

Climate Change Trends for Planning at Glacier National Park, Montana

Prepared by Nicholas Fisichelli, NPS Climate Change Response Program July 22, 2014

Climate Change and National Parks

Climate change, in conjunction with other stressors, impacts all aspects of park management from natural and cultural resource protection to park operations and visitor experience. Effective planning and management must be grounded in our comprehension of past dynamics as well as the realization that future conditions may shift beyond the historical range of variability. Climate change will manifest itself not only as shifts in mean conditions (e.g., increasing mean annual temperature and sea level) but also as changes in climate variability (e.g., more intense storms and flooding). Park managers are dealing with both rapid directional change and tremendous uncertainty (Heller and Zavaleta 2009), and understanding climate change projections and associated levels of uncertainty will facilitate planning actions that are robust regardless of the precise magnitude of change experienced in the coming decades.

Historical climate trends (1895-2010)

Historical annual temperature and precipitation trends (1895-2012) for Glacier National Park are based on gridded climate data (PRISM, www.prism.oregonstate.edu) averaged across the entire park area. Over the 116 year record, mean annual temperature showed an increasing linear trend (+0.08 °C [0.14 °F] per decade, $p = 0.0003$; Fig. 1), and warming has accelerated since 1980 (+0.45 °C [0.8 °F] per decade, $p = 0.009$). Annual precipitation showed strong interannual variability and no significant linear trend across the entire record (Fig. 1). Recent snowfall and snowmelt trends across the western U.S. also reflect the changing climate. More precipitation is falling as rain rather than snow and snowmelt is beginning earlier, resulting in anomalously low spring snowpack (Knowles et al. 2006, Pederson et al. 2011). Glaciers have been receding within Glacier National Park, with 67% of glaciers present in 1850 gone by 1980 (Carrara and McGimsey 1981). The pattern of glacial melt and retreat is most strongly related to increasing summer temperatures (Hall and Fagre 2003).

Future climate projections

Future climate projections for the area including Glacier National Park are from multi-model averaged data (Kunkel et al. 2013). Mean annual temperature, compared with the 1971-1999 average, is projected to increase 1.7-2.8 °C (3-5 °F) by mid-century and 2.2-3.9 °C (4-7 °F) by the end of the century, depending on the greenhouse gas emissions scenario (Fig. 1). Past greenhouse gas emissions, long residence time of these gases in the atmosphere, and our current emissions trajectory suggest that climate change will be substantial (Wigley 2005, Peters et al. 2013). Warming by mid-century is projected for all seasons, with the greatest increases likely in summer (Fig. 2). There is wide agreement among individual climate models in the direction and general magnitude of warming over the coming decades. Total annual precipitation may increase slightly by mid-century, with increases coming in winter and decreases in summer (Fig. 1,3);

however, precipitation variability is likely to remain large over the coming decades, and there is greater uncertainty in precipitation than temperature projections (Kunkel et al. 2013).

In addition to warmer mean temperatures and changes in annual and seasonal precipitation, climate change will exhibit itself in many other ways. These include more frequent heat waves, droughts, floods, and an extended frost-free season. The length of the frost-free season is projected to expand by 3-4 weeks for the region including Glacier (high [A2] emissions scenario 2041-2070 compared with 1980-2000; Kunkel et al. 2013). Spring snowmelt and the beginning of the growing season (spring greening) may occur a month earlier by the end of the century (Boisvenue and Running 2010). Additionally, the period of late-summer dryness is projected to expand 6-8 weeks by the end of the century with 85% of years (2006-2089) with water stress levels above the 1950-2005 average (Boisvenue and Running 2010). Glaciers will continue to disappear with the rate of glacial melt accelerating with temperature; under a high greenhouse gas emissions scenario, all glaciers may be lost by 2030 (Hall and Fagre 2003).

Future climate projections for Glacier include both rapid directional change and complex uncertainties. For example, temperatures have been rising and this trend is very likely to continue. Key uncertainties include actual future greenhouse gas emissions, precise sensitivity of the climate system to these emissions, and ongoing short-term variations in climate (Hawkins and Sutton 2009). Given these trends and our understanding of climate science, it is essential to consider the broad, plausible range of future conditions within Glacier rather than a single forecast of the future.

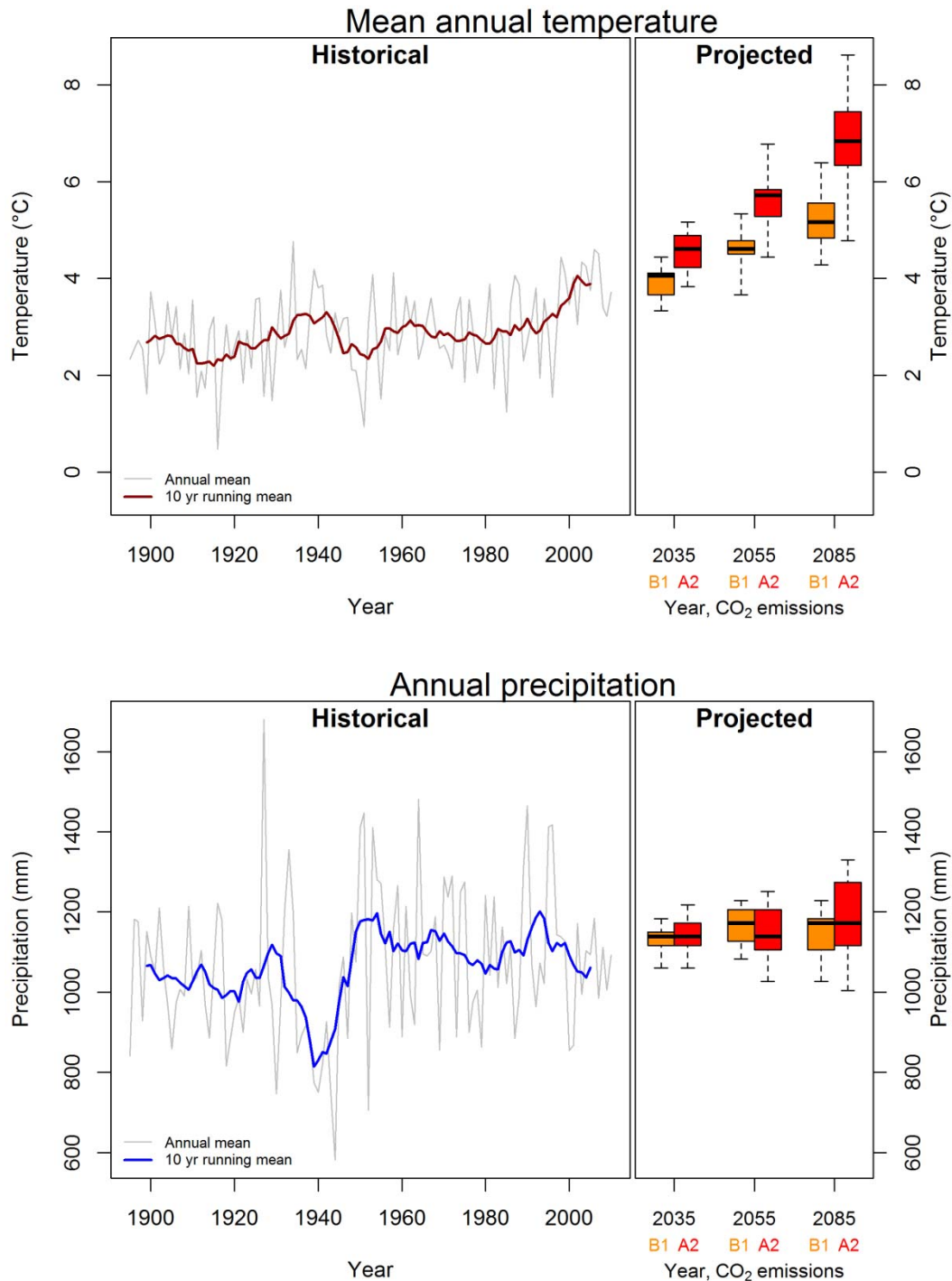


Figure 1. Historical and projected mean annual temperature and annual precipitation for Glacier National Park region. Historical trends are based on gridded climate data (www.prism.oregonstate.edu) averaged across the entire park. Projected climate change (30 year means) for the region including the park (data from Kunkel et al. 2013, see Tables 4, 6 and Figures 13, 24) are for three future periods centered on 2035 (2021-2050), 2055 (2041-2070), and 2085 (2070-2099). Two greenhouse gas emissions scenarios are presented, the low (B1) and high (A2) scenarios (IPCC 2007). Projected climate boxplots indicate the variability in future projections among 14-15 CMIP3 climate models. Values for the area including Glacier are based on the mean model output for that location (bold horizontal black line) and the range of climate model projections for the region (the upper and lower bounds of the boxes indicate the 25th and 75th percentile model output values and the whiskers show the minimum and maximum change).

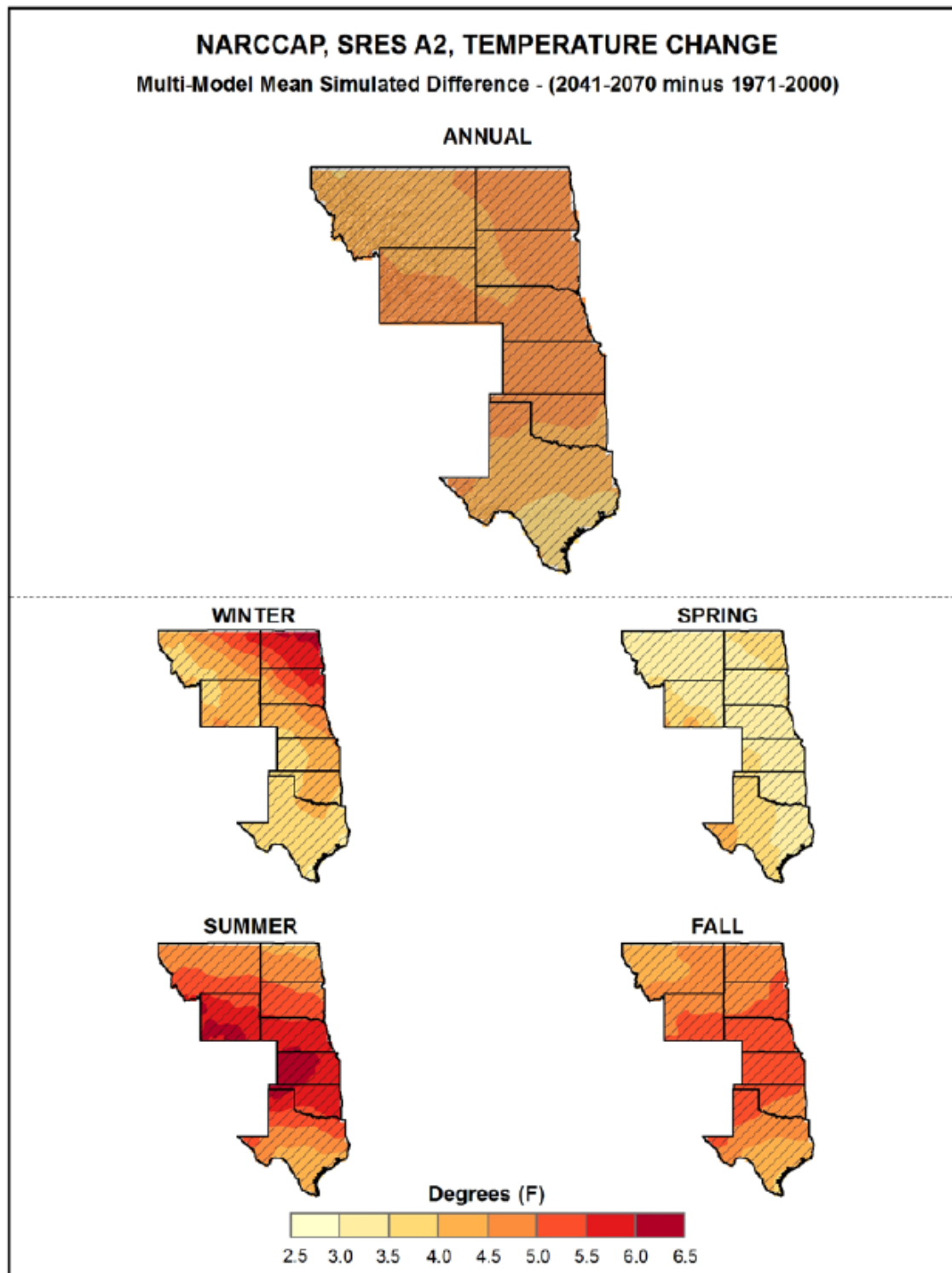


Figure 2. Projected annual and seasonal temperature change. Maps show projected change in average surface air temperature in mid-century (2040-2070) relative to the later part of the last century (1971-2000). Projected changes are averages from 11 NARCCAP regional climate simulations for the high (A2) emissions scenario. Color with hatching indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change. Figure and legend from Kunkel et al. (2013).

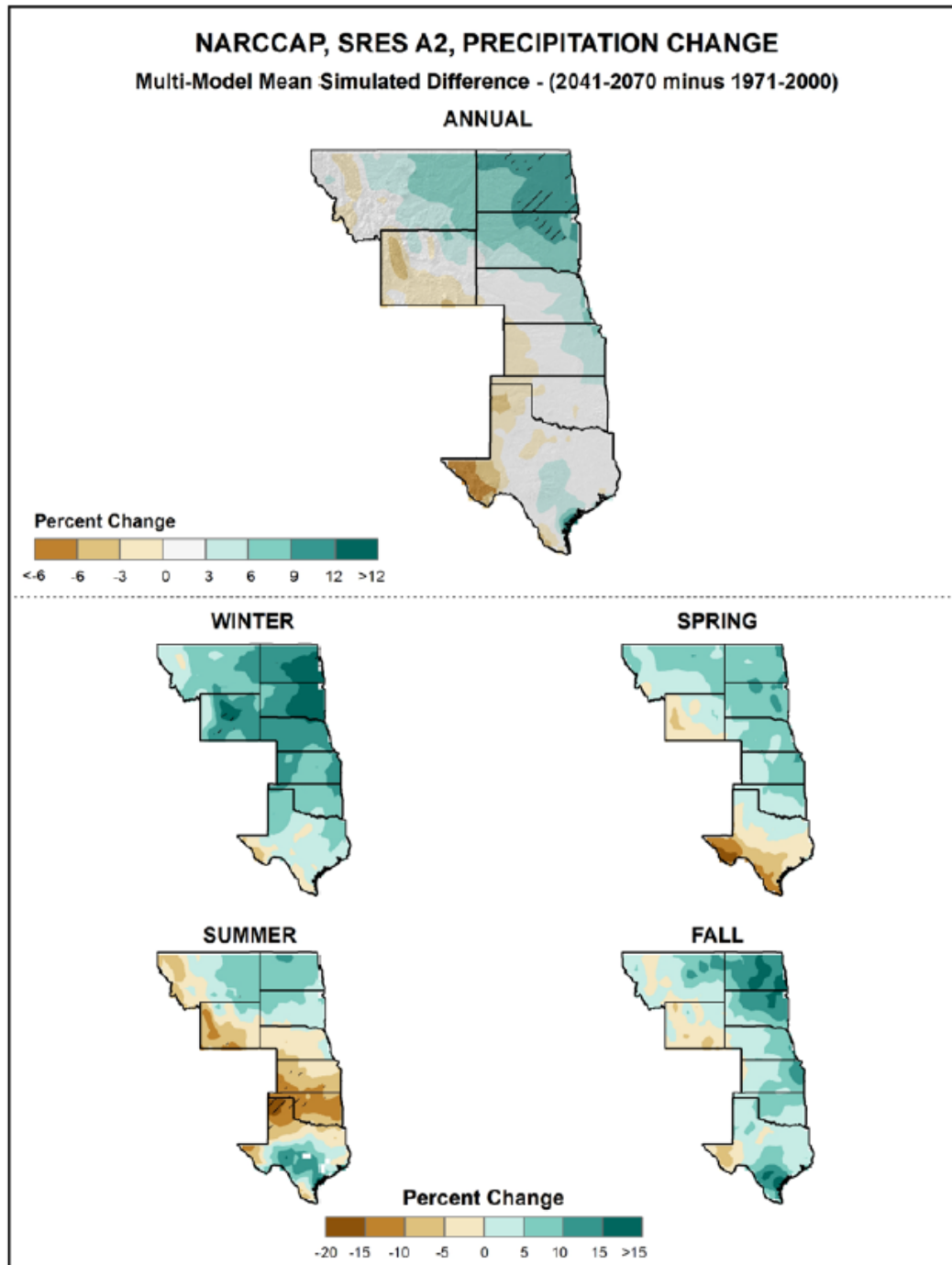


Figure 3. Projected annual and seasonal precipitation change. Maps show projected change in precipitation for mid-century (2040-2070) relative to the later part of the last century (1971-2000). Projected changes are averages from 11 NARCCAP regional climate simulations for the high (A2) emissions scenario. Color only indicates that less than 50% of the models show a statistically significant change in precipitation. Color with hatching indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change. Whited out areas indicate that more than 50% of the models show a statistically significant change in precipitation, but less than 67% agree on the sign of the change. Figure and legend from Kunkel et al. (2013).

References

- Boisvenue, C., S. W. Running. 2010. Simulations show decreasing carbon stocks and potential for carbon emissions in Rocky Mountain forests over the next century. *Ecological Applications* 20:1302-1319.
- Carrara, P. E., R. G. McGimsey. 1981. The late-neoglacial histories of the Agassiz and Jackson glaciers, Glacier National Park, Montana. *Arctic and Alpine Research* :183-196.
- Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28:2031-2064.
- Hall, M. H., D. B. Fagre. 2003. Modeled climate-induced glacier change in Glacier National Park, 1850-2100. *Bioscience* 53:131-140.
- Hawkins, E., R. Sutton. 2009. The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society* 90:1095-1107.
- Heller, N. E., E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation* 142:14-32.
- Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States. *Journal of Climate* 19:4545-4559.
- Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, M.C. Kruk, D.P. Thomas, M. Shulski, N. Umphlett, K. Hubbard, K. Robbins, L. Romolo, A. Akyuz, T. Pathak, T. Bergantino, and J.G. Dobson, 2013: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 4. Climate of the U.S. Great Plains.
- Pederson, G. T., S. T. Gray, C. A. Woodhouse, J. L. Betancourt, D. B. Fagre, J. S. Littell, E. Watson, B. H. Luckman, and L. J. Graumlich. 2011. The unusual nature of recent snowpack declines in the North American Cordillera. *Science* 333:332-335.
- Peters, G. P., R. M. Andrew, T. Boden, J. G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M. R. Raupach, and C. Wilson. 2012. The challenge to keep global warming below 2 °C. *Nature Climate Change*.
- Wigley, T. M. 2005. The climate change commitment. *Science* 307:1766-1769.