Projected Changes in Temperature, Precipitation, and Snow in Clackamas River Watershed

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Report Summary

Overview

Future changes in temperature, precipitation, and snow are analyzed over the Clackamas River Watershed (CRW) using climate model data. First, we discuss future trends in watershed-average seasonal temperature and total precipitation projections. Then, we show how the proportion of precipitation that falls as rain instead of snow increases over the higher elevations of the watershed.

Key Findings

1. Average temperatures over CRW increase by 5°F – 8.4°F compared with current climate.
2. Average number of days below freezing (32°F) decreases by 53% – 74% compared with current climate.
3. Average number of days above 90°F increases by 8x – 20x compared with current climate.
4. There are no discernible trends or changes in average precipitation by 2100.
5. The average percentage of days receiving precipitation that are snow decreases from 42.5% to 18.3% by 2100.
6. At Clackamas Lake, less than 25% of days with precipitation will be snow days by 2040 while less than 10% of days with precipitation will be snow days by 2082. This means that by the end of the century, over 90% of precipitation days at Clackamas Lake will be rain days.

Full Report

Motivation

In the Pacific Northwest, watersheds rely on the storage of freshwater for drinking, irrigation, and recreational activities during dry summer months. Historically, average temperatures during the wettest months of the year in the upper CRW are close to freezing (Figure 1). However, projected warming due to anthropogenic climate change will reduce the number of days with temperatures below freezing, and therefore increase the proportion of precipitation that falls as rain versus what falls as snow. A thorough and precise picture of how changes in climate will impact water resources at a local-scale is vital.

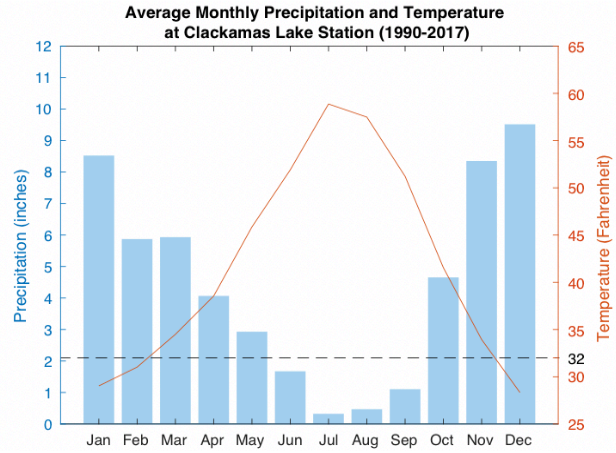

Fig. 1. Monthly average precipitation in inches (blue) and temperature (orange) in degrees Fahrenheit measured at Clackamas Lake Station, averaged over the record spanning 1990–2017. Freezing (32°F) is denoted by the black dashed line.

Research Questions

Our research analyzes climate model projected climate change over the Clackamas River Watershed (CRW). There are two main objectives to this work:

1. How are temperature and precipitation in CRW likely to change by the end of the century?
2. How will the ratio of snow days versus rain days change in the future over CRW?

Research Approach

To address each question, we use data from climate models, which are mathematical representations of the earth-climate system grounded in known physical processes. [For more information, see https://www.climate.gov/maps-data/primer/climate-models]. Climate models generally have low spatial resolutions that mask fine-scale topographical features such as mountainous terrain, which influence local weather and climate. Therefore, we consider two different approaches to answer research questions at the watershed-scale.

For projections of temperature and precipitation in CRW, we use data from 19 climate models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) that have been statistically downscaled. [For more information on the data and downscaling process, see http://www.climatologylab.org/maca.html]. Projected changes in watershed-average temperature and precipitation are computed using three greenhouse gas emissions pathways: Historical (1950–2005), Moderate (2006–2099), and Business-as-usual (2006–2099). Changes are computed as the difference between the average 30-year value at the end of the Moderate or Business-as-usual simulation (2070–2099), and the average value over the entire historical period (1950–2005).

For computing the ratio of snow days versus rain days, we use cold-season (November–April) data from 24 CMIP5 models. Analysis is conducted at the point location of Clackamas Lake Station (Figure 2), which is part of the SNOTEL network. Snow and rain days are defined based on the height of the snow level relative to station elevation (3400 ft). Snow level is the height in the atmosphere at which falling snow completely melts into rain, and is based on the altitude where temperature equals freezing. On days receiving precipitation, if the simulated snow level is at or below the elevation of Clackamas Lake Station, snow is occurring at the surface and this is referred to as a "snow day". Projected changes in cold-season snow levels and the proportion of snow days out of all days receiving precipitation are computed using Historical (1950–2005) and Business-as-usual (2006–2099) greenhouse gas emissions pathways.

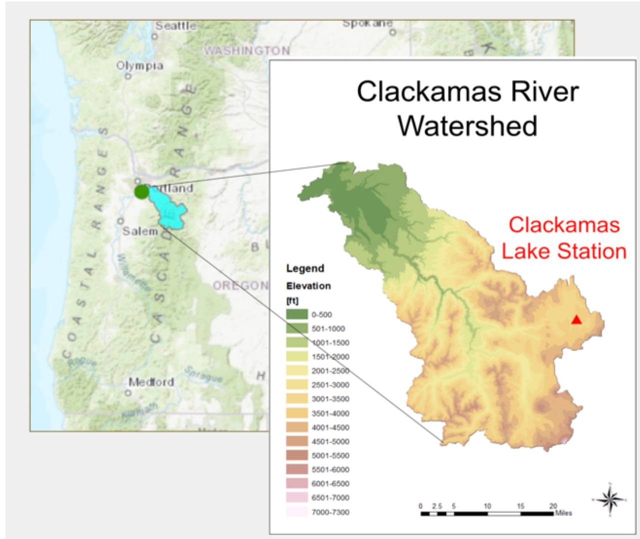

Fig. 2. Geographical location and elevation of Clackamas River Watershed, as well as the location of Clackamas Lake Station within the watershed (in red).

Findings

1) Temperature

Simulated annual surface temperatures for each emissions pathway are plotted in Figure 3. Overall, temperatures averaged across all models increase by the end of the century under both Moderate and Business-as-usual scenarios. By 2100, average surface temperatures over CRW increase by 5°F under a Moderate scenario, and 8.4°F under a Business-as-usual scenario. Results from a seasonal analysis also indicate a rise in average surface temperatures throughout the year, with a more rapid increase during summer (June, July, and August) and autumn (September, October, and November).

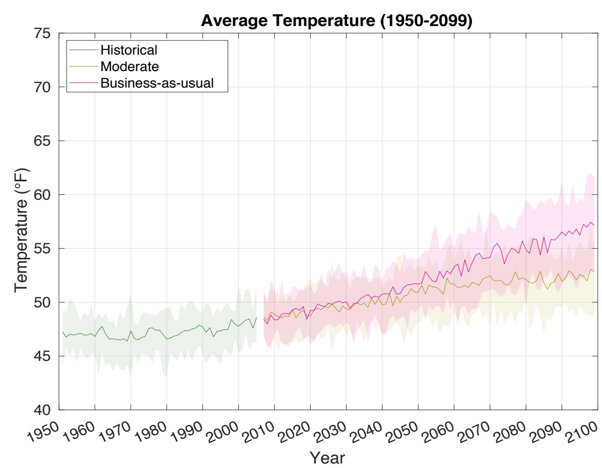

Fig. 3. Average annual surface temperatures simulated under Historical (green), Moderate (yellow) and Business-as-usual (red) emissions pathways. Solid lines indicate the median across models, and shading represents range across all model simulations.

Changes in the frequency of days below freezing and days above 90°F are also examined (Figure 4). To compute the annual frequency, the number of days with daily average temperatures below freezing (or above 90°F) is summed over each year and averaged across CRW. Results indicate a decline in the average number of days below freezing by 53% (Moderate) or 74% (Business-as-usual) from historical values. The average number of days with temperatures exceeding 90°F increases by 8x (Moderate) or 20x (Business-as-usual) historical values.

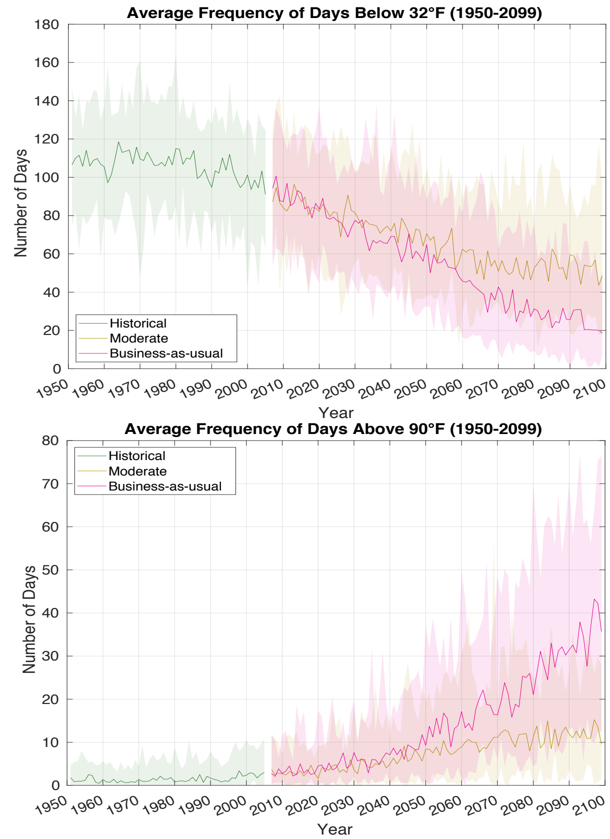

Fig. 4. As in Figure 3, but for average annual frequencies of (top) days with temperatures below freezing (32°F) and (bottom) days with temperatures above 90°F.

2) Total Precipitation

Unlike temperature, average annual total precipitation does not exhibit any discernible trends over the next century under either Moderate or Business-as-usual scenarios (Figure 5). Seasonal average precipitation over the wet-season (November–April) and dry-season (May–October) also does not show any changes by 2099.

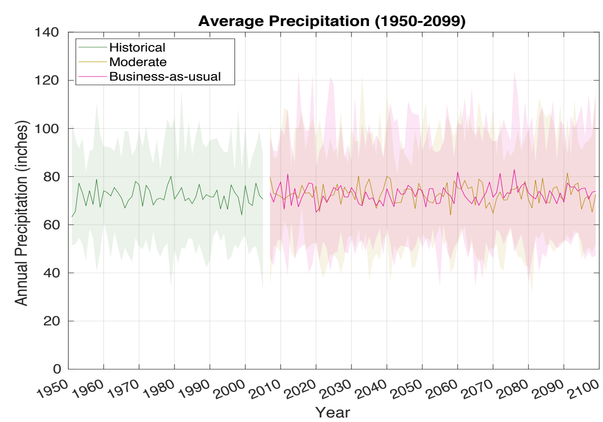

Fig. 5. As in Figure 4, but for average annual precipitation.

3) Snow

The distributions of all cold-season wet-day snow levels across 25-year periods are displayed in Figure 6. The black curve represents the historical distribution derived from an observation-based dataset. Projected changes in snow levels are computed relative to the historical distribution to reduce the influence of model biases. The entire distribution of snow levels rises from historical to mid-century and mid-century to end-of-century periods, as indicated by the rightward shift (Figure 6). Snow levels in each distribution that are at or below the station elevation are highlighted by grey stippling, representing days with snow at the surface. Therefore, the positive shift in the distribution of snow levels over this century indicates a decline in the percentage of days with precipitation falling as snow. This percentage during the historical period is 42.5%, which declines to 30.3% by mid-century and to 18.3% by end-of-century. Overall, the average snow level at Clackamas Lake

Station rises 1919 ft by 2100 (dashed lines), resulting in a decrease in the average ratio of snow days versus rain days of 24.2%.

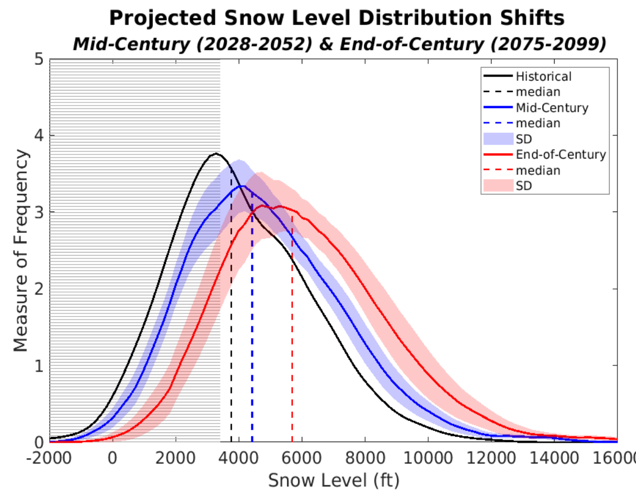

Fig. 6. Distributions of snow levels at Clackamas Lake Station. The observation-based distribution over the historical period (1981–2005) is in black, and the projected distribution at mid-century (2028–2052) and end-of-century (2075–2099) periods is in blue and red, respectively. One standard deviation (SD) across all climate models is shaded, and dashed lines are median snow levels. Grey stippling indicates levels below station elevation.

Another approach to considering changes in the proportion of precipitation days falling as snow is to determine the timing of this proportion falling below specific thresholds. Results indicate that by 2040, less than one quarter of precipitation days will be snow days on average, and by 2082, less than one tenth of precipitation days will be snow days on average. There is considerable uncertainty in these precise years, including ± 9 years owing to model variability, and an additional ± 3 years owing to choices in methodology. Nevertheless, critical years provide an approximation of the timeline over which CRW grows vulnerable to potentially significant decreases in the ratio of snow days versus rain days.