



Weather of Shenandoah National Park

Mid-Atlantic Network Summary Report for 2010

Natural Resource Data Series NPS/MIDN/NRDS—2011/182



ON THE COVER

View from Skyline Drive, Shenandoah National Park.

Photograph by: James Comiskey, National Park Service.

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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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, 2010, and to place current patterns and trends in an appropriate historical, regional, and global context (Marshall et al., in review). 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., in review). 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 2010'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 on an annual basis and periodically in separate and more thorough reports. These key indicators are further described in the protocol (Marshall et al., in review) and summarized in 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/usclimate/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 damage.

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 typically occurs in late April and first frosts appear in October.

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, 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 tropical 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 six weather observing networks were selected around Shenandoah NP. 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., in review). 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 2010 report: Luray, Madison, Staunton Sewage Plant, Waynesboro, Front Royal, Charlottesville-Albemarle, Headquarters, Sawmill Ridge, and Big Meadows (Figure 1, Table 1).

Of the nine stations, three have a Period of Record (POR) sufficiently long for a 30-year normal (1971–2000). However, Charlottesville-Albermale 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/gmaps/NPS_DEVELOPMENT/interface.php.

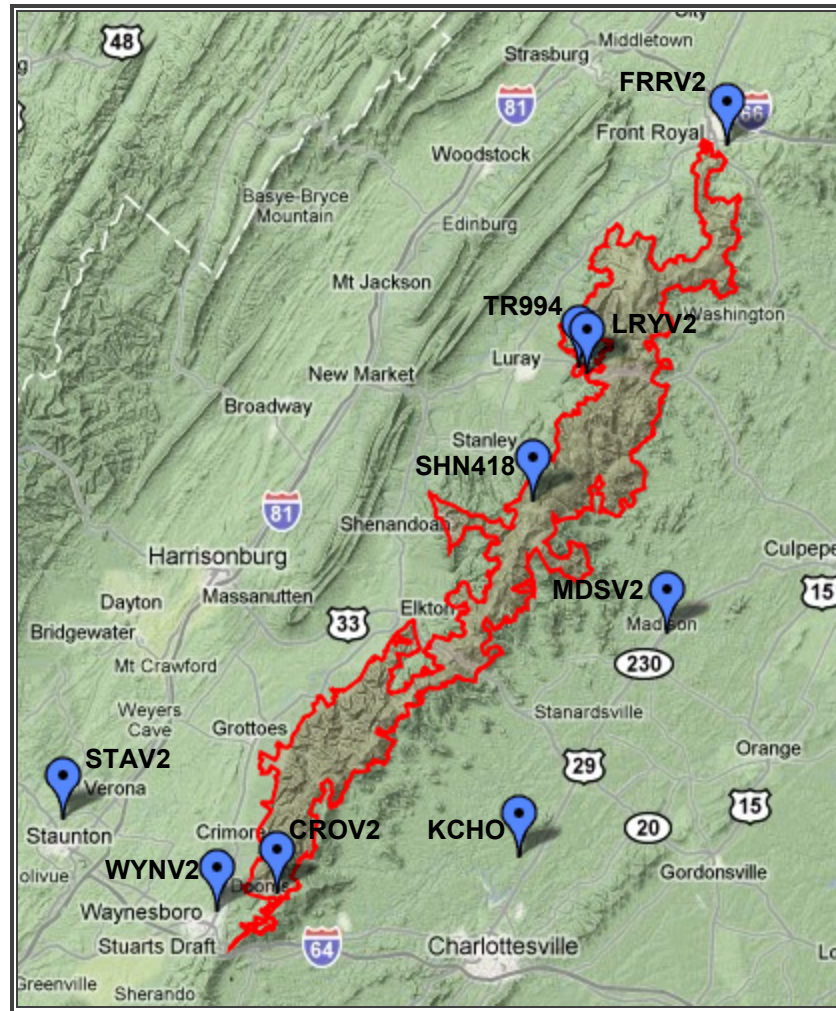


Figure 1. Location of weather observing stations around Shenandoah National Park selected as most representative of the park in 2010. See Table 1 for station names.

Table 1. List of weather observing stations around Shenandoah National Park selected as most representative of the park in 2010.

Station	Observing Network ¹	Name	Period of Record (POR)		Percentage of time reporting temperature for 2010	Percentage of time reporting precipitation for 2010	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	99.2	92.3	97.0
MDSV2	COOP	Madison	01/01/1996	Present	93.7	95.9	62.6	65.6
STAV2	COOP	Staunton WTP	01/01/1893	Present	100.0	100.0	95.8	91.4
WYNV2	COOP	Waynesboro WTP	10/01/2000	Present	81.6	83.0	93.3	92.9
FRRV2	COOP	Front Royal	12/01/1995	Present	100.0	99.5	100.0	99.1
KCHO	ASOS	Charlottesville-Albemarle Airport	01/07/1973	Present	100.0	100.0	34.3*	26.5*
SHN418	CASTNet	Big Meadows	07/01/1988	Present	95.9	95.9	99.6	99.6
TR994	RAWS	Headquarters	11/15/2006	Present	93.5	93.5	95.9	95.9
CROV2	RAWS	Sawmill Ridge	11/15/2006	Present	93.3	93.3	81.4	81.4

* The percentage of time reporting temperature and precipitation for KCHO is 99.9 from 2001 through 2010.

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.

Temperature Summary

Temperatures for the year were slightly above average (Table 2) with departures varying from -0.6°F (0.4°C) to $+0.8^{\circ}\text{F}$ (0.5°C) (Figures 2 and 3)¹. January and February were quite cold, averaging between 1.2°F to 9.4°F (0.8°C to 4.8°C) below normal across Shenandoah NP (Tables 3 and 4). Noticeably milder temperatures during March (Figures 2 and 3) led to positive departures between 0.8°F to 5.0°F (0.5°C to 2.4°C). The average of the winter months (January through March) was the 31st coolest since records began in 1895 across the Western Piedmont and Central Mountains of Virginia, which encompass the southern and western sections of the park (Tables 5 and 7); however, in the Northern Virginia division, the winter averaged nearly normal, ranking 55th of 116 years (Table 6). The number of cold days was well above normal, but the lowest readings of the winter, which occurred at the start of February, were several degrees higher than normal (Table 2).

All of the spring months averaged above-normal temperatures at each station (Table 4). Temperatures during the months of April and June varied more above normal than did May and the result in the three climate divisions was that the spring ranked as the 1st or 2nd warmest on record (Tables 5, 6 and 7). The growing season started much earlier than normal and ended a little later than in past years so that 2010 had one to five weeks more of frost-free season than usual (Table 2).

The summer of 2010 continued the string of above normal temperatures at all stations for each of the months. The number of days in which the maximum temperature exceeded 90°F (32.2°C) was twice the normal (Table 2) and the highest readings of the year were several degrees above the usual values (98°F [36.7°C] and 100°F [37.8°C], Table 2). In fact, the summer of 2010 ranked as the third warmest since 1895 in the Northern Virginia Climate Division (Table 6). During July, readings were as much as 5.8°F (3.2°C) above normal in Big Meadows, VA (Table 4). Cooler nights (Figure 3) prevailed during September which still averaged above-normal readings due to several warm spells (Table 4).

The year concluded with increasing chill with respect to normal. October was slightly warmer than normal in most sections (Figures 2 and 3). However, cooler conditions returned during November as mean temperatures averaged as much as 2.9°F (1.6°C) below normal at Luray, VA. The year ended with much below-normal temperatures in December. The largest anomalies of the year occurred during the final month as Big Meadows, VA averaged -10.8°F (6.0°C) below the long-term mean. Overall, autumn 2010 varied from the 9th to the 45th coolest for the three climate divisions encompassing Shenandoah NP (Tables 5, 6, and 7).

¹ The maps in Figures 2 and 3 were created using estimates from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM uses an interpolation scheme for temperature between actual observations and corrects these estimates for changes in topography across the region (Daly et al. 2002). More information can be found at <http://www.prism.oregonstate.edu/>.

Shenandoah National Park
Departure from Average Monthly Maximum Temperature
2010 vs. 1971–2000

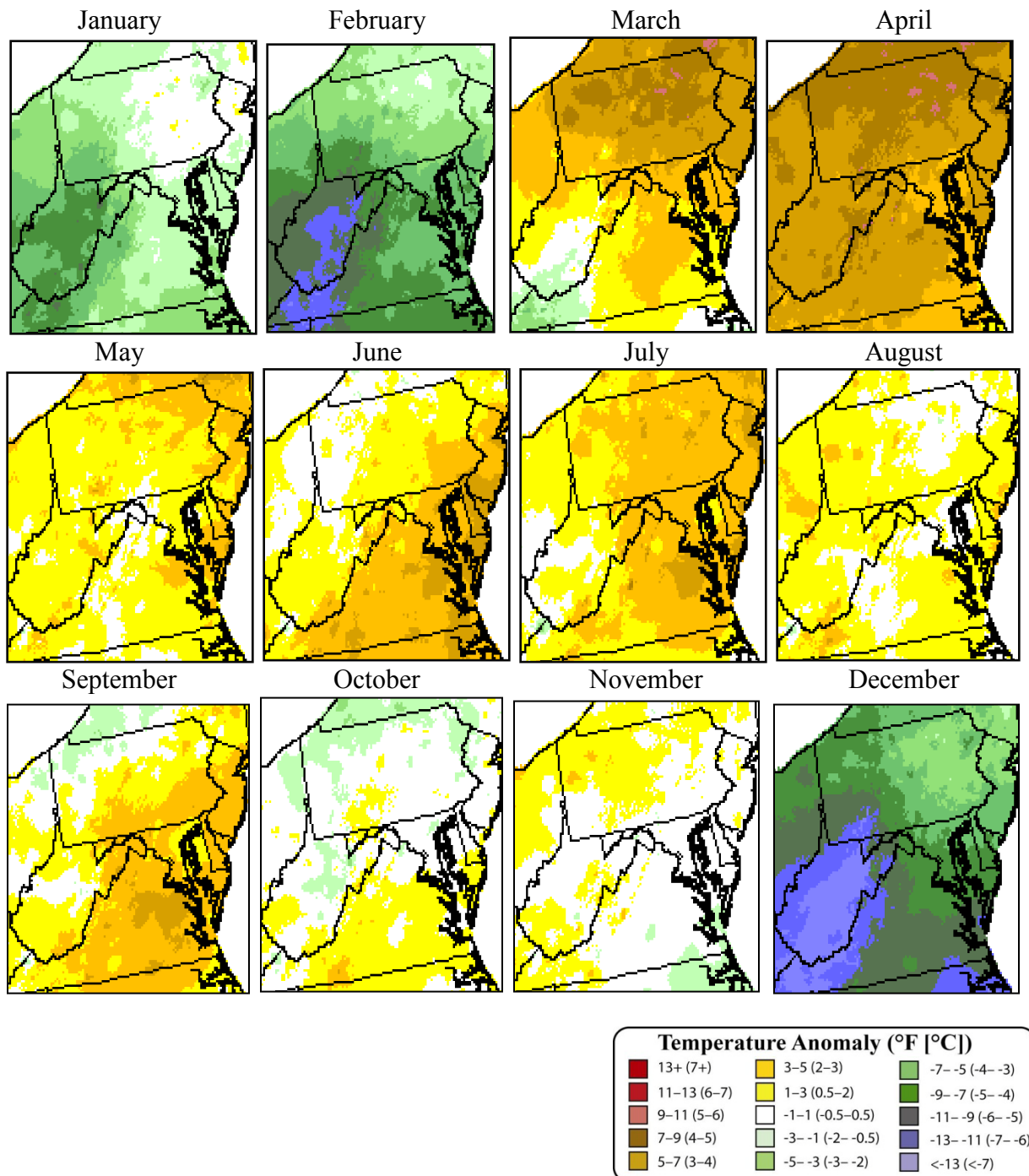


Figure 2. Maps showing departure from average monthly maximum temperature compared to the 30-year normal (1971–2000).

Shenandoah National Park
Departure from Average Monthly Minimum Temperature
2010 vs. 1971–2000

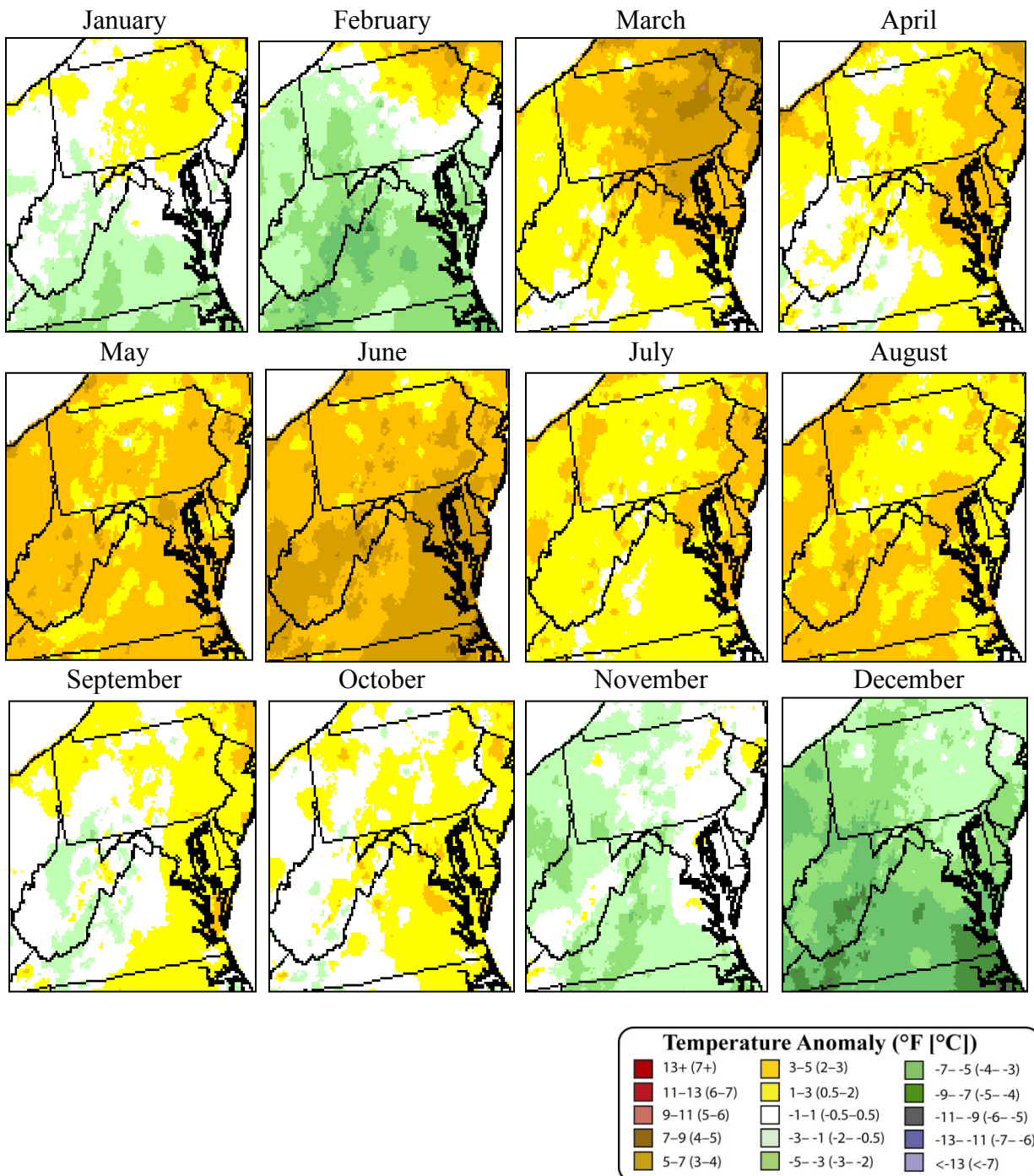


Figure 3. Maps showing departure from average monthly minimum temperature compared to the 30-year normal (1971–2000).

Table 2. Status of 2010 temperature indicators compared to the 30-year normal (1971–2000) at the Luray 5 E (LRYV2) and Staunton WTP (STAV2) weather observing stations.

Temperature Indicator	Luray 5 E 2010	Luray 5 E 1971–2000	Staunton WTP 2010	Staunton WTP 1971–2000
Average Annual Temperature	54.3°F 12.4°C	54.9°F 12.7°C	54.2°F 12.3°C	53.4°F 11.9°C
Average Annual Maximum Temperature	66.0°F 18.9°C	68.8°F 20.4°C	64.3°F 17.9°C	65.7°F 18.7°C
Maximum Temperature	100.0°F 37.8°C	95.8°F 35.4°C	98.0°F 36.7°C	93.9°F 34.4°C
Hot Days (days with Tmax≥90°F/32°C)	44	22	28	12
Average Annual Minimum Temperature	42.5°F 5.8°C	41.1°F 5.1°C	44.2°F 6.8°C	41.1°F 5.1°C
Minimum Temperature	1.0°F -17.2°C	-2.3°F -19.1°C	3.0°F -16.1°C	1.2°F -17.1°C
Cold Days (days with Tmax≤32°F/0°F)	21	13	41	11
Sub-freezing Days (days with Tmin≤32°F/0°C)	127	126	107	108
Sub-zero Days (days with Tmin≤0°F/-18°C)	0	2	0	2
Growing Season Length (days between last spring Tmin 32°F/0°C and first fall Tmin32°F/0°C)	166	158	197	162

Table 3. Summary of 2010 monthly average temperatures for selected stations.

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	30.6°F	29.5°F	45.7°F	57.0°F	65.0°F	74.0°F	76.2°F	74.1°F	68.9°F	56.0°F	44.2°F	28.5°F	54.1°F
		-0.8°C	-1.4°C	7.6°C	13.9°C	18.3°C	23.3°C	24.5°C	23.4°C	20.5°C	13.4°C	6.8°C	-1.9°C	12.3°C
Madison	MDSV2	37.4°F	35.9°F	M	M	67.2°F	77.1°F	79.3°F	77.0°F	71.5°F	60.2°F	48.2°F	M	M
		3.0°C	2.2°C	M	M	19.6°C	25.1°C	26.3°C	25.0°C	21.9°C	15.7°C	9.0°C	M	M
Staunton WTP	STAV2	29.5°F	27.4°F	45.9°F	58.2°F	64.3°F	75.0°F	76.4°F	73.7°F	68.9°F	57.3°F	45.1°F	27.4°F	52.7°F
		-1.4°C	-2.6°C	7.7°C	14.5°C	18.0°C	23.9°C	24.7°C	23.1°C	20.5°C	14.1°C	7.3°C	-2.6°C	12.6°C
Waynesboro WTP	WYNV2	29.7°F	27.4°F	44.5°F	55.5°F	M	73.9°F	75.6°F	M	67.1°F	56.1°F	42.6°F	27.9°F	M
		-1.3°C	-2.6°C	6.9°C	13.1°C	M	23.3°C	24.2°C	M	19.5°C	13.4°C	5.9°C	-2.3°C	M
Front Royal	FRRV2	31.9°F	30.5°F	46.9°F	58.6°F	65.1°F	75.8°F	78.7°F	75.6°F	70.0°F	58.5°F	45.6°F	30.0°F	55.6°F
		-0.1°C	-0.8°C	8.3°C	14.8°C	18.4°C	24.3°C	25.9°C	24.2°C	21.1°C	14.7°C	7.6°C	-1.1°C	13.1°C
Charlottesville-Albermarle Airport	KCHO	34.5°F	31.7°F	49.7°F	59.8°F	67.5°F	77.6°F	79.7°F	78.1°F	72.1°F	59.8°F	47.4°F	33.0°F	57.6°F
		1.4°C	-0.2°C	9.8°C	15.4°C	19.7°C	25.3°C	26.5°C	25.6°C	22.3°C	15.4°C	8.6°C	0.6°C	14.2°C
Big Meadows	SHN418	23.7°F	23.0°F	39.8°F	51.0°F	56.7°F	64.9°F	67.9°F	65.9°F	61.7°F	50.1°F	39.1°F	19.3°F	46.9°F
		-4.6°C	-5.0°C	4.3°C	10.6°C	13.7°C	18.3°C	19.9°C	18.8°C	16.5°C	10.1°C	3.9°C	-7.1°C	8.3°C
Headquarters	TR994	30.5°F	29.5°F	45.9°F	57.7°F	64.5°F	73.4°F	75.3°F	73.0°F	67.9°F	54.7°F	42.8°F	27.8°F	53.6°F
		-0.8°C	-1.4°C	7.7°C	14.3°C	18.1°C	23.0°C	24.1°C	22.8°C	19.9°C	12.6°C	6.0°C	-2.3°C	12.0°C
Sawmill Ridge	CROV2	30.7°F	29.1°F	46.5°F	59.8°F	64.6°F	74.4°F	76.8°F	73.1°F	69.6°F	57.2°F	45.6°F	26.8°F	54.5°F
		-0.7°C	-1.6°C	8.1°C	15.4°C	18.1°C	23.6°C	24.9°C	22.8°C	20.9°C	14.0°C	7.6°C	-2.9°C	12.5°C

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

Table 4. Summary of 2010 departure from normal temperature based on 30-year normal (1971–2000) for selected stations.

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	-3.7°F	-7.8°F	0.8°F	2.1°F	2.1°F	3.6°F	2.1°F	1.7°F	2.3°F	0.3°F	-2.9°F	-8.9°F	-0.7°F
		-2.1°C	-4.3°C	0.4°C	1.2°C	1.2°C	2.0°C	1.2°C	1.0°C	1.3°C	0.2°C	-1.6°C	-5.0°C	-0.4°C
Staunton WTP	STAV2	-1.2°F	-6.2°F	4.2°F	7.4°F	4.5°F	7.1°F	4.3°F	3.2°F	5.0°F	5.2°F	2.0°F	-7.0°F	1.0°F
		-0.7°C	-3.4°C	2.3°C	4.1°C	2.5°C	3.9°C	2.4°C	1.8°C	2.8°C	2.9°C	1.1°C	-3.9°C	0.5°C
Front Royal*	FRRV2	-2.4°F	-5.1°F	3.7°F	4.3°F	2.9°F	4.5°F	3.8°F	1.2°F	2.8°F	2.7°F	-1.0°F	-6.6°F	0.9°F
		1.3°C	2.8°C	2.1°C	2.4°C	1.6°C	2.5°C	2.1°C	0.7°C	1.6°C	1.5°C	-0.6°C	-3.7°C	0.5°C
Charlottesville-Albermarle Airport*	KCHO	-3.4°F	-9.4°F	2.4°F	1.9°F	2.1°F	4.0°F	3.7°F	2.2°F	2.9°F	1.3°F	-2.0°F	-6.9°F	-0.1°F
		-1.9°C	-5.2°C	1.4°C	1.0°C	1.2°C	2.2°C	2.1°C	1.2°C	1.6°C	0.7°C	-1.1°C	-3.9°C	-0.04°C
Big Meadows*	SHN418	-4.1°F	-5.3°F	5.0°F	5.4°F	3.4°F	7.6°F	5.8°F	5.3°F	5.7°F	2.2°F	-0.2°F	-10.8°F	1.6°F
		-2.3°C	-3.0°C	2.8°C	3.0°C	1.9°C	4.2°C	3.2°C	2.9°C	3.2°C	1.2°C	-0.1°C	-6.0°C	0.9°C

*Indicates a station's Period of Record is less than 30 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 temperature and precipitation rankings over 116 years for the Western Piedmont (NOAA 2010).

Climate Division 3 Rankings Western Piedmont	Jan–Feb–Mar WINTER	Apr–May–Jun SPRING	Jul–Aug–Sep SUMMER	Oct–Nov–Dec AUTUMN
Temperature-2010	84	2	9	107
Precipitation-2010	16	99	41	65

1 = warmest/wettest year and 116 = coldest/driest year

Table 6. Seasonal temperature and precipitation rankings over 116 years for Northern Virginia (NOAA 2010).

Climate Division 4 Rankings Northern Virginia	Jan–Feb–Mar WINTER	Apr–May–Jun SPRING	Jul–Aug–Sep SUMMER	Oct–Nov–Dec AUTUMN
Temperature-2010	55	1	3	71
Precipitation-2010	13	101	67	49

1 = warmest/wettest year and 116 = coldest/driest year

Table 7. Seasonal temperature and precipitation rankings over 116 years for the Central Mountains (NOAA 2010).

Climate Division 5 Rankings Central Mountains	Jan–Feb–Mar WINTER	Apr–May–Jun SPRING	Jul–Aug–Sep SUMMER	Oct–Nov–Dec AUTUMN
Temperature-2010	84	1	15	107
Precipitation-2010	27	105	50	73

1 = warmest/wettest year and 116 = coldest/driest year

Precipitation Summary

Precipitation totals in 2010 averaged somewhat below normal throughout Shenandoah NP (Table 8). Wet spells were notable at the end of September and the start of December while dry spells were common in the warmer half of the year (Table 9). Overall, reporting stations in the region tallied annual precipitation between 86 and 121 percent of normal values (Table 11).

The wettest period occurred during February and March. All three climate divisions in which the park resides (Western Piedmont, Northern Mountains, and Central Mountains) reported winter precipitation totals between the 27th to 13th wettest winters since 1895 (Tables 5, 6, and 7). March was the wettest of the three months, with precipitation totals between 115 and 256 percent of average (Table 11). There was one long dry spell totaling 10 days when no measurable precipitation was recorded in February despite it being a snowy month (Table 9). Two of the wettest days of 2010 occurred within two weeks in mid-winter; on January 25 and February 7 (Table 9). Snowfall was near normal in the northern half of Shenandoah NP, but was much above average in the southern sector (Table 8).

In contrast to winter, the spring months of 2010 had well below-average precipitation, particularly in the months of April and June. In the three climate divisions in which the park resides, that three-month period in 2010 was the 11th–16th driest since 1895. Rainfall during April averaged between 22-42 percent of normal and all stations reported less than average precipitation during each of the three months (Table 11).

The summer months in Shenandoah NP had varied rainfall (Figure 4), with the northern sections ranking as the 49th driest and the southern portion ranking the 41th wettest since 1895 (Tables 5, 6 and 7). A minority of stations reported more than 100 percent of normal rainfall in all of the three months (Table 11), and several sites, notably Madison, averaged only 76 percent of normal precipitation. More typical of summer months, there was a long dry spell without rain in Luray from August 26–September 11 (Table 9). There was also the indirect effect of Tropical Storm Nicole in Shenandoah NP in late September.

The remainder of the calendar year was drier than normal, with Charlottes-Albermarle station reporting 72 percent of their average rainfall for the months of October through December, collectively (Table 11). Two more wet days occurred in October and December with a total of more than 4.7 in (119 mm) (Table 9). For the first time in several years, autumn precipitation was below seasonal levels (Table 8). The number of days with heavy rain was close to average, but frequency of micro-droughts was more than average, thus the drier than usual conditions in 2010.

Table 8. Status of 2010 precipitation indicators compared to the 30-year normal (1971–2000) at the Luray 5 E (LRYV2) and Staunton WTP (STAV2) weather observing stations.

Precipitation Indicator	Luray 5 E 2010	Luray 5 E 1971–2000	Staunton WTP 2010	Staunton WTP 1971–2000
Annual Precipitation	40.0 in 1,016 mm	41.6 in 1,057 mm	33.5 in 851 mm	38.9 in 988 mm
Autumn (Oct, Nov, Dec) Precipitation	9.1 in 231 mm	9.5 in 241 mm	7.4 in 188 mm	8.5 in 216 mm
Heavy Precipitation Days (days with ≥ 1.0 in (25 mm) rain)	11	10	8	9
Extreme Precipitation Days (days with ≥ 2.0 in (51 mm) rain)	4	2	0	1
Micro-drought (strings of 7+ days without rain)	14	9	11	8
Annual Snowfall	24.8 in 63.0 cm	24.6 in 62.5 cm	35.9 in 91.2 cm	18.9 in 48 cm
Measurable Snow Days (days with ≥ 0.1 in (0.3 cm) snow)	5	9	16	7
Moderate Snow Days (days with ≥ 2.0 in (5.0 cm) snow)	3	5	7	4
Heavy Snow Days (days with ≥ 5.0 in (15.2 cm) snow)	1	2	3	1

Table 9. Top five wettest days and top five dry spells (consecutive days with a trace or less of rainfall) during 2010 from weather observing stations at Luray 5 E (LRYV2) and Staunton WTP (STAV2).

Wettest Days in 2010	Dry Spells in 2010
Feb. 7: 2.71 in (69 mm)	Jun. 21–Jul. 8
Oct. 1: 2.70 in (69 mm)	Aug. 26–Sep. 11
Sep. 30: 2.0 in (51 mm)	Oct. 2–13
Dec. 1: 2.0 in (51 mm)	Nov. 18–29
Jan. 25: 1.94 in (49 mm)	Feb. 13–22

Table 10. Summary of 2010 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	2.8 in	3.3 in	5.9 in	1.2 in	3.3 in	3.0 in	3.7 in	3.8 in	4.0 in	4.3 in	2.1 in	2.7 in	40.0 in
		72 mm	84 mm	149 mm	30 mm	83 mm	75 mm	93 mm	98 mm	101 mm	109 mm	53 mm	68 mm	1,015 mm
Madison	MDSV2	3.4 in	3.4 in	M	0.7 in	3.1 in	3.7 in	1.6 in	1.8 in	5.7 in	4.4 in	2.5 in	2.1 in	M
		86 mm	86 mm	M	18 mm	79 mm	94 mm	41 mm	46 mm	145 mm	112 mm	64 mm	53 mm	M
Staunton WTP	STAV2	3.7 in	2.6 in	3.7 in	1.0 in	3.4 in	1.8 in	3.1 in	3.3 in	3.6 in	3.2 in	2.3 in	1.9 in	33.6 in
		94 mm	66 mm	94 mm	25 mm	86 mm	46 mm	79 mm	84 mm	91 mm	81 mm	58 mm	48 mm	853 mm
Waynesboro WTP	WYNV2	5.1 in	2.8 in	5.5 in	1.1 in	M	1.7 in	5.0 in	M	7.2 in	1.5 in	4.2	0.4 in	M
		130 mm	71 mm	140 mm	28 mm	M	43 mm	127 mm	M	183 mm	38 mm	107 mm	10 mm	M
Front Royal	FRRV2	4.2 in	3.4 in	7.3 in	1.5 in	3.2 in	0.9 in	2.9 in	4.4 in	3.1 in	4.7 in	2.0 in	3.1 in	40.7 in
		107 mm	86 mm	185 mm	38 mm	81 mm	23 mm	74 mm	112 mm	79 mm	119 mm	51 mm	79 mm	1,034 mm
Charlottesville-Albemarle Airport	KCHO	3.9 in	2.7 in	4.9 in	1.3 in	3.6 in	1.5 in	2.2 in	2.4 in	5.5 in	2.1 in	3.2 in	2.3 in	35.6 in
		99 mm	69 mm	124mm	33 mm	91 mm	38 mm	56 mm	61 mm	140 mm	53 mm	81 mm	58 mm	904 mm
Big Meadows	SHN418	6.0 in	3.5 in	10.2 in	1.0 in	3.7 in	2.8 in	5.5 in	4.0 in	9.9 in	2.3 in	4.0 in	4.0 in	56.9 in
		152 mm	89 mm	259 mm	25 mm	94 mm	71 mm	140 mm	102mm	251 mm	58 mm	107 mm	102 mm	1,445 mm
Headquarters	TR994	3.6 in	1.7 in	6.7 in	1.3 in	3.0 in	4.7 in	1.8 in	3.2 in	5.4 in	2.7 in	2.7 in	2.5 in	39.4 in
		91 mm	43 mm	170mm	33 mm	76 mm	119 mm	46 mm	81 mm	137 mm	69 mm	69 mm	64 mm	1,001 mm
Sawmill Ridge	CROV2	5.5 in	2.8 in	5.9 in	1.3 in	4.8 in	1.7 in	1.7 in	6.9 in	7.8 in	2.3 in	2.1 in	3.1 in	45.7 in
		140 mm	71 mm	150 mm	33 mm	122 mm	43 mm	43 mm	175 mm	198 mm	58 mm	53 mm	79 mm	1,204 mm

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

Table 11. Summary of 2010 percent of normal precipitation based on 30-year normal (1971–2000) for selected stations.

Station name	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luray 5 E	LRYV2	91	125	175	38	84	75	98	108	92	123	60	95	96
Madison*	MDSV2	102	121	M	22	72	91	33	48	148	112	67	68	M
Staunton WTP	STAV2	127	104	115	34	89	50	81	94	95	95	78	76	86
Front Royal*	FRRV2	150	163	199	40	80	20	92	133	54	156	58	116	97
Charlottesville-Albemarle Airport*	KCHO	186	136	168	42	91	34	63	73	134	60	85	72	90
Big Meadows*	SHN418	186	175	256	25	81	60	142	108	170	63	96	126	121

*Indicates a station's Period of Record is less than 30 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.

Shenandoah National Park
Percent of Average Monthly Precipitation
2010 vs. 1971–2000

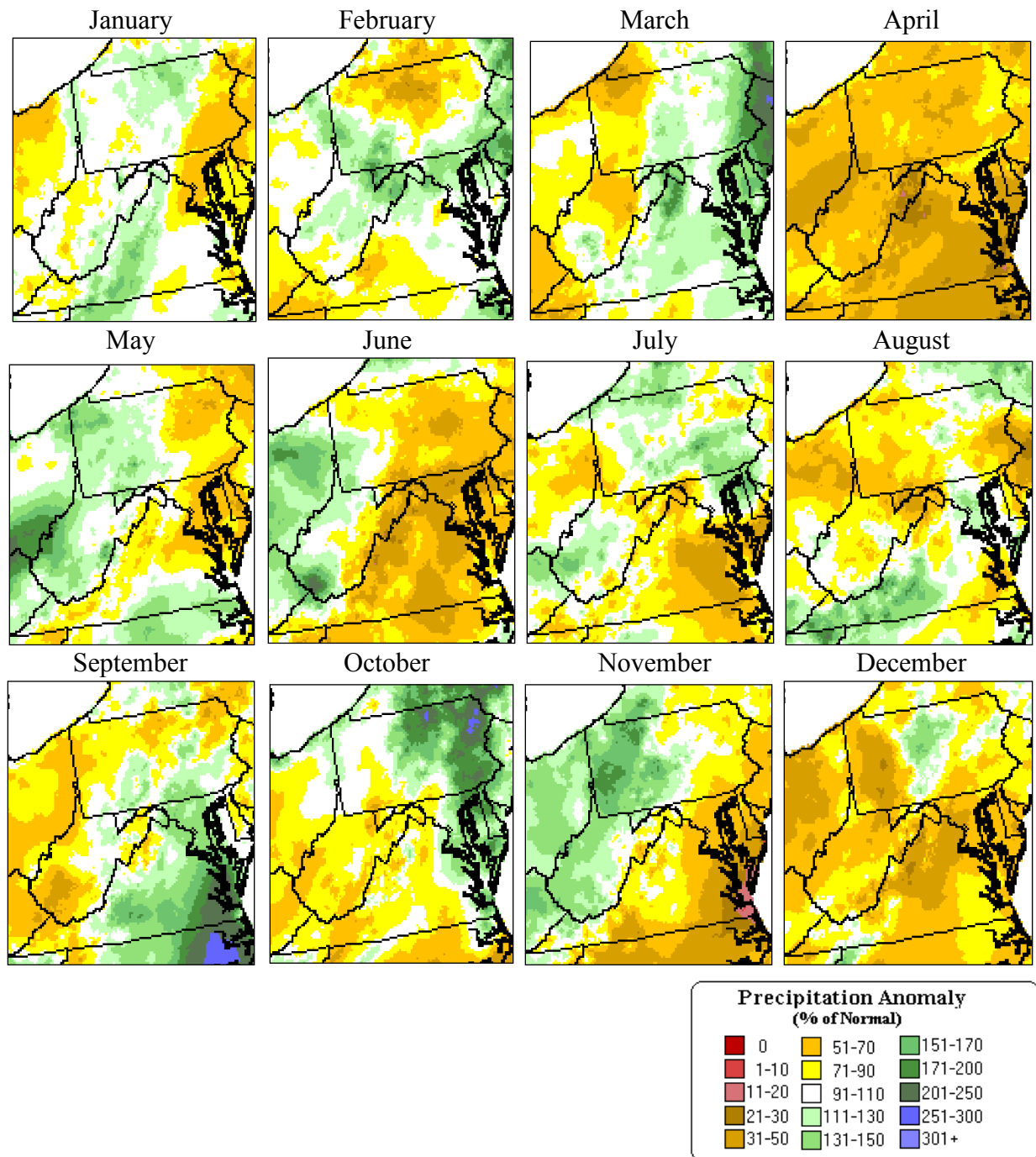


Figure 4. Maps showing percent of average monthly precipitation compared to the 30-year normal (1971–2000).

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 2010 are shown in Figure 5.

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 2010). 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 2010.

According to the PDSI, 2010 started above 0, or wetter than average. Then a change in the weather pattern led to increasing dryness that continued through the end of the year, though with some moderation due to wet conditions in October. Dry weather during the spring (Figures 5, 6, and 7) brought the index into negative values and, in fact, by August, it was approaching moderately-severe dry conditions. Wet weather returned early in the autumn and raised the PDSI during the fall. This past year was the driest during the growing season of the last three years.

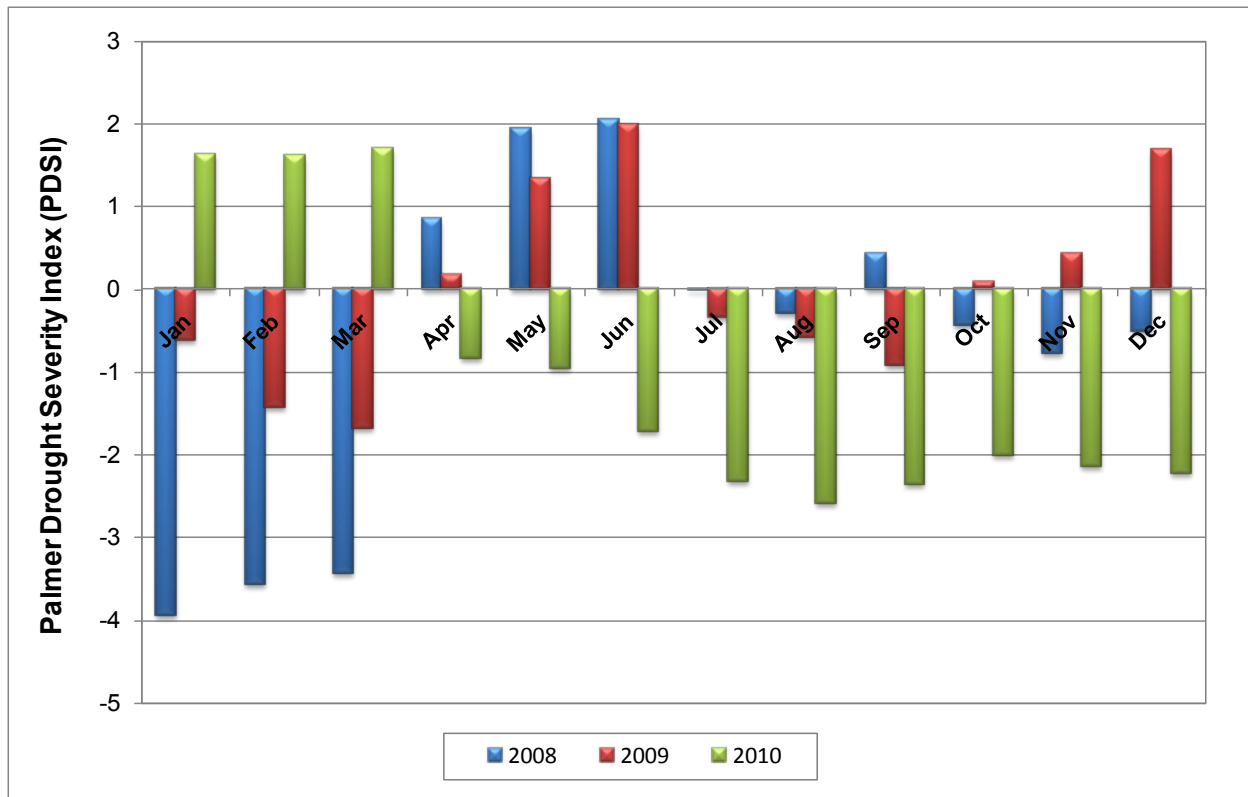


Figure 5. Palmer Drought Severity Index (PDSI) for Northern Virginia, 2008–2010.

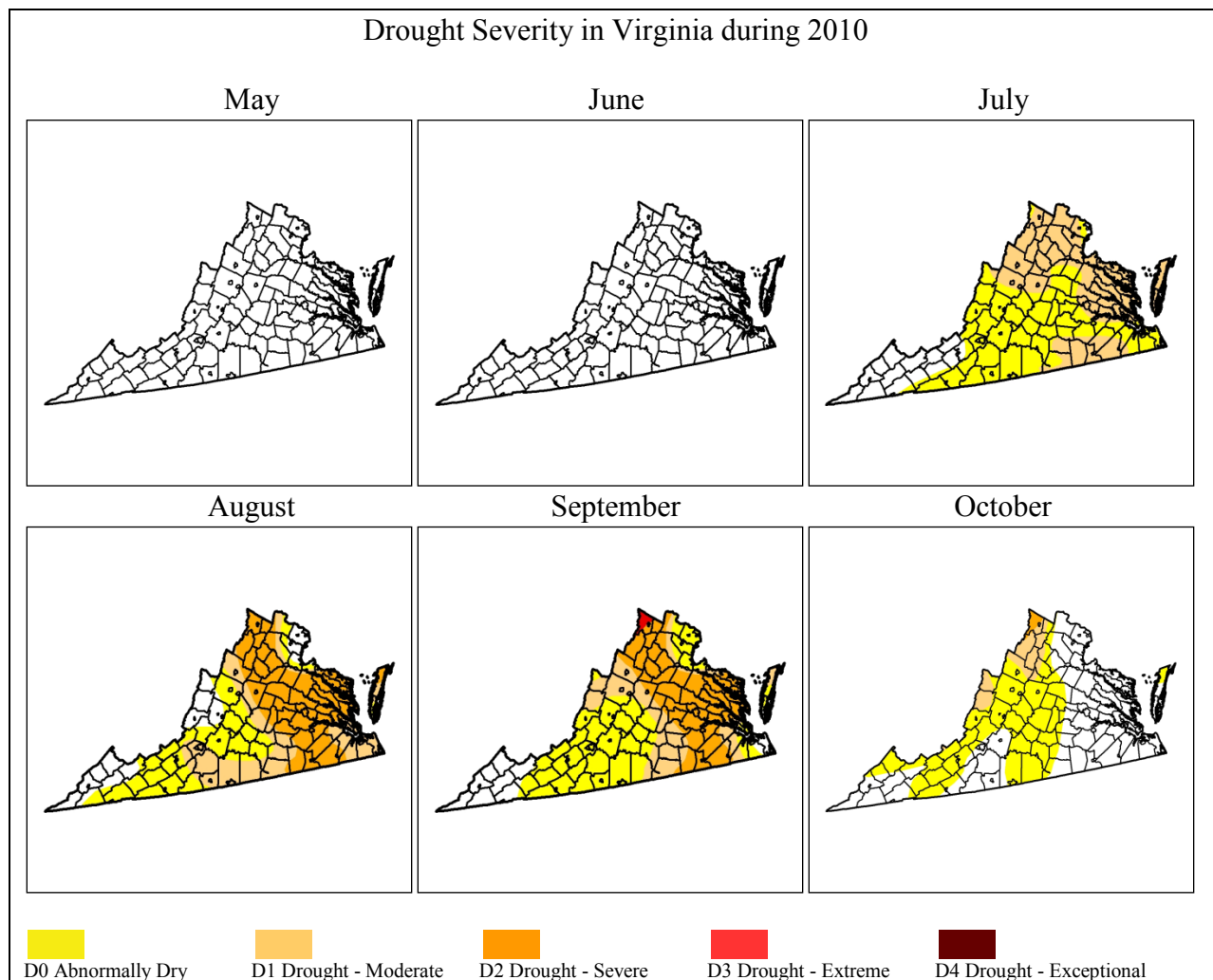


Figure 6. Mid-month values of the Palmer Drought Severity Index for Virginia in 2010.

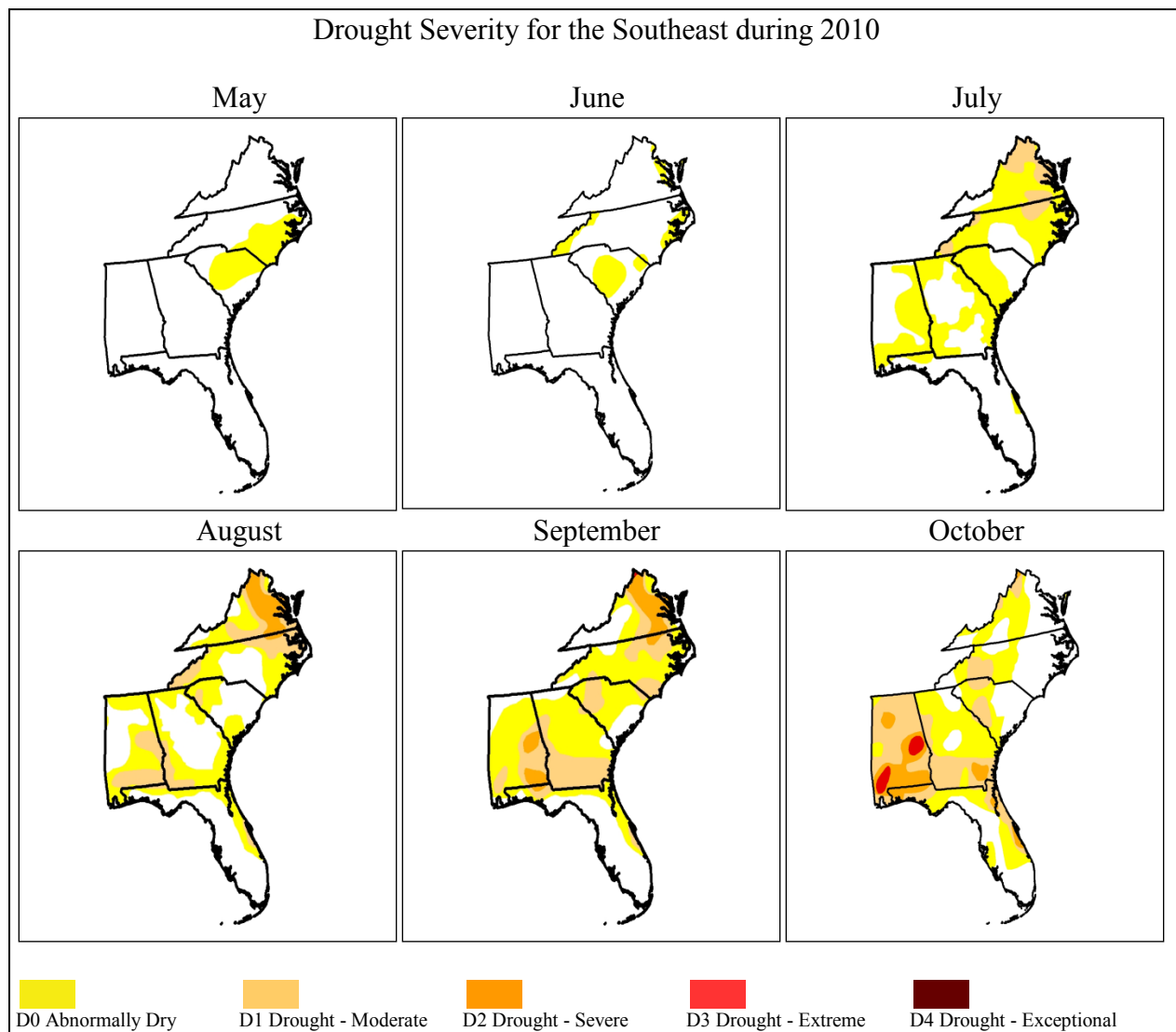


Figure 7. Mid-month values of the Palmer Drought Severity Index for the Southeast in 2010.

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