Future Climate Scenarios for Colorado's Front Range Forests

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Introduction

This chapter provides a summary of the climate change analysis done for Colorado's Front Range forests that include the Pike-San Isabel and Arapaho-Roosevelt (PSI-AR) National Forests. This analysis includes assessment of historical climate trends and future climate projections by 2050. Because of the wide range of future climate projections simulated by global climate models, four divergent future climate scenarios were selected to incorporate that large range and to quantify plausible future climate scenarios for PSI-AR. Following sections provide information on the (1) data and approaches used for the analysis and (2) the main findings from it. Not all of the results and output from the analysis are shown here, and they can be accessed elsewhere as described below.

Dataset and Methods

Table 1 describes the different climate datasets employed for the analysis of historical climate trends and future climate projections. This analysis was also done using different spatial boundary considerations as shown in figure 1, including a point location which allowed for inclusion of several other ecologically relevant climate metrics. These considerations were made to derive scale-appropriate quantification of climate and hydrological projections. For example, the rectangular boundary that encompasses all of the Colorado Front Range forests (fig. 1a) was considered for the selection of future climate change scenarios because a larger regional consideration is generally more appropriate for this purpose. Forest boundaries specific shapefiles were considered to quantify projections in hydroclimate variables that were specific to either Pike-San Isabel (PSI) or Arapaho-Roosevelt (AR) Forests. Finally, a point location along the middle of the north-south extent of the PSI-AR Forest, that is largely representative of the Front Range forests, was identified to derive specific ecologically sensitive metrics that require a very localized spatial consideration.

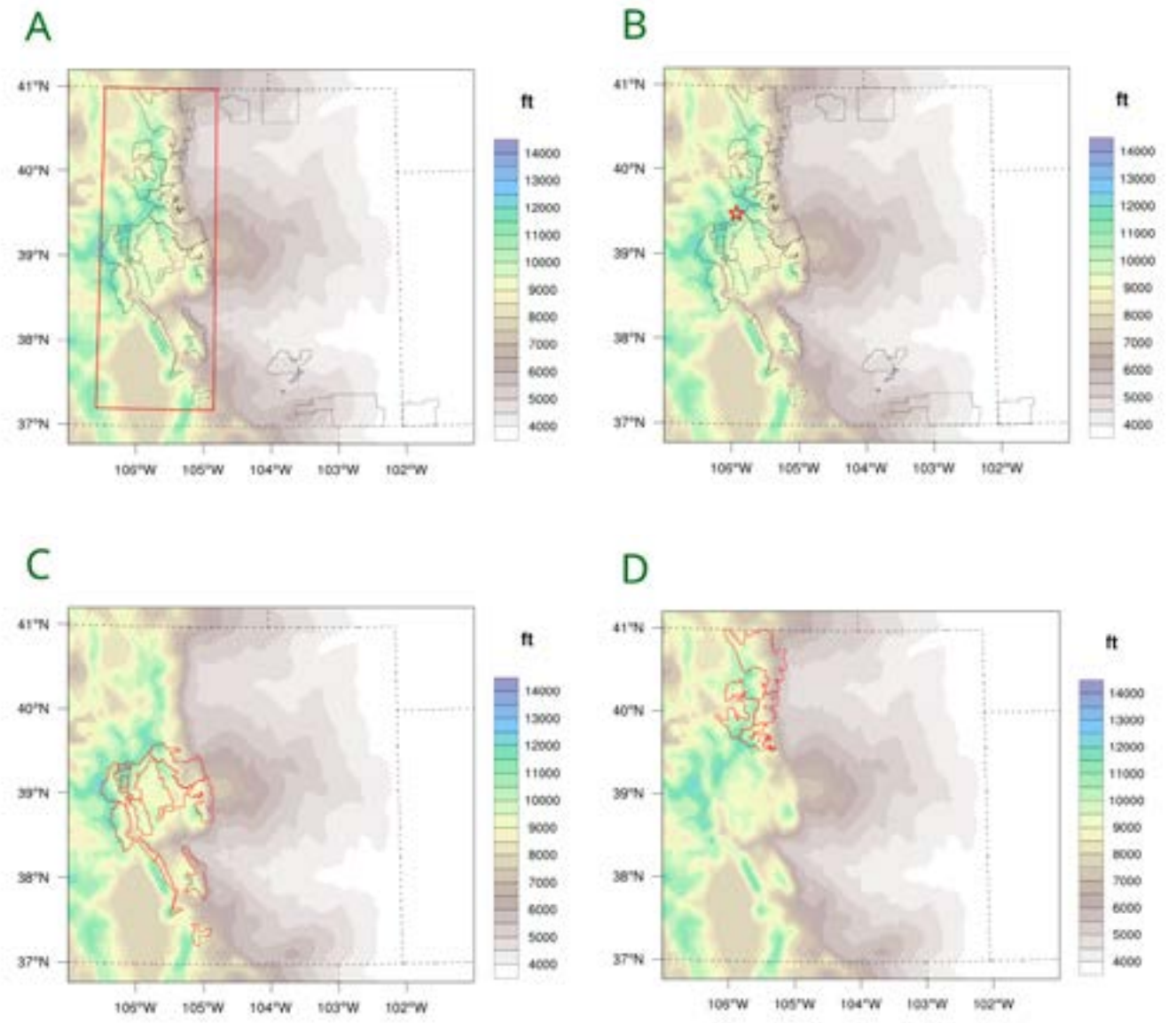

Figure 1a-d—Spatial consideration for climate analysis for the Pike, San Isabel, Arapaho, and Roosevelt (PSI-AR) National Forests. Four different considerations were made: (a) rectangular region between 37.2-41°N latitude and 104.85-106.6°W longitude, (b) point location at 39.5°N and 106°W, (c) PSI, and (d) AR forests boundaries. Colored contours in the background show elevation in feet.

Different datasets were considered for the analysis because no single dataset had all the attributes that were desired. Nonetheless, these different datasets are largely consistent with each other in terms of describing long-term historical trends or interannual variability. For assessing long-term (1895–2018) historical trends in temperature and precipitation, the 5 km monthly NOAA's NCEI nClimDiv data (Vose et al. 2014) are analyzed. Monthly precipitation and vapor pressure deficit data between 1979 and 2018 from the 4 km gridMET data (Abatzoglou 2013) are used to estimate Forest Drought Stress Index (FDSI) based on the relationship described in Williams et al. (2013). Trends

in the atmospheric freezing level during the cold season (October–May) between 1949 and 2018 are obtained from North American Freezing Level Tracker (Abatzoglou et al. 2017). A linear regression is performed between this freezing level height data and high resolution (800 m) temperature data (Topo Wx; Oyler et al. 2014) at a point location in PSI-AR to assess the relationship between the two variables. This relationship is then used to estimate changes in future freezing level heights.

Projected climate change is quantified for the nominal "2050" time horizon, which is defined as the change between historical (1985–2015) and future (2035–2065) time periods. The selection of these time periods was guided by the larger project team. For quantifying future climate projections, two statistically downscaled global climate model datasets were considered. For selecting future climate scenarios and quantifying projected change in several primary hydroclimate variables, US DOI Bureau of Reclamation's statistically downscaled (bias correction spatially disaggregated; BCSD) CMIP5 Climate and Hydrology Projection dataset available at both 1° (~100 km; for temperature and precipitation only) and 1/8° (~12 km; for all other variables) grid cell resolutions are considered (Reclamation 2014). Future climate scenarios are selected based on changes in annual temperature and precipitation from 34 Global Climate Models (GCMs) and two emissions scenarios—Representative Concentration Pathway (RCP) 4.5 (moderate emissions) and RCP 8.5 (high emissions). These GCMs are identified in table A1 in Appendix A of this chapter. Projected change in several ecologically relevant metrics were quantified for a point location (39.5°N, 106°W; mean grid cell elevation = 10,895 ft) based on the Multivariate Adaptive Climate Analog (MACA) downscaled climate projections ((Abatzoglou and Brown 2012; see table 1 for specific metrics).

Rasters (as geotiff) and datafile (as netcdf) of seasonal and annual mean values of nine variables—Mean, Maximum and Minimum Temperatures, Precipitation, Soil Moisture, Potential Evapotranspiration, Actual Evapotranspiration, Runoff, and Snow Water Equivalent—for the historical and future (all four scenarios) periods are produced for a larger domain surrounding the Front Range forests based on the Bureau of Reclamation's BCSD CMIP5 Climate and Hydrology Projection dataset. These datasets can be accessed at http://tinyurl.com/rasters-all. Nine variables between the future and historical period across the four scenarios can be found at http://tinyurl.com/spatial-plots (figs. A1–A7).

Table 1—Observed historical and future climate projections data used in the analysis.

	Dataset	Variables	Time period	Spatial resolution	Source
Historical climate observations	NOAA NCEI nClimDiv Dataset	Temperature, Precipitation	1895–2018	5 km	https://www.ncei.noaa.gov/pub/data/cirs/climdiv/
	gridMET	Precipitation, Vapor Pressure Deficit	1979–2018	4 km	https://www.climatologylab.org/gridmet.html
	North American Freezing Level Tracker	Atmospheric Freezing Level	1949–2018	2.5°	https://wrcc.dri.edu/cwd/products/
	Topo Wx	Temperature	1948–2016	800 m	http://www.scrimhub.org/resources/topowx/
Future climate projections	Reclamation BCSD CMIP5 Climate and Hydrology Projection	Temperature, Precipitation, Soil Moisture, Potential Evapotranspiration, Actual Evapotranspiration, Runoff, Snow Water Equivalent	1950–2099	12 km, 1°	https://gdo-dcp.ucllnl.org
	MACA Downscaled Climate Projections	Temperature, Precipitation, Vapor Pressure Deficit, Coldest Winter Temperature, Hottest Summer Temperature, Date of First Fall Freeze, Date of Last Spring Freeze, Growing Season Length, Wildfire Metrics	1950–2099	4 km	http://www.climatologylab.org/maca.html

Results

Historical Climate Trends

Long-term observational record (since late 19th century) shows that temperatures in PSI-AR have increased by at least 2 °F (fig. 2a) when comparing the mean of the last two decades (1995–2017) with the 20th century period mean (1895–2000). The largest portion of this warming has occurred since the 1990s. Since 1994, only 1 year (2008) has been cooler than the long-term average, albeit only marginally. The period between 2001 and 2017 has been 1.5 °F warmer than the 20th century. The precipitation record, however, does not show any long-term trend (fig. 2b). Recent decades have been slightly on the wetter side despite severe droughts in the early 2000s, 2012 and 2018. The precipitation record also shows substantial interannual variability—varying between 20 percent to +20 percent about the long-term average. Examination of drought indices such as the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Evapotranspiration Index (SPEI) between 1900 and 2019 (fig. 3) shows that comparably extreme and even longer-lasting droughts have occurred in the past (e.g., 1930s Dust

Bowl era); however, there are indications that intensity of recent droughts, e.g., 2002, 2012, or 2018, have been greater. Consistent with increasing trends in temperature, the atmospheric freezing level (a proxy for mountain snowline) has shifted higher in elevation by 700 ft between 1948 and 2018. Atmospheric freezing level controls whether precipitation falls as snow or rain. Therefore, as it shifts higher, we expect an increase in the proportion of precipitation falling as rain rather than snow; elevation and seasonality will influence the extent to which that will occur at a given location.

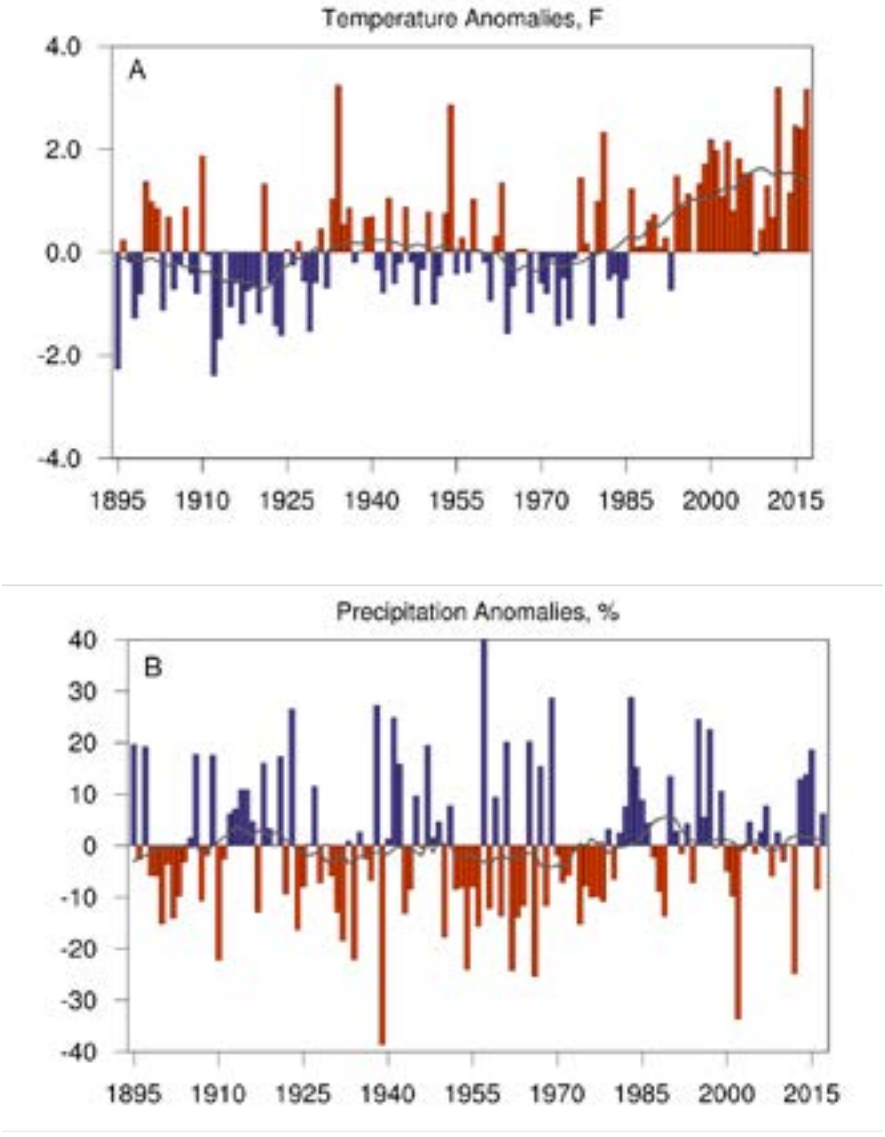

Figure 2a-b—Historical trends in (A) temperature (°F) and (B) precipitation (%) between 1895 and 2017 for the PSI-AR region bounded by 37.2-41°N latitude and 104.85-106.6°W longitude (fig. 1a). The Y-axis shows anomalies in the two variables relative to the 1901–2000 period. Bars show annual values, and the gray line depicts 10-year moving average. Dataset: 5 km monthly NOAA's NCEI nClimDiv data.

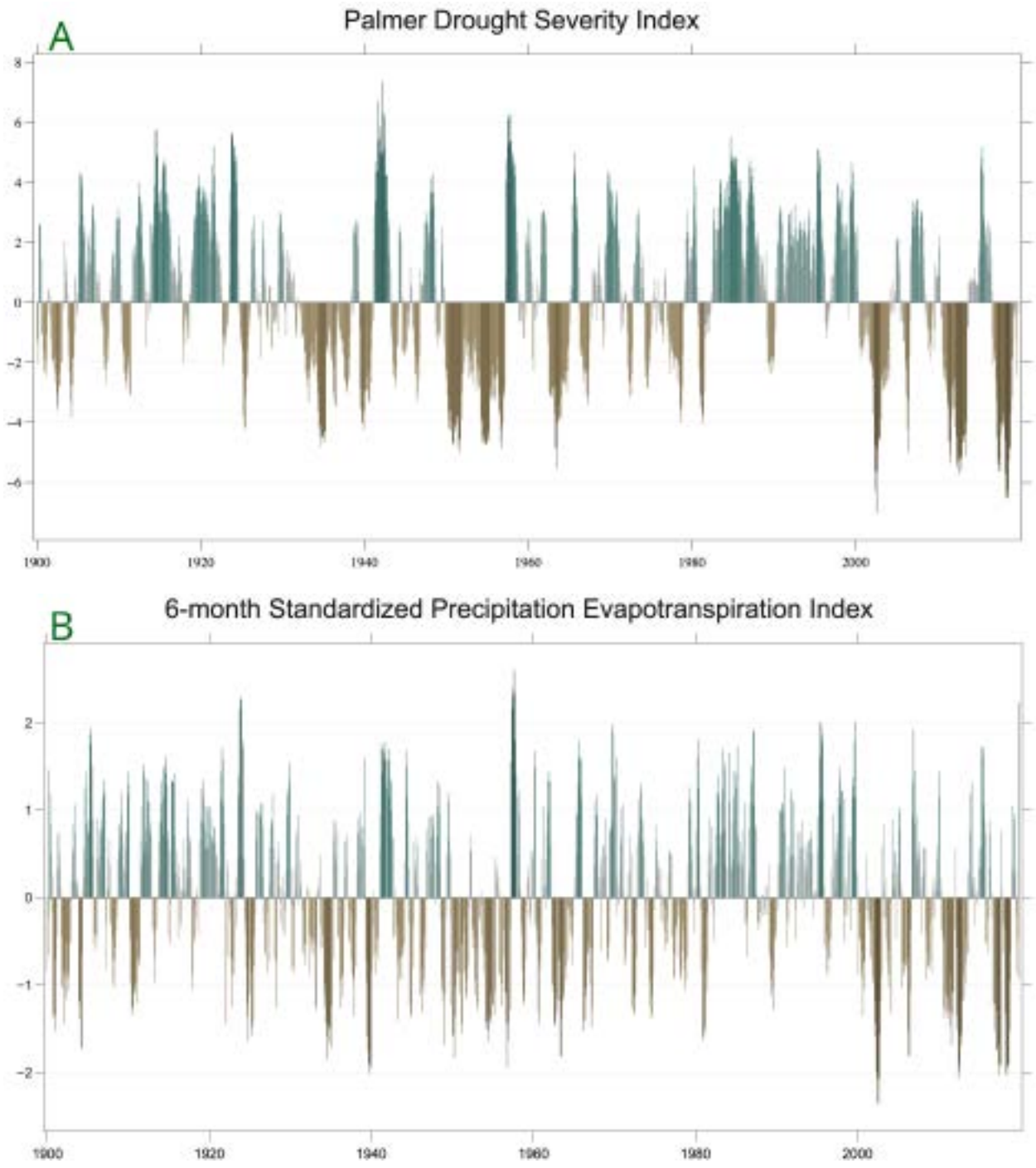

Figure 3a-b—Time series of the Palmer Drought Severity Index (PDSI) and 6-month integrated Standardized Precipitation Evapotranspiration Index (6 month-SPEI) between 1900 and 2019 for the PSI-AR region bounded by 37.2-41°N latitude and 104.85-106.6°W longitude (fig. 1a). Plots are produced using the University of Colorado's Drought Index Portal (DriP; https://droughtindexportal.colorado.edu/). Dataset: The West Wide Drought Tracker (Abatzoglou et al. 2017).

Future Climate Projections

Four future climate scenarios by 2050 were selected from a range of projected changes in annual temperature and precipitation from 34 GCMs and two emission scenarios—totaling 68 climate projections—as shown in figure 4. The primary selection criterion was to pick for divergence in the range of projections. Additional, although secondary, consideration included how a model ranks in representing historical climate (Joyce and Coulson 2020; Rupp et al. 2013). Only projections from RCP 8.5 were considered for the final selection, and because there is a high overlap between the projected changes from the two emissions scenarios by 2050 (fig. 4), this selection choice is expected to have limited influence on the findings. The four future climate scenarios identified are named:

1. **Very Hot and Dry** (model = IPSL-CM5A-MR.rcp85)
2. **Very Hot and Wet** (model = CanESM2.rcp85)
3. **Hot** (model = CNRM-CM5.rcp85)
4. **Warm and Wet** (model = GFDL-ESM2M.rcp85)

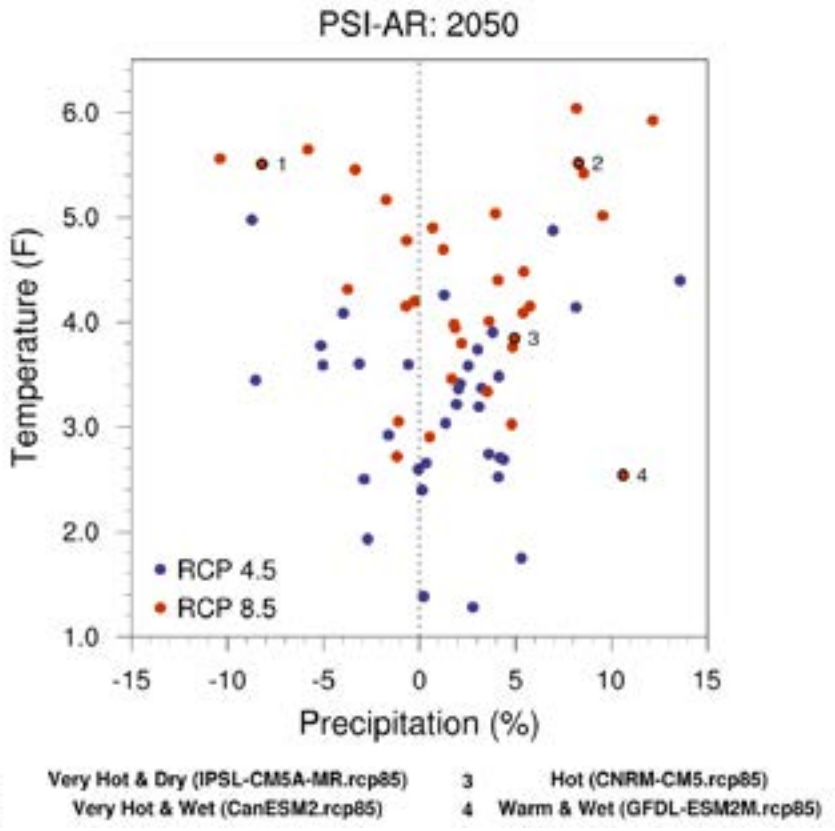

Figure 4—Selection of four future climate scenarios by 2050 based on changes in annual temperature and precipitation from 34 Global Climate Models (GCMs) and two emissions scenarios: Representative Concentration Pathway (RCP) 4.5 (moderate emissions) and RCP 8.5 (high emissions) for the PSI-AR region bounded by 37.2-41°N latitude and 104.85-106.6°W longitude (fig. 1a). Dataset: Reclamation BCSD CMIP5 1o Regridded Projection.

Table 2 provides changes in several primary climate and hydrological variables by 2050 (relative to 1985–2015) across these four climate future scenarios for the PSI-AR region, a region bounded by 37.2 °N – 41 °N latitude and 104.85 °W – 106.6 °W longitude. A summary of these changes includes:

1. Temperature increases by 2.5 to 5.5°F
2. Precipitation changes between -10 percent and +10 percent
3. Summer soil moisture decreases in all scenarios, except Warm and Wet for which it increases slightly; for the two Very Hot scenarios, it decreases by 10 percent
4. Snowpack decreases in all scenarios; for three scenarios the decreases are between -15 percent and -40 percent
5. Annual runoff changes between +10 percent and -30 percent
6. Spring runoff increases substantially in all scenarios between +20 percent and +80 percent
7. Summer and fall runoff decrease in all scenarios; summer decreases are between -10 percent and -50 percent
8. Potential evapotranspiration (a measure of drought and heat stress from a drier atmosphere) increases between 5 percent and 10 percent

These changes are also quantified separately for the region under PSI and AR boundaries in tables A2 and A3 in the Appendix for this chapter.

Table 3 describes changes in several ecologically sensitive climate variables by 2050 (relative to 1971–2000 period) across the four climate scenarios at a point location (39.5 °N, 106 °W, figure 1b; mean grid cell elevation = 10,895 ft) in the PSI-AR region. Main summary of these changes includes:

1. Coldest winter day warms by 3 to 10 °F
2. Hottest summer day warms by 4 to 8 °F
3. First fall freeze occurs later by 3 to 5 weeks
4. Last spring freeze occurs earlier by 2 to 3 weeks, except for the Warm and Wet scenario, where no change occurs
5. Growing season increases by 3 to 8 weeks
6. Freezing level (mountain snowline) shifts uphill by 1,000 to 2,000 ft
7. Severe droughts, such as in 2002 or 2012, occur every 2 to 3 years, except for the Warm and Wet scenario, where they do not occur
8. “High” to “extreme” fire danger days increase by several days and weeks, particularly in the Very Hot and Dry scenario; for the Warm and Wet they either decrease or do not change
9. Extreme rainfall increases by 10 to 20 percent with higher frequency of those events in the wetter scenarios

Table 2—Climate change in PSI-AR by 2050 under the four climate scenarios. These changes are estimated for a rectangular region surrounding PSI-AR and bounded by 37.2-41oN latitude and 104.85-106.6oW longitude (see fig. 1a). Dataset: Reclamation BCSD CMIP5 Climate and Hydrology Projection. (DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; and SON = September, October, November.)

Climate metric	Annual/ Seasonal	Scenarios (GCMs) Very Hot and Wet (CanESM2.rcp85)	Hot (CNRM-CM5.rcp85)	Warm and Wet (GFDL-ESM2M.rcp85)	Very Hot and Dry (IPSL-CM5A_MR.rcp85)
Average temperature	Annual, °F	5.5	3.8	2.5	5.5
	Winter, DJF, °F	5.8	4.6	2.7	5.3
	Spring, MAM, °F	6.6	3.0	3.1	5.0
	Summer, JJA, °F	4.8	4.0	1.3	6.0
	Fall, SON, °F	4.8	3.8	3.1	5.7
Precipitation	Annual, %	8.3	5.0	10.6	-8.2
	Winter, DJF, %	12.8	2.8	5.9	0.2
	Spring, MAM, %	0.7	3.8	10.0	-13.8
	Summer, JJA, %	13.5	6.6	16.7	-16.3
	Fall, SON, %	7.3	5.0	1.4	-2.8
Minimum temperature	Annual, °F	5.8	3.9	2.3	6.0
	Winter, DJF, °F	6.9	5.0	3.0	6.4
	Spring, MAM, °F	6.5	3.3	3.1	5.4
	Summer, JJA, °F	4.9	3.8	0.8	6.3
	Fall, SON, °F	4.8	3.7	2.4	6.0
Maximum temperature	Annual, °F	5.4	3.6	2.9	6.0
	Winter, DJF, °F	4.7	3.8	2.4	7.5
	Spring, MAM, °F	7.0	2.8	3.2	5.2
	Summer, JJA, °F	5.0	3.8	2.2	5.8
	Fall, SON, °F	5.1	4.1	3.9	5.7
Soil moisture	Annual, %	-1.0	1.2	0.4	-7.9
	Winter, DJF, %	0.4	2.2	-0.3	-4.6
	Spring, MAM, %	6.5	5.8	2.6	-1.9
	Summer, JJA, %	-8.1	-1.0	-0.2	-13.5
	Fall, SON, %	-2.6	-2.3	-0.9	-11.5
Snow water equivalent (SWE)	Annual, %	-26.5	-17.3	-6.5	-38.8
	Winter, DJF, %	-14.8	-22.0	-3.6	-29.3
	Spring, MAM, %	-24.5	-11.0	-3.2	-39.3
	Summer, JJA, %	-81.5	-45.0	-40.6	-78.6
	Fall, SON, %	-63.5	-35.2	-43.7	-31.9

Table 2 continued.

Climate metric	Annual/ Seasonal	Scenarios (GCMs) Very Hot and Wet (CanESM2.rcp85)	Hot (CNRM-CM5.rcp85)	Warm and Wet (GFDL-ESM2M.rcp85)	Very Hot and Dry (IPSL-CM5A_MR.rcp85)
Runoff	Annual, %	1.1	4.5	9.9	-27.2
	Winter, DJF, %	12.3	7.3	3.0	-10.8
	Spring, MAM, %	80.4	42.4	50.1	14.3
	Summer, JJA, %	-45.6	-15.4	-12.0	-52.4
	Fall, SON, %	-14.6	-13.3	-1.4	-43.1
Evapotranspiration	Annual, %	14.4	7.3	11.6	-3.2
	Winter, DJF, %	5.8	1.6	1.1	5.1
	Spring, MAM, %	27.1	12.4	16.3	8.9
	Summer, JJA, %	7.5	6.5	11.3	-10.6
	Fall, SON, %	22.7	4.4	10.7	-1.2
Potential evapotranspiration	Annual, %	9.4	5.8	4.2	12.5
	Winter, DJF, %	11.1	9.7	5.2	22.3
	Spring, MAM, %	13.4	4.1	5.7	11.9
	Summer, JJA, %	7.4	5.0	1.5	11.0
	Fall, SON, %	6.9	7.8	7.1	11.3

Table 3—Changes in selective climate extremes under the four climate scenarios by 2050 for a point location in the Colorado Front Range forests at 39.5°N, 106°W and elevation of 10,895 ft (see fig. 1b).

Climate Metric	Very Hot and Wet	Hot	Warm and Wet	Very Hot and Dry	Historical
Coldest Winter Day (°F)	-7	-9	-12	-5	-15
Hottest Summer Day (°F)	80	77	77	81	73
First Fall Freeze	Sep 28	Sep 20	Sep 16	Sep 25	Aug 25
Last Spring Freeze	May 31	Jun 3	Jun 16	May 29	Jun 17
Growing Season Length (# days)	116	109	92	119	69
Growing Degree Days (°F; 32°F base)	4,190	3,690	3,537	4,267	2,643
Freezing Level or Snowline, ft	10,400	9,600	9,360	10,250	8,400
Frequency of Severe Droughts like 2012	every 3 years	every 5 years	do not occur	every 2 years	—
“High” Fire Danger Days	76	87	61	121	73
“Very High” Fire Danger Days	45	43	32	74	36
“Extreme” Fire Danger Days	17	17	11	36	11
Extreme Rainfall, i.e., % increase in short duration extreme value	18	14	7	21	—

(—) indicates no data.

Above values are based on MACA metdata v2 (4km downscaled climate projections) and gridMET (4km observed climate data for Historical, which is the 1971-2000 time period). Drought severity is estimated using Forest Drought Stress Index (FDSI). Freezing level (FL) changes are estimated based on historical relationship between Oct-May FL and temperature. Extreme rainfall risk is based using a scaling factor of 3.5% increase with every 1°F increase in temperature. Growing Degree Days are an estimation of heat accumulation during the growing season calculated by adding daily values of diurnal-average temperature exceedance above a certain threshold (here 32°F) over a year.

Caveats

Consideration of results from multiple climate scenarios and for different geographical boundaries (as done in fig. 1) provides us with a range of future climate and hydrological conditions that differ based on the combination of those choices. Consideration of multiple scenarios allows us to incorporate the large range of plausible climate change and impacts in our study but they are not an exhaustive consideration of all possible outcomes. Specific consideration of results related to a specific geographical choice is also relevant. For example, if one is primarily interested in understanding impacts for the AR region then the consideration of results described in table A3 are more appropriate than those in table 2, which are for a larger region. Furthermore, the results associated with a point location (as shown in table 3) are also appropriate to extrapolate to a different region if one ignores the absolute values but applies the change factors (changes between historical and future periods) quantified for this location to the historical values of another region. With the exception of "growing degree days," change factors from all other variables in table 3 could be extrapolated to another location in the Front Range forests to understand the nature of regional-scale change. And lastly, because of large topographical differences across the Front Range forests, it is also important to recognize how hydrological response such as soil moisture and runoff will vary across the landscape at any given time as shown in figures A1–A7.

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Appendix A

Table A1—List of the 68 Global Climate Model (GCM) projections considered in the study to select the future climate scenarios.

1. access1-0.1.rcp45
2. access1-0.1.rcp85
3. access1-3.1.rcp45
4. access1-3.1.rcp85
5. bcc-csm1-1.1.rcp45
6. bcc-csm1-1.1.rcp85
7. bcc-csm1-1-m.1.rcp45
8. bcc-csm1-1-m.1.rcp85
9. canesm2.1.rcp45
10. canesm2.1.rcp85
11. ccsm4.1.rcp45
12. ccsm4.1.rcp85
13. cesm1-bgc.1.rcp45
14. cesm1-bgc.1.rcp85
15. cesm1-cam5.1.rcp45
16. cesm1-cam5.1.rcp85
17. cmcc-cm.1.rcp45
18. cmcc-cm.1.rcp85
19. cnrm-cm5.1.rcp45
20. cnrm-cm5.1.rcp85
21. csiro-mk3-6-0.1.rcp45
22. csiro-mk3-6-0.1.rcp85
23. ec-earth.2.rcp45
24. ec-earth.6.rcp85
25. fgoals-g2.1.rcp45
26. fgoals-g2.1.rcp85
27. fgoals-s2.2.rcp45
28. fgoals-s2.2.rcp85
29. fio-esm.2.rcp45
30. fio-esm.2.rcp85
31. gfdl-cm3.1.rcp45
32. gfdl-cm3.1.rcp85
33. gfdl-esm2g.1.rcp45
34. gfdl-esm2g.1.rcp85
35. gfdl-esm2m.1.rcp45
36. gfdl-esm2m.1.rcp85
37. giss-e2-r.1.rcp45
38. giss-e2-r.1.rcp85
39. hadgem2-ao.1.rcp45
40. hadgem2-ao.1.rcp85
41. hadgem2-cc.1.rcp45
42. hadgem2-cc.1.rcp85
43. hadgem2-es.1.rcp45
44. hadgem2-es.1.rcp85
45. inmcm4.1.rcp45
46. inmcm4.1.rcp85
47. ipsl-cm5a-lr.1.rcp45
48. ipsl-cm5a-lr.1.rcp85
49. ipsl-cm5a-mr.1.rcp45
50. ipsl-cm5a-mr.1.rcp85
51. ipsl-cm5b-lr.1.rcp45
52. ipsl-cm5b-lr.1.rcp85
53. miroc-esm.1.rcp45
54. miroc-esm.1.rcp85
55. miroc-esm-chem.1.rcp45
56. miroc-esm-chem.1.rcp85
57. miroc5.1.rcp45
58. miroc5.1.rcp85
59. mpi-esm-lr.1.rcp45
60. mpi-esm-lr.1.rcp85
61. mpi-esm-mr.1.rcp45
62. mpi-esm-mr.1.rcp85
63. mri-cgcm3.1.rcp45
64. mri-cgcm3.1.rcp85
65. noresm1-m.1.rcp45
66. noresm1-m.1.rcp85
67. noresm1-me.1.rcp45
68. noresm1-me.1.rcp85

Table A2—Climate change in Pike and San Isabel (PSI) National Forests by 2050 under the four climate scenarios. These changes are estimated for the region under the PSI National Forest boundaries. Dataset: Reclamation BCSD CMIP5 Climate and Hydrology Projection. (DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; and SON = September, October, November.)

Climate metric	Annual/ Seasonal	Scenarios (GCMs) Very Hot and Wet (CanESM2.rcp85)	Hot (CNRM-CM5.rcp85)	Warm and Wet (GFDL-ESM2M.rcp85)	Very Hot and Dry (IPSL-CM5A_MR.rcp85)
Average temperature	Annual, °F	5.6	3.8	2.6	5.5
	Winter, DJF, °F	5.9	4.6	2.8	5.3
	Spring, MAM, °F	6.7	3.0	3.3	5.0
	Summer, JJA, °F	4.8	3.8	1.1	6.0
	Fall, SON, °F	4.8	3.7	3.0	5.7
Precipitation	Annual, %	6.8	6.0	10.5	-10.1
	Winter, DJF, %	11.9	3.3	5.8	-0.3
	Spring, MAM, %	-2.3	3.2	8.9	-13.7
	Summer, JJA, %	13.6	8.8	17.3	-19.7
	Fall, SON, %	5.2	6.3	1.5	-6.9
Minimum temperature	Annual, °F	5.4	4.5	2.4	6.1
	Winter, DJF, °F	6.1	5.7	2.7	6.7
	Spring, MAM, °F	5.5	3.8	2.4	5.5
	Summer, JJA, °F	5.1	4.4	1.7	6.5
	Fall, SON, °F	4.8	4.1	2.7	5.7
Maximum temperature	Annual, °F	5.3	4.4	2.8	5.8
	Winter, DJF, °F	4.9	4.6	2.4	6.9
	Spring, MAM, °F	6.1	3.4	2.4	5.3
	Summer, JJA, °F	5.4	4.8	2.3	5.9
	Fall, SON, °F	4.8	4.5	4.0	5.3
Soil moisture	Annual, %	-0.4	0.2	1.2	-10.4
	Winter, DJF, %	1.2	1.0	0.6	-8.2
	Spring, MAM, %	5.4	3.7	2.4	-5.6
	Summer, JJA, %	-7.5	-1.3	0.9	-13.4
	Fall, SON, %	-0.4	-2.7	0.9	-14.4
Snow water equivalent (SWE)	Annual, %	-20.3	-10.9	-2.2	-28.0
	Winter, DJF, %	-10.2	-15.7	-1.2	-18.7
	Spring, MAM, %	-13.5	-2.9	2.2	-26.0
	Summer, JJA, %	-76.9	-38.7	-28.2	-69.6
	Fall, SON, %	-53.8	-19.8	-33.7	-18.9

Table A2 continued.

Climate metric	Annual/ Seasonal	Scenarios (GCMs) Very Hot and Wet (CanESM2.rcp85)	Hot (CNRM-CM5.rcp85)	Warm and Wet (GFDL-ESM2M.rcp85)	Very Hot and Dry (IPSL-CM5A_MR.rcp85)
Runoff	Annual, %	-1.8	4.8	10.9	-30.6
	Winter, DJF, %	16.5	9.7	8.8	-27.9
	Spring, MAM, %	109.3	50.0	49.0	17.5
	Summer, JJA, %	-51.6	-14.9	-10.3	-52.8
	Fall, SON, %	-5.9	-7.5	9.8	-57.0
Evapotranspiration	Annual, %	15.4	8.0	11.9	-2.2
	Winter, DJF, %	11.0	4.1	3.1	8.2
	Spring, MAM, %	22.1	8.8	15.0	4.5
	Summer, JJA, %	10.8	8.5	11.4	-6.5
	Fall, SON, %	24.4	6.7	13.1	-1.4
Potential evapotranspiration	Annual, %	9.6	6.1	4.5	13.1
	Winter, DJF, %	12.1	11.0	6.2	22.5
	Spring, MAM, %	14.3	4.7	6.0	12.8
	Summer, JJA, %	7.2	4.8	1.9	11.5
	Fall, SON, %	6.8	8.0	7.0	11.6

Table A3—Climate change in Arapaho and Roosevelt (AR) National Forests by 2050 under the four climate scenarios. These changes are estimated for the region under the AR boundaries. Dataset: Reclamation BCSD CMIP5 Climate and Hydrology Projection. (DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; and SON = September, October, November.)

Climate metric	Annual/ Seasonal	Scenarios (GCMs) Very Hot and Wet (CanESM2.rcp85)	Hot (CNRM-CM5.rcp85)	Warm and Wet (GFDL-ESM2M.rcp85)	Very Hot and Dry (IPSL-CM5A_MR.rcp85)
Average temperature	Annual, °F	5.3	4.1	2.5	5.5
	Winter, DJF, °F	5.5	4.8	2.2	5.3
	Spring, MAM, °F	6.4	3.0	2.4	4.9
	Summer, JJA, °F	4.7	4.6	2.0	6.0
	Fall, SON, °F	4.7	4.1	3.3	5.6
Precipitation	Annual, %	12.8	0.3	9.7	-1.5
	Winter, DJF, %	18.4	3.6	6.7	2.7
	Spring, MAM, %	9.3	5.8	13.5	-12.7
	Summer, JJA, %	12.2	-5.3	11.8	-6.5
	Fall, SON, %	15.3	1.1	0.0	13.6
Minimum temperature	Annual, °F	5.6	4.1	2.8	6.0
	Winter, DJF, °F	6.4	5.3	2.7	6.2
	Spring, MAM, °F	6.3	3.3	2.9	5.9
	Summer, JJA, °F	4.7	4.1	2.4	6.2
	Fall, SON, °F	4.8	3.8	3.1	5.8
Maximum temperature	Annual, °F	5.2	4.0	2.2	5.7
	Winter, DJF, °F	4.5	3.9	1.6	7.2
	Spring, MAM, °F	6.7	2.8	1.9	4.2
	Summer, JJA, °F	4.9	4.9	1.7	5.6
	Fall, SON, °F	4.8	4.5	3.7	5.6
Soil moisture	Annual, %	1.5	-1.1	1.1	-5.7
	Winter, DJF, %	3.3	-0.5	-0.7	0.9
	Spring, MAM, %	15.9	7.7	4.7	6.7
	Summer, JJA, %	-8.5	-3.6	1.5	-16.1
	Fall, SON, %	-3.6	-8.7	-1.9	-12.4
Snow water equivalent (SWE)	Annual, %	-23.8	-16.7	-3.9	-39.2
	Winter, DJF, %	-9.2	-20.0	1.6	-28.6
	Spring, MAM, %	-20.4	-10.4	-0.1	-38.1
	Summer, JJA, %	-80.3	-44.9	-43.2	-80.8
	Fall, SON, %	-64.9	-41.2	-43.9	-39.0

Table A3 continued.

Climate metric	Annual/ Seasonal	Scenarios (GCMs) Very Hot and Wet (CanESM2.rcp85)	Hot (CNRM-CM5.rcp85)	Warm and Wet (GFDL-ESM2M.rcp85)	Very Hot and Dry (IPSL-CM5A_MR.rcp85)
Runoff	Annual, %	7.3	0.7	11.7	-22.6
	Winter, DJF, %	29.5	2.9	0.4	13.0
	Spring, MAM, %	108.6	46.3	64.4	33.1
	Summer, JJA, %	-44.6	-18.5	-12.6	-53.9
	Fall, SON, %	-20.1	-28.8	-5.1	-41.0
Evapotranspiration	Annual, %	17.1	5.8	10.9	3.5
	Winter, DJF, %	7.5	3.0	-0.7	9.6
	Spring, MAM, %	33.7	13.5	15.5	19.0
	Summer, JJA, %	9.5	4.4	11.2	-4.7
	Fall, SON, %	23.9	0.6	8.5	6.5
Potential evapotranspiration	Annual, %	8.5	6.2	2.7	10.7
	Winter, DJF, %	8.2	8.2	2.0	19.9
	Spring, MAM, %	12.0	3.2	3.5	9.2
	Summer, JJA, %	7.2	6.0	0.2	9.6
	Fall, SON, %	6.5	9.3	7.1	10.1