Rapid-Response Climate Assessment to Support the FWS Status Review of the American Pika

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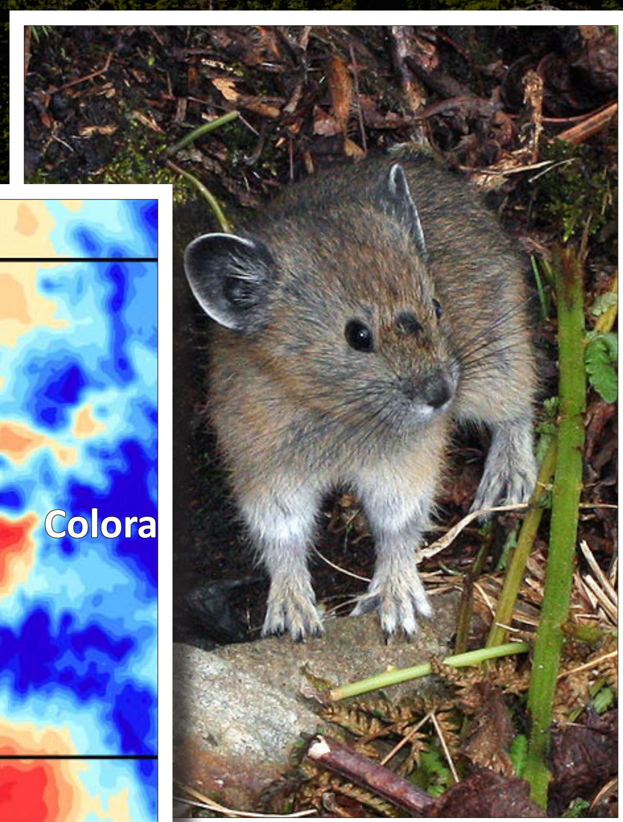

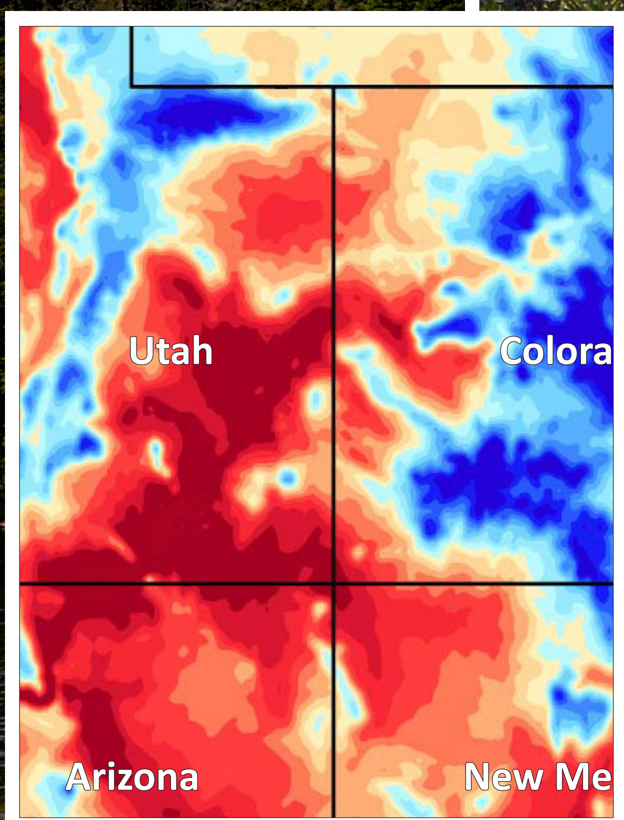

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Table of Contents

List of Figures and Tables

Figures

Tables

1 Executive Summary

The U.S. Fish and Wildlife Service is conducting a 12-month status review of the American pika (*Ochotona princeps*) in response to an initial review of a petition (CBO, 2008) seeking to protect the American pika under the Endangered Species Act (ESA) (see http://www.fws.gov/mountain-prairie/pressrel/09-34.html). The petition asserted that climate change is an important threat for the species.

This report provides a rapid-response assessment of climate observations and projections of change in pika habitat, focusing on mountainous regions of the western United States. We summarize findings from peer-reviewed studies, interpret downscaled climate projections, and present new graphics and data summaries derived from existing datasets. Knowledge about climate variability and change is rapidly evolving, so this report is a snapshot of the best available science as of mid-2009. The report provides a climatological context for the status review. Some of the results have not been published elsewhere, and further analysis is recommended. However, in the expert judgment of the authors, the major conclusions of this report are expected to be robust because of the large spatial scale of the observed and projected warming.

American Pika (photo courtesy FWS)

Key Findings

Observations

- There are few long-term meteorological observations at pika locations, especially in higher elevation habitat. Climate averages and trends may be inferred from nearby observations, from large-scale climate patterns, and by adjusting for elevation. In the absence of detailed site-specific studies, gridded observational datasets are the best source to infer the climate where pikas live.

- The U.S. West has warmed about 1°C (2°F) during the past 30 years. One study has attributed at least part of the observed pattern of warming in mountainous regions of the West to the effects of anthropogenic greenhouse gases and aerosols. Natural variability is and will continue to be a factor in the climate of the western U.S. during the next century.

- The magnitudes of observed temperature trends vary by observing station or pika location, season, and time period analyzed. Climate stations near pika locations in the Sierra Nevada and western Great Basin and in Oregon show 1°-2.4°C warming (1.7°-4.3°F) in the summer during the past 30 years, a statistically significant finding.

- Spring has warmed more than other seasons at many locations in the U.S. West. The onset of spring has come earlier, by 2-3 weeks, and snow cover, postulated to provide insulation to pikas during spring cold air outbreaks, is melting out earlier. These temperature-dependenthydrological changes have been observed at many mountainous locations, and one set of analyses has attributed about half of the magnitude of the trends in temperature-associated hydrologic variables to anthropogenic changes in greenhouse gases, ozone, and aerosols.

Projections

- Global climate models project warming over all land areas of the globe, including North America, though 2100. These models project larger summertime warming over the western U.S. than elsewhere North America, +5°F (3-7°F) and winters by about +3°F (2-5°F).

- For the mid-21st century, the overall magnitude of projected temperature increases is quantitatively similar for the greenhouse gas (GHG) emissions scenarios investigated by the Intergovernmental Panel on Climate Change (B1, A1B, and A2 scenarios). In the latter half of the 21st century, considerable spread will have developed among these emissions scenarios, so the range of temperature projections depends on human and societal factors in intervening years including policy decisions regarding GHG emissions.

- High-resolution regional climate models (RCMs) also show a broad pattern of projected warming across the West Through the 21st century. Both GCMs and RCMS indicate a tendency for less warming (2°C) in parts of the Pacific Northwest compared to other regions in the West.

- Statistical downscaling is used to downscale GCMs to 4-km scale appropriate for pika habitat. We report projections West-wide and for 22 specific pika locations for 20-year periods averaged around 2025, 2050 (mid-century), and 2100, driven by three IPCC emissions scenarios. Maps of the projected changes in temperature illustrate the increase as a shift of temperature zones northward and upward in elevation. The shift of temperature zones continues through the end of the 21st century.

- The average of summertime (June-July-August) projections around 2050 is consistently higher than the recent past by about 3°C (5.4°F). In comparison, the average summer months of the mid- 21st century will be warmer than the warmest (90th percentile)summer months of the recent past.

- Individual global climate models exhibit a range of projected warming for the study region for the mid 21st century. The low-end model projections are about 1°C cooler and high-end projections are about 1°C warmer than the multi-model average projections. Other sources of uncertainty not considered here may act to broaden this range of projections beyond that shown by the climate models.

Implications for Pikas

- Summer average temperatures at where pikas currently live range from about 9°C (48°F) in the Sierras to around 14°C (57°F) at Warner and Ruby Mountain sites (1950-1999 climatology, gridded observational data). Scaling temperature for the relationship of temperature and elevation (lapse rate) suggests that they experience temperatures of about +/-3°C (5.4°F) around this value for an area with a 1000m vertical range. Local topography and microclimate may also influence the temperature in ways not represented in this dataset.

- We suggest 2050 as a “foreseeable future” for climate for the pika because the overall magnitude of projected temperature increases are quantitatively similar through the mid-21st century for the GHG emissions scenarios investigated (B1, A1B, and A2). IPCC projections indicate continued global and regional warming into the second half of this century, and that if emissions follow the higher scenarios, warming in 2090 could be double that in 2050.

- The 2050 summer (JJA) temperature projections average about 3°C (5.4°F) higher than the recent climatology for most of the western U.S., and for the 22 specific locations analyzed as representative of pika habitats.

- The limited number of observing sites and the inherent variability of precipitation make it difficult to make inferences or projections about precipitation amounts at pika sites. However, due to the impacts of temperature, projections show a precipitous decline in lower-elevation snowpack (below 8200 ft/2500 m) by the mid-21st century, with more modest declines at elevations above 8200 ft where some pika populations live. The 2050 summer (JJA) temperature projections average about 3°C (5.4°F) higher than the recent climatology for most of the western U.S., and for the 22 specific locations analyzed as representative of pika habitats.

2 Introduction

The U.S. Fish and Wildlife Service is conducting a 12-month status review of the American pika (*Ochotona princeps*) in response to an initial review of a petition (CBO 2008) seeking to protect the American pika under the Endangered Species Act (ESA) (see http://www.fws.gov/mountain-prairie/pressrel/09-34.html). The petition provided information suggesting that climate change might have effects resulting in individual mortality, population extirpations, and reduced species range for the pika. The Service is undertaking an in-depth, scientific review of the American pika to determine whether to propose adding the species to the federal list of threatened and endangered wildlife and plants. The technical level of this report is intended to be accessible to interested parties and scientists who are not experts in climate science.

This report provides the climatological context for the status review, focusing on past observations and projections of change in temperature in mountainous regions of the western United States that include pika habitat. The "FWS 90-day finding" (FWS 2009) reviews IPCC (2007) findings on climate change. This report adds western regional detail from recent literature and new findings from analyzing published observational datasets and interpreting the model projections analyzed by the IPCC at smaller spatial scales. The core finding of the report is the large spatial scale of recent and projected warming trends in the region. Statistically downscaled temperature projections are used to relate these large-scale trends to elevation bands in selected mountain ranges where pika have been studied. This report provides a more detailed analysis of historical temperature trends in two regions where pika are thought to be more vulnerable to climate change. Published results from regional climate models are discussed briefly in order to assess the robustness of the statistical downscaling results. Comparative regional climate model studies are only

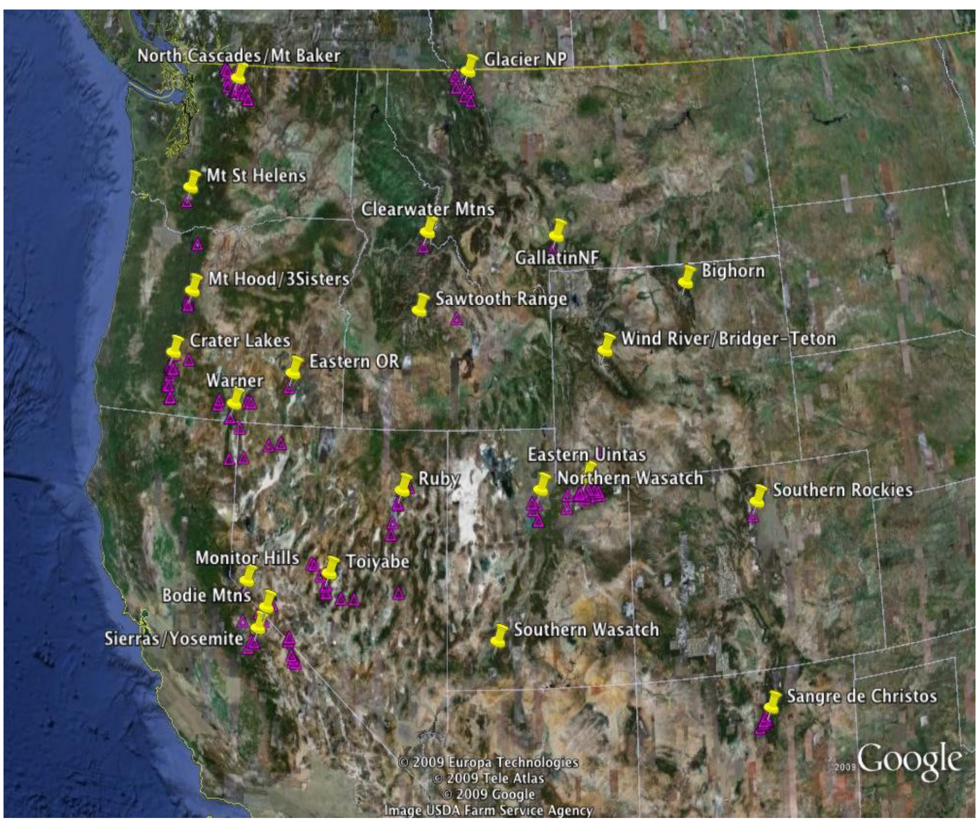


Figure 1. Western U.S. with pika observation locations in pink triangles and mountain range areas for analysis identified by the FWS indicated by yellow pins. (Source: Google Earth, created by J. Barsugli, NOAA-CIRES).

now becoming available to researchers and will provide an important dataset for future analysis.

Temperatures across the western North America have shown a pronounced warming over the past 50 years, according to the IPCC Fourth Assessment Report (2007); temperature may be warming faster at higher elevation (Diaz and Eischeid 2007). Springtime snowpack, measured as snow water equivalent (SWE) on April 1st, has decreased in many areas of the west, and there is evidence in many areas that snowcover is melting out earlier in the spring (Mote et al 2006). Probabilities of extreme events may have changed as well (CCSP 3.3, 2008). In recent decades most of North America has been experiencing more unusually hot days and nights and fewer unusually cold days and nights (CCSP 3.3 2008). Pikas may be sensitive to changes in the mean summer temperature, summer maximum temperatures, and to winter minimum temperatures when combined with an absence of insulating snow cover (FWS 2009).

The recent IPCC Fourth Assessment Report (2007) assessed projections of climate to the year 2100 and beyond from global climate models (GCMs, also known as general circulation models) developed at modeling centers around the world. These models agree that global average temperature will increase, and agree in general that the global hydrologic cycle will become more intense – with wet areas becoming wetter and dry areas drier. The models also agree in projecting warming over all land areas of the globe, and that land areas as a whole warm more than does the global average that includes both land and ocean temperatures. In these models, the western United States exhibits particularly large summertime warming compared to the rest of North America and compared to the smaller wintertime warming.

There is a growing literature that analyzes the observations of climate in the western U.S., relevant impacts, and assesses the risks of climate change. However, important studies are lacking that would help understand climate trends and projections in high elevation ecosystems relevant to pikas, and to connect potentially relevant climate studies specifically to pika. This assessment reviews available climate observations relevant for pika habitat areas, time series and trends of observations of climate variables, as well as projections interpreted and scaled to pika habitat.

Temperature changes in the U.S. West are the primary focus of the analysis of observations and projections developed for this report (Section 7-8), because of the concern about the impacts increasing temperature documented in the listing petition. Precipitation trends are harder to assess. Trends in annual and seasonal total precipitation are difficult to detect against a naturally variable climatological background. Groisman et al. 2004 found a trend of increasing precipitation over the 20th century in much of the US, with the exception of the southwest, but these regional trends were not statistically significant. Zhang et al. 2007 find no evidence that precipitation responded to greenhouse forcing in the 20th century, either globally or in the zonal mean in the 30°-50° N latitude band (including the continental U.S.). There is a general tendency for global climate models to project a wetter wintertime climate in the northern tier of states (with the most model agreement in Montana, Wyoming and Colorado) and to project summertime drying for the entire West (with the most model agreement in Oregon, Washington and Idaho). There is, however, more disagreement among the models regarding precipitation than temperature. We present projections of precipitation from the literature, but we did not make additional downscaled precipitation projections for this report.

However, temperature affects precipitation-related variables in ways that may provide useful insights for the pika review. We concur with the discussion of precipitation in the FWS “90-day finding” (FWS 2009, p. 21304) that temperature changes are expected to affect precipitation, snowpack and snowmelt in the range of the American pika. The literature provides documented changes in these variables and projections, described below. We also discuss some new findings in the literature with respect to precipitation-related variables in the western U.S. thus adding some regional studies and projections to the review of precipitation in the FWS 90-day finding.

The temporal focus for the analysis of observations and projections is summer, i.e. June-July-August (JJA) season, again because of the focus on the listing petition. Monthly analyses are available but do not resolve features such as the melt out of snowpack or summer heat waves at that time scale. While it is possible to analyze data on shorter time scales, even daily, this was not possible in the time frame of the status review.

This report begins with a discussion of the climate observations available in the Western U.S. and in pika habitat areas (Section 3). Climate observations are the basis for understanding past and recent climate variability, and are the basis for evaluating projections of future climate. However, observing stations are limited at the elevations of many pika populations, so we will discuss what is known about elevation and temperature. We then provide background on climate models and modeling methodology (Section 4) and on downscaling techniques, intended to provide the background for later sections on the attribution of recent trends and climate projections. Section 5 describes recent trends in temperature across the western U.S. and the attribution of these to climate change, based on the literature. Section 6 follows with the authors' analysis of climate observations in several specific areas occupied by pikas as provided to us by the Fish and Wildlife Service.

Westwide climate projections from the literature and created for this report are described in Section 7. Section 8 provides projections for a set of 22 mountain ranges specified by FWS (Figure 1, Table 1), distributed among pika subspecies habitat. Both westwide temperature projections and those for pika locations are reported for periods centered around 2025, 2050 (mid-century), and 2100, for 20-year periods averaged around these years. These temperature projections are based on the Coupled Model Intercomparison Project, Phase 3 (CMIP3), which is the most recent comprehensive multi-model study of climate change. These model projections were assessed in the IPCC AR4. Output of these models is at a spatial scale of about 200-km that is of limited use for directly assessing impacts on pika, so we have used statistically downscaled projections at a 4-km scale.

Knowledge about climate and climate change is rapidly evolving, so this report is a snapshot of available information, based on the available data and results as of 2009. Additional and more detailed analysis of climate observations at specific pika locations could be performed. The IPCC Fifth Assessment Report, expected out in 2013, will provide additional projections using updated models and a subset of simulations run at 50km resolution. New impacts analysis at regional scales is also underway under this IPCC effort. Efforts such as the North American Regional Climate Change (NARCCAP, Mearns 2009) are expected to contribute significantly to understanding of climate at regional scales, which would be relevant to pika habitat, however, climate change simulations from NARCCAP are just being released to the climate research community for analysis.

Table 1. Pika Areas for Climate Projections*
Cascades Subspecies
Crater Lakes
Eastern Oregon
Mt. Hood/Three Sisters
Mt. St. Helens
North Cascades/Mt Baker
Northern Rockies Subspecies
Northern Wasatch
Clearwater Mountains
Sawtooth Range
Glacier National Park
Gallatin National Forest
Wind River/Bridger Teton NF
Bighorn NF
Southern Rockies Subspecies
Southern Rockies/Niwot Ridge
Sangre de Christos
Uinta Subspecies
Eastern Uintas
Sierra Nevada/Great Basin Subspecies
Southern Wasatch
Toiyabe
Ruby Mtns
Monitor Hills
Bodie Mtns
Sierra/Yosemite
Warner Mtns

* See table 2 for location and elevation information.

3 Background on Climate Observations

Climate observations are the long-term measurement of meteorological variables such as temperature and precipitation with sufficient consistency and quality control that climatological averages, trends and variability may be investigated. Observations are the basis for understanding past and recent climate variability, and are the basis for evaluating the models used to make projections of future climate. This report takes advantage of observations of temperature and other climate variables at elevation around the U.S. West. This report does not undertake any new observations, but relies on those in published databases described below.

Data

Existing observation networks and databases providing climate and weather information near pika habitat areas include: 1) The National Weather Service (NWS) Cooperative Observer Program (COOP, http://www.nws.noaa.gov/om/coop), which produces a data set of daily and monthly records of observational meteorological variables, which includes the United States Historical Climatology Network (USHCN); 2) the Snowpack Telemetry system (SNOTEL), a west-wide system for measuring snow water equivalent, precipitation, air temperature, and soil moisture at some sites (http://www.wcc.nrcs.usda.gov/snow/); 3) the Parameter-elevation Regressions on Independent Slopes Model (PRISM), a gridded observational data set of climate variables at 4-km resolution, including surface temperatures (Daley et al 2002) (http://www.prism.oregonstate.edu/); 4) the NOAA/NCAR Reanalysis, a regularly updated gridded data set of atmospheric variables (Kistler et al. 2001).

A limitation of the observing networks for studying pikas – or any other high altitude species – is that there are few stations at higher altitudes (CIRMOUNT 2006). Figure 2 shows the locations of observed pika populations provided by FWS and their proximity to climate observing stations; select stations and climate divisions are analyzed for trends in Section 6. Another limitation is that observing stations may not be in close proximity to pika locations. While in a few cases, there are climate stations with long records located near pika study sites, but in many cases, the nearest observations are many kilometers away as well as at much lower elevation. Recently, some pika researchers are deploying *in situ* temperature sensors (such as the

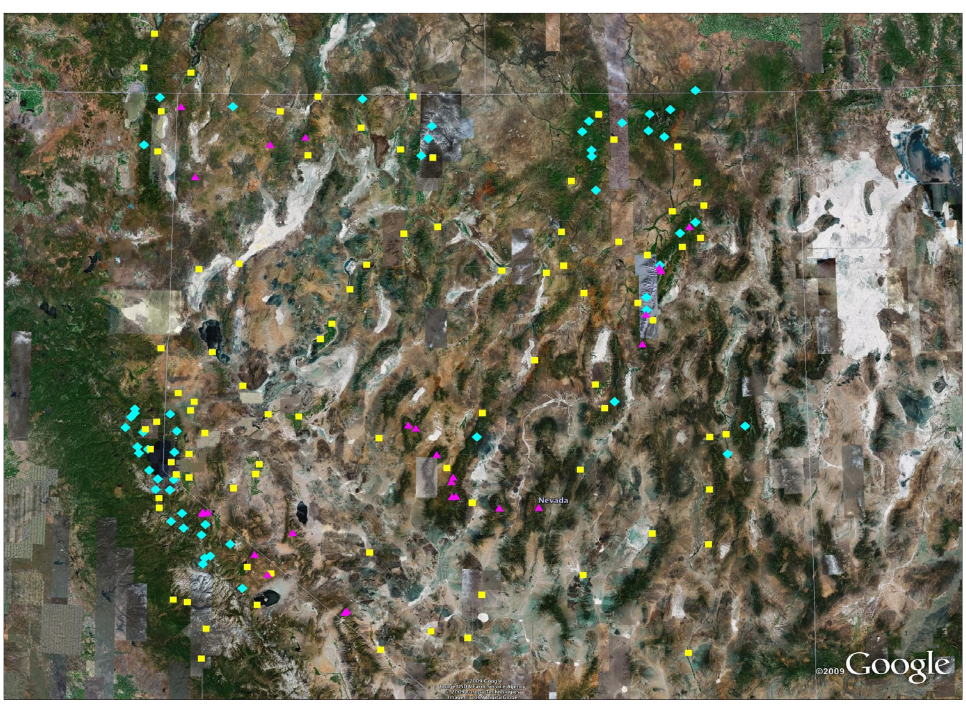


Figure 2. Sierra Nevada and Western Great Basin Climate observation stations and observed pika sites. Select observed pika locations in pink triangles; SNOTEL stations in blue diamonds, and COOP stations in yellow; thin white lines show the boundaries of Nevada with Utah, California, Oregon, and Idaho. (Source: Google Earth, pika observations from FWS.

brand iButton) in pika locations and within the talus, but this data has short record length and is not yet published.

Climate averages and trends at the pika study sites may be inferred from nearby observations, large-scale climatological patterns, and data about the terrain. Gridded (spatially interpolated) data such as PRISM can be used for this purpose. An obvious limitation in the data is that microclimates in which pika live may not be represented in the data. Examples of microclimatic effects include small spatial scale variations in surface temperature due to shading by mountain ridges or trees, differing land surface characteristics, proximity to small bodies of water, and valley drainage winds and cold air pooling. Therefore the temperatures presented here should be interpreted as indicators or likely correlates of the temperatures where pika live. Table 3 (below) shows the summer (June-July-August, JJA) mean temperature from the PRISM dataset at 18 sites where we had specific location information, which range from about 9°C (48°F) for a gridbox in the Sierras to around 14°C (57°F) at Warner and Ruby Mountain sites.

Relationship of temperature and elevation

Because pikas primarily live in higher elevation areas, it is critical to understand the relationship of temperature with elevation. Furthermore, populations across a mountain range or even within a few kilometers of each other may exist in areas separated by hundreds of meters of elevation. Climate station observations nearby may not be at the same elevation as pikas. Figure 3a illustrates the relationship of elevation, temperature, and pika sites. Part of the challenge for understanding the temperature changes pikas may face, is the need to understand what the temperatures observed at climate stations represent with respect to the temperatures where pikas are living, e.g., in adjacent areas at higher or lower elevations, or in nearby places at similar elevations.

Vertically, temperature in the atmosphere generally decreases with elevation due to the colling effec of expanding air described by the lapse rate equation. Horizontally, temperature is a relatively broad scale phenomenon, in which temperatures at one place or

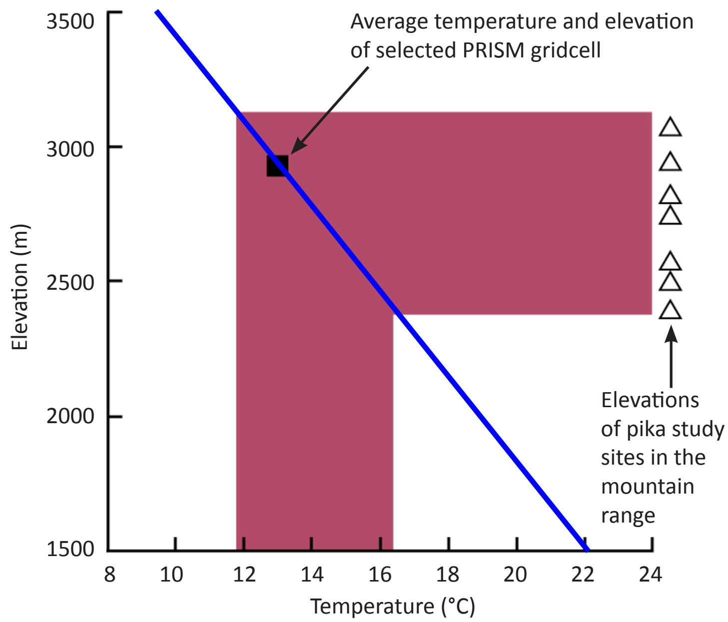


Figure 3a. Schematic of elevation, temperature, and pika sites. Elevation is one of the most important determinants of temperature in mountainous terrain. PRISM dataset temperatures that are used to compute the historical mean and percentiles represent the average over an area that is 2.5 arc-minutes on a side (roughly 3x4km). This report uses the PRISM climatology from a representative site in a given mountain range, whereas pikas live at a variety of elevations in a given mountain range. Therefore, when interpreting the temperature value for a grid box, consider that a range of temperatures are represented by the single value, with lower elevations pika sites likely experiencing warmer temperatures. A Standard Atmosphere temperature lapse rate of 6.5 C/km is used for this example. Note 14°C = 57°F, 2500m = 8200ft.

mountaintop are relatively consistent with others at the same elevation. Given the realities of the observing system, two underlying assumptions are that temperatures at a different elevations (vertical scale) can be estimated using lapse rates, and that temperature observations at the same elevation but nearby (horizontal scale) can be considered representative. The PRISM methods include these factors as well as additional variables, such as the aspect of the slope, in its regression models.

It is important to distinguish the lapse rate in the "free atmosphere" from a "surface-based lapse rate." The free atmosphere lapse rate relates to temperatures in the atmosphere away from the surface, and can be measured, for example, by using a weather balloon or radiosonde. The surface-based lapse rate can be measured using a transect of surface temperature observations at different elevations. Wintertime free-atmosphere temperatures may not be a reliable predictor

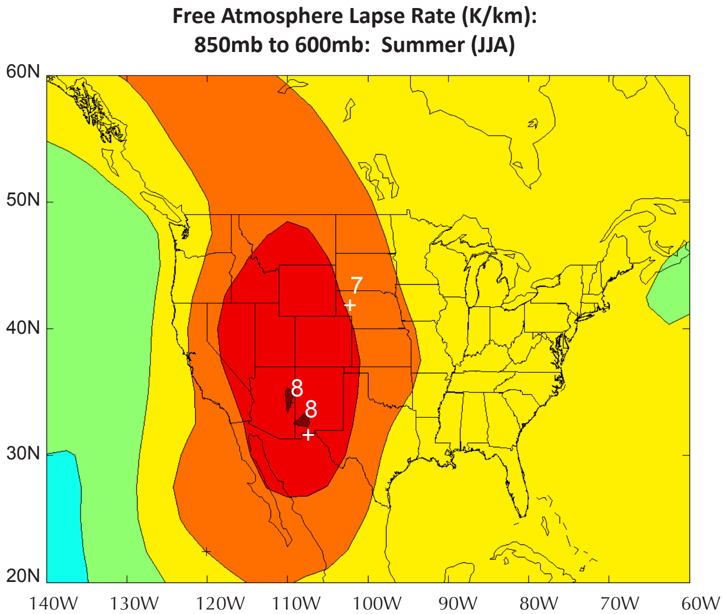


Figure 3b. Westwide free atmosphere lapse rates, Summer (JJA) average. Westwide lapse rates calculated from the 1950-2009 average NOAA/NCEP Reanalysis by taking the difference between temperatures at the 600 mb (about 4200m /13800 feet) and 850 mb level (about 1450 m/4750 ft) and dividing by the difference in height of these two levels. Gridbox scale 2.5 degrees lat-longitude, ~250 km. Note that the lapse rate in the PNW is lower than in the interior west. Lapse rates are indicated as the positive numbers on the map contours, the rate at which temperature decreases with height.

of surface temperatures because of the possibility of near-surface temperature inversions (cold air lying under warm). Summertime free atmosphere temperatures are a better predictor of surface temperatures because the summertime atmosphere is in general much better mixed by convection and other processes. Figure 3b illustrates lapse rates across the continental US calculated from the NOAA NCAR reanalysis data set. Typical summertime values of the climatological free-atmosphere lapse rate are around 5 – 8 °C/km (2.7 – 3.8 °F/1,000 ft). See Mote et al (2009) for a discussion of lapse rates in the free atmosphere vs. those defined by surface observations in the Pacific northwest.

A graphic developed by the Washington Climate Change Impacts Assessment (WACCIA) illustrates how temperature varies with elevation and observed temperature, using 1970-1999 summer seasonal temperature (Figure 4). Along a west-east transect at the latitude of Seattle, Washington, the graphics illustrate that temperatures are lower over the higher-elevation mountain terrain of the Olympic (124-123°W) and Cascade ranges (~121°W) and higher over the coast and the interior Columbia Valley (east of ~121°W). This graphic also illustrates how the temperature at elevation and terrain is represented in two pairs of global and regional downscaled climate models (CCSM3-WRF and ECHAM5-WRF) along the same transect, and in maps of the Pacific Northwest (Figure 5). Overall, the authors conclude that temperature is well represented in the simulations: the influence of the major geographical features is captured, and the seasonal cycle is reproduced (figures for December-February season not reproduced here, see Salathé et al. 2009). Both regional climate models exhibit a substantial cold bias relative to the gridded observations (Salathé et al. 2009).

Temperature can be adjusted for elevation using an assumed lapse from a simple equation:

$$T_1 = T_0 - (z_1 - z_0)*L$$

where T_0 and z_0 are the temperature and elevation of the gridcell, and T_1 and z_1 are the elevation of the minimum (or maximum) elevations in the range given; L is the lapse rate. This should be a good approximation of surface conditions during the summer. In this report we use a lapse-rate adjustment only for summer temperature, and the adjustment is over a relatively small elevation range, so that an error in lapse rate would translate into only a small temperature error. This simplified adjustment assumes that the lapse rate stays the

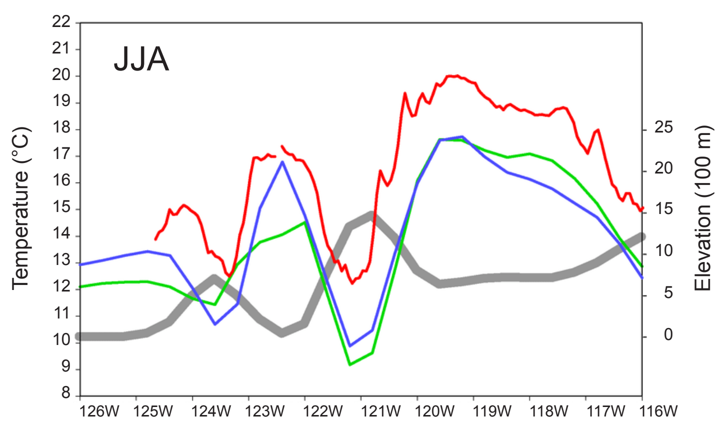


Figure 4. Elevation and observed temperature and simulated temperature. 1 970-1999 seasonal mean temperature (°C) and simulated temperature from downscaled GCM-RCM models along a West-East transect in Washington State at 47.8°N, a line roughly through Seattle to Spokane, WA and through the Olympic and Wenatchee Mountains. Terrain height is indicated by the thick gray line. Red is observed, green is ECHAM5-WRF, and Blue is CCSM3-WRF (From Salathe et al 2009, Figure 1).

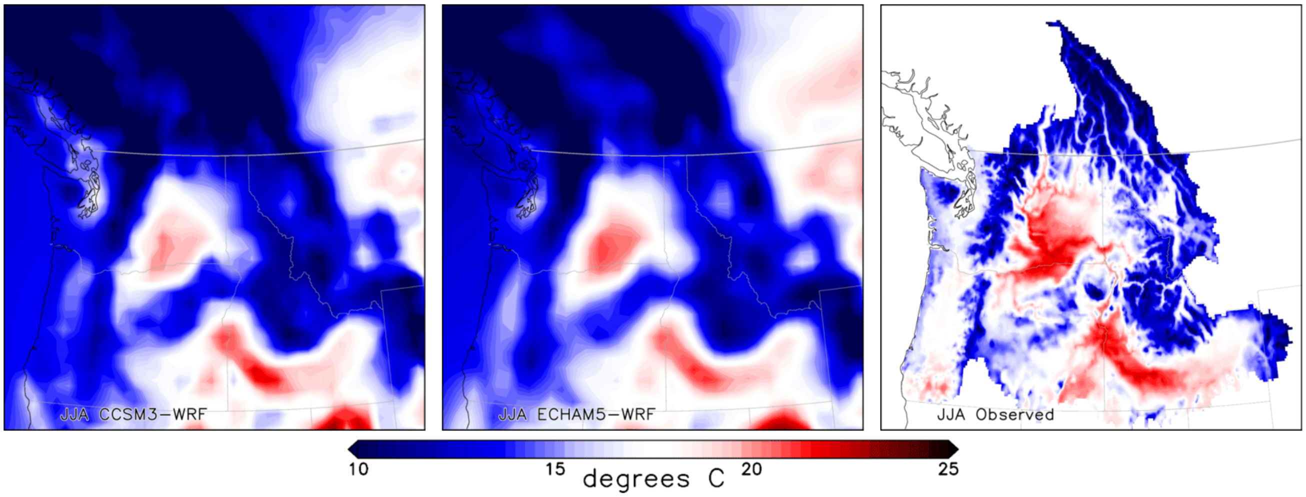


Figure 5. 1970-1999 June-July-August (JJA) observed seasonal mean temperature (°C) and simulated in two dynamically downscaled GCM-RCM pairs: CCSM3-WRF (left panel), ECHAM5-WRF (middle) and gridded observations (right). The observations are gridded data from station observations interpolated to a 1/16-degree grid using an empirical model for the effects of terrain on temperature and precipitation (From Salathe et al 2009, Figure 1).

same in the future – this matter of debate in the scientific community – as some studies suggest that higher elevations will warm more than lower ones.

There also has been recent debate over whether temperature trends may be larger elevation (Pepin and Losleben 2001; Diaz and Eischeid 2007). Analyzing the temperature record using the PRISM dataset (http://www.prism.oregon state.edu/), Diaz and Eischeid (2007) find larger warming trends at high elevations. PRISM temperatures at these elevations are estimated from extrapolating in situ observations at lower elevation and from free atmosphere (above the land surface) temperatures. The magnitude of estimated temperature trends from Diaz and Eischeid (2007) may not be consistent with in situ observational data from alpine and subalpine locations, such as the Colorado sites Niwot Ridge Mountain Research Station (M. Williams 2009, pers. comm.) (>11,000 ft) and Loch Vale in Rocky Mountain National Park (>10,000 ft) (Baron et al. 2009).

However, in a global study of over 1000 stations ranging in altitude from 500-4700m (1650-15500ft), Pepin and Lundquist found no simple increase in warming rates at elevation. They found that trends are highest near the annual 0°C (32°F) isotherm, and suggest that ecosystems at this isotherm are at increased risk from accelerated warming. However, they found that exposed mountain summits and free-draining slopes are dominated by free-air advection and have consistent (not accelerating) trends in temperature change and more consistency between observing sites compared to more complex terrain in incised valleys and urban sites. Their article says that there is no evidence that the enhanced warming in smaller scale studies is ubiquitous – they find evidence for increased warming right at snowline related to changes in albedo, but overall, temperatures follow the expected free-atmosphere lapse rate with elevation.

In Section 6, we describe observed surface-based lapse rates calculated from climate observing stations near or in pika locations, and these rates range from somewhat below typical values to higher values especially in the summer. For areas where data is available to calculate lapse rates, this information may provide insight into the temperatures experienced at pika sites, and an estimate of how future changes in temperature might translate into vertical shifts in climate zones.

Although climate observations are not always closely associated with observations of pikas, the findings of Pepin and Lundquist (2008) suggest that it is reasonable to look at broad-scale temperatures and compare sites at similar elevations in mountain summits and free-draining slopes (the horizontal scale). Furthermore, it is reasonable to use standard lapse rates to estimate temperatures between stations or pika observations at different elevations (the vertical scale).

4 Background on Climate Models and Modeling

This section provides some relevant background on climate modeling as a preface to the following discussion of attribution of recent trends to climate change, and for the presentation of model projections in Section 7 and 8. Detailed background on climate models – written for audiences not experts in climate science – can be found in Brekke et al 2008 and Ray et al 2008, Chapter 3; Mote and Salathé (2009) provides a discussion of model evaluation for GCMs and regional downscaling in the Pacific Northwest.

In the past, it was common in studies of climate impacts to present the results of only one or two global climate models. With greater opportunities and technical abilities for analyzing multiple model simulations, ensembles are now the state of the science (Mote and Salathé 2009). Current assessments of climate change look at projections from a number of different climate models that are produced during model intercomparison projects. The current state of the art climate models are from the Coupled Model Intercomparison Project, Phase 3 (CMIP3), a coordinated large set of climate model runs performed at modeling centers worldwide using 22 global climate models. Output of most of these models is at large resolution (a 200-km grid is common) that is of limited use for directly using model output to assess impacts on pika. Each of these global models has strengths and weaknesses in simulating different processes, but for any set of model simulations, the average of all models is consistently more accurate than any individual result. In a few cases, this report shows results of a single model to provide an example, or because no ensemble is available. However, most projections shown in Sections 7 and 8 are multi-model average projections rather than individual models.

These model runs include simulations of the 20th century climate and projections to the end of the 21st century. These CMIP3 runs formed the so-called "multi-model ensemble" that was the basis of one of the main analyses in the IPCC Fourth Assessment Report (IPCC AR4 2007). Each model run, with simulations of past climate and one or more future scenarios is a major computational effort. Modelling centers archived the output for many variables at various time and space scales. Climate scientists around the world have analyzed these model runs. In Section 8 we provide analysis relevant to the pika review from these archived model runs.

Three emissions scenarios in the Special Report on Emissions Scenarios (IPCC SRES), labeled B1, A1B, and A2, were intensively studied by the climate modeling community. These three scenarios have become *de facto* low, medium, and high emissions scenarios based on the resulting greenhouse gas concentrations and global climate changes in year 2100. For planning horizons up to about mid-century, these three emissions scenarios result in very similar projections of global and regional climate change (Figure 6). Consequently, the implications of these three scenarios are similar to one another for 25- to 50-year planning and adaptation horizons. For this reason, we have chosen

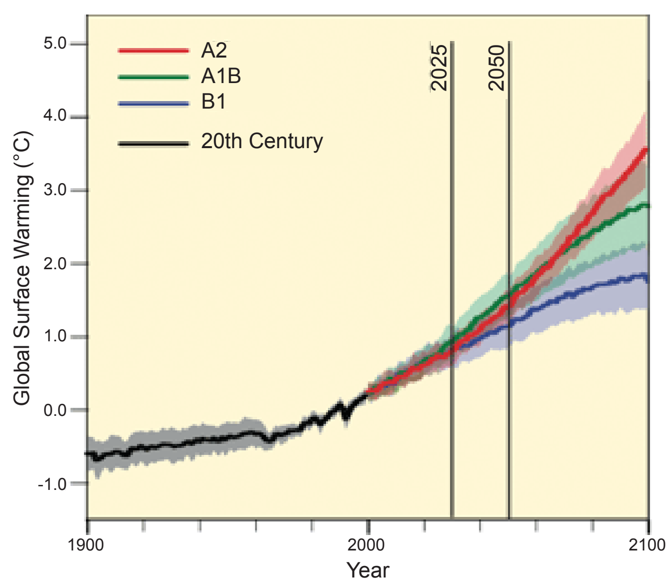


Figure 6. Global mean surface temperature and model projections (relative to a baseline of 1980–99) for various emissions scenarios. Shaded regions depict the range of modeled historical simulations and projections. Note 1°C = 1.8°F, 2°C = 3.6°F. Temperature projections for scenario B1 start to diverge appreciably from A1B and A2 by the middle of the 21st century. A2 and A1B diverge in the latter quarter of the century. Continental and regional patterns of temperature and precipitation in these models also evolve in a similar manner (From IPCC AR4 WGI, 2007, Figure TS.32).

scenario A1B for many of the projections in Sections 7 and 8. The scenarios diverge in the latter half of the century reflecting the climate response to different assumptions, including those about future greenhouse gas emissions. A new set of emissions scenarios has been developed for use in Phase 5 of CMIP that will be analyzed for the IPCC Fifth Assessment Report planned for 2013 (see http://ipcc-wg1.ucar.edu/ for more information). These new scenarios will reflect the fact that greenhouse gas emissions over the past decade have been at or above the upper range of the SRES scenarios, and also explicitly include assumptions about future greenhouse gas mitigation policy.

Downscaling Global Climate Models

In order to use the coarse-grid global climate model output to study climate change impacts in smaller areas, such as pika habitat, the model output must be related to the detailed topography and climate of the state through a process called "downscaling." In addition a "bias correction" or "calibration" step is needed that removes known model biases in the average climate. Fowler et al. (2007) presents an overview of several downscaling methods.

Statistical downscaling methods include a wide variety of methods to statistically relate coarse-grid model output to the small-scale climate variations. A subset of these methods, sometimes called "simple downscaling" or "disaggregation" relates the temperature and precipitation at a model grid to the smaller-scale variations within that grid (see Sidebar 3-1 in Ray et al. 2008). The statistical downscaling procedure may be as simple as adding a model's projected changes in a gridbox to the high-resolution temperature climatology for the area within that gridbox – this procedure is used in the projections presented in Section 8. For precipitation, the percent change is typically applied to the high-resolution climatology (Salathé 2005).

An alternative to statistical downscaling, called dynamical downscaling, uses high-resolution regional climate models (RCMs)—many of which are derived from numerical weather prediction models—to simulate small-scale processes. These RCMs typically input the global model grids surrounding their geographical domain and then simulate wind, temperature, clouds, evapotranspiration, and variables on a much finer grid (see Wigley 2004;Wilby and Wigley 1997). RCMs and dynamical downscaling are computationally expensive; thus most studies are still only using one or two models and ensembles (as provided by GCMs and statistical downscaling) and multi-model intercomparisons like CMIP are not yet available.

The salient strengths and weaknesses of statistical versus dynamical downscaling are summarized in Fowler, 2007. In practice, the simpler statistical methods are primarily used to generate downscaled datasets on many of the global model simulations used in the AR4 report. RCM downscaling has typically involved using one or two global models downscaled with a single RCM. While this is very useful in studying how climate processes might change, it gives a very limited picture of the range and distribution of possibilities.

The ongoing North American Regional Climate Change Assessment Project (NARCCAP) has just released the first large dynamically downscaled dataset that uses six RCMs to downscale the projections four of the IPCC AR4 models (Mearns 2009). This will enable amore comprehensive analysis of the full range of projections. Some of their early results are provided below in Section 7. Even at the 30-mile (50-km) resolution of these RCMs, further downscaling may be needed depending on the application, for example for some ecological studies.

To provide projections at pika locations in Sections 7 & 8, we have taken advantage of statistically downscaled climate model projections, one is based on the Salathé (2005) method, the other is known as the "Bias Corrected Spatial Disaggregation" (BCSD) dataset, that were developed as input to hydrology models for the Department of Interior Bureau of Reclamation (Maurer 2007; Bureau of Reclamation 2007; Christensen et al. 2004; Christensen and Lettenmaier 2006).

"Foreseeable Future"

We were asked to comment on the "foreseeable future" with respect to climate for the pika. The IPCC provides projections to 2100 and beyond, based on several emissions scenarios. However, until about mid-century, emissions scenarios result in a quan-

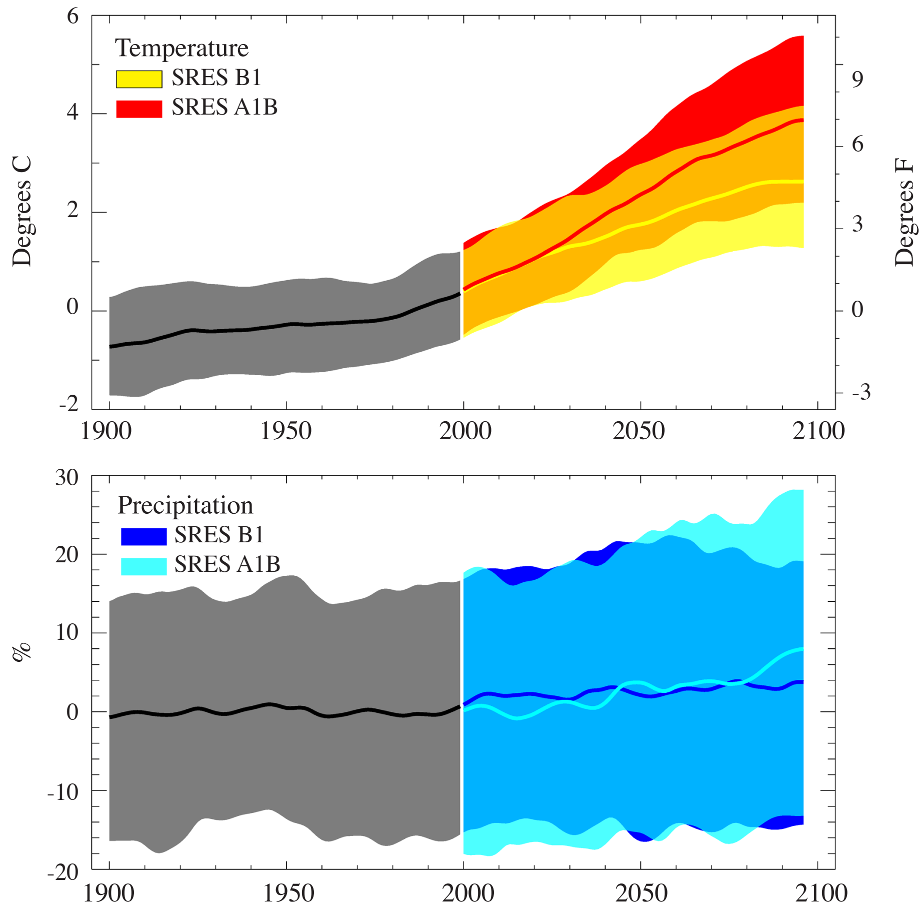


Figure 7. Pacific Northwest regional average projections of temperature and precipitation. Ensemble averages and model ranges in temperature (top) and precipitation (bottom) for 20th (grey) and 21st century (colored) model simulations for the PNW, percent relative to the 1970-99 mean. The heavy smooth curve for each scenario is a value of ensemble averaging, calculated for each year and then smoothed. The top and bottom bounds of the shaded area are the 5th and 95th percentiles of the annual values (in a running 10-year window) from the ~20 simulations, smoothed in the same manner as the mean value. Mean warming rates for the 21st century differ substantially between the two SRES scenarios after 2020, whereas for precipitation the range is much wider than the trend and there is little difference between scenarios (From Mote & Salathe, 2009, Figure 7).

titatively similar range of projections of global and regional temperature change (Figure 6). A recent effort at the University of Washington provided a regional view of GCM temperature projections based on scenarios B1 and A1B for the Pacific Northwest. A figure from that report shows a similar story for that region as for the global averages – considerable overlap in the model projections for both temperature and precipitation out to the mid-21st century (Figure 7).

The range in the spread of the model projections for any scenario is due both to details in the formulation of each individual model as well as "natural" variability in climate, for example natural decadal variability. Furthermore, there is a "committed warming" anticipated due to greenhouse gasses already in the atmosphere. However, beyond 2050, considerable spread will have developed among the emissions scenarios – so the range of projections depends on choices made by humans in the intervening years. Consequently, the implications of the three emissions scenarios are similar for temperature out to mid-century (around 2050), but uncertainties in emissions scenarios will dominate after that.

Therefore, we suggest mid-century, around 2050, as a "foreseeable future" for climate for the pika. This report focuses on projections for 2050 (Tables 2 and 3), but projections for around 2025 and out to 2100 are provided for comparison. IPCC projections indicate continued global and regional warming into the second half of this century; if emissions follow the higher scenarios, warming in 2090 could be double that in 2050.

5 Recent Climate Trends in the Western U.S. and Attribution

Temperature

In North America, temperatures have increased by about ~2°F (~ 1°C) in the past 30 years, "human induced warming has likely caused much of the average temperature increase in North America over the past fifty years" (CCSP SAP 3.3, p. 3) "and it is likely that greenhouse gases produced from human activities alone caused much of this increase (CCSP SAP 3.3, 2008). In North America, the largest annual mean temperature increases since the middle of the 20th century have occurred over the northern and western parts of the continent (IPCC 2007), with an increase of ~1.5F° (°0.8 C) in both the Southwest and the Northwest (Karl et al. 2009).

A warming trend is evident between 1950 and 2007 in the Western United States (Figure 8, left panel). The time series of annual North American-averaged temperatures (Figure 8, right panel) shows that every year from 1997 to 2007 was warmer than the 30-year climatological reference of 1971–2000. Note, however, that the rise in temperature has not been constant, as large year-to-year fluctuations are superimposed on an increasing trend. Figure 9 shows how global models simulate or reproduce these observations of the recent past.

Many studies point to a broad-scale warming across the western U.S. Knowles et al (2006) found positive temperature trends at stations across the West, with the greatest warming generally observed at the higher elevations and in March (Figure 10, see Knowles et al for other months). Das and co-authors (2009 and references therein) find strong warming trends across 89% of the western U.S., and a substantial part (37%–42%) of the mountainous western U.S. They find the strongest changes in the hydrologic variables, unlikely to be associated with natural variability alone, at medium elevations (2500–3000m) where warming has pushed temperatures from slightly below to slightly above freezing. Knowles et al. (2006) found positive temperature trends at the vast majority of stations across the west. Other observed changes include an advance in the timing of snowmelt runoff & plant blooming (Cayan et al. 2001).

Precipitation

Precipitation variations in the western U.S., including the recent drought of 2000-2007, are consistent with the natural variability observed in long term and paleoclimatic records (Barnett et al. 2008). Observed warming may have increased the severity of droughts

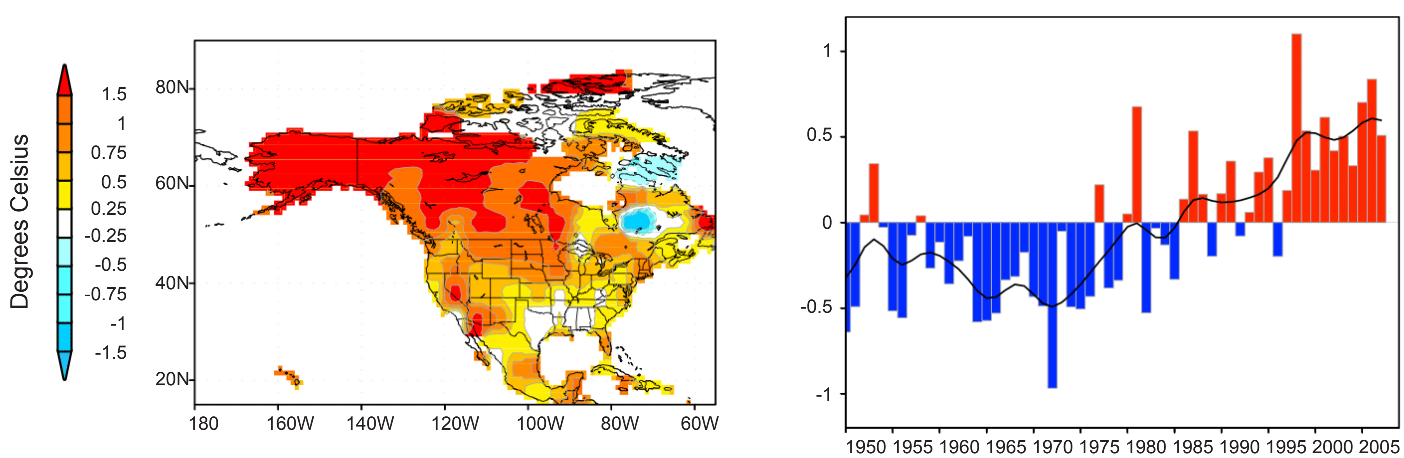


Figure 8. Observed Annual Average North American Surface Temperature (1950–2007). The 1950–2007 trend in observed annual average North American surface temperature (°C, left) and the time series of the annual values of surface temperature averaged over the whole of North America (right). Annual anomalies are with respect to a 1971–2000 reference. The smoothed curve (black line) highlights low frequency variations. Note 1°C =1.8°F (From Ray et al. 2008, Figure 4-1, adapted from CCSP 1.3, Figure 3.3).

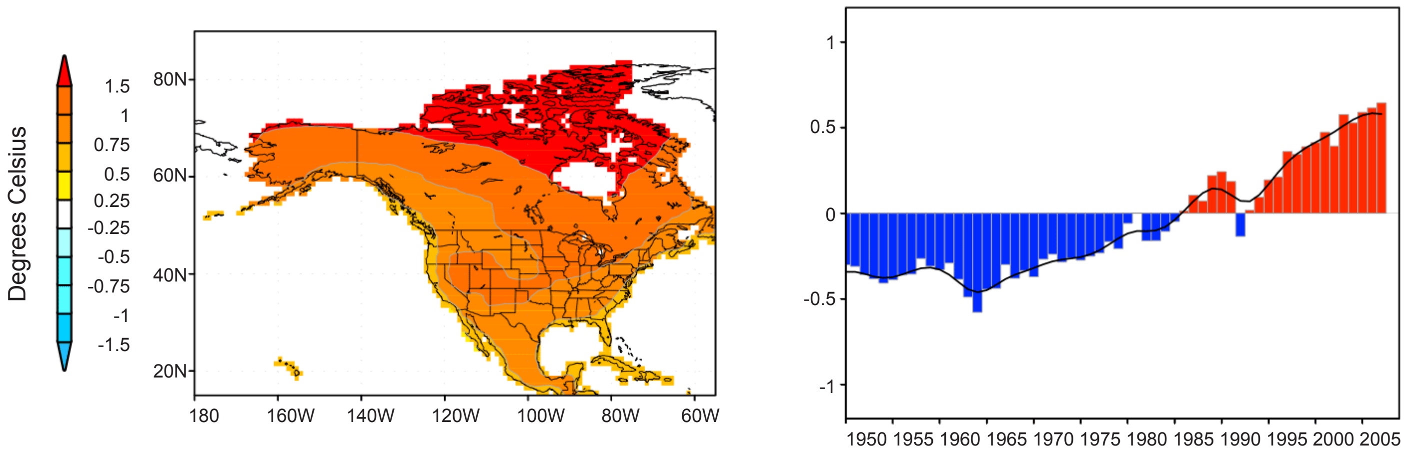


Figure 9. Modeled Annual Averaged North American Surface Temperature (1950–2007). The 1950–2007 trend in annual average North American surface temperature (°C) from 22 IPCC (CMIP3) model simulations forced with the greenhouse gas, aerosol, solar, and volcanic forcing from 1950 to 1999, and the A1B emissions scenario from 2000 to 2007 (left). Annual values of surface temperature averaged over the whole of North America (anomalies compared to 1971–2000 average) (right). The smoothed curve highlights low frequency variations. Comparison of these climate models with Figure 8 suggests that anthropogenic greenhouse gas emissions have contributed about 1°F (1.8°C) of the observed warming in the last 30 years (From Ray et al. 2008, Figure 4-2, adapted from CCSP 1.3, Figure 3.3)

(Andreadis and Lettenmeier 2006) and exacerbated drought impacts (Breshears et al. 2005).

However, due to few observing stations and the length of records changes in precipitation variables are difficult to detect. At the smaller scales of pika habitat, only a few COOP and SNOTEL are located near pika sites, so observations of precipitation are generally lacking to evaluate precipitation trends and impacts in pika locations. Where data is available, precipitation trends are difficult to detect from the background variability (see for example, trends at climate stations at http://ccc.atmos.colostat.edu).

The trends that have been statistically significant in most places are for variables affected by temperature, e.g., snowmelt, seasonal accumulation expressed as snow water equivalent (SWE) and snow cover. Stewart et al. 2005 documented widespread trends in earlier onset of springtime snowmelt and streamflow onset across most of western North America. Groisman et al. 2004 document a strong spring warming and earlier spring onset (by 2–3 weeks during the past 50 yr) in the western U.S.; they document decreases in snow cover extent on March 1st in 4 regions of the western U.S., but this trend is not significant for the region including Colorado, Utah, Arizona and New Mexico. Brown and Mote (2009) found

complex relationships between increasing temperature and snow cover duration, varying with regional climate, elevation, and snow cover variable, with the largest changes in snow cover in moist climates with snow season temperatures in the range ±5°C. In Colorado, Clow (2007; conference proceedings) found a earlier snowmelt and runoff throughout the State, with an average change of 0.5 days per year, or about two

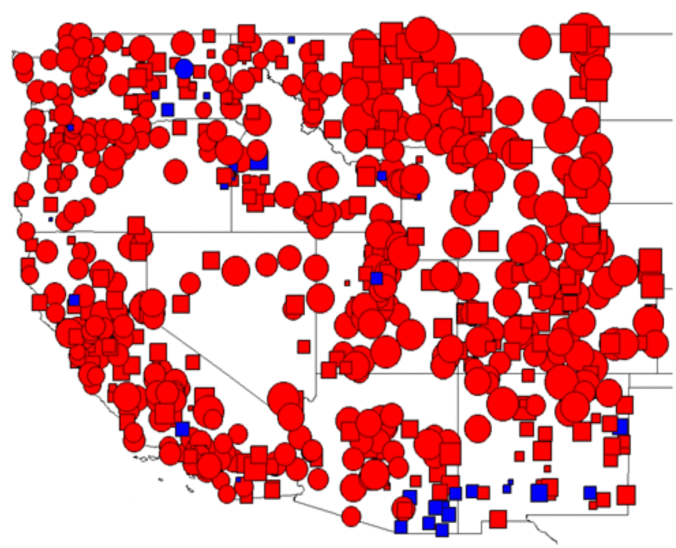


Figure 10. Trend in March average minimum temperature on days with precipitation. Trends from 1949–2004, the latest data available at the time of their analysis. Red indicates an increase in temperature and blue indicates a decrease. The size of the circle is proportional to the temperature change. For scale, the arrow indicates a 5°F (2.7°C) change. The circles represent statistically significant findings and the squares are not significant. (From Knowles et. al. 2006, Figure 9)

weeks earlier over 1978 to 2004. A widespread increase in fraction of precipitation falling as rain vs. snow also is attributed to warming (Knowles et al. 2006) (Figure 10). We note that 2004, the last year of data availabe at the time of their analysis, contained an anomalously warm March compared to subsequent years.

Elevation is a factor in changes in snowpack. An increase in rain vs. snow, and reduction in snow water equivalent (SWE) have been observed especially at lower elevation sites in Sierras & Pacific Northwest (1949–2004, Knowles et al. 2006) (Figure 11). Stations below 2500m (8200ft) show the largest reductions in SWE (Regonda et al 2005), but these reductions have not been detected in the higher elevation Rockies, for example Colorado snowpack (Udall and Bates, 2007). Mote et al (2005) report that the amount of water contained in the accumulated snow on April 1 has been declining in low-elevation areas while snowfall in higher elevations of the southern portion of the Sierra Nevada has been increasing (Figure 12). A decline in spring snow water equivalent (SWE) in the mountains of western North America (Mote 2006; Pierce et al. 2008) has been observed in some parts of the west, but this trend diminishes at higher elevations above around 2500m (8200ft) elevations (Jain 2008; Pierce et al. 2008).

Lower elevations are more vulnerable to the effects of warming since a small rise in average temperature will create an earlier snowmelt or a shift from snow to precipitation. At high elevations (around 2500m from the literature), cooler temperatures provide a buffer that can maintain the snowpack until spring, but this "safety" factor is being eroded by observed warming of the Sierra Nevada. Most of the snowpack in the Rockies, for example, and observed pika habitat in many mountain ranges – is above this elevation, where winter temperatures remain well below freezing. Nevertheless, areas that retain their winter snowpack, may still be vulnerable to Springtime warming accelerating the snowmelt.

Although changes in snowcover, snowpack as SWE, are documented trends in precipitation-related variables that may affect pikas. For example, snow cover is postulated to provide insulation to pikas during spring cold air outbreaks (CBD 2007). There is a need to document what specific precipitation variables are of concern, and how to connect them to the biology and health of the pikas.

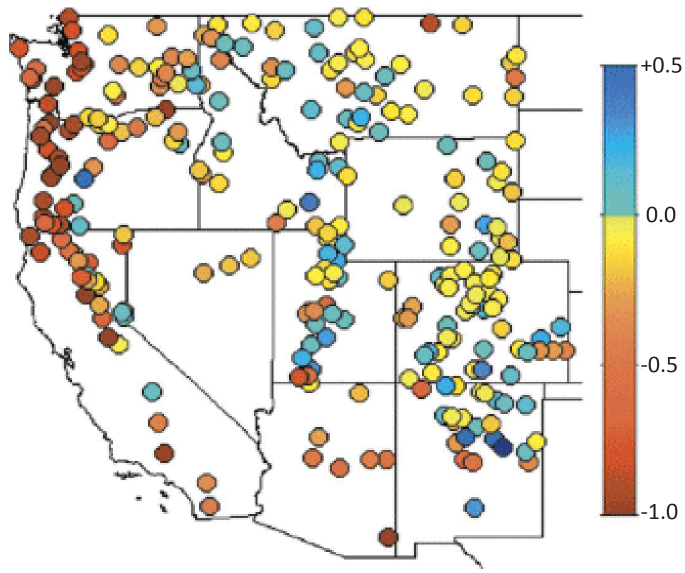


Figure 11. Changes in the fraction of winter precipitation falling as snow vs. rain. Trends after correcting for trends in precipitation amount, data from 1949–2004, the latest data available at the time of their analysis. Blue shades indicate increasing fraction of snow; yellow-reds decreasing fraction. Data are from NWS COOP stations (From Knowles et. al. 2006, Figure 7).

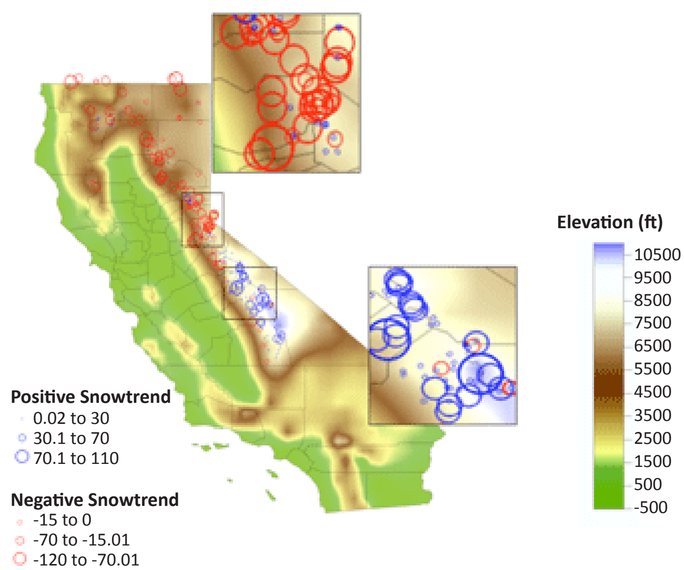


Figure 12. April 1 snow trends 1950-1997. The red points/circles indicate percent decrease in April 1 snow amount and blue points/circles indicate percentage increase. (From California Climate Update, Figure 6, adapted from Mote et al 2005).

Attribution: Can the changes be linked to man-made causes?

Attribution is the process of establishing the principal causes for observed climate phenomena. Attribution of man-made, or anthropogenic, climate change, part of the focus of the Intergovernmental Panel on Climate Change (IPCC) assessment reports, has the specific objective of explaining a detected climate change that is significantly different from that which could be expected from natural variations of the climate system. The requirements for determining an attribution for detected change are that first, scientists can demonstrate that the change is consistent with a combination of anthropogenic and natural causes, and second, that these changes are inconsistent with alternative, physically plausible explanations of recent climate change that exclude anthropogenic causes (IPCC TAR WG1 2001). If attribution is established, the IPCC may assign a likelihood statement for the probability that the identified cause resulted in the observed conditions or trends.

Attribution studies use both empirical analyses of past climate relationships and simulations with climate models in which cause-and-effect relations are evaluated. Statistical analysis is used to compare the model simulations with the observed record, including estimates of natural variability and trends from climate models, historical observations, and in some cases, paleoclimate reconstructions of past temperatures. "Fingerprint" methods seek the unique signature of climate change by simultaneously looking at changes in many variables. Attribution studies are also used to assess the natural and anthropogenic causes of drought and other extreme climate events.

Studies have been conducted to determine a cause, or attribution of the observed warming of annual-averaged temperatures in western and northern North America over the past half-century (Figure 6 above, left panel). In these studies, annually averaged North American surface temperatures from 1950–2007 were computed from the IPCC (CMIP3) model simulations. The models were forced with the observed record of greenhouse gases, volcanic aerosols, and solar forcing during 1950–99, and subsequently (2000-2100) with the A1B scenario (see Section 4) of greenhouse gas emissions (Figure 7, left panel. Similarities between these results and the observed trends provide the best available evidence for external climate forcing of surface temperature change by anthropogenic greenhouse gases. First, the bulk of the warming occurs after about 1970 in both time series. Second, the externally forced warming of about 1°C (1.8°F) since 1950 is close to the observed warming rate.

A series of recent studies sought to "detect and attribute" climate change in the western U.S. (Bonfils et al. 2008; Pierce et al. 2008, Hidalgo et al. 2009; Das et al. 2009). These studies share common authors, datasets, and methodology. Bonfils and colleagues conducted a very detailed analysis of climate models thought to best simulate the climate of the western U.S. These authors used the same 1/8 degree downscaled dataset and PRISM dataset as used in projections reported in Section 8. These authors find that natural variability is insufficient to explain changes in temperature variables, including an increase in daily minimum and maximum temps; a sharp decline in frost days; a rise in degree days above 0°C; and a decline snowpack at low and mid-elevations. They ruled out solar variability and volcanic forcing as a cause. They find that the anthropogenic signal is detectable by the mid-1980s in signal-noise ratio of minimum temperature. Other attribution papers focus on streamflow (Hidalgo et al. 2009), snowpack (Pierce et al. 2008) and structure and detectability of hydrological variables (Das et al. 2009). Attribution studies have estimated that up to about half of the trends in temperature and associated hydrologic variables can be attributed to anthropogenic causes (Barnett et al. 2008; Pierce et al. 2008).

6 Analysis of Climate Observations Near Pika Locations

We analyzed climate observations at climate stations in two regions with observed pika populations thought to be at higher risk: the Nevada/California border region and southern Oregon. Due to time constraints of this rapid-response report, only two regions were analyzed. The priority of these regions was determined in consultation with the USFWS. The observational record is complicated. This analysis illustrates that the magnitude of observed temperature trends may vary depending on the station or area, the season vs. annual average, and the time period analyzed. Although not discussed here, trends may also vary if maximum or minimum temperatures are analyzed, or daily average temperatures vs. the monthly averages here. Lapse rates were calculated from available station data to illustrate how much local conditions can vary from one region to the next, even though most of the summertime lapse rates fall into the typical free atmospheric range of 6-8°C/km that is illustrated in Fig. 3b. However, as with most areas where pika live, the analysis is limited by the vertical range of COOP stations, which are often lower than the elevations of reported pika colonies.

Observations analyzed are from the U. S. Cooperative Observing Network (COOP). Climatic trends at individual stations may not be representative of regional climate because of local atmospheric processes at those stations. For this reason, climatologists assess long-term regional variability by grouping observing stations together. Regional trends may emerge (e.g., be statistically detectable) when the records from these stations are averaged together. Thus groups of stations in climate divisions were analyzed to detect trends and to estimate lapse rates – the relationship of temperature and elevation.

The existing official climate divisions of the NOAA National Climatic Data Center (NCDC) group climate data into regions across the west, but these divisions are not necessarily representative of the complex regional climates in the West. These divisions were designed to organize climate data across the country, but often matched up with crop reporting districts, county lines, and/or drainage basins, rather than representing coherent climate areas (Gutman and Quayle 1996). Therefore, we utilized a new set of climate divisions that has been developed (Wolter and Allured 2007). These new divisions (Figure 13) are based on groups of observing stations that vary in a similar manner

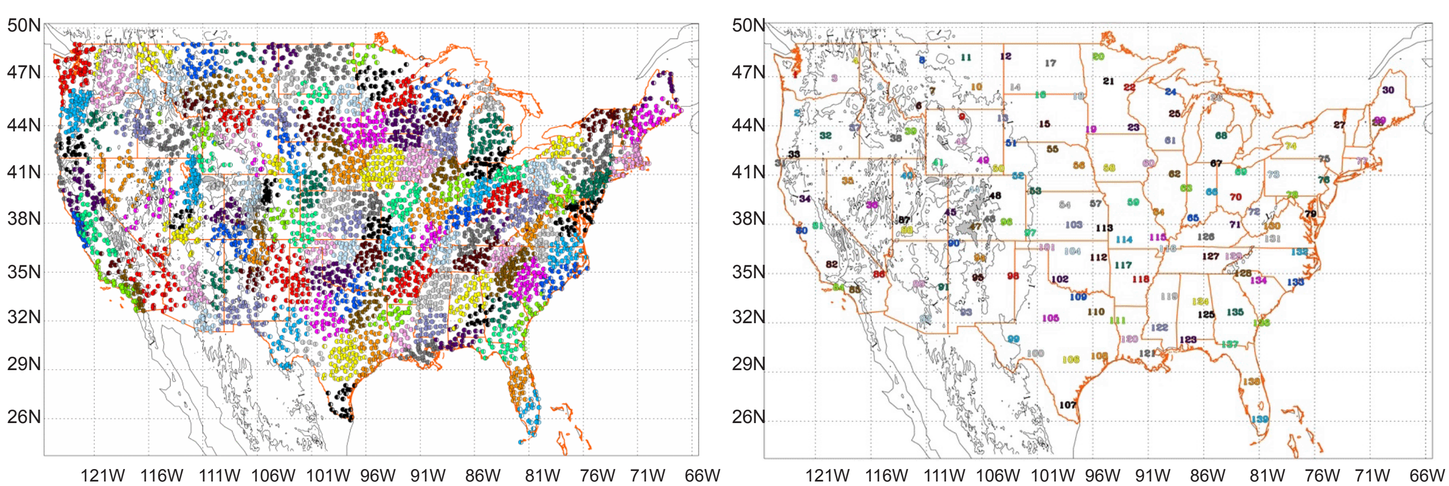


Figure 13. Climate Observing stations in new climate divisions. New ("experimental") climate divisions based on multivariate cluster analyses of data from 1978-2006, which assign COOP stations (colored dots) to a new division. Each colored group of dots represents a new climate division (a); numbers assigned to each division are in the same color (b), Note Divisions 32, 35, 36, 83 discussed in the text. Unlike the traditional NCDC Climate Divisions that assign regions in the West largely on geographical features such as river basins, this new classification is based on stations that have similar climatological variability. (Source: Klaus Wolter, NOAA-CIRES, http://www.cdc.noaa.gov/people/klaus.wolter/ClimateDivisions/).

from year to year, and are thought to reflect similar regional climate processes.

Sufficient data are available to construct time series of temperature for most of these new climate divisions back to the early 1930s. Figure 14 shows the seasonal and average monthly temperature series for Bodie, CA and Fort Bidwell, OR as examples from the two regions. Analysis of the observed records within each division help to detect regional temperature trends by reducing local climate factors that are not indicative of regional climate at each observing station.

Sierra Nevada and Western Great Basin

Three "new" climate divisions in this region in the Sierra Nevada and the Western Great Basin were analyzed, Divisions 35, 36, and 83 (see Figure 13b), using the high-quality stations closest to observed pika locations. For this region as a whole, there is warming in the annual trend over the last 75+ years, with the last 30 years showing most pronounced warming in the summer season. In the 50-year trends, a springtime warming trend dominates the warming trend, a feature also described in Abatzoglou and Redmond (2007).

Climate Division 36 includes stations Dyer, Mina, Silverpeak, Smokey Valley, and Tonopah, at elevations from 4260-5625ft, a smaller vertical range than in division 35. Warming trend in summer is +1.7°C (3.1°F) in the last 30 years, the largest and most significant trend for any season. Only one station (Mina) goes back to the 1930s; it shows a clear warming trend throughout its entire record. The lapse rates are highest in spring and summer, reaching 7.5°C/1000m (4.15°F/1000 ft) in recent summers, somewhat higher than typical lapse rates. Assuming that this surface lapse rate remains constant in the future, a further warming of +2°C in the summer would shift temperature zones up slope by less than 300m (1000ft) in elevation.

Climate Division 83 includes climate observing stations at Bishop, Bodie, and Bridgeport, with a vertical elevation range from 4100' to 8370', and located within 37.4-38.3N and 118.3-119.2W. The Bodie COOP station at 8370ft is only about 2.6km (1.5mi) from observed pika; Figure 14 shows the seasonal and

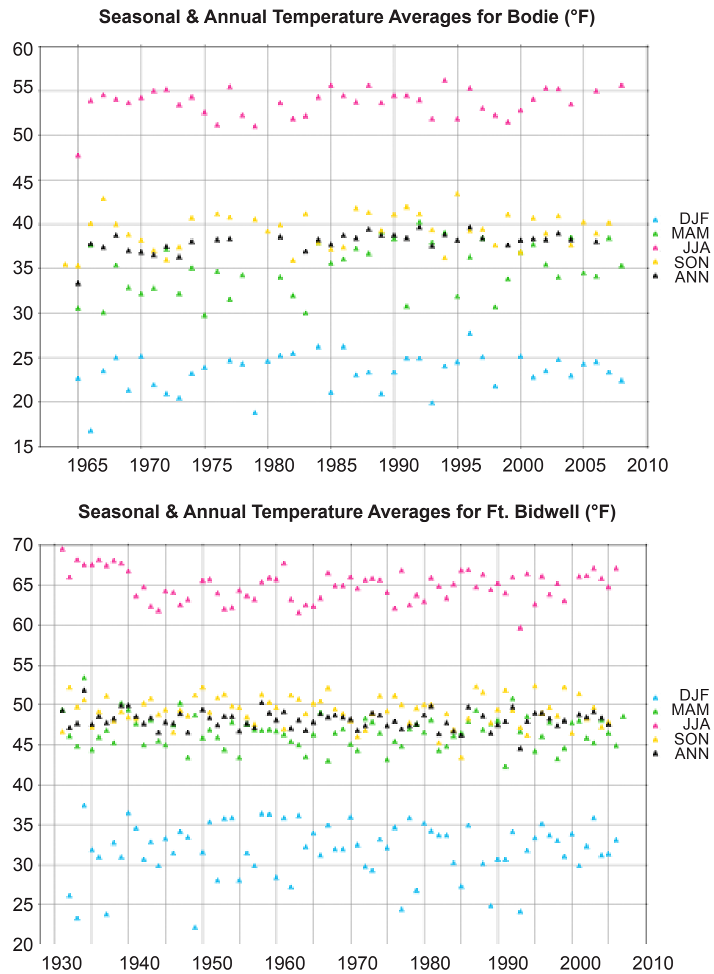


Figure 14. Station Time Series for Two Climate stations. Annual and seasonal average temperatures at Bodie, CA (8370ft, upper panel) and Fort Bidwell, OR (5700ft, lower panel), illustrating the annual and seasonal variability at two stations with close proximity to reported pika locations. The Bodie COOP station is about 2.6km (1.5mi) from the "Bodie" reported pika location; Ft. Bidwell is about 25.8km(16 mi) from reported pika locations in the Warner Mountains. Black triangles indicate the annual average temperature at the station, colors indicate seasonal averages: pink is June-July-August (note 55°F = 13°C, 65°F = 18°C), blue is December-January-February, green is March-April- May, yellow is September-October-November. The "Bodie" COOP station is about 2.6km (1.5mi) from the pika location of the same name; "Fort Bidwell" COOP is about 25.8km (16 mi) from pika locations in the Warner Mtns.

average monthly temperature series for Bodie. Reported pika elevations at Bodie are 8530-8635ft. The warming trend in summer is highest of all seasons in last 30 years, +1°C (1.7°F) for the average of all three stations, somewhat less than in the other two climate divisions. This division has no records prior to 1943, so there is no comparison possible with the 1930s. The lapse rate between Bodie and Bridgeport stations 6.1°C/1000m in last 30 years. Using this lapse rate, a future increase of +2°C would shift temperature zones up slope in the summer by 300-400m (1000-1300ft), similar to Climate Division 36.

Climate division 35 includes COOP stations in northwestern Nevada: Austin, Fallon, Smith, Wabuska, and Yerington, roughly in the box: 38.9-39.5N, 117.1-119.3W; this division extends across the border to Oregon, but the Oregon stations were analyzed separately (see below). This area includes pika locations studied by Millar and Westfall (2009) and Beever et al (2003), for example, Pinchot Creek, Toby Canyon, Mustang Mountain, Arc Dome, and Big Indian Mountain. For the last 30 years there is an annual trend of +1.6°C (3°F) in the annual mean, and 2.4°C (4.3°F) in the summer, a highly statistically significant increase that is shared across all five stations, at elevations from 3960ft to 6780ft. Looking back at the 1930s when records exist for Austin, Fallon, and Yerington, the most recent decade is the warmest on record. Recent summer-time lapse rates based on station temperatures have been fairly small, around 2.5°F/1000’ (4.5°C/1000m). This calculation is based on the average temperature differences between three low-elevation and two high-elevation stations, not completely eliminating possible local effects. This estimate deserves further investigation that was not possible in the time frame of this report. If the summertime lapse rate remained the same in the future, and the overall regional climate warmed by about 2°C, temperature zones would move up slope in elevation by more than 400m (over 1400ft).

Southern and Eastern Oregon

Three “new” climate divisions in southern and eastern Oregon were analyzed, using nine high-quality stations closest to observed pikas. Six of the nine climate stations in this region (41.3-43.0N/119.6-121.5W, include the 1930s. This area includes pika sites studied by Beever et al (2003), for example, Ft Bidwell, Crane Mountain, Hays Canyon, Thomas Creek Ranger Station. The last 30 years feature the pronounced warming in the summer season while 50-year trends feature the springtime warming trend described in Abatzoglou and Redmond (2007).

Climate division 32 includes the COOP stations Hart Mountain Refuge, Paisley, Summer Lake, and Tulelake; 42.0-43.0N and 119.6-121.5N, the northern portion of this region), station elevations range from 4035-5617ft, below most observed pika habitat locations in this area (5800-7925ft, eastern Oregon; 6436-7660ft at Crater Lakes). Summer has the highest warming trend of any season in the past 30 years, +1.6°C (2.9°F), other seasons show less than 1°C (2°F) warming. The familiar spring warming trend is evident in periods 50 years and longer. For the two stations with records that extend back to the 1930s (Tulelake and Paisley), we find statistically no difference between the 1930s and most recent decade at Paisley, and some warming compared to the 1930s at Tulelake, anchored by the summer season. The lapse rate analysis is handicapped because only one station is located at higher elevations, and that station is below the known elevations of most pika colonies. Lapse rates between these stations are highest in spring (about 3°F/1000’, or 5.5°C/km), with summer season lapse rates close behind (about 10% less). During the summer, a 2°C (4°F) increase would result in temperature zones moving up slope 360-400m (~1200ft). The warming of 1.6°C over the past 30 years in the summer suggests that a vertical displacement of temperature zones of just under 300m (1000ft) has already taken place.

Climate Division 35 includes stations Alturas, Cedarville, Ft. Bidwell (Figure 14b), Jess Valley, and Lakeview, at elevations from 4400-5400ft, located in a fairly small area, 41.3-42.2N and 120.1-120.3W. The Ft. Bidwell COOP station at 5700ft, is about 25.8km (16 mi) from reported pika locations in the Warner Mountains, where pika are reported at 5429-8267ft. This division extends across the border to Nevada, but calculations were performed with the five stations in Oregon. Warming trend in summer is +1.8°C (+3.2F) over the last three decades. Longer trends are more ambiguous, with fall cooling balancing out spring warming over the last five or six decades. The three stations with data back to 1931 (Alturas, Ft. Bidwell, and Lakeview) show little change from the 1930s to the present, while Cedarville has cooled over the last three-quarter century. Lapse rates were computed based on the average of four low-elevation stations vs. Hart Mountain Refuge that is only 813ft higher than the average of the lower elevation stations. Lapse rates have been highest in spring and summer, reaching 6.4°C/km (3.5°F/1000ft). A future warming of 2°C in the summer season would translate into a shift upslope of climate zones by about 300m (1000ft).

In summary, climate divisions near pika locations – only a few analyzed out of the many pika locations reported -- show statistically significant warming of 1°C (1.7°F) to 2.4°C (4.3°F) in the summer over the past 30 years. Warming trends also are significant in the 50-year record, especially in the spring. The warming trends are not as pervasive over the past 75-80 years. The magnitudes of observed temperature trends vary depending on the observing station or pika location, the season, and the time period analyzed. Some divisions have already experienced warming in the last 30 years of about 2°C – similar to the additional warming expected through mid-century. Lapse rates are highest during the spring and summer seasons, which would minimize the vertical displacement of temperature zones due to the observed warming. In climate division 32, for example, warming of 1.6°C over the past 30 years in the summer suggests that a vertical displacement of just under 300 m (1000 ft) has already taken place.

7 Climate Projections in the Western U.S.

Global models project broad-scale increases in temperature in North America through the mid-21st century. Projected changes compared to a recent baseline (1950–99 average) through mid-century (2040–60 average) are shown in Figure 15. For much of the interior western U.S., in orange, the multi-model average projects an annual mean warming of about 2°C (4°F) by 2050. In addition to the multi-model ensemble mean, individual global models also have a broad-scale pattern of warming, though of different magnitudes across models. The range of climate model projections (10th and 90th percentiles of the model projections) is from about +2.5°F to + 5.5°F. The projections show summers warming by about +5°F (range: 3-7°F) and winters by about +3°F (range: 2-5°F) (Figure 15, top row). The multi-model average, and many individual global models show diminished warming within several hundred kilometers of the Pacific coast. This feature may be a result of the inability of the global models to simulate the effects of the coastal mountain ranges, and hence the moderating coastal influence penetrates too far inland. Regional climate modeling studies corroborate this, showing large values of summertime warming much closer to

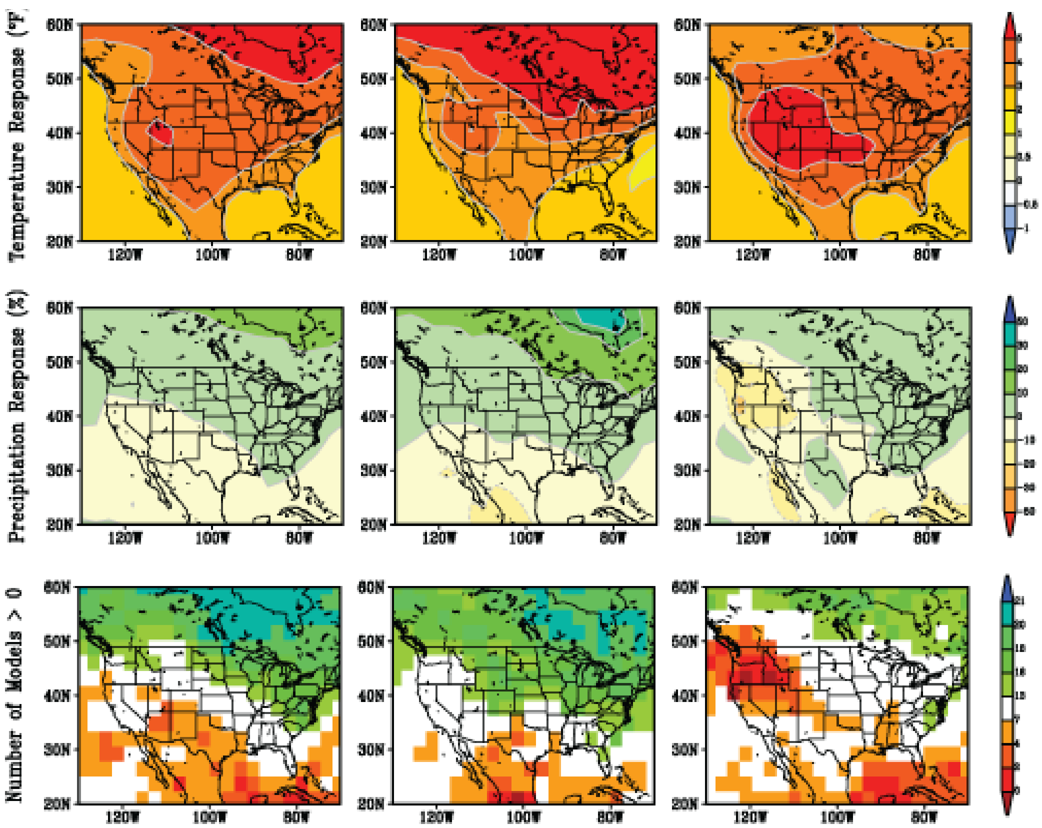


Figure 15. Temperature (°F) and Precipitation Changes over North America Projected for 2050. Temperature and precipitation changes over North America projected for 2050 (2040–60 average) by an ensemble of 22 climate models used in the IPCC AR4. Changes are shown relative to the 1950–99 baseline average. The top row is the multi-model average temperature change for the annual mean (left), winter (center), and summer (right). For Colorado for example, the average projected temperature changes are about 4°F (2.2°C) (annual), 3°F (1.7°C) (winter), and 5°F (2.7°C) (summer). The second row shows the percentage change in total precipitation. The multi-model average shows small changes in precipitation in Colorado, although individual model projections (not shown) exhibit a range of projected changes. For much of the western U.S., there is only weak agreement among the models whether annual precipitation will increase or decrease (third row), though there is an indication of an increase in winter and a decrease in summer. This graphic is based on Figure 11.12 in the IPCC AR4 WG1 (2008) report. However, compared to the IPCC figure, we plot projections for 2050 rather than 2090, and zoom into the conterminous United States showing state boundaries. (From Ray et al. 2008, Figure 5-1, data source: CMIP3 multi-model archive, IPCC AR4 WG1, 2008)

the coast than for the global models.

For total annual precipitation, the dominant pattern in North America projects a wetter climate in the northern tier and a drier climate in the southwestern U.S. (Figure 15, middle row). However, for much of the interior west, the models do not show substantial agreement on whether annual total precipitation increase or decreases (Figure 15, bottom row). Two seasonal features stand out, however – an increase in wintertime precipitation extending from Montana southward into Colorado, and a decrease in summertime precipitation in the Pacific Northwest.

Westwide Climate: Statistically Downscaled Projections

For much of the West, GCMs project about 2°C (4°F) rise in temperatures (the orange shading in Figure 15, top row), with somewhat less warming near the Pacific coast. To illustrate what the projected rise in temperatures would mean for western regional climate compared to the existing north-south and elevational gradients of climate in the western U.S., downscaled temperature data from the CMIP3 22-model average projection for the A1B emissions scenario (from IPCC AR4) were added to the PRISM climatology (at a 2.5 arc-minute scale, or roughly 4km) for the June-July-August season. This downscaling method makes minimal, physically based corrections to the global simulation while preserving much of the statistics of interannual variability in the climate model (described by Salathé 2005). When considering only the time-average changes, this method is similar to the so-called "delta method," in which the temperature changes (the "deltas") from GCMs are spatially interpolated and added to a high-resolution climatology. The CMIP multi-model average was used rather than individual models because the current understanding of modeling is that the average of multiple models is a better approximation than one or a few models.

The maps depict projected average daily temperature, dividing the western U.S. in three regions, the northwest (Figure 16), California and Nevada (Figure 17), and the Utah, Colorado, and New Mexico (Figure 18) for the 1950–99 climatology and projections for around 2025, 2050, 2090. These graphics illustrate

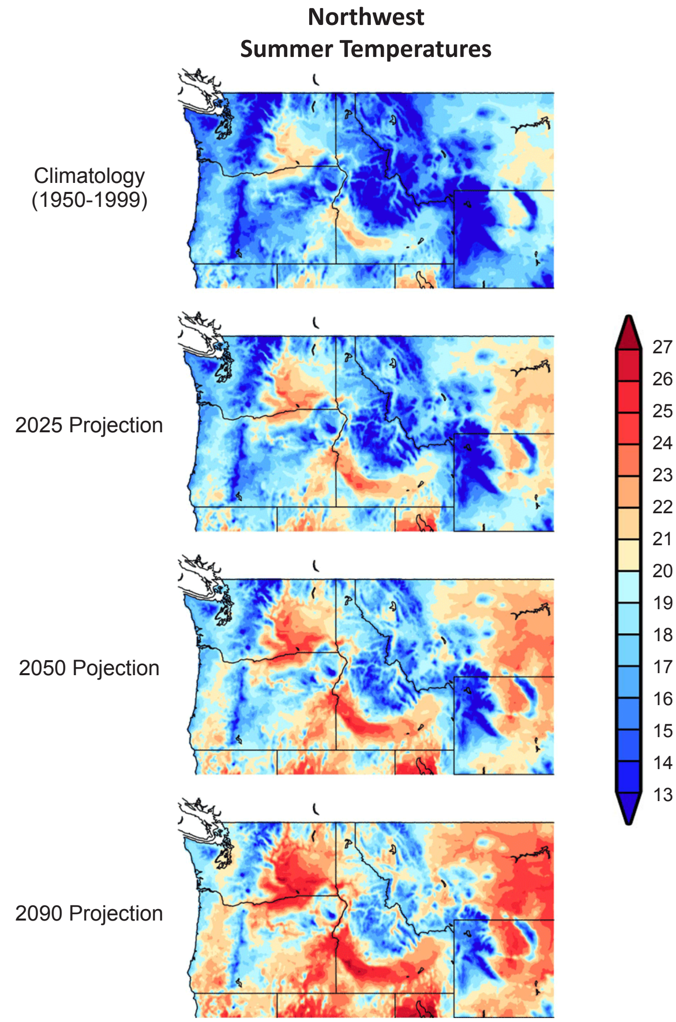


Figure 16. Summer Observed Average Temperatures and Statistically Downscaled Projections for the Northwest. June-July-August (summer) observed average seasonal temperature in the Northwest for 1950–99 (top panel). Note 16°C = 61°F, 20°C = 68°F). Lower panels show projections for 10-year averages beginning in 2025 (2nd panel), 2050 (3rd panel), and 2090 (bottom panel). Projections were calculated by adding the multi-model average temperature changes to the 4km PRISM climatology. Observed climatological averages are from PRISM (DiLuzio et al. 2008), projected changes from the IPCC (CMIP3) 22-model average for the A1B emissions scenario.

that at large spatial scales, by 2050 the projected changes in summer (June-July-August) climate can be visualized as a shift of temperature zones northward and upward in elevation (3rd panel in each figure). This shift of temperature zones continues through the end of the 21st century (lower panel in each figure).

Note that the maps depict summer averages; the observed temperature climatology does not capture the year-to-year or day-to-day variations, nor do the climate projections, which are 20-year averages. There are a number of unknowns about how climate

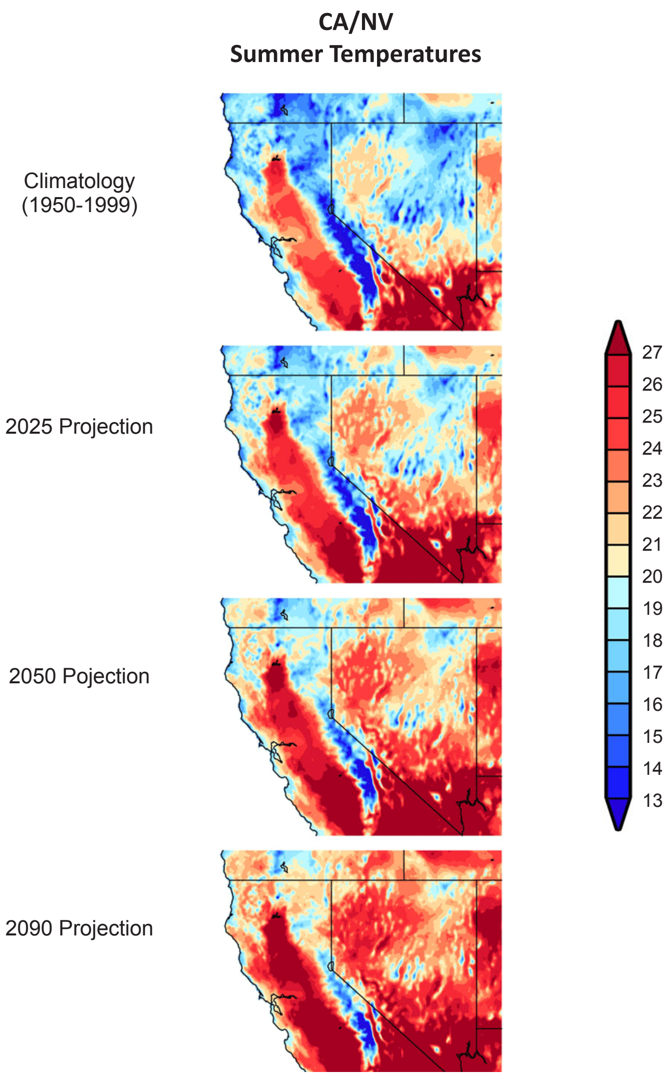


Figure 17. Summer Observed Average Temperatures and Statistically Downscaled Projections for California and the Western Great Basin. Same as Figure 16, but for California and Nevada, including the western Great Basin.

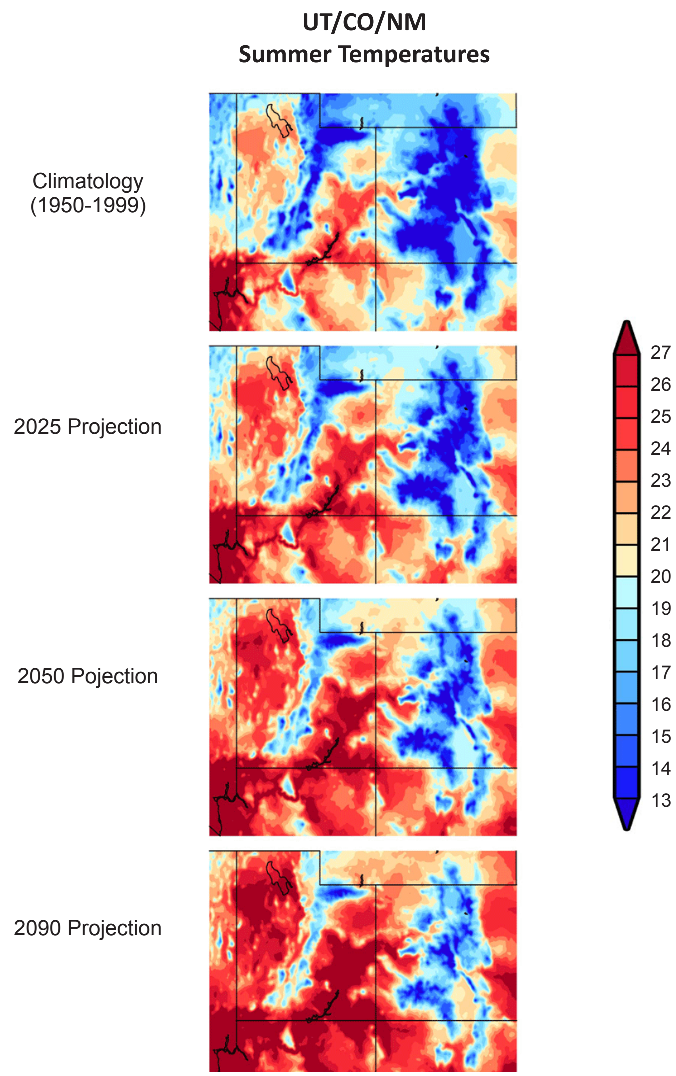


Figure 18. Summer Observed Average Temperatures and Statistically Downscaled Projections for Utah, Colorado, and New Mexico. Same as Figure 16, but for Utah, Colorado and New Mexico.

will evolve at any given location – as some local effects may reduce, or amplify the large-scale pattern of widespread warming that is projected over the Western United States. While these figures illustrate climate change in the western U.S., it is unclear how the details will play out at any given location. It is difficult to establish these local variations, until higher resolution dynamical downscaling is performed, and until projected local land use and potential ecosystem changes (e.g., forest cover changes resulting from pine beetle infestation) are incorporated.

These averages are considered the best estimate: the larger picture is that widespread warming is projected for most of the western United States. As shown in Section 8 the projected changes, especially in summer, are large compared to present-day climate variations—an indication that the warming signal may be clearly seen throughout the western U.S. by 2050.

Regional Climate Models: Dynamically Downscaled Projections

The statistically downscaled projections shown in this report inherit the broad scale warming patterns seen in the global models, and therefore tell a similar story of change as global models. Results from high-resolution regional climate models (RCMs), also called "dynamical downscaling, are capable of simulating the different patterns of climate change. Fewer dynamical downscaling studies have been published, so there are few projections for intercomparison than for GCMs. The available dynamically downscaled global models add some texture and detail to the warming pattern from the global models, but still provide a consistent story of projected broad scale warming.

The Washington Climate Change Impacts Assessment (WACCIA) dynamically downscaled two individual global models from CMIP3, the CCSM3 (NCAR Community Climate System Model) and ECHAM5 (European Center-Hamburg model). The GCMs project increases in average annual temperature in the Pacific Northwest for 2030-2059 (Figure 19) of 1.1°C (2.0°F) by the 2020s, 1.7°C (3.2°F) by the 2040s, and 2.9°C (5.3°F) by the 2080s (compared to 1970-1999). The output of these global models was downscaled using a 50-km version of the Weather Research and Forecasting (WRF) RCM, though slightly different downscaling methodologies are used in the two simulations.

Salathé and coauthors (2009) note considerable difference in the temperature response between the two global models and with season. The dynamically downscaled model temperature changes from these models using the WRF regional model are shown in Figure 20. They attribute these temperature changes largely to the global model used to force the regional model, and to feedbacks within the regional model driven by changes in precipitation, cloudiness, and surface radiation. In the winter season (DJF), the spatial pattern of warming in a regional model is strongly linked to changes in snowpack and cloud cover, which alters the surface radiation balance (Leung et al. 2004;

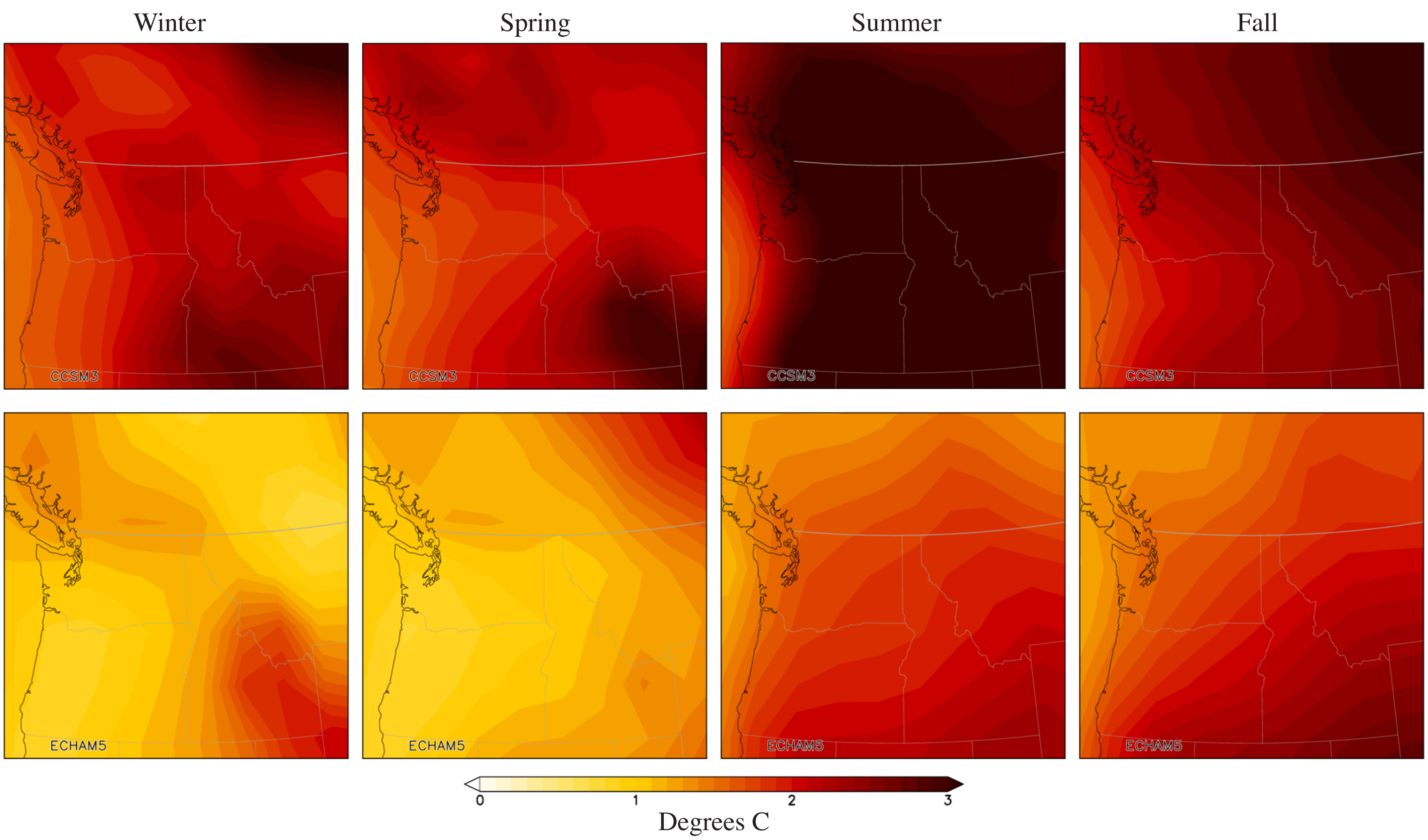


Figure 19. Global climate model projections for the Pacific Northwest. Change in temperature (°C) from 1970-1999 to 2030-2059 for CCSM3-WRF (top row) and ECHAM5-WRF (bottom row) for the winter (DJF), spring (MAM), summer (JJA) and fall (OND) seasons. Note 1°C = 1.8°F, 2°C = 3.6°F (From Salathe et al 2009, Figure 8).

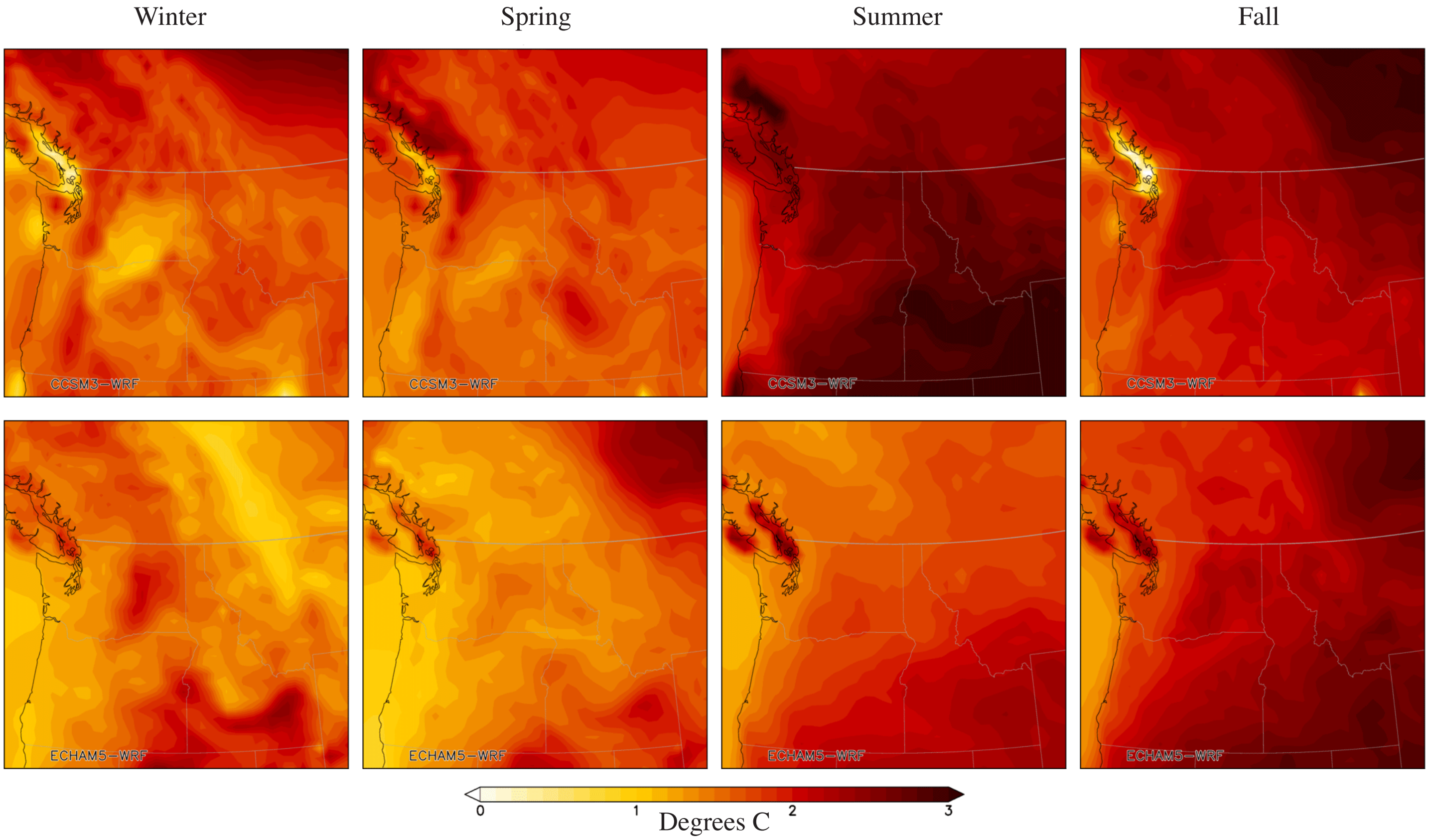


Figure 20. Dynamically downscaled regional climate model projections for the Pacific Northwest. Change in temperature (°C) from 1970-1999 to 2030-2059 for CCSM3-WRF (top row) and ECHAM5-WRF (bottom row) for the winter (DJF), spring (MAM), summer (JJA) and fall (OND) seasons. Note 1°C = 1.8°F, 2°C = 3.6°F (From Salathe et al 2009, Figure 7)

Salathé et al., 2008). For example, where snowpack is lost, either due to warmer temperatures or less precipitation, the albedo is decreased, more solar radiation is absorbed at the surface, and the warming is amplified. Precipitation is discussed in the section below.

For the summer season, both regional models closely follow the global model, which suggests that mesoscale processes–such as mountain winds, thunderstorms, and local wind fields–are not as critical to the summer temperature sensitivity. In spring (MAM) and summer (JJA), both the global and regional models indicate less warming in coastal areas than inland. In some areas, the regional models reduce the coastal warming relative to the global model. Because of their enhanced resolution of coastal mountains, the RCMs confine the region of moderating coastal influence closer to the coastline compared to the global models.

The state of California is supporting efforts to dynamically downscale projections for the state. As part of the Climate Change Impacts Assessment Project regional climate models have been enhanced and validated and probabilistic climate projections are being developed for California at a resolution that will be adequate for local and regional impacts (Moser et al. 2009). These scenarios are expected to be available in late 2009.

Another dynamical downscaling effort involving additional global and regional models is the North American Regional Climate Change Assessment Program (NARCCAP). NARCCAP is an international program to produce 50-km resolution climate change simulations in order to investigate uncertainties in regional scale projections of future climate and generate climate change scenarios for use in impacts research (Mearns et al 2009). NARCCAP modelers are running a set of six regional climate models (RCMs) driven by a set of four atmosphere-ocean general circulation models (AOGCMs) over a domain covering the conterminous United States and most of Canada.

The AOGCMs were forced with the A2, or "high" emissions scenario for the 21st century. Simulations with these models were also produced for the current (historical) period. The RCMs are nested within the AOGCMs for the recent past 1971-2000 and for the future period 2041-2070. As a preliminary step to evaluate the performance of the RCMs over North America, the RCMS are driven with NCEP Reanalysis II data for the period 1979-2004.

Climate projections from NARCCAP for the 2041-2070 period are just becoming available for analysis by researchers. Preliminary results from two simulations indicate the potential for the regional models to modify the global model results. These are designated CGCM-CRCM (the Canadian General Circulation Model downscaled with the Canadian Regional Climate Model, (Figure 21), and the NOAA GFDL-RCM, (Geophysical Fluid Dynamics Laboratory Atmosphere Model 2.0 downscaled with the GFDL Regional Climate Model, (Figure 22). All simulations – GCM and RCM – show a large-scale pattern of summertime warming in the western United States. These simulations, as well as the ones from the WACCIA shown in Figure 19, indicate a tendency for less warming (2°C) in parts of the Pacific Northwest compared to other regions in the West, consistent with the multi-model average of the GCMs.

The RCM results also differ in detail from one another

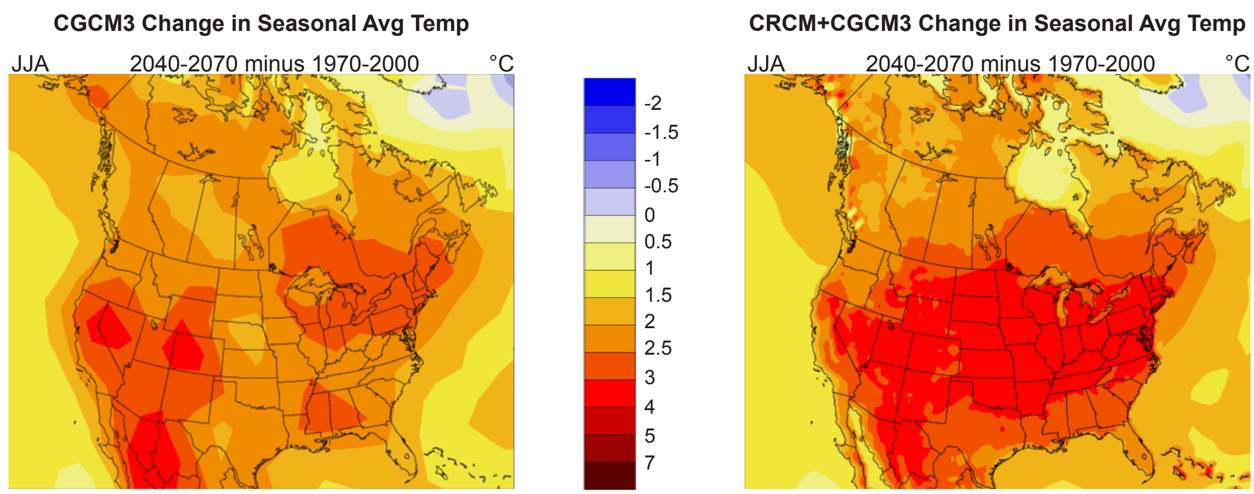


Figure 21. NARCCAP Canadian General Circulation Model and Canadian Regional Model downscaled projections. Summer (JJA) seasonal average temperature change for the periods 2041-2070 minus 1971-2000 for the CGCM3 global model the CRCM regional model driven with the CGCM3 global model boundary conditions. Note 3°C = ~5.4F. (Source http://www.narccap.ucar.edu/results; other seasons not shown).

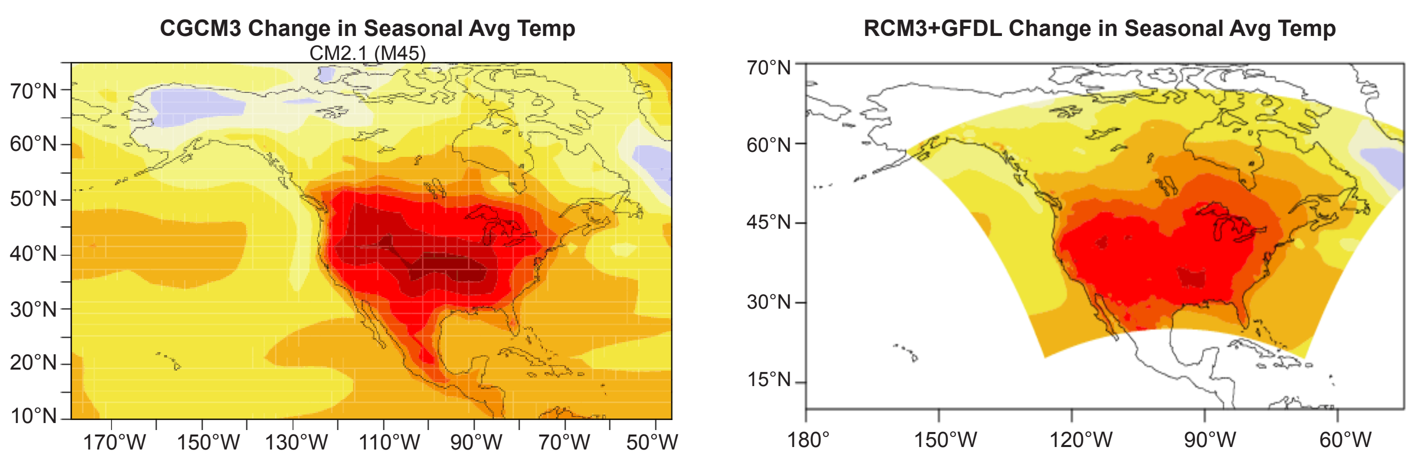


Figure 22. NARCCAP Geophysical Fluid Dynamics Laboratory (GFDL) global and regional downscaled projections. Summer (JJA) average temperature change for the periods 2041-2070 minus 1971-2000 for the NOAA/GFDL global model (a) and the GFDL regional model driven with the CGCM3 global model boundary conditions (b). Note 3°C = ~5.4F. (Source http://www.narccap.ucar.edu/results; other seasons not shown).

and from the forcing GCMs. For this reason it is essential to look at an ensemble of dynamically downscaled results to better understand the uncertainty in these projections. Even with the results that are available, RCMs can increase our understanding of physical mechanisms, such as snow-albedo feedback, that may be important for climate change in areas of pika habitat. A better understanding can potentially guide efforts to monitor and understand climate change in these regions.

Projections of Precipitation

The FWS 90-day petition finding lists precipitation changes as one of the factors that may affect the range and habitat quality of the pika, and it reviews the literature on precipitation projections in the western U.S. We concur with their discussion (FWS 2009, p. 21304) that temperature changes are expected to affect precipitation, snowpack and snowmelt in the range of the American pika, with expected decreases in snow season length and snowpack depth (Christensen et al, 2007), an increase in the proportion of precipitation falling as snow in the Cascades and Sierras (Leung et al 2004), and earlier seasons snowmelt (Rauscher et al, 2008).

Precipitation variability makes trends difficult to statistically detect, and leads to substantial uncertainty in attribution of observed patterns of precipitation and projections. The IPCC stated: "Models suggest that changes in mean precipitation amount, even where robust, will rise above natural variability more slowly than the temperature signal" (IPCC AR4 WGI 2007, p. 74).

Potential future changes in precipitation in the western U.S. are also smaller than the year-to-year and decade-to-decade variations observed in the historical record. Leung et al (2004) found that changes in the amount of precipitation for the Cascades and Sierras were not significant except a drying trend in summer. Mote and Salathé 2009 found only small changes in the amount annual precipitation (+1 to +2%, figures not reproduced here), averaged over all global models for the Pacific northwest but some models project an enhanced seasonal precipitation cycle with changes toward wetter autumns and winters and drier summers. They conclude, that precipitation projections are "equivocal," (p.31) although they project changes in snowpack that are primarily driven by changes in temperature.

However, statistically significant trends have been detected in variables affected by temperature, e.g snowmelt, seasonal accumulation expressed as snow water equivalent (SWE) and snow cover. Snowpack changes are a result of both changes in precipitation and changes in temperature (Mote et al., 2008), but still, projections show projected losses in Washington snowpack (Figure 23, for more detail see Salathé et al. 2009). They find that for the magnitude of snow loss, warming plays a prominent role in determining future snowpack, counteracting potential increases in precipitation. The CCSM3-WRF simulation (left) yields much larger snow loss than ECHAM5-WRF (right) over the entire domain, but particularly for the Cascade and Olympic mountains. This difference between the simulations may be due partly to the finer grid spacing in CCSM3-WRF, allowing better representation of smaller terrain features such as the Olympics. Warmer temperatures may counteract a potential increase in wintertime precipitation, due to more precipitation falling as rain rather than snow and hence less snowpack accumulation in addition to earlier snow melt.

These studies focus on the Sierras and the Pacific Northwest. Studies are underway for other mountainous areas of the western U.S., for example, NARCCAP is developing dynamically downscaled projections of precipitation. These have just been made available, but have not been analyzed in detail yet (http://www.narccap.ucar.edu).

Another view of snowpack is how the projected changes vary with elevation. Christenson and Lettenmaier (2006) show downscaled projections of changes in the Colorado River Basin April 1 SWE for 30-year averages centered on 2025, 2055, and 2085 for the B1 and A2 emissions scenarios (Figure 24), with elevation ranges of pikas superimposed). The snowpack sources for the Colorado River Basin includes mountains with pika habitat in eastern Utah, western Colorado, southwestern Wyoming, and northwestern New Mexico. The authors note that the average snowpack

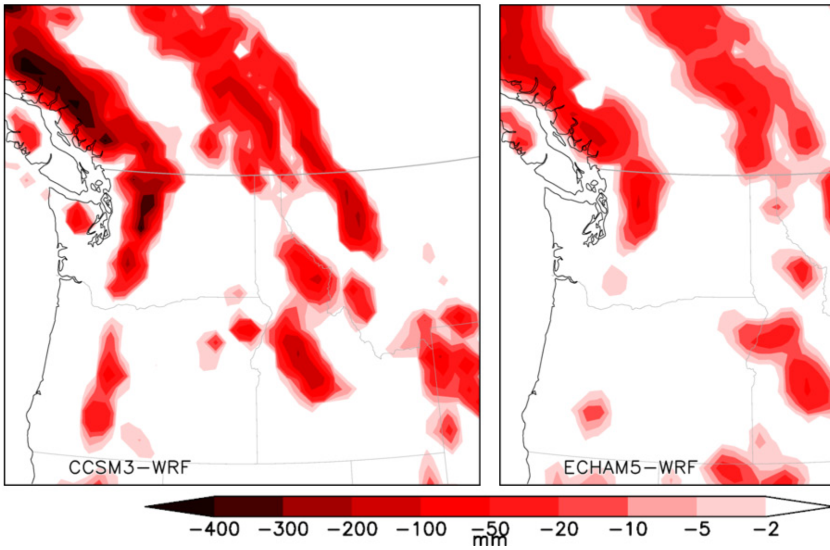


Figure 23. Projected Changes in Spring Pacific Northwest Snowpack. Change in April 1 snow water equivalent (mm) the change in average spring snowpack from the present to future climate (represented by the average March-April-May snow water equivalent, MAM). Projections from CCSM3-WRF (left) and ECHAM5- WRF (right). Note 50mm = ~2in. Substantial losses of snowpack are found in both regional simulations (From Salathe et al, 2009, Figure 9).

declines projected are a function of both the snow water equivalent and the amount of time snow is on the ground. Most of the snowpack in the higher elevation Rockies of Wyoming, Colorado, Utah, and New Mexico that feeds the Colorado River lies above 2500 m (8200 ft) in elevation. Modest declines in snowpack are projected at these high elevations, and larger declines (80–90%) may occur at lower elevations.

Summertime precipitation is projected to decrease over much of the conterminous United States, but there is more disagreement among the models than for winter. For example, the thunderstorms that dominate Colorado's summer precipitation are difficult to simulate and must be parameterized in the climate models. Larger scale systems such as the North American Monsoon that influence summertime precipitation in the Southwest are not well simulated by climate models (Lin et al. 2008). Despite these shortfalls, the magnitude of potential changes in the timing of precipitation is small compared to year-to-year or even decade-to-decade variations in precipitation. Consequently, interpretation of these projections suggests that for precipitation, the future out to 2050 will be dominated by natural variations.

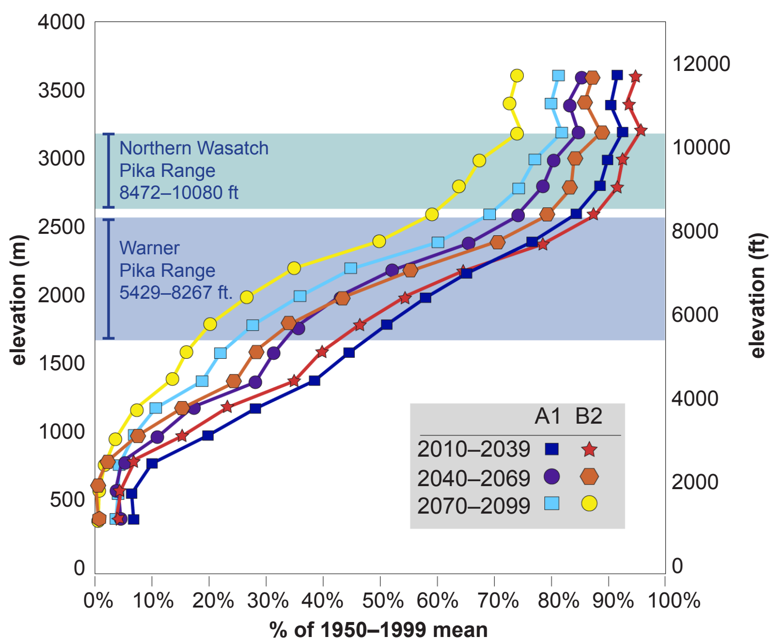


Figure 24. Projections of snowpack changes as a function of elevation with elevations of pikas superimposed. Colored lines depict projected percent decline in average snow water equivalent for the Colorado River Basin. Projections driven by the B1 and A1B emissions scenarios from 11 climate models for 30-year averages centered on 2025, 2055, and 2085. Most of the snowpack that feeds the Colorado River lies above 2500 m (8200 ft) in elevation. Modest declines in snowpack are projected at these high elevations, and larger declines (80–90%) are projected to occur at lower elevations. (After Ray et al., 2008, Figure 5-10, projection data from Christenson and Lettenmaier 2007, pika elevations from FWS).

8 Climate Projections Downscaled to Pika Locations

This section presents results of temperature projections statistically downscaled to 22 mountain ranges around the western U.S. identified by the FWS. This analysis illustrates implications of model-projected changes for the seasonal cycle, the relationship of projected climate change to historical climate variability, and the time-evolving nature of the ensemble of projections throughout the century. The results are shown in Figures 25-33, and are summarized for all areas in Tables 2-3.

Specific locations for analysis were selected based on pika habitat areas and specific pika observations in the 22 mountain ranges (see Figure 1), and on proximity and elevation of climate observations. If specific pika observation points were available, we selected a gridcell at or near that point or points. If no specific sites of pika observations were provided for a given mountain range, we selected a summit in that mountain range. Some mountain ranges have pika observations but few climate observations nearby (e.g. the Toiyabe Range in central Nevada).

The methodology for this analysis used a modified version of the Statistically Downscaled WCRP CMIP3 Climate Projections that were created by the DOI/Bureau of Reclamation and the University of Santa Clara and hosted at the Lawrence Livermore National Laboratory (LLNL) Program for Climate Model Diagnosis and Intercomparison (PCMDI). The statistical downscaling technique is "Bias Corrected Spatial Disaggregation" (BCSD) and was originally developed for hydrologic impact studies (Wood et al. 2004, Maurer 2002). This dataset downscales the projections to 1/8-degree (12km) grid in latitude and longitude (approximately 11x14 km at 40° North latitude). Documentation of this dataset is available on the website (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections) and in the references cited there.

For this report we adapted this dataset to the 4-km PRISM climatology (DiLuzio et al 2008). We were concerned that the roughly 12km grid (specifically, 7.5 arc minute) of the BCSD dataset did not resolve the mountainous regions well enough for the scale of pika locations. To better represent the small-scale climatology, for any particular gridcell we added the projected changes in temperature from the BCSD dataset to the PRISM monthly climatological averages (1950-1999). In effect, we took the timeseries from the BCSD dataset and adjusted that timeseries by the difference between the Maurer (2002) and PRISM monthly climatology for that PRISM gridcell, as in Figures 16-18. In calculating climatologic averages, the BCSD/PRISM method is almost identical to using the "delta method" described in Section 7. BCSD/PRISM uses an ensemble of 16 climate models vs. 22 in section 7.

The resulting estimates adjusted to PRISM are among the best inference for temperature at this scale. However, it is important to understand what is represented by the mean and range of historical temperatures in Table 2 and Figures 25-33. The range may not correspond to the actual temperature extremes that are observed at the pika locations because the PRISM temperatures are representative of an area average, and because they are based on interpolation from station observations that may be distant from the grid box and pika location (see Figure 2).

Temperature Projections: Seasonal Cycle and Decadal Variability

We looked in more detail at 22 specific locations with pika observations to illustrate the implications of the model-projected changes to around 2050, including the seasonal cycle, the spread of the projections, and relation to historical temperature variability, (see list, Table 1 and map, Figure 1).

Graphics show projections for individual 4-km PRISM grid boxes anchored on specific pika observation locations at 4 of the 22 locations around the U.S. West, the Bodie Mountains on the Nevada-California border (Figure 25), the Ruby Range in Nevada (Figure 26), the Northern Wasatch Range in Utah (Figure 27), and the Warner Range in Oregon (Figure 28) illustrate projected temperatures. Projected temperatures from the BCSD/PRISM downscaling for A1B emissions scenario are shown in red, with the average projection

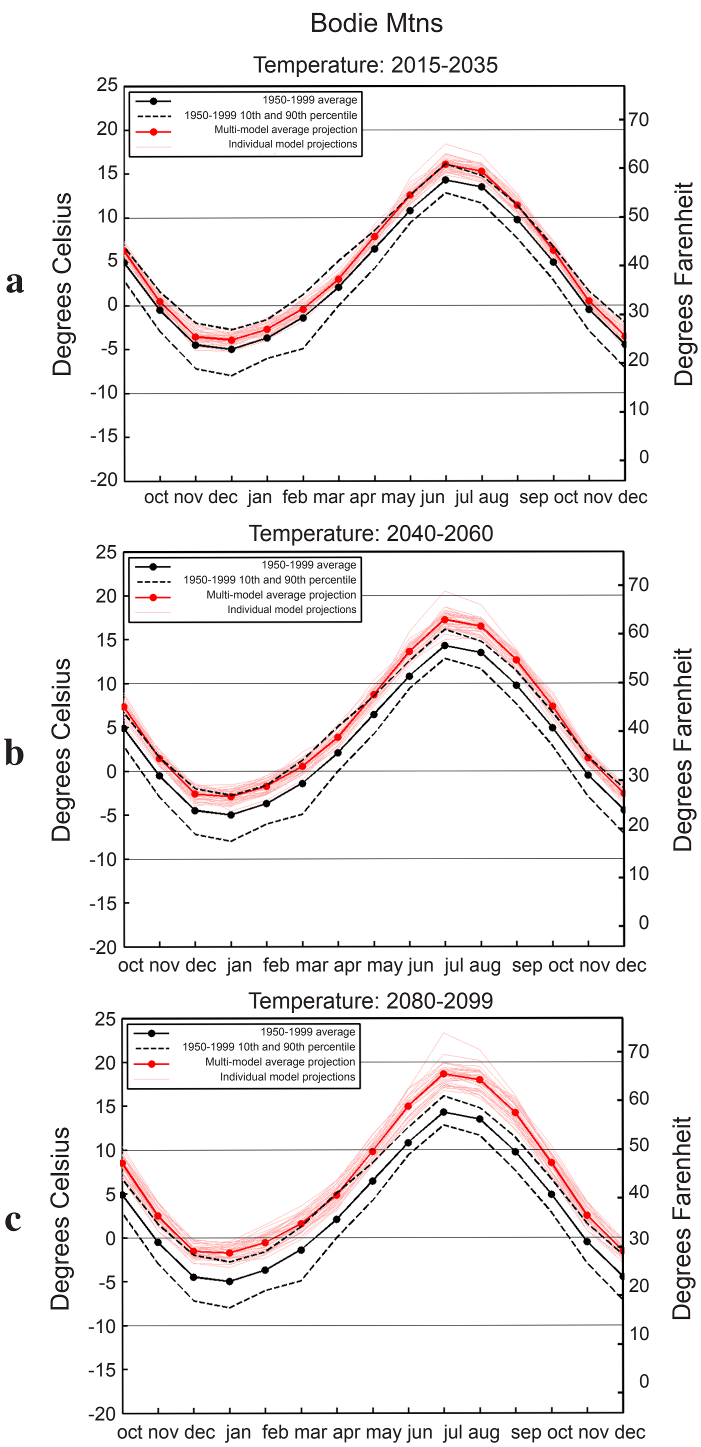
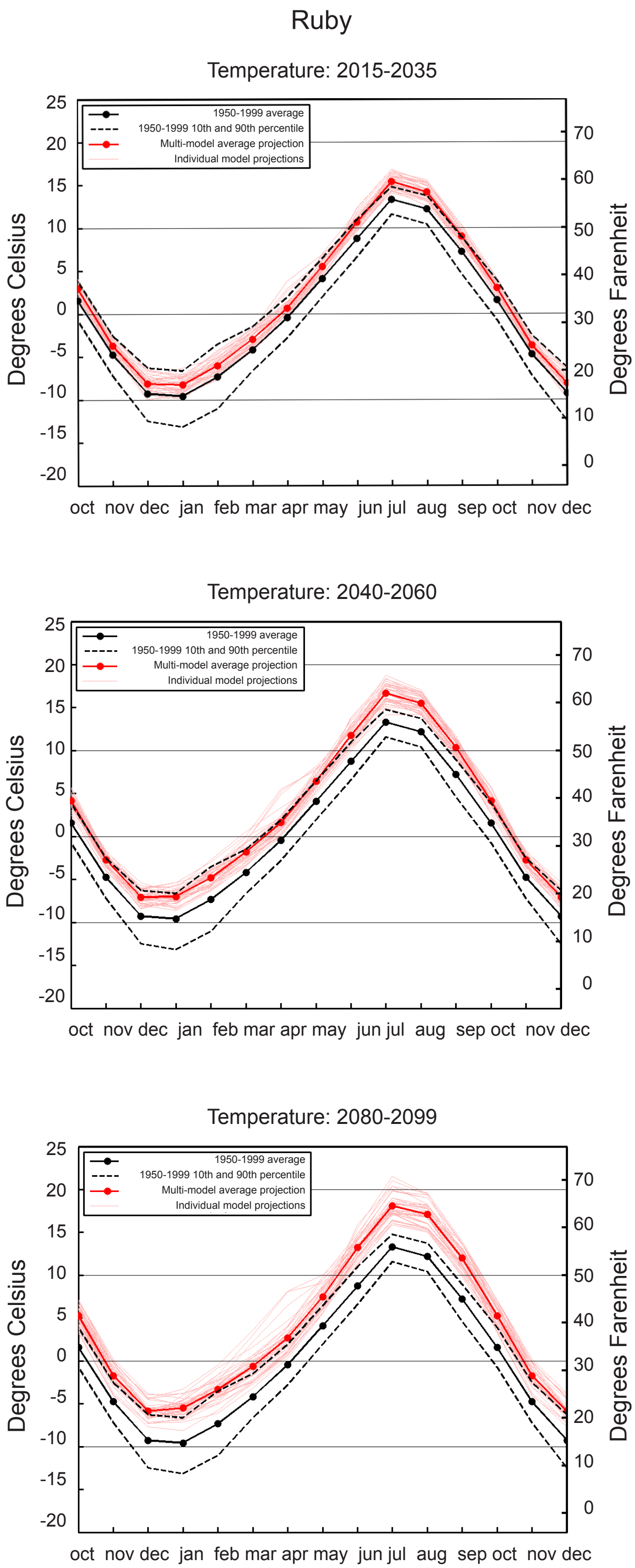


Figure 25(a-c). Bodie Summer (June-July-August) temperature projections. Climatology and 20-year temperature projections centered on 2025 (a), 2050 (b), and 2090(c). Climatology and projections are for a 4-km grid cell (approx 30 x 40 mile) around a site with observed pikas at Bodie State Park, CA. Each graphic shows observed monthly average temperatures compared with projections for each period. The observed monthly averages (solid black) and 10th and 90th percentiles values (dashed black lines) are based on observations over the period 1950–99. Projected monthly climatologies (thin red lines) are from the multi-model ensemble for the 20-year period centered on 2050. Average of the projections is shown as a heavy red line. Data are derived from Maurer et al. 2007). Note that the magnitude of projected temperature change is comparable to or greater than variations in the historical record.

over all these runs shown in the dark red curve. The monthly climatology for the periods 2015-2035, 2040-2060, and 2080-2099 (centered on 2025, 2050, and near 2090) from each model run for the A1B emissions scenario in the CMIP3 downscaled archive are shown in light red (39 model runs in all, with multiple runs of some models). Note that for a given emissions scenario (A1B here) there is still a range in the spread of the model projection. This spread is due both to details in the formulation of the models that differ among the individual models and to natural variability in climate that is simulated by the models.

To provide a reference for how unusual the projected temperatures (red lines) will seem compared to today, the 1950-1999 PRISM climatology of the monthly average temperature (solid black line), and the 10th and 90th percentiles of monthly average temperatures are also shown (dashed black lines). These percentiles represent the top-five-warmest and top-five-coolest months in the period 1950–99. The monthly average temperature is defined as the average of the minimum and maximum temperatures on each day, averaged over the month. The projected and climatological temperatures are displayed for a 15-month period that encompasses both the water year and the calendar year.

At all four sites (as well as the other 18 not shown here), the temperature increases are largest in summer. The July temperatures from almost all the model projections at the four sites lie at or above the 90th percentile of the present climate. Most of the projections suggest that typical summer temperatures will equal or exceed the extreme warm summers of the last half of the 20th Century (1950-1999 climatology). The projected temperature changes are somewhat smaller in winter and the year-to-year variations are larger. While the proportion of warm winter months are projected to increase, most years, even in 2050, will not be extreme (above the 90th percentile) compared to the present climatology. Winter warming will be manifest in the relative absence of months colder than the current average and in the cumulative effects of consecutive warm winters, with an increase in the number of extreme warm winter months. Precipitation projections are not shown, but a recent similar downscaling effort for Colorado found that, unlike temperature projections,



a

b

c

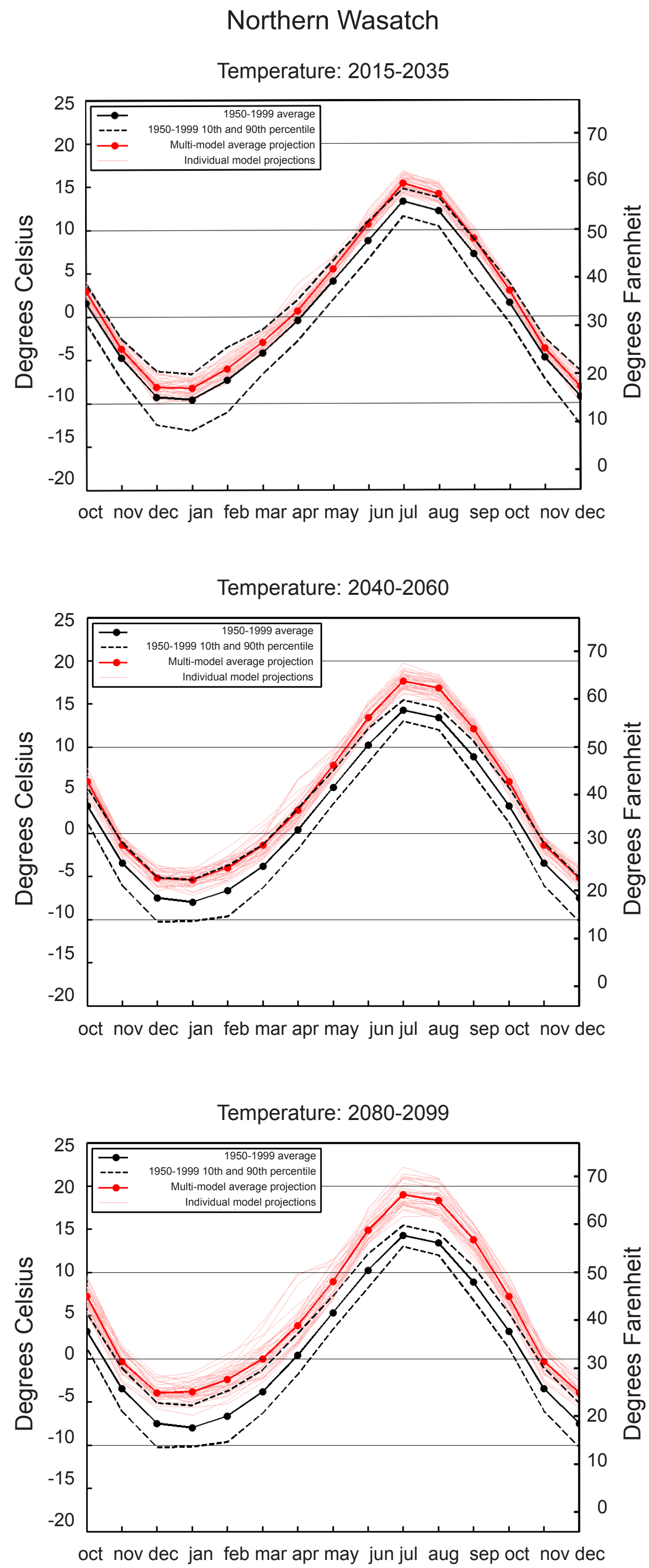


Figure 26(a-c). Ruby Mountains (June-July-August) temperature projections. Same as Figure 25, but for a site with observed pikas in the Ruby Mountains in northeastern Nevada.

Figure 27(a-c). **Northern Wasatch (June-July-August) temperature projections.** Same as Figure 25, but for a site with observed pikas in the Northern Wasatch Mountains in north central Utah.

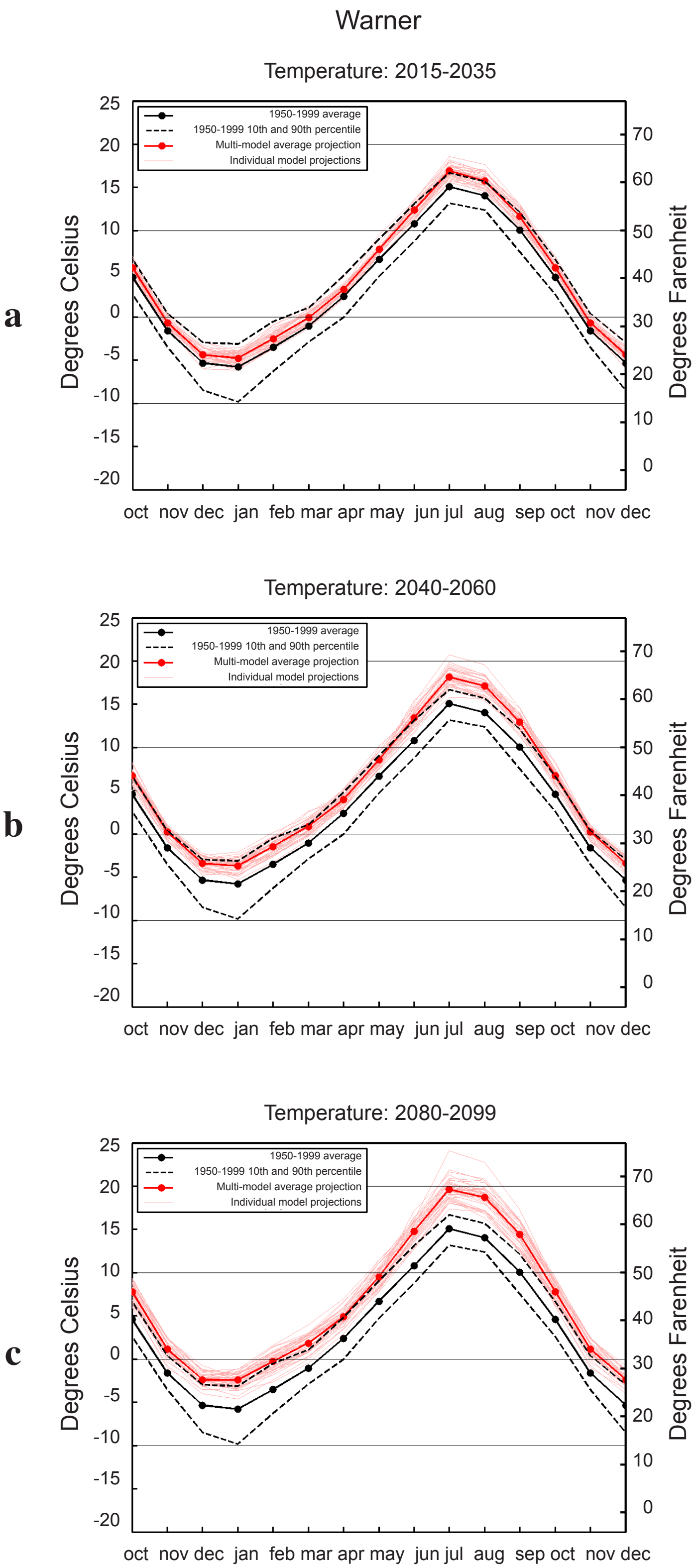


Figure 28(a-c). **Warner Range (June-July-August) temperature projections.** Same as Figure 25, but for a region in the Warner Range which span the border from southern Oregon to northeast California.

potential future changes in precipitation are smaller than the year-to-year and decade-to-decade variations observed in the historical record (Ray et al 2008).

Figures 29-32 show the time evolution of 20-year moving averages from the downscaled model projections at the 4 locations, illustrating the past and model-simulated multidecadal variability. Natural variability is a feature of current climate and will continue to be a feature in the climate of the Western U.S. over the next century. Because of this variability, some scientists prefer to report the averages of projections for 20-30 years. Even for this longer time average, the climate models – and observations – show considerable variability.

A second point illustrated by these time series is that the projections from any individual model must be interpreted with care. The spread about the average projection is a result of two factors: differences in model climate sensitivity (the response of a particular model to climate forcing) and model-simulated multi-decadal variability. Thus the uncertainty implied by the ranges of the light red lines in Figures 25-28 may be larger than the true uncertainty due to differences in climate sensitivity among the models studied. For this reason, some scientists prefer to emphasize the multi-model average projection. Because of the BCSD/PRISM downscaling method is based on the CMIP3 projections, the multi-model average projections shown in these figures are consistent with the large-scale patterns of warming shown in the GCM temperature change maps (see Figure 15). Figure 33 shows the multi-model average temperature projections for three emissions scenarios, B1, A1B, and A2.

Thus the overall pattern that emerges is for hotter summers and somewhat warmer winters. For the first two time periods investigated, around 2025 and around 2050, the multi-model average projections from all three emissions scenarios are nearly the same. Only in the latter half of the century (the 2080-2099 average, "c" in figures Figures 25-28) do the temperature changes from the different emissions scenarios diverge appreciably from one another. Figure 33 shows the multi-model average for each of the three emissions scenarios.

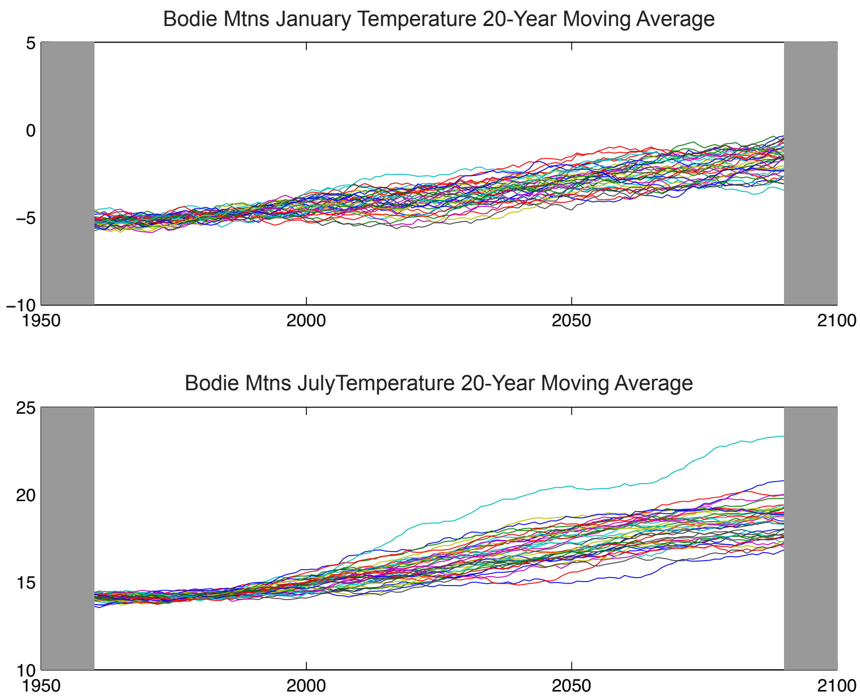


Figure 29. Timeseries for Bodie, CA, of Historic and Projected Temperature from Individual Models. Timeseries of winter (January, lower panel) and summer (June, upper panel) temperature projections from 16 different climate models illustrate a pronounced multi-decadal variability in many of the projections, for the same gridbox as used in Figure 25. Lines show 20-year moving average of temperature from statistically downscaled projections for the area around Bodie, CA. Each line is a separate model projection from 16 climate models (some models performed multiple climate projections). Because of the climate projection and downscaling methodology, the historical period simulates an envelope of climate variability that is consistent with observations rather than the exact time history of climate during that period. The gray areas on either end of the time periods indicate that the moving average contains fewer than 20-years of data. Note that the temperature scale is higher in the summer than in the winter.

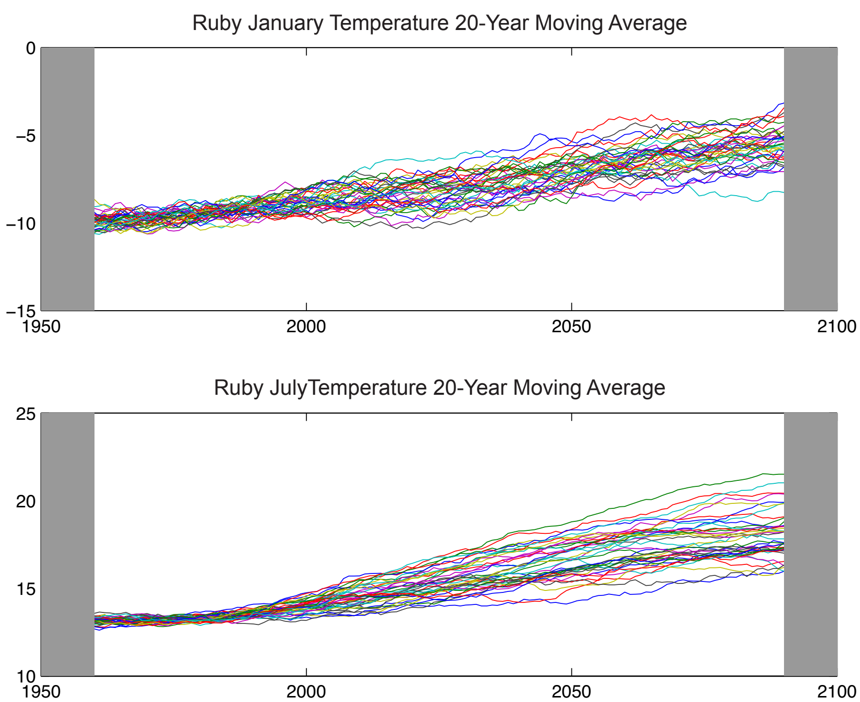


Figure 30. Timeseries for Ruby Mountains of Historic and Projected Temperature from Individual Models. Same as Figure 29, but for the Ruby Mountains in northeastern Nevada, the same gridbox as used in Figure 26

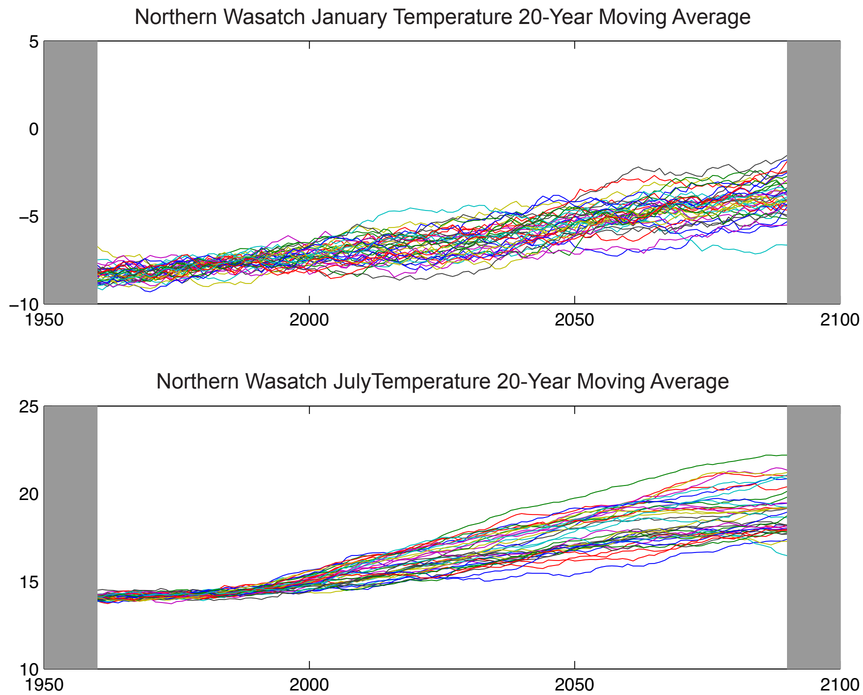


Figure 31. Timeseries for the Northern Wasatch of Historic and Projected Temperature from Individual Models. Same as Figure 29, but for the Northern Wasatch Mountains in northeastern Utah, the same gridbox as used in Figure 27

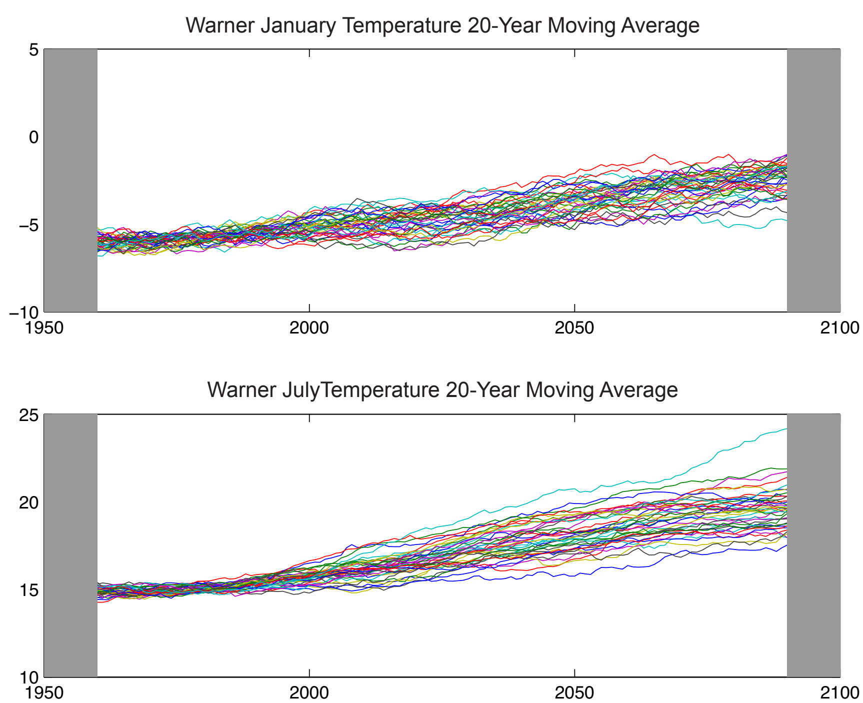


Figure 32. Timeseries of Historic and Projected Temperature from Individual Models for the Warner Range. Same as Figure 29, but for the Warner Mountains on the California-Oregon border, the same gridbox as used in Figure 28.

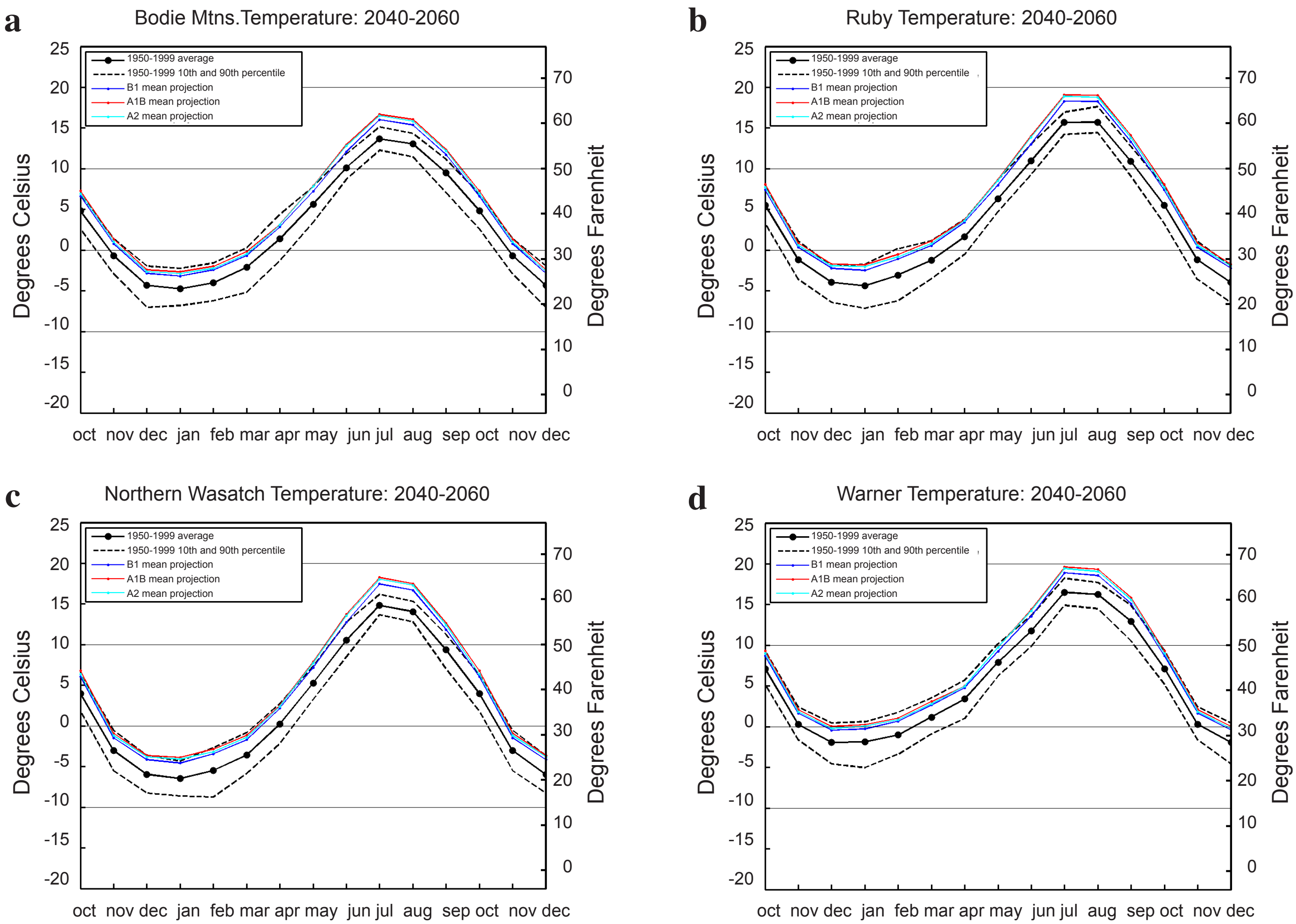


Figure 33(a-d). Multi-model average temperature projections for three emissions scenarios. a) Bodie, b) Ruby, c) Northern Wasatch, d) Warner, multi-model average of for each emissions scenario for 2040-2060, B1 ("low" emissions) in dark blue, A1B ("medium") in red, and A2 ("high") in light blue. The monthly average (solid black) and 10th and 90th percentiles values (dashed black lines) are based on observations over the period 1950–99. The red line is the same as the A1B multimodel average in Figures 25-28.

Mid-Century Average Projections and Extremes at 22 Locations

Temperature projections for 2050 from the A1B scenario for June-July-August (JJA) at all 22 locations are summarized in Table 2, and compared to average temperatures from PRISM climatology (1950 to 1999). The first column is the location name, organized by subspecies for 22 locations. The next four columns show the coordinates of the 4-km PRISM gridbox center, mean elevation of the gridbox in feet and meters, the elevation of the pika observation the grid box was "anchored" on.

The mean elevation in each PRISM gridcell is determined from a high-resolution Digital Elevation Model (DEM) by using a weighted average that emphasized values within that gridcell, and also includes non-zero weights for points in nearby gridcells (see http://www.prism.oregonstate.edu/docs/meta/dem_25m.htm and Barnes 1964.

The next three columns show the 1950-1999 climatology of the PRISM gridbox: the historical monthly means for June-July-August (JJA) summer temperature, and 10th and 90th percentile values of the historic distribution.

The projections for "2050" (the 2040-2060 average) follow, in three columns with the mean of the multi-model ensemble projection for JJA, and the JJA value the 10th and 90th percentiles of the model projections. Note that the distributions of observations and projections represent different quantities. The distribution of PRISM seasonal averages is shown in order to compare the magnitude of the average climate shift to the

Table 2. Mid-Century Average Projections and Extremes at 22 Locations *(See text for description)*

Location	Gridbox lat/lon	Mean Grid-box Elev (m)	Mean Gridbox Elev (ft)	Pika site elev (ft)	JJA PRISM 10th %-ile 1950-1999	JJA PRISM Mean 1950-1999	JJA PRISM 90th %-ile 1950-1999	Low Model (10th %-ile) A1B 2040-2060	JJA CMIP Projection Mean 2040-2060	High Model (90th %-ile) A1B 2040-2060	Range of low minus high models
Cascades Subspecies											
Crater Lakes	42.94, -122.13	2158	7121.4	**	8.97	10.63	12.28	12.25	13.17	13.95	1.7
Eastern OR	42.69, -118.56	2303	7599.9	6300	11.62	12.81	14.15	14.72	15.87	17.1	2.38
Mt Hood/ 3Sisters	44.19, -121.81	2443	8061.9		8.61	9.85	11.21	11.48	12.39	13.24	1.76
Mt St Helens	46.19, -122.19	1839	6068.7	*	10.53	12.34	14.14	13.92	14.71	15.6	1.68
North Cascades /Mt Baker	48.44, -121.06	1587	5237.1	**	8.5	10.04	11.51	11.67	12.52	13.77	2.1
Northern Rockies Subspecies											
Northern Wasatch	40.56, -111.56	2956	9754.8	9213	12.2	13.15	14.18	15.4	16.49	17.68	2.28
Clearwater Mtns	45.56, -114.81	2467	8141.1	*	10.24	11.14	12.18	13.03	14.14	15.5	2.47
Sawtooth Range	44.06, -114.94	2753	9084.9	6857	10.44	11.31	12.35	13.26	14.4	15.76	2.5
Glacier NP	48.69, -113.56	1866	6157.8	4574	10.16	10.99	12	12.69	13.74	15.13	2.44
GallatinNF	45.44, 110.94	2778	9167.4	9180	9.27	10.39	11.38	12.25	13.44	14.84	2.59
Wind River/ Bridger-Teton	43.19, -109.69	3683	12153.9	*	4.81	6.3	7.97	8.39	9.55	10.96	2.57
Bighorn	44.44, -107.19	3651	12048.3	*	6.25	7.19	8.04	8.99	10.17	11.44	2.45
Southern Rockies Subspecies											
Southern Rockies	40.06, -105.56	3267	10781.1	11844	10.88	12.06	13.07	13.94	15.15	16.45	2.51
Sangre de Christos	35.94, -105.56	3393	11196.9	**	9.18	9.8	10.73	11.73	12.69	13.67	1.94
Uinta Subspecies											
Eastern Uintas	40.81,-110.56	3611	11916.3	11622	6.51	7.47	8.8	9.72	10.83	12.09	2.37
SN/GB Subspecies											
Southern Wasatch	37.69, -112.81	3188	10520.4	10896	11.52	12.86	14.24	15.1	15.99	16.89	1.79
Toiyabe	38.94, -117.31	2755	9091.5	8650	11.3	12.39	13.52	14.36	15.5	16.49	2.13
Ruby	40.56, 115.44	2932	9675.6	9740	13.2	14.11	14.95	16.17	17.36	18.66	2.49
Monitor Hills	38.69, -119.56	2500	8250	8816	11.76	13.03	14.3	14.83	15.98	16.8	1.97
Bodie Mtns	38.19, 119.06	2679	8840.7	8530	11.15	12.29	13.34	14.11	15.22	16.02	1.91
Sierras/ Yosemite	37.81, -119.19	3112	10269.6	**	7.92	8.97	10.25	10.72	11.79	12.56	1.84
Warner	42.06, -120.19	2220	7326	7900	13.54	14.84	15.97	16.6	17.78	18.93	2.33

* Local summit chosen as representative
** Location chosen among multiple pika sites based on climate obs sites
For all others, the "pika obs" elevation is a specific obs provided by FWS

historical variability, i.e. to illustrate how the projected increase in the JJA average temperature (e.g., 2°C) relates to the extremes from the recent 50 years of PRISM data. The low and high model projections illustrate the uncertainty in the projection of 20-year average climates, even for a given emissions scenario. High-end projections are approximately 1°C warmer than the multi-model average, and would indicate increased risk at a number of sites, including at the maximum elevations in some study areas.

The 2050 JJA projection is consistently higher than the recent climatology by about 3°C – which is the westwide projected increase. The value of the low model projection (representing the 10th percentile of the distribution) is in most cases higher than the 90th percentile of the recent climatology, suggesting that the coolest summers of the mid-21st century will be warmer than the warmest summers of the recent past.

Are these projections statistically significantly different from the observed variability? That is, what is the chance that the changes projected by the climate models could have arisen due to natural variability? First, the observed temperature increases in the West have been attributed, at least in part, to human causes, meaning that they are not consistent with a purely natural cause (Bonfils et al, 2008). Projected changes are even larger. Second, the projected mean temperatures in 2050 (column 10) are as large or larger than the 90th percentile of the historical monthly variability (column 9), indicating a substantial shift in the mean that cannot be accounted by sampling variations. As a simple test of significance, we used block resampling from the observed record to produce a synthetic set of 20-year climatologies. Comparing this synthetic observed climatology (an estimate of the variance of the 20-year averages) to the model climatology indicates that the chance of producing the set of model projections is extremely low. So taken as a set of projections, they are highly significantly different from the historical climatology.

Temperature Projections Scaled to Observed Pika Elevations

The ensemble mean temperature projections at the elevation of the grid box, however, do not tell the whole story. Recall the relationship of elevation on temperature in mountainous terrain: temperature generally decreases with altitude in the atmosphere. Typical 4-km grid boxes include a range of elevations in mountainous areas. The boxes chosen are representative, but any single gridbox chosen may not represent the range of elevations occupied by pikas, which in some mountain ranges are observed over an elevation range of 2-3000ft or nearly 1000m. For example, pikas have been found in Toiyabe Range of southern Nevada from 7896-11023ft, and the Sangre de Christos, Glacier, Toiyabe, and Eastern Oregon also have documented large elevation ranges of observed pikas. The schematic of elevation, temperature and pika locations (see Figure 3) illustrates this issue. Recall that we had adjusted from the 12-km BCSD dataset to the PRISM 4-km grid to reduce the misrepresentation of temp at elevation b/c it's a smaller area. PRISM is an estimation technique – but more important, elevation is still an issue (esp 15.7-16.0, because 1 degree C is about 150m of elevation. Given typical summertime lapse rates are 5-7°C/1000m or X°/1000ft, a 3000ft elevation difference corresponds to 5-6°C between pika habitats. Table 3 shows the temperature projections scaled for the range of pika observations provided by the FWS.

To account for the observed elevation ranges in a given mountain range (e.g., Eastern Oregon) we used lapse rates to convert or scale the projected temperatures in a grid box to the range of temperatures. In situ lapse rates could be calculated from observed climate data where available (as described in Section 6), but these have not been calculated for most areas, and may be problematic due to the data available (as discussed above). The analysis of the observed lapse rates among a few stations (Section 6) shows values from 4.5°C to > 7.5°C/ km for summer conditions. Therefore, in Table 3 we use a typical and plausible summer value of 6.5°C/km, except in the Pacific Northwest where Lundquist (2004) noted a 5°C/km lapse rate. We calculated lapse rates based on the equation shown above in Section 3.

Table 3 shows the results of this calculation for all 22 areas, including the vertical range of pika distributions, the assumed lapse rate, the PRISM and projec-

Table 3. Temperature Projections Scaled to Observed Pika Elevations										
Location	Mean Gridbox Elev (ft)	JJA PRISM Mean 1950-1999	JJA CMIP Projection Mean 2040-2060	Pika Obs min. elev (ft)	Pika Obs max. elev (ft)	Lapse Rate (°C/km)	JJA PRISM Mean 1950-1999 scaled to min. elev	JJA PRISM Mean 1950-1999 scaled to max. elev	JJA CMIP Projections Mean 2040-2060 scaled to min. elev	JJA CMIP Projections mean 2040-2060 scaled to max. elev
Cascades Subspecies										
Crater Lakes	7121	10.6	13.2	6436	7660	6.5	12.0	9.6	14.5	12.1
Mt Hood/ 3Sisters	8062	9.9	12.4	6242	7621	6.5	13.5	10.7	16.0	13.3
Mt St Helens (excl. summit) #	3691	13.3	15.7	3000	4200	5	14.3	12.5	16.7	14.9
North Cascades /Mt Baker	5207	10.0	12.5	3800	7210	5	12.2	7.0	14.7	9.5
Northern Rockies Subspecies										
Northern Wasatch	9755	13.2	16.5	8472	10800	6.5	15.7	11.1	19.0	14.4
Clearwater Mtns	8141	11.1	14.1			6.5				
Sawtooth Range	9085	11.3	14.4	6857	8382	6.5	15.7	12.7	18.8	15.8
Glacier NP	6158	11.0	13.7	4574	8337	6.5	14.1	6.7	16.9	9.4
GallatinNF	9167	10.4	13.4	9180	9180	6.5	10.4	10.4	13.4	13.4
Wind River/ Bridger-Teton	12154	6.3	9.6	N/A	N/A	6.5				
Bighorn	12048	7.2	10.2	N/A	N/A	6.5				
Ruby	9676	14.1	17.4	8664	10413	6.5	16.1	12.6	19.4	15.9
Southern Rockies Subspecies										
Southern Rockies	10781	12.1	15.2	9005	1487	6.5	10.0	10.0	13.0	13.0
Sangre de Christos	11197	9.8	12.7	7562	12263	6.5	17.0	7.7	19.9	10.6
Uinta Subspecies						6.5				
Eastern Uintas	11916	7.5	10.8	9810	12076	6.5	11.6	7.2	15.0	10.5
SN/GB Subspecies										
Southern Wasatch	10520	12.9	16.0	8472	10800	6.5	16.9	12.3	20.0	15.4
Toiyabe	9092	12.4	15.5	7896	11023	6.5	14.8	8.6	17.9	11.7
Monitor Hills	8250	13.0	16.0	8105	8822	6.5	13.3	11.9	16.3	14.8
Bodie Mtns	8841	12.3	15.2	8530	8635	6.5	12.9	12.7	15.8	15.6
Sierras/ Yosemite	10270	9.0	11.8	9657	11160	6.5	10.2	7.2	13.0	10.0
Warner	7326	14.8	17.8	5429	8267	6.5	18.6	13.0	21.5	15.9
Eastern OR	7600	12.8	15.9	5800	7925	6.5	16.4	12.2	19.4	15.2

* Local summit chosen as representative

** Location chosen among multiple pika sites based on climate obs sites for all others, the “pika obs” elevation is a specific obs we were given

Average of estimates from 14 gridcells surrounding the mountain (excl., Summit cells)

N/A: No pika obs elev reported in WY or the Clearwater Range (ID) tion means, and the PRISM and projection means scaled for the minimum and maximum reported elevations of pikas. The first column is the location name, organized as in Table 2 by subspecies for the 22 locations. The next three columns show information repeated from Table 2: the mean gridbox elevation, the JJA PRISM mean and CMIP projection mean. The next two columns are the minimum and maximum elevation of pikas reported to us by FWS. Based on the assumed lapse rate in the 7th column, we scaled the PRISM climatology and the CMIP projections to the minimum and maximum elevations, shown in the 4 columns to the right.

The elevation-adjusted temperatures may range several degrees C above and below the average gridbox elevation, depending on the observed elevation range of the pikas. For example, the elevation range in the Sangre de Christo Range is 7562-12263 feet; the projected temperatures at the minimum elevation (7562) is ~7°C higher than the average elevation of the gridbox, and projected temperatures at the highest pika observations are ~2°C lower than the projection.

Some of the gridcells chosen for analysis were higher on average -- and hence colder -- than most pika locations in a particular mountain range, which is simply an artifact how well a particular gridcell represented the pika observation location. We had no specific locations of pika at Mt St Helens, so as a compromise, the PRISM mean and projections are an average of estimates from 14 gridcells surrounding the mountain, excl excluding the summit grid cells which were thought to be too high.

Summer average temperatures at PRISM gridboxes where pikas currently live range from about 9°C (48°F) for a gridbox in the Sierras to around 14°C (57°F) at Warner and Ruby Mountain sites (1950-1999 climatology). Within a given area, scaling temperature for lapse rate and the observed vertical range of pikas suggests that they experience temperatures of +/-2.5°C (4.5°F) around this value. Local topography and microclimate may also influence the temperature in ways not represented in this dataset.

9 Discussion and Key Findings

This report is a rapid-response assessment of climate observations and projections of change. Focusing on the mountainous regions of the western U.S., it provides a climatological context for the status review of the American pika. We synthesize findings from peer-reviewed regional studies, interpret downscaled climate projections, and present new graphics and data summaries derived from existing datasets. Knowledge about climate variability and change is rapidly evolving, so this report is a snapshot of the best available science as of mid-2009. The report provides a climatological context for the status review. Some of the results have not been published elsewhere, and further analysis is recommended. However, in the expert judgment of the authors, the major conclusions of this report are expected to be robust because of the large spatial scale of the observed and projected warming.

A limitation of the observing networks for studying pikas is that there are few long-term meteorological observations at the locations where pika have been studied, and there are few observations above about 2500m (8200ft) where many populations live. For an analysis of many sites, the statistical downscaling and the representation of climate through the PRISM gridded observational dataset provides the best estimates at the scales relevant to the pika. Lapse rates, the relationship between temperature and elevation, can be used to scale temperature across the vertical distribution of pikas.

GCMs are at large scales, commonly 200-km grids. For projections at smaller scales, statistical downscaling using spatially interpreted datasets such as PRISM, provides the best source to infer the climate of the future at scales appropriate for pika habitat. Climate modeling cannot yet account for details of the dynamics at smaller scales, until smaller scale dynamical modeling is available, such as that from regional climate models.

Another limitation is that the critical environmental variables connecting pikas and climate are not well documented. Some of the variables that are postulated to be critical for pikas are average summer (JJA) temperature, winter minimum temperature, and number of days below certain thresholds in winter or above certain thresholds in summer. Springtime cold air outbreaks may also pose a risk after the insulating snowcover has melted out. The ambient temperature in the talus is postulated to be important – both winter and summer. But currently, there are only a few sites with observations within-talus. Relationships between above- and within-talus air temperatures are not well established, and have not been published as of late 2009. Temperature thresholds may exist, but are they the same across the range – including populations living at very different ambient temperatures, or are there different thresholds for different subspecies? The ambient temperature in the talus is postulated to be important. However, there are only a few sites within talus measurements and thus relationships between above talus and ambient air have only been calculated in a few places, and these are not yet unpublished.

Precipitation is also postulated to impact pikas, by affecting the vegetation that is their food, but unclear what the implications of precipitation for vegetation. Even if we had more detailed observations or projections of precipitation, the connection between precipitation and pika habitat or pika health is not well known – for example, would more or less precipitation or earlier springs affect the vegetation negatively and thus pika health? Or would a longer growing season benefit pikas? What specific precipitation-related variables (e.g. snow depth, melt out, summer ppt) would be useful to understand pika habitat and pika health?

However, comprehensive studies documenting the connection between pikas and climate are not available, so the climate analysis is handicapped. Better understanding of the specific aspects of temperature affecting pikas would facilitate tailoring the climate assessment to the issue, and would point to specific areas for analysis and diagnostics.

We have reported results of a survey of 22 pika sites based on available data and based on large-scale projections. An important factor that we could not account for is the microclimates in mountain habitat; microclimates such as deeper talus, ice rock, aspect (e.g. north facing), or cool air drainage cannot be assessed at this scale. While the PRISM dataset is the best source to infer climate in a survey of sites as we have done, detailed field studies would be necessary to understand microclimates.

Another uncertainty is how well the vertical ranges of temperature are represented by the lapse rate interpolation, or scaling. The 90-day finding (FWS, 2009) cites that IPCC expects the snowline in mountainous regions to rise 150 m (484ft) for every 1°C increase in temperature (Christensen 2007). Their estimate is similar to the lapse rates we estimated from a few stations and those used in Table 3. Local calculations of lapse rates for calculations like those in Table 3 could be used to both understand recent shifts in temperature zones as well as to better project future shifts across habitat elevations. In Section 6, we calculated lapse rates from climate observing stations near or in pika locations, and these rates range from somewhat below typical values to higher values especially in the summer. For areas where data is available to calculate lapse rates, this information may provide insight into the temperatures experienced at pika sites, and an estimate of how future changes in temperature might translate into vertical shifts in climate zones (See Section 6).

More detailed analyses of climate are possible, given time and resources. However, to design those analyses, and to coax out more information from existing observations and projections, we need a better understanding – or at least clearer hypotheses – of what are the critical environmental variables are connecting pikas and climate. Thus, this report provides a context for the status review and is a first step in providing synthesized climate information to understand the implications of climate change for the American pika.

Key Findings

Observations

- There are few long-term meteorological observations at pika locations, especially in higher elevation habitat. Climate averages and trends may be inferred from nearby observations, from large-scale climate patterns, and by adjusting for elevation. In the absence of detailed site-specific studies, gridded observational datasets are the best source to infer the climate where pikas live.
- The U.S. West has warmed about 1°C (2°F) during the past 30 years. One study has attributed at least part of the observed pattern of warming in mountainous regions of the West to the effects of anthropogenic greenhouse gases and aerosols. Natural variability is and will continue to be a factor in the climate of the western U.S. during the next century.
- The magnitudes of observed temperature trends vary by observing station or pika location, season, and time period analyzed. Climate stations near pika locations in the Sierra Nevada and western Great Basin and in Oregon show 1°-2.4°C warming (1.7°-4.3°F) in the summer during the past 30 years, a statistically significant finding.
- Spring has warmed more than other seasons at many locations in the U.S. West. The onset of spring has come earlier, by 2-3 weeks, and snow cover, postulated to provide insulation to pikas during spring cold air outbreaks, is melting out earlier. These temperature-dependenthydrological changes have been observed at many mountainous locations, and one set of analyses has attributed about half of the magnitude of the trends in temperature-associated hydrologic variables to anthropogenic changes in greenhouse gases, ozone, and aerosols.

Projections

- Global climate models project warming over all land areas of the globe, including North America, though 2100. These models project larger summertime warming over the western U.S. than elsewhere North America, +5°F (3-7°F) and winters by about +3°F (2-5°F).
- For the mid-21st century, the overall magnitude of projected temperature increases is quanti-

tatively similar for the greenhouse gas (GHG) emissions scenarios investigated by the Intergovernmental Panel on Climate Change (B1, A1B, and A2 scenarios). In the latter half of the 21st century, considerable spread will have developed among these emissions scenarios, so the range of temperature projections depends on human and societal factors in intervening years including policy decisions regarding GHG emissions.

- High-resolution regional climate models (RCMs) also show a broad pattern of projected warming across the West Through the 21st century. Both GCMs and RCMS indicate a tendency for less warming (2°C) in parts of the Pacific Northwest compared to other regions in the West.
- Statistical downscaling is used to downscale GCMs to 4-km scale appropriate for pika habitat. We report projections West-wide and for 22 specific pika locations for 20-year periods averaged around 2025, 2050 (mid-century), and 2100, driven by three IPCC emissions scenarios. Maps of the projected changes in temperature illustrate the increase as a shift of temperature zones northward and upward in elevation. The shift of temperature zones continues through the end of the 21st century.
- The average of summertime (June-July-August) projections around 2050 is consistently higher than the recent past by about 3°C (5.4°F). In comparison, the average summer months of the mid- 21st century will be warmer than the warmest (90th percentile)summer months of the recent past.
- Individual global climate models exhibit a range of projected warming for the study region for the mid 21st century. The low-end model projections are about 1°C cooler and high-end projections are about 1°C warmer than the multi-model average projections. Other sources of uncertainty not considered here may act to broaden this range of projections beyond that shown by the climate models.

Implications for Pikas

- Summer average temperatures at where pikas currently live range from about 9°C (48°F) in the Sierras to around 14°C (57°F) at Warner and Ruby Mountain sites (1950-1999 climatology, gridded observational data). Scaling temperature for the relationship of temperature and elevation (lapse rate) suggests that they experience temperatures of about +/-3°C (5.4°F) around this value for an area with a 1000m vertical range. Local topography and microclimate may also influence the temperature in ways not represented in this dataset.
- We suggest 2050 as a “foreseeable future” for climate for the pika because the overall magnitude of projected temperature increases are quantitatively similar through the mid-21st century for the GHG emissions scenarios investigated (B1, A1B, and A2). IPCC projections indicate continued global and regional warming into the second half of this century, and that if emissions follow the higher scenarios, warming in 2090 could be double that in 2050.
- The 2050 summer (JJA) temperature projections average about 3°C (5.4°F) higher than the recent climatology for most of the western U.S., and for the 22 specific locations analyzed as representative of pika habitats.
- The limited number of observing sites and the inherent variability of precipitation make it difficult to make inferences or projections about precipitation amounts at pika sites. However, due to the impacts of temperature, projections show a precipitous decline in lower-elevation snowpack (below 8200 ft/2500 m) by the mid-21st century, with more modest declines at elevations above 8200 ft where some pika populations live.

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