COMPUTATIONALLY MODELING CLIMATE CHANGE IMPACTS ON SAGEBRUSH ECOSYSTEMS

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ABSTRACT. Big sagebrush (*Artemisia tridentata*) ecosystems are projected to experience warmer temperatures, altered precipitation patterns, and sharply reduced snowpack across the American West. Using an ensemble of 20 CMIP5 global circulation models, we compared historical (1980–2000) climate at 2 740 m and 3 650 m elevations on a south-central Colorado ranch with mid-century (2040–2050) and late-century (2080–2100) projections under RCP4.5 and RCP8.5. Mean summer temperatures rise 2.3–5.9 °C while winter gains are similar or higher; winter–spring precipitation increases slightly ($\leq$ 10%), but summer totals decline. Simulated snow-water equivalent drops 35–80%, foreshadowing drier soils, higher fire frequency, and elevated invasive pressure. Montane sagebrush stands face the greatest mid-elevation drying, whereas already arid steppe and shrubland types remain most vulnerable to drought-related mortality. Land managers must adapt grazing, fire, and weed strategies to sustain habitat quality through these rapid climatic shifts.
Keywords. big sagebrush; climate change; RCP4.5; RCP8.5; snow-water equivalent; fire risk

1. 1. Background and Context

Successful land management requires regular monitoring and conservation of natural resources. This includes aiding in nutrient recycling and sustainable harvesting of vegetation and wildlife. The ranch shares these broad land management goals for its diverse ecosystems such as the grassland valleys, big sagebrush habitat, 14,000+ ft snow-capped peaks, freshwater systems, and aspen/conifer forests. However, management is made more difficult with changing conditions like parasitic insects, plant diseases, long-lasting droughts, increased rate of forest fires, etc. These conditions are often projected to be exacerbated by climate change and increasing global temperatures. Plant communities, for example, are highly determinate based on disturbance regimes and climate conditions. Big sagebrush ecosystems, which constitute a large portion of ranch property, and provide critical habitat for around 350 species of conservation concern (Davies et al., 2011), are sensitive to annual climate and available soil water (ASW) variation (Kleinhesselink & Adler, 2018).

2. 2. Climate Scenarios and Model Framework

Under the most drastic projected climate scenarios, temperatures are estimated to increase in big sagebrush communities on average by 5.5 °C, while precipitation changes are less certain with projected positive and negative differences of around 10% (IPCC, 2013). There are three primary big sagebrush ecosystems found in the western United States: Intermountain Basins Big Sagebrush Shrubland (SB-Shrubland), Intermountain Basins Big Sagebrush Steppe (SB-Steppe), and Intermountain Basins Montane Sagebrush Steppe (SB-Montane). These ecosystems are differentiated by their climatic niches, soil properties, and geography, and therefore are expected to respond differently to temperature and precipitation changes (Palmquist et al., 2016). SB-Montane is the big sagebrush vegetation type found at the ranch, and with available soil water projected to decrease in the summer season with increasing temperatures, we expect to see dry mid-elevation SB-Montane sites dry out the most (Palmquist et al., 2016). However, despite smaller reductions in summer ASW, SB-Steppe and SB-Shrubland will continue to be the driest ecosystems in the future, which may make these portions of the big sagebrush region more vulnerable to drought-related mortality and increased fire frequency (Palmquist et al., 2016).

Differences in future estimated concentrations of atmospheric greenhouse gasses produce the heterogeneity of future climate scenarios. These trajectories are called Representative Concentration Pathways (RCP). RCP4.5 is considered the intermediate scenario where atmospheric CO_2 peaks below 600 ppm around 2040 and then declines. RCP8.5 is the direst scenario where emissions continue to rise throughout the 21st century well past 1 000 ppm CO_2. For the purposes of assessing potential future temperature and precipitation changes at the ranch, we chose to analyze these future RCP climate scenarios and compared their outcome to historical weather data. We chose weather data at 9,000 and 12,000 ft elevations since most of the ranch lies between 8,000 and 13,000 ft.

Through our own analysis of 20 different global circulation models' (GCM) historical weather data and future RCP4.5 and RCP8.5 scenarios, we calculated the difference in average monthly temperature (Figure 1. & 2.) and total monthly precipitation (Figure 3. & 4.) between future projected climate data and historical data. Additionally, we simulated daily snowpack water equivalent (SWE) difference between historical and future RCP4.5 and RCP8.5 data using the same GCM weather data (Figure 5.).

3. 3. Projected Mid- and Late-Century Impacts

By the middle of the century (2040–2050), at 9,000 ft we can expect temperatures at the ranch to increase on average by 2.28 °C from June to September and by 2.07 °C from October to May following the RCP4.5 scenario. Following the RCP8.5 scenario compared to historical data, we anticipate temperatures will increase on average during the summer from June to September by 2.70 °C while during all other seasons (October to May) temperatures will increase by 2.54 °C. By the end of the century (2079–2099), at 9,000 ft we can expect temperatures at the ranch to increase on average by 2.98 °C from June to September and by 2.95 °C from October to May following the RCP4.5 scenario. Following the RCP8.5 scenario compared to historical data, we anticipate temperatures will increase on average during the summer from June to September by 5.87 °C while during all other seasons (October to May) temperatures will increase by 5.28 °C.

In accordance with the results of Palmquist et al. (2016), we estimate that precipitation will increase at the ranch at both 9,000 and 12,000 ft elevations under both RCP4.5 and RCP8.5 scenarios during the winter and spring, but decrease compared to historical averages during the summer (Figure 3. & 4.).

Additionally, we expect SWE to decrease significantly under both RCP4.5 and RCP8.5 scenarios (Figure 5.). Compared to historical data-simulated snowpack on the ranch at 9,000 ft elevation, RCP4.5 SWE is estimated to decrease on average by 35.7% mid-century and 51.3% end-century between November and March, and, specifically during April, by 86.3% mid-century and 95.4% end-century. Assuming we reach RCP8.5 greenhouse gas concentrations, we expect a decrease on average by 48.4% mid-century and 78.7% end-century between November and March, and, specifically during April, by 90.5% mid-century and 99.7% end-century.

If either the RCP4.5 or RCP8.5 climate scenarios are to ensue by the middle or end of the 21st century, big sagebrush ecosystems will have to adapt to many changing daily and seasonal conditions. SB-Montane systems, although by some estimates will benefit from higher regeneration due to warmer winters (Palmquist et al., 2016), will likely deal with increased competition from invasive species such as cheatgrass, which are restrained by minimum winter temperatures at high elevation (Chambers et al., 2007). Furthermore, the predicted drier summers forecast a more fire-prone future for big sagebrush ecosystems. Fire frequency and severity have been predicted to increase with lower SWE with the consequential decrease in snowpack mediation of lighting-ignited fires (Lutz et al., 2009). Lower SWE also poses the threat of unbalancing water availability, particularly for mid- and low-elevation sagebrush ecosystems that are snow poor (Schlaepfer et al., 2012).

The combination of increasing average temperatures, prolonged droughts, altered seasonal precipitation patterns, fires, and disease/insect invasion all propose a challenging future for not only sagebrush communities, but more broadly the ecosystem dynamics and diversity of Midwest rangelands. Our results, based on south-central Colorado weather ranch will likely endure similar challenges to maintaining ecosystem diversity and population abundance of key plant and wildlife species that the broader Midwest will face in the coming decades.

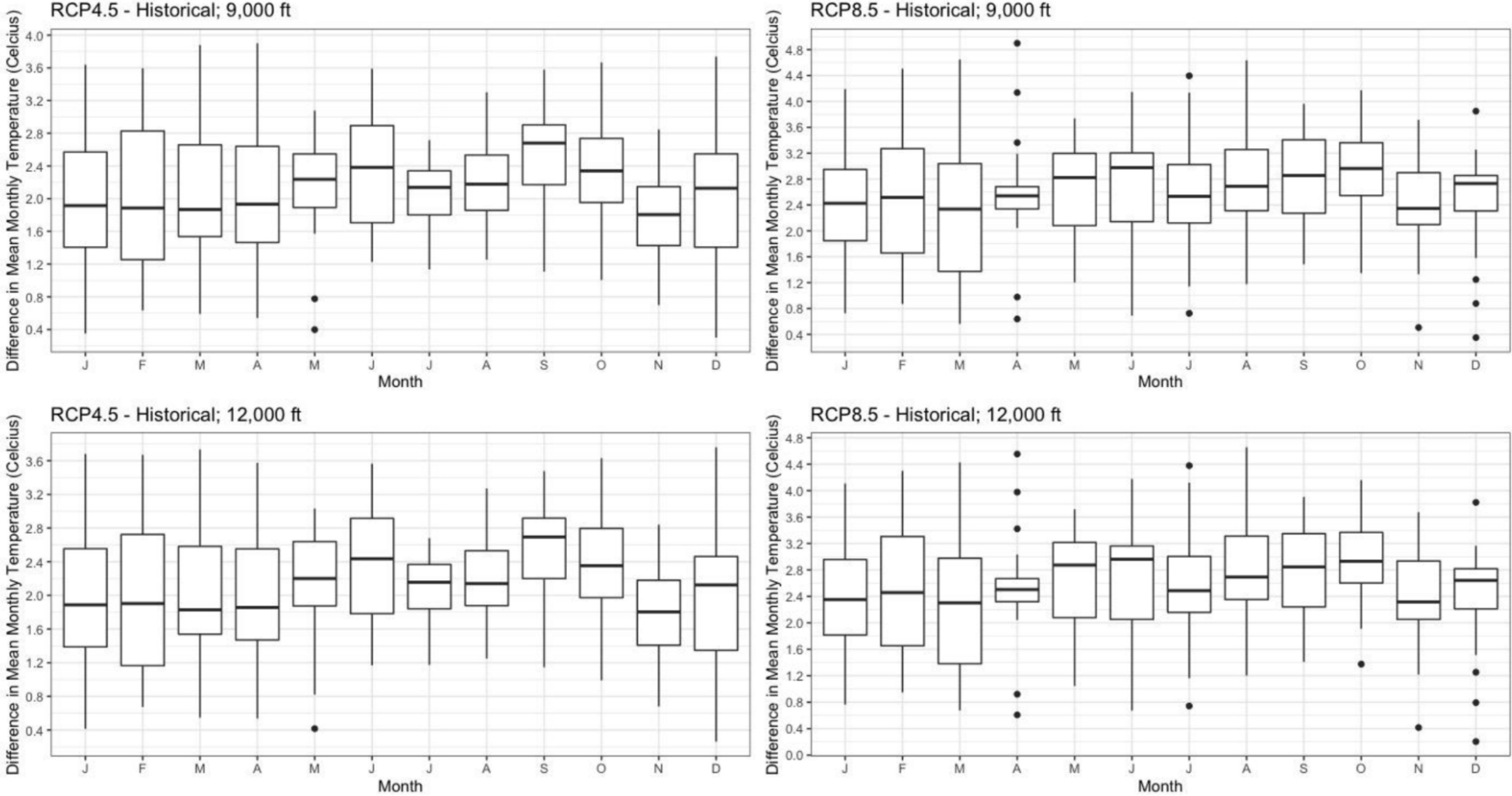


Figure 1. Difference of mean monthly temperature between mid-century future climate projection data and historical weather data for 9,000 and 12,000 ft elevations at the ranch. Boxplots calculated with 20 GCMs averaged from 1950 - 2005 (historical) and 2040 - 2050 (RCP4.5 & RCP8.5).

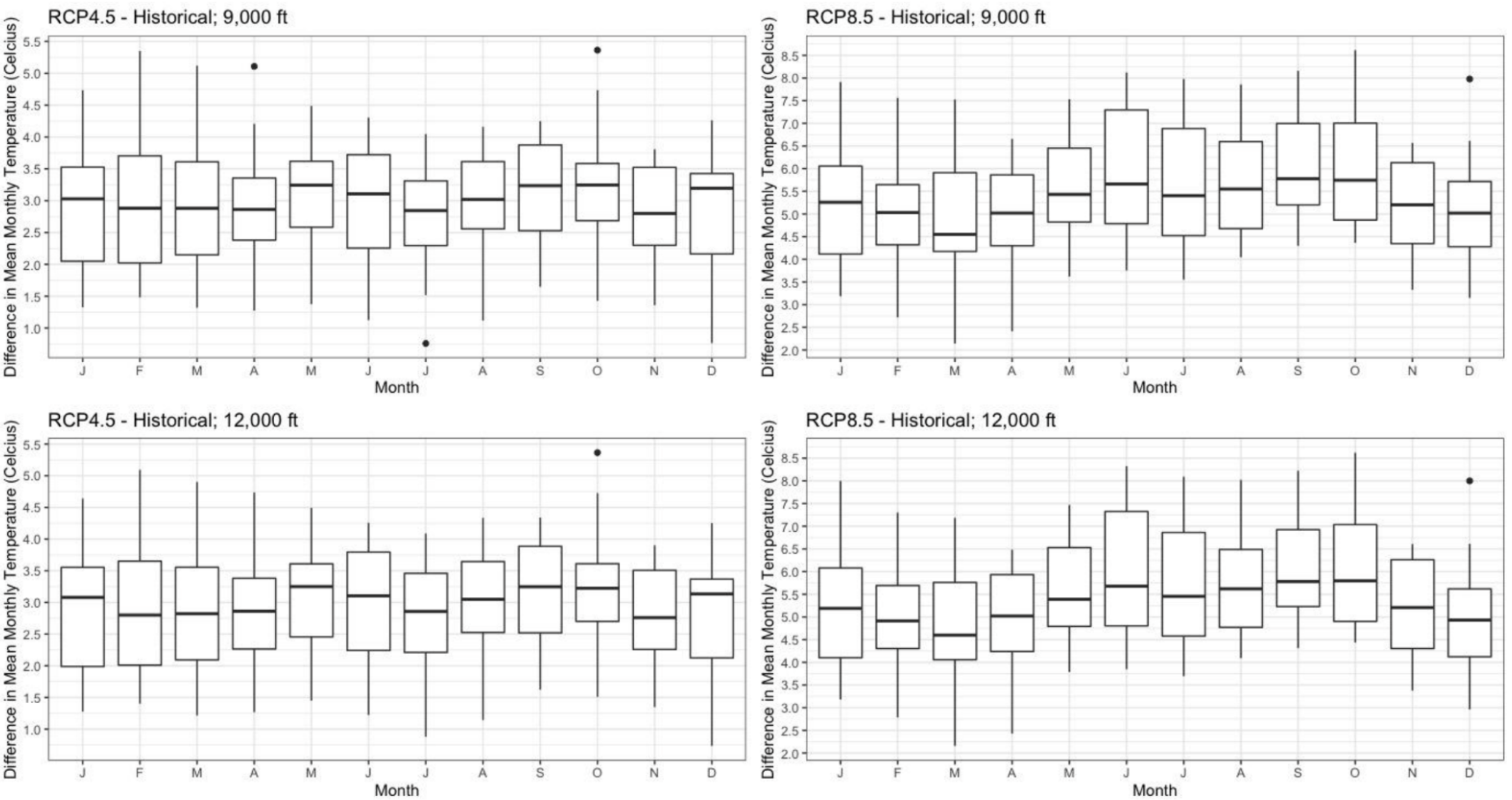


Figure 2. Difference of mean monthly temperature between end-century future climate projection data and historical weather data for 9,000 and 12,000 ft elevations at the ranch. Boxplots calculated with 20 GCMs averaged from 1950 - 2005 (historical) and 2079 - 2099 (RCP4.5 & RCP8.5).

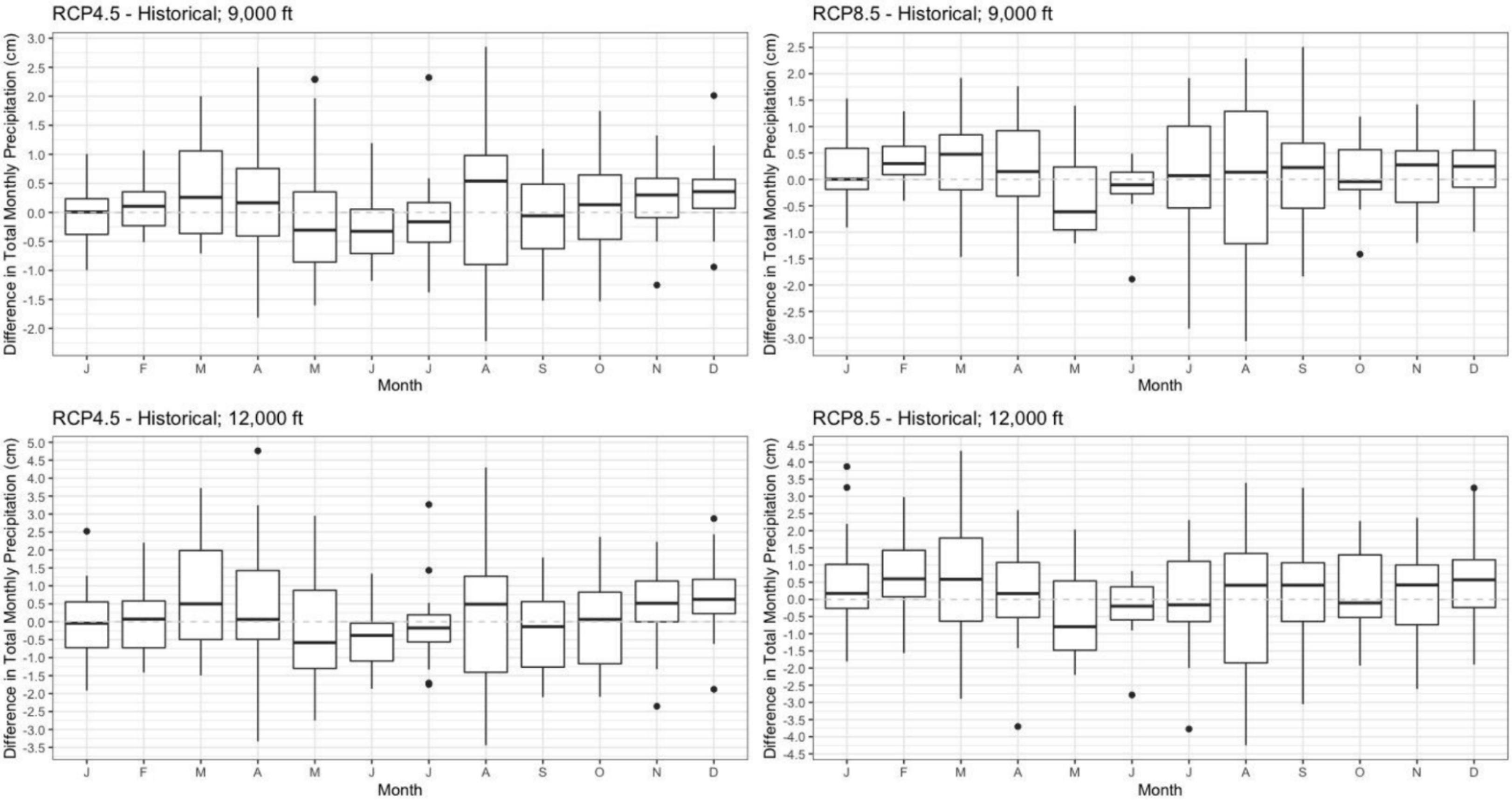


Figure 3. Difference of total monthly precipitation means between mid-century future climate projection data and historical weather data for 9,000 and 12,000 ft elevations at the ranch. Boxplots calculated with 20 GCMs averaged from 1950 - 2005 (historical) and 2040 - 2050 (RCP4.5 & RCP8.5).

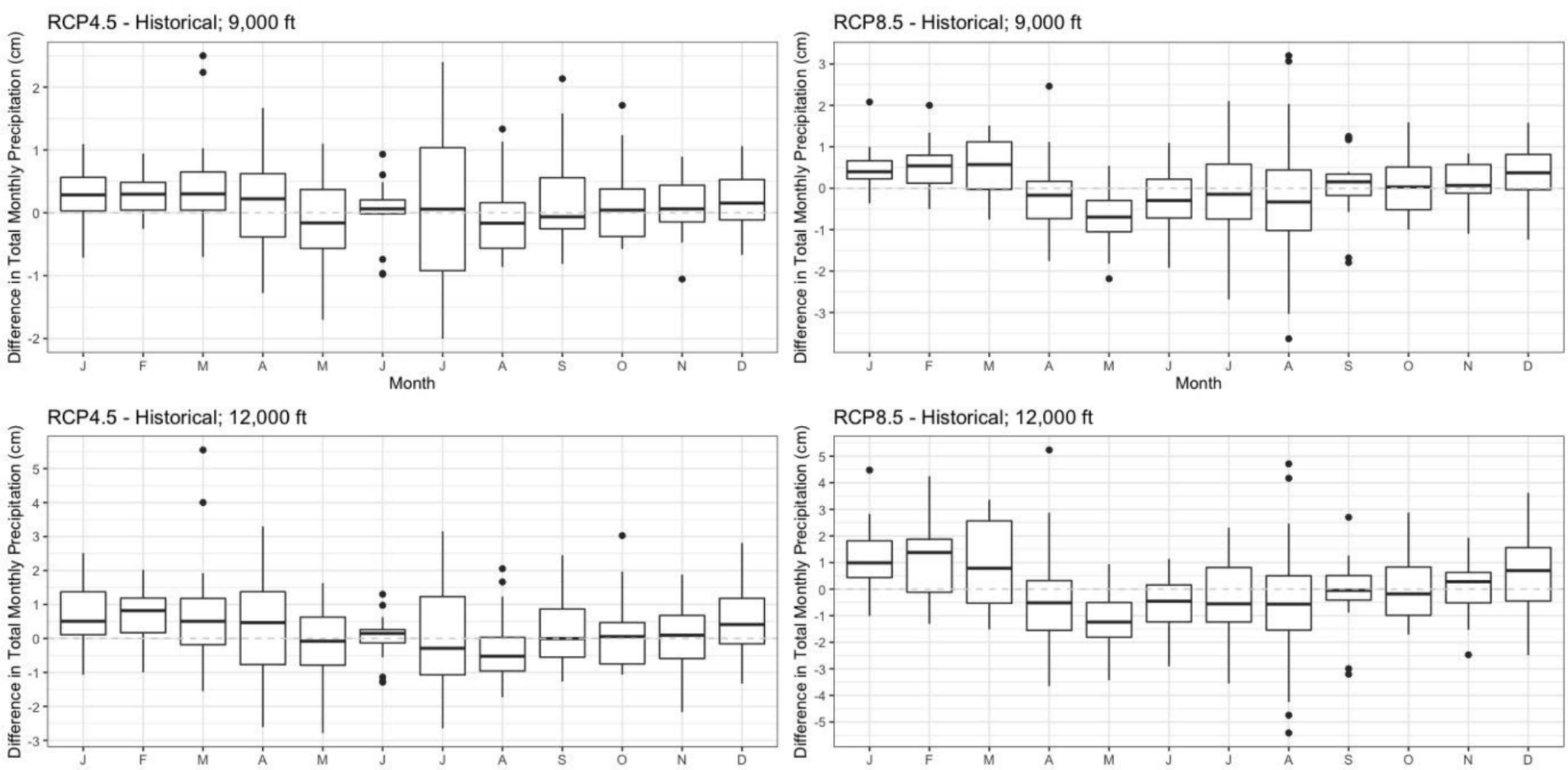
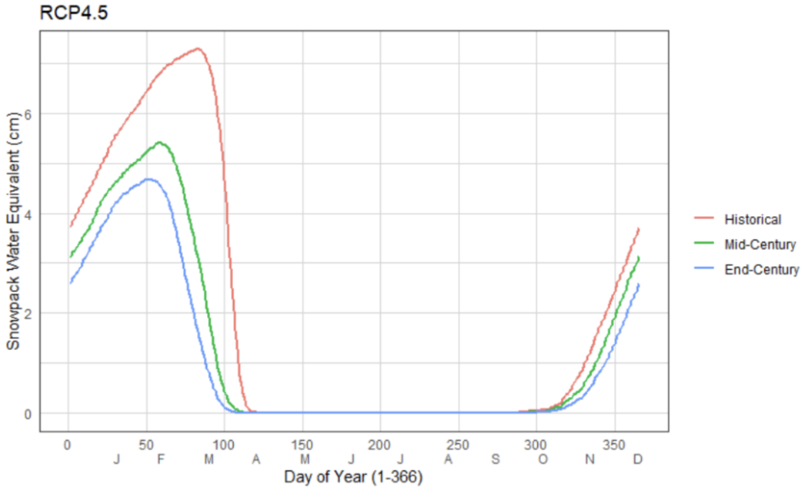


Figure 4. Difference of total monthly precipitation means between end-century future climate projection data and historical weather data for 9,000 and 12,000 ft elevations at the ranch. Boxplots calculated with 20 GCMs averaged from 1950 - 2005 (historical) and 2079 - 2099 (RCP4.5 & RCP8.5).



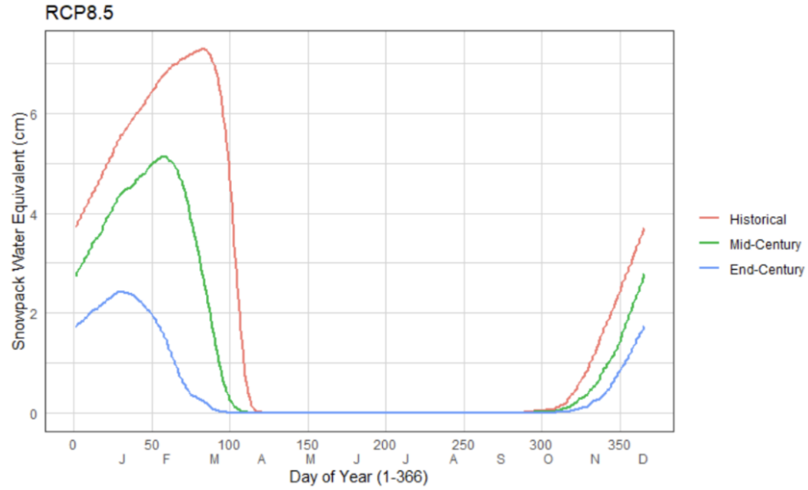


Figure 5. STEPWAT2 simulated snowpack water equivalent comparison between historical (1950-2005), mid-century (2040-2050), and end-century (2079-2099) time periods. Projections calculated based on 9000 ft elevation weather data averaged over 20 GCMs for RCP4.5, RCP8.5, and historical data.

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