Chapter 2
Historical and Projected Climate in the Northern Rockies Region

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Abstract Climate influences the ecosystem services we obtain from forest and rangelands. An understanding of how climate may change in the future is needed to consider climate change in resource planning and management. In this chapter, we present the current understanding of the future changes in climate for the Northern Rockies region. Projected climate was derived from climate models in the Coupled Model Intercomparison Project version 5 (CMIP5) database, which was used in the most recent Intergovernmental Panel on Climate Change reports. Climate models project that the Earth's current warming trend will continue throughout the twenty-first century in the Northern Rockies. Compared to observed historical temperature, average warming across the Northern Rockies is projected to be about 2–3 °C by 2050, depending on greenhouse gas emissions. Seasonally, projected winter maximum temperature begins to rise above freezing in the mid-twenty-first century in several parts of the region. Projections for precipitation suggest a slight increase in the future, but precipitation projections, in general, have much higher uncertainty than those for temperature.

Keywords Precipitation • Temperature • Representative concentration pathways • CMIP5

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2.1 Introduction

Climate influences the ecosystem services that our society obtains from forest and rangeland ecosystems. Climate is described by the long-term characteristics of precipitation, temperature, wind, snowfall, and other measures of weather in a particular place. Day to day implementation of resource management practices are made in response to weather conditions; resource management strategies and plans are developed using our understanding of climate, the long-term average conditions. With the need to consider climate change in planning and management, an understanding of how climate may change in the future in a resource management planning area is valuable. In this chapter, we present the current understanding of potential future changes in climate for the Northern Rockies region.

Climate within the Northern Rockies region is influenced by the warm, wet maritime airflows from the Pacific Ocean and the cooler, drier airflows from Canada. In the Western, Central, Eastern, and Greater Yellowstone Area subregions (see Fig. 1.1 in Chap. 1), climate, especially at local scales, is strongly influenced by interactions among topography, elevation, and aspect. On the eastern edge of the Northern Rockies region, the Grassland subregion is influenced primarily by the cooler, drier airflows from Canada. Consequently, there are broad east-west changes in precipitation seasonality and amount, as well as strong elevation influences on temperatures. Trends and drivers for climatic variations will differ greatly from east to west.

2.2 Climate Model Overview

Global climate models have been used to understand the nature of global climate, how the atmosphere interacts with the ocean and the land surface. Scientists can use these models to pose questions about how changes in atmospheric chemistry affect global temperature and precipitation patterns. Given a set of plausible greenhouse gas emission scenarios, these models can be used to project potential future climate. These projections can be helpful in understanding how the environmental conditions of plants and animals might change in the future; how streamflow might vary with precipitation and timing of snowmelt; how wildfire, insects and disease outbreaks might be affected by changes in climate; and how humans might respond in their use of the outdoors and natural resources.

The Coupled Model Intercomparison Project (CMIP) began in 1995 to coordinate a common set of experiments for evaluating changes to past and future global climate (Meehl et al. 2007). This approach allows comparison of results from different global climate models around the world and improves our understanding of the "range" of possible climate change. The third CMIP modeling experiments, or CMIP3, were used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007), whereas CMIP5, the latest experiments, were used in the IPCC Fifth Assessment Report (IPCC 2013). The CMIP3 simulations of the twenty-first century were forced with emission scenarios from the Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000). The CMIP5 simulations of the twenty-first century are driven by representative concentration pathways (RCPs) (van Vuuren et al. 2011). The RCPs do not define emissions, but instead define concentrations of greenhouse gases and other agents influencing the climate system. RCPs represent the range of current estimates regarding the evolution of radiative forcing, the total amount of extra energy entering the climate system throughout the twenty-first century and beyond. Projections made with RCP 2.6 show a total radiative forcing increase of 2.6 Wm^{-2} by 2100; projected increased radiative forcing through the scenarios of RCP 4.5, RCP 6.0 and RCP 8.5 indicate increases of 4.5, 6.0, and 8.5 Wm^{-2}, respectively. Unlike the SRES scenarios used in CMIP3, the RCPs in CMIP5 do not assume any particular climate policy actions.

2.3 Methods Used to Assess Future Climate in the Northern Rockies Region

In this chapter, we use results from the CMIP5 climate models to explore potential changes in the climate of the Northern Rockies region. Because output from global climate models is generally too coarse to represent climate dynamics in subregions and management areas relevant for the Northern Rockies, we utilized one of the many methods to bring climate projection information down to a scale that can be helpful to resource managers. We drew on climate projections that had been downscaled using the bias-correction and spatial disaggregation (BCSD) method (Maurer et al. 2007). Historical modeled and projected monthly temperature and precipitation for the 1950–2099 period were obtained from the Climate and Hydrology Projections archive at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. We used projections from 36 climate models for RCP 4.5 and 34 climate models for RCP 8.5 (Joyce et al. 2017). Spatial resolution of the data is 1/8-degree latitude-longitude and covers the entire Northern Rockies region.

Many of the resource chapters in this book drew on the CMIP3 projections that have been widely used in other assessments, such as the National Climate Assessment (Walsh et al. 2014), and the Forest Service Resource Planning Act Assessment (U.S. Department of Agriculture Forest Service 2012). Climate projections by Littell et al. (2011) have been used widely in the Pacific Northwest, hence we compared the CMIP5 results with the CMIP3 projections of Littell et al. (2011). For the Northern Rockies Region, projected change in temperature by the 2040–2060 period ranges from just under 1.1 °C to nearly 4.4 °C, with greater projected change under the RCP 8.5 scenario than the RCP 4.5 scenario. Change in precipitation across these CMIP5 models ranges from a decrease of 5% to an increase of 25% with a mean projected change of around 6% and 8% for RCP 4.5 and RCP 8.5, respectively. We conclude that the CMIP3 results for this region are in the same temperature range for the 2040–2060 period as the CMIP5 results presented here, but the CMIP5 precipitation projections are slightly wetter in the future (Joyce et al. 2017).

To report on the CMIP5 results for the Northern Rockies region, we used a base period of 1970–2009 for the historical climate, and compare projections for two periods (2030–2059, 2070–2099) with this historical climate (Fig. 2.1). These time periods were selected in an attempt to summarize climate that has influenced the current conditions (base period) and two future periods that will be relevant to long-term management action (such as road construction, hydrological infrastructure [see Chap. 3], or vegetation planting [see Chap. 5]). We report on the potential variability in projected climate across the Northern Rockies region by summarizing temperature and precipitation in the five subregions: Western Rockies, Central Rockies, Eastern Rockies, Greater Yellowstone Area, and Grassland (see Fig. 1.1 in Chap. 1). Data analysis was carried out in R (R Core Team 2016).

2.4 Projected Future Climate in the Northern Rockies

All subregions in the Northern Rockies will see increasingly warmer temperatures through the twenty-first century (Fig. 2.1). The historical map reflects the cooler temperatures in the mountainous regions, with the Greater Yellowstone Area subregion the coolest area and the Grassland subregion the warmest (Fig. 2.1). All areas are projected to warm under both RCPs, but warming is greater under RCP 8.5. Projections for precipitation suggest a slight increase in the future. However, precipitation projections, in general, have much higher uncertainty than those for temperature.

In the Western Rockies subregion, mean temperature is projected to increase 2.8–5.6 °C by 2100. Historically, winter, spring, and autumn minimum temperatures have been below freezing, a biologically important threshold. Spring minimum temperatures rise above freezing by mid-twenty-first century for RCP 8.5 and by 2080 in the RCP 4.5 scenario. Winter minimum temperatures remain below freezing in both future scenarios. However, maximum temperatures for winter, historically just below freezing, rise above freezing in both scenarios by the end of the century. Seasonal precipitation is projected to be slightly wetter in winter and spring, and slightly drier in summer.

In the Central Rockies subregion, annual mean monthly minimum temperature is projected to increase 3.3–6.7 °C, and annual mean monthly maximum temperature is projected to increase 2.8–6.1 °C by 2100. Summer mean maximum temperatures are projected to rise 2.8–6.5 °C, with the projected temperatures for the RCP 8.5 scenario outside of the historical ranges. Mean monthly minimum temperature (spring and autumn) and the mean monthly maximum temperature (winter), all historically below freezing, may rise above freezing by mid- to late-century. Seasonal precipitation is projected to be slightly wetter in winter and spring, and slightly drier in summer.

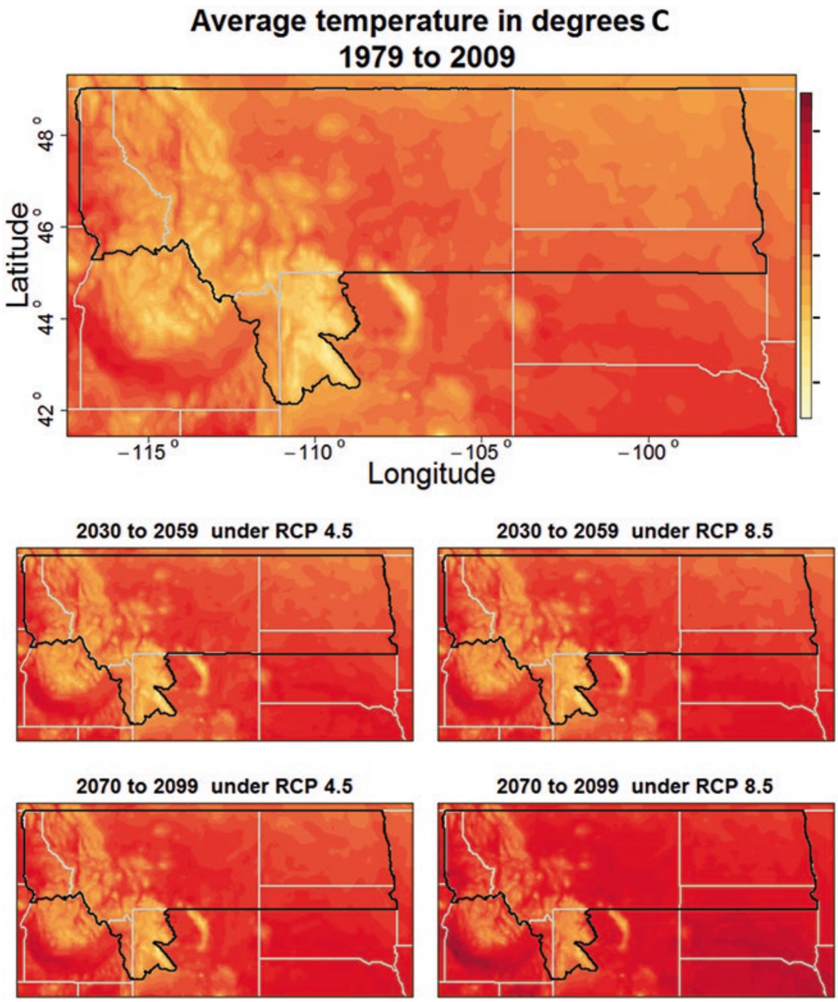

Fig. 2.1 Historical (1970–2009) and projected (2030–2059 and 2070–2099) mean annual monthly temperature for the Northern Rockies region under RCP 4.5 and RCP 8.5 scenarios. Projected climate results are the mean of 36 models for RCP 4.5 and 34 models for RCP 8.5. Spatial resolution of the data is 1/8-degree latitude-longitude

By 2100, annual mean monthly minimum temperature in the Eastern Rockies subregion is projected to increase 3.3–6.1 °C, and annual mean monthly maximum temperature is projected to increase 2.8–6.1 °C. Mean monthly maximum and minimum temperatures are projected to increase for all seasons. Mean monthly minimum temperature (spring and autumn) have historically been below freezing; these seasonal temperatures are projected to increase 2.8 °C for RCP 4.5, resulting in temperatures around freezing by end of twenty-first century. For the warmer scenario, summer maximum temperatures are projected to increase by 5.5 °C. The majority of the model projections rise above the historical range by the end of the century.

In the Greater Yellowstone Area subregion, annual mean monthly minimum temperature is projected to increase 2.8–5.6 °C, and annual mean monthly maximum temperature is projected to increase 3.9–6.7 °C by 2100. Winter maximum temperature is projected to rise above freezing in the mid-twenty-first century. Projected summer temperature is projected to increase 2.8 °C by 2060 and 5.6 °C by 2100. The Greater Yellowstone Area subregion is an area where changes at the local scale may differ from these broader estimates because of the complexities of topography, elevation, and aspect. These terrain complexities as well as snowpack conditions may provide areas of refugia for both plants and animals as climate changes.

For the Grassland subregion, warming trends indicate that future climate will be similar to the area south of this region. There is a pattern of a drier west and wetter east, with the average of climate models showing a slight shift to more of the wetter east. However, even with little or no change in precipitation, there is the potential for summer drying or drought caused by increased heat and increased evapotranspiration. Summer maximum temperatures increase by more than 6.5 °C; the majority of the projections by 2100 are outside of the historical range of maximum summer temperatures. Early snowmelt from the west will imply changes in streamflow and temperature, and therefore reservoir management and stream ecology.

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References

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate change 2007—The physical science basis. Climate change 2007 working group I contribution to the fourth assessment report of the IPCC*. New York: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2013). *Climate change 2013—The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge/New York: Cambridge University Press.

Joyce, L. A., Talbert, M., Sharp, D., et al. (2017). Historical and projected climate in the Northern Rockies Adaptation Partnership Region. In: J. E. Halofsky, D. L. Peterson, S. K. Dante-Wood, et al. (Eds.), *Climate change vulnerability and adaptation in the Northern Rocky Mountains* (General Technical Report RMRS-XXX). Fort Collins: U.S. Forest Service, Rocky Mountain Research Station.

Littell, J. S., Elsner, M. M., Mauger, G., et al. (2011). Regional climate and hydrologic change in the northern US Rockies and Pacific Northwest: Internally consistent projections of future climate for resource management. Seattle: Climate Impacts Group, University of Washington

College of the Environment. http://cses.washington.edu/picea/USFS/pub/Littell_etal_2010. 5 Dec 2016.

Maurer, E. P., Brekke, L., Pruitt, T., & Duffy, P. B. (2007). Fine-resolution climate projections enhance regional climate change impact studies. *Eos Transactions of the American Geophysical Union, 88*(47), 504–504.

Meehl, G. A., Covey, C., Delworth, T., et al. (2007). The WCRP CMIP3 multimodel data set. *Bulletin of the American Meteorological Society, 88*(9), 1383–1394.

Nakićenović, N., Davidson, O., Davis, G., et al. (2000). *Special report on emissions scenarios: A special report of working group III of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

R Core Team. (2016). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Vienna, Austria. Url: https://www.R-project.org/

U.S. Department of Agriculture, Forest Service. 2012. Future of America's forests and rangelands: Forest Service 2010 Resources Planning Act Assessment (General Technical Report WO-87). Washington, DC: U.S. Forest Service.

van Vuuren, D. P., Edmonds, J., Kainuma, M., et al. (2011). The representative concentration pathways: An overview. *Climatic Change, 109*(1-2), 5–31.

Walsh, J., Wuebbles, D., Hayhoe, K., et al. (2014). Our changing climate. In J. M. Melillo, T. C. Richmond, & G. W. Yohe (Eds.), *Climate change impacts in the United States: The third National Climate Assessment* (pp. 19–67). Washington, DC: U.S. Global Change Research Program.