Climate Trends Primer:
Town of Truckee, California

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Introduction

People around the world are experiencing changing conditions that affect their daily lives. Many changes are due to human-caused climate change, resulting from combustion of fossil fuels and deforestation. Climate change is a global problem, yet the impacts and opportunities for action are local. As climate change accelerates with continued greenhouse gas emissions, local communities will need to be prepared for impacts and take action to protect people and the natural resources they depend on.

Like other cities, the Town of Truckee is experiencing rapid change in climate and the natural environment. In response, the Town of Truckee is conducting a climate change vulnerability assessment and developing strategies that will increase community resilience in the face of change. This climate trends primer is in support of that process.

Throughout California, residents report changes in severe storms, heat waves, timing of the seasons, water availability, wildfire, and plants and wildlife. All of these changes can affect peoples' health, culture, and livelihoods. Local infrastructure such as roads and bridges are also at risk from severe heat, storms, and flooding. Many changes are already occurring, and many more are expected to occur in the future.

If global action to greatly reduce greenhouse gas emissions is taken quickly, the long-term severity of climate change will be reduced, and local

Glenshire Bridge, Grant Kaye, 2011

strategies to adapt will be more successful. Even if action is taken, however, the next few decades are expected to experience drastic change because of long-lasting greenhouse gases already emitted. Local action and planning to reduce the impacts of climate changes are needed.

This climate change primer provides information on the trends and impacts expected with climate change, specific to Truckee and the surrounding region (Fig. 1). Understanding climate change trends and impacts is the first step in identifying climate-related risks and vulnerabilities. The next step will be to develop strategies that build overall resilience for both people and natural resources of the region.

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What Climate Change Means for Truckee

The climate is what defines any given locality and, for many of us, makes it home. As climate change progresses, many important features and resources are at risk. Each community experiences unique impacts associated with climate change, and some are more predictable than others. Some predicted impacts of continued climate change in Truckee include:

Bruce C. Cooper

- Loss of natural water storage in the form of snowpack
- Changes in forests, wildfire, and snow expected to impact tourist economy
- Drought and wildfire resulting in impacts to health and well-being, including respiratory illness, vector-borne disease, and stress and mental trauma associated with disasters
- Increased frequency and severity of severe heat, affecting outdoor workers, elders, people without homes, people without air conditioning, infants, and other vulnerable populations
- Increase in frequency and severity of large storms, leading to more flooding
- Fire risk to critical emergency response infrastructure, homes, businesses, and peoples' health and safety
- Less demand for electricity and/or natural gas for heating
- Increased disruptions in electric supply with drought, lower streamflow and heat waves
- Increases in cost of road construction and maintenance, from higher temperatures, more severe storms, and other extreme events (but decreased snow removal)
- Loss of many native species and ecosystems, including many dominant tree species, threatened and endangered species, game species, wetlands, and others
- Increase in invasive species, pests, and pathogens, such as bark beetles
- Lower and warmer streams, degradation of aquatic habitat, impacts to water quality, and declines among cold-water fishes
- Loss of important benefits from natural systems, including water filtration, flood abatement, tourism, and recreational opportunities

Truckee Study Area

Figure 1. The California side of the Truckee subbasin (dark blue dotted line) was the Study Area used for assessing most climate change projections for this primer.

Climate Trends Snapshot – Town of Truckee, California

HISTORICAL TRENDS (change 1937-2017)

- ⬆ Temperature +2.0° F
- ⬇ Precipitation –1%
- ⬇ 8 fewer days below freezing
- ⬆ 10 more days above 90° F

MID-CENTURY PROJECTIONS 2040–2069

Averages:

- ⬆ Minimum temp. +4° to +7° F
- ⬆ Maximum temp. +6° to +7° F
- ⬇⬆ Precipitation –11% to +37%
- ⬇ April 1st SWE –68% to –71%

Extremes:

- ⬆ 14-31 more days above 90° F
- ⬇ 55-68 fewer nights below 32° F
- ⬇⬆ Extreme rainfall –1 to +6 days

LATE-CENTURY PROJECTIONS 2070–2099

Averages:

- ⬆ Minimum temp. +7° to +11° F
- ⬆ Maximum temp. +8° to +11° F
- ⬆ Precipitation +1% to +61%
- ⬇ April 1st SWE -84% to –96%

Extremes:

- ⬆ 32-57 more days above 90° F
- ⬇ 78-115 fewer nights below 32° F
- ⬇⬆ Extreme rainfall –1 to +5 days

Climate Change Data and Models

The Earth's climate is regulated by a layer of gases commonly referred to as greenhouse gases for their role in trapping heat and keeping the earth at a livable temperature. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapor (H_2O). CO_2 plays an especially large role due to its long-lasting nature and amount compared to other gases. The atmospheric concentration of CO_2 has risen from 280 to more than 400 parts per million (ppm) in the past century, driven largely by the burning of fossil fuel, deforestation, and other human activity.

Information from ice cores allows us a glimpse into CO_2 levels over hundreds of thousands of years. This data shows us that CO_2 has fluctuated between about 175 and 300 ppm over the last 800,000 years and the current level of 400ppm is far above anything detected in that time period. As CO_2 levels changed in the past, it has tracked closely with changes in temperature, and we can expect this relationship to hold in the future as CO_2 and other greenhouse gases continue to increase.

For over a century, we have known that increases in the concentration of greenhouse gases in the atmosphere result in warmer temperatures. Long-term tracking data from weather stations and other research support this expected trend. Traditional knowledge from indigenous communities around the globe also indicates that there has been significant change in conditions over time, especially since the end of the last ice age.

In order to look at projected future climate, we use computer models based on understanding of the Earth's climate. The Intergovernmental Panel on Climate Change (IPCC), which is made up of thousands of leading scientists from around the world, has created a group of 25+ global climate models (GCMs) from different institutions with which to predict future trends. These models were created independently, and vary

substantially in their output. Yet most of the uncertainty in future conditions comes not from the models themselves, but from estimating how much action will be taken to reduce greenhouse gas emissions in the future. The different possible greenhouse gas concentrations (called Regional Concentration Pathways, or RCPs), depend on whether or not the international community cooperates on reducing emissions (Fig. 3). In this report, we provide projections based on a lower emissions pathway where emissions are greatly reduced (RCP 4.5) and a higher emissions pathway where emissions are only slightly reduced (RCP 8.5) and that is similar to the current global trajectory.

Many data on future trends in this report are compiled from four global climate models,[1] which have been adjusted to reflect variation across the local landscape using a statistical technique, called LOCA,[2] developed by the Scripps Institute of Technology. The four models show a range of projections, some hotter, cooler, wetter, and drier, than others. Taken as a group, they provide information on uncertainty and potential magnitude of change. In general, projections about rainfall are harder to predict (i.e. more variation among models) while temperature projections are associated with more certainty. Also, short- to mid-term projections are more reliable than those further out.

Global Trends

Global climate is changing quickly compared to past climate change throughout the Earth's history. Heat waves and rainfall are increasing in both how often they occur and how severe they are across most of the world.[3]

The hottest year on record was 2016, which was the third consecutive year that a new global annual temperature record was set (Fig. 2). The average global temperature across land and ocean surface areas for 2016 was 1.7° F (about 1° C) above the 20th century average. The fourth hottest year was 2018.[4] The last few years have also seen record-breaking, climate-related weather extremes. In the U.S., there were 14 weather- and climate-related events that cost more than $1 billion each in 2018. This cost the economy $91 billion. Only 3 other years were more costly (2005, 2012, and 2017), with a record set in 2017 at $317 billion.[5]

Models project continued average global warming of 5.0° to 10.2° F (2.8° to 5.7° C) by the end of this century and continued warming for the next two centuries if emissions continue in the current pathway (Fig. 3). Because higher latitudes (closer to the poles) warm faster than areas closer to the equator, the U.S. is expected to warm significantly more than the global average.

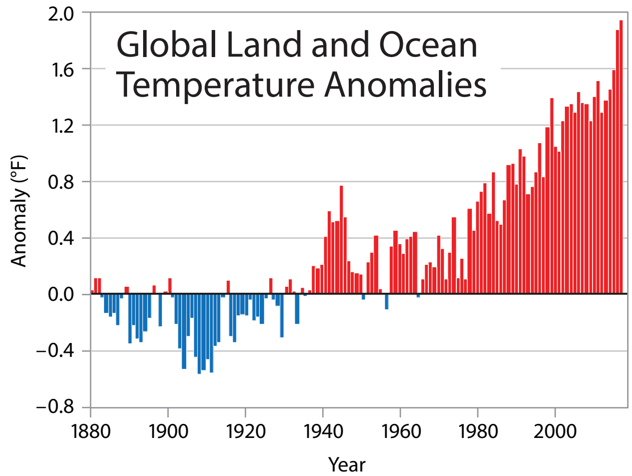


Figure 2. Average global temperature (left) has increased more than 1.7° F (1° C) compared to the historical average (1901-1960), shown as the horizontal black line. Red bars show temperatures above average, whereas blue bars show temperatures below average. Surface temperature change for the period from 1986-2016 is shown on the map on the right.[3]

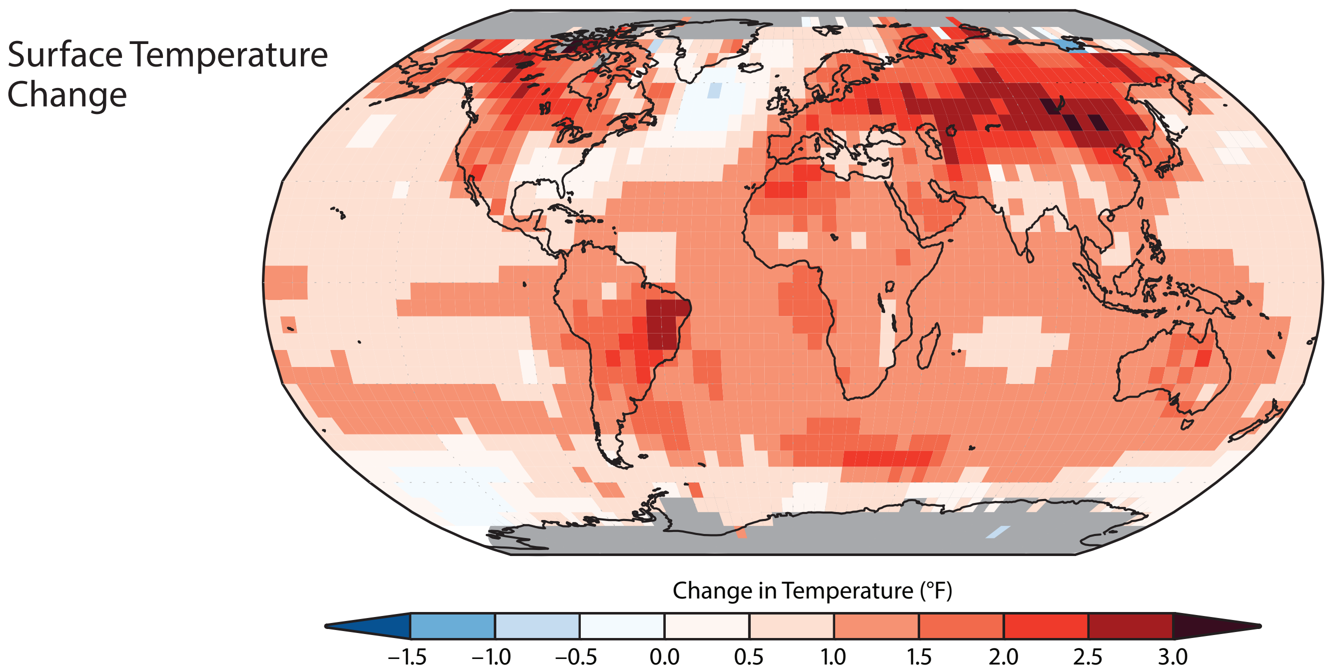
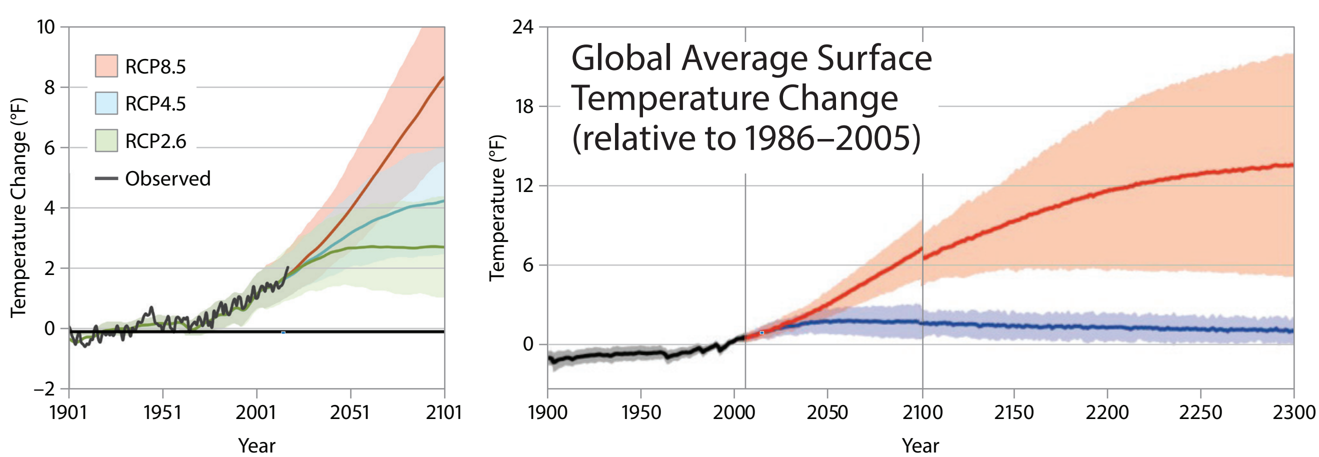


Figure 3. Whether or not people continue to emit large amounts of greenhouse gases will determine how warm the earth gets. By the end of this century (graph on the left), average global temperatures could increase anywhere from 1° F to more than 10° F, based on three different scenarios. Over longer timescales, warming would level off if emissions are reduced, or continue to rise (as much as 23° F) for many centuries if they continue unabated.



Chris Bartkowski

Historical Trends in California and the Sierra Nevada

Miguel Stanley

Temperature

Averages – Most of California has warmed more than the global average of 1.7° F, with many areas exceeding 2-3° F (Fig. 4).

Severe Heat – Extreme heat is responsible for more fatalities than any other form of severe weather. Interestingly, "extreme heat" is relative. In areas that normally experience high temperatures, a heat wave of 100° F may have little impact on the population at large. In an area that does not usually experience high temperatures, however, a heat wave in the 80s and 90s can lead to health impacts and death.

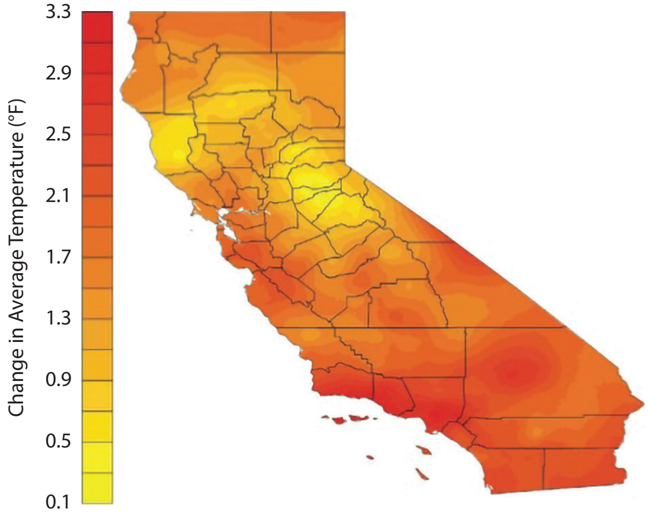


Figure 4. Observed changes in annual average temperature (°F), showing substantial changes across most of the state. Changes are based on the difference between present day averages (1986-2016) and historical averages (1901-60). Map from the California Climate Assessment.[1]

As climate change has progressed, heat waves have increased in California and across the nation. In California, heat waves have increased in intensity as well as duration, frequency, and timing.[6] Extreme heat days have increased statewide at a rate of about 1 per year, since 1950.[7] Nighttime heat has increased more than daytime heat.

Precipitation

Averages – On average, precipitation has increased by 4% across the U.S. While annual precipitation has increased across much of the eastern and northern U.S., it has decreased across much of the southern and western U.S. (Fig. 5).[8] California has some of the highest year-to-year and multi-year variation in precipitation in the nation. Annual precipitation can fluctuate between about 50% of average to 200% of average from year to year.[9]

Ice, Snow and SWE – Snowpack throughout the Western U.S. is vital for both water storage and streamflow. With warmer temperatures, however, precipitation falls increasingly as rain instead of snow, with extensive societal and economic impacts. Studies indicate that snowpack (measured as the amount of water stored in snowpack, or snow water equivalent, SWE) has declined 15-30% across the western U.S. between the 1950s and 2016 (Fig. 6). Also, glaciers in the Sierra Nevada have lost more than 70% of their area since the beginning of the 20th century.[10]

Percent change in annual precipitation

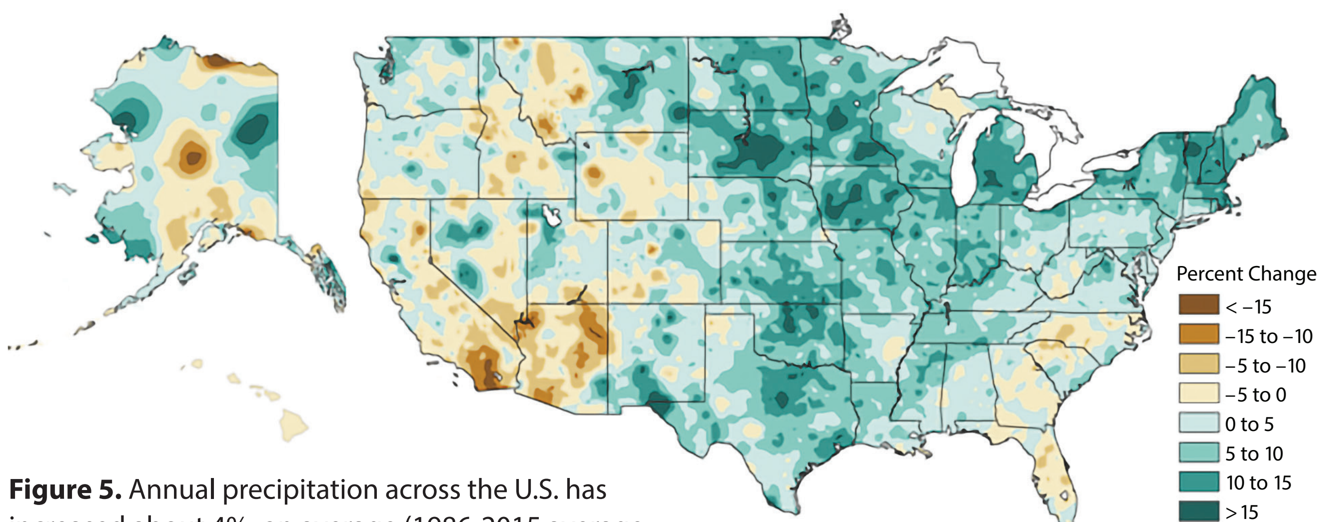


Figure 5. Annual precipitation across the U.S. has increased about 4%, on average (1986-2015 average, compared to the 1901-60 historical period). From the National Climate Assessment.

Extreme precipitation – Across the U.S., the frequency and intensity of extreme precipitation events have increased more than average precipitation. Most of the heaviest precipitation events in California occur during winter, as many arise during "atmospheric river" storms that are fed by long streams of water vapor transported from the Pacific Ocean, often from lower latitudes.[11] More than other regions of the western United States, the presence or absence of these large storms within a given winter season determines California's water resources because of their contribution to snowpack.[12] Over the last half century, the percent of precipitation occurring in large storms has been increasing.[13]

Drought – Higher temperatures cause drier soils based on increasing evaporation, even with modest increases of precipitation. Thus, heat is leading to higher intensity and extent of drought conditions. For example, the drought of 2012-2016 was especially severe because of higher temperatures associated with climate change, as well as low snowpack levels. This drought has been called a "harbinger" of future dry spells, which are expected to continue to be exacerbated by warming.[14]

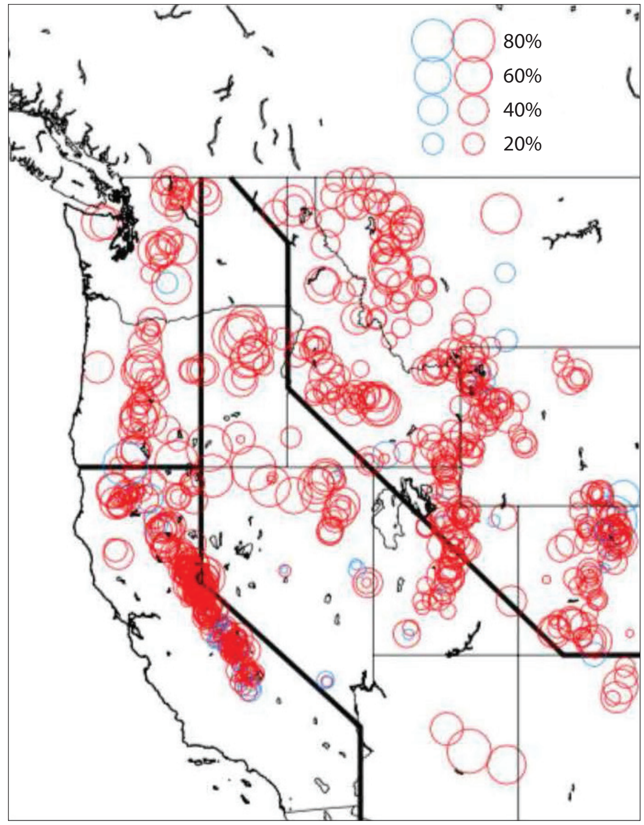


Figure 6. Observed changes in April 1 SWE from 1955-2016. Declines are shown in red while increases in SWE are shown in blue. From Mote et al. 2018.

Donner Lake, Truckee, California / MaxPixel.Public Domain / freegreatpicture.com 3803697

Climate Trends in and around Truckee

Temperature

Average – Average annual temperature data obtained from the BOCA weather station near Truckee (Lat/Long = 36.3886, –120.0936) displayed a steady warming trend for the region (Fig. 7). In a comparison between the historical 30-year period (1937-1966) and the recent 30-year period (1987-2016), the Truckee region has warmed approximately 2.0° F.

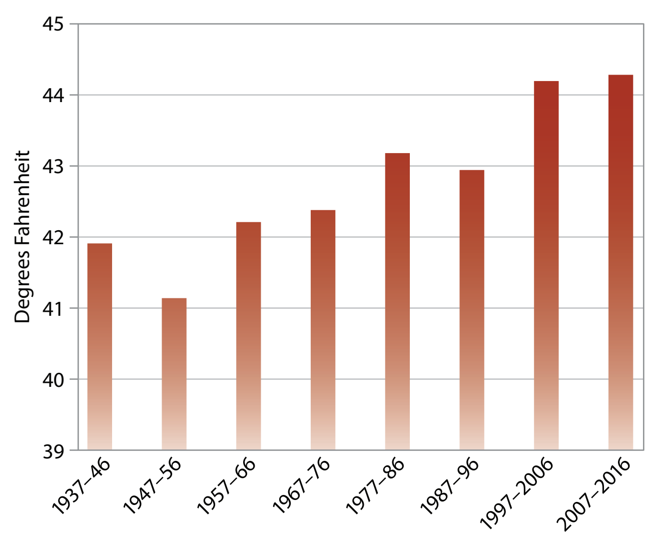


Figure 7. Average historical temperature at the BOCA weather station near Truckee, California.

Average annual temperature in Truckee and the surrounding area is expected to rise an additional 5-7° F by mid-century (2040-69) and 8-11° F by late-century (2070-99), as compared to the

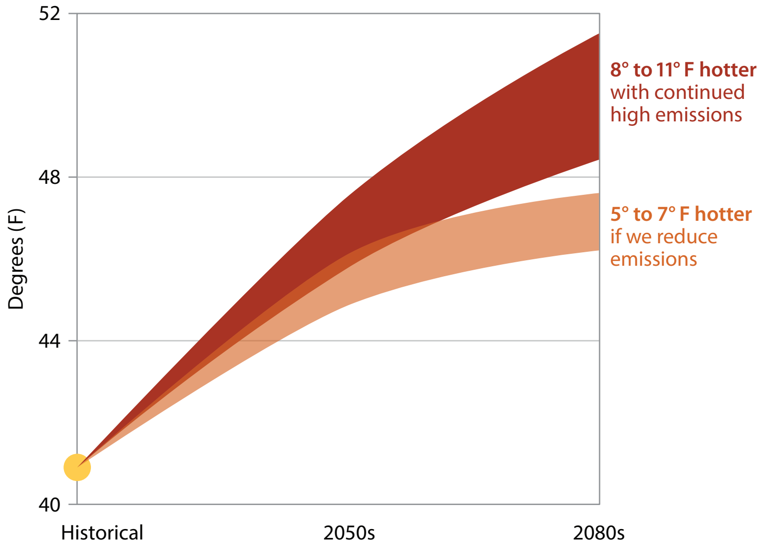


Figure 8. Average temperature across the Truckee Study Area. Warming shown for two future time periods: mid-century (2040-69) and late-century (2070-99), based on a lower emissions pathway (RCP4.5) and higher emissions pathway (RCP8.5). Data based on 4 global climate models from Cal-Adapt.

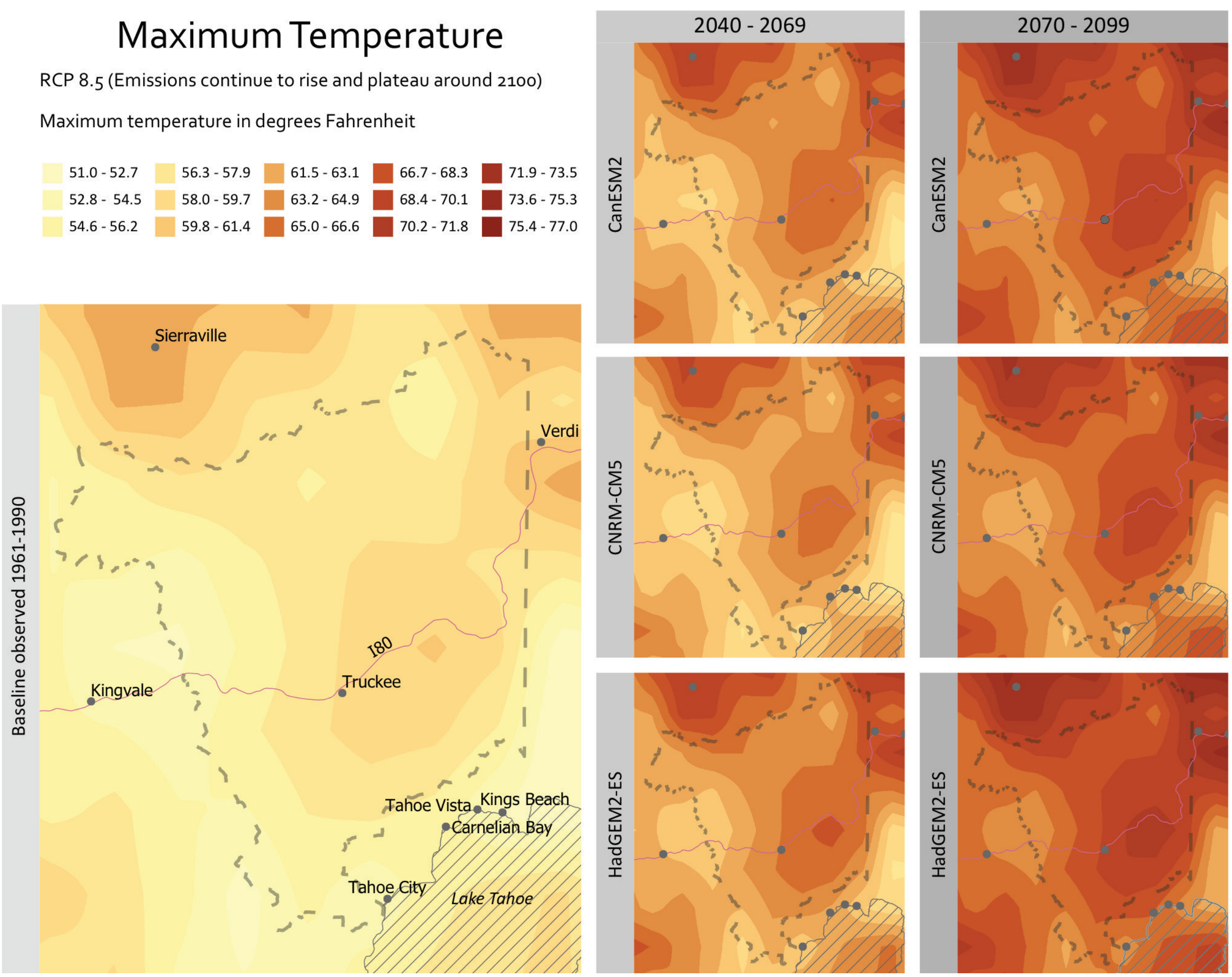


Figure 9. Average maximum temperature across the Truckee Study Area. Warming shown for two future time periods: mid-century (2040-69) and late-century (2070-99), based on the higher emissions pathway (RCP8.5). Data based on three global climate models from Cal-Adapt.

historical period (1961-1990). This projection is based on an assumption of continued higher greenhouse gas emissions. If emissions are lowered, warming can be limited to approximately 5° F by mid-century and 6-7° F by late century.[15]

Days below freezing – The number of days below freezing has been declining over the past century (Fig. 10). On average, there are approximately 8 fewer days below freezing each year in the recent period (1987-2016), than there were in the historical period (1937-1966).

Projections indicate 55-68 fewer days below freezing by mid-century and 78-115 days fewer by late-century. The addition of 3-4 months above freezing can have significant impacts on native vegetation, water and energy demand, road maintenance, and a variety of other aspects of day-to-day life in Truckee.

Severe Heat – Exposure to dangerously high temperatures are a health threat expected to increase with climate change. The number of days per year above 90° F has increased steadily throughout the last century (Fig. 11). On average, there are approximately 10 more days above 90° F in the recent period (1987-2016), than there were in the historical period (1937-1966).

The number of days above 90° F is expected to continue to increase by 14-31 days per year by mid-century, and by 32-57 more days per year by late-century.[16]

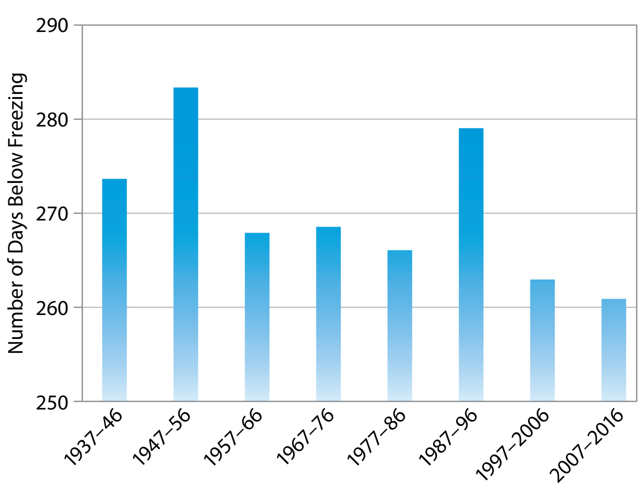


Figure 10. Average historical number of days below freezing at the BOCA weather station near Truckee, California.

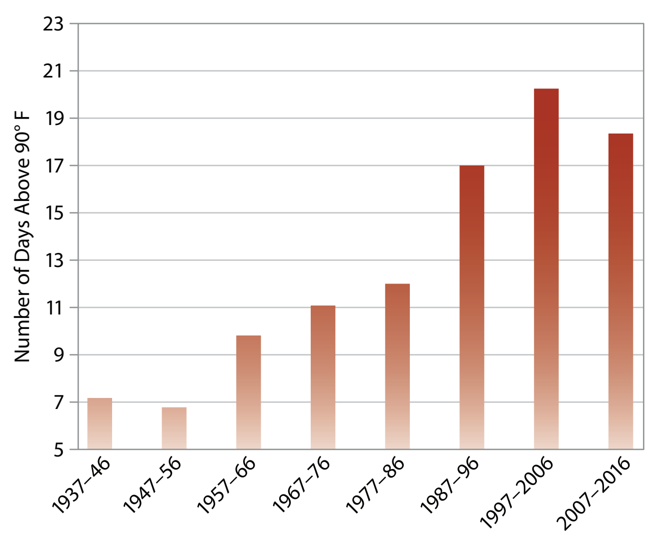


Figure 11. Average historical number of days above 90° F at the BOCA weather station near Truckee, California.

Precipitation

Average – Precipitation varies substantially year to year (Fig. 12). On average, there has not been much change in precipitation in the recent period (1987-2016), than there was in the historical period (1937-1966) although variability may be increasing.

Global climate models show little agreement on future precipitation for the region. Projections for mid-century range from -11% to +37%. Projections for late-century range from +1% to +61% in precipitation gains, assuming continued higher greenhouse gas emissions (Fig. 14). Even with higher precipitation, however, water availability and soil moisture could decline due to increased evaporation from longer growing seasons and higher temperatures.

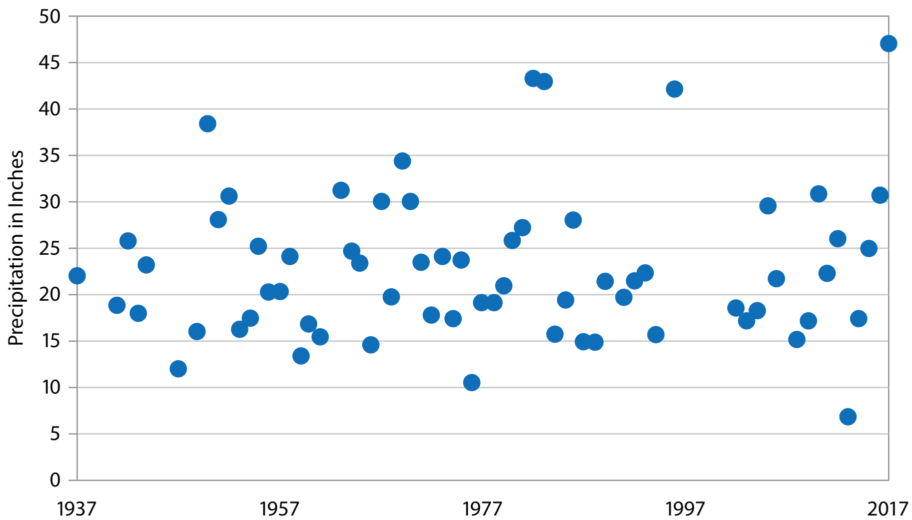


Figure 12. Average annual precipitation, in inches, at the BOCA weather station near Truckee, California.

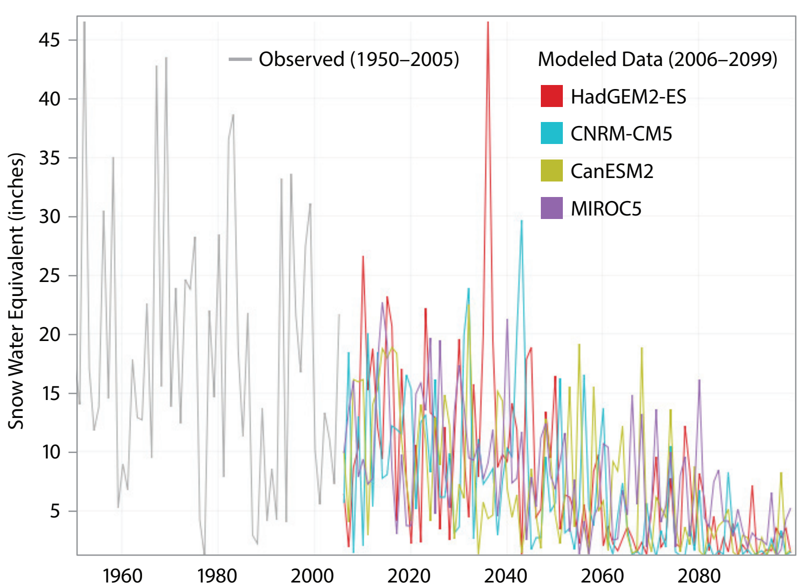


Figure 13. April 1st snow water equivalent (SWE), in inches, from 1950 to 2099, for the Prosser Creek-Truckee River Watershed, California. Graph downloaded from the Cal-Adapt website.[17]

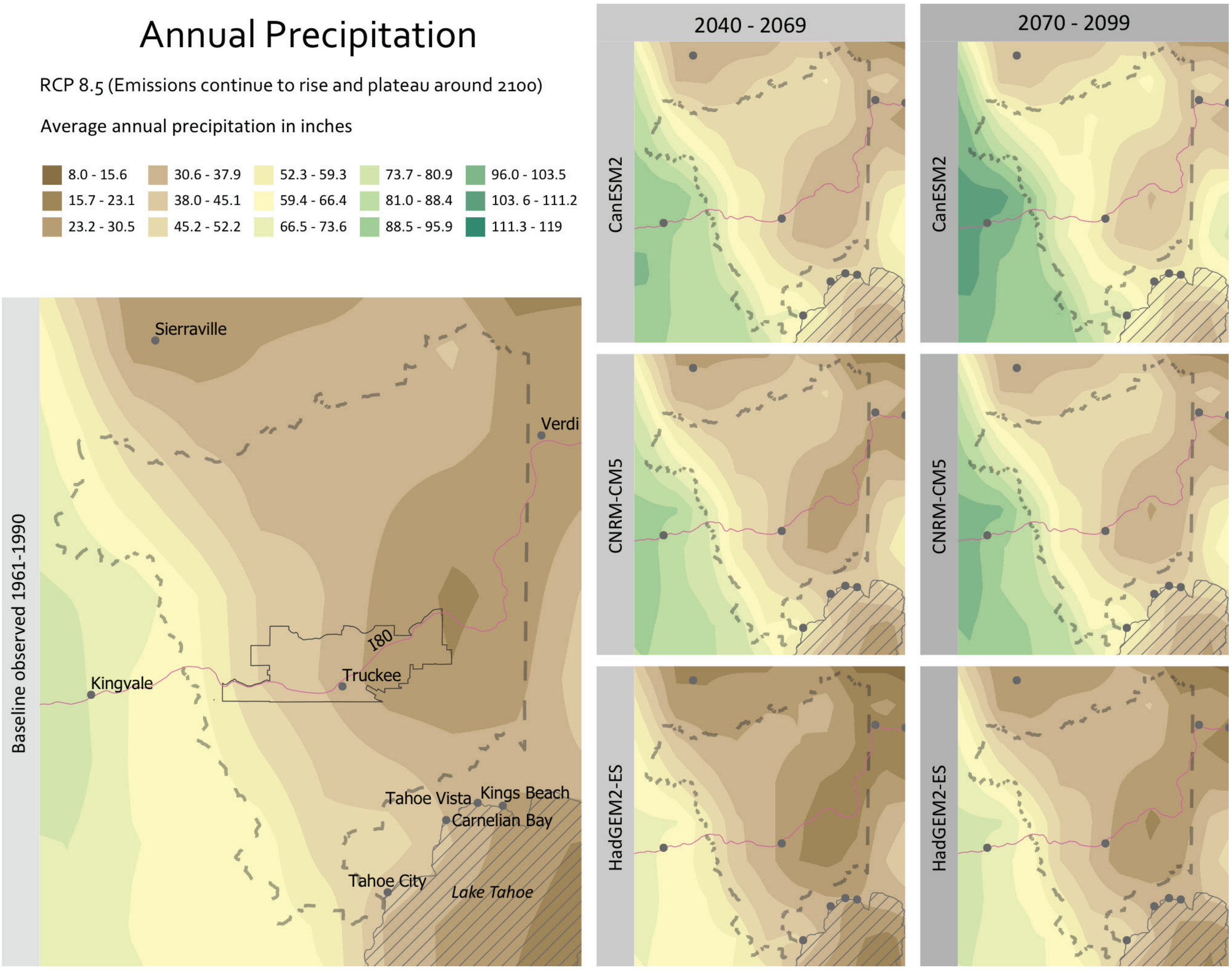


Figure 14. Historical and future projected precipitation across Truckee and the surrounding region. Precipitation, in inches, is shown for two future time periods: mid-century (2040-69) and late-century (2070-99), based on the higher emissions pathway (RCP8.5). Data based on four global climate models from Cal-Adapt (MIROC5 not shown).

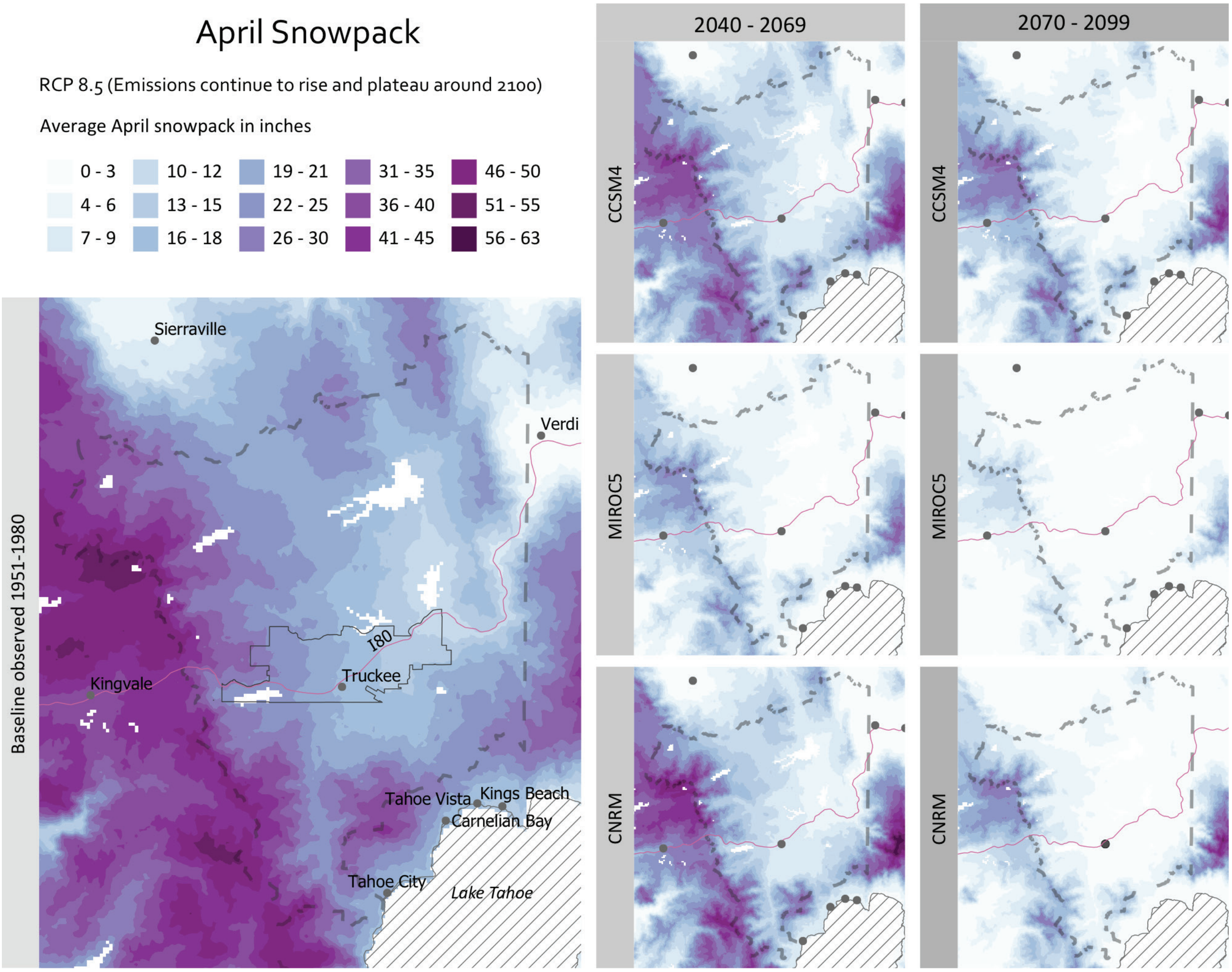


Figure 15. Historical and future projected April snowpack across Truckee and the surrounding region. Snowpack, in inches, is shown for two future time periods: mid-century (2040-69) and late-century (2070-99), based on the higher emissions pathway (RCP8.5). Data based on three global climate models from the Basin Characterization Model.

April Snowpack – The snow water equivalent (SWE) measured on April 1st is a common measure of snowpack levels. SWE has steadily declined in the Prosser Creek-Truckee River watershed since 1950 (Fig. 13). All four downscaled global climate models agree on continued declines in snowpack through the end of this century (Fig. 13).[17] By mid-century, declines are expected to reach 68-71% and by late-century snowpack is expected to decline by 84-96%. By late-century, only the highest elevations of the study area are expected to retain April snowpack (Fig. 15).

Drought Stress – The Climatic Water Deficit is a measure of drought stress across the landscape. Drought stress is expected to increase due to higher temperatures and more evaporation, as well as any changes in precipitation levels. Climatic water deficit is expected to increase throughout the century, ranging from 32-51% increase by 2040-2069 and 44-78% increase by 2070-2099 (Figure 16). These projections indicate that the region is expected to become substantially drier.

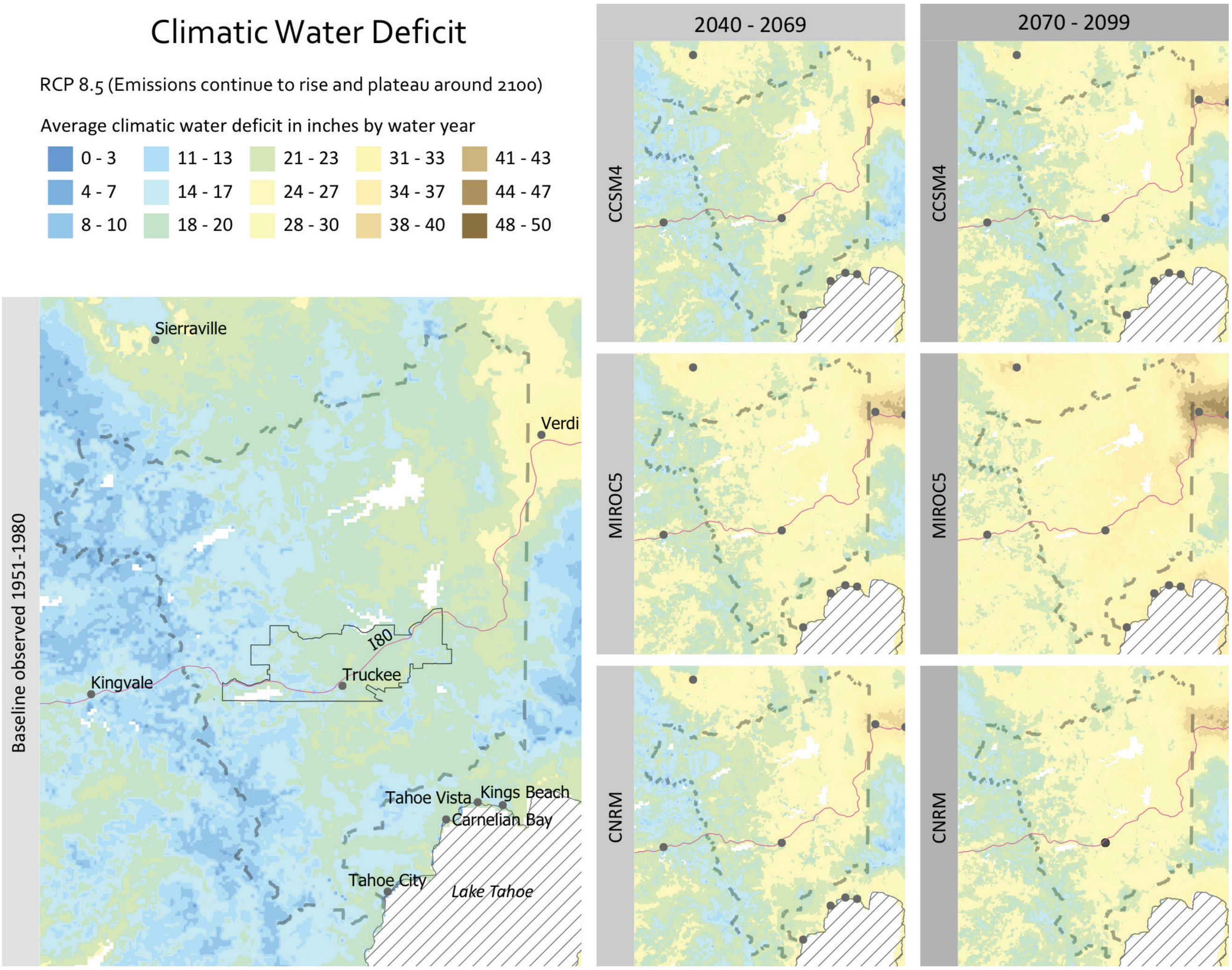


Figure 16. Historical and future projected Climatic Water Deficit across Truckee and the surrounding region. CWD, in inches, is shown for two future time periods: mid-century (2040-69) and late-century (2070-99), based on the higher emissions pathway (RCP 8.5). Data based on three global climate models from the Basin Characterization Model.

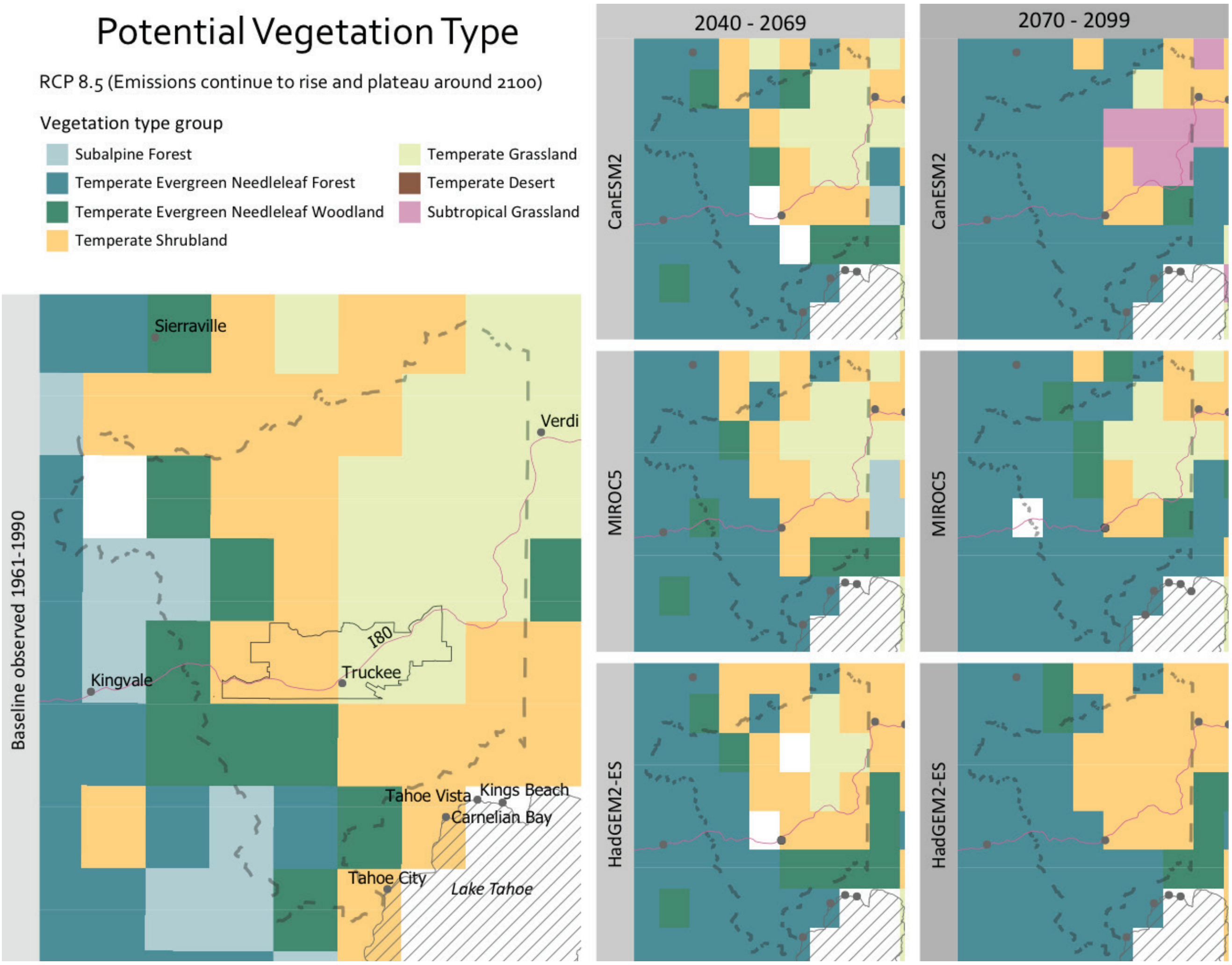


Figure 17. Historical and future projected dominant vegetation type across Truckee and the surrounding region. Dominant vegetation type is shown, by grid cell, for two future time periods: mid-century (2040-69) and late-century (2070-99), based on the higher emissions pathway (RCP 8.5). Data based on four global climate models from Cal-Adapt (MIROC5 not shown).

Dominant Vegetation

The Truckee area is characterized by towering Jeffrey pines and abundant red fir, interspersed with shrublands, meadows, and riparian vegetation. As climate change leads to changing combinations of temperature, precipitation, and seasonality, these dominant types of vegetation are expected to shift and change, sometimes dramatically. Vegetation models can help us better understand some of the expected patterns and thresholds for change, but are not able to provide precise predictions of species changes and timing. Thus, their utility lies in helping us better understand the magnitude and overall types of expected change.

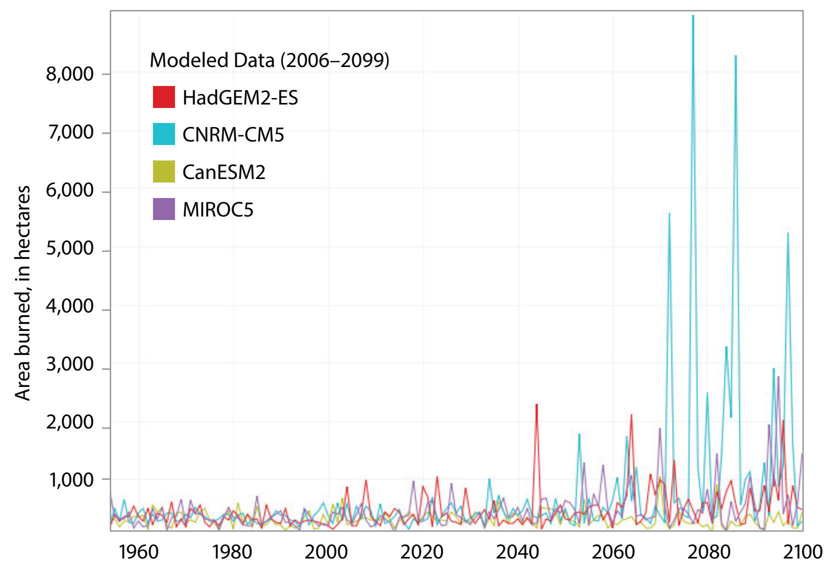
The MC2 vegetation model[18] indicates a loss of subalpine vegetation (e.g. whitebark pine, mountain hemlock, lodgepole pine, and red fir) at higher elevations, along with an expansion of temperate evergreen needleleaf forest (e.g. Jeffrey pine, white fir, incense cedar, sugar pine) throughout the western half of the study area (Fig. 17). Temperate grasslands on the eastern half of the study area are largely replaced by shrublands, according to the projections and assuming continued higher greenhouse gas emissions (RCP8.5).

Wildfire

Wildfire is a serious hazard in the Sierra Nevada. Several studies indicate that wildfire risk is expected to increase with climate change. The Cal-Adapt website provides projections from a statistical wildfire model that includes historical climate, vegetation, population density, and fire history, coupled with the same four downscaled global climate models. Output was processed for the Prosser Creek-Truckee River watershed (Fig. 18). Wildfire projections vary substantially among the four models, ranging from an 8% decline to a 91% increase in wildfire area burned. Three of the four models projected an increase in wildfire area burned by late-century.

In addition to area burned, another important measure of wildfire is the amount of biomass consumed by wildfire. A grass fire, for example, consumes far less biomass than a forest fire, and emits lass carbon into the atmosphere. Based on results from the MC2 model, biomass consumed by wildfire was mapped for the Truckee study area for two different time periods (mid- and late-century) and three models (Fig. 19).

Figure 18. Historical and future projected area burned by wildfire (in hectares) across the Prosser Creek-Truckee River watershed, based on the higher emissions pathway (RCP 8.5). Data from four global climate models from Cal-Adapt.



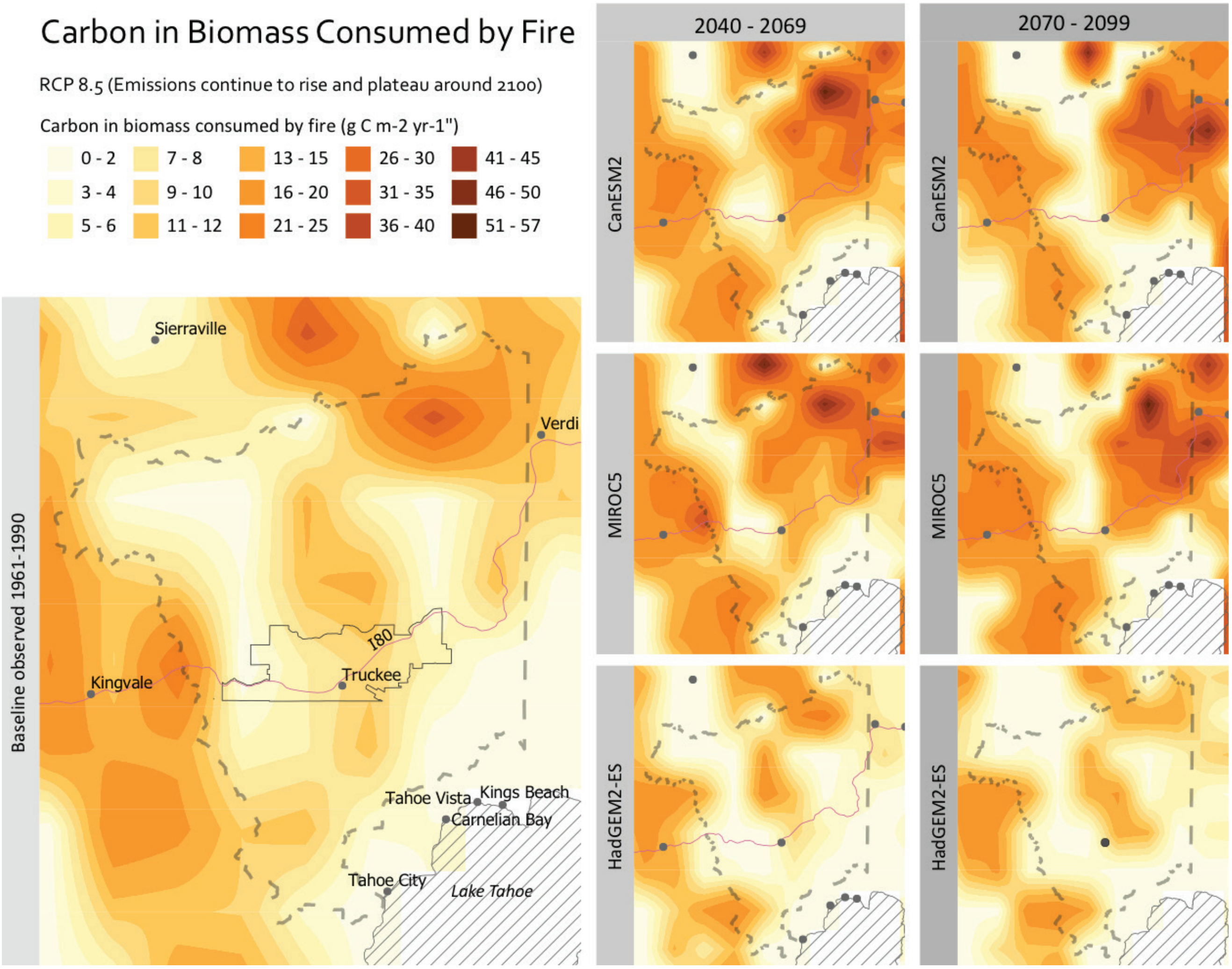


Figure 19. Historical and future projected biomass consumed by wildfire (in grams of carbon per sq. meter/year) across the Study Area, based on the higher emissions pathway (RCP 8.5).

Conclusions

Legacy Trail / Grant Kaye

Climate change is already apparent throughout the U.S. and throughout the Sierra Nevada range. Indications of a changing climate include changes in wildlife populations, frequency of severe heat and storms, and spread of pests and disease.

Warming is expected to continue and to accelerate in the coming decades and century, as greenhouse gases already emitted continue to trap heat and change local weather patterns. The magnitude of late-century warming and impacts depends on whether or not local communities around the world collectively reduce emissions of greenhouse gases such as carbon dioxide.

There is much we can do to reduce the overall impacts of near-term climate change, ensuring that the most vulnerable populations, resources, and infrastructure are protected and resilient to ongoing change. Our ability to adapt to long-term changes will depend heavily on how much we reduce emissions. This Climate Trends Primer is intended to inform the development of a Vulnerability Assessment and Climate Adaptation Plan for the Town of Truckee that results in strategies that increase overall resilience for both people and nature.

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16. Projections based on four global climate models (Can-ESM2, CNRM-CM5, HadGEM2-ES, and MIROC5) accessed from Cal-Adapt and projected for the Study Area in Fig. 1).

17. Projections based on four global climate models (Can-ESM2, CNRM-CM5, HadGEM2-ES, and MIROC5) accessed from Cal-Adapt and projected for the Prosser Creek-Truckee River Watershed).\

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