Asymmetric warming projections for the inland Pacific Northwest

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Increased temperature is a fundamental response to increased concentrations of atmospheric greenhouse gases. However, the way in which warming is manifesting may vary substantially geographically, across seasons and even from night to day. Observed warming over the last century has not been uniform; rather, high-latitude land masses have warmed at a faster rate than oceans or lower-latitude land masses. Across western North America, the increase in spring temperatures since 1950 has substantially exceeded the increase in autumn temperatures. And finally, while the annual mean temperature over the northwestern United States has warmed by 1.3°F since 1900, the coldest night each winter has warmed at nearly three times that rate.

IMPACT

The rate of projected warming for the warmest and coolest days may vary, resulting in additional opportunities and stressors for agriculture in the inland PNW. Whereas the mean increase in temperature projected for the region by the latter half of the 21st century is around 9°F, the rate of warming is projected to be far more acute for the coldest days of the year and slightly higher for the hottest days of the year. Collectively, this would result in significant changes in cold hardiness zones across the region that may allow for more cold-intolerant perennial crops not currently suited to cultivation in the region.

Climate projections often focus on the amount of warming in mean annual temperature for a geographic region. However, given the ways in which temperature changes have occurred, identifying robust aspects of projected temperature change may help better focus adaptation efforts. For example, will climate change lead to a uniform amount of warming throughout the year in both daytime high and overnight low temperatures? Will the hottest days of the summer warm disproportionately more than an ordinary summer day? Will overnight low temperatures in winter warm more than daytime highs in winter?

To answer these questions, REACCH scientists combed through daily maximum and minimum temperatures from 20 global climate models (GCMs) run for historical (1950 to 2005) and future (2006 to 2099) experiments. They examined differences in rates of seasonal warming, as well as changes in maximum (T_{max}) and minimum temperature (T_{min}) during both winter (December through January) and summer (June through August) from the last half of the 20th century to the last half of the 21st century. Because warming rates may vary geographically, they focused on regional-averaged rates of temperature change covering the inland Pacific Northwest (PNW) (42° to 49°N, 111° to 121°W), consisting of the entire REACCH region, including all of Idaho and western Montana.

Projected changes in temperature across the inland PNW by the latter half of the 21st century depict an average warming of 9°F (5.5° to 11.5°F), assuming a continuation of greenhouse gas emissions. However, this warming of 9°F is not uniform in time and space. Seasonally, temperatures are projected to warm slightly more during the summer (10°F) than in the other seasons (Figure 1a). Also, additional modeling experiments by REACCH scientists using regional climate models that are capable of resolving the Cascades and Northern Rockies reveal amplified warming during the spring at higher elevations due to the recession of snow cover.

All models project amplified warming rates for overnight low temperatures compared to daytime high temperatures during the winter months, with minimum temperatures warming nearly 2°F more than maximum temperatures (Figure 1b). Enhanced warming of winter overnight temperatures may curtail cold damage for agricultural systems, although cold damage may paradoxically increase in the absence of snow cover. Conversely, nearly all models project daytime high temperatures to warm faster than overnight low temperatures in the summer months. The additional warming of daytime high temperatures coincides with general declines in summer precipitation, relative humidity, and cloud cover. These changes collectively result in increased potential evapotranspiration and moisture stress for irrigated agriculture as well as native ecosystems.

Impacts often result from exceptional meteorological events, and the severity and frequency of these events may change as the climate changes. Temperature extremes have notable impacts on human health, ecosystem function, and energy demand. The models project amplified rates of warming for the coldest winter minimum temperatures compared to the average warming in daily minimum temperatures during winter. While there is a broad range of projections across the different models, the coldest winter night that one might experience per decade (strictly defined as having a 0.1% chance of occurring during any winter day) warms by 16°F in the multimodel average, nearly twice the rate of warming projected for the warmest winter night one might experience in a decade (Figure 2a). Likewise, the models project an amplified warming rate of the warmest summer daytime temperatures relative to the average increase in daily maximum temperatures in summer, whereas the coolest daytime high temperatures in summer will warm at a slower rate (Figure 2b). The researchers hypothesize that these asymmetric changes will arise due to a combination of thermodynamic and land-surface feedback factors. For example, heightened warming rates for the

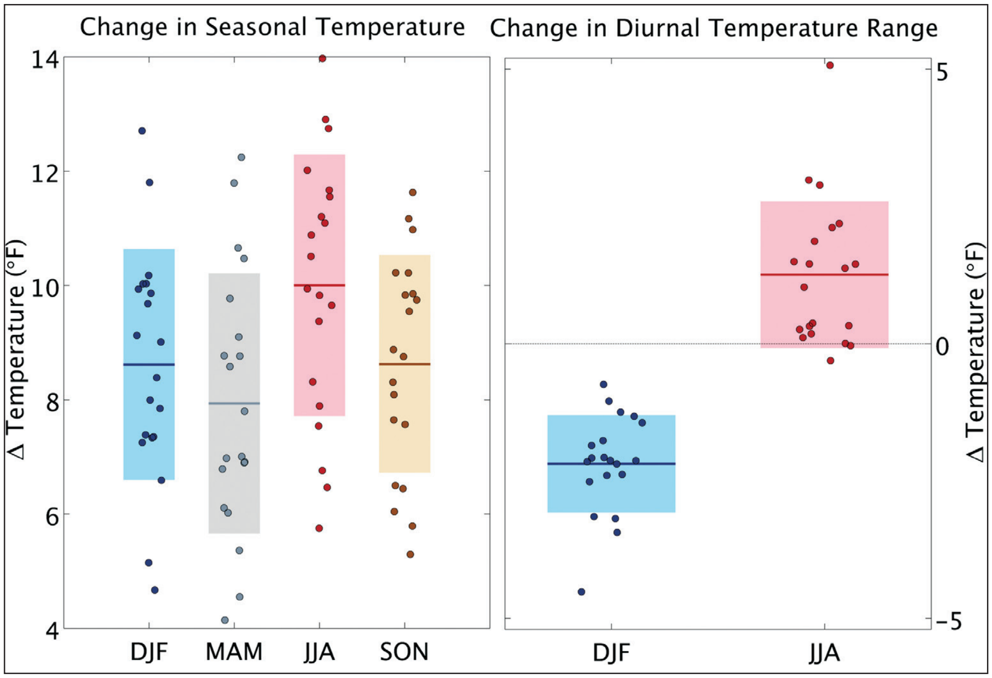

Figure 1. *Differences in temperature between 2050 to 2099 and 1950 to 1999, averaged over the inland PNW (42° to 49°N, 111° to 121°W) for 20 global climate models run using representative concentration pathway (RCP) 8.5. (a) Mean temperature changes for winter (December through February), spring (March through May), summer (June through August), and autumn (September through November). (b) Change in diurnal temperature range (daily high temperature minus daily low temperature). The results for each model are denoted by a dot, the horizontal line shows the 20-model mean, and shading denotes values within one standard deviation from the mean.*

coldest winter nights are a likely consequence of amplified warming over interior Canada, which serves as a source region for outbreaks of cold air, whereas amplified warming for the warmest summer days may arise due to a reduction in summer soil moisture, which allows more energy to be used to heat the land surface rather than to evaporate water.

These changes have implications for adaptation to climate change that might otherwise be neglected by assuming a constant warming rate. For example, the significant warming of the coldest nights of winter may result in dramatic changes in both agricultural crops and pests that can successfully overwinter in the region. These changes may also allow for the establishment of agricultural systems novel to the inland PNW that may otherwise be considered unviable under uniform warming. Additional warming of peak summer temperatures will likely have implications for peak energy demand and pose risk to systems that are not thermally adaptive. Collectively, the asymmetric warming projected by the GCMs presents both challenges and potential opportunities for agriculture in the inland PNW.

Figure 2. *Cumulative probability of differences in (a) winter daily minimum temperature and (b) summer daily maximum temperature between 2050 to 2099 and 1950 to 1999, averaged over the inland Pacific Northwest (42° to 49°N, 111° to 121°W). Results for individual models are shown by light lines, while the bold red line shows the 20-model average. For reference, the dashed horizontal line shows the 20-model mean change.*