



Past and Future Climate Patterns

Introduction

Climate change has the potential to profoundly alter national parks, with potential impacts to vegetation, wildlife, and cultural resources (Monahan and Fisichelli 2014, Tercek et al. 2021). During this time of unprecedentedly rapid change (Intergovernmental Panel on Climate Change [IPCC] 2022), proactive management—planning that anticipates the future—is more likely to be successful than reactive management, which merely responds to crises as they arise. Proactive management plans depend on a clear understanding of both the changes that have occurred so far and what we might expect in the future. In this resource brief, we discuss historical climate patterns at Capulin Volcano National Monument (NM) and compare them to the range of conditions that we expect for the late 21st century. This will provide park managers with important insights for climate-change planning efforts.

Looking to the Future

Our discussion of the future is based on climate “projections.” Unlike weather “forecasts,” which typically extend only a few days to a few months into the future, climate projections extend decades into the future. They are based on complex computer models of Earth’s atmosphere and geological systems. They are not meant to predict the temperature or rainfall on a particular day or month in the future; rather, climate projections are skilled at capturing long-term (decades to centuries) future trends in the average annual and seasonal patterns that we might expect.

There are more than 40 climate projections available for Capulin Volcano NM. They all call for some amount of future warming, but there is disagreement on whether precipitation will increase or decrease. As future warming interacts with changes in precipitation, it will change the amount of water that is available for plants and animals. A large amount of warming would greatly increase evaporation and transpiration (plant



Cinder cone at Capulin Volcano National Monument. Photo: NPS / M. Owen.

water use), but less warming would require a smaller increase in precipitation to maintain historically

Summary of Future Climate at Capulin

- Climate projections, based on computer models of Earth’s atmosphere and geological systems, capture long-term trends in average annual and seasonal patterns.
- All climate projections for Capulin Volcano NM call for future warming, but there is disagreement on whether precipitation will increase or decrease.
- There will be 6–12°F of warming (compared to historical average) by the late 21st century.
- The number of days per year with extremely warm temperatures is projected to increase, and the number of days per year below freezing is expected to decrease.
- The futures described here are likely to increase the frequency of drought, affect fire regimes, and alter the composition of plant communities at Capulin Volcano NM.

normal moisture levels. The climate projection with the greatest precipitation increase might not be the wettest from a biological perspective if it also includes a great deal of warming.

In this resource brief, we highlight two climate projections (out of more than 40) that capture the range of wettest (i.e., most biologically available water) versus driest (i.e., least biologically available water) conditions projected for the late 21st century (2070–2099) (Table 1). To illustrate the interaction between warming and precipitation, we also include a third projection that has both a large precipitation increase and substantial warming.

Precipitation Patterns: Past and Future

Historical (1940–2022) precipitation from the Grenville, New Mexico, weather station did not have a clearly increasing or decreasing trend, but instead had alternating periods with below- and above-average precipitation (Figure 1). The three future projections that we chose in order to bracket the range of future moisture conditions (measured in terms of biologically available water) call for precipitation changes ranging from a 26% decrease to a 17% increase by the late 21st century (see Table 1).

Temperature Patterns: Past and Future

Historical (1964–2022) temperatures from the Grenville, New Mexico, weather station have missing values that limit our ability to characterize trends

over the period of record. However, night-time low temperatures (or daily low temperatures) increased by roughly 2–3°F over the period of record (Figure 2, bottom graph). At the same time, daytime highs had little to no apparent trend (Figure 2, top graph). Several years in the 1970s and 1980s had daily low temperatures between 34 and 35°F. Since 2004, for years with sufficient data to characterize daily low temperatures, most years had daily lows at or above 37°F.

The three future projections we chose call for roughly 6–12°F of warming by late century compared to the historical average (Figure 3). This warming would cause sharp decreases in the number of days per year below freezing. Under the wettest future (blue, Figures 3 and 4), the median number of days below freezing (128 days) would be similar to the lowest count observed historically (137 days in 2012, Figure 4), while the medians for the two hotter projections would be about half the historical median (red and purple, Figure 4).

Extremely warm temperatures are projected to increase sharply in the future. The largest historical count of days per year above 85°F (71 days in 2011) is similar to the projected median count for the wettest late-century future (Figure 5). The medians for the other two futures are 5–6 times the historical median.

Moisture Availability: Will Plants Get the Water they Need?

The future is quite likely to be warmer, but will it be

Table 1. Alternative future projections considered for Capulin Volcano National Monument. Average annual temperature increase and total annual precipitation increase/decrease are calculated for 2070–2099 (relative to 1979–2022). The first two projections (“Driest” and “Wettest”) bracket the range of projected future moisture conditions. The third projection illustrates how a large future increase in precipitation (+17%) can interact with substantial warming (+10°F) to produce drier than historical conditions. Historical data are taken from GRIDMET gridded data, and future data are produced using the MACA downscaling method (see Abatzoglou and Brown [2012] and Abatzoglou [2013]).

Projection Name	Temperature Increase	Precipitation Increase / Decrease	Global Climate Model (Model Name)
“Driest”: Hot + Less Precipitation	12°F	- 4.6 inches (-26%)	IPSL-CM5A-LR.rcp85
“Wettest”: Warm + More Precipitation	6°F	+ 1.1 inches (+6%)	MRI-CGCM3.rcp45
Hotter + More Precipitation	10°F	+ 3.1 inches (+17%)	CanESM2.rcp85

GRIDMET, an abbreviation for Gridded Surface Meteorological Data, is a daily climate dataset with a spatial resolution of ~2.5 miles (~4 km) covering the contiguous U.S. from 1979-yesterday and available at <http://www.drought.gov>.
MACA, an abbreviation for Multivariate Adaptive Constructed Analogs, is a statistical downscaling method to adjust Global Climate Model (GCM) projections to a higher spatial resolution grid.

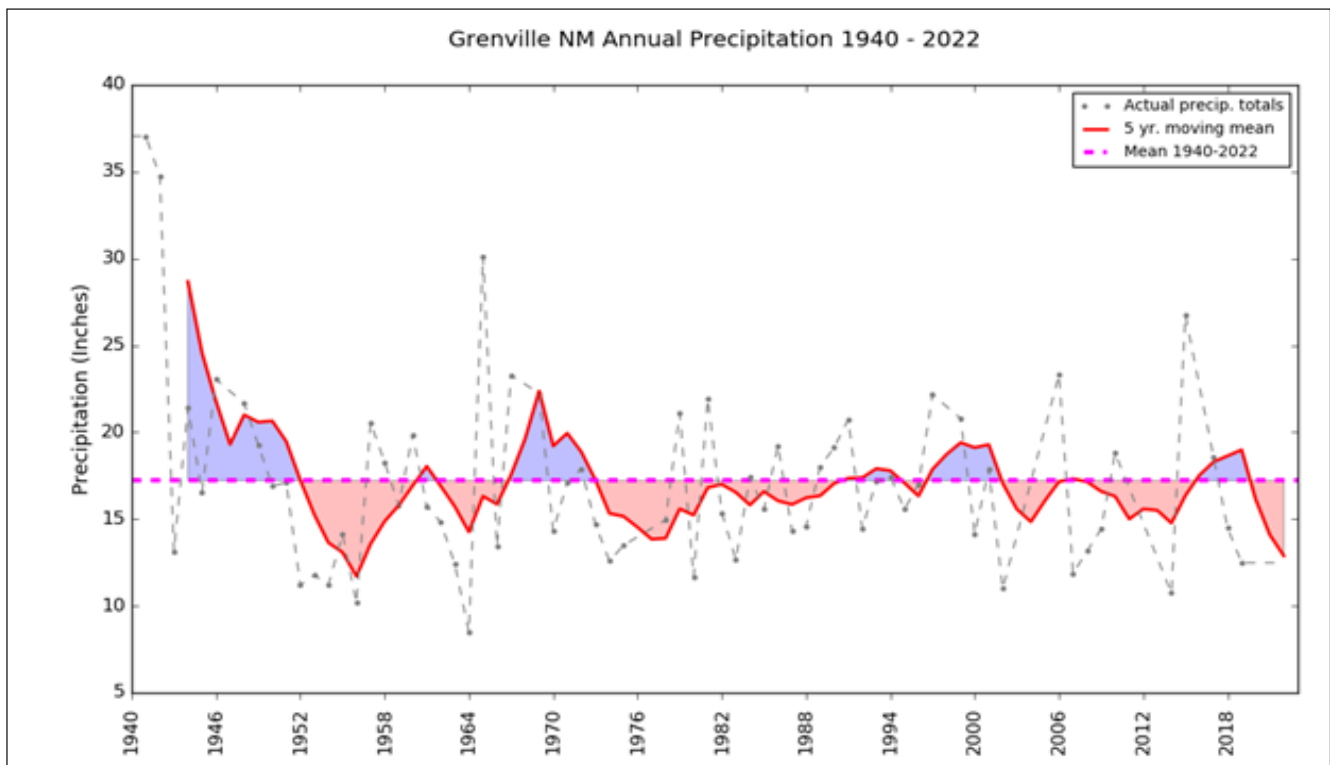


Figure 1. Historical annual precipitation, 1940–2022, at Greenville, New Mexico, near Capulin Volcano National Monument. Areas shaded blue and red are periods when the 5-year running mean (solid red line) was above (blue) or below (red) the 1940–2022 average. Missing years (16 out of 83 years in the gray dashed line) were interpolated. Weather station data are available from www.ClimateAnalyzer.org.

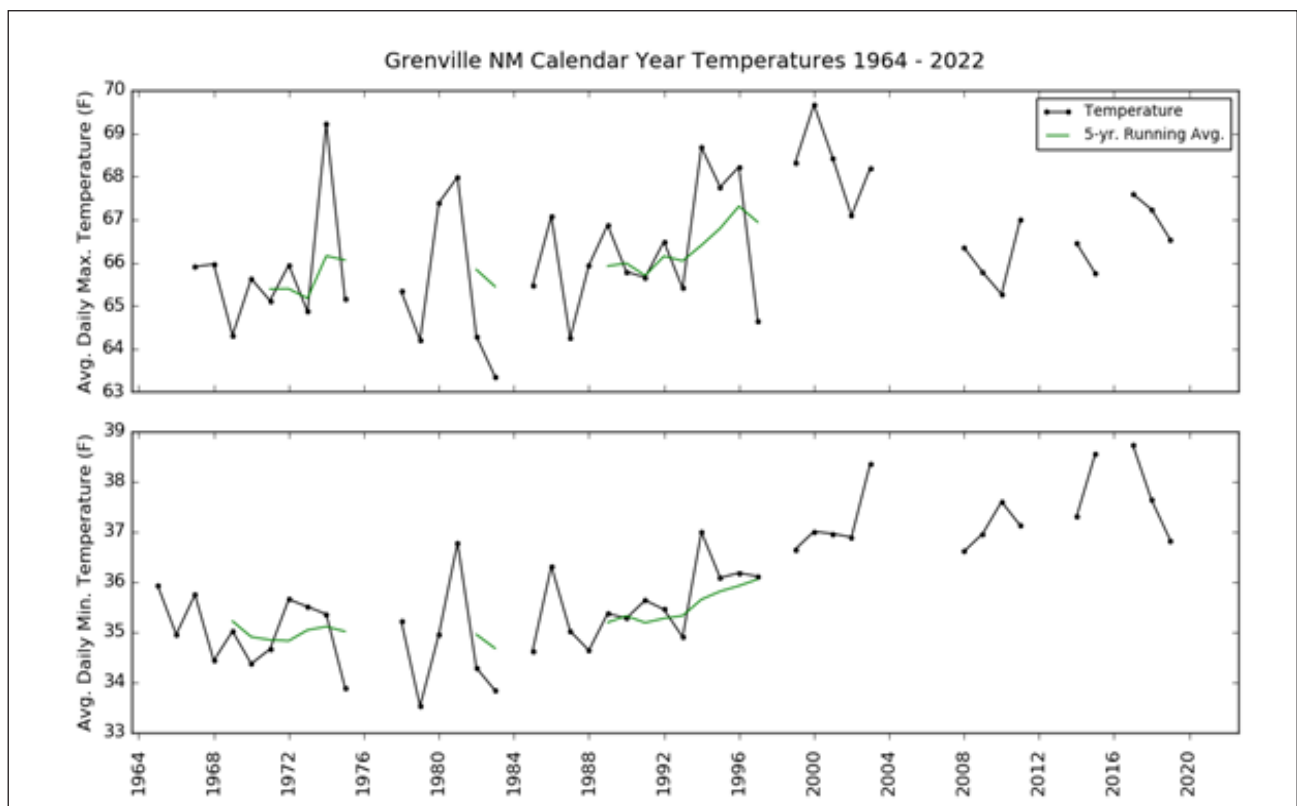


Figure 2. Historical annual averages of daily high temperatures (top) and night-time low temperatures (bottom) at Greenville, New Mexico, near Capulin Volcano National Monument. Line breaks are years with insufficient data to report an average. Weather station data are available from www.ClimateAnalyzer.org, but temperature data before 1964 were unavailable.

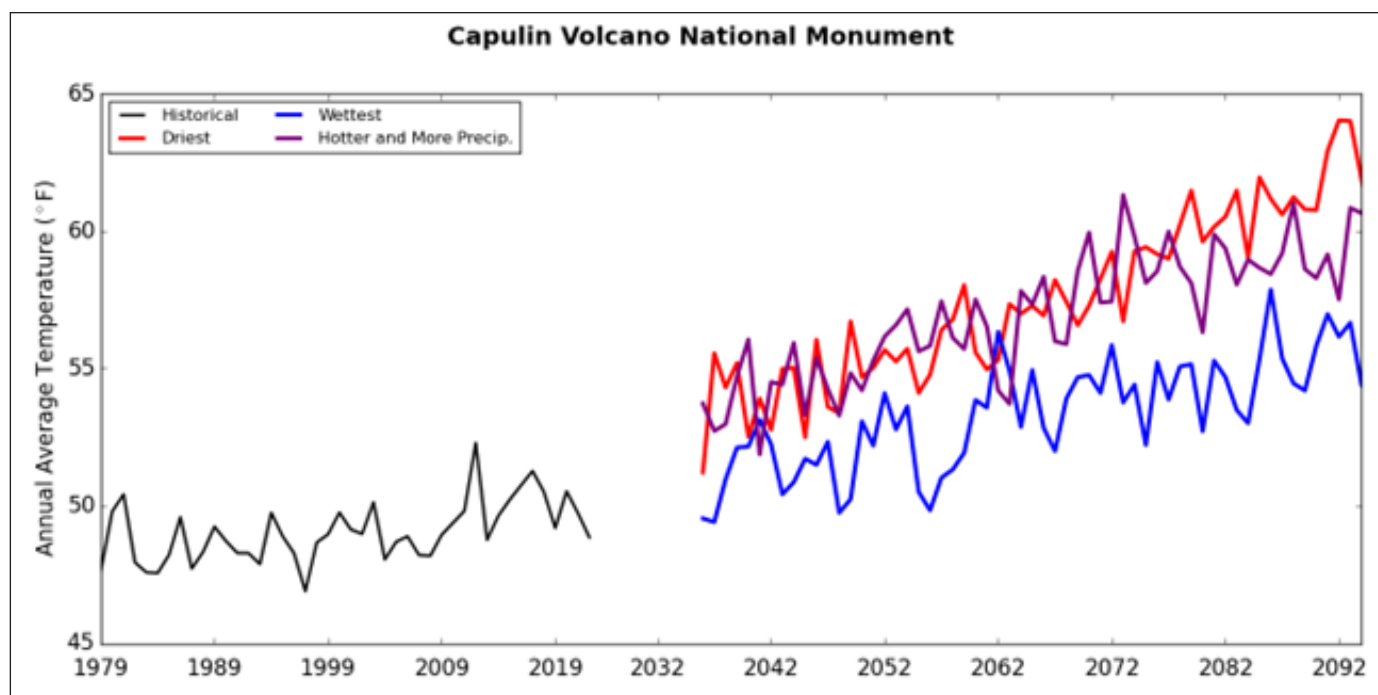


Figure 3. Historical average annual temperatures (left; black) and three temperature projections (driest [red], wettest [blue; bottom line], and hotter and more precipitation [purple]) that bracket the range of expected future conditions at Capulin Volcano National Monument. Historical data are GRIDMET; future data are MACA, see Abatzoglou and Brown (2012) and Abatzoglou (2013).

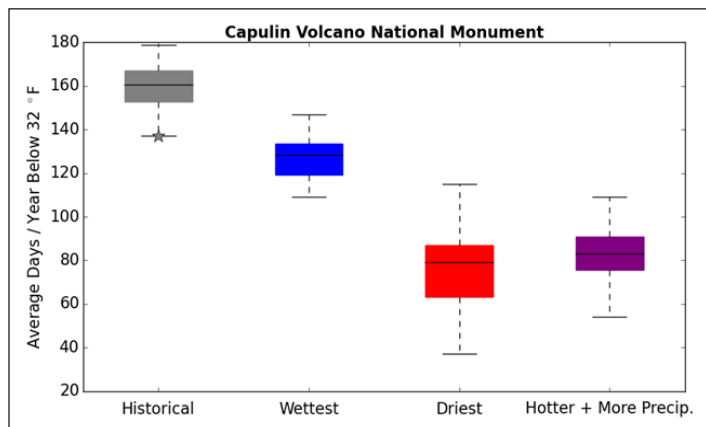


Figure 4. Annual number of days per year with low temperatures below freezing (32°F). The gray star marks the lowest historical count (137 days), in 2012. This historical extreme is similar to the median of the wettest projection (128 days, horizontal line in middle of blue boxplot) by late century (2070–2099). The other two futures (driest [red], and hotter and more precipitation [purple]) have a median number of days below freezing (79 and 83 days, respectively) that are roughly half the historical median (160 days below 32°F). Historical data are GRIDMET; future data are MACA, see Abatzoglou and Brown (2012) and Abatzoglou (2013).

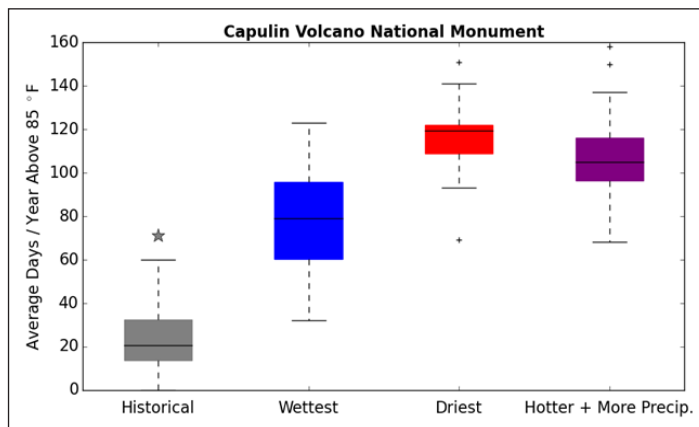


Figure 5. Annual number of days per year with temperatures above 85°F. The gray star marks the highest historical count (71 days in 2011). This historical count is similar to the wettest median (79 days, horizontal line in blue boxplot). The medians for the driest (red) and hotter and more precipitation (purple) futures (120 and 105 days, respectively) are roughly 5–6 times the historical median (gray, 21 days). Plus signs (+) indicate data values that are outliers. Historical data are GRIDMET; future data are MACA, see Abatzoglou and Brown (2012) and Abatzoglou (2013).

wetter or drier? At first, this might seem like a difficult question to answer, as future projections for Capulin Volcano NM show either an increase or a decrease in precipitation. However, the future is more certain than one might think. As described below, even the third projection highlighted in this brief—the one with a large precipitation increase and substantial warming—still results in a relatively dry future.

Capulin Volcano NM is expected to get drier in future summers because warmer temperatures will use up any extra precipitation. This can be seen in Figure 6, where the wettest projection (blue) has late-century soil moisture (second panel) drier than the historical average (gray) during every month except September. Similarly, the “hotter and more precipitation” projection (purple) has soil moisture less than historical levels for most of the year, and it is drier than the wettest future during the spring and summer even though it calls for a 17% increase in annual precipitation. Since both the wettest future and the hotter and more precipitation projections do not yield increased soil moisture, they lead to little change in warm-season plant water use (Figure 6, actual evapotranspiration, top panel), except for a slight increase relative to historical levels in late summer. The driest future projection, meanwhile, shows marked decreases in warm-season plant water use and soil moisture, which is not surprising given the projected decreases in precipitation (Figure 6, third panel, red).

Conclusions and Implications: What does all this mean for Capulin Volcano NM?

Future precipitation projections for Capulin Volcano NM are mixed, calling for either substantial increases or decreases. Despite this uncertainty in future precipitation, summers are likely to be drier because warming will increase evapotranspiration, which draws more water from the soil and limits plant water use. In this brief we highlighted future projections that bracket the range of modeled future soil moisture and actual evapotranspiration, and observed that even the wettest future has significantly less biologically available water during most of the year. Importantly, our third future projection, which called for a larger increase in precipitation (17%) than the wettest future, had even lower soil moisture during the summer.



Pinyon-juniper savanna at Capulin Volcano National Monument. Photo taken during grasslands monitoring by the Southern Plains Network in 2022. Photo: NPS / M. Owen.

Future warming is projected to reduce the annual number of days below 32°F by up to 50%, and to cause an up to six-fold increase in the annual number of days above 85°F. A drier and warmer future has implications for the plant life at Capulin Volcano NM. Pinyon-juniper communities, such as the woodland that currently covers the cone, are predicted to decline (Noel et al. 2023). Evidence for this can be found from studies on recent regional droughts. From 2002–2004, warmer temperatures and low precipitation, followed by bark beetle infestations, resulted in abnormally high rates of pinyon pine (*Pinus edulis*) mortality across the Southwest. A smaller but similar response was seen in mortality rates of one-seed juniper (*Juniperus monosperma*), the dominant juniper species at Capulin Volcano (Breshears et al. 2005). Drought stress has also been shown to disproportionately affect the establishment of new seedlings. At Capulin Volcano NM, climate-induced pinyon-juniper declines could shift the vegetation toward deciduous shrubs and grass cover (Noel et al. 2023). In the grasslands themselves, warm-season tallgrasses, such as big bluestem (*Andropogon gerardii*), are predicted to decline in abundance and be replaced by shorter, more drought-tolerant grasses, such as blue grama (*Bouteloua gracilis*).

Climate-induced shifts in the current vegetation communities at Capulin Volcano NM are expected. These shifts are likely to result from the individual or

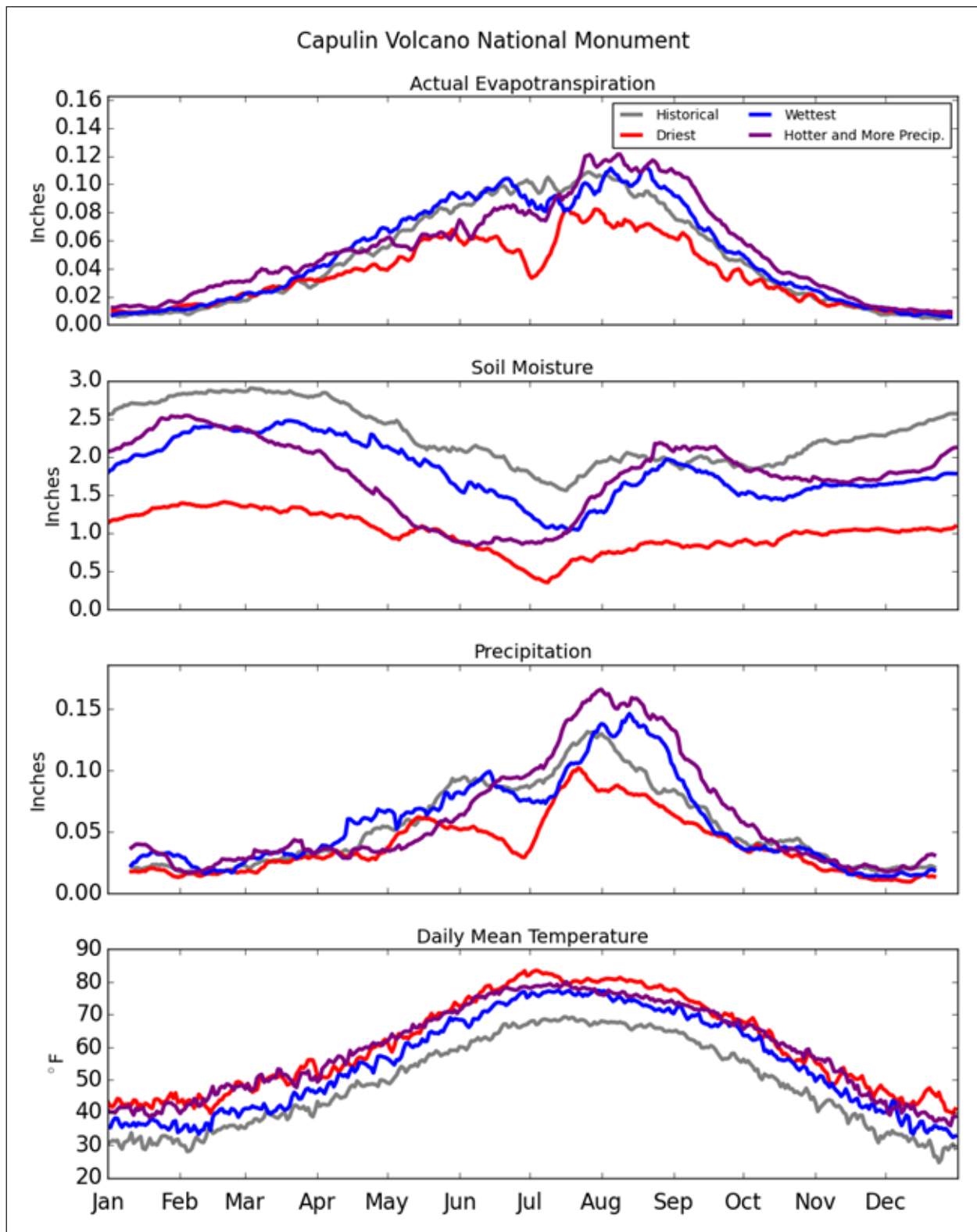


Figure 6. Historical (1979–2022) seasonal patterns (gray lines) in actual evapotranspiration, soil moisture, precipitation, and temperature, compared to late 21st century (2070–2099) seasonal patterns. Data sources for precipitation and temperature are listed in Table 1. Actual evapotranspiration and soil moisture data source = Tercek et al. (2021) and Tercek et al. (2023).



Vegetation and view along the Crater Rim Trail on the cinder cone at Capulin Volcano NM.
Photo: NPS / M. Owen.

interactive effects of climate-related changes in fire regimes, heat-related tree mortality, insect infestations, and the ongoing expansion of invasive species across the region. Managing for current and future threats to native plant communities remains challenging. However, limiting the impacts of individual stressors by managing for and rapidly responding to exotic plant outbreaks, managing and responding to bark beetle outbreaks, and developing future-focused fire management plans can help to build resilience into managed lands (e.g., Redmond et al. 2023). Further, managing pinyon-juniper and native grasslands for resilience cannot rest fully on the NPS. Instead, partnering in regional conservation strategies (e.g., Intermountain West Joint Venture) provides a robust foundation of science-based practices that protect native plant communities and advance natural resource stewardship on NPS lands and across the broader landscape.

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Erosion on the cinder cone at Capulin Volcano NM in 2019. Both vegetation on the cone and Volcano Road, an important part of the monument's cultural landscape, are impacted by erosion from rainfall events like this one in August 2019. Increased amounts of precipitation or intensity of rainfall events associated with a future, warmer climate (e.g., Myhre et al. 2019) could lead to future erosion events like this one. NPS Photo.

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