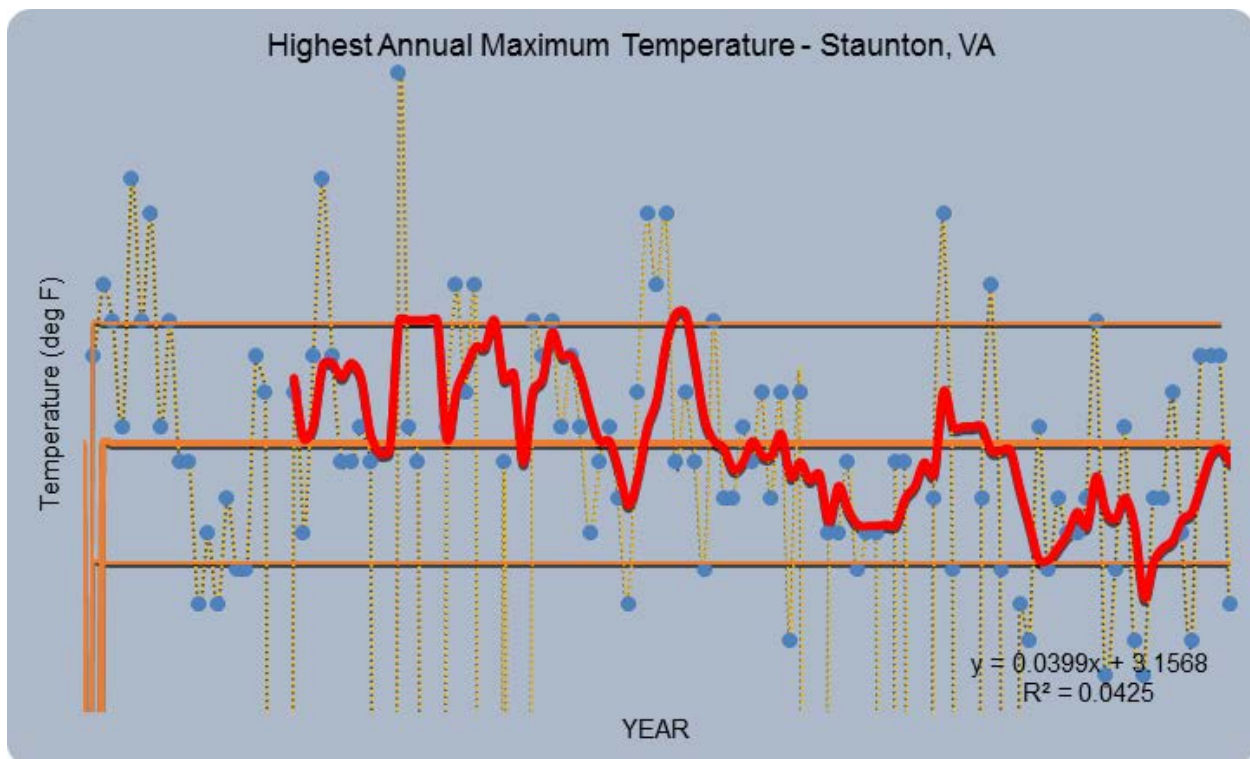
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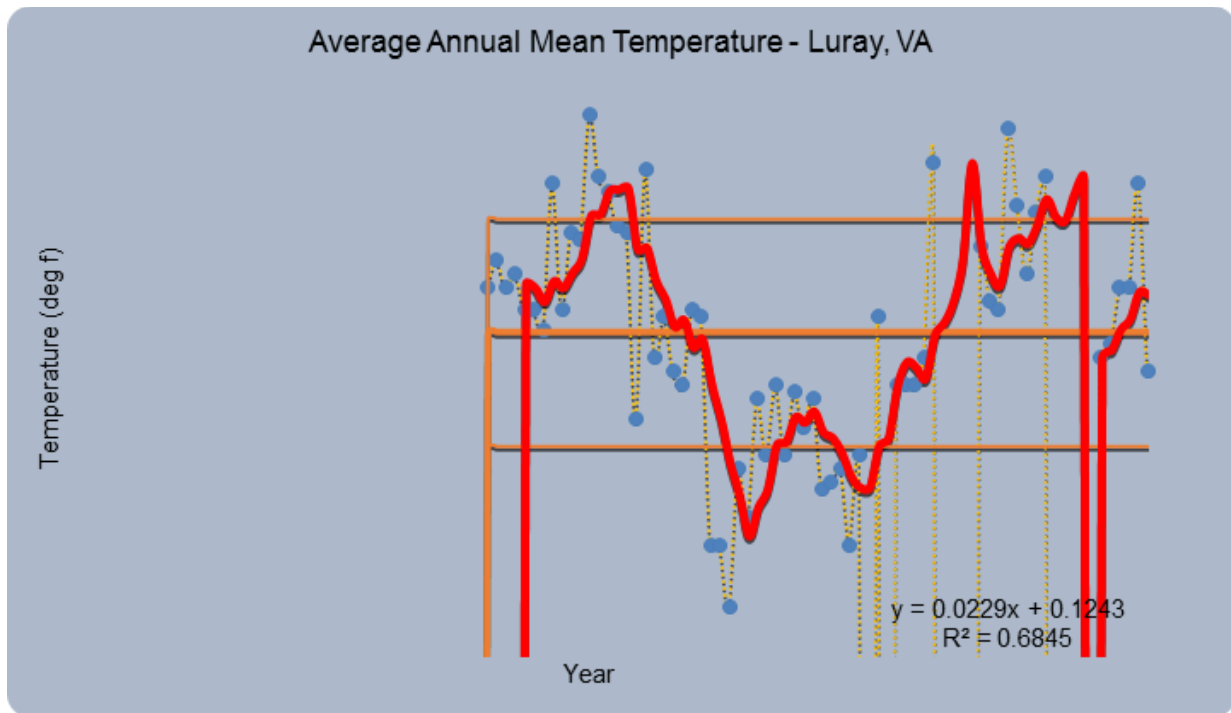
Appendix

Below are graphs illustrating long-term trend analysis for multiple climate indicators at the Luray and Staunton weather stations. For temperature indicators, yearly values are marked by the dotted orange line, the 5-year moving average is indicated by the thick red line, the long-term linear trend is shown by the dotted yellow line, the long-term mean is marked by the thick orange line, and the first standard deviation above and below the long-term mean are delineated by the solid orange lines. Similarly for precipitation indicators, yearly values are marked by the dotted teal line, the 5-year moving average is indicated by the thick green line, the long-term linear trend is shown by the dotted yellow line, and the long-term mean is delineated by the thick light blue line.

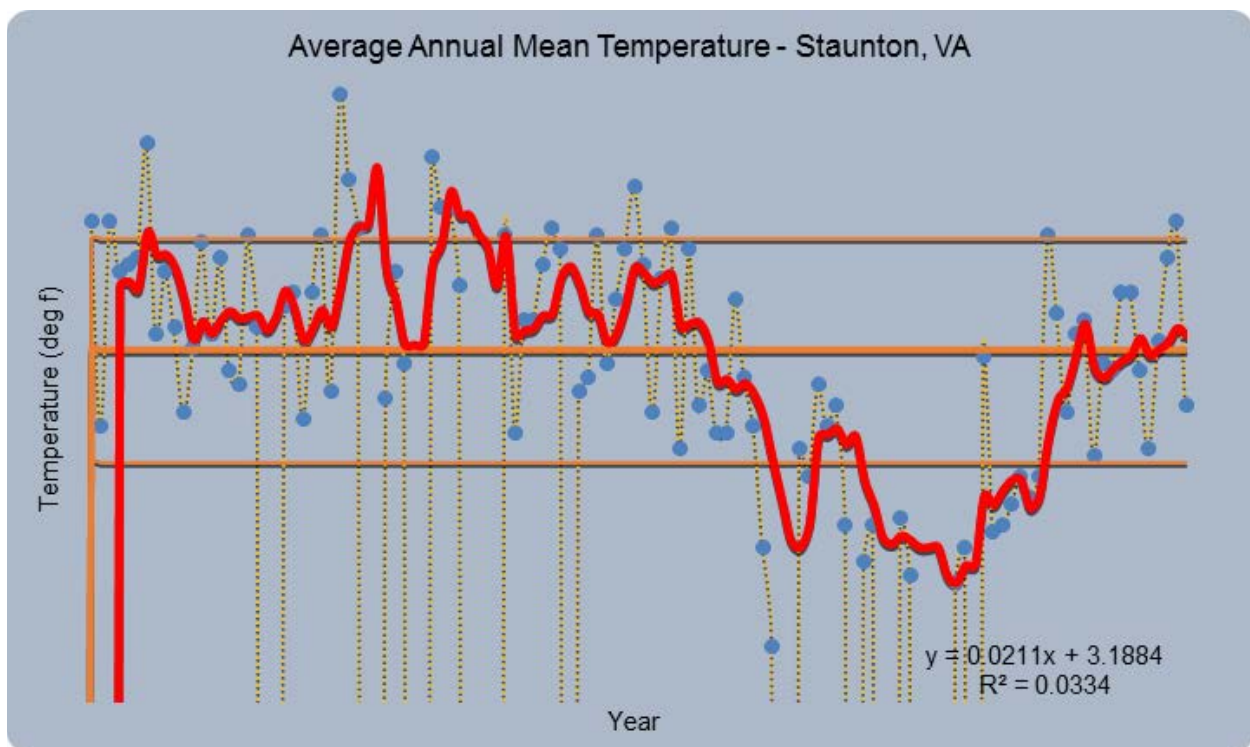


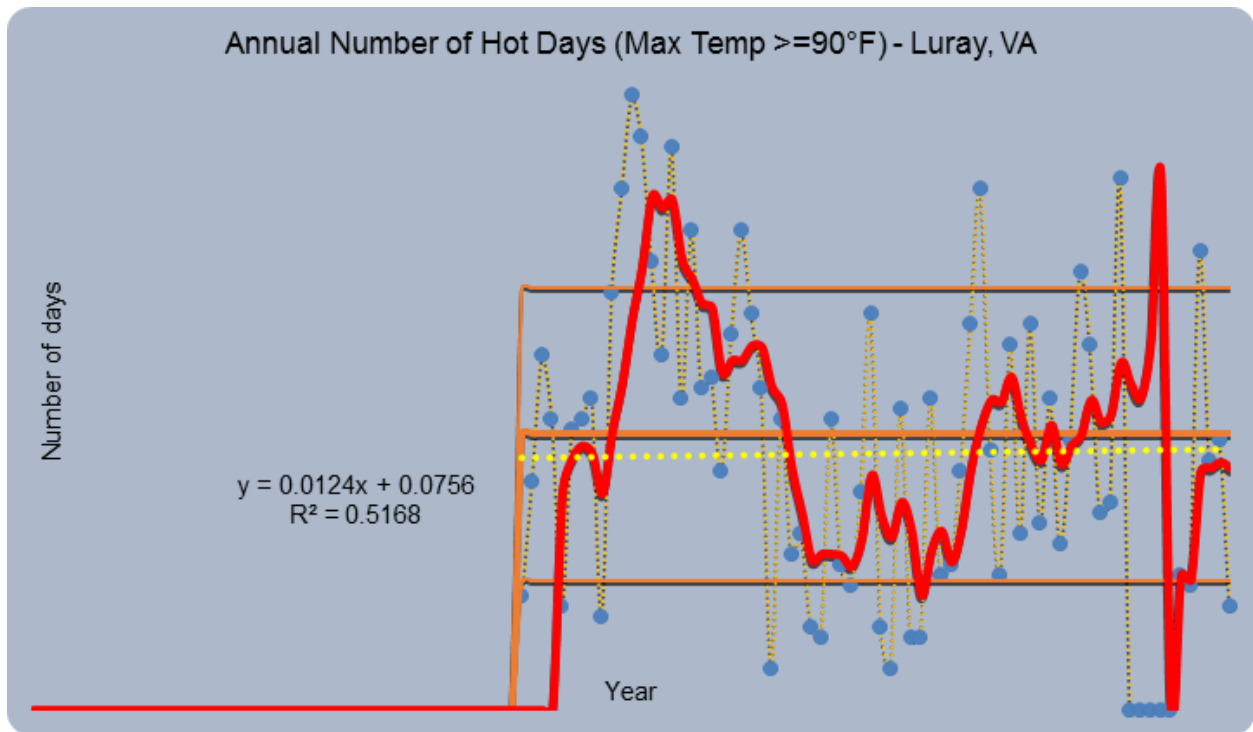
Annual Maximum Trends: Over the past ~70 years, Luray's annual maximum temperatures show no trend while Staunton has seen a decreasing trend in maximum temperatures of about 4 degrees Fahrenheit over the period of record. The average annual maximum temperature is 96.5°F (± 1 SD ranges from 93.4-99.5°F) at Luray and 95.6°F (± 1 SD ranges from 92.2-98.9°F) at Staunton (Table 2).



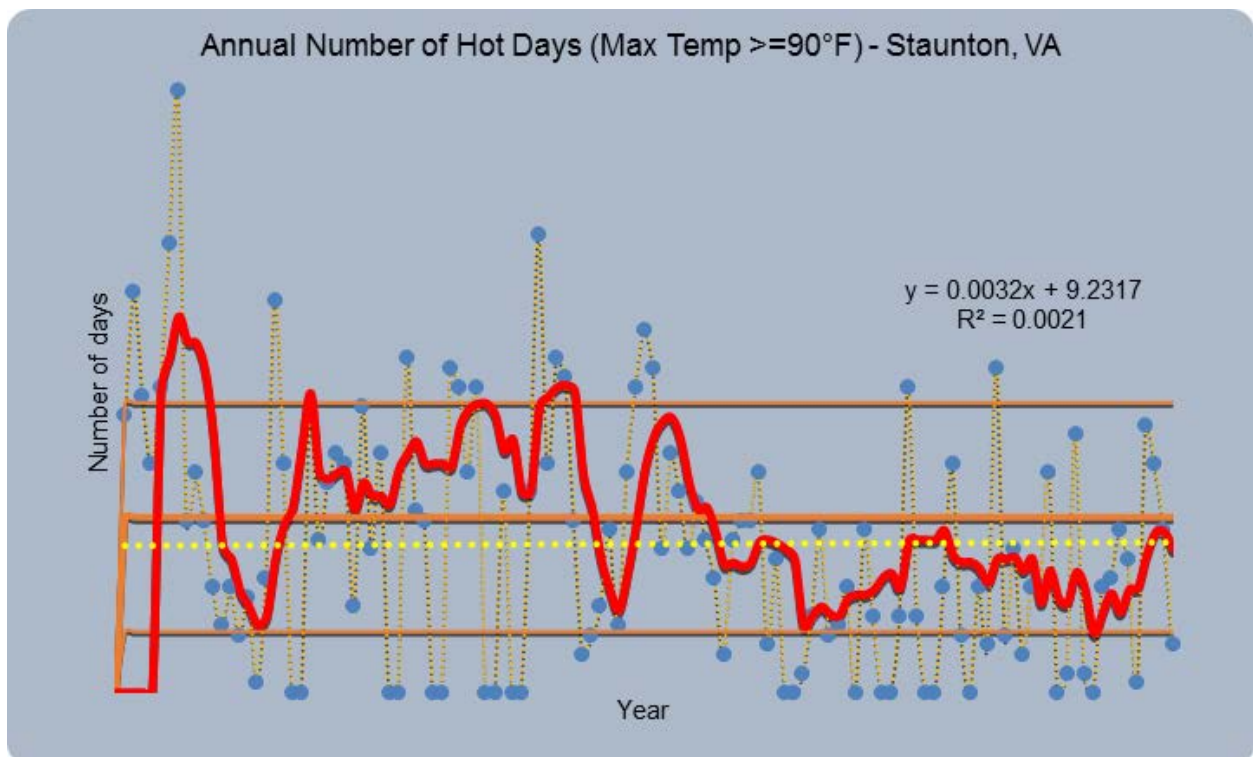


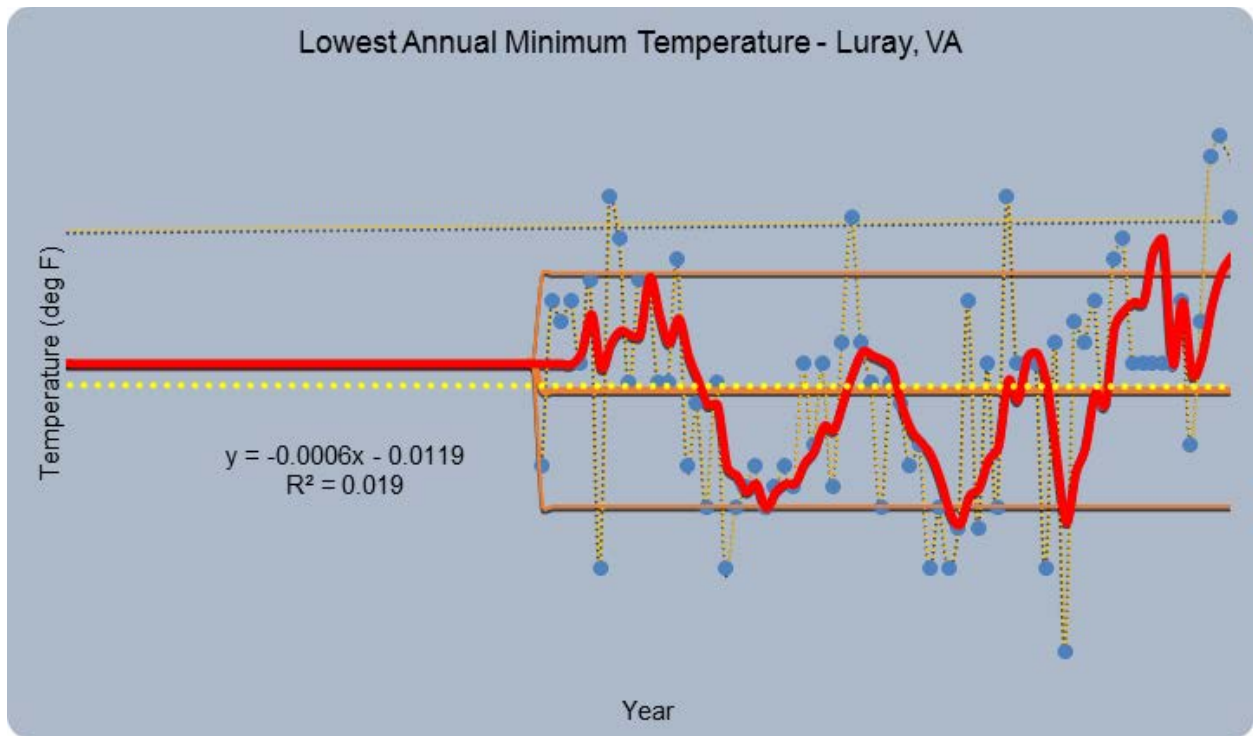
Annual Mean Trends: Similar to annual maximum temperatures, no trend is observed in Luray while Staunton has seen a substantial decreasing trend (over 2°F) over the past century or so. The average annual mean temperature at Staunton is 54.0°F (±1SD ranges from 52.4-55.6°F) and 53.6°F (±1SD ranges from 52.0-55.3°F) at Luray (Table 2).



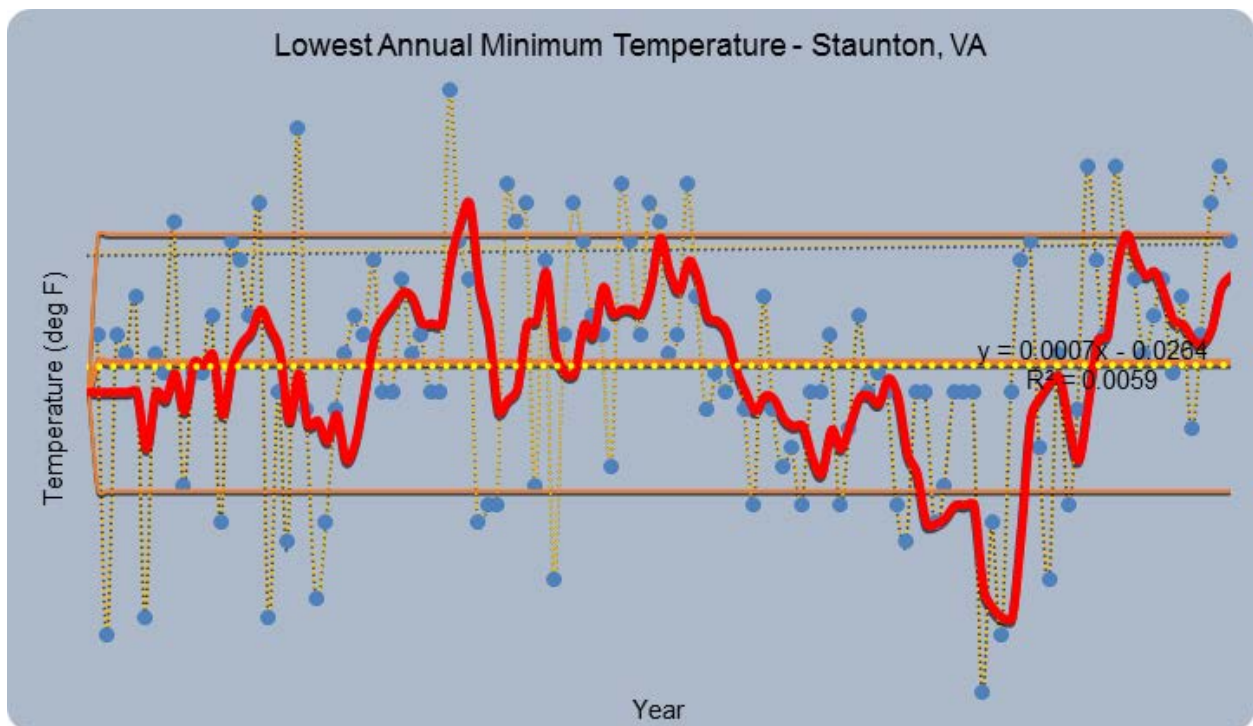


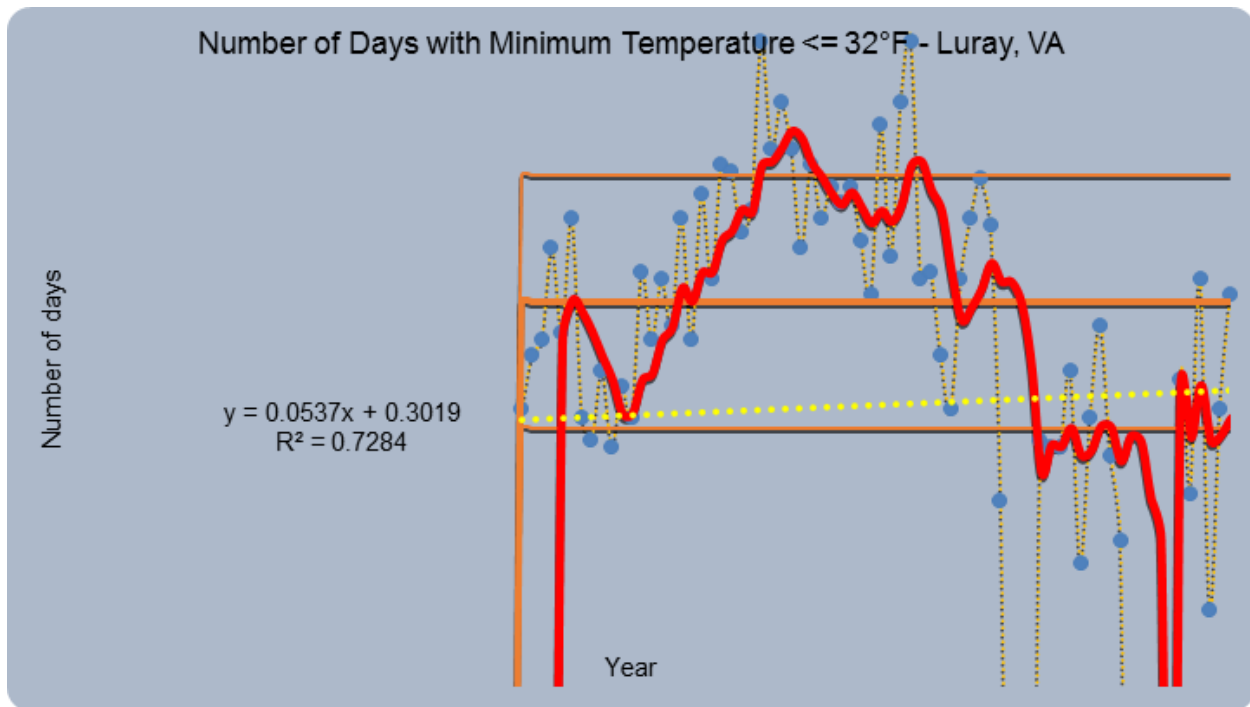
Annual Number of Hot Days: Both stations have seen a declining trend in the number of hot days over their periods of record, with Staunton having the larger decrease of the two (~15 days). The average number of annual hot days is 26 ($\pm 1\text{SD}$ ranges from 12-40) at Luray and 18 ($\pm 1\text{SD}$ ranges from 6-30) at Staunton (Table 2).



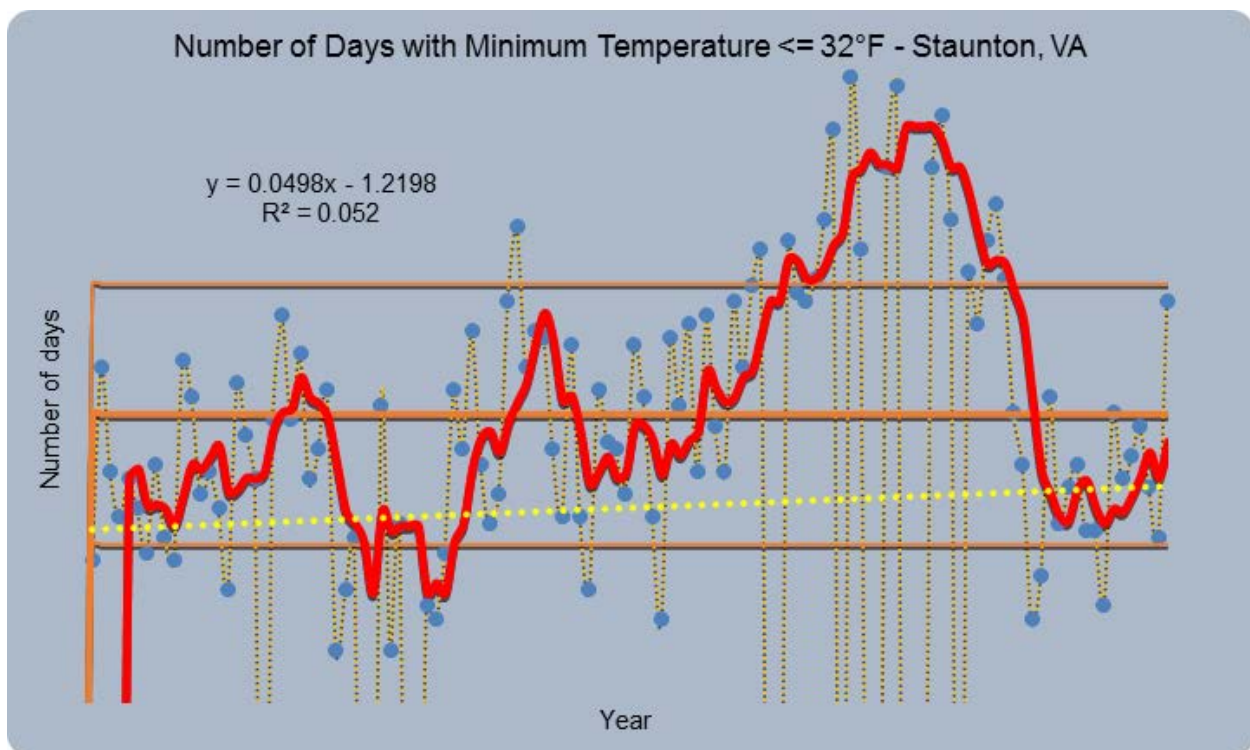


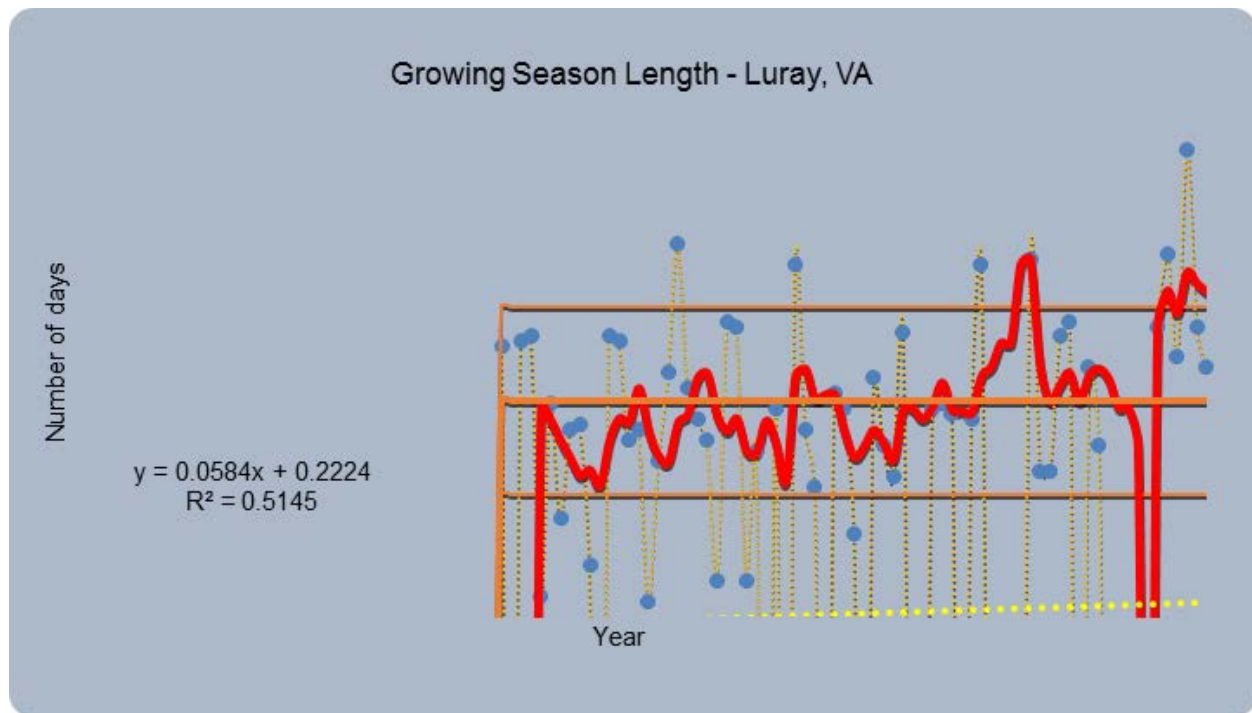
Annual Lowest Minimum Temperature: Annual minimum temperatures have increased in Luray by a couple of degrees Fahrenheit over the period of record while Staunton shows virtually no trend. The average annual minimum temperature is -1.3°F (1SD ranges from -6.9 to 4.3°F) at Luray and 1.5°F (1SD ranges from -5.3 to 8.3°F) at Staunton (Table 2).



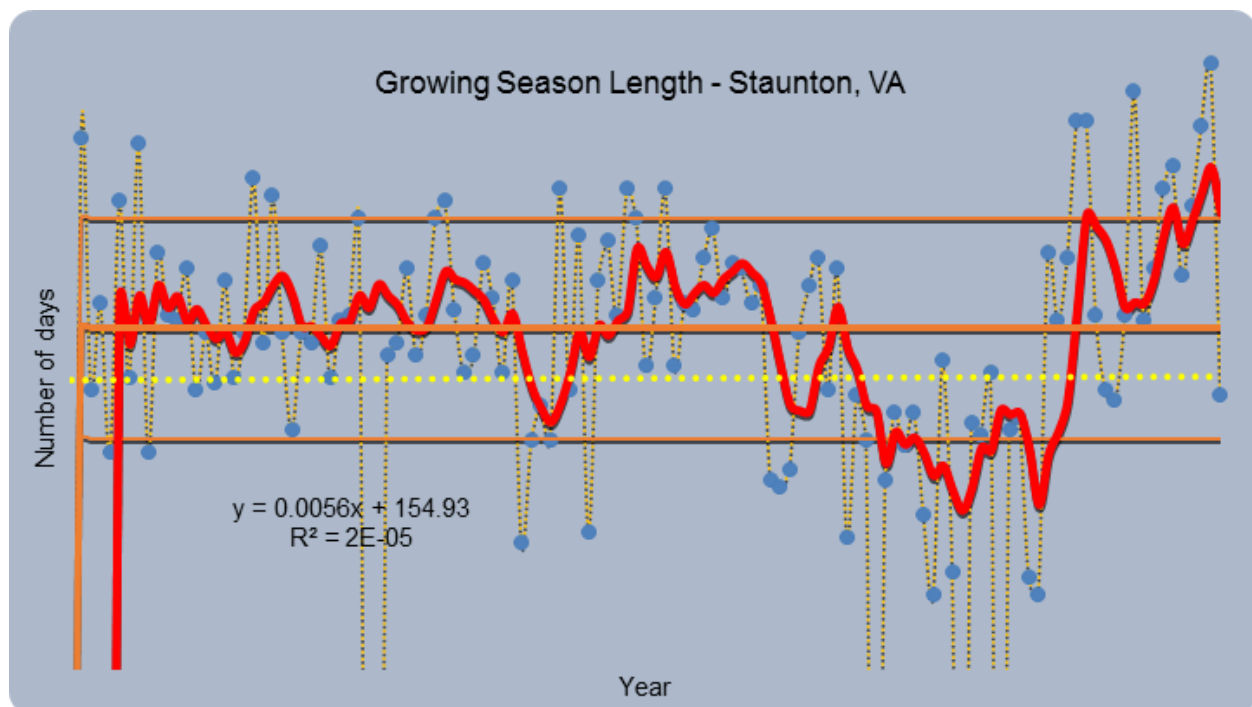


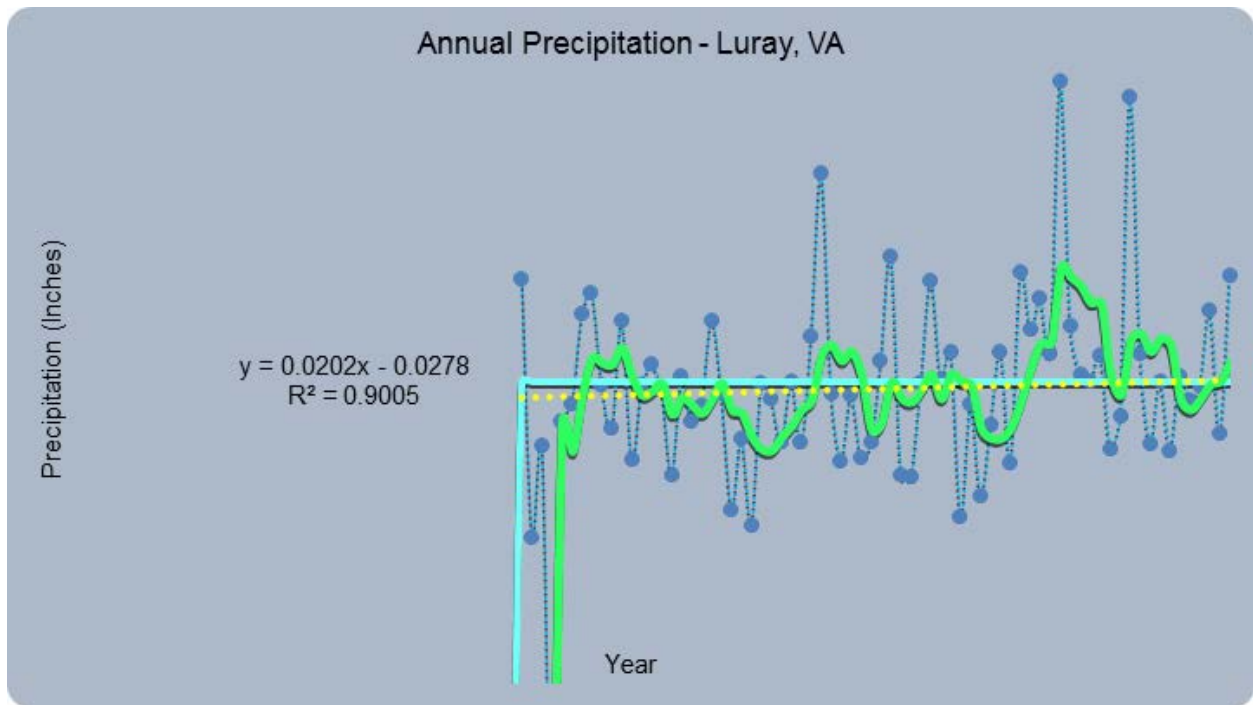
Annual Number of Days with Minimums at or below Freezing: For the number of sub-freezing nights, Luray has seen a decrease of about 20 days while Staunton has seen the opposite – an increase of about 20 days over the period of record. The average number of nights is 120 ($\pm 1\text{SD}$ ranges from 104-137) at Luray and 108 ($\pm 1\text{SD}$ ranges from 91-126) at Staunton (Table 2).



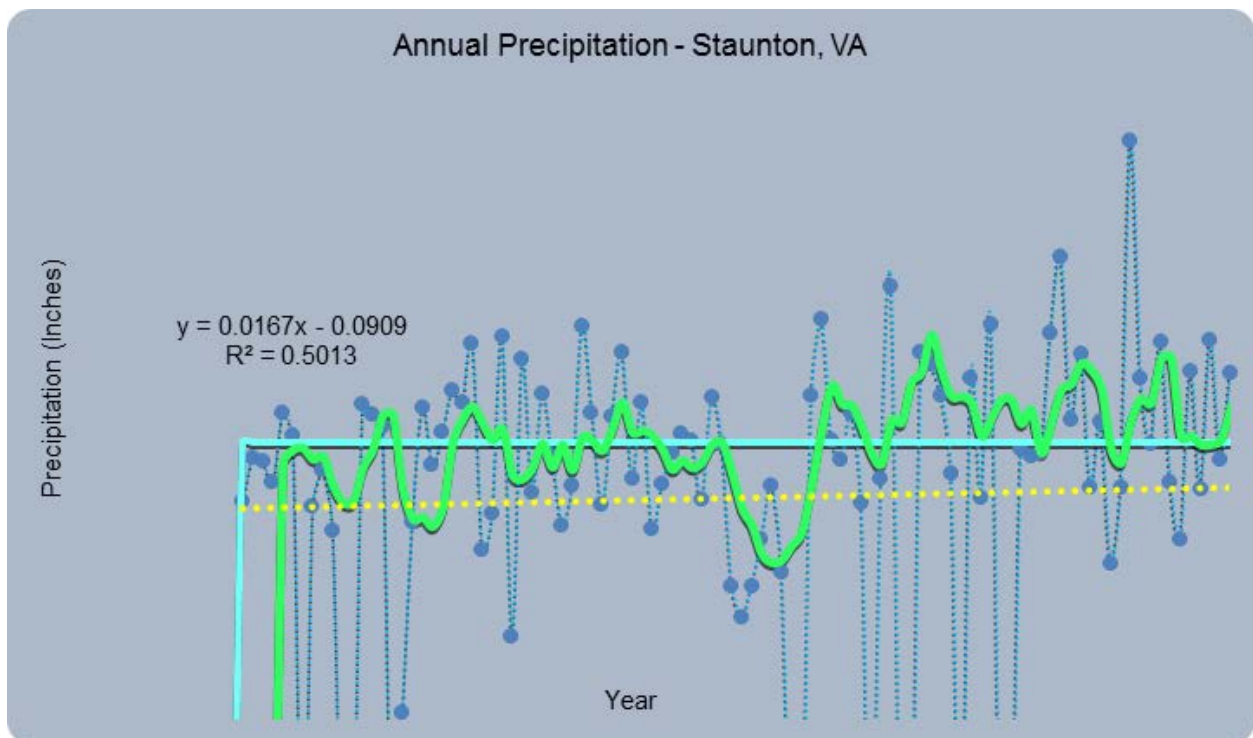


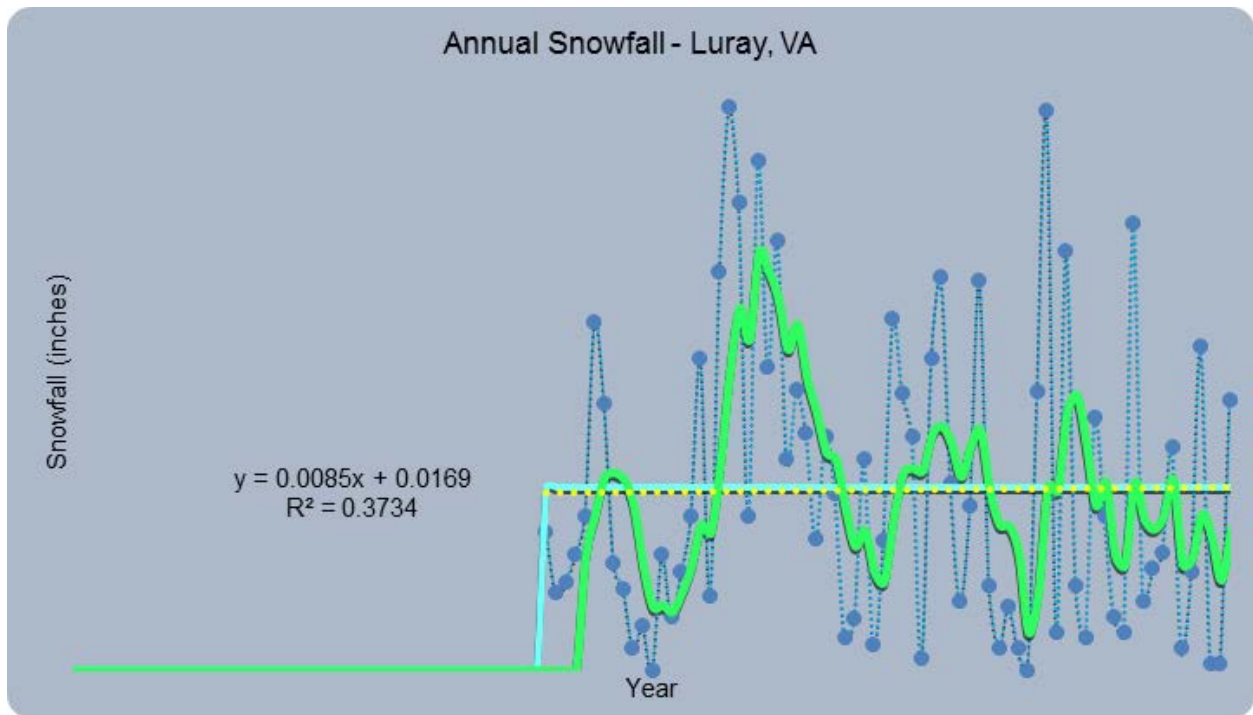
Growing Season Length Trends: The growing season has not changed in length in Staunton over the historical period, but Luray has seen a significant lengthening of the growing season (~3 weeks). The average annual number of days in the growing season is 157 ($\pm 1SD$ ranges from 139-175) at Luray and 175 ($\pm 1SD$ ranges from 155-194) at Staunton (Table 2).



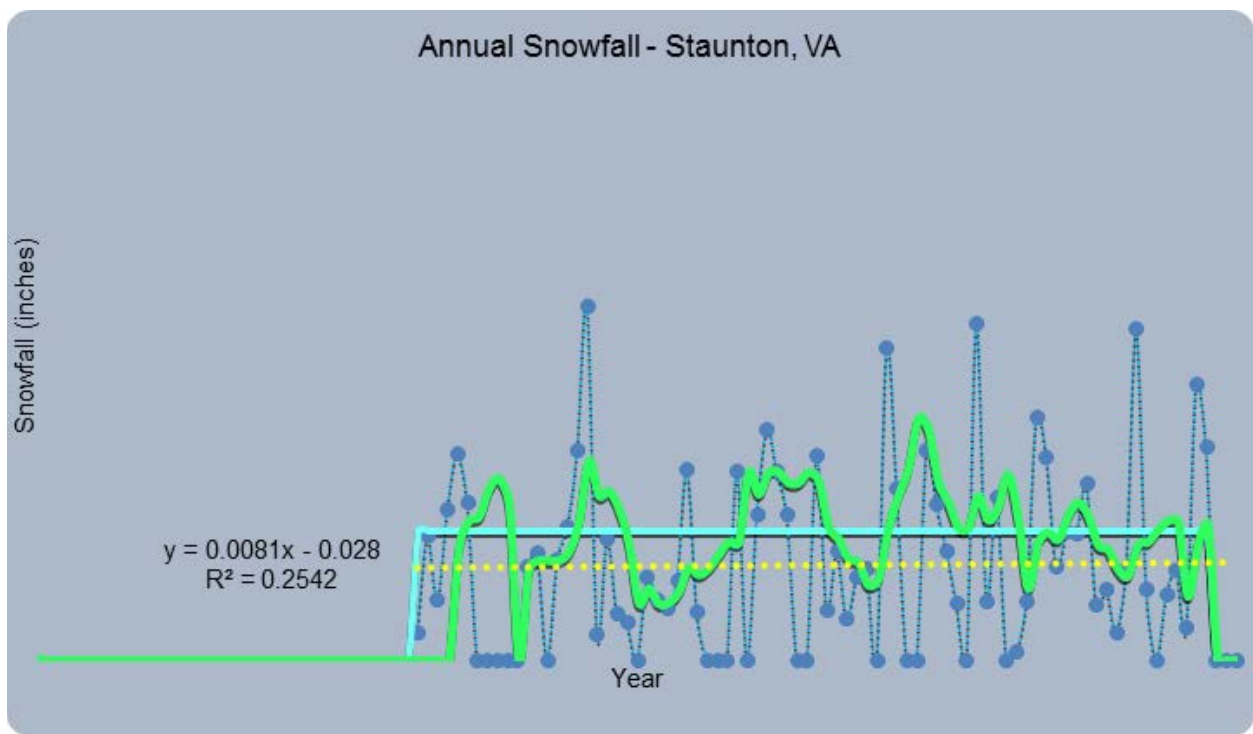


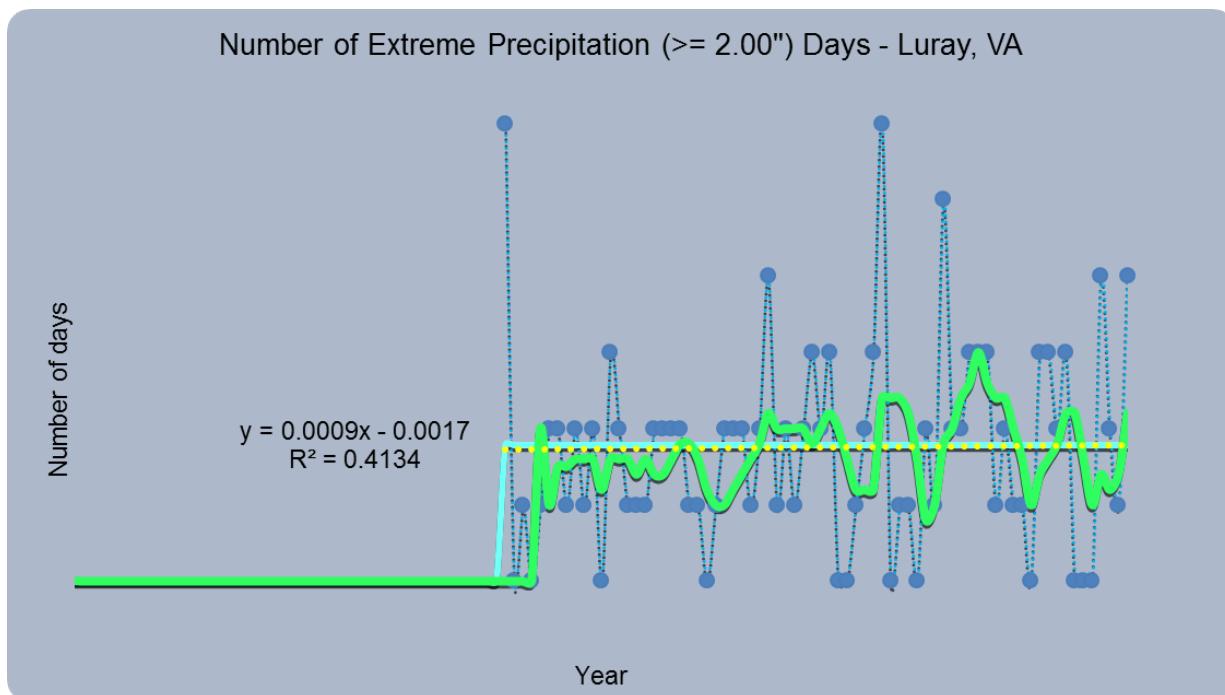
Annual Precipitation Trends: Both Luray and Staunton have seen annual precipitation amounts increase by about 5 inches over their respective periods of record. The average annual precipitation at Staunton is 37.2 in. (min of 15.5 in and max of 61.5 in) and 40.4 in (min of 27.3 in and max of 65.9 in) at Luray (Table 8).



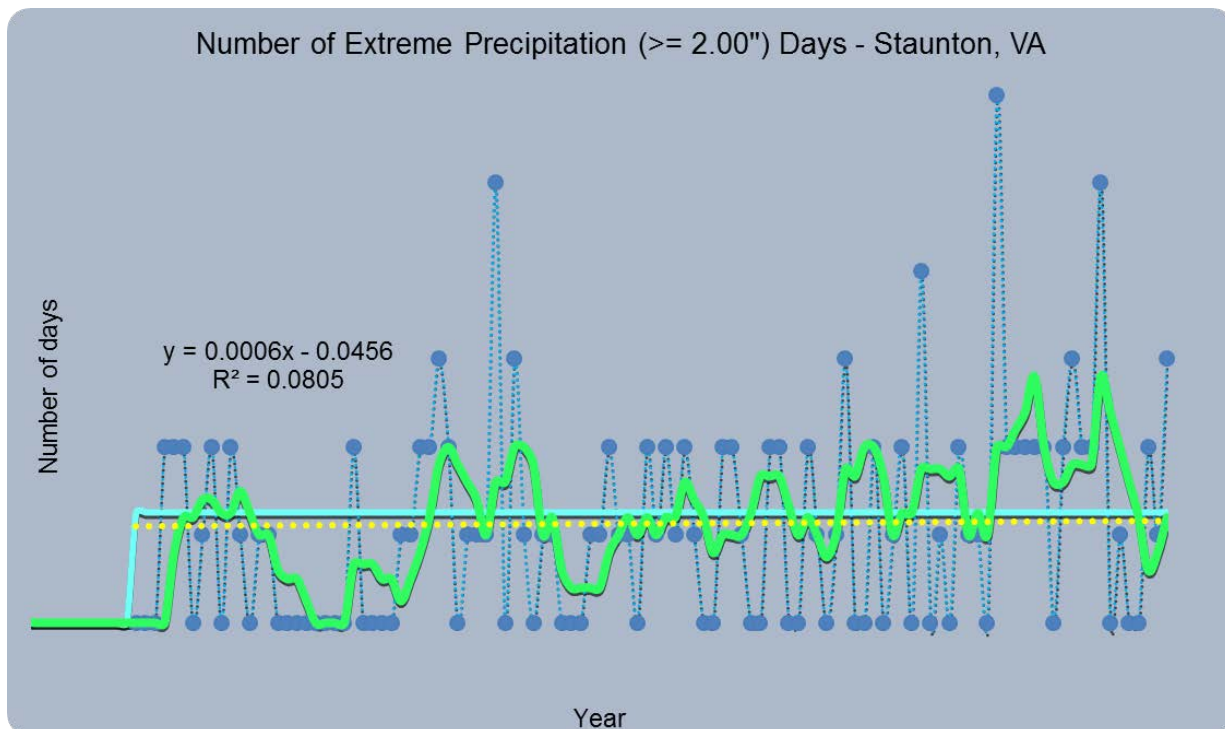


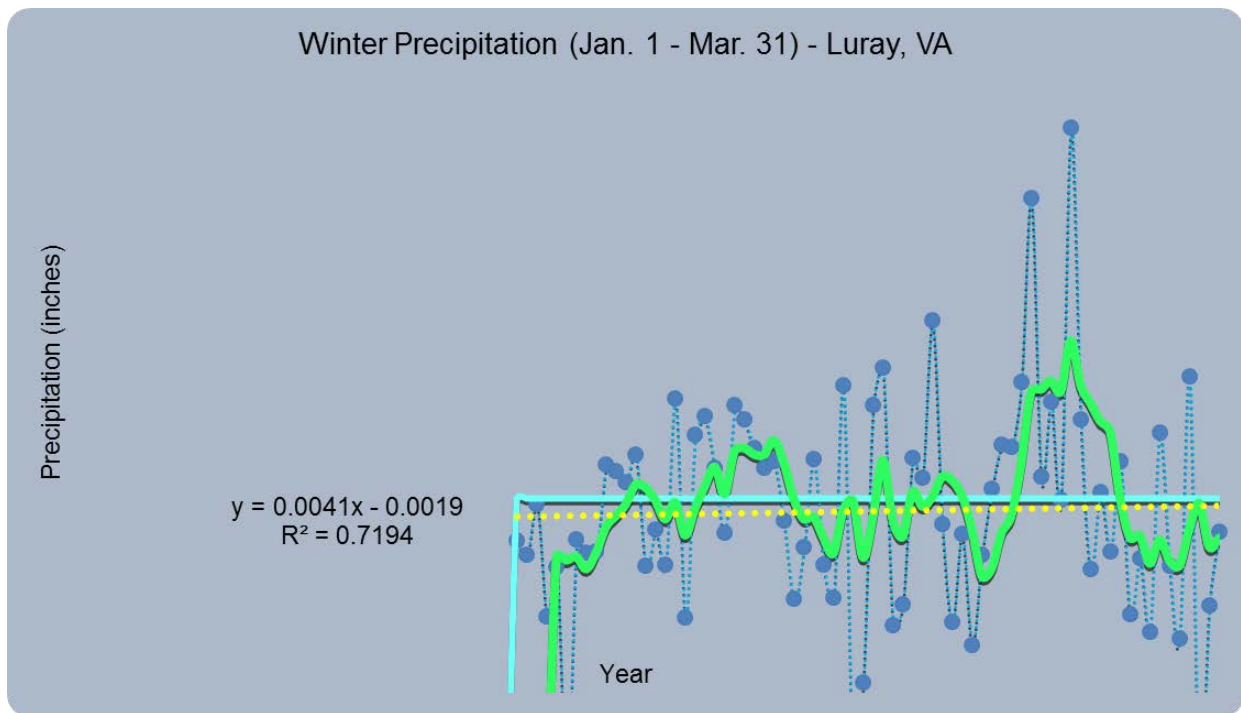
Annual Snowfall Trends: Luray has seen annual snowfall amounts decrease by about 5 inches but Staunton's annual snowfall trend shows little change. The average annual snowfall amount at Luray is 17.2 in. (min of 0 in and max of 53.0 in) and 21.8 in (min of 1.3 in and max of 60.0 in) at Staunton (Table 8).



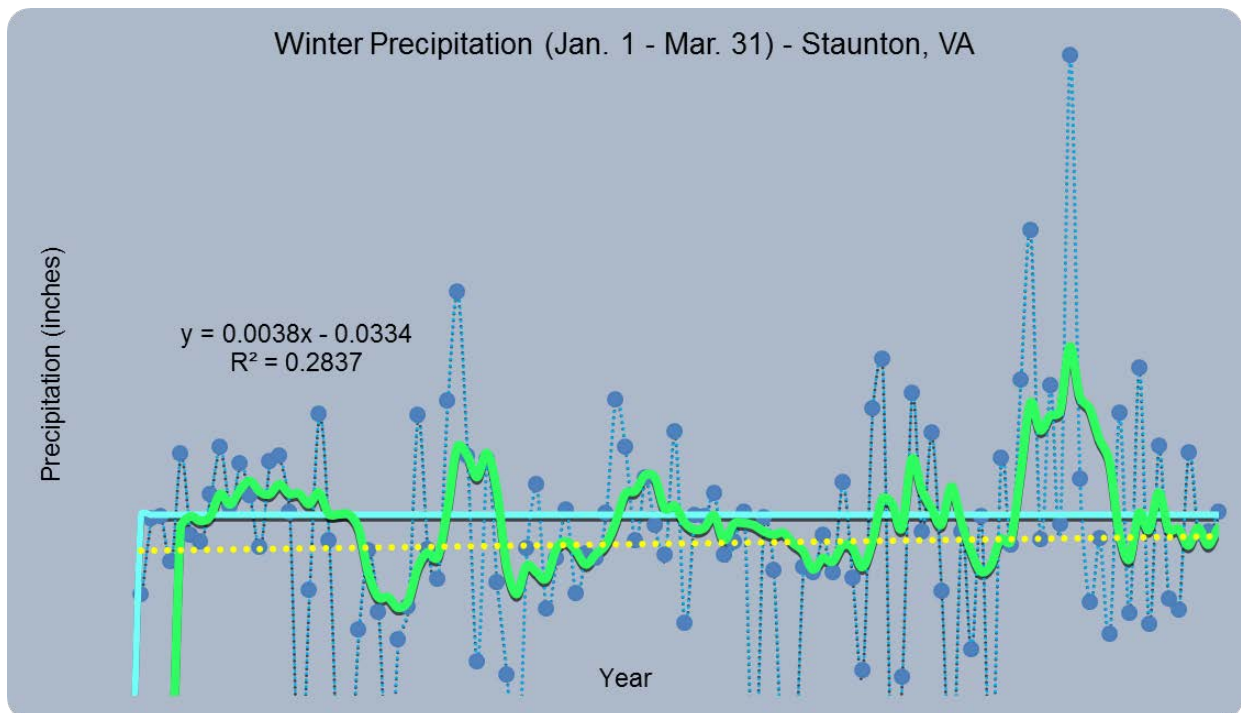


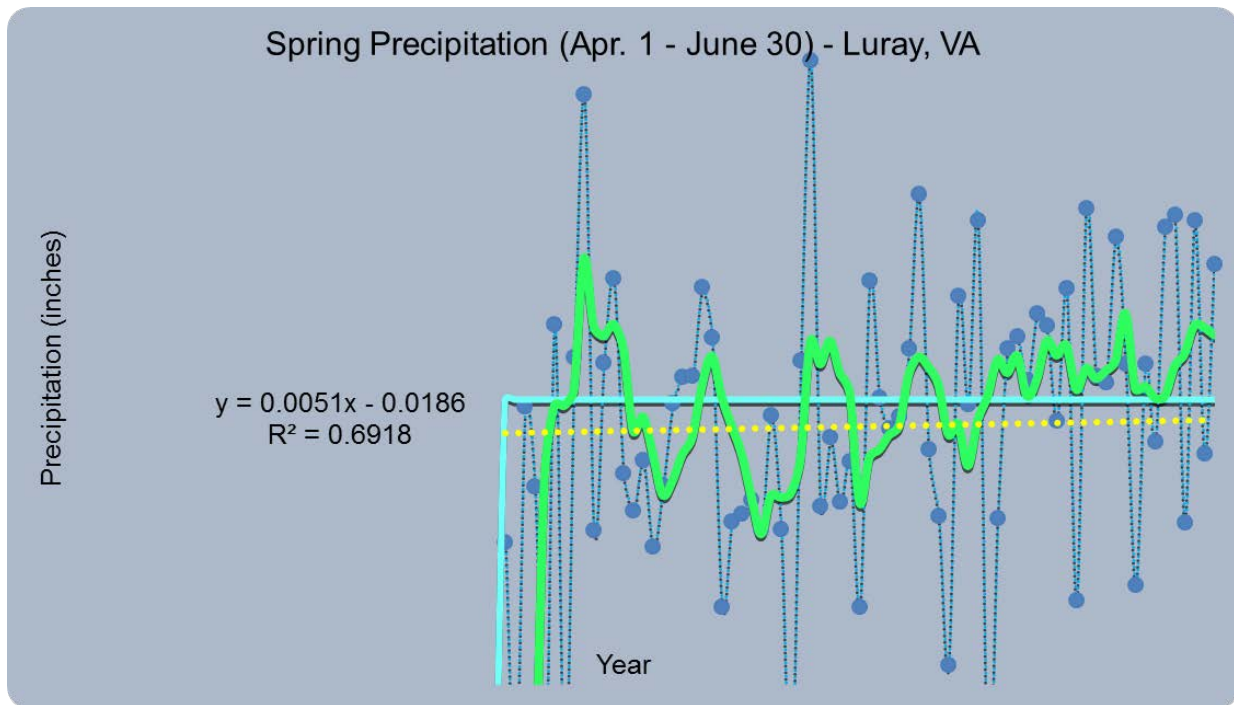
Annual Number of Extreme Precipitation Events: Extreme precipitation events have increased by 0 to 1 event annually over both station's periods of record. The average number of days at Staunton is 1 (min of 0 and max of 6) and 2 (min of 0 and max of 6) at Luray (Table 8).



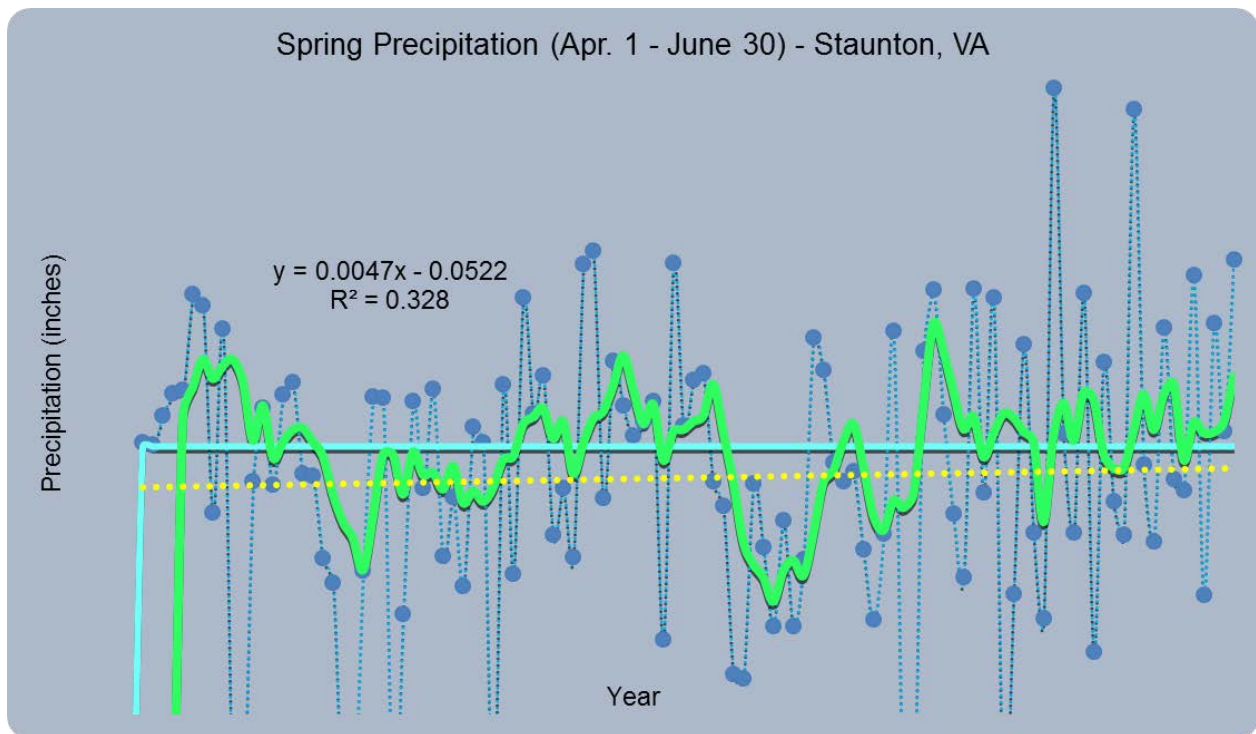


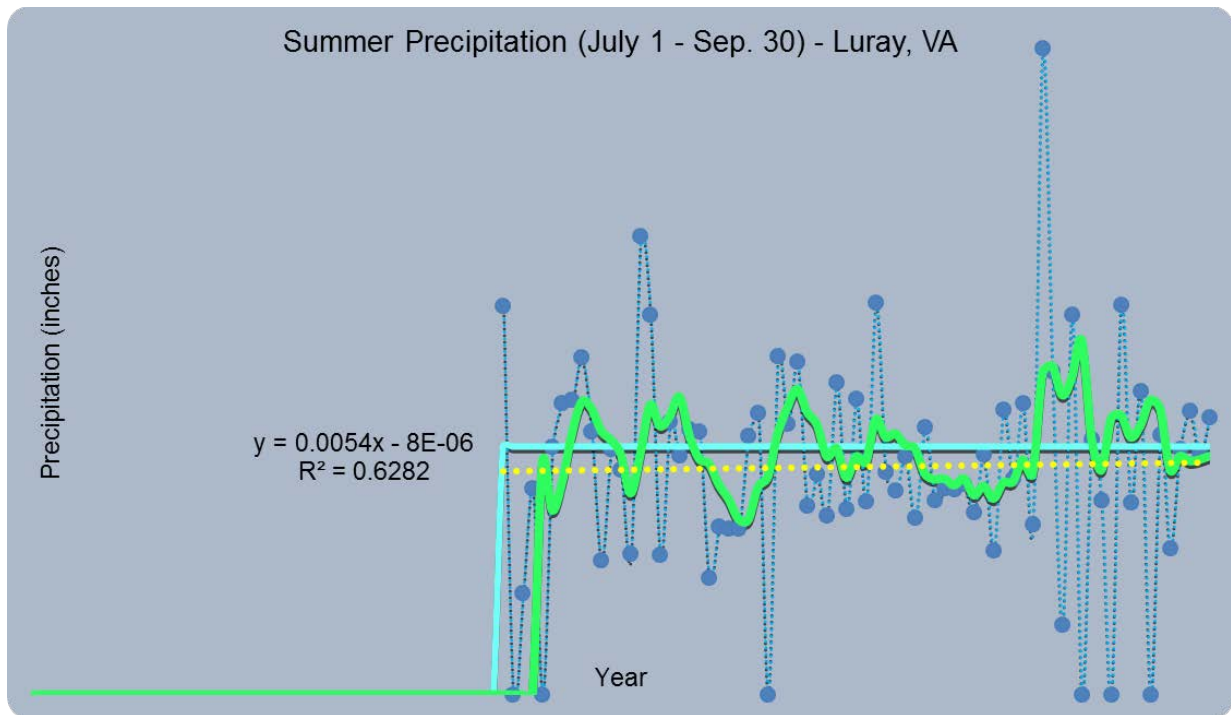
Winter Precipitation Trends: Winter precipitation has not changed dramatically at both locations over the past 70-120 years. Staunton's winter precipitation has ranged between 3.5 in to as much as 21.4 in over its period of record while Luray has ranged from 3.3 in to 19.3 in.



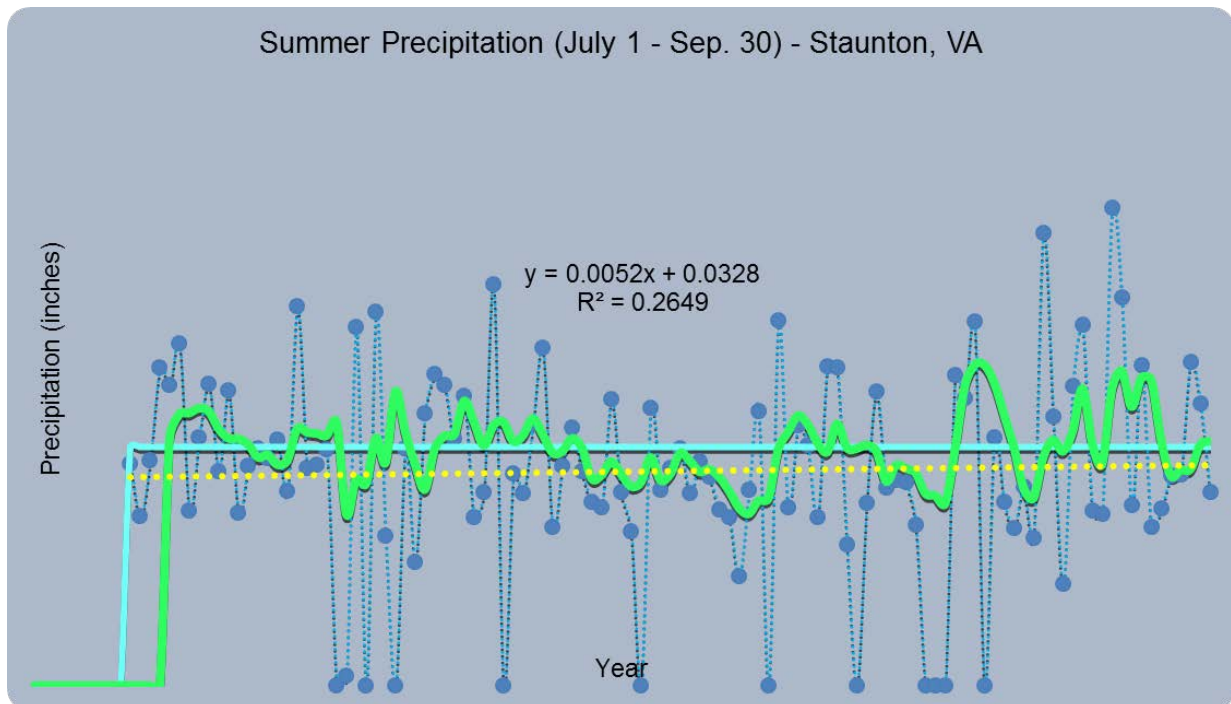


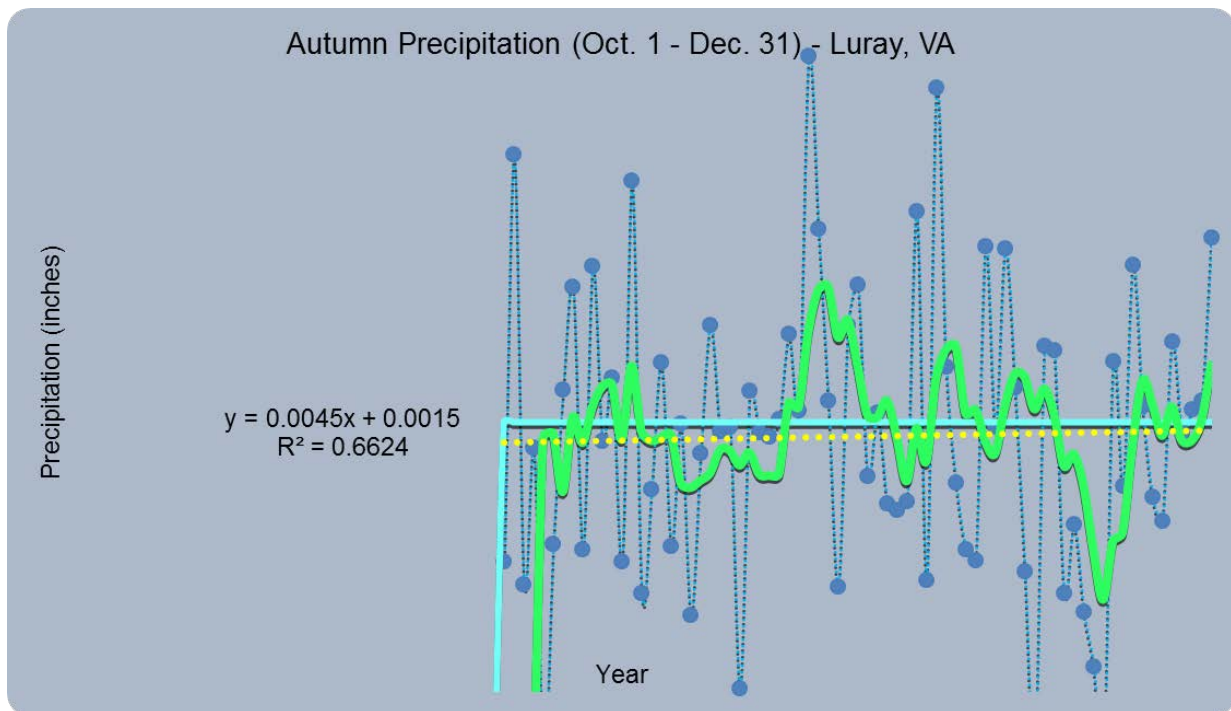
Spring Precipitation Trends: Spring precipitation shows no trend in Staunton whereas Luray has seen an increase of about 4 inches. Luray has seen as much as 20.2 in and as little as 3.5 in during the spring while Staunton has seen between 4.0 and 19.6 in over the last 100 years.



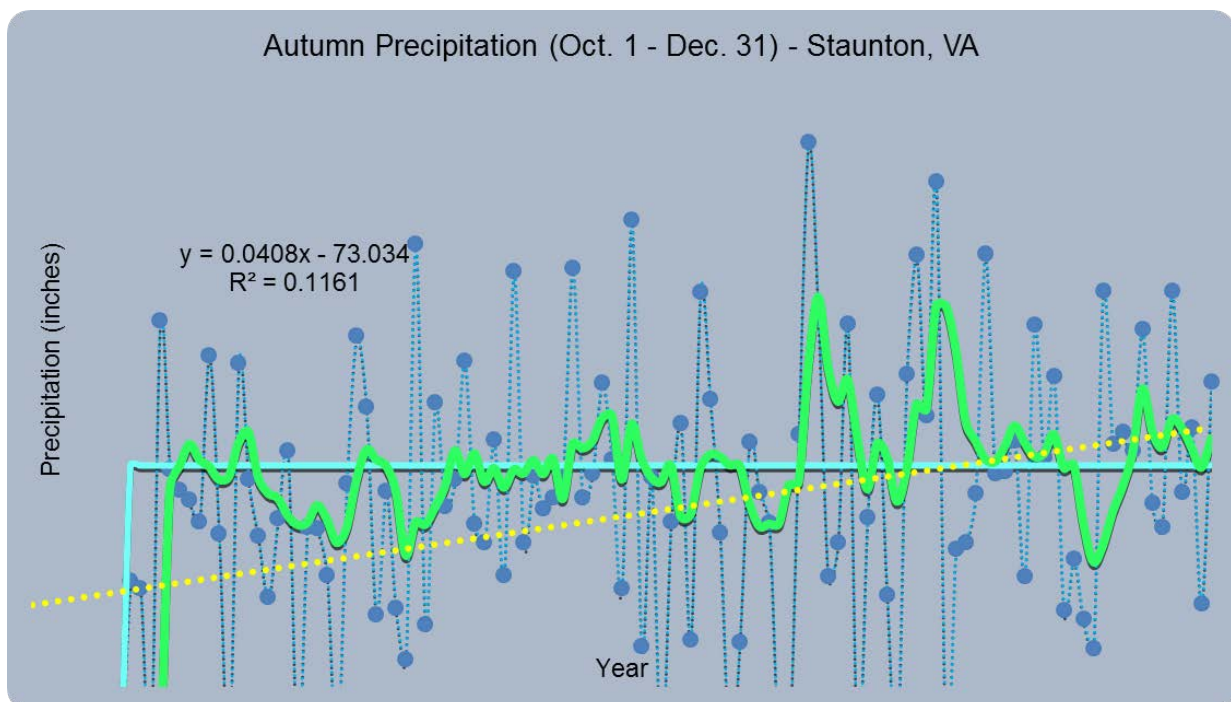


Summer Precipitation Trends: Summer precipitation has changed little over the historical record at both locations. Staunton's summer precipitation has ranged between 0.5 to 22.7 in. while Luray has seen a minimum of 3.2 in to a maximum of 30.2 in





Autumn Precipitation Trends: Staunton has seen an increase in fall precipitation of about 2 inches, whereas Luray's autumn precipitation shows no trend. The average sum of precipitation during the autumn is 9.3 in (min of 2.1 and max of 19.4 in) at Luray compared to an average of 8.1 in (min of 2.7 and max of 17.1 in) at Staunton.



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National Park Service
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