Future Precipitation in the Denver Metro Area

By
Stephen Saunders, Tom Easley,
and Melissa Mezger

A report by the
Rocky Mountain Climate Organization

To
Denver Environmental Health

June 2017

The Rocky Mountain Climate Organization works to reduce climate disruption and its impacts to help keep the Interior West the special place we cherish. We do this in part by spreading the word about what a disrupted climate can do to us here and what we can do about it, through reports such as this, and also by advocating public and private actions.

RMCO does much of its work in partnership with local governments, including through the Colorado Climate Network, which supports local climate programs and is administered by RMCO for its members. The City and County of Denver is a charter member of the Network.

The Rocky Mountain Climate Organization
PO Box 270444, Louisville, CO 80027
303-861-6481
www.rockymountainclimate.org

Denver's Department of Environmental Health is dedicated to advancing Denver's environmental and public health goals. DEH works collaboratively with city, state, and community partners to conduct education, community engagement, and enforcement to ensure healthy people, healthy pets, and a sustainable environment. Our mission is to create a city with a world class environment and healthy communities for all ages and incomes, and where the well-being of our pets also matters. Through the Climate Action Plan, Denver Energy Challenge, and other programs, DEH works with partners to conserve energy, reduce greenhouse gasses, and promote sustainability.

Acknowledgements

The authors wish to thank for providing counsel, information, or comments on a draft of this report or on two previous RMCO reports that provided an analytic foundation for this report: Nolan Doesken, Colorado Climate Center, Colorado State University; Taryn Finnessey, Colorado Water Conservation Board; Alexander Gershunov, Scripps Institution of Oceanography, University of California, San Diego; Jeff Lukas, Western Water Assessment, University of Colorado, Boulder; Kelly Mahoney, Earth Systems Research Laboratory, National Oceanic and Atmospheric Administration; Imtiaz Rangwala, Western Water Assessment; and Bradley Udall, Colorado Water Institute, Colorado State University.

We also thank for their assistance throughout this project Elizabeth Babcock, David Erickson, and Tom Herrod, Department of Environmental Health, City and County of Denver.

Introduction

This report, a companion to a larger report by the Rocky Mountain Climate Organization (RMCO) on projected temperature extremes in the Denver metropolitan area,[1] describes how climate change is projected to lead to changes in precipitation in that area. The methodology for this report follows that for the report on temperature extremes, and readers are referred to that report for more details beyond those presented here.

Geographic area

This analysis covers a grid of one-quarter of a degree of latitude by one-quarter of a degree of longitude, or about 14 miles by 18 miles. This is much of the Denver metro area, as shown below.

Denver metro grid for projections

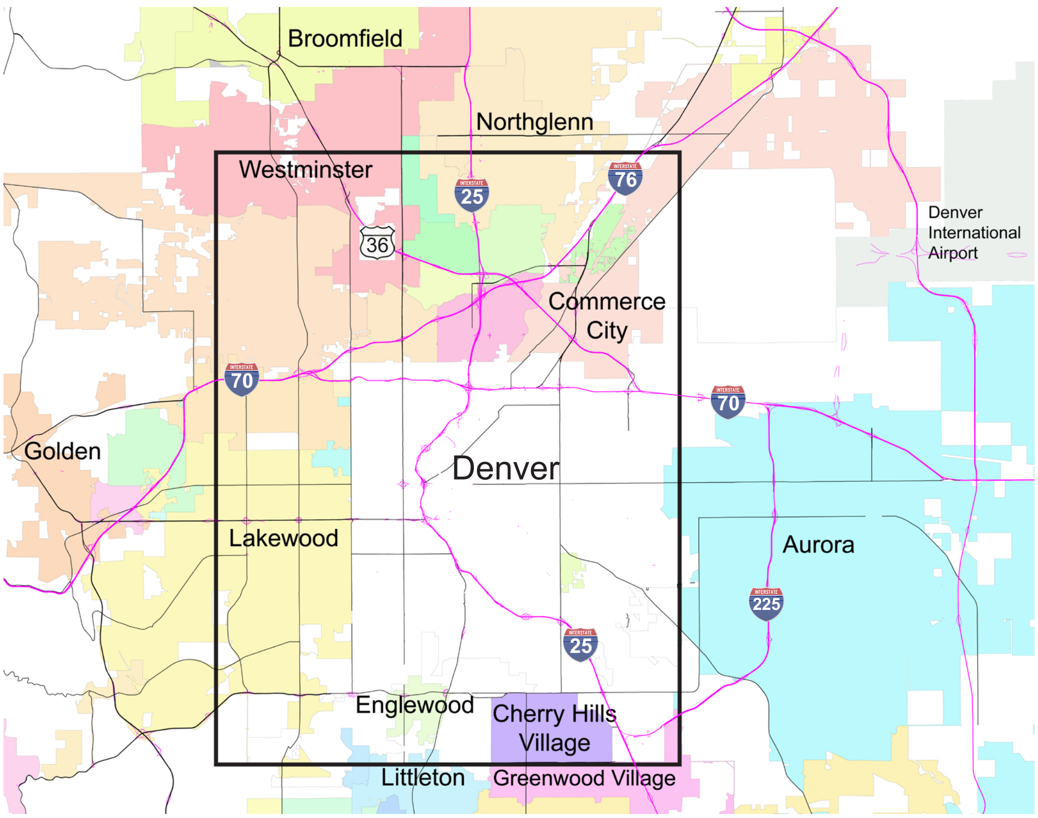


Figure 1. The area for which climate projections were analyzed.

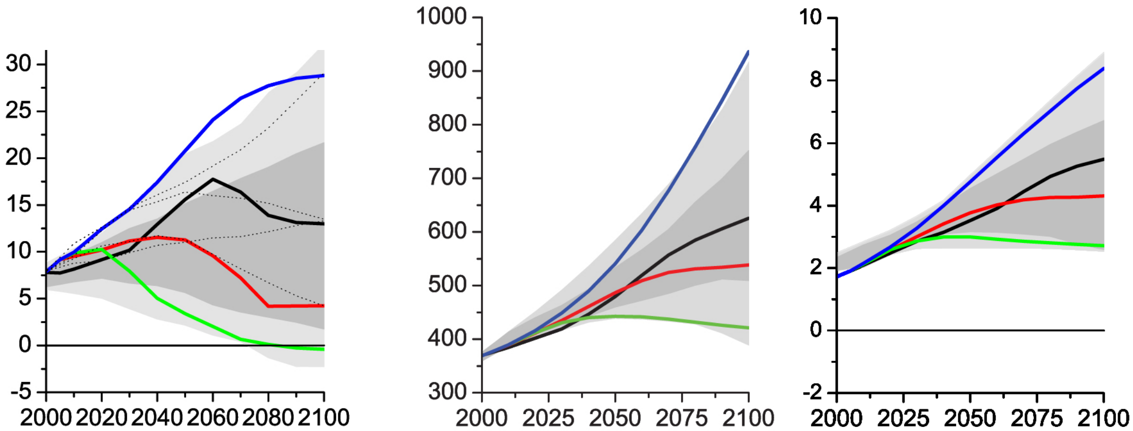
Emissions scenarios

This report analyzes projections for future precipitation within the grid shown in Figure 1 for four different, alternative future levels of heat-trapping emissions. These four scenarios, comprising the latest generation of such inputs for modeling future climate, are:[2]

- What we call here the **high** scenario. Officially known as Representative Concentration Pathway (or RCP) 8.5, it assumes no reduction in the current trend of annually increasing emissions, and so can be considered a business-as-usual approach. The high scenario is represented by the blue lines in Figure 2, on the next page.
- A **medium #1** scenario. Officially known as RCP 6.0, it starts out with the lowest initial emissions levels of all scenarios but then has sharp increases. After the 2060s, it leads to the second highest level of atmospheric concentrations of heat-trapping gases. This scenario is represented by the black lines in Figure 2.

- A **medium #2** scenario, or RCP 4.5. It starts out with higher emissions than medium #1 but then has major reductions after mid-century, as shown by the red lines in Figure 2.
- A **very low** scenario, RCP 2.6. It assumes emissions cuts of more than 70 percent from current levels by 2050 and an elimination of net human emissions by about 2080—assumptions chosen to result in about 2.5° of average warming in this century. The very low scenario is represented by the green lines in Figure 2.

Scenarios of Future Heat-Trapping Emissions



A. Annual Emissions of Carbon Dioxide

B. Atmospheric Concentrations of Carbon Dioxide

C. Radiative Forcing

Figure 2. Key values for the four emissions scenarios used in this analysis: A, annual global emissions of carbon dioxide, the principal heat-trapping pollutant, in gigatons of carbon; B, atmospheric concentrations of carbon dioxide, in parts per million; and C, radiative forcing, or the average warming at Earth's surface resulting from heat-trapping pollution, in watts per square meter. In all three parts of the figure, the blue lines represent the scenario identified as "high" in this report; the black lines, "medium #1"; the red lines, "medium #2"; and the green lines, "very low." Figures provided by Detlef van Vuuren.[3]

Climate models

The precipitation projections used in this analysis were obtained by RMCO from an online archive created by the U.S. Bureau of Reclamation and other institutions.[4] The projections are from the latest generation of climate models, known as CMIP5 models. (For more details, see the Methodology section on page 18 of the companion RMCO report on temperature extremes referred to on page 1.) The projections analyzed here are for daily precipitation amounts, with one set of projections obtained from each of the available models using the different emission scenarios—20 climate models for the high scenario, 12 for medium #1, 19 for medium #2, and 16 for the very low scenario. Projections for individual days have no particular reliability, but the projected frequency of particular conditions over extended periods (such as the 20-year periods used here) does have value. Analyzing daily data in this way is rare, as it requires starting with thousands of times more individual projections than for a comparable analysis of average conditions.

In all, about 15 million individual projections of daily precipitation amounts were obtained, covering 150 years, 67 emissions scenario/climate model pairings, and the four small grids comprising the area analyzed here.

For this report, 15 million projections of future daily precipitation amounts were analyzed.

Precipitation Projections

The projections obtained for this report were analyzed for how 68 different measures of the Denver metro area's precipitation may change over time in response to the different levels of heat-trapping gases assumed in the four emission scenarios. These 68 climate values include the projected frequency of storms of different intensity; total precipitation amounts per year, season, and more. For the full results of the analysis of all 68 climate values, see the spreadsheet available at rockymountainclimate.org/extremes/denver.

Uncertainties

To begin with, there are greater uncertainties with the precipitation projections presented here than for the temperature projections presented in the companion RMCO report on future extreme heat in the Denver metro area. The greater uncertainties about the precipitation projections result from several reasons.

First, climate models are more uncertain for precipitation than for temperature on regional scales, particularly in mid-latitude areas (such as Colorado) between northern areas where precipitation increases are clearly projected and sub-tropical areas where decreases are clearly projected.[5]

Second, model variations are even larger for small areas (like the grid analyzed here) than for large ones. Statewide projections for mid-century with continued high emissions range from a 3 percent decrease to an 8 percent increase (the 10th to the 90th percentiles of the projections), compared to 1971–2000.[6] For the Denver metro grid analyzed here, the corresponding projections from the same climate models have a wider spread, from -4 percent to +21 percent, as shown in Table 1 on pages 5-6.

Third, climate models are more accurate in projecting overall precipitation amounts than extreme precipitation events, which by definition are relatively rare.[7]

Fourth, today's climate models do not do a good job of simulating the North American monsoon and thunderstorms that drive much of Colorado's summer precipitation, making summer projections for this area more uncertain.[8]

Finally, as a careful examination of the precipitation projections presented here shows, there is not the same clear relationship between the different levels of atmospheric concentrations of heat-trapping gases assumed in the different scenarios and the extents of the projected changes. By contrast, there is such a clear relationship in the temperature projections from the same models, as documented in the companion RMCO report on projected extreme heat.

The Projections

Even with the above caveats, the projections provide useful information, primarily by strongly suggesting that there could be an increase in the frequency of heavy storms.

Figure 3 on the next page shows the projections for storms of different intensity—routine wet days, with less than a quarter-inch of precipitation in a day; storms of 1/4 inch up to 1/2 inch of precipitation; and those of a 1/2 inch or more. The frequency of the routine wet days is projected to change only a little. There is variation in the projections for the larger storms, with some projections (those indicated by the lighter colors in the figure's columns) suggesting decreased frequencies. Most of the projections, though, suggest that storms of moderate intensity will increase somewhat in frequency, and that the heavier storms will have even larger percentage increases in their average frequency.

Table 1, which follows on pages 5–6, presents key data from the precipitation analysis, including the numerical values graphically illustrated in Figure 3.

The projections strongly suggest that climate change could lead to an increase in the frequency of intense storms.

Frequency of storms by intensity
Comparisons to 1970–1999

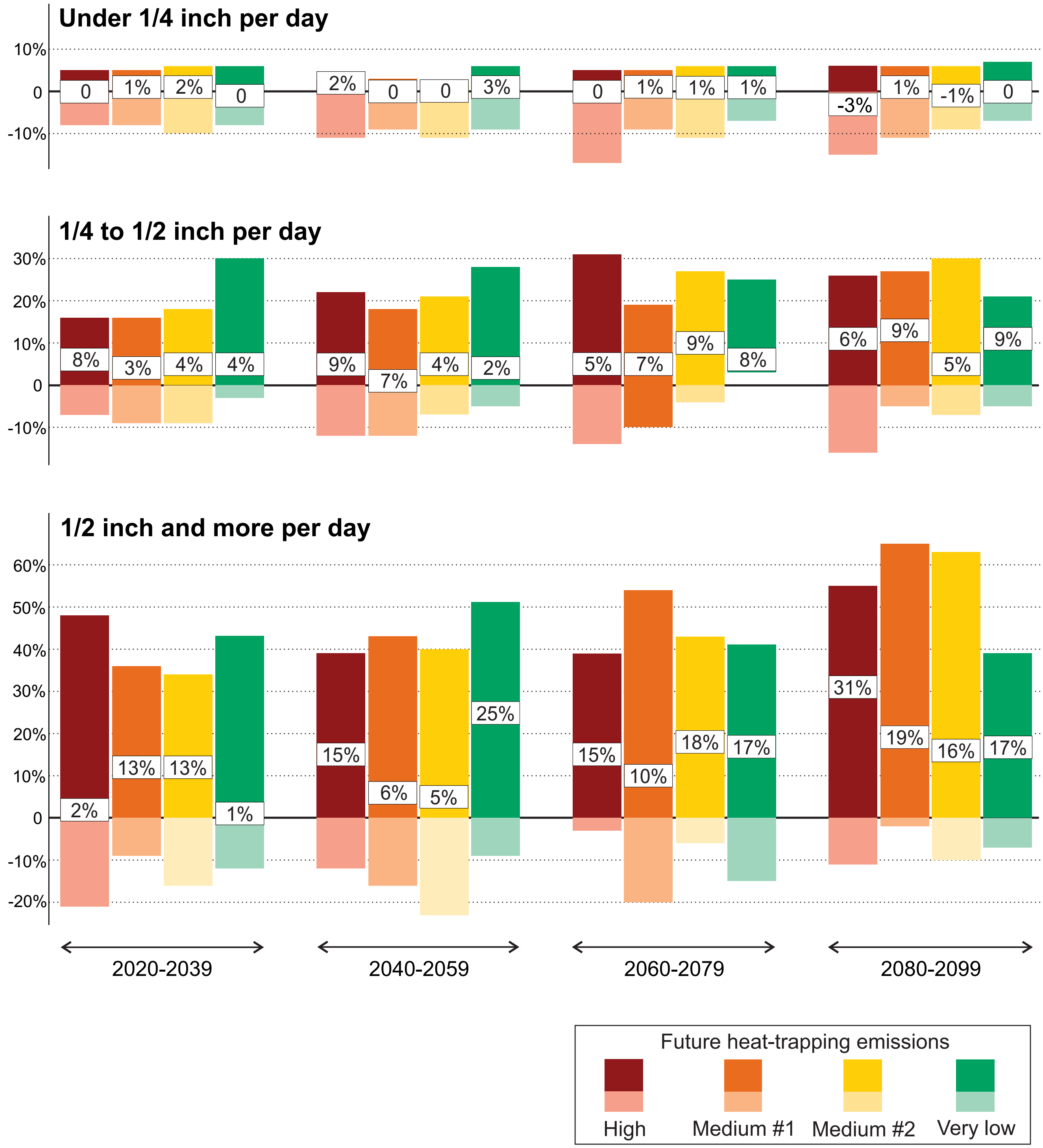


Figure 3. Annual frequency of storms by size, in inches of precipitation per day, for the four alternative scenarios of future heat-trapping emissions levels identified on pages 1–2, compared to average modeled values for 1970–1999 from all 20 climate models, in the Denver metro area.[9] The columns represent the range of the middle 80 percent of projections (in other words, from the 10th percentile to the 90th percentile), with darker colors representing projected increases and lighter colors projected decreases. For the actual average frequencies of these storms in 1970–1999, see Table 1 on pages 5–6.

Daily precipitation in Denver metro area

Actual values for 1970–1999 and projected changes compared to 1970–1999

	1970-99 Actual	Projections with Different Emission Levels: 2020–2039 High	Med. #1	Med. #2	Very Low	2040–2059 High	Med. #1	Med. #2	Very Low
Days w/ less than 0.25 in. precip	116	0% *-8/5%*	1% *-8/5%*	2% *-10/6%*	0% *-8/6%*	2% *-11/6%*	0% *-9/4%*	0% *-11/5%*	3% *-9/7%*
Days w/ 0.25 in. to 0.5 in. precip	11	8% *-7/16%*	3% *-9/16%*	4% *-9/18%*	4% *-3/30%*	9% *-12/22%*	7% *-12/18%*	4% *-7/21%*	2% *-5/28%*
Days w/ 0.5 in. or more precip	5	2% *-21/48%*	13% *-9/36%*	13% *-16/34%*	1% *-12/44%*	15% *-12/39%*	6% *-16/43%*	5% *-23/40%*	25% *-9/51%*
Days w/ 0.5 in. to 1 in. precip	4	6% *-18/47%*	13% *-14/34%*	12% *-14/35%*	4% *-10/43%*	19% *-9/38%*	8% *-15/34%*	8% *-25/35%*	24% *-6/56%*
Days w/ 1 in. or more precip	1	-2% *-58/53%*	34% *-39/134%*	-4% *-31/54%*	-2% *-48/70%*	5% *-58/47%*	12% *-52/49%*	10% *-48/107%*	5% *-48/84%*
Precip in wettest day in year	1.2 in.	0% *-14/17%*	6% *-2/13%*	-4% *-12/11%*	1% *-14/13%*	3% *-10/12%*	-1% *-11/8%*	-1% *-14/18%*	3% *-13/11%*
Avg precip of 3 wettest days in yr	0.9 in.	0% *-11/15%*	5% *-1/17%*	1% *-9/12%*	3% *-7/13%*	4% *-7/14%*	4% *-9/10%*	-1% *-11/21%*	7% *-6/13%*
Precip amount in year	16.6 in.	4% *-6/11%*	4% *-3/10%*	-1% *-4/11%*	3% *-5/14%*	3% *-7/13%*	-2% *-6/13%*	0% *-7/13%*	4% *-4/21%*
Precip amount in Dec-Jan-Feb	2.3 in.	12% *-1/28%*	12% *5/21%*	8% *1/15%*	11% *5/19%*	18% *6/34%*	13% *2/29%*	12% *-1/22%*	7% *0/24%*
Precip amount in Mar-Apr-May	6.0 in.	1% *-14/16%*	7% *-5/17%*	1% *-6/19%*	6% *-10/26%*	7% *-9/24%*	1% *-6/23%*	3% *-10/22%*	6% *-4/25%*
Precip amount in Jun-Jul-Aug	5.7 in.	2% *-13/11%*	3% *-4/8%*	-3% *-15/15%*	-2% *-6/10%*	0% *-21/14%*	-4% *-9/3%*	-6% *-17/8%*	2% *-4/13%*
Precip amount in Sep-Oct-Nov	3.0 in.	6% *-11/15%*	2% *-9/11%*	-7% *-11/16%*	0% *-10/8%*	0% *-11/13%*	-9% *-11/4%*	1% *-8/9%*	0% *-15/21%*

Table 1 above, which continues on the next page, shows the projections for the frequencies of the storms of the three intensity categories (as illustrated in Figure 3) and projections for nine of the other values that were analyzed. (Again, the full results for all 68 values can be found in a spreadsheet at www.rockymountainclimate.org/extremes/denver.)

Daily precipitation in Denver metro area
continued

Projections with Different Emission Levels

	2060–2079				2080–2099			
	High	**Med. #1**	**Med. #2**	**Very Low**	**High**	**Med. #1**	**Med. #2**	**Very Low**
Days w/ less than 0.25 in. precip	0% *-17/5%*	1% *-9/5%*	1% *-11/6%*	1% *-7/6%*	-3% *-15/6%*	1% *-11/6%*	-1% *-9/6%*	0% *-7/7%*
Days w/ 0.25 in. to 0.5 in. precip	5% *-14/31%*	7% *-10/19%*	9% *-4/27%*	8% *3/25%*	6% *-16/26%*	9% *-5/27%*	5% *-7/30%*	9% *-5/21%*
Days w/ 0.5 in. or more precip	15% *-3/39%*	10% *-20/54%*	18% *-6/43%*	17% *-15/41%*	31% *-11/55%*	19% *-2/65%*	16% *-10/63%*	17% *-7/39%*
Days w/ 0.5 in. to 1 in. precip	17% *-1/43%*	7% *-20/51%*	13% *-8/42%*	16% *-17/36%*	30% *-11/55%*	19% *-4/44%*	17% *-10/56%*	16% *-5/45%*
Days w/ 1 in. or more precip	19% *-18/69%*	41% *-11/107%*	24% *-12/123%*	18% *-34/84%*	26% *-32/123%*	64% *-38/215%*	-4% *-31/101%*	-15% *-28/51%*
Precip in wettest day in year	3% *-6/20%*	7% *-6/23%*	4% *-6/22%*	5% *-10/19%*	3% *-9/20%*	8% *-8/17%*	3% *-8/18%*	0% *-9/12%*
Avg precip of 3 wettest days in yr	5% *-3/18%*	8% *-2/20%*	5% *-4/19%*	8% *-7/18%*	7% *-7/23%*	8% *-3/24%*	4% *-6/19%*	2% *-5/9%*
Precip amount in year	4% *-9/20%*	5% *-5/18%*	6% *-4/16%*	6% *-1/16%*	6% *-10/19%*	9% *-4/24%*	4% *-5/17%*	5% *-4/14%*
Precip amount in Dec-Jan-Feb	25% *3/39%*	16% *-2/24%*	14% *3/39%*	8% *-1/29%*	34% *14/60%*	23% *5/36%*	17% *3/27%*	10% *3/27%*
Precip amount in Mar-Apr-May	6% *-16/26%*	9% *-11/35%*	6% *-8/26%*	10% *-3/32%*	4% *-7/21%*	12% *-8/44%*	3% *-5/33%*	6% *-1/33%*
Precip amount in Jun-Jul-Aug	-8% *-25/11%*	0% *-8/12%*	-2% *-17/22%*	4% *-5/11%*	-9% *-37/23%*	0% *-15/11%*	-2% *-15/13%*	3% *-11/11%*
Precip amount in Sep-Oct-Nov	1% *-19/13%*	-1% *-11/12%*	2% *-9/12%*	1% *-12/12%*	3% *-13/15%*	4% *-11/11%*	3% *-12/13%*	1% *-11/9%*

The projections suggest that climate change could lead to an increase in winter precipitation and a decrease in summer precipitation.

Methodology

The climate projections used in this analysis were obtained from an online archive created by a consortium of partners: the U.S. Bureau of Reclamation, Climate Analytics Group, Climate Central, Lawrence Livermore National Laboratory, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, U.S. Geological Survey, and National Center for Atmospheric Research and maintained on a website operated by Santa Clara University.[11] For details on the methodology used for this analysis, see the explanation in the Methodology section of the companion RMCO report on projected extreme heat in the Denver metro area.[12]

The baseline values shown in the left-most column of Table 1 (on pages 5–6) are from an observed/gridded dataset on the same archive, in which records from weather stations have been extrapolated to provide a historic baseline for each 1/8-degree grid, both to provide an observation-based baseline for the projections and to enable the downscaling to a local scale of projections from the global climate models.

Notes

1. S. Saunders, T. Easley, and M. Mezger, Future Extreme Heat in the Denver Metro Area, report by the Rocky Mountain Climate Organization to the Department of Environmental Health, City and County of Denver (Denver: Department of Environmental Health, City and County of Denver, 2017), http://www.rockymountainclimate.org/extremes/denver.

2. For general information on the emissions scenarios, see J. Lukas and others, *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation (Second Edition—August 2014)*, (Boulder: University of Colorado Boulder, 2014), report by Western Water Assessment, University of Colorado Boulder, to the Colorado Water Conservation Board, p. 41, http://wwa.colorado.edu/climate/co2014report/Climate_Change_CO_Report_2014_FINAL.pdf.

3. Figures provided by D. van Vuuren, University of Utrecht, and are the same as in D. van Vuuren and others, “The representative concentration pathways: an overview,” *Climatic Change*, vol. 109 (2011), pp. 5–31, https://link.springer.com/article/10.1007/s10584-011-0148-z.

4. U.S. Bureau of Reclamation and others, “Downscaled CMIP3 and CMIP5 climate and hydrology projections,” http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/#Welcome. See also L. Brekke and others, 2013, “Downscaled CMIP3 and CMIP5 climate projections: Release of downscaled CMIP5 climate projections, comparison with preceding Information, and summary of user needs,” http://gdodcp.ucllnl.org/downscaled_cmip_projections/techmemo/downscaled_climate.pdf.

5. J. Walsh and others, “Chapter 2: Our changing climate,” in Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, T. C. Richmond, and G. W. Yohe, editors, (Washington: U.S. Global Change Research Program, 2014), p. 31; and Lukas and others (see note 2), p. 31.

6. Lukas and others, p. 64.

7. A. Gershunov and others, “Chapter 7: Future climate: Projected extremes,” in Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, G. Garfin and others, editors (Washington: Island Press, 2013).

8. K. Mahoney and others, “High-resolution downscaled simulations of warm-season extreme precipitation events in the Colorado Front Range under past and future climates,” Journal of Climate, volume 26 (2013), pp. 8671– 8689.

9. Data source: Bureau of Reclamation and others (see note 4).

10. Data source: Bureau of Reclamation and others.

11. Bureau of Reclamation and others.

12. Saunders and others (see note 1).