



# Weather of Shenandoah National Park

## *Mid-Atlantic Network Summary Report for 2013*

Natural Resource Data Series NPS/MIDN/NRDS—2014/716



**ON THE COVER**

Shenandoah National Park.  
Photograph by: Bill Tucker.

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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, 2013, 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 2013'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/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 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 2013 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 are 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 2013) 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 were 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-Albermale) have a Period of Record (POR) sufficiently long for a 30-year normal (1981–2010). 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/NPS/interface.php>.

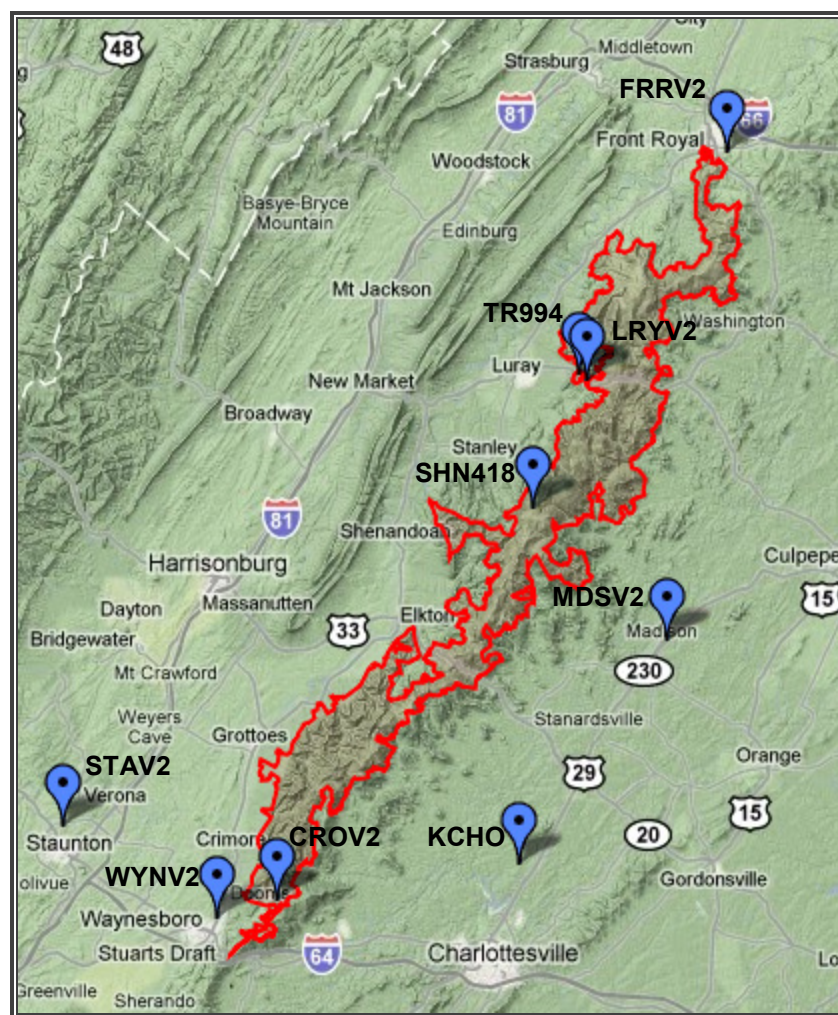


**Figure 1.** Location of weather observing stations around Shenandoah National Park selected as most representative of the park in 2013. See Table 1 for station names.

**Table 1.** List of weather observing stations around Shenandoah National Park selected as most representative of the park in 2013.

| Station | Observing Network <sup>1</sup> | Name                              | Period of Record (POR) |         | Percentage of time reporting temperature for 2013 | Percentage of time reporting precipitation for 2013 | 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                                               | 92.5                                                    | 96.9                                                      |
| MDSV2   | COOP                           | Madison                           | 01/01/1996             | Present | 74.2                                              | 63.0                                                | 65.4                                                    | 66.0                                                      |
| STAV2   | COOP                           | Staunton WTP <sup>3</sup>         | 01/01/1893             | Present | 100.0                                             | 100.0                                               | 95.8                                                    | 91.7                                                      |
| WYNV2   | COOP                           | Waynesboro WTP <sup>3</sup>       | 10/01/2000             | Present | 99.7                                              | 99.7                                                | 94.6                                                    | 93.8                                                      |
| FRRV2   | COOP                           | Front Royal                       | 12/01/1995             | Present | 98.6                                              | 98.6                                                | 99.8                                                    | 99.0                                                      |
| KCHO    | ASOS                           | Charlottesville-Albemarle Airport | 01/07/1973             | Present | 99.7                                              | 100.0                                               | 39.1 <sup>2</sup>                                       | 31.9 <sup>2</sup>                                         |
| SHN418  | CASTNet                        | Big Meadows                       | 07/01/1988             | Present | 97.8                                              | 94.8                                                | 98.5                                                    | 98.3                                                      |
| TR994   | RAWS                           | Headquarters                      | 11/15/2006             | Present | 99.7                                              | 99.7                                                | 97.2                                                    | 97.2                                                      |
| CROV2   | RAWS                           | Sawmill Ridge                     | 11/15/2006             | Present | 100.0                                             | 100.0                                               | 88.3                                                    | 88.3                                                      |

<sup>1</sup> 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.

<sup>2</sup> The percentage of time reporting temperature and precipitation for KCHO is 99.9 from 2001 through 2010.

<sup>3</sup> WTP – Water Treatment Plant

## Temperature Summary

Temperatures for 2013 were slightly below average for the area around Shenandoah NP (Table 2) with departures varying from 0.4°F (0.2°C) to 1.7°F (1.0°C) below normal (Figures 2 and 3)<sup>1</sup>. January was very mild, averaging between 2.8°F to 4.8°F (1.6°C to 2.6°C) above normal across Shenandoah NP (Tables 3 and 4). It turned noticeably colder during February (Figures 2 and 3) which led to negative departures between -1.0°F to -2.4°F (-0.6°C to -1.4°C). March brought even colder air with readings ranging from -5.3°F (-2.9°C) at Staunton to -5.7°F (-3.1°C) at Big Meadows. The average of the winter months (January through March) was the 49<sup>th</sup> coolest since records began in 1895 across the Western Piedmont and 49<sup>th</sup> warmest in the Northern Virginia (Tables 5, 6 and 7) division. The number of cold days was near normal at Luray but below normal at Staunton), but the lowest readings of the winter, which occurred on January 25<sup>th</sup>, was about 11°F (6.1°C) higher than normal (Table 2).

During spring, only May averaged a bit below-normal temperatures at most stations (Table 4). Temperatures during the months of April and June averaged above normal at all stations and the result in the three climate divisions was that the spring ranked as the 30<sup>th</sup> to 43<sup>rd</sup> warmest in 119 years, however, noticeably cooler than 2012 (Tables 5, 6 and 7). The growing season started a little later than normal (April 22<sup>nd</sup>) and ended somewhat later (October 25<sup>th</sup>) than in past years so that 2013 had about a week more of a frost-free season than usual (Table 2).

The summer of 2013 continued the string of above-normal temperatures at many stations in July, though August and September at Luray averaged below normal in August (-2.2°F, [-1.3°C]) and September (-1.5°F, [-0.9°C]). Both Staunton and Front Royal also averaged more than 2.0°F (1.1°C) below normal in August. The number of days in which the maximum temperature exceeded 90°F (32.2°C) was less than half of the normal at Staunton (Table 2), and the highest readings of the year were several degrees below the usual values 93°F (33.9°C) and 98°F (36.7°C, Table 2). In fact, the summer of 2013 ranked as the 42<sup>nd</sup> coolest since 1895 in the Central Mountains Climate Division (Table 7). During July, readings were as much as 1.5°F (0.8°C) above normal in Charlottesville (Table 4). Cooler times prevailed during August, which averaged near to below-normal readings at most stations due to a series of cool days (August 14-20, Figure 3).

The year concluded with chill in November and rather mild conditions in October and December. November brought the coolest readings relative to normal in most sections (Figures 2 and 3). However, warmer conditions returned during December as mean temperatures averaged as much as 3.3°F (1.9°C) above normal at Charlottesville. Overall, autumn 2013 varied from the 38<sup>th</sup> to the 54<sup>th</sup> warmest for the three climate divisions encompassing Shenandoah NP (Tables 5, 6, and 7).

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<sup>1</sup> 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  
2013 vs. 1981–2010

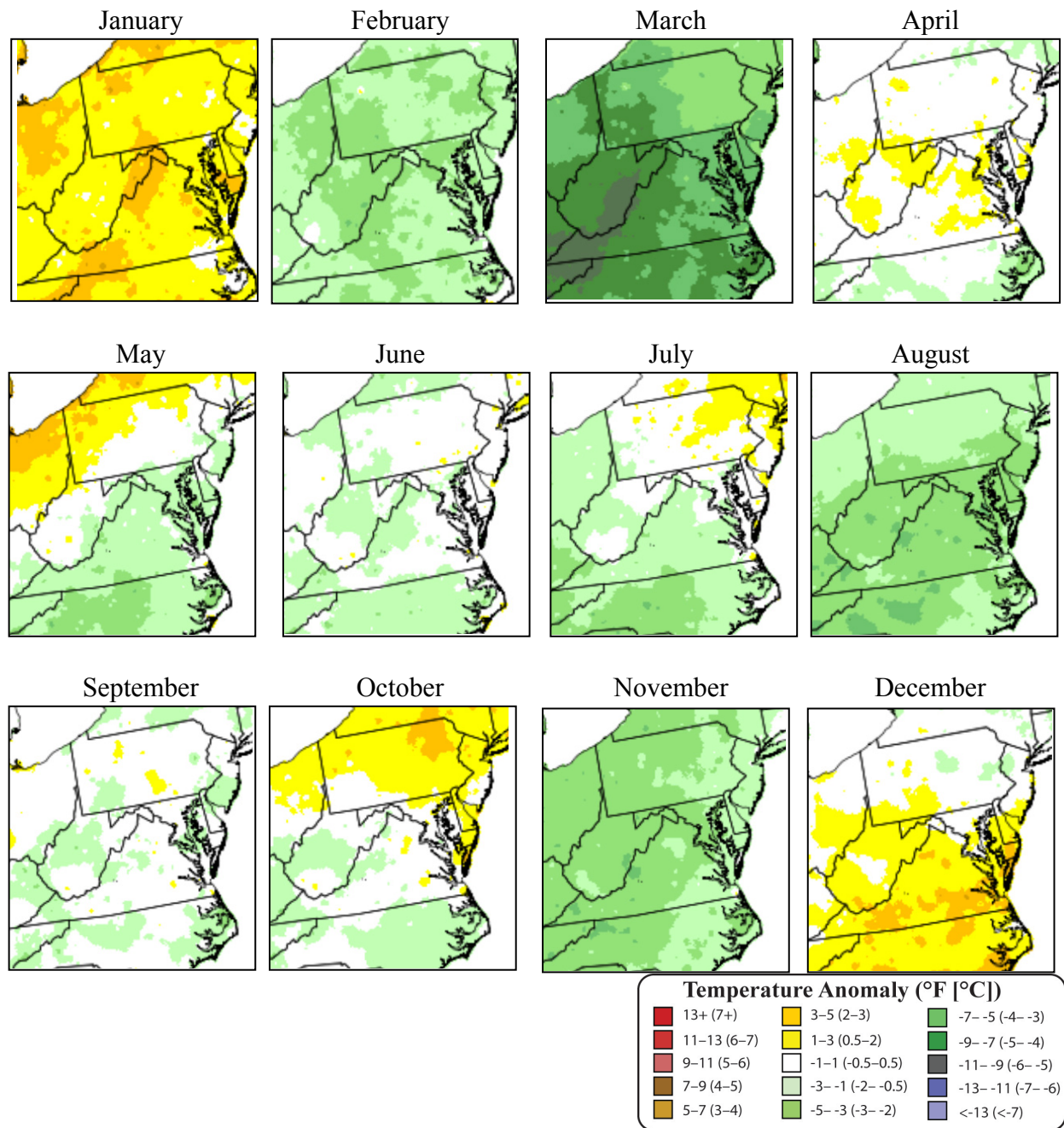


**Figure 2.** Maps showing departure from average monthly maximum temperature compared to the 30-year normal (1981–2010).

Shenandoah National Park  
Departure from Average Monthly Minimum Temperature  
2013 vs. 1981–2010

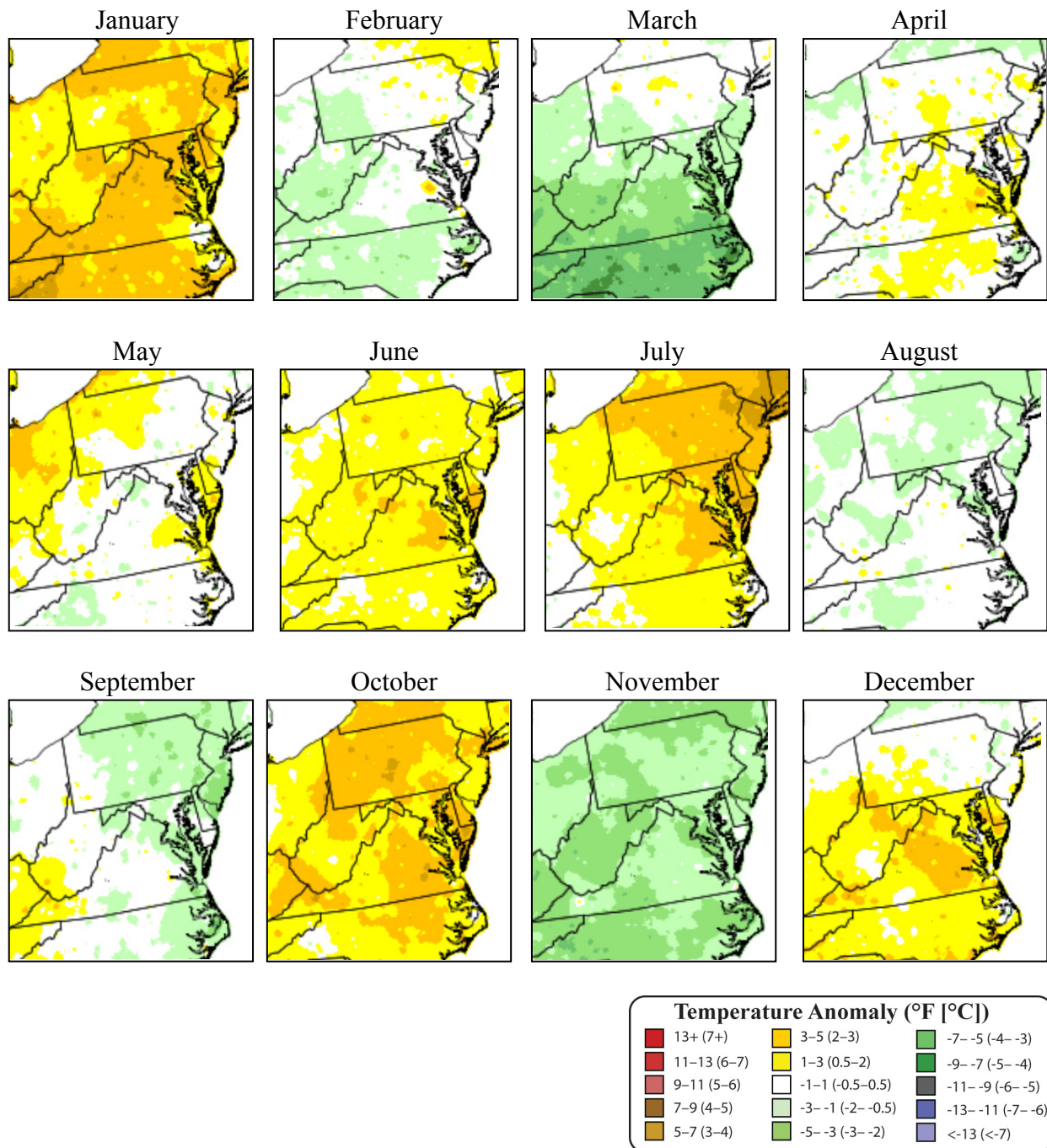


**Figure 3.** Maps showing departure from average monthly minimum temperature compared to the 30-year normal (1981–2010).

**Table 2.** Status of 2013 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<br>2013 <sup>1</sup> | Luray 5 E<br>1981–2010 | Staunton<br>WTP<br>2013 | Staunton<br>WTP<br>1981–2010 |
|---------------------------------------------------------------------------------------------|--------------------------------|------------------------|-------------------------|------------------------------|
| Average Annual Temperature                                                                  | 53.1°F<br>11.7°C               | 54.7°F<br>12.7°C       | 53.2°F<br>11.7°C        | 53.6°F<br>12.0°C             |
| Average Annual Maximum Temperature                                                          | 63.8°F<br>17.7°C               | 67.2°F<br>19.6°C       | 63.0°F<br>17.2°C        | 64.0°F<br>17.8°C             |
| Maximum Temperature                                                                         | 93.0°F<br>33.8°C               | 97.4°F<br>36.3°C       | 91.0°F<br>32.8°C        | 94.7°F<br>34.8°C             |
| Hot Days (days with Tmax≥90°F/32°C)                                                         | 10                             | 25                     | 5                       | 10                           |
| Average Annual Minimum Temperature                                                          | 42.5°F<br>5.8°C                | 42.3°F<br>5.7°C        | 43.3°F<br>6.2°C         | 43.1°F<br>6.2°C              |
| Minimum Temperature                                                                         | 8.7°F<br>-12.9°C               | -1.9°F<br>-18.8°C      | 9.0°F<br>-12.7°C        | -1.8°F<br>-18.8°C            |
| Cold Days (days with Tmax≤32°F/0°F)                                                         | 9                              | 10                     | 7                       | 14                           |
| Sub-freezing Days (days with Tmin≤32°F/0°C)                                                 | 121                            | 111                    | 124                     | 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 Tmin 32°F/0°C) | 163                            | 160                    | 185                     | 174                          |

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

**Table 3.** Summary of monthly average temperatures for 2013 for the selected station

| Station name                       | Station | Jan    | Feb    | Mar    | Apr    | May    | Jun    | Jul    | Aug    | Sep    | Oct    | Nov    | Dec    | Annual |
|------------------------------------|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Luray 5 E                          | LRYV2   | 36.6°F | 33.5°F | 37.7°F | 54.4°F | 60.5°F | 70.3°F | 74.2°F | 70.1°F | 64.2°F | 55.6°F | 41.8°F | 38.5°F | 53.1°F |
|                                    |         | 2.5°C  | 0.8°C  | 3.1°C  | 12.4°C | 15.8°C | 21.2°C | 23.4°C | 21.1°C | 17.8°C | 13.1°C | 5.4°C  | 3.6°C  | 11.7°C |
| Madison                            | MDSV2   | 40.4°F | 36.0°F | M      | 56.7°F | 62.9°F | 73.0°F | 77.1°F | 71.5°F | 65.8°F | 58.3°F | 46.8°F | 37.5°F | 56.8°F |
|                                    |         | 4.7°C  | 2.2°C  | M      | 13.7°C | 17.2°C | 22.8°C | 25.1°C | 21.9°C | 18.8°C | 14.6°C | 8.2°C  | 3.0°C  | 13.7°C |
| Staunton WTP                       | STAV2   | 37.1°F | 33.6°F | 37.1°F | 54.2°F | 60.9°F | 70.7°F | 73.6°F | 69.9°F | 64.9°F | 55.5°F | 41.8°F | 38.9°F | 53.2°F |
|                                    |         | 2.8°C  | 0.9°C  | 2.8°C  | 12.3°C | 16.1°C | 21.5°C | 23.1°C | 21.1°C | 18.3°C | 13.1°C | 5.4°C  | 3.8°C  | 11.7°C |
| Waynesboro WTP                     | WYNV2   | 36.4°F | 34.3°F | 37.6°F | 54.0°F | 60.1°F | 70.5°F | 74.4°F | 70.0°F | 64.2°F | 55.1°F | 41.3°F | 39.0°F | 53.1°F |
|                                    |         | 2.4°C  | 1.3°C  | 3.1°C  | 12.2°C | 15.6°C | 21.4°C | 23.6°C | 21.1°C | 17.9°C | 12.8°C | 5.2°C  | 3.8°C  | 11.7°C |
| Front Royal                        | FRRV2   | 36.9°F | 33.8°F | 38.2°F | 55.5°F | 60.8°F | 71.4°F | 75.7°F | 70.6°F | 64.8°F | 56.1°F | 41.7°F | 38.0°F | 53.6°F |
|                                    |         | 2.7°C  | 1.0°C  | 3.4°C  | 13.1°C | 16.0°C | 21.9°C | 24.3°C | 21.4°C | 18.2°C | 13.4°C | 5.4°C  | 3.3°C  | 12.0°C |
| Charlottesville-Albermarle Airport | KCHO    | 39.0°F | 37.1°F | 41.0°F | 57.4°F | 63.3°F | 73.0°F | 76.9°F | 72.2°F | 65.9°F | 58.2°F | 43.9°F | 41.1°F | 55.8°F |
|                                    |         | 3.9°C  | 2.8°C  | 5.0°C  | 14.1°C | 17.4°C | 22.8°C | 24.9°C | 22.3°C | 18.8°C | 14.6°C | 6.6°C  | 5.06°C | 13.2°C |
| Big Meadows                        | SHN418  | 31.0°F | 25.9°F | 29.1°F | 46.3°F | 53.8°F | 62.4°F | 65.5°F | 62.0°F | 56.7°F | 49.3°F | 35.3°F | 33.6°F | 46.4°F |
|                                    |         | -0.6°C | -3.4°C | -1.6°C | 8.0°C  | 12.1°C | 16.9°C | 18.6°C | 16.6°C | 13.7°C | 9.6°C  | 1.9°C  | 0.9°C  | 8.0°C  |
| Headquarters                       | TR994   | 36.5°F | 32.5°F | 37.5°F | 55.5°F | 61.4°F | 69.9°F | 73.3°F | 69.1°F | 62.5°F | 54.6°F | 40.8°F | 37.3°F | 52.6°F |
|                                    |         | 2.5°C  | 0.3°C  | 3.1°C  | 13.0°C | 16.3°C | 21.1°C | 23.0°C | 20.6°C | 16.9°C | 12.6°C | 4.9°C  | 2.9°C  | 11.4°C |
| Sawmill Ridge                      | CROV2   | 37.6°F | 33.3°F | 36.8°F | 54.6°F | 61.3°F | 69.9°F | 72.8°F | 69.3°F | 64.3°F | 55.9°F | 41.3°F | 39.5°F | 53.0°F |
|                                    |         | 3.1°C  | 0.7°C  | 2.6°C  | 12.6°C | 16.2°C | 21.1°C | 22.7°C | 20.7°C | 18.0°C | 13.3°C | 5.2°C  | 4.2°C  | 11.7°C |

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

**Table 4.** Summary of 2013 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   | 3.8°F | -2.3°F | -5.5°F | 0.7°F | -1.3°F | 0.5°F | 0.6°F | -2.2°F | -1.5°F | 0.2°F | -4.6°F | 1.6 °F | -1.6°F  |
|                                                 |         | 2.1°C | -1.3°C | -3.1°C | 0.3°C | -0.8°C | 0.2°C | 0.3°C | -1.3°C | -0.9°C | 0.1°C | -2.6°C | 0.9°C  | -0.9°C  |
| Staunton WTP                                    | STAV2   | 4.8°F | -1.5°F | -5.3°F | 1.9°F | 0.1°F  | 1.5°F | 0.7°F | -1.9°F | 0.3°F  | 2.0°F | -2.9°F | 3.1°F  | -0.3 °F |
|                                                 |         | 2.6°C | -0.8°C | -2.9°C | 1.0°C | 0.1°C  | 0.8°C | 0.4°C | -1.0°C | 0.2°C  | 1.2°C | -1.7°C | 1.8°C  | -0.2°C  |
| Front Royal <sup>1</sup>                        | FRRV2   | 2.8°F | -2.0°F | -5.3°F | 1.0°F | -1.5°F | 0.0°F | 1.0°F | -3.5°F | -2.0°F | 0.4°F | -4.5°F | 1.7 °F | -0.9°F  |
|                                                 |         | 1.5°C | -1.1°C | -3.0°C | 0.6°C | -0.8°C | 0.0°C | 0.6°C | -2.0°C | -1.1°C | 0.2°C | -2.5°C | 0.9°C  | -0.6°C  |
| Charlottesville-Albermarle Airport <sup>1</sup> | KCHO    | 2.8°F | -1.0°F | -5.5°F | 1.2°F | -0.2°F | 0.7°F | 1.5°F | -3.0°F | -1.4°F | 1.7°F | -4.2°F | 3.3 °F | 0.3°F   |
|                                                 |         | 1.6°C | -0.6°C | -3.1°C | 0.7°C | -0.1°C | 0.4°C | 0.8°C | -1.7°C | -0.8°C | 1.0°C | -2.3°C | 1.9°C  | 0.2°C   |
| Big Meadows <sup>1</sup>                        | SHN418  | 3.2°F | -2.4°F | -5.7°F | 0.7°F | 0.5°F  | 5.1°F | 3.4°F | 1.4°F  | 0.7°F  | 1.4°F | -4.0°F | 3.5 °F | 1.1 °F  |
|                                                 |         | 1.7°C | -1.4°C | -3.1°C | 0.5°C | 0.3°C  | 2.8°C | 1.9°C | 0.7°C  | 0.4°C  | 0.7°C | -2.1°C | 2.0°C  | 0.6°C   |

<sup>1</sup>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 2013 over 119 years for the Western Piedmont (NOAA 2013).

| <b>Climate Division 3 Rankings<br/>Western Piedmont</b> | <b>Jan–Feb–Mar<br/>WINTER</b> | <b>Apr–May–Jun<br/>SPRING</b> | <b>Jul–Aug–Sep<br/>SUMMER</b> | <b>Oct–Nov–Dec<br/>AUTUMN</b> | <b>Jan–Dec<br/>YEAR</b> |
|---------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------|
| Temperature-2013                                        | 67                            | 43                            | 78                            | 34-T                          | 53-T                    |
| Precipitation-2013                                      | 21                            | 6                             | 52                            | 33                            | 10                      |

1 = warmest/wettest year and 119 = coldest/driest year. T = Tie between two or more years.

**Table 6.** Seasonal and annual temperature and precipitation rankings for 2013 over 119 years for Northern Virginia (NOAA 2013).

| <b>Climate Division 4 Rankings<br/>Northern Virginia</b> | <b>Jan–Feb–Mar<br/>WINTER</b> | <b>Apr–May–Jun<br/>SPRING</b> | <b>Jul–Aug–Sep<br/>SUMMER</b> | <b>Oct–Nov–Dec<br/>AUTUMN</b> | <b>Jan–Dec<br/>YEAR</b> |
|----------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------|
| Temperature-2013                                         | 49                            | 30-T                          | 73                            | 39-T                          | 38-T                    |
| Precipitation-2013                                       | 38                            | 33                            | 76                            | 12                            | 16                      |

1 = warmest/wettest year and 119 = coldest/driest year. T = Tie between two or more years.

**Table 7.** Seasonal and annual temperature and precipitation rankings for 2013 over 119 years for the Central Mountains (NOAA 2013).

| <b>Climate Division 5 Rankings<br/>Central Mountains</b> | <b>Jan–Feb–Mar<br/>WINTER</b> | <b>Apr–May–Jun<br/>SPRING</b> | <b>Jul–Aug–Sep<br/>SUMMER</b> | <b>Oct–Nov–Dec<br/>AUTUMN</b> | <b>Jan–Dec<br/>YEAR</b> |
|----------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------|
| Temperature-2013                                         | 69                            | 43-T                          | 78-T                          | 42-T                          | 54-T                    |
| Precipitation-2013                                       | 35-T                          | 13                            | 48                            | 25                            | 9                       |

1 = warmest/wettest year and 119 = coldest/driest year. T = Tie between two or more years.

## Precipitation Summary

Precipitation totals in 2013 averaged somewhat above normal throughout Shenandoah NP (Table 8). Wet spells were notable in June and December while dry spells were most pronounced in March and late October and November (Table 9). Overall, reporting stations in the region tallied annual precipitation between 92 and 117 percent of normal values (Table 10 and 11). The year ranked as the 9<sup>th</sup> wettest in the Central Mountains since 1895.

The year began with a dry stretch during January (1-14). All three-climate divisions in which the park resides (Western Piedmont, Northern Mountains, and Central Mountains) reported winter precipitation totals between the 21<sup>st</sup> to 38<sup>th</sup> wettest winters since 1895 (Tables 5, 6, and 7). January, oddly, was the wettest of the three months, with precipitation totals between 115 and 214 percent of average (Table 11). Snowfall was well above normal throughout Shenandoah NP (Table 8) due in part to a snowstorm in early March.

In a similar way to winter, the spring months of 2013 had above average precipitation, particularly in the months of May and June. In the three climate divisions in which the park resides, that three-month period in 2013 was the 6<sup>th</sup> to the 33<sup>rd</sup> wettest since 1895 in the Northern and Western Piedmont climate divisions. Rainfall during May averaged between 84-252 percent of normal and all stations reported below average precipitation during April (Table 11). However there was another long dry spell totaling 10 days when no measurable precipitation was recorded in mid-May (Table 9).

The summer months in Shenandoah NP had varied rainfall (Figure 4), with the Central Mountains ranking as the 48<sup>th</sup> wettest and Northern Virginia ranking the 44<sup>th</sup> driest since 1895 (Tables 5, 6 and 7). Only one station reported less than 100 percent of normal rainfall in July and August (Table 11), and several sites, notably Luray, averaged 160 percent of normal precipitation for this period. Atypical of summer months, there were no long dry spells (Table 9). There were no direct effects of tropical storms in Shenandoah NP during the summer of 2013.

The remainder of the calendar year continued wetter than normal, with Staunton reporting 123 percent of its average rainfall for the months of October through December (Table 11). The autumn was the 12<sup>th</sup> wettest in Northern Virginia. Out of sync with a wet autumn, two long dry spells occurred in October and November with the dry spells stretching 13 and 14 days respectively (Table 9). The number of days with heavy rain was notably above the average, but the frequency of micro-droughts was also above the average and despite this, there were wetter than usual conditions in 2013.

**Table 8.** Status of 2013 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<br>2013 <sup>1</sup> | Luray 5 E<br>1981–2010 | Staunton<br>WTP<br>2013 | Staunton<br>WTP<br>1981–2010 |
|-------------------------------------------------------------------|--------------------------------|------------------------|-------------------------|------------------------------|
| Annual Precipitation                                              | 49.54 in<br>1258 mm            | 42.3 in<br>1,074 mm    | 42.91 in<br>1089 mm     | 39.1 in<br>993 mm            |
| Autumn (Oct, Nov, Dec) Precipitation                              | 14.4 in<br>365 mm              | 9.7 in<br>246 mm       | 10.4 in<br>264 mm       | 8.8 in<br>224 mm             |
| Heavy Precipitation Days (days with $\geq 1.0$ in (25 mm) rain)   | 13                             | 11                     | 11                      | 9                            |
| Extreme Precipitation Days (days with $\geq 2.0$ in (51 mm) rain) | 4                              | 2                      | 3                       | 2                            |
| Micro-drought (strings of 7+ days without rain)                   | 12                             | 10                     | 13                      | 9                            |
| Annual Snowfall                                                   | 31.4 in<br>79.7 cm             | 17.9 in<br>45.5 cm     | 25.1 in<br>63.7 cm      | 22.7 in<br>57.7 cm           |
| Measurable Snow Days (days with $\geq 0.1$ in (0.3 cm) snow)      | 10                             | 6                      | 13                      | 9                            |
| Moderate Snow Days (days with $\geq 3.0$ in (7.6 cm) snow)        | 4                              | 3                      | 2                       | 3                            |
| Heavy Snow Days (days with $\geq 5.0$ in (15.2 cm) snow)          | 3                              | 1                      | 2                       | 1                            |

<sup>1</sup>Luray 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 2013 from weather observing stations at Luray 5 E (LRYV2) and Staunton WTP (STAV2).

| Wettest Days in 2013     | Dry Spells in 2013 |
|--------------------------|--------------------|
| May 8: 3.01 in (76 mm)   | Sept. 23-Oct. 6    |
| July 12: 2.79 in (71 mm) | Nov. 2-15          |
| June 18: 2.53 in (64 mm) | Jan. 1-14          |
| June 7: 2.40 in (61 mm)  | Oct. 19- 31        |
| Jan 31: 1.85 in (47 mm)  | May. 12-22         |

**Table 10.** Summary of 2013 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   | 3.2 in | 1.5 in | 3.0 in | 1.5 in | 7.3 in  | 5.8 in  | 6.5 in  | 5.4 in | 1.1 in | 6.8 in | 2.6 in | 5.03 in | 49.54 in             |
|                                   |         | 81 mm  | 37 mm  | 76 mm  | 38 mm  | 185 mm  | 147 mm  | 165 mm  | 137 mm | 28 mm  | 173 mm | 66 mm  | 128 mm  | 1258 mm              |
| Madison                           | MDSV2   | 3.4 in | 0.5 in | M      | 0.3 in | 4.8 in  | 8.5 in  | 4.6 in  | 6.4 in | 1.8 in | 5.3 in | 2.2 in | 2.7 in  | 41.0 in <sup>1</sup> |
|                                   |         | 86 mm  | 13 mm  | M      | 8 mm   | 122 mm  | 216 mm  | 117 mm  | 163 mm | 46 mm  | 135 mm | 56 mm  | 69 mm   | 1041 mm <sup>1</sup> |
| Staunton WTP                      | STAV2   | 3.5 in | 1.1 in | 3.6 in | 2.4 in | 5.0 in  | 7.6 in  | 3.6 in  | 4.3 in | 1.3 in | 2.5 in | 2.0 in | 5.9 in  | 42.9 in              |
|                                   |         | 89 mm  | 28 mm  | 91 mm  | 61 mm  | 127 mm  | 193 mm  | 91 mm   | 109 mm | 33 mm  | 64 mm  | 51 mm  | 150 mm  | 1090 mm              |
| Waynesboro WTP                    | WYNV2   | 5.0 in | 1.6 in | 6.9 in | 3.2 in | 4.6 in  | 7.7 in  | 4.2 in  | 6.0 in | 0.8 in | 4.8 in | 2.5 in | 3.5 in  | 50.6 in              |
|                                   |         | 127 mm | 41 mm  | 175 mm | 81 mm  | 117 mm  | 196 mm  | 107 mm  | 152 mm | 20 mm  | 122 mm | 64 mm  | 88 mm   | 1286 mm              |
| Front Royal                       | FRRV2   | 3.8 in | 1.4 in | 3.9 in | 1.5 in | 3.4 in  | 6.3 in  | 3.2 in  | 3.4 in | 1.2 in | 5.9 in | 2.0 in | 5.0 in  | 41.0 in              |
|                                   |         | 97 mm  | 36 mm  | 99 mm  | 38 mm  | 86 mm   | 160 mm  | 81 mm   | 86 mm  | 30 mm  | 150 mm | 51 mm  | 127 mm  | 1041 mm              |
| Charlottesville-Albemarle Airport | KCHO    | 5.1 in | 1.4 in | 3.1 in | 3.0 in | 4.4 in  | 7.1 in  | 3.7 in  | 6.1 in | 0.7 in | 3.5 in | 2.9 in | 4.7 in  | 45.6 in              |
|                                   |         | 130 mm | 36 mm  | 79 mm  | 76 mm  | 112 mm  | 180 mm  | 94 mm   | 155 mm | 18 mm  | 89 mm  | 74 mm  | 120 mm  | 1158 mm              |
| Big Meadows                       | SHN418  | 3.9 in | 2.6 in | M      | 3.2 in | 11.5 in | 7.2 in  | 11.2 in | 5.2 in | 1.5 in | 9.1 in | 4.3 in | M       | M                    |
|                                   |         | 99 mm  | 65 mm  | M      | 81 mm  | 292 mm  | 184 mm  | 284 mm  | 131 mm | 38 mm  | 232 mm | 110 mm | M       | M                    |
| Headquarters                      | TR994   | 3.2 in | 1.6 in | 2.5 in | 1.5 in | 6.9 in  | 5.5 in  | 6.4 in  | 4.9 in | 1.1 in | 6.6 in | 2.6 in | 0.8 in  | 43.6 in              |
|                                   |         | 81 mm  | 41 mm  | 64 mm  | 38 mm  | 174 mm  | 140 mm  | 163 mm  | 123 mm | 29 mm  | 167 mm | 66 mm  | 20 mm   | 1107 mm              |
| Sawmill Ridge                     | CROV2   | 5.3 in | 1.2 in | 3.1 in | 3.0 in | 6.3 in  | 11.8 in | 4.4 in  | 4.7 in | 0.8 in | 4.8 in | 2.7 in | 5.2 in  | 53.2 in              |
|                                   |         | 134 mm | 30 mm  | 80 mm  | 75 mm  | 160 mm  | 298 mm  | 112 mm  | 120 mm | 20 mm  | 121 mm | 69 mm  | 131 mm  | 1350 mm              |

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

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

**Table 11.** Summary of 2013 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   | 122 | 53  | 121 | 90  | 186 | 142 | 158 | 161 | 24  | 231 | 73  | 165 | 117             |
| Madison <sup>1</sup>                           | MDSV2   | 115 | 19  | M   | 10  | 108 | 158 | 124 | 198 | 36  | 163 | 66  | 77  | 92 <sup>2</sup> |
| Staunton WTP                                   | STAV2   | 136 | 40  | 107 | 76  | 134 | 211 | 91  | 116 | 32  | 89  | 65  | 215 | 109             |
| Front Royal <sup>1</sup>                       | FRRV2   | 133 | 59  | 110 | 44  | 84  | 142 | 101 | 103 | 21  | 199 | 57  | 177 | 100             |
| Charlottesville-Albemarle Airport <sup>1</sup> | KCHO    | 214 | 72  | 106 | 100 | 116 | 169 | 108 | 179 | 15  | 113 | 90  | 150 | 107             |
| Big Meadows <sup>1</sup>                       | SHN418  | 121 | 130 | M   | 79  | 253 | 156 | 289 | 140 | 26  | 249 | 104 | M   | M               |

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

<sup>1</sup> 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.

<sup>2</sup> 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  
2013 vs. 1981–2010

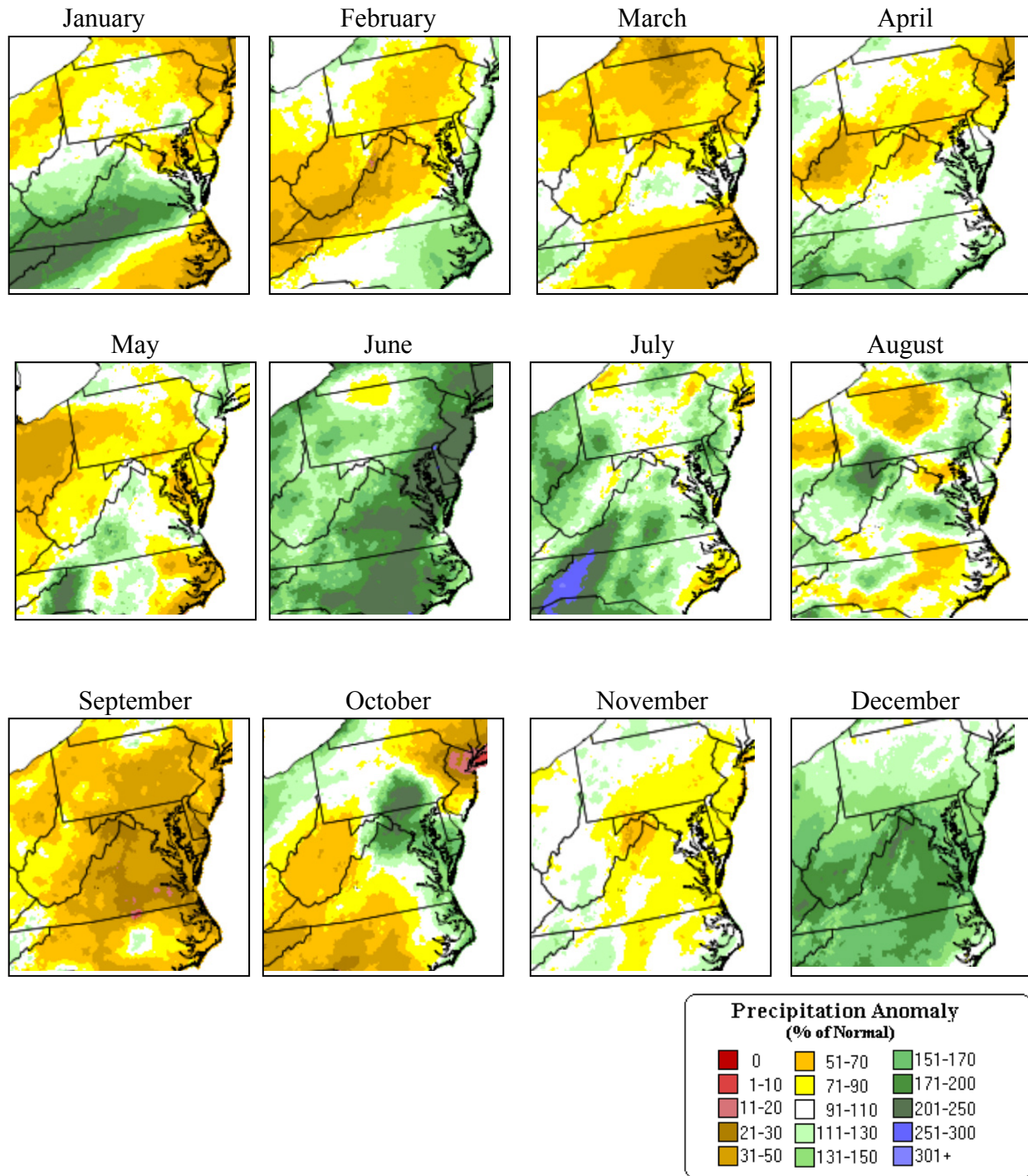


**Figure 4.** Maps showing percent of average monthly precipitation compared to the 30-year normal (1981–2010).

## 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 2013 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 2013). 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 2013. Other than for a dry spell in September, no drought was evident during the growing season.

According to the PDSI, 2013 moist conditions dominated all months of the year as the drought index rose to values above  $+2$ , moderately moist, by June and above  $+3$ , very moist, in July and August (Figures 5, 6, and 7). Several active fronts deposited enough moisture to keep the index in the moist values until the end of the year. When compared to the previous two years, 2013 had the longest spell of moist conditions, most of which occurred during the growing season and autumn. This is the first summer with wet weather. Much like in 2011, important rains in October brought a moist end to the warm season.

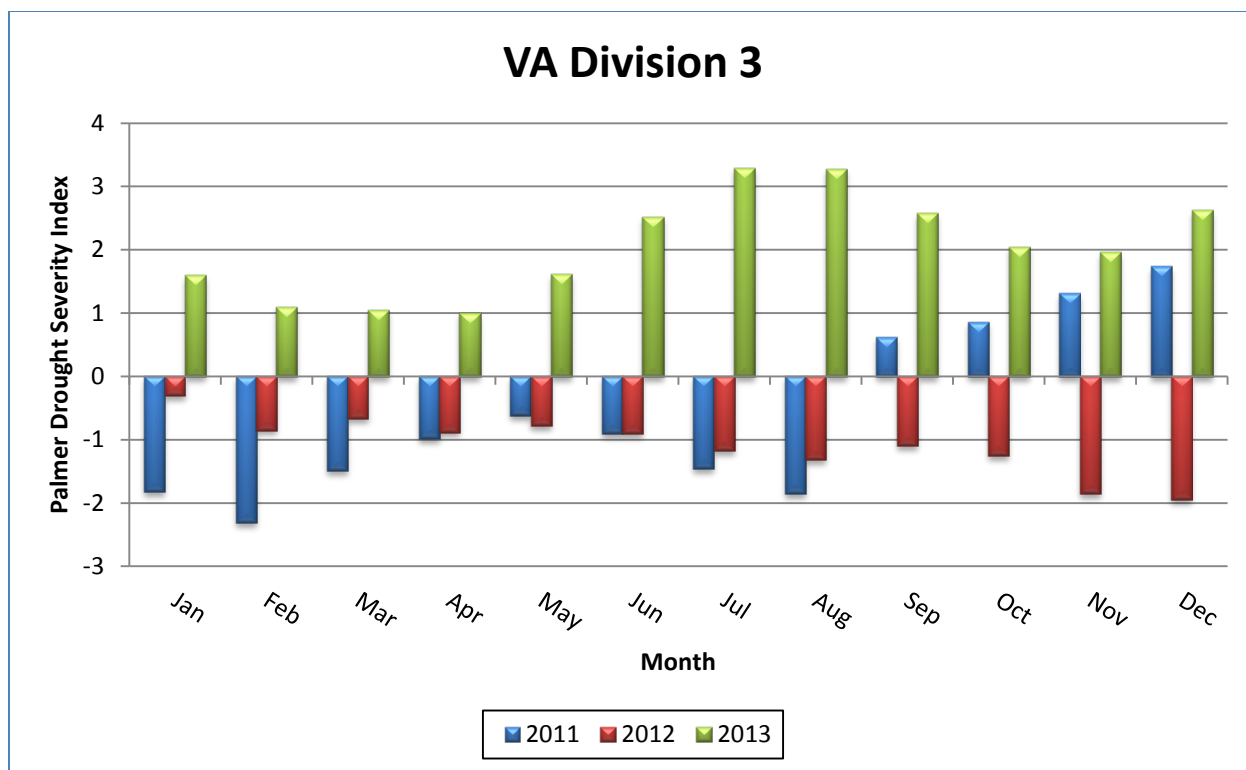


**Figure 5.** Palmer Drought Severity Index (PDSI) for Western Piedmont, 2011–2013.

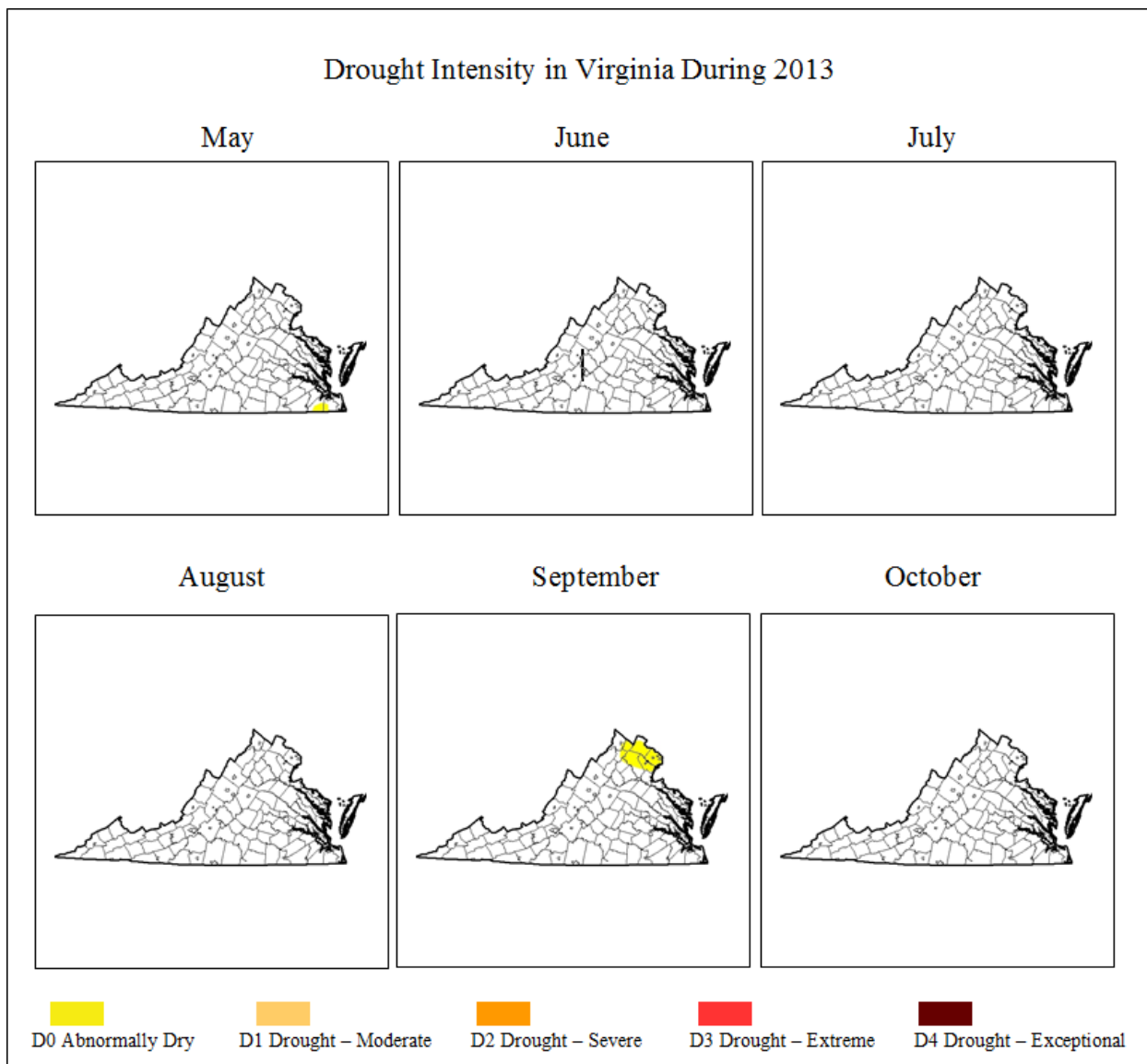


**Figure 6.** Mid-month values of the United States Drought Monitor (DM) - Drought Intensity Index for Virginia in 2013.

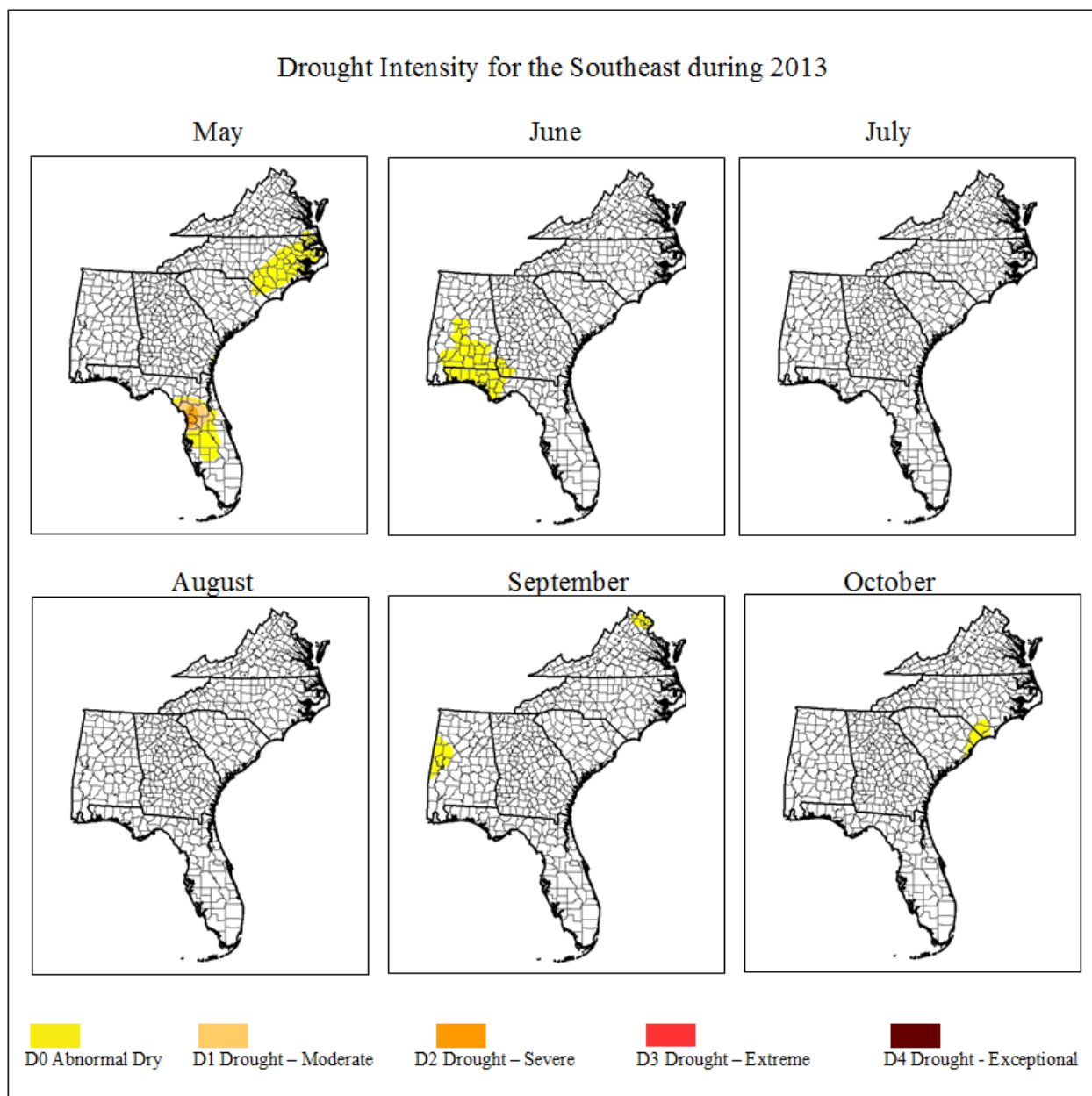


**Figure 7.** Mid-month values of the United States Drought Monitor (DM) - Drought Intensity Index for the Southeast in 2013.

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NPS 134/126803, October 2014

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