



Weather of Shenandoah National Park

Mid-Atlantic Network Summary Report for 2011

Natural Resource Data Series NPS/MIDN/NRDS—2012/342



ON THE COVER

Big Meadows, Shenandoah National Park.

Photograph by: Kristina Callahan, 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, 2011, 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 2011'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. 2012) 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 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, 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 four 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. 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 2011 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).

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 2011) 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 will be 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 be 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 (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/gmaps/NPS_DEVELOPMENT/interface.php.

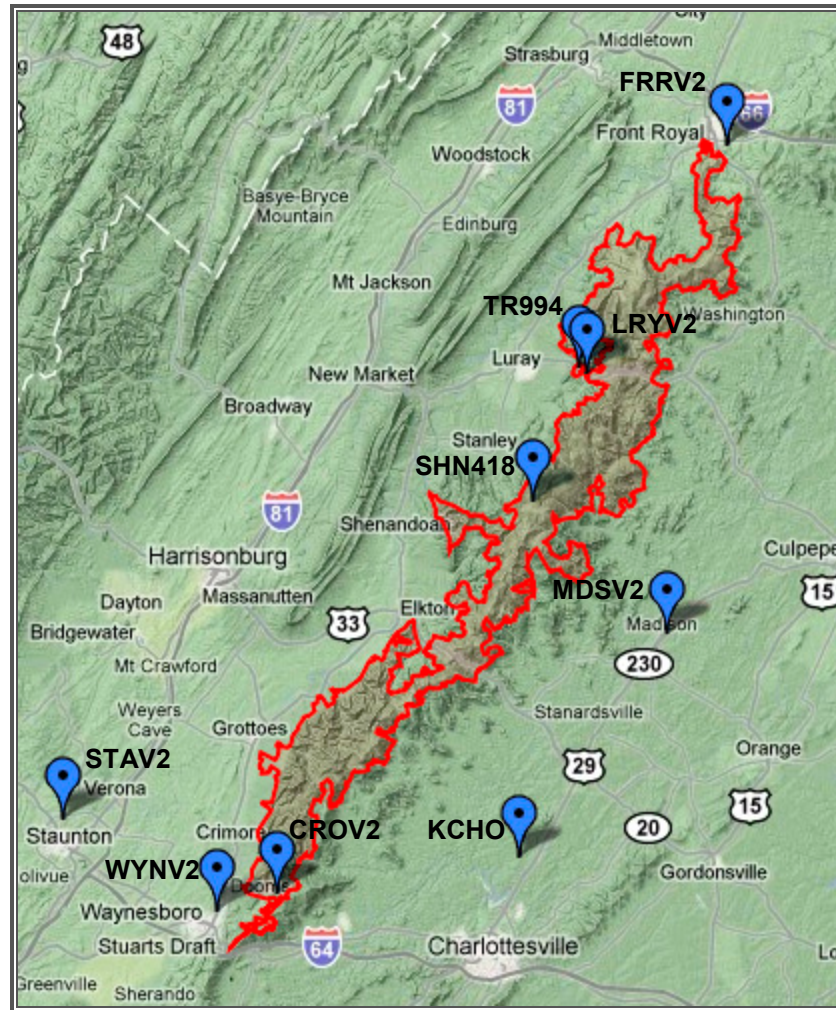


Figure 1. Location of weather observing stations around Shenandoah National Park selected as most representative of the park in 2011. See Table 1 for station names.

Table 1. List of weather observing stations around Shenandoah National Park selected as most representative of the park in 2011.

Station	Observing Network ¹	Name	Period of Record (POR)		Percentage of time reporting temperature for 2011	Percentage of time reporting precipitation for 2011	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	91.5	91.5	92.3	96.9
MDSV2	COOP	Madison	01/01/1996	Present	88.8	77.3	64.2	66.3
STAV2	COOP	Staunton WTP ³	01/01/1893	Present	100.0	100.0	95.8	91.5
WYNV2	COOP	Waynesboro WTP ³	10/01/2000	Present	99.2	91.5	93.8	92.8
FRRV2	COOP	Front Royal	12/01/1995	Present	98.4	97.0	99.9	99.0
KCHO	ASOS	Charlottesville-Albemarle Airport	01/07/1973	Present	100.0	100.0	36.0 ²	28.4 ²
SHN418	CASTNet	Big Meadows	07/01/1988	Present	76.7	71.2	98.6	98.4
TR994	RAWS	Headquarters	11/15/2006	Present	98.4	98.4	96.3	96.3
CROV2	RAWS	Sawmill Ridge	11/15/2006	Present	100.0	100.0	84.5	84.5

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

³ WTP – Water Treatment Plant

Temperature Summary

Temperatures for 2011 were well above average for the area around Shenandoah NP (Table 2) with departures varying from 1.8°F (1.0°C) to 2.8°F (1.5°C) above normal (Figures 2 and 3)¹. January was quite cold, averaging between 1.0°F to 5.9°F (0.6°C to 3.3°C) below normal across Shenandoah NP (Tables 3 and 4). Noticeably milder temperatures during February (Figures 2 and 3) led to positive departures between 1.9°F to 4.9°F (1.1°C to 2.8°C). March was more seasonable with readings ranging from -0.6°F (-0.3°C) at Luray to +1.4°F (0.8°C) at Charlottesville. The average of the winter months (January through March) was the 64th warmest since records began in 1895 across the Western Piedmont and 51st and 41st warmest in the Central Mountains of Virginia (Tables 5, 6 and 7) and the Northern Virginia division respectively. The number of cold days was near to below normal (3 compared with 10 at Luray, although this is likely too low due to missing data, and a normal 14 at Staunton), but the lowest readings of the winter, which occurred on January 23rd, was about 12°F (6.7°C) 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 4th to 14th warmest in 117 years, or only slightly cooler than 2010 (Tables 5, 6 and 7). The growing season started a bit earlier than normal (April 6th) and ended a little later (October 29th) than in past years so that 2011 had several more weeks of frost-free season than usual (Table 2).

The summer of 2011 continued the string of above-normal temperatures at all stations for each of the months until September at Luray, which averaged slightly below normal (-0.3°F, [-0.2°C]). The number of days in which the maximum temperature exceeded 90°F (32.2°C) was over twice the normal at Staunton (Table 2), and the highest readings of the year were several degrees above the usual values (99°F [37.2°C] and 98°F [36.7°C], Table 2). In fact, the summer of 2011 ranked as the eighth warmest since 1895 in the Northern Virginia Climate Division (Table 6). During July, readings were as much as 6.8°F (3.8°C) above normal in Big Meadows (Table 4). Cooler days prevailed during September, which still averaged above-normal readings due to several very warm nights (Figure 3).

The year concluded with chill in October and increasingly milder conditions in November and December. October was slightly cooler than normal in most sections (Figures 2 and 3). However, warmer conditions returned during November as mean temperatures averaged as much as 3.9°F (2.2°C) above normal at Staunton. The year ended with much above-normal temperature in December. The most widespread positive anomalies of the year occurred during the final month as Staunton averaged 5.9°F (3.3°C) above the long-term mean. Overall, autumn 2011 varied from the 13th to the 28th warmest 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
2011 vs. 1981–2010

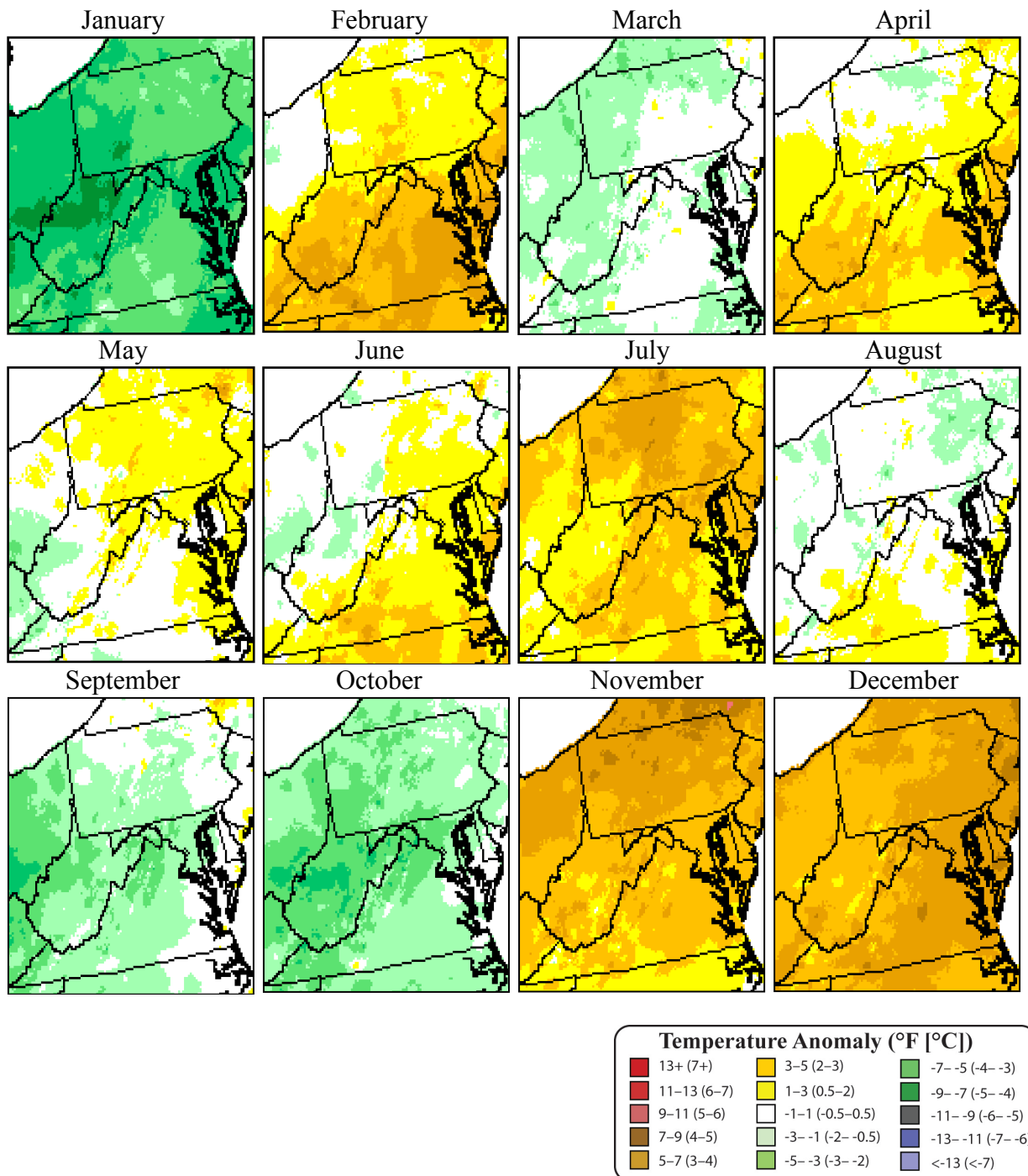


Figure 2. Maps showing departure from average monthly maximum temperature compared to the 30-year normal (1981–2010).

Shenandoah National Park
Departure from Average Monthly Minimum Temperature
2011 vs. 1981–2010

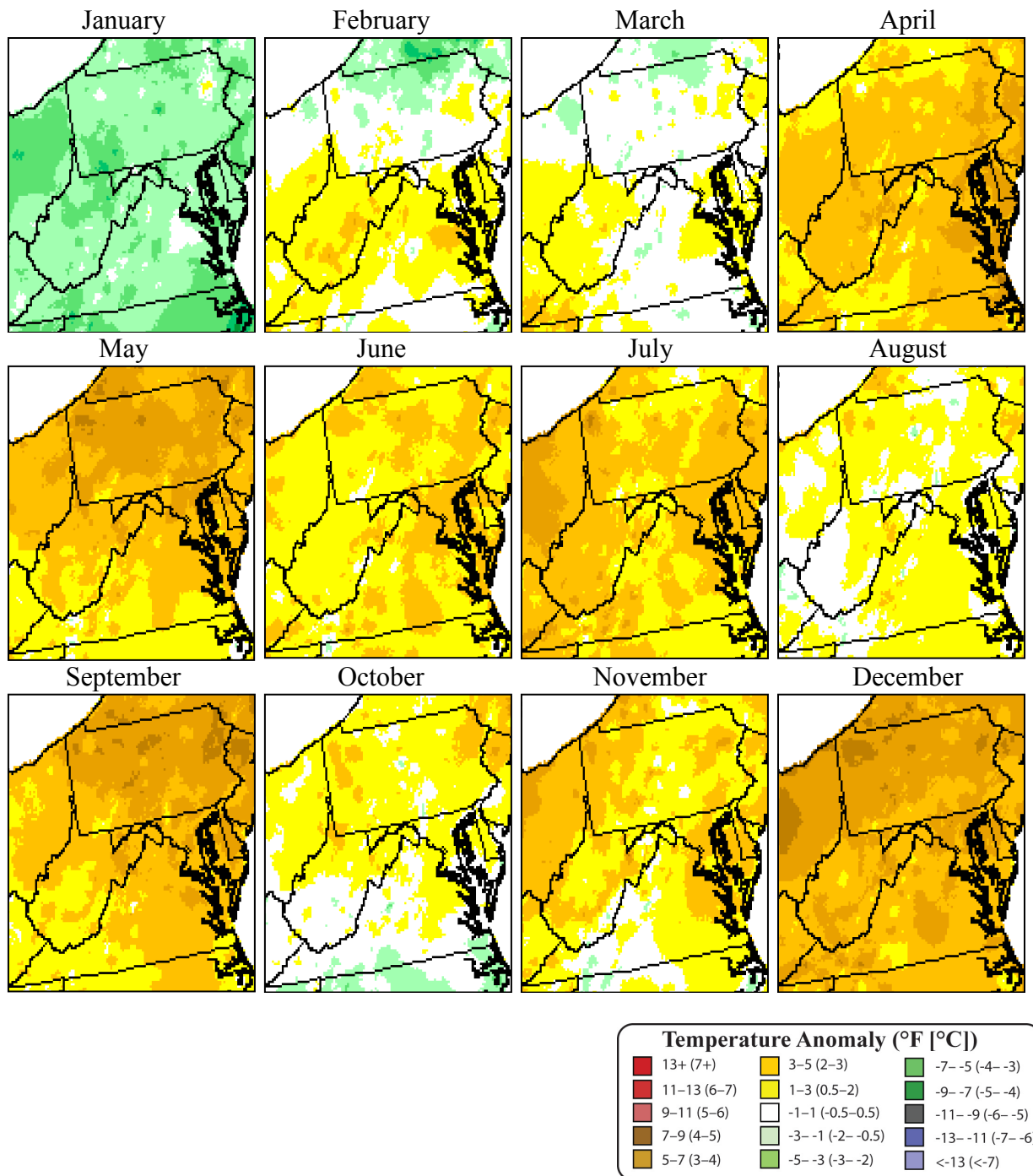


Figure 3. Maps showing departure from average monthly minimum temperature compared to the 30-year normal (1981–2010).

Table 2. Status of 2011 temperature indicators compared to the 30-year normal (1981–2010) at the Luray 5 E (LRYV2) and Staunton WTP (STAV2) weather observing stations.

Temperature Indicator	Luray 5 E 2011 ¹	Luray 5 E 1981–2010	Staunton WTP 2011	Staunton WTP 1981–2010
Average Annual Temperature	57.6°F 14.2°C	54.8°F 12.7°C	55.4°F 13.0°C	53.6°F 12.0°C
Average Annual Maximum Temperature	69.0°F 20.6°C	67.2°F 19.6°C	65.6°F 18.7°C	64.0°F 17.8°C
Maximum Temperature	99.0°F 37.2°C	97.4°F 36.3°C	98.0°F 36.7°C	94.7°F 34.8°C
Hot Days (days with Tmax≥90°F/32°C)	24	25	24	10
Average Annual Minimum Temperature	46.2°F 7.9°C	42.3°F 5.7°C	45.2°F 7.3°C	43.1°F 6.2°C
Minimum Temperature	10.0°F -12.2°C	-1.9°F -18.8°C	10.0°F -12.2°C	-1.8°F -18.8°C
Cold Days (days with Tmax≤32°F/0°F)	3	10	14	14
Sub-freezing Days (days with Tmin≤32°F/0°C)	80	111	99	105
Sub-zero Days (days with Tmin≤0°F/-18°C)	0	2	0	1
Growing Season Length (days between last spring Tmin 32°F/0°C and first fall Tmin32°F/0°C)	209	160	210	174

¹Luray 5 E (LRYV2) contained missing data for much of January – this will be reflected in temperature indicator values.

Table 3. Summary of 2011 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	M	39.4 °F	43.7 °F	56.2 °F	63.9 °F	70.9 °F	76.4 °F	73.5 °F	66.2 °F	53.5 °F	49 °F	40.4 °F	57.6 °F
		M	4.1 °C	6.5 °C	13.4 °C	17.7 °C	21.6 °C	24.7 °C	23.1 °C	19 °C	11.9 °C	9.4 °C	4.7 °C	14.2 °C
Madison	MDSV2	M	M	M	59.1 °F	66.4 °F	74.3 °F	78.8 °F	75.5 °F	68.7 °F	57 °F	51.2 °F	44.2 °F	63.9 °F
		M	M	M	15.1 °C	19.1 °C	23.5 °C	26 °C	24.2 °C	20.4 °C	13.9 °C	10.7 °C	6.8 °C	17.7 °C
Staunton WTP	STAV2	30.0 °F	38.5 °F	43.3 °F	55.6 °F	63.5 °F	72 °F	77 °F	73.3 °F	65.9 °F	53.9 °F	49.1 °F	41.7 °F	55.3 °F
		-1.1 °C	3.6 °C	6.3 °C	13.1 °C	17.5 °C	22.2 °C	25 °C	22.9 °C	18.8 °C	12.2 °C	9.5 °C	5.4 °C	12.9 °C
Waynesboro WTP	WYNV2	29.8 °F	39.3 °F	44.6 °F	55.7 °F	63.5 °F	70.6 °F	76.8 °F	73.3 °F	67.5 °F	54.4 °F	47.4 °F	40.1 °F	55.3 °F
		-1.2 °C	4.1 °C	7.0 °C	13.2 °C	17.5 °C	21.4 °C	24.9 °C	22.9 °C	19.7 °C	12.4 °C	8.6 °C	4.5 °C	12.9 °C
Front Royal	FRRV2	30.6 °F	38.1 °F	44.2 °F	57.3 °F	65.1 °F	72.4 °F	77.8 °F	74.3 °F	66.7 °F	54.3 °F	48.7 °F	41.2 °F	55.9 °F
		-0.8 °C	3.4 °C	6.8 °C	14.1 °C	18.4 °C	22.4 °C	25.4 °C	23.5 °C	19.3 °C	12.4 °C	9.3 °C	5.1 °C	13.3 °C
Charlottesville-Albermarle Airport	KCHO	34.2 °F	43.1 °F	47.3 °F	60.4 °F	67.6 °F	76.2 °F	80.5 °F	77 °F	69.9 °F	56.8 °F	50.1 °F	43.2 °F	58.9 °F
		1.2 °C	6.2 °C	8.5 °C	15.8 °C	19.8 °C	24.6 °C	26.9 °C	25 °C	21.1 °C	13.8 °C	10.1 °C	6.2 °C	14.9 °C
Big Meadows	SHN418	21.9 °F	33.1 °F	34.7 °F	49.1 °F	56.7 °F	63.5 °F	68.9 °F	64.6 °F	M	47.3 °F	M	M	48.9 °F
		-5.6 °C	0.6 °C	1.5 °C	9.5 °C	13.7 °C	17.5 °C	20.5 °C	18.1 °C	M	8.5 °C	M	M	9.4 °C
Headquarters	TR994	29.0 °F	38.4 °F	43.3 °F	56.7 °F	64.0 °F	70.4 °F	75.6 °F	71.7 °F	65.2 °F	52.3 °F	48.9 °F	43.4 °F	54.9 °F
		-1.7 °C	3.6 °C	6.3 °C	13.7 °C	17.8 °C	21.3 °C	24.2 °C	22.1 °C	18.4 °C	11.3 °C	9.4 °C	6.4 °C	12.7 °C
Sawmill Ridge	CROV2	29.5 °F	39.3 °F	42.6 °F	56.7 °F	63.6 °F	71.4 °F	76.4 °F	72.7 °F	64.8 °F	53.9 °F	49.8 °F	42.3 °F	55.2 °F
		-1.4 °C	4.0 °C	5.9 °C	13.7 °C	17.6 °C	21.9 °C	24.7 °C	22.6 °C	18.2 °C	12.2 °C	9.9 °C	5.7 °C	12.9 °C

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

Table 4. Summary of 2011 departure from normal temperature based on the 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	M	2.9 °F	-0.6 °F	1.6 °F	1.1 °F	0 °F	1.9 °F	0.4 °F	-0.3 °F	-3 °F	2.1 °F	3.5 °F	0.9 °F
		M	1.6 °C	-0.3 °C	0.8 °C	0.6 °C	0 °C	1.1 °C	0.2 °C	-0.2 °C	-1.7 °C	1.1 °C	2 °C	0.5 °C
Staunton WTP	STAV2	-2.6 °F	2.9 °F	0.1 °F	2.7 °F	2 °F	2 °F	3.4 °F	1 °F	0.7 °F	-0.3 °F	3.9 °F	5.9 °F	1.8 °F
		-1.4 °C	1.6 °C	0.1 °C	1.5 °C	1.1 °C	1.1 °C	1.9 °C	0.5 °C	0.4 °C	-0.1 °C	2.2 °C	3.3 °C	1.0 °C
Front Royal ¹	FRRV2	-2.3 °F	1.9 °F	1 °F	3 °F	2.7 °F	1.2 °F	2.8 °F	0.4 °F	0.1 °F	-1.8 °F	2.3 °F	4.9 °F	1.4 °F
		-1.3 °C	1.1 °C	0.6 °C	1.7 °C	1.5 °C	0.6 °C	1.5 °C	0.2 °C	0.1 °C	-1 °C	1.3 °C	2.7 °C	0.8 °C
Charlottesville-Albermarle Airport	KCHO	-1.0 °F	4.9 °F	1.4 °F	5.1 °F	4.4 °F	4.3 °F	5.1 °F	3 °F	3.1 °F	0.8 °F	3.2 °F	5.4 °F	3.3 °F
		-0.6 °C	2.8 °C	0.8 °C	2.9 °C	2.5 °C	2.4 °C	2.8 °C	1.7 °C	1.8 °C	0.5 °C	1.8 °C	3 °C	1.8 °C
Big Meadows ¹	SHN418	-5.9 °F	4.8 °F	-0.1 °F	3.5 °F	3.4 °F	6.2 °F	6.8 °F	4.0 °F	M	-0.5 °F	M	M	3.6 °F
		-3.3 °C	2.7 °C	-0.1 °C	1.9 °C	1.9 °C	3.4 °C	3.8 °C	2.2 °C	M	-0.3 °C	M	M	2.0 °C

¹Indicates 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 2011 over 117 years for the Western Piedmont (NOAA 2011).

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-2011	64	14	29	T-28	T-25
Precipitation-2011	90	45	50	17	36

1 = warmest/wettest year and 117 = coldest/driest year. T = Tie between two years.

Table 6. Seasonal and annual temperature and precipitation rankings for 2011 over 117 years for Northern Virginia (NOAA 2011).

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-2011	41	5	8	13	7
Precipitation-2011	75	19	40	35	19

1 = warmest/wettest year and 117 = coldest/driest year.

Table 7. Seasonal and annual temperature and precipitation rankings for 2011 over 117 years for the Central Mountains (NOAA 2011).

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-2011	51	4	18	23	8
Precipitation-2011	75	6	43	19	11

1 = warmest/wettest year and 117 = coldest/driest year.

Precipitation Summary

Precipitation totals in 2011 averaged somewhat above normal throughout Shenandoah NP (Table 8). Wet spells were notable from March into August while dry spells were evenly distributed throughout the year (Table 9). Overall, reporting stations in the region tallied annual precipitation between 103 and 118 percent of normal values (Table 10 and 11).

The driest period occurred during January and February. All three-climate divisions in which the park resides (Western Piedmont, Northern Mountains, and Central Mountains) reported winter precipitation totals between the 28th to 43rd driest winters since 1895 (Tables 5, 6, and 7). March was the wettest of the three months, with precipitation totals between 128 and 170 percent of average (Table 11). There was one long dry spell totaling 11 days when no measurable precipitation was recorded in February (Table 9). One of the wettest days of 2011 occurred on March 7 (Table 9). Snowfall was below normal throughout Shenandoah NP, but was closer to average in the southern sector (Table 8).

In contrast to winter, the spring months of 2011 had well above-average precipitation, particularly in the month of April. In the three climate divisions in which the park resides, that three-month period in 2011 was the 6th to the 19th wettest since 1895 in the Northern and Central Mountains climate division. Rainfall during April averaged between 140-247 percent of normal and all stations reported above average precipitation during April and much of May (Table 11).

The summer months in Shenandoah NP had varied rainfall (Figure 4), with the northern sections ranking as the 40th wettest and the southern portion ranking the 50th wettest since 1895 (Tables 5, 6 and 7). A minority of stations reported less than 100 percent of normal rainfall in all of the three months (Table 11), and several sites, notably Staunton, averaged 136 percent of normal precipitation. More typical of summer months, there was a long dry spell without rain in Luray from July 15-24 (Table 9). There was also the direct effect of Hurricane Irene in eastern portions of Shenandoah NP in late August.

The remainder of the calendar year continued wetter than normal, with Charlottesville-Albermarle station reporting 130 percent of their average rainfall for the months of October through December, collectively (Table 11). Oddly, two dry spells occurred in October and December with the October dry spell stretching 15 days into November (Table 9). The number of days with heavy rain was above the average, but the frequency of micro-droughts was below the average, thus the wetter than usual conditions in 2011.

Table 8. Status of 2011 precipitation indicators compared to the 30-year normal (1981–2010) at the Luray 5 E (LRYV2) and Staunton WTP (STAV2) weather observing stations.

Precipitation Indicator	Luray 5 E 2011 ¹	Luray 5 E 1981–2010	Staunton WTP 2011	Staunton WTP 1981–2010
Annual Precipitation	46.5 in 1,181 mm	42.3 in 1,074 mm	45.5 in 1,156 mm	39.1 in 993 mm
Autumn (Oct, Nov, Dec) Precipitation	9.7 in 246 mm	9.7 in 246 mm	9.1 in 231 mm	8.8 in 224 mm
Heavy Precipitation Days (days with ≥ 1.0 in (25 mm) rain)	10	11	12	9
Extreme Precipitation Days (days with ≥ 2.0 in (51 mm) rain)	2	2	2	2
Micro-drought (strings of 7+ days without rain)	5	10	8	9
Annual Snowfall	4.5 in 11.4 cm	17.9 in 45.5 cm	10.6 in 26.9 cm	22.7 in 57.7 cm
Measurable Snow Days (days with ≥ 0.1 in (0.3 cm) snow)	3	6	6	9
Moderate Snow Days (days with ≥ 3.0 in (7.6 cm) snow)	1	3	1	3
Heavy Snow Days (days with ≥ 5.0 in (15.2 cm) snow)	0	1	1	1

¹Luray 5 E (LRYV2) contained missing data for January – this will be reflected in the precipitation indicators.

Table 9. Top five wettest days and top five dry spells (consecutive days with a trace or less of liquid precipitation) during 2011 from weather observing stations at Luray 5 E (LRYV2) and Staunton WTP (STAV2).

Wettest Days in 2011	Dry Spells in 2011
May 18: 3.28 in (83 mm)	Oct. 31—Nov.15
Jul. 25: 2.41 in (61 mm)	Dec. 9—21
Mar. 7: 2.18 in (55 mm)	May 29—Jun 10
June 20: 1.64 in (42 mm)	Feb. 11—21
Aug. 14: 1.96 in (50 mm)	Jul. 15—24

Table 10. Summary of 2011 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	M	2.1 in	5.6 in	6.6 in	5.9 in	3.3 in	2.9 in	5.1 in	5.2 in	3.8 in	2.1 in	3.8 in	46.4 in ¹
		M	54 mm	143 mm	168 mm	149 mm	84 mm	75 mm	129 mm	133 mm	98 mm	53 mm	97 mm	1182 mm ¹
Madison	MDSV2	M	M	M	4.6 in	3.2 in	M	1.4 in	4.3 in	M	M	0.2 in	2.5 in	16.2 in ¹
		M	M	M	117 mm	82 mm	M	35 mm	109 mm	M	M	5 mm	63 mm	410 mm ¹
Staunton WTP	STAV2	1.0 in	1.6 in	5.0 in	5.7 in	4.8 in	2.9 in	4.2 in	4.9 in	6.2 in	2.8 in	2.4 in	3.9 in	45.4 in
		26 mm	41 mm	126 mm	146 mm	121 mm	72 mm	107 mm	125 mm	158 mm	72 mm	62 mm	99 mm	1155 mm
Waynesboro WTP	WYNV2	0.8 in	1.5 in	3.3 in	7.8 in	5.7 in	2.9 in	2.5 in	4.0 in	8.4 in	3.5 in	3.6 in	4.6 in	48.6 in
		20 mm	38 mm	85 mm	198 mm	145 mm	74 mm	64 mm	102 mm	213 mm	90 mm	91 mm	117 mm	1235 mm
Front Royal	FRRV2	1.3 in	1.7 in	4.8 in	8.1 in	5.8 in	3.9 in	1.3 in	1.7 in	4.8 in	4.3 in	2.4 in	3.0 in	43.1 in
		32 mm	42 mm	122 mm	205 mm	148 mm	100 mm	33 mm	43 mm	122 mm	108 mm	62 mm	76 mm	1093 mm
Charlottesville-Albemarle Airport	KCHO	0.9 in	1.7 in	6.2 in	5.2 in	6.0 in	1.3 in	2.9 in	3.6 in	7.6 in	5.3 in	3.1 in	4.4 in	48.2 in
		23 mm	43 mm	158 mm	133 mm	153 mm	33 mm	73 mm	92 mm	193 mm	135 mm	80 mm	111 mm	1227 mm
Big Meadows	SHN418	M	1.1 in	5.1 in	9.4 in	M	5.8 in	2.3 in	5.6 in	M	8.2 in	M	M	37.5 in ¹
		M	28 mm	129 mm	238 mm	M	148 mm	58 mm	143 mm	M	209 mm	M	M	953 mm ¹
Headquarters	TR994	1.2 in	1.9 in	5.8 in	7.4 in	6.2 in	3.5 in	3.1 in	5.3 in	5.1 in	4.5 in	2.2 in	2.9 in	49.1 in
		31 mm	49 mm	148 mm	187 mm	156 mm	89 mm	79 mm	135 mm	130 mm	114 mm	57 mm	73 mm	1248 mm
Sawmill Ridge	CROV2	1.0 in	1.6 in	5.9 in	10.2 in	6.6 in	3.7 in	2.2 in	3.2 in	6.3 in	4.3 in	3.1 in	4.6 in	52.6 in
		26 mm	41 mm	149 mm	261 mm	166 mm	93 mm	55 mm	81 mm	159 mm	110 mm	80 mm	116 mm	1337 mm

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

¹ Indicates annual values with numerous months missing, thus total values will be lower than what actually occurred.

Table 11. Summary of 2011 percent of normal precipitation based on the 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	M	80	145	192	147	84	72	153	116	127	57	125	118
Madison ¹	MDSV2	M	M	M	140	72	M	33	118	M	M	5	70	36 ²
Staunton WTP	STAV2	39	64	152	182	127	79	108	136	164	95	79	142	114
Front Royal ¹	FRRV2	52	63	128	247	139	97	39	56	107	135	65	106	103
Charlottesville-Albemarle Airport	KCHO	32	62	170	156	152	35	66	100	169	171	82	138	111
Big Meadows ¹	SHN418	M	55	128	235	M	124	59	151	M	225	M	M	80 ²

¹ 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.

² Indicates annual values with numerous months missing, thus, total values will be lower than what actual percent of normal would be.

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

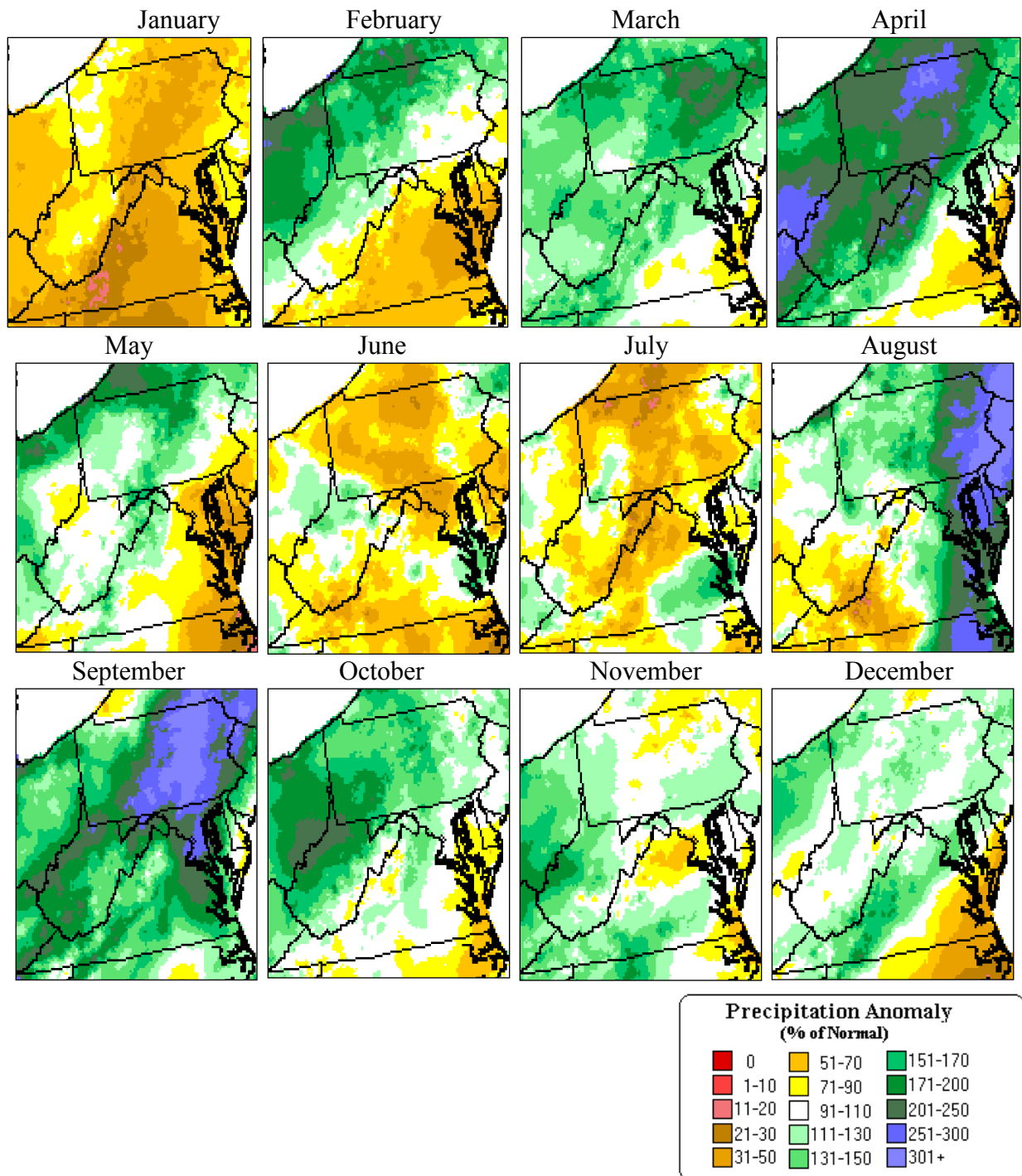


Figure 4. Maps showing percent of average monthly precipitation compared to the 30-year normal (1981–2010).

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 2011 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 2011). 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 2011.

According to the PDSI, 2011 started below -2, or moderate drought. Then a change in the weather pattern led to increasing wetness that continued until the early summer, which turned dry. Dry weather ended in the late summer (Figures 5, 6, and 7) with tropical moisture bringing the index into positive values by September and this continued for the most part until the end of the year. The alternating negative and positive value of the PDSI by season was the signature of the 2011 rainfall pattern in Shenandoah. Drought patterns in 2011 were remarkably similar to 2009 during the warmer half of the year.

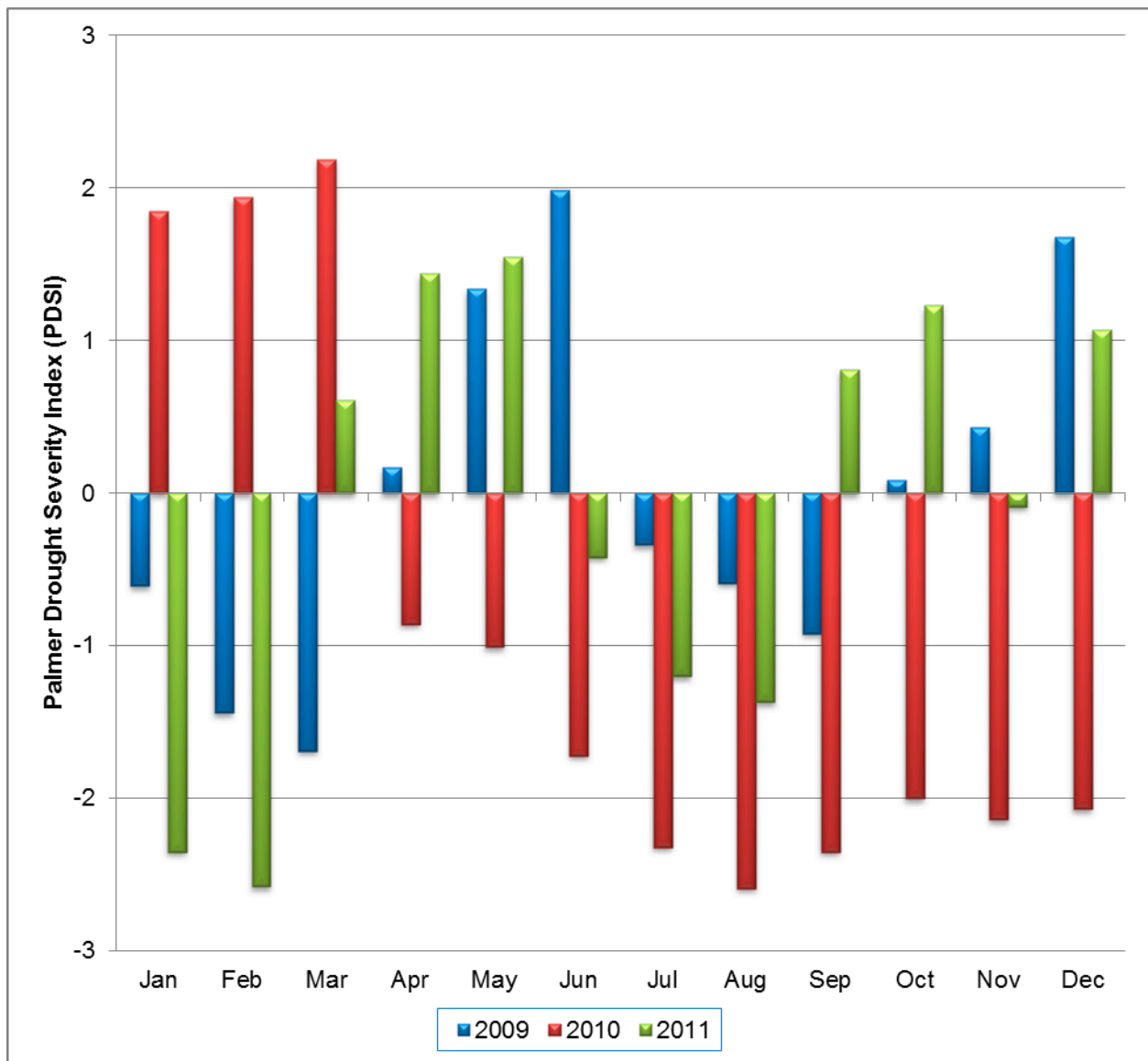


Figure 5. Palmer Drought Severity Index (PDSI) for Northern Virginia, 2009–2011.

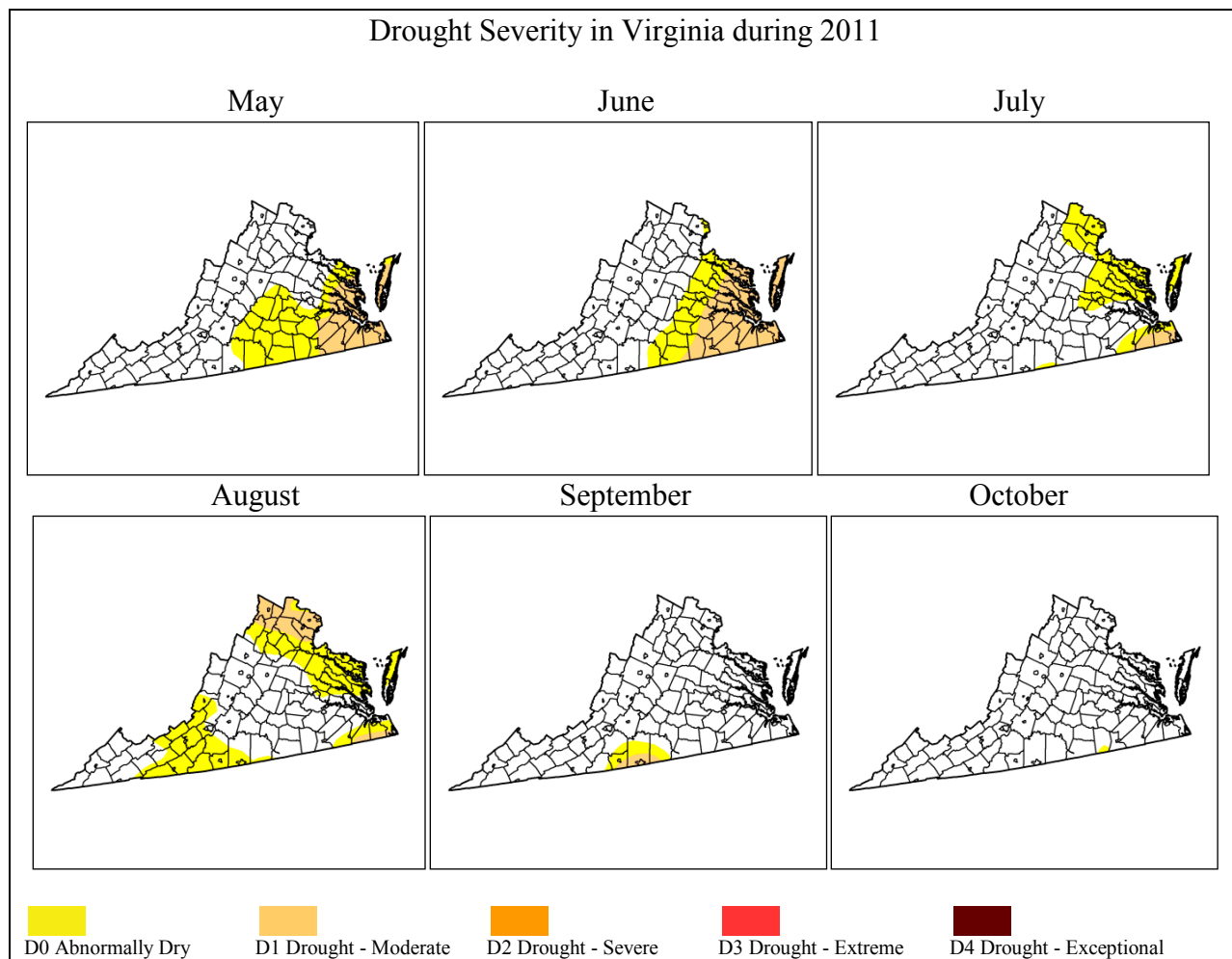


Figure 6. Mid-month values of the United States Drought Monitor (DM) – Drought Intensity Index for Virginia in 2011.

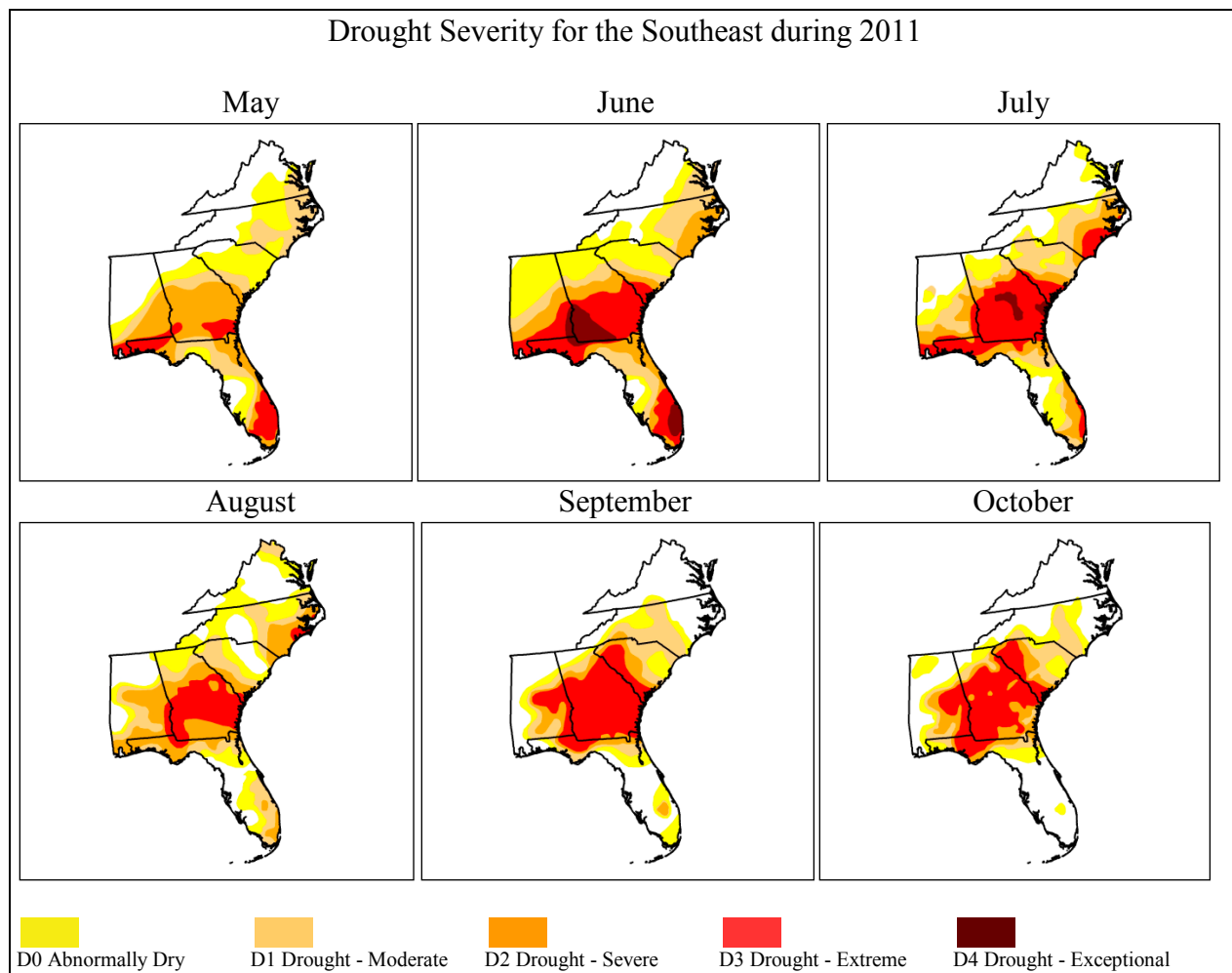


Figure 7. Mid-month values of the United States Drought Monitor (DM) – Drought Intensity Index for the Southeast in 2011.

References

- Comiskey, J. A., and K. K. Callahan. 2008. Mid-Atlantic Network vital signs monitoring plan. Natural Resource Report NPS/MIDN/NRR—2008/071. National Park Service, Fort Collins, CO.
- Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. *Climate Research* 22:99–113.
- Davey, C. A., K. T. Redmond, and D. B. Simeral. 2006. Weather and Climate Inventory, National Park Service, Mid-Atlantic Network. Natural Resource Technical Report NPS/MIDN/NRTR—2006/013. National Park Service, Fort Collins, CO.
- Gawtry, S., and J. Stenger. 2007. Climate Summary, Shenandoah National Park. Natural Resources Report NPS/NER/NRR—2007/017. National Park Service, Philadelphia, PA.
- Kocin, P. J., and L. W. Uccellini. 2004. Northeast Snowstorms Volume 1: Overview. Meteorological Monographs. Vol 32. No 54. American Meteorological Society. Boston, MA.
- Marshall, M., P. Knight, and J. Comiskey. 2012. Weather and climate monitoring protocol: Eastern Rivers and Mountains Network and Mid-Atlantic Network. Natural Resource Report NPS/ERMN-MIDN/NRR-2012/498. National Park Service, Fort Collins, Colorado.
- National Oceanic and Atmospheric Administration (NOAA). 2011. National Climatic Data Center. Climate of 2011 – Annual Review, Global and U.S. Summary. <http://lwf.ncdc.noaa.gov/oa/climate/research/2011/ann/us-summary.html>.
- National Integrated Drought Information System (NIDIS). 2011. National Climate Data Center and United States Department of Agriculture. <http://drought.unl.edu/dm/archive.html>.

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