Projections of Climate Change Effects on Wildfire Risks in Colorado's Northern Front Range

A Rocky Mountain Climate Organization White Paper

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This white paper summarizes six scientific studies projecting how future climate change may affect future wildfire risks in areas encompassing Colorado's Northern Front Range, including the mountain portions of Boulder and Larimer counties. This white paper is a complement to two reports by the Rocky Mountain Climate Organization (RMCO) on how climate change is projected to lead to increases in extreme temperature and precipitation in the two counties.[1] The white paper is intended to enable local governments and others in the two counties compare the possible future local climate conditions identified in the RMCO reports with the climate conditions considered in the studies and the wildfire risks projected to result from those conditions.

Projected climate changes in the RMCO reports

The two RMCO reports present projections of future temperature and precipitation, showing how climate change may affect both average and extreme conditions in Boulder and Larimer counties. Projections are presented for all four current scenarios for future levels of heat-trapping emissions, from high to very low levels, covering four 20-year time periods in this century. There are separate projections for four local areas, each a rectangle 7 miles by 9 miles, with one grid in the mountains of each county and one grid in urbanized lowland areas. As mountain areas are more relevant to wildfires, the information presented here is on the projections for the two mountain grids.

Examples of projections relevant to future wildfire risks are those for the **average temperature of the hottest day in a year**, which in the Boulder County mountains:

- In 1970–1999, averaged 85°.
- With high future emissions, would average 92° in mid-century and 97° late in the century, according to the median projections from many models.
- With very low emissions, would instead average 89° in both time periods.

The projections for precipitation are more uncertain than for temperature, but on balance they show that the amount of summer rainfall is not likely to increase enough to offset the drying effects of higher temperatures. The median projections are that in Boulder County mountains, the **amount of summer precipitation**:

- With high emissions, would decrease 1 percent in mid-century and 5 percent in late century, compared to 1970–1999.
- With very low emissions, would increase 2 percent in mid-century and 2 percent in late century.

The projections for Larimer County mountains are similar for both temperature and precipitation. A table on page 8 of this white paper summarizes the projections for Boulder County and Larimer County that are most relevant to wildfire risks. More projections are in the full RMCO reports.

[1] *Future Climate Extremes in Boulder County*, available at www.rockymountainclimate.org/extremes/boulder.htm and *Future Climate Extremes in Larimer County*, at www.rockymountainclimate.org/extremes/larimer.htm.

Scientific studies projecting climate change effects on wildfires

RMCO reviewed the scientific literature to identify scientific studies that use downscaled global climate models incorporating scenarios about future levels of heat-trapping emissions to project how climate change may affect future wildfire risks in areas including Colorado's Northern Front Range forests. We found six such studies.

For clarity's sake, we emphasize that there are many additional scientific studies that assess relationships between climate conditions and wildfire. Some focus on past climate conditions, and some focus on current climate conditions. As the sole purpose of this white paper is to present a synthesis of what scientific studies say about how *future* climate change may affect wildfire risks in Colorado's Northern Front Range forests, we do not address those other studies. We instead consider only those studies that project future wildfire risks based in part on climate models incorporating possible future levels of heat-trapping emissions.

RMCO's original intent for this white paper was to prepare one overall synthesis identifying the common elements of the studies that meet our criteria described above. However, we found that the six studies vary so much, beginning with which climate conditions they identify as most important in determining future wildfire risks, that such an overall summary is not possible. Others have reached the same conclusion about the current state of scientific information, as evidenced by the lack of such a summary in the U.S. government's Third National Climate Assessment or any technical papers prepared as inputs to it, including the U.S. Forest Service's summary of information on climate change impacts on the nation's forests (Vose, Peterson, and Patel-Weynands 2012). We concluded that the most accurate synthesis of what scientists now say on this subject is to separately summarize what the six studies say, which we do beginning on the next page.

Dr. William H. Romme, a professor emeritus at Colorado State University who has extensively studied wildfire in the West, in personal communications to the authors offered two major thoughts to readers of this white paper in evaluating these studies.

First, Dr. Romme recommends placing the greatest confidence in those studies that emphasize future temperature trends in projecting future fire frequency and extent. This is because current climate models are relatively robust when it comes to projecting future temperatures, but far less robust with respect to precipitation and related factors such as humidity and soil moisture. Also, there are empirical studies, based on data for the last several decades, that identify a relatively high correlation between annual area burned and annual temperature, especially for years with exceptionally large extents of area burned (for example, Westerling and others 2011).

Second, Dr. Romme points out that the two studies out of the six that are based solely or primarily on temperature make projections that are consistent on the direction and somewhat so on the extent of the changes in wildfire risks for areas including the Northern Front Range:

- National Research Council (2011) projects a 656% increase in this region in area burned by the time average global temperature has increased by 1.8° Fahrenheit (1° C).
- Spracklen and others (2009) project nearly a three-fold increase in this region in area burned by mid-century under a climate scenario assuming a medium level of heat-trapping emissions.

In the summaries of the six studies that follow, beginning on the next page, the studies are listed from the most recent to the oldest.

Summaries of Scientific Studies

Stavros and others (2014)	
E. N. Stavros and others. 2014. Regional projections of the likelihood of very large wildland fires under a changing climate in the contiguous western United States. *Climatic Change* 126:455–468.	
Projected changes for region including the Northern Front Range	By 2100, very large wildland fires (50,000 acres or larger) would be about 15 times more frequent with high future heat-trapping emissions,[2] and about 5 times more frequent with a medium level of emissions,[3] compared to 1979–2010. By mid-century, large fires would be about 5 times more frequent under both scenarios.
The studied region that includes the Northern Front Range	The Rocky Mountains region—nearly all of Colorado, including Larimer and Boulder counties, and nearly all of Wyoming except the Greater Yellowstone Ecosystem. Altogether, eight regions are studied, corresponding to U.S. National Interagency Fire Center fire-management areas.
Comparison to other studied regions	The Rocky Mountains region has the largest projected increase in very large fires under both emission scenarios. The Rocky Mountains region also has the largest variability in the range of the projected changes.
Key climate inputs for wildfire projections	After analyzing many climate inputs and the effects of them, the authors found that in the Rocky Mountains region soil moisture was most linked to very large wildfires. They did not specify which climate inputs were most linked to soil moisture, although both temperature and precipitation clearly are.
Climate models and methods	Climate projections were made from 14 global climate models spanning the years until 2099, using the two emissions scenarios specified above.
Relevance of RMCO climate projections	The climate models analyzed by RMCO do not directly address soil moisture.
Litschert, Brown, and Theobald (2012)	
S. E. Litschert, T. C. Brown, and D. M. Theobald. 2012. "Historic and future extent of wildfires in the Southern Rockies Ecoregion, USA." *Forest Ecology and Management*, volume 269, pp. 124–133.	
Projected changes for region including the Northern Front Range	Overall, median percent burned area would be about 3–5 times higher under a high-emissions future[4] and about 5–6 times higher under a low scenario[5] over the period 2010–2070 than in 1970–2006. Median percent burned area would increase over time during the period from 2010 to 2070. Greater percent burned area is associated with lower precipitation in the current summer; lower precipitation in the previous autumn; and higher average precipitation and temperature in the previous five years.

[2]Officially known as Representative Concentration Pathway (RCP) 8.5, the high emissions scenario considered in the RMCO reports.

[3] Officially known as RCP 4.5, the medium #2 emissions scenario considered in the RMCO reports.

The studied region that includes the Northern Front Range	The Southern Rocky Mountains ecoregion (as defined by Bailey—see References), which includes the Northern Front Range as well as most mountainous areas in Colorado mountains and those areas in nearby parts of southern Wyoming, northeastern Utah, and northern New Mexico.
Comparison to other studied regions	No other region was studied.
Key climate inputs for wildfire projections	Five-year averages and seasonal averages of temperature and precipitation.
Climate models and methods	Two downscaled climate models were used, each considering the two emissions scenarios identified above.
Relevance of RMCO climate projections	The RMCO reports considered 19 climate models based on what those reports call a high emissions scenario (officially known as RCP 8.5), and 16 based on a very low scenario (RCP 2.6), which are somewhat similar to the older generation scenarios used in this study. In this study, the two models projected higher precipitation levels with high emissions than they did with low emissions. In the RMCO analysis, the median projections with high emissions are for somewhat lower, not higher, summer precipitation levels than are the median projections with very low emissions.
National Research Council (2011)	
National Research Council. 2011. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. Washington, DC: National Academies Press.	
Projected changes for region including the Northern Front Range	Median annual area burned would increase 656% compared to 1950–2003 with a global 1.8°F (1°C) increase in temperature.
The studied region that includes the Northern Front Range	The Southern Rocky Mountains ecoregion (as in Litschert, Brown, and Theobald (2012) above).
Comparison to other studied regions	The projected increase for the Southern Rocky Mountains is greater than for any of the 13 other ecoregions in the West.
Key climate inputs for wildfire projections	The National Research Council projection is based on the work of Littell and others (2009), who linked burned area in mountainous areas of the West to these conditions in the seasons immediately preceding the fire: • low precipitation • drought; and • high temperature.

[4] Officially known as emissions scenario A2 from the previous generation of emissions scenarios, which assumes a high level of future emissions but not quite as high as in the high scenario considered in the RMCO reports.

[5] Officially known as emissions scenario B1 from the previous generation of emissions scenarios, which assumes a low level of future emissions but not as low as the very low scenario considered in the RMCO reports.

Climate models and methods	Based on an input of an increase in average global temperature, not a particular climate model.
Relevance of RMCO climate projections	The RMCO projections show greater local temperature increases in all time periods and under all emissions scenarios than 1.8°F. Even with very low emissions, the RMCO projections show obviously larger temperatures increases than those on which the National Research Council wildfire projections are based.
Spracklen and others (2009)	
D. V. Spracklen and others. 2009. “Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States.” *Journal of Geophysical Research*, volume 114, at p. D20301.	
Projected changes for region including the Northern Front Range	The area burned would increase by 2.75 times from 1996–2005 to 2046–2055.
The studied region that includes the Northern Front Range	A Rocky Mountains Forest region derived by aggregating Bailey ecoregion provinces (see reference below), which includes much of Colorado and portions of seven other states. Altogether, six regions are studied across the West.
Comparison to other studied regions	The projected increase in area burned was higher for the Rocky Mountains Forest region than any other. Next highest was 1.78 times more area in the Pacific Northwest region.
Key climate inputs for wildfire projections	For the Rocky Mountains Forest region, the climate variable (along with at least one non-climate factor) highly associated with more area being burned is higher temperature.
Climate models and methods	Based on precipitation and temperature estimates from one model using a medium-high emissions scenario[6] for the period 2001-2055.
Relevance of RMCO climate projections	The RMCO reports considered 12 models based on an emissions scenario, called medium #1 in the reports and officially known as RCP 6.0, that is somewhat similar to the one considered in this report.
McKenzie and others (2004)	
D. McKenzie and others. 2004. “Climatic change, wildfire, and conservation.” *Conservation Biology*, volume 18, pp. 890–902.	
Projected changes for region including the Northern Front Range	Area burned would nearly double by 2070–2100, compared to the twentieth century.

[6]Officially known as emissions scenario A1B from the previous generation of emissions scenarios, which assumes a medium-high level of future emissions similar to the medium #1 scenario considered in the RMCO reports.

The studied region that includes the Northern Front Range	The state of Colorado.
Comparison to other studied regions	Seven other western states were projected to have greater increases in area burned than Colorado, with projected increases of up to five times the 20th Century values. Only California, Idaho, and Nevada had lower projections than Colorado.
Key climate inputs for wildfire projections	Greater area burned is associated primarily with two climatic variables: • above-average summer temperature, and • below-average summer precipitation.
Climate models and methods	Projections are based on two climate models, each based on only one scenario, for low emissions.
Relevance of RMCO climate projections	The RMCO reports considered 19 models based on a medium emissions scenario (identified in those reports as medium #2, or RCP 4.5) that is somewhat similar at mid-century to the previous-generation scenario considered in this report, but with lower emissions by the end of the century.
Brown and others (2004)	
T. J. Brown, B. L. Hall, and A. L. Westerling. 2004. "The Impact of Twenty-First Century climate change on wildland fire danger in the western United States: An applications perspective." *Climatic Change*, volume 62, pp. 365–388.	
Projected changes for region including the Northern Front Range	The number of days of high fire danger would not increase significantly in the Northern Front Range from 2010-2089 compared to 1975-1996.
The studied region that includes the Northern Front Range	The western United States was studied as a whole; regional projections can be inferred from maps showing how the projections vary regionally, but regional results are not explicitly identified.
Comparison to other studied regions	The number of high fire danger days would increase in some other regions, including the Northern Rockies, Great Basin, and Southwest, compared to the projection that those days would not increase for the Northern Front Range.
Key climate inputs for wildfire projections	The only climate input driving the results is projected future relative humidity, with high fire danger associated with low relative humidity. The report mentions that relative humidity from the model output might be overestimated for the Front Range.

Climate models and methods	Based on two runs of one climate model under a business-as-usual scenario from two generations of scenarios ago.
Relevance of RMCO climate projections	The current climate projections analyzed by RMCO do not include humidity values. Temperature and precipitation are relevant to humidity, but impossible to directly translate into future humidity projections.

On the following page is a table summarizing some of the temperature and precipitation projections from the RMCO climate extremes reports for the mountainous areas of Boulder and Larimer counties. For brevity, this table includes projections for only some climate values and for only two of the four 20-year periods considered in the RMCO reports. Projections for additional climate values and for all four 20-year periods can be found in the full RMCO reports (see the References on page 9).

Temperature and Precipitation Projections
Boulder County Mountains and Larimer County Mountains
Actual values for 1970–1999 and projections with climate change

	1970-99 Actual	Projections with Different Emission Levels: 2040–2059 High	2040–2059 Med. #1	2040–2059 Med. #2	2040–2059 Very Low	2080–2099 High	2080–2099 Med. #1	2080–2099 Med. #2	2080–2099 Very Low
BOULDER CO. MTS.									
Daily high temps									
Temperature of year's hottest day	85°	92° *90 / 94°*	90° *90 / 91°*	90° *90 / 92°*	89° *88 / 91°*	97° *95 / 102°*	93° *91 / 95°*	92° *90 / 94°*	89° *88 / 91°*
Avg temp of year's 5 hottest days	84°	90° *89 / 92°*	89° *88 / 90°*	89° *88 / 91°*	88° *87 / 89°*	95° *94 / 100°*	91° *90 / 94°*	90° *89 / 93°*	87° *86 / 90°*
Avg temp of year's 30 hottest days	81°	87° *86 / 89°*	86° *85 / 87°*	86° *85 / 87°*	85° *83 / 86°*	92° *90 / 96°*	88° *87 / 91°*	87° *86 / 89°*	85° *83 / 86°*
Average daily high in Jun-Jul-Aug	73°	79° *78 / 82°*	78° *77 / 79°*	79° *77 / 80°*	77° *76 / 78°*	85° *83 / 89°*	81° *79 / 83°*	79° *78 / 82°*	77° *75 / 79°*
Precipitation									
Precip amount in year	24 in.	5% *-4 / 14%*	1% *-4 / 13%*	1% *-5 / 14%*	4% *-2 / 20%*	8% *-6 / 19%*	11% *0 / 23%*	2% *-2 / 18%*	6% *-3 / 15%*
Precip amount in Jun-Jul-Aug	6.4 in.	-1% *-16 / 11%*	-3% *-7 / 0%*	-3% *-15 / 8%*	2% *-1 / 10%*	-5% *-28 /20%*	3% *-11 /12%*	-1% *-12 / 16%*	2% *-9 / 10%*
LARIMER CO. MTS.									
Daily high temps									
Temperature of year's hottest day	86°	93° *91 / 94°*	91° *89 / 92°*	91° *90 / 93°*	90° *89 / 92°*	97° *96 / 101°*	93° *89 / 96°*	93° *91 / 95°*	90° *89 / 92°*
Avg temp of year's 5 hottest days	85°	90° *88 / 92°*	89° *88 / 91°*	90° *89 / 91°*	89° *87 / 90°*	96° *95 / 100°*	92° *87 / 95°*	91° *89 / 93°*	88° *87 / 90°*
Avg temp of year's 30 hottest days	82°	88° *87 / 90°*	86° *84 / 87°*	87° *85 / 88°*	86° *84 / 87°*	93° *91 / 96°*	88° *84 / 91°*	88° *86 / 90°*	85° *84 / 87°*
Average daily high in Jun-Jul-Aug	74°	80° *79 / 82°*	78° *77 / 80°*	79° *77 / 81°*	78° *76 / 79°*	85° *84 / 89°*	81° *77 / 84°*	80° *79 / 83°*	78° *76 / 80°*
Precipitation									
Precip amount in year	19 in.	3% *-6 / 15%*	0% *-5 / 13%*	1% *-5 / 13%*	4% *-2 / 20%*	7% *-6 / 19%*	10% *-1 / 22%*	1% *-2 / 16%*	7% *-3 / 15%*
Precip amount in Jun-Jul-Aug	5.8 in.	-1% *-20 / 9%*	-3% *-8 / 1%*	-3% *-15 / 7%*	3% *-2 / 10%*	-5% *-24 / 17%*	2% *-12 / 9%*	-15 *-12 / 15%*	2% *-7 / 9%*

Table 1. Selected projections for the Boulder County mountains grid and the Larimer County mountains grid used in the RMCO reports (see page 1 and References). Projections show median values from multiple climate models and in italics the 10th and 90th percentiles of the projections; precipitation projections are percentage change compared to 1970–1999. See the reports for more details and additional projections.

References

R. G. Bailey, "Ecoregions of the United States," U.S. Forest Service, Rocky Mountain Research Station, available online at http://www.fs.fed.us/rm/ecoregions/products/map-ecoregions-united-states/.

J. S. Littell, D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. "Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003." *Ecological Applications*, volume 19, pp. 1003–1021. The methodology used in this study was incorporated in the projection by the National Research Council (2011).

J. M. Melillo, T. C. Richmond, and G. W. Yohe, editors. 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*, (Washington: U.S. Global Change Research Program).

S. Saunders, T. Easley, and M. Mezger, *Future Climate Extremes in Boulder County*, report of the Rocky Mountain Climate Organization (RMCO) (Louisville, CO: RMCO, 2016), www.rockymountainclimate.org/extremes/boulder.htm.

S. Saunders, T. Easley, and M. Mezger, *Future Climate Extremes in Larimer County*, report of the Rocky Mountain Climate Organization (RMCO) (Louisville, CO: RMCO, 2016), www.rockymountainclimate.org/extremes/larimer.htm.

J. M. Vose, D. L. Peterson, and T. Patel-Weynand, editors. 2012. *Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector* (Portland OR: U.S. Forest Service, Pacific Northwest Research Station), at http://www.treesearch.fs.fed.us/pubs/42610.

A. L. Westerling and others. 2011. "Continued warming could transform Greater Yellowstone fire regimes by mid-21st century," *Proceedings of the National Academy of Sciences*, volume 108, pp. 13165–13170.

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