Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California

A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy (VAAS) process

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GEOS INSTITUTE

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Note: This document is intended to be a supplement to Morelli et al. 2011. A Climate Change Primer for Land Managers: An Example From the Sierra Nevada. USDA FS Pacific Southwest Research Station Research Paper PSW-RP-262.

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INTRODUCTION

The Sierra Nevada mountain range runs generally north-south for 400 miles, from Fredonyer Pass in the north to Tehachapi Pass in the south. The Sierra Nevada increases in elevation from north to south, with Mount Whitney (14,505 ft.), the highest peak within the contiguous U.S. near the southern end.

The ecology of the Sierra Nevada is diverse and complex. Ecological zones range from scrub and chaparral at lower elevations to subalpine forest and alpine meadows at higher elevations. Because the eastern Sierra lies in a rain shadow, climate and species composition vary substantially from one side of the crest to the other.

More than half the land area of the Sierra Nevada is in federal ownership. USFS and BLM own 52% while 15% of the Sierra is protected as parks or wilderness areas.

Broad scale changes in climate are already impacting local conditions across the West and are likely to continue and accelerate in the coming decades. Changes include the timing and availability of water, changes in tree and wildlife species, and changes in wildfire frequency and intensity. Local communities will need to plan for such changes in order to continue to provide vital services to local residents and to support the economy.

Climate change presents us with a serious challenge as we plan for the future. Our current planning strategies at all scales (local, regional, and national) rely on historical data to anticipate future conditions. **Yet due to climate change and its associated impacts, the future is no longer expected to resemble the past.**

This report provides community members and decision-makers throughout the Sierra Nevada with local climate change projections that can help them make educated planning decisions. We also provide supplementary information from the scientific literature. This report is intended to precede a vulnerability assessment and development of adaptation strategies for stakeholders in the Sierra Nevada.

Many of the impacts of climate change are inevitable due to current levels of greenhouse gas emissions already in the atmosphere. Preparing for these impacts to reduce their severity is called "adaptation" (see box). Preventing even more severe impacts by reducing future emissions is called "mitigation." Both are needed.

MITIGATION – Reducing the amount of greenhouse gases in the atmosphere in order to prevent rapid and irreversible climate change. Irreversible climate change occurs when positive feedbacks kick in to such an extent that emissions reductions are no longer effective.

ADAPTATION – Planning for expected and inevitable impacts of climate change and reducing our vulnerability to those impacts.

MODELS AND THEIR LIMITATIONS

To determine what conditions we might expect in the future, climatologists created models based on physical, chemical, and biological processes that form the earth's climate system. These models vary in their level of detail and assumptions, making output and future scenarios variable. Differences among models stem from differences in assumptions regarding what variables (and how many) are important to include in models to best represent conditions we care about. Differences also stem from different assumptions about greenhouse gas emissions. Because of the variation across models and assumptions, it is useful to look across numerous models to assess the full range of potential future conditions.

The Intergovernmental Panel on Climate Change (IPCC) uses numerous models to make global climate projections. The models are developed by different institutions and countries and have slightly different inputs or assumptions. Specific inputs to these models include such variables as greenhouse gas emissions, air and ocean currents, ice and snow cover, plant growth, particulate matter, and many others.[1]

Most climate models project the future climate at global scales. Managers and decision makers, however, need information about how climate change will impact the local area. Global climate models can be adjusted to local scales using a variety

HIGH CERTAINTY:

Higher temperatures – Greater concentrations of greenhouse gases trap more heat. Measured warming tracks model projections.

Lower snowpack – Higher temperatures cause a shift from snow to rain at lower elevations and cause earlier snow melt at higher elevations.

Shifting distributions of plants & animals – Many species are limited in extent or number by climatic conditions that are expected to change.

MEDIUM CERTAINTY:

More severe storms – Changes to storm patterns will be regionally variable.

Changes in precipitation – Current models show wide disagreement on precipitation patterns, but the model projections converge in some locations.

Wildfire patterns – The relationship among fire, temperature, and available moisture has been well documented, but other components also play a role (such as vegetation, below).

LOW CERTAINTY:

Changes in vegetation – Vegetation may take decades or centuries to keep pace with changes in climate.

of different methods for "downscaling." Downscaling involves using locally specific data on historical temperature and precipitation variation over a landscape. The historical relationships between topography and climate variables are assumed to remain intact even as climate changes (a rainshadow, for example, is assumed to remain a rainshadow, even as overall levels of precipitation change over time).

The utility of the model results presented in this report is to help resource managers and other decision makers picture what the conditions and landscape might look like in the future and the magnitude and direction of change. Some model outputs have greater certainty than others (see box on previous page). Information is provided here to explore the types of potential changes, but actual conditions may be quite different, especially if greenhouse gas emissions change substantially.

Uncertainty associated with projections of future conditions, however, should not be used as a reason for delaying action on climate change. The likelihood that future conditions will resemble historic conditions is very low, so **managers and policy makers are encouraged to begin to plan for an era of change, even if the precise trajectory or rate of such change is uncertain.**

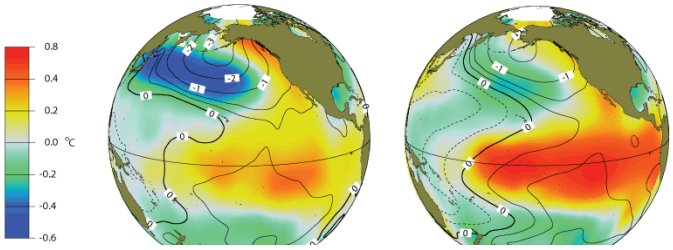
REGIONAL CLIMATE PATTERNS

The climate of the Western U.S. is heavily influenced by the Pacific Decadal Oscillation (PDO). The PDO cycles between a warm phase and a cool phase (Figure 1). Over the last century or more, these cycles have lasted about 20-30 years[2] (Figure 2). Data collected since 1998 (not shown) indicate some potential movement back towards a cool phase of the PDO.[3]

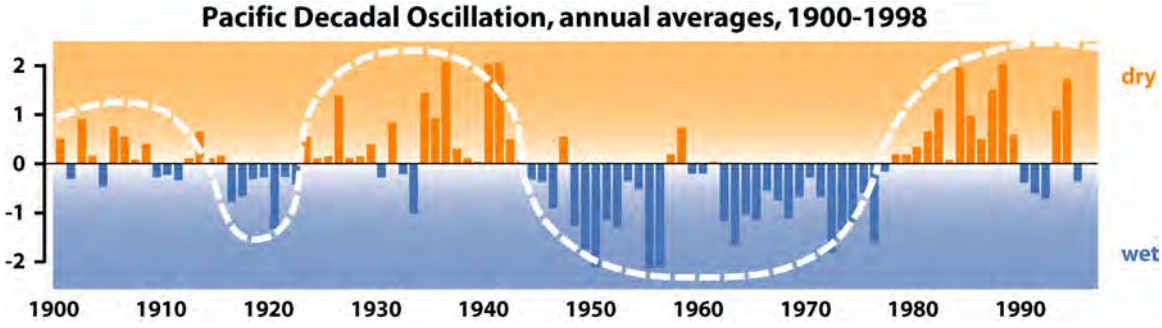
During the warm phase, the surface of the ocean along the coast of North America is unusually warm and low pressure is enhanced over the central North Pacific. This results in warmer than average air temperatures across western North America, especially west of the Rocky Mountains. Some of the characteristics of the warm phase of the PDO are hot dry summers, warmer than average winters, and reduced snowpack. The warm phase of the PDO has been linked to increased wildfire and bark beetle outbreaks. [3]

Embedded within the decades long cycles of the PDO are the one- to two-year cycles known as El Niño-Southern Oscillation (ENSO). When the warm and dry cycle of the PDO coincides with the dry years brought by ENSO, extreme drought and wildfire can occur.

Unfortunately, the precise cause and duration of PDO cycles are not well understood. The PDO was recognized as recently as 1996, and the drivers of the system are still being investigated. While our understanding increases every year, predicting future patterns and, more specifically, the influence of climate change on the PDO are not possible at this time.



Source: Climate Impacts Group, University of Washington



Source: Big Sky Institute, Montana State University

Figures 1 (top) and 2 (bottom). Warm phase PDO (top left) and warm phase ENSO (top right) sea surface temperature anomalies. Lower graph shows a century of Pacific Decadal Oscillation, based on the PDO index.

CLIMATE PROJECTIONS FOR THE SIERRA NEVADA

Climate change projections are provided here in two different formats – as regional and seasonal averages and as maps that show variation across the region and over future time periods. We mapped climate, vegetation, hydrology, and wildfire variables for historical period (1961-1990 for all variables except hydrology variables, where the historical period was 1971-2000) and for three future periods (these varied among the different variables projected). Due to the different sources of data, the historic and future time periods are not always the same among the different variables displayed.

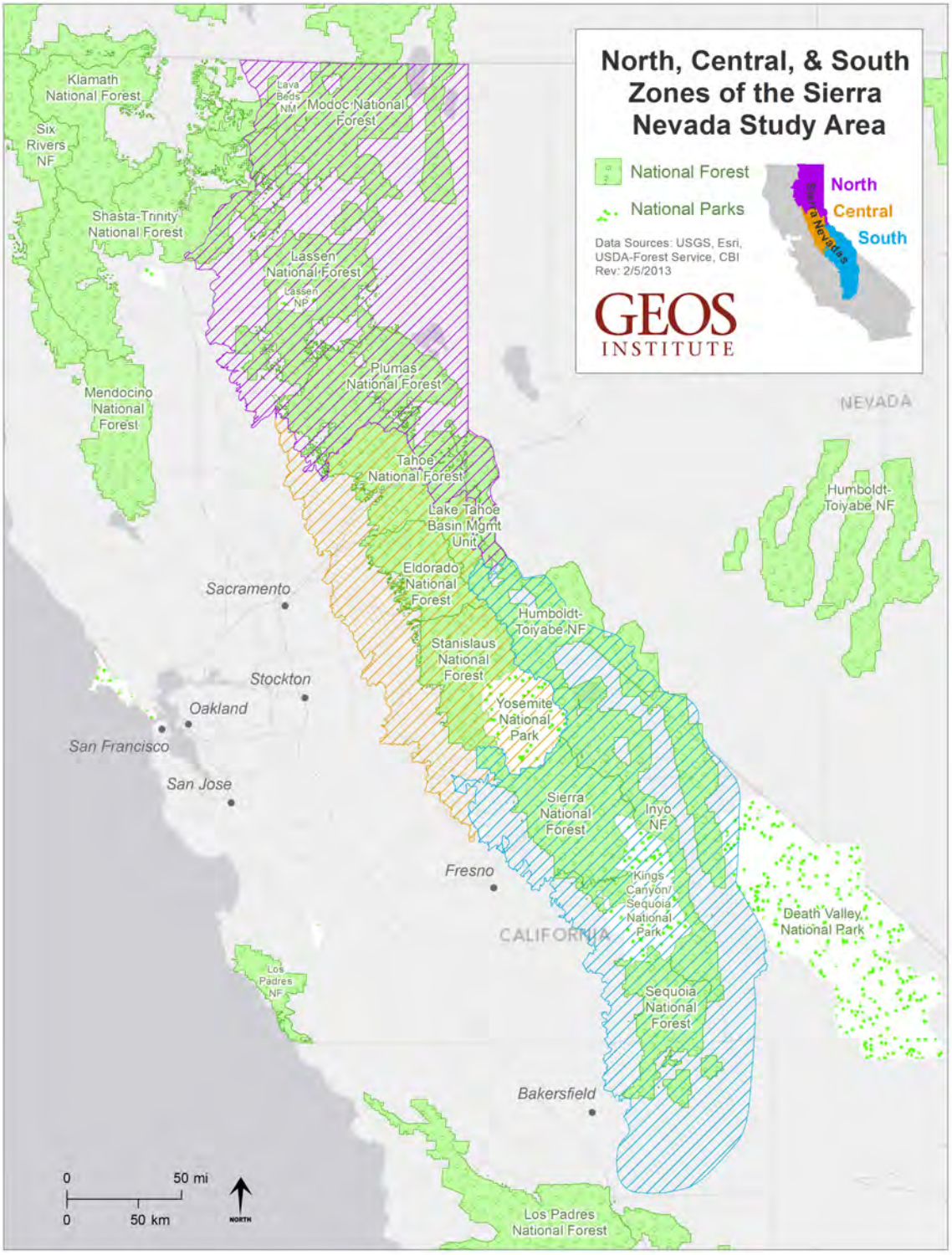
The IPCC emission scenario used in this assessment was the "business-as-usual" trajectory (A2) that assumes that most nations fail to act to lower emissions.[4] If the U.S. and other key nations drastically and immediately cut emissions, some of the more severe impacts, like irreversible climate change, may still be avoided.

Due to climate system inertia, restabilization of atmospheric gases will take many decades even with drastic emissions reductions. Reducing emissions is vital to prevent the Earth's climate system from reaching certain tipping points that will lead to sudden and irrevocable changes.

Throughout this report we present mid- and late-century model outputs. **We have more certainty in mid-century projections, due to greenhouse gases already released, but late-century projections may change, depending on future emission levels.**

Historic trends were based on PRISM data.[5] All projections were developed using the same two global coupled ocean-atmospheric climate models – GFDL (Geosphysical Fluid Dynamics Laboratory)[6], and Parallel Climate Model (PCM; National Center for Atmospheric Research, USA)[7] based on the A2 emissions scenario.

Figure 3. National forests and parks in the Sierra Nevada.



TEMPERATURE

On average, summer temperatures are expected to rise more than winter temperatures (Table 1). Due to emissions already released, mid-century (2035-45) projections are highly likely to be realized while late-century (2060-79) projections are less certain due to potential changes in emissions or positive feedbacks that could accelerate change.

Table 1. Projected average temperature and temperature change across the three regions of the Sierra (North, Central, and South), based on output from two different global climate models (GFDL and PCM).

	Historic	2010-29	2030-49	2060-79
Annual				
North	8.5° C	+1.1° to +1.4° C	+1.5° to 1.7° C	+2.7° to +3.1° C
	47.4° F	+2.0° to +2.5° F	+2.7° to +3.1° F	+4.8° to +5.5° F
Central	10.7° C	+1.2° to +1.3° C	+1.5° to +1.8° C	+2.8° to +3.1° C
	51.3° F	+2.2° to +2.4° F	+2.7° to +3.2° F	+5.0° to +5.5° F
South	9.1° C	+1.3° to +1.4° C	+1.7° to +1.9° C	+2.9° to +3.4° C
	48.4° F	+2.3° to +2.6° F	+3.0° to +3.4° F	+5.1° to +6.1° F
SUMMER				
North	17.3° C	+0.9° to +1.5° C	+1.6° to +2.2° C	+2.5° to +3.9° C
	63.2° F	+1.6° to +2.8° F	+2.9° to +4.0° F	+4.5° to +7.0° F
Central	18.9° C	+0.8° to +1.4° C	+1.6° to +2.1° C	+2.4° to +3.6° C
	66.1° F	+1.4° to +2.5° F	+2.8° to +3.8° F	+4.4° to +6.4° F
South	18.0° C	+0.8° to +1.5° C	+1.6° to +2.4° C	+2.4° to +4.0° C
	64.3° F	+1.4° to +2.7° F	+2.8° to +4.3° F	+4.2° to +7.1° F
WINTER				
North	0.6° C	+0.8° to +1.2° C	+0.9° to +1.5° C	+2.2° to +2.9° C
	33.2° F	+1.4° to +2.1° F	+1.7° to +2.8° F	+4.0° to +5.2° F
Central	3.5° C	+1.0° C	+0.8° to +1.6° C	+2.3° to +2.6° C
	38.4° F	+1.7° to +1.8° F	+1.5° to 2.9° F	+4.2° to 4.3° F
South	1.4 °C	+1.1° C	+1.0° to +1.9° C	+2.7° C
	34.6° F	+1.9° to +2.1° F	+1.8° to +3.4° F	+4.8° F

Annual Average Temperature

Northern Region
Sierra Nevada

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Temperature in degrees C

-4 - -2	12.1 - 14
-1.9 - 0	14.1 - 16
0.1 - 2	16.1 - 18
2.1 - 4	18.1 - 20
4.1 - 6	20.1 - 22
6.1 - 8	22.1 - 24
8.1 - 10	24.1 - 26
10.1 - 12	26.1 - 28

0 100 mi
0 100 km

NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

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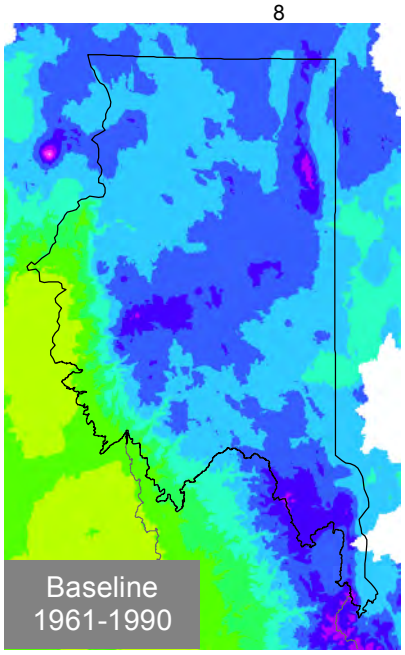

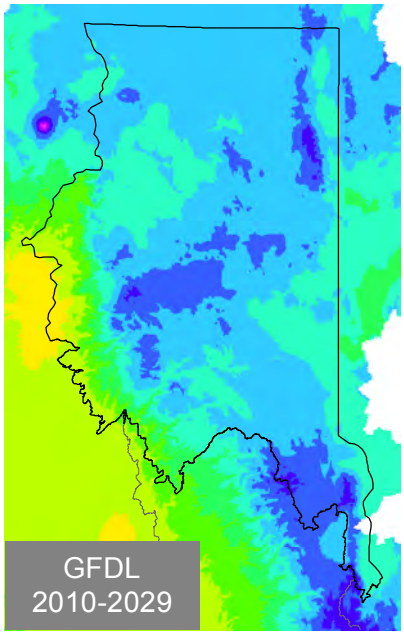

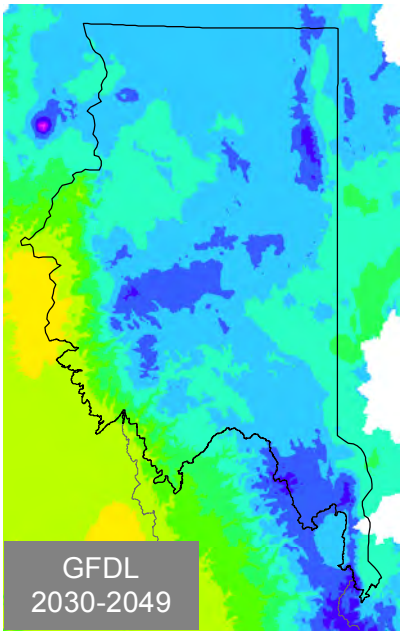

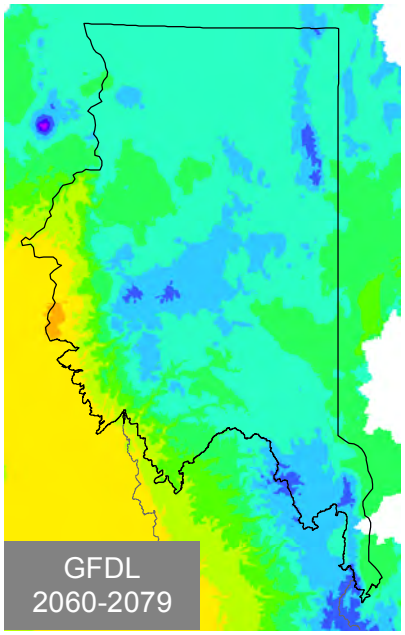

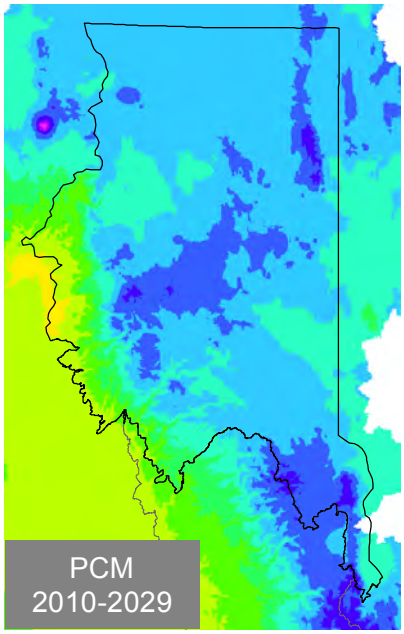

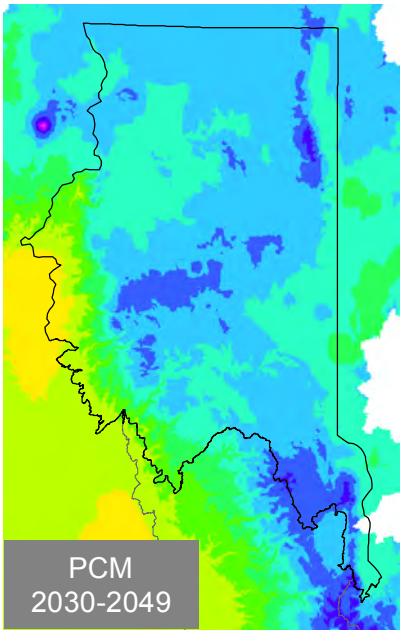

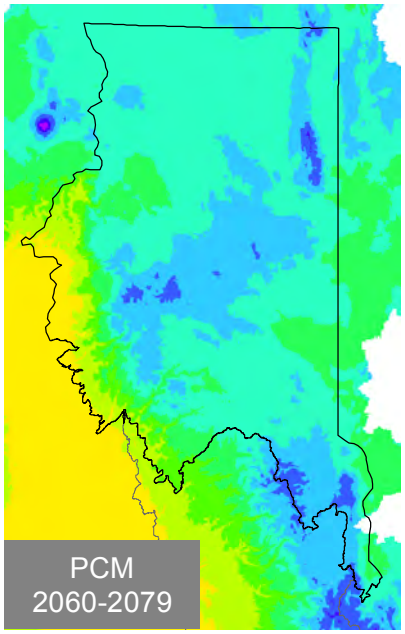

Annual Average Temperature

Central Region
Sierra Nevada

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Temperature in degrees C

-4 - -2	12.1 - 14
-1.9 - 0	14.1 - 16
0.1 - 2	16.1 - 18
2.1 - 4	18.1 - 20
4.1 - 6	20.1 - 22
6.1 - 8	22.1 - 24
8.1 - 10	24.1 - 26
10.1 - 12	26.1 - 28

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
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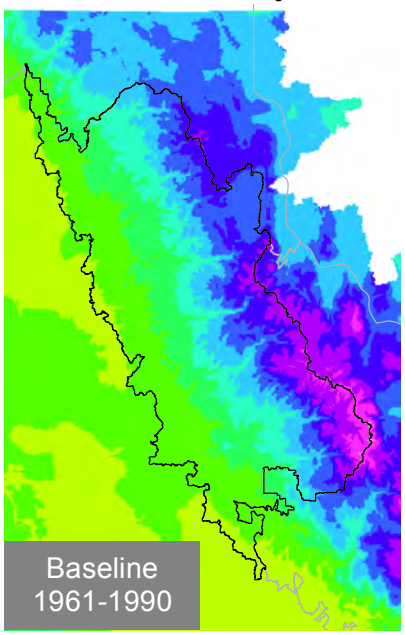

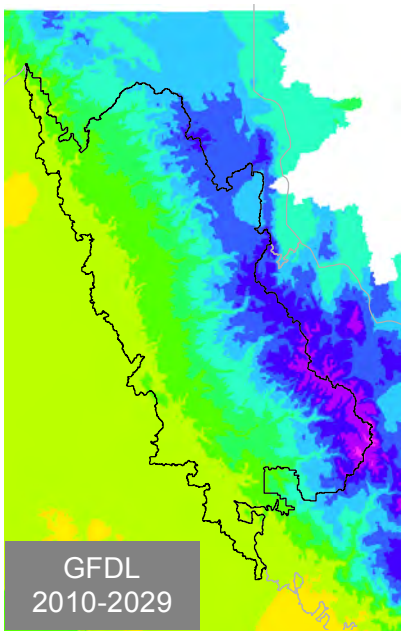

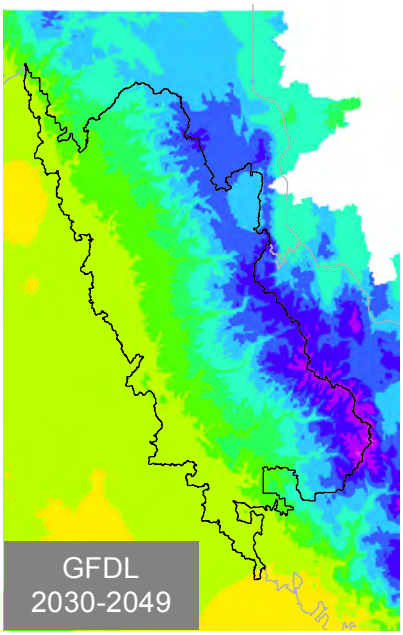

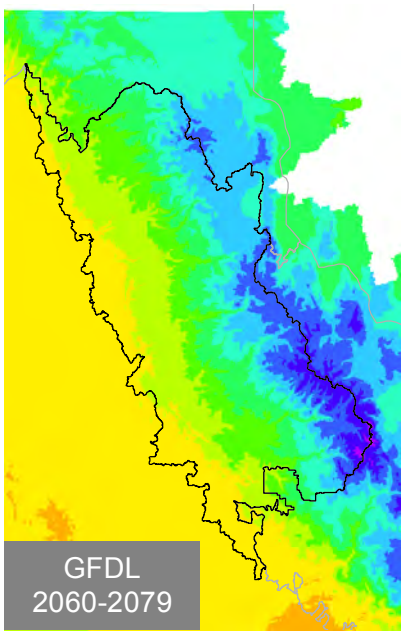

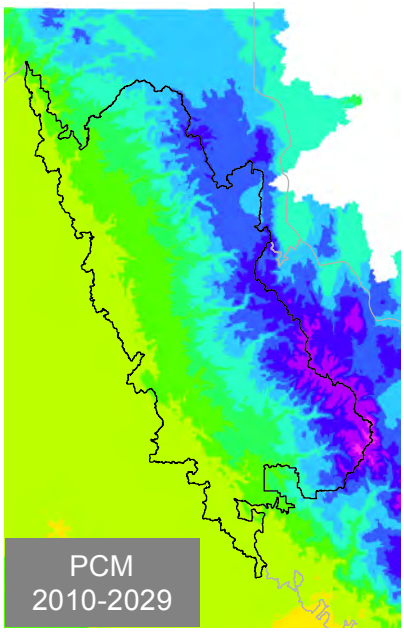

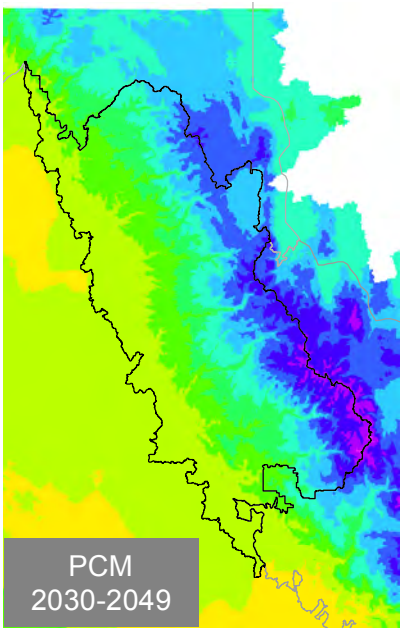

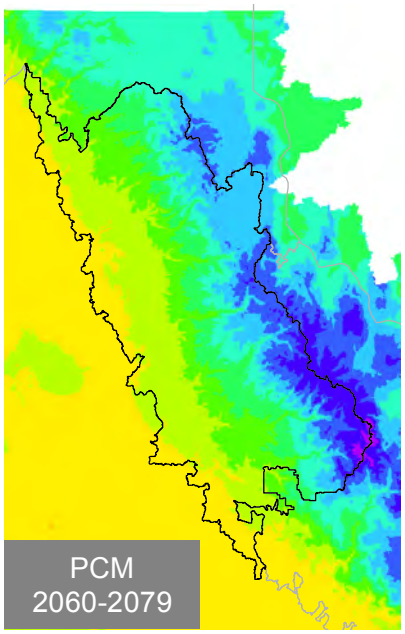

Annual Average Temperature

Southern Region
Sierra Nevada

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Temperature in degrees C

-4 - -2	12.1 - 14
-1.9 - 0	14.1 - 16
0.1 - 2	16.1 - 18
2.1 - 4	18.1 - 20
4.1 - 6	20.1 - 22
6.1 - 8	22.1 - 24
8.1 - 10	24.1 - 26
10.1 - 12	26.1 - 28

0 100 mi
0 100 km

NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
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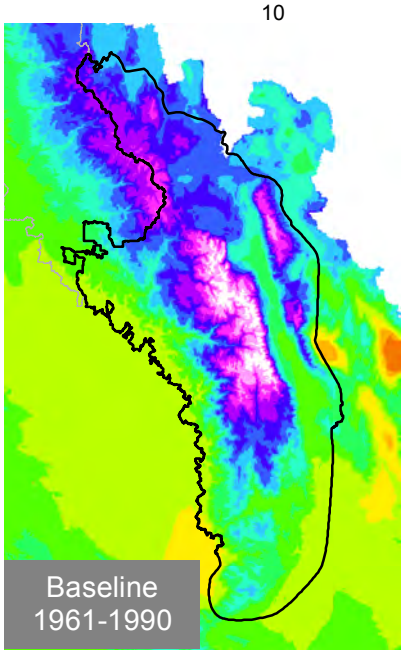

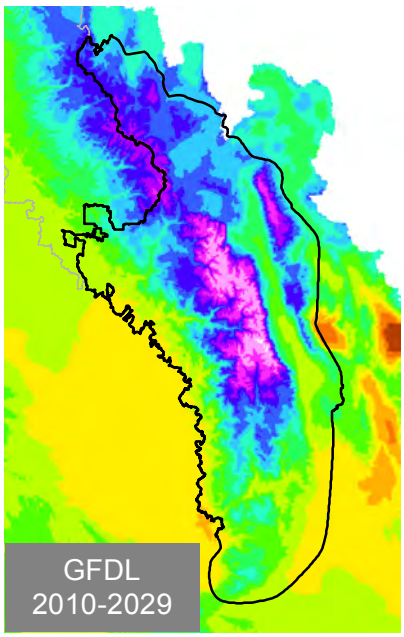

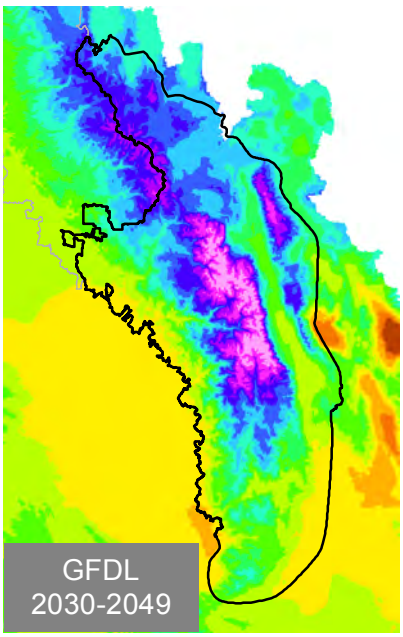

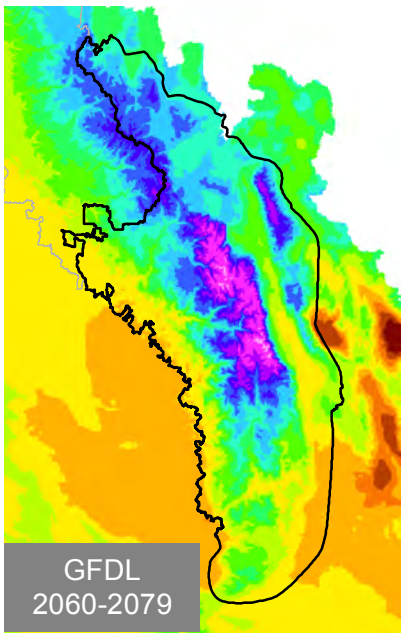

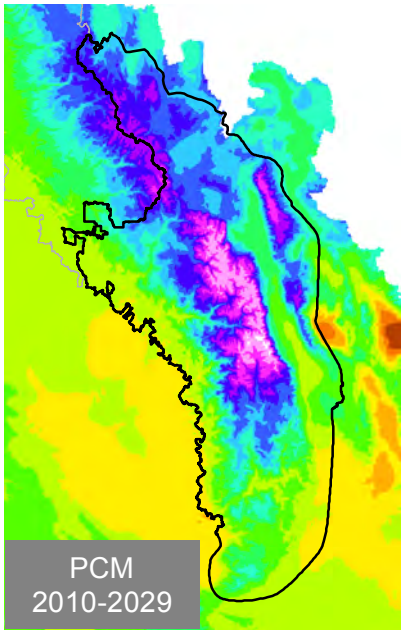

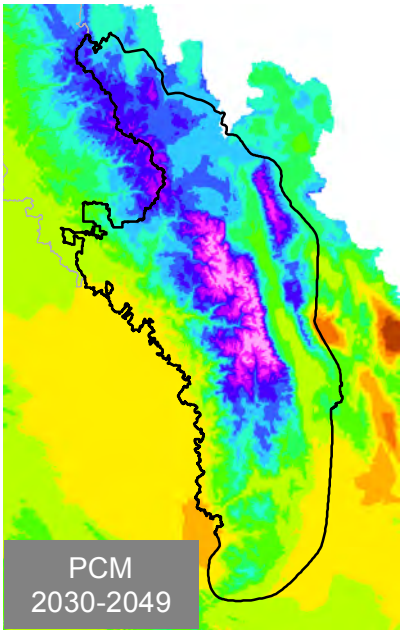

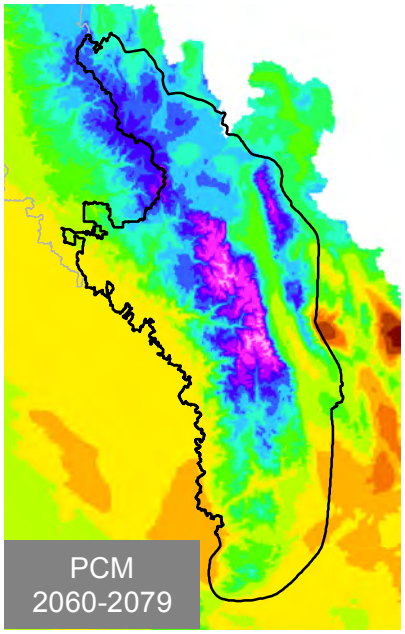

Winter Average Temperature

Northern Region
Sierra Nevada

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Temperature in degrees C

-11 - -7.8	14.6 - 17.7
-7.7 - -4.6	17.8 - 20.9
-4.5 - -1.4	21 - 24.1
-1.3 - 1.8	24.2 - 27.3
1.9 - 4.9	27.4 - 30.4
5 - 8.1	30.5 - 33.6
8.2 - 11.3	33.7 - 36.8
11.4 - 14.5	36.9 - 40

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
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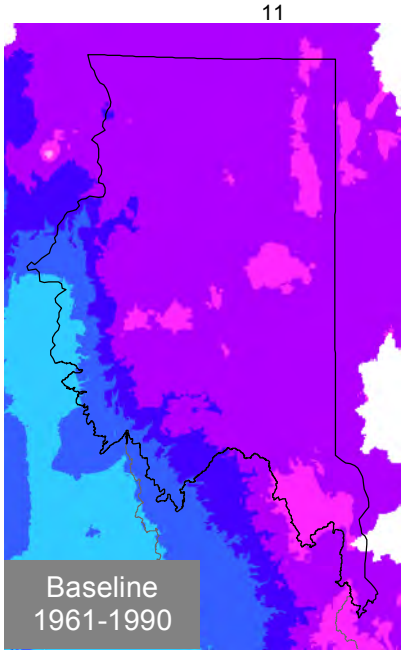

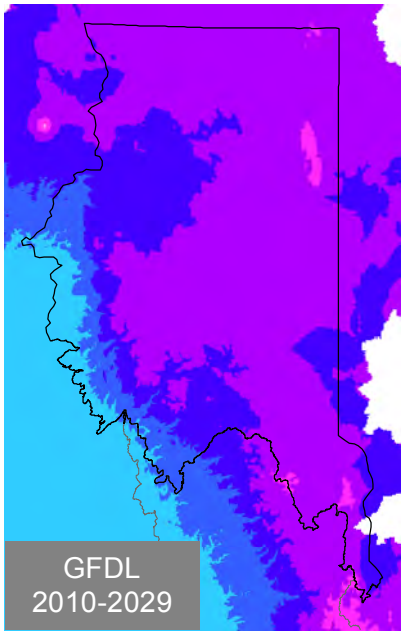

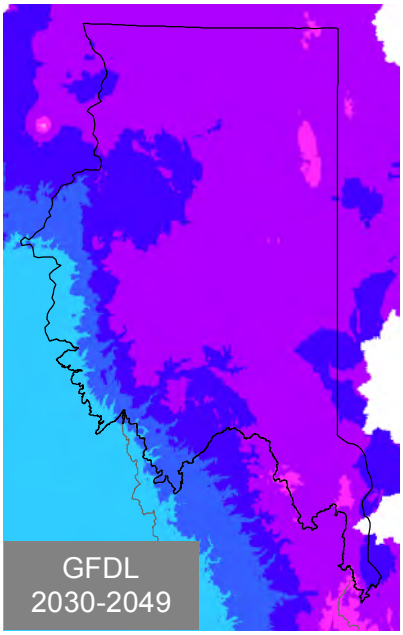

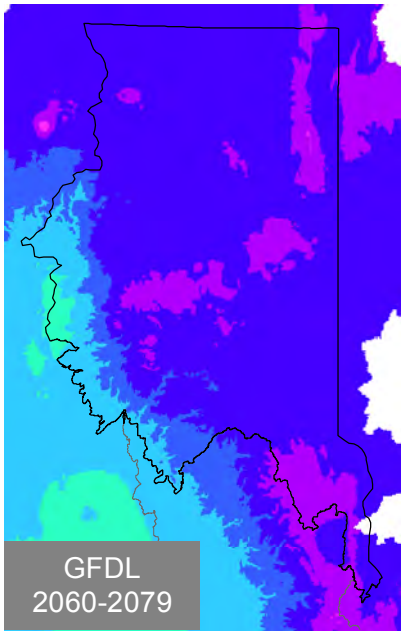

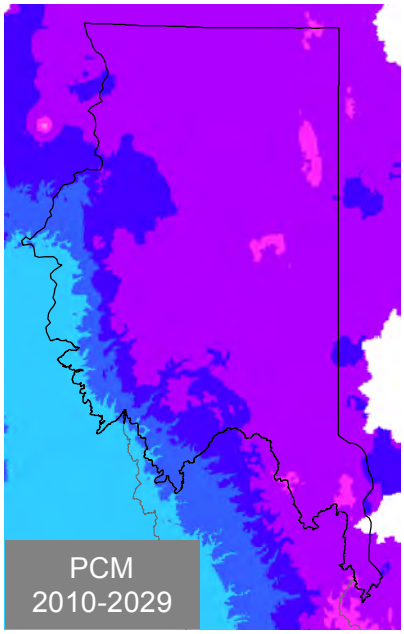

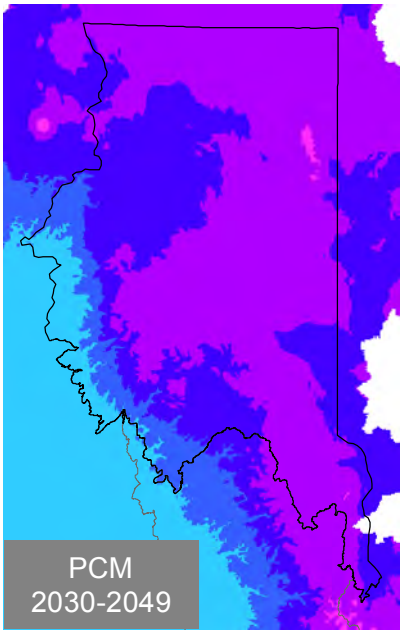

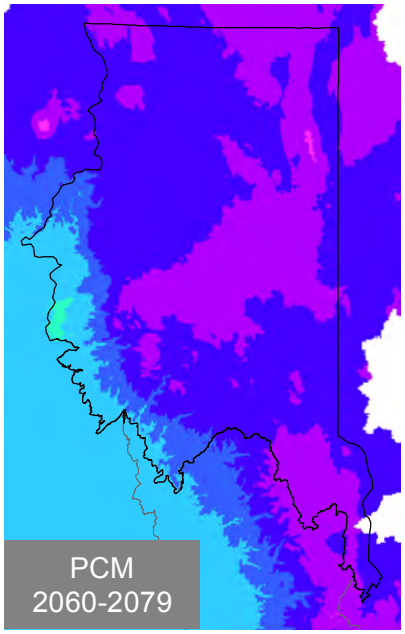

Winter Average Temperature

Central Region
Sierra Nevada

GEOS INSTITUTE

Temperature in degrees C

-11 - -7.8	14.6 - 17.7
-7.7 - -4.6	17.8 - 20.9
-4.5 - -1.4	21 - 24.1
-1.3 - 1.8	24.2 - 27.3
1.9 - 4.9	27.4 - 30.4
5 - 8.1	30.5 - 33.6
8.2 - 11.3	33.7 - 36.8
11.4 - 14.5	36.9 - 40

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

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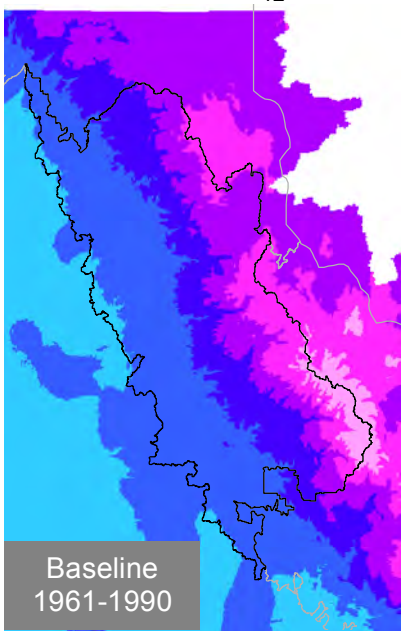

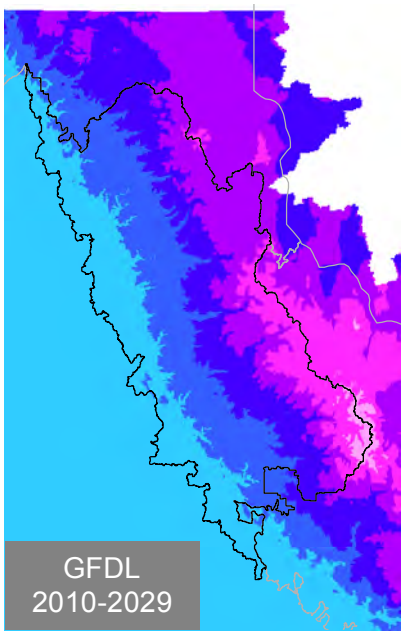

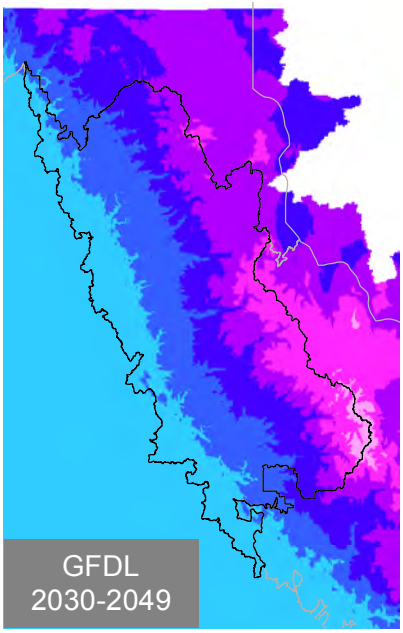

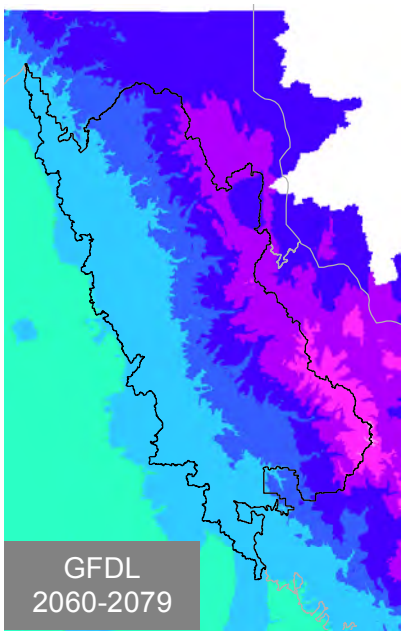

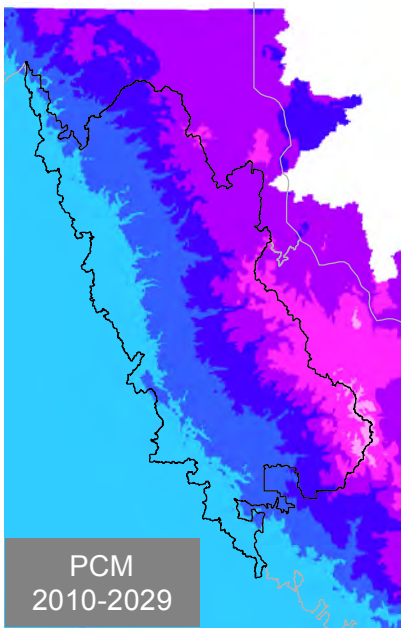

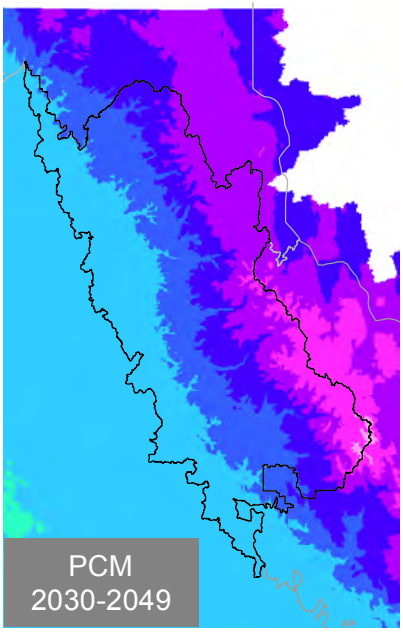

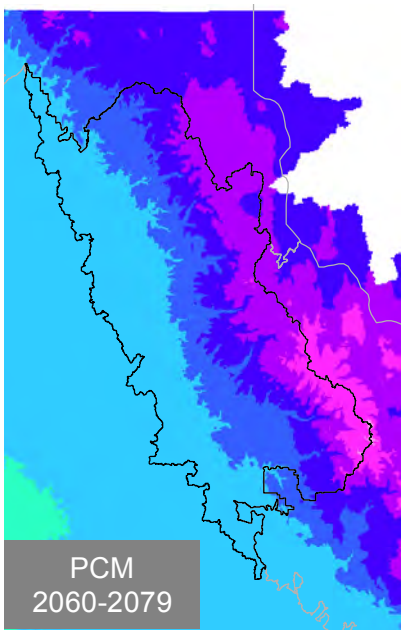

Winter Average Temperature

Southern Region
Sierra Nevada

GEOS INSTITUTE

Temperature in degrees C

-11 - -7.8	14.6 - 17.7
-7.7 - -4.6	17.8 - 20.9
-4.5 - -1.4	21 - 24.1
-1.3 - 1.8	24.2 - 27.3
1.9 - 4.9	27.4 - 30.4
5 - 8.1	30.5 - 33.6
8.2 - 11.3	33.7 - 36.8
11.4 - 14.5	36.9 - 40

0 100 mi
0 100 km

NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
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Downscaled following Flint and Flint (2012)[8]

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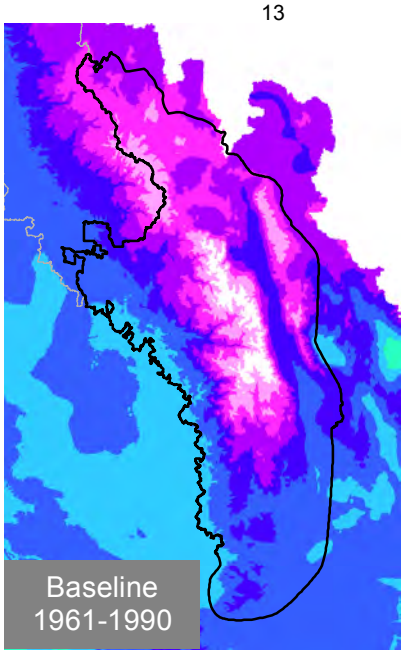

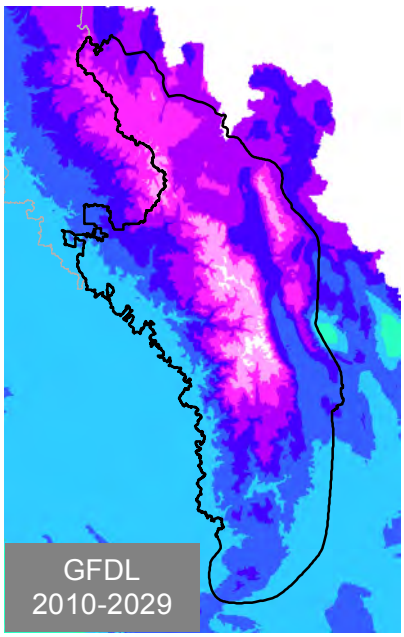

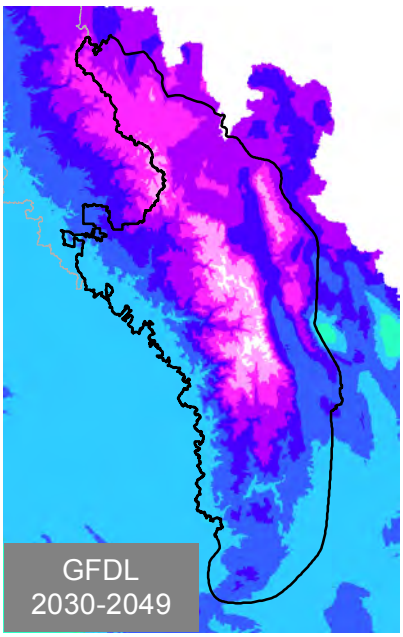

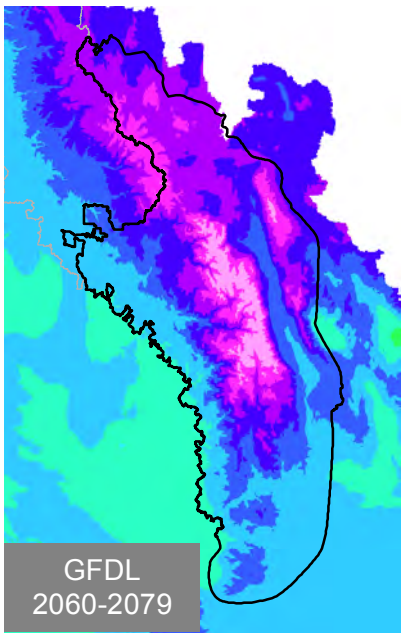

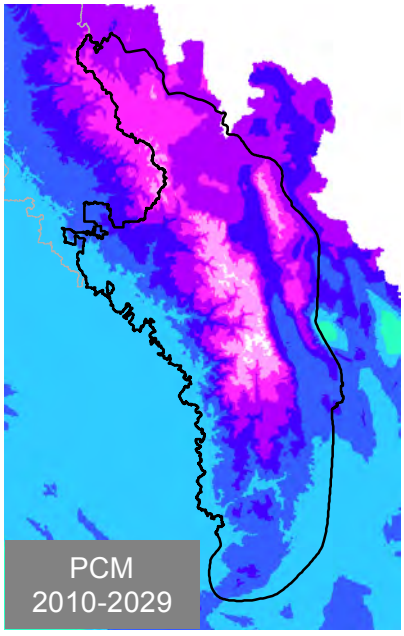

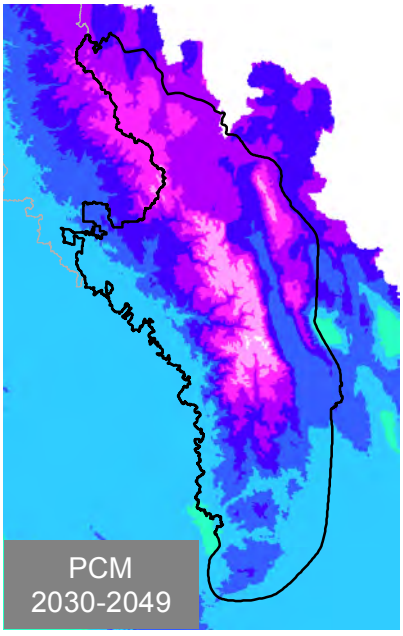

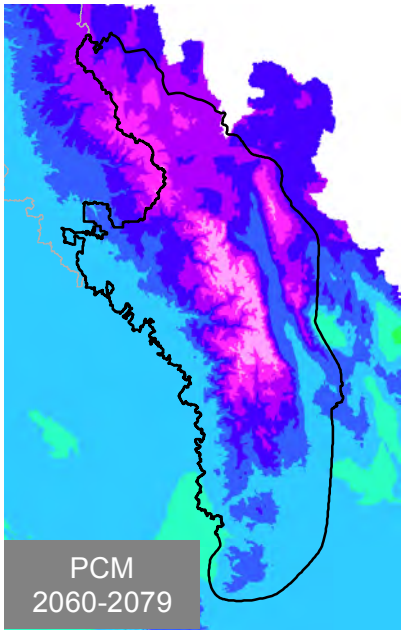

Summer Average Temperature

Northern Region
Sierra Nevada

GEOS INSTITUTE

Temperature in degrees C

-11 - -7.8	14.6 - 17.7
-7.7 - -4.6	17.8 - 20.9
-4.5 - -1.4	21 - 24.1
-1.3 - 1.8	24.2 - 27.3
1.9 - 4.9	27.4 - 30.4
5 - 8.1	30.5 - 33.6
8.2 - 11.3	33.7 - 36.8
11.4 - 14.5	36.9 - 40

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
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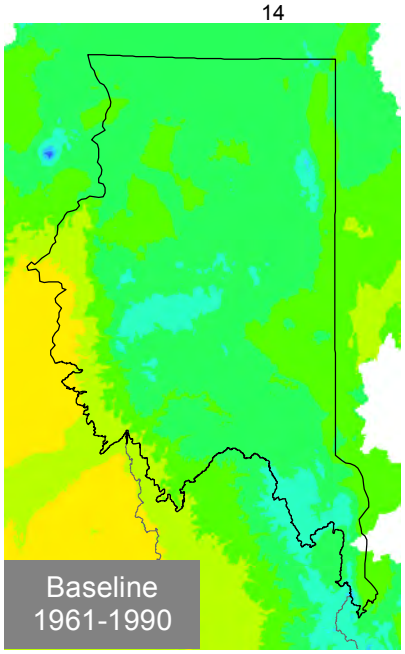

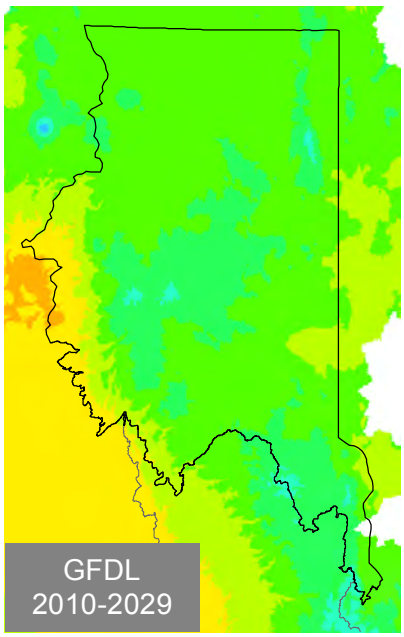

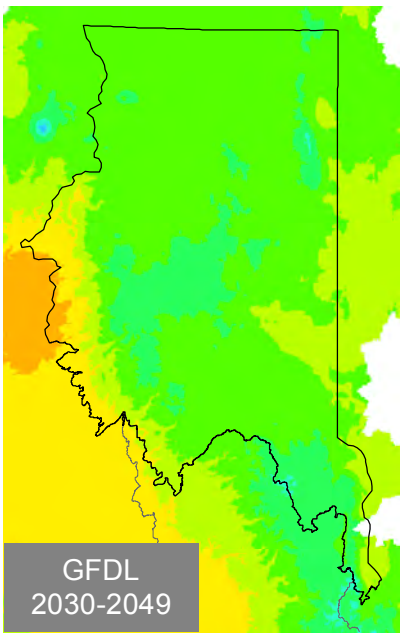

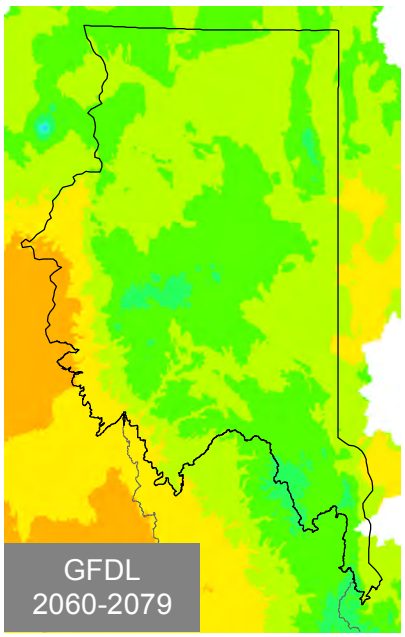

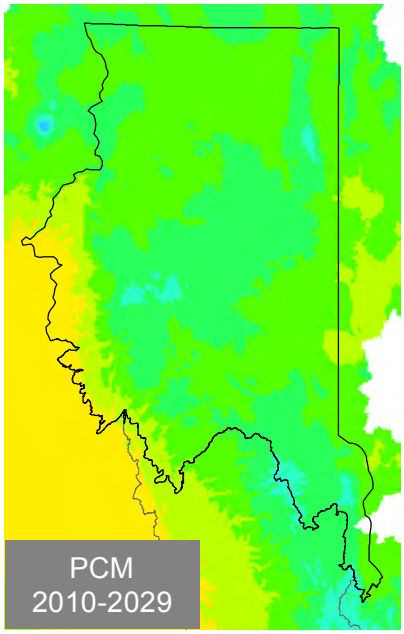

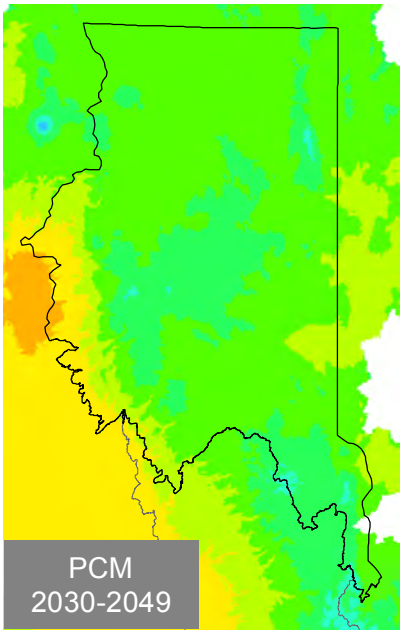

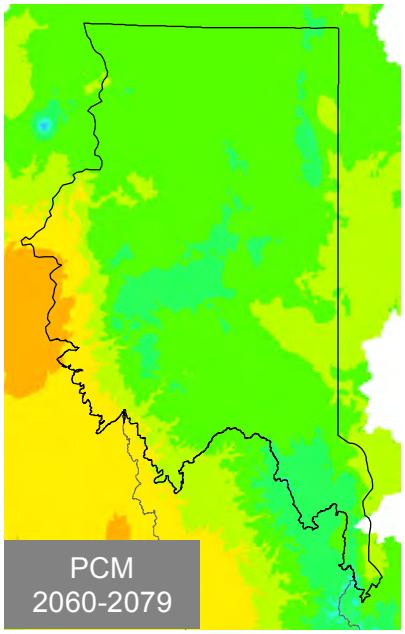

Summer Average Temperature

Central Region
Sierra Nevada

GEOS INSTITUTE

Temperature in degrees C

-11 - -7.8	14.6 - 17.7
-7.7 - -4.6	17.8 - 20.9
-4.5 - -1.4	21 - 24.1
-1.3 - 1.8	24.2 - 27.3
1.9 - 4.9	27.4 - 30.4
5 - 8.1	30.5 - 33.6
8.2 - 11.3	33.7 - 36.8
11.4 - 14.5	36.9 - 40

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
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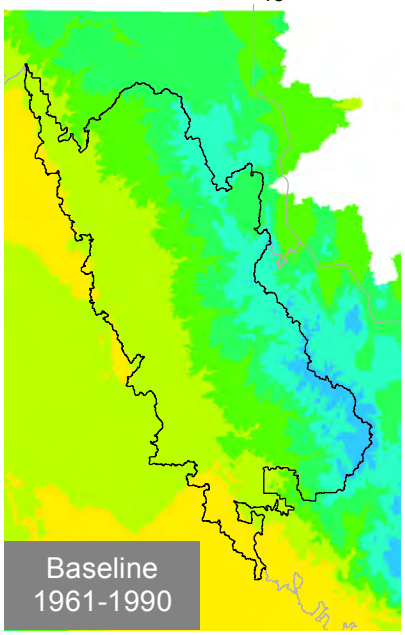

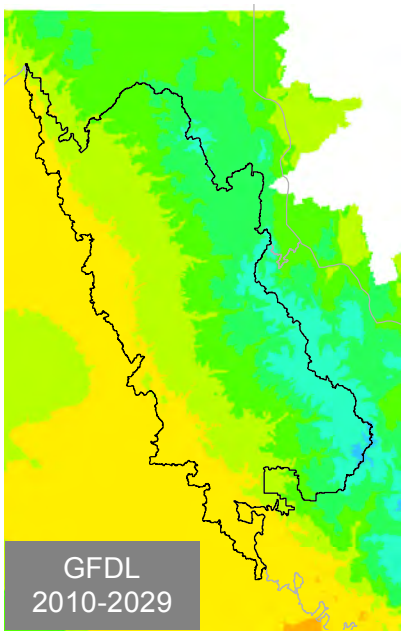

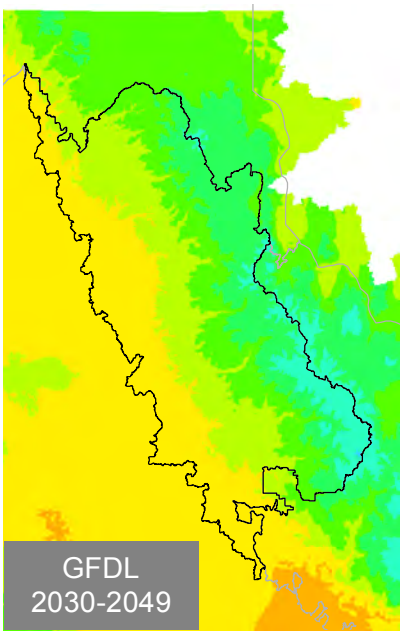

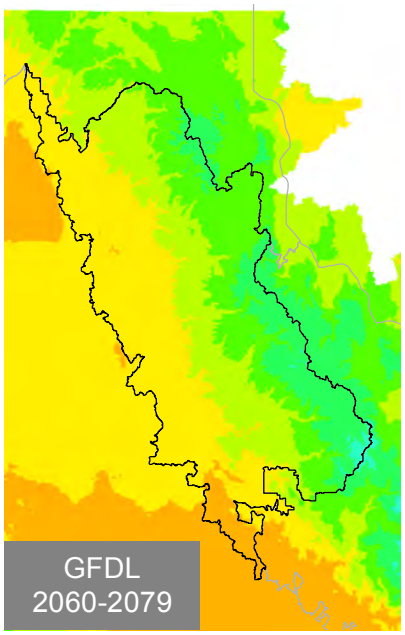

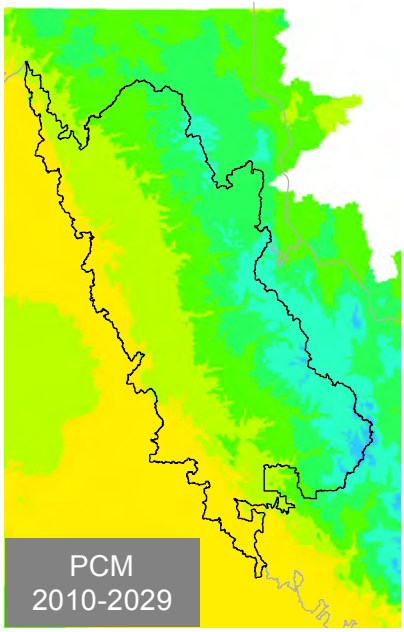

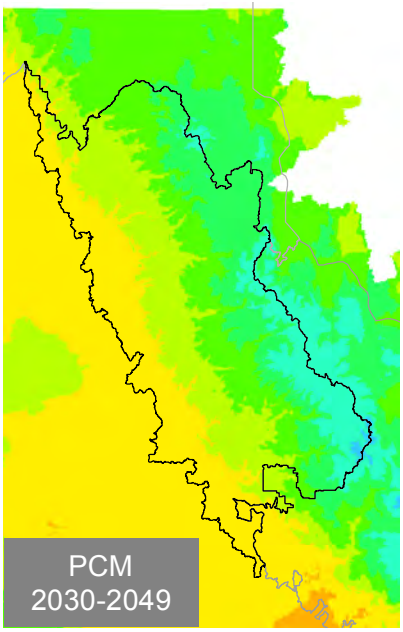

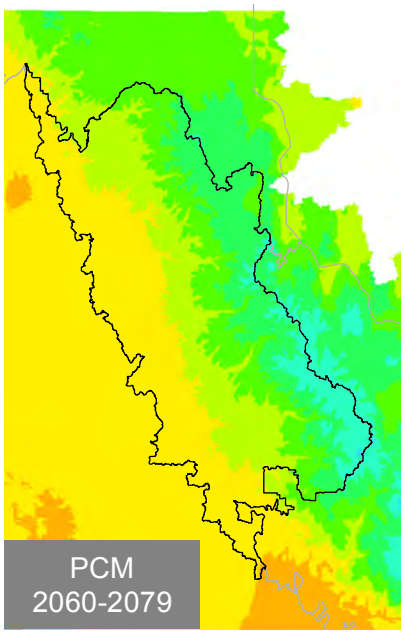

Summer Average Temperature

Southern Region
Sierra Nevada

GEOS INSTITUTE

Temperature in degrees C

-11 - -7.8	14.6 - 17.7
-7.7 - -4.6	17.8 - 20.9
-4.5 - -1.4	21 - 24.1
-1.3 - 1.8	24.2 - 27.3
1.9 - 4.9	27.4 - 30.4
5 - 8.1	30.5 - 33.6
8.2 - 11.3	33.7 - 36.8
11.4 - 14.5	36.9 - 40

0 100 mi
0 100 km

NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
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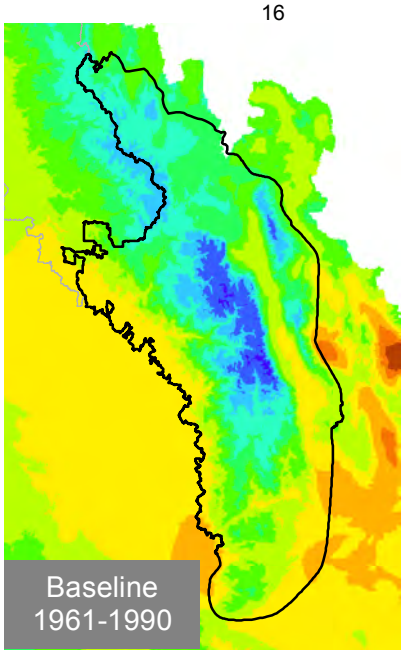

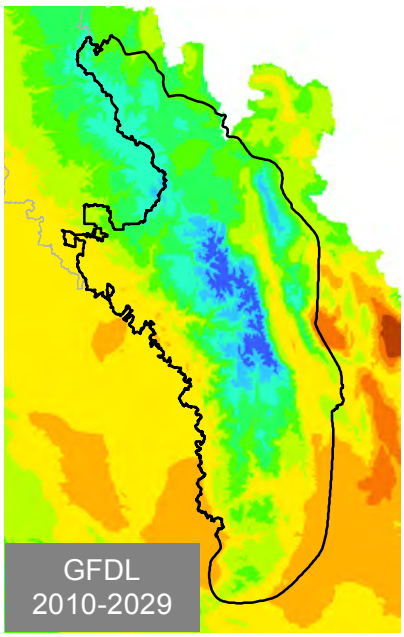

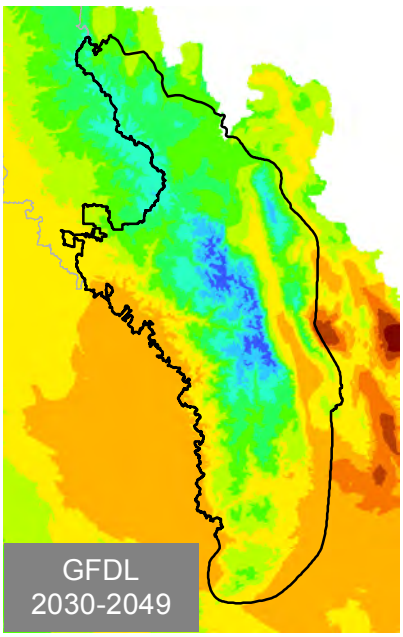

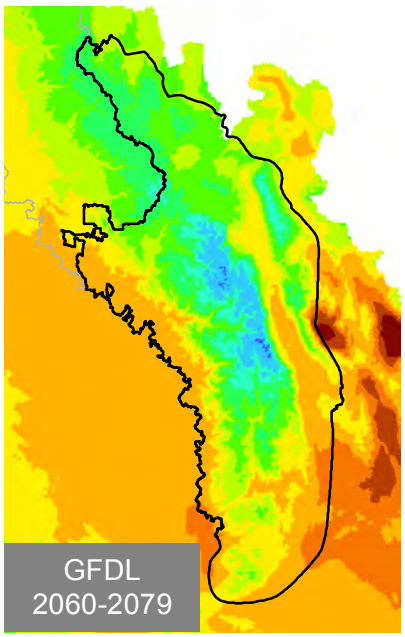

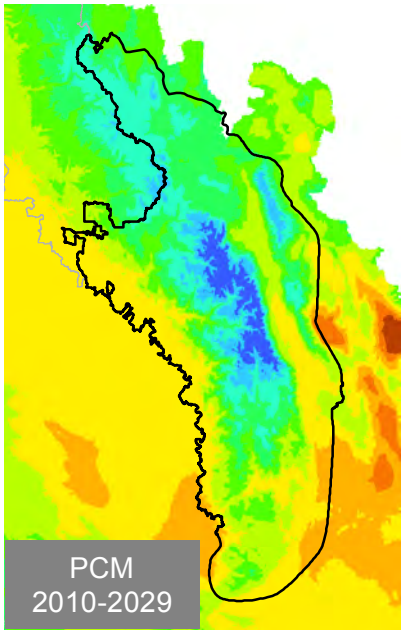

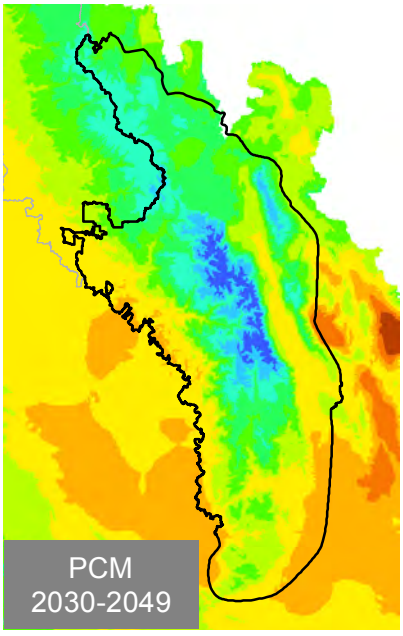

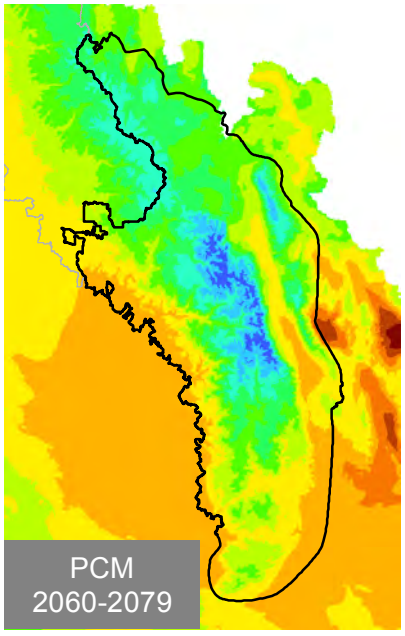

PRECIPITATION

Projections for future precipitation varied among the two models. Both models indicated a long-term trend towards drier summer and fall but wetter winters (Table 2). Even with increased precipitation in the winter, overall drier conditions are expected to develop due to increases in temperature and evaporation. This can be seen in the water deficit projections (page 35).

Table 2. Projected average annual precipitation (and percent change from historic) across the three regions of the Sierra (North, Central, and South), based on output from two different global climate models (GFDL and PCM). Precipitation measurements and projections include both rainfall and snow water equivalent.

	Historic	2010-29	2030-49	2060-79
Annual				
North	770mm	0 to +5%	-3 to +10%	-11 to +10%
Central	1119mm	+1 to +5%	+1 to +11%	-9 to +13%
South	528mm	+2 to +7%	+1 to +8%	-10 to +16%
SPRING				
North	65mm	0 to +16%	-10 to +19%	+4 to +24%
Central	98mm	-2 to +11%	-15 to +16%	0 to +20%
South	47mm	-5 to +18%	-16 to +15%	-5 to +21%
SUMMER				
North	15mm	+3 to +40%	-21 to +2%	-52 to +6%
Central	10mm	+38 to +45%	-25 to +11%	-44 to +16%
South	8mm	-11 to +24%	-32 to 0%	-10 to -40%
FALL				
North	61mm	-5 to -14%	0 to +2%	-14 to -27%
Central	86mm	-1 to -12%	+3 to +7%	-5 to -25%
South	33mm	-1 to +7%	+9%	-1 to -13%
WINTER				
North	116mm	0 to +6%	0 to +12%	-4 to +16%
Central	180mm	+ 3 to +8%	+10%	-4 to +18%
South	87mm	+3 to +6%	+6 to +11%	-8 to +22%

Annual Average Precipitation

Northern Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

50 - 250	1,651 - 1,850
251 - 450	1,851 - 2,050
451 - 650	2,051 - 2,250
651 - 850	2,251 - 2,450
851 - 1,050	2,451 - 2,650
1,051 - 1,250	2,651 - 2,850
1,251 - 1,450	2,851 - 3,050
1,451 - 1,650	3,051 - 3,250

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

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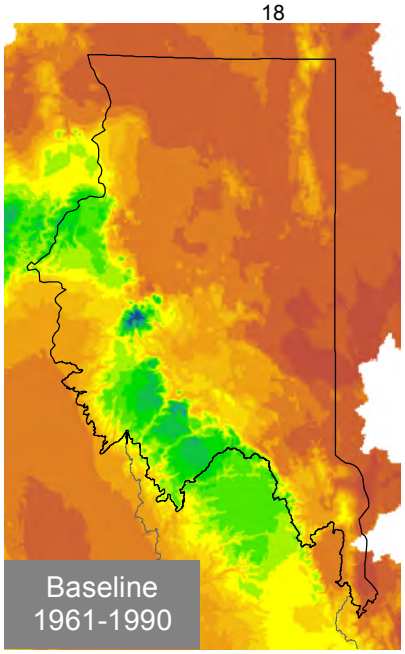

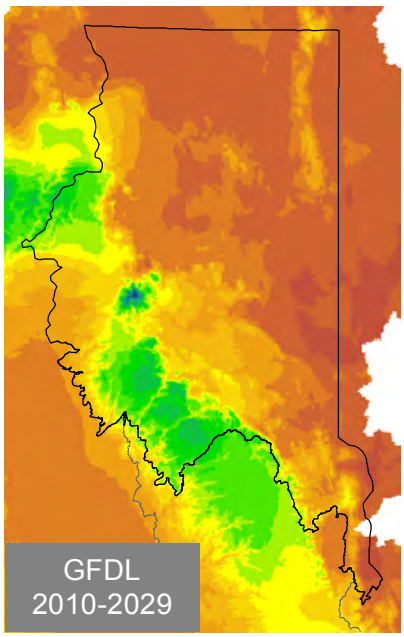

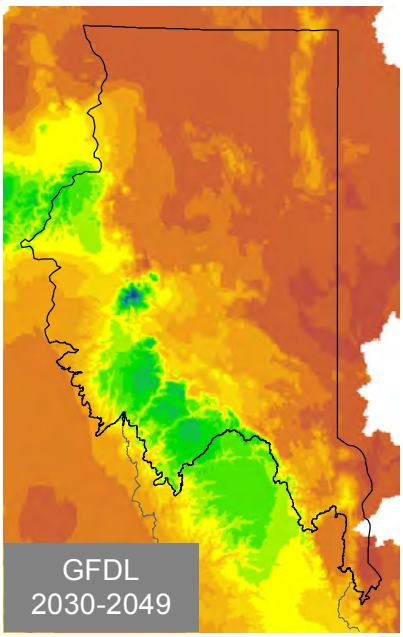

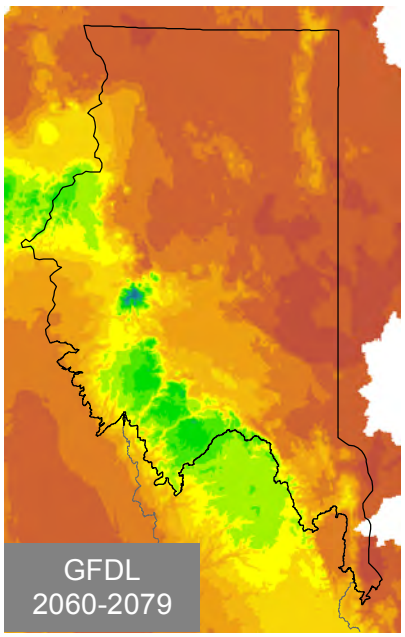

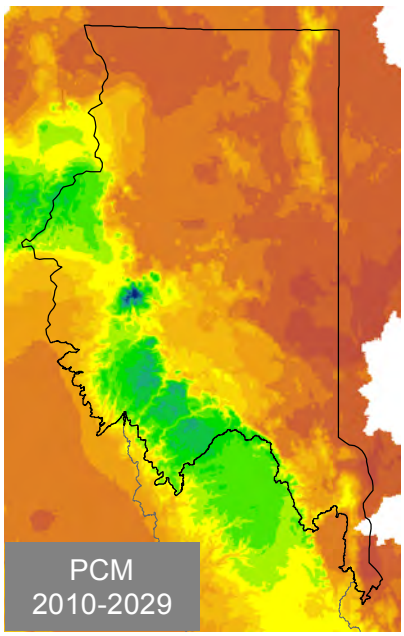

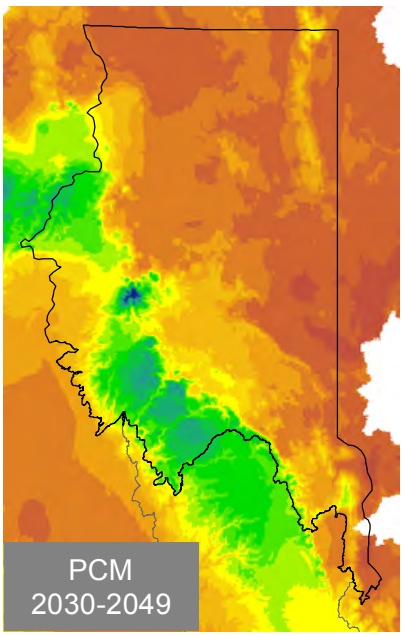

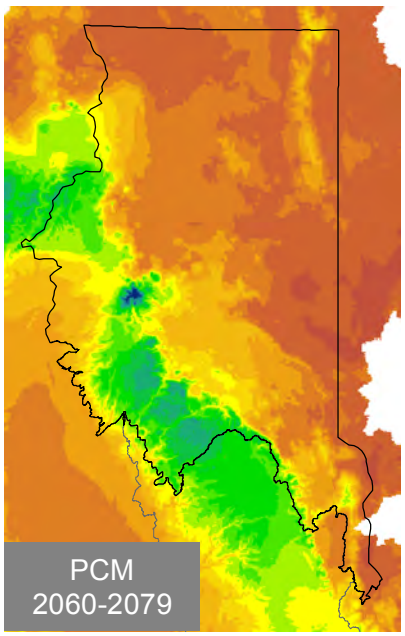

Annual Average Precipitation

Central Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

50 - 250	1,651 - 1,850
251 - 450	1,851 - 2,050
451 - 650	2,051 - 2,250
651 - 850	2,251 - 2,450
851 - 1,050	2,451 - 2,650
1,051 - 1,250	2,651 - 2,850
1,251 - 1,450	2,851 - 3,050
1,451 - 1,650	3,051 - 3,250

0 100 mi
0 100 km
NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
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Downscaled following Flint and Flint (2012)[8]

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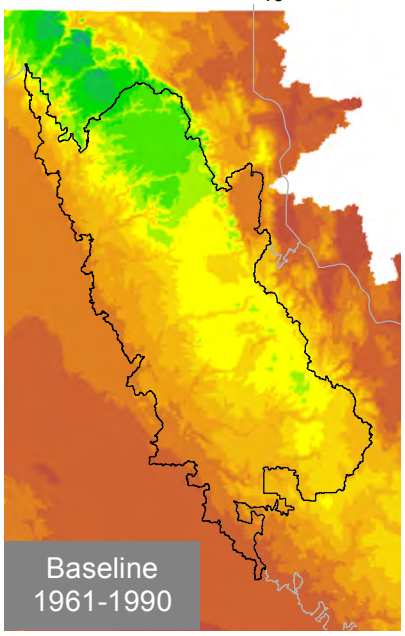
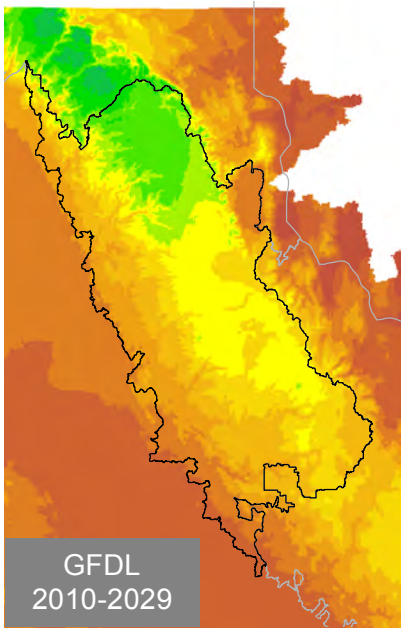
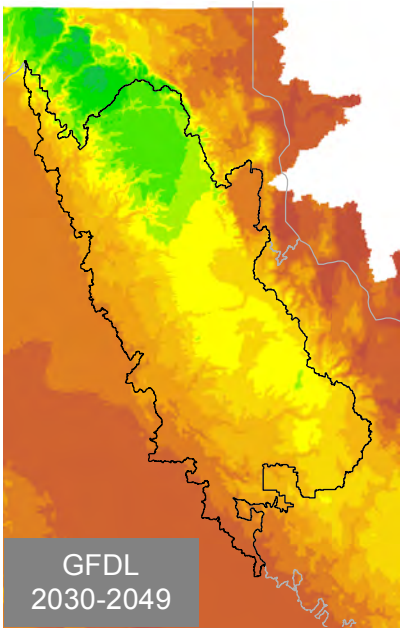
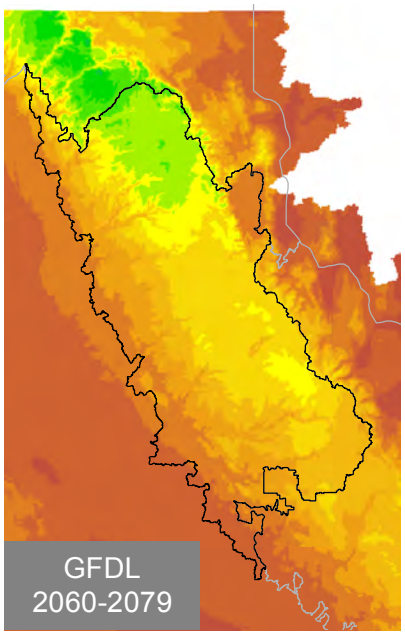
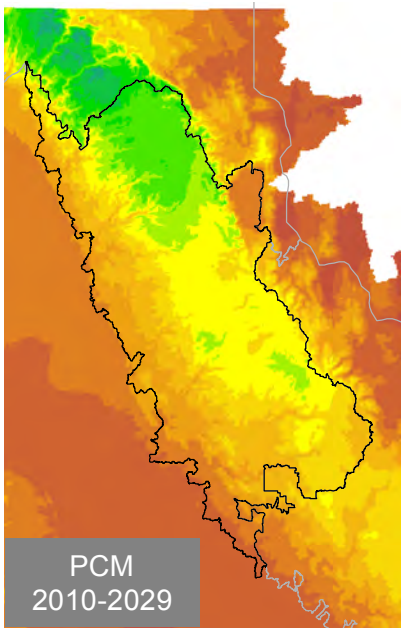
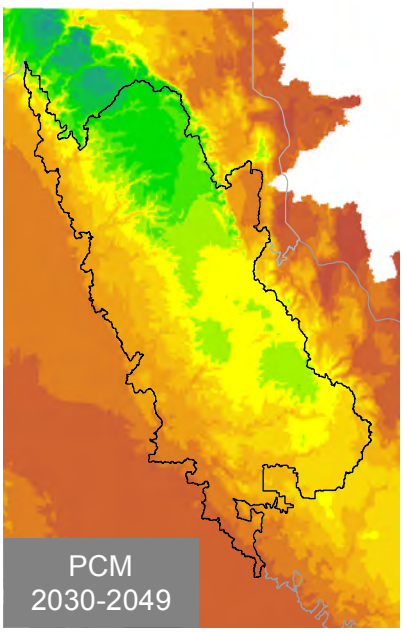


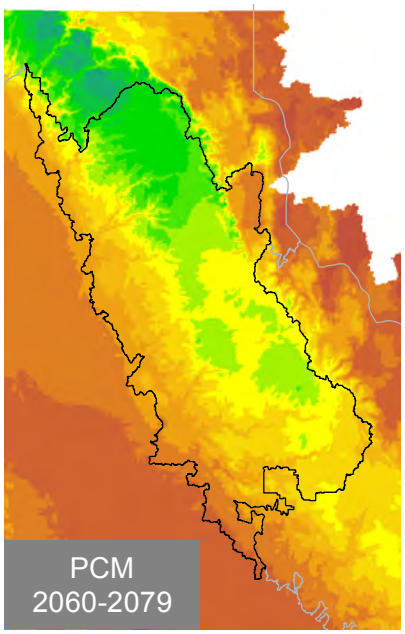












Annual Average Precipitation

Southern Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

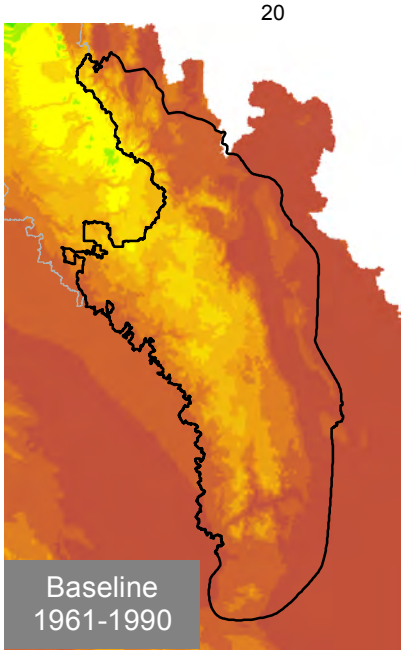
50 - 250	1,651 - 1,850
251 - 450	1,851 - 2,050
451 - 650	2,051 - 2,250
651 - 850	2,251 - 2,450
851 - 1,050	2,451 - 2,650
1,051 - 1,250	2,651 - 2,850
1,251 - 1,450	2,851 - 3,050
1,451 - 1,650	3,051 - 3,250

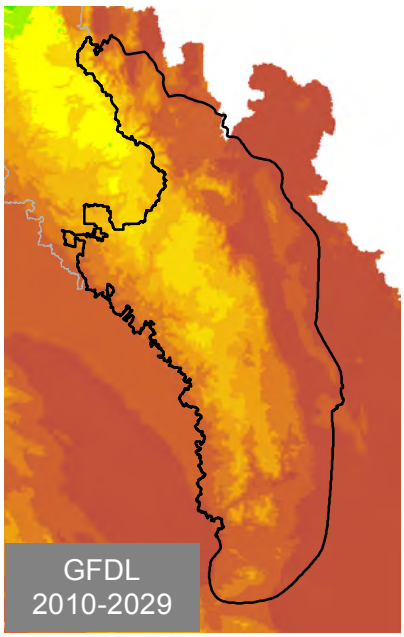
0 100 mi
0 100 km

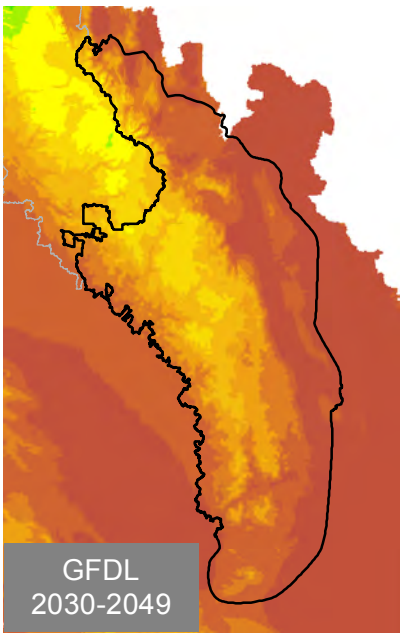
NORTH

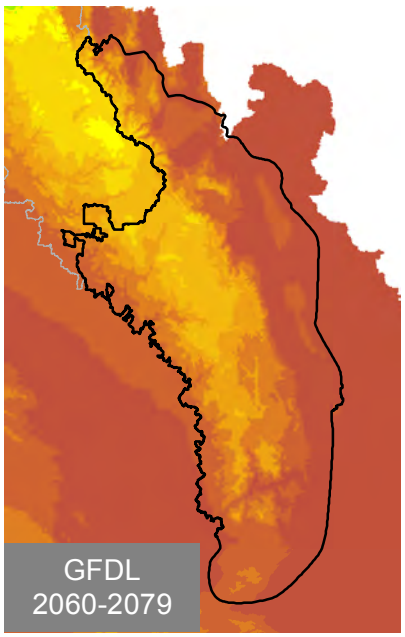
Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

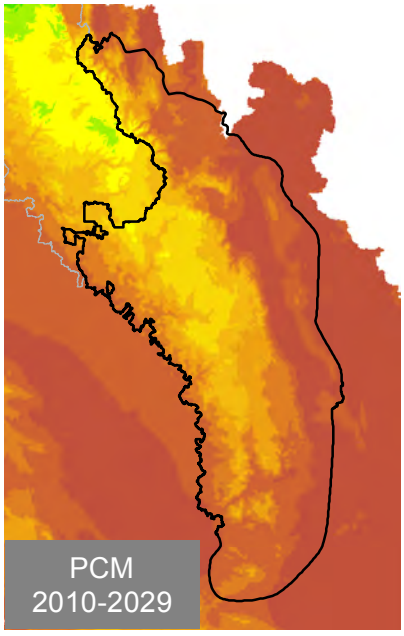
Rev: 2/22/2013

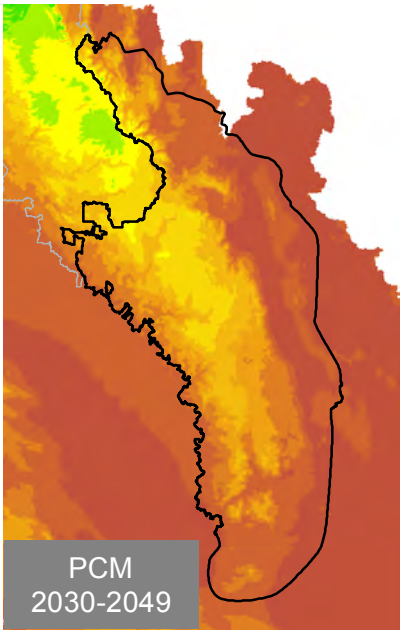


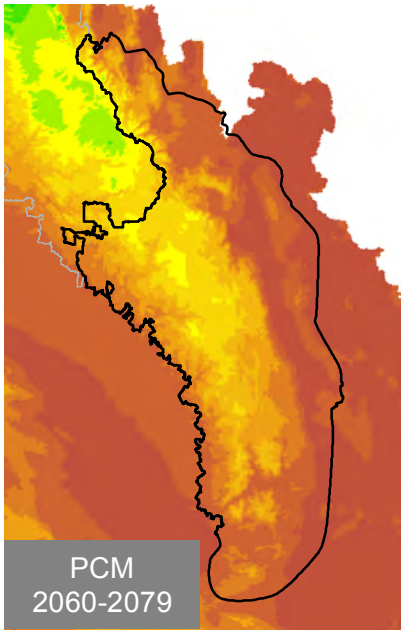












Winter Average Precipitation

Northern Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

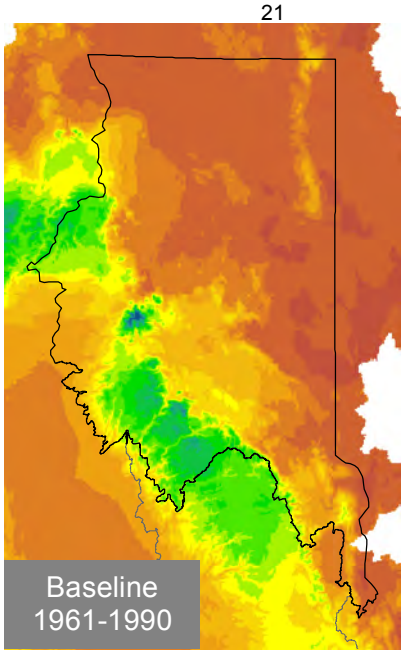
0 - 33	261 - 293
34 - 65	294 - 325
66 - 98	326 - 358
99 - 130	359 - 390
131 - 163	391 - 423
164 - 195	424 - 455
196 - 228	456 - 488
229 - 260	489 - 520

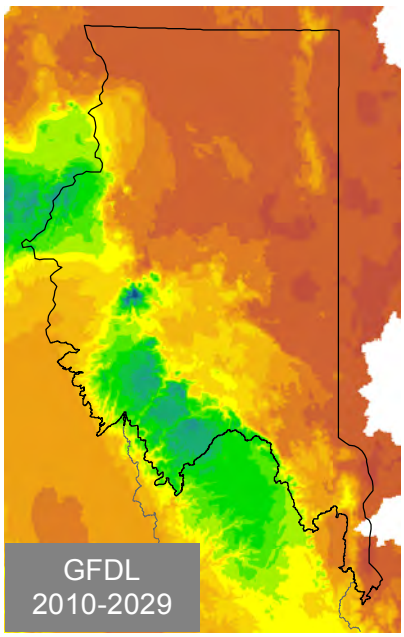
0 100 mi
0 100 km

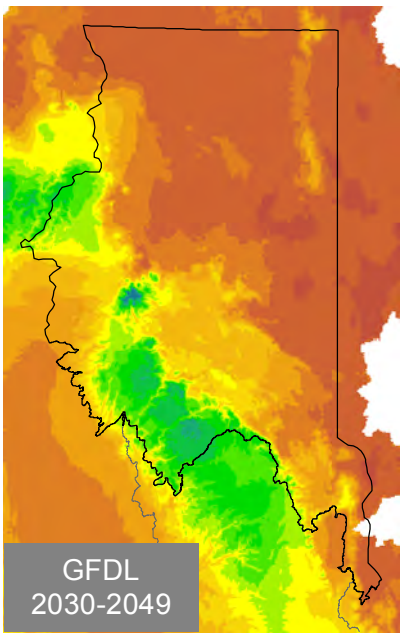
NORTH

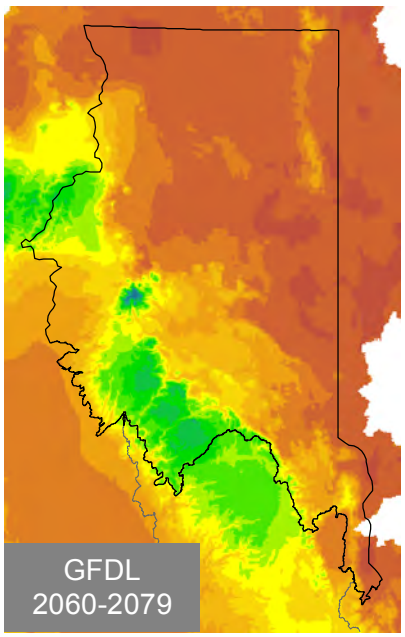
Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

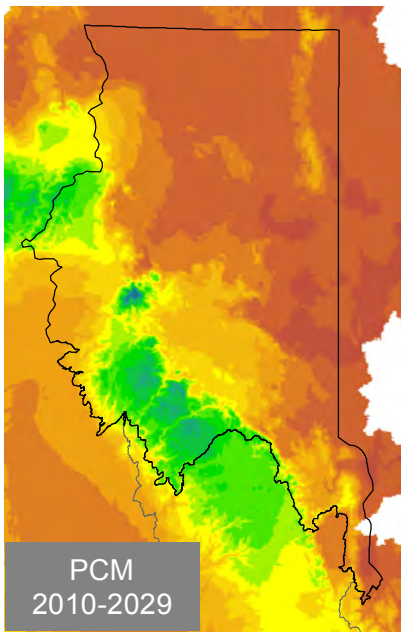
Rev: 2/22/2013

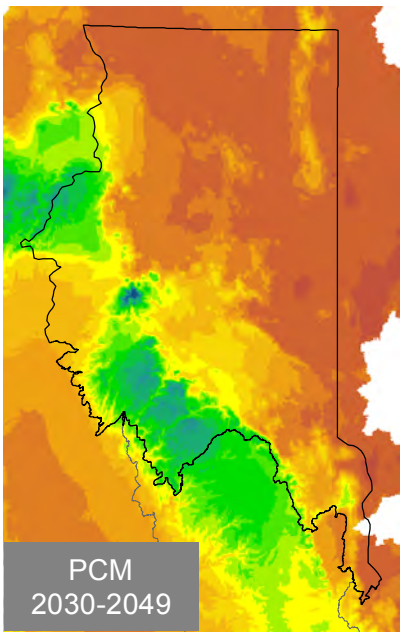


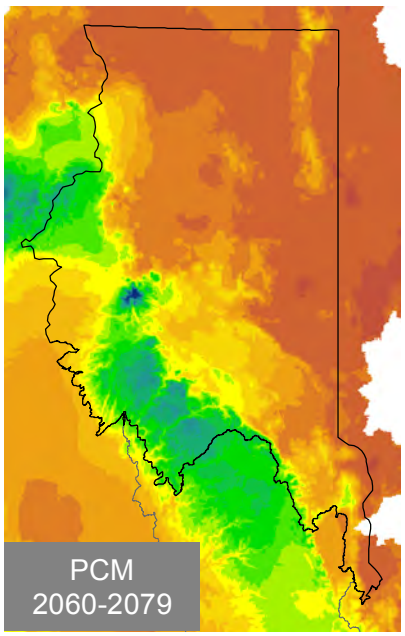












Winter Average Precipitation

Central Region
Sierra Nevada

GEOS INSTITUTE

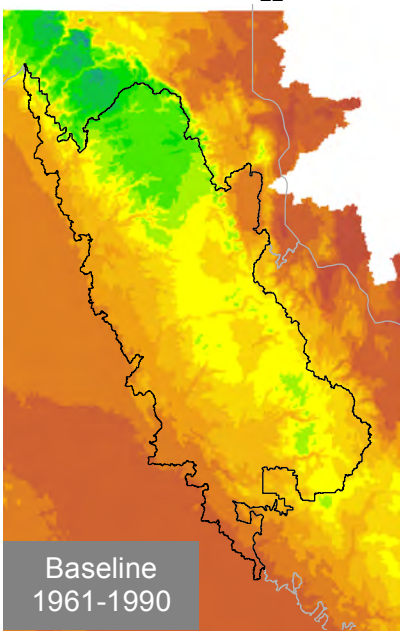
Precipitation in mm

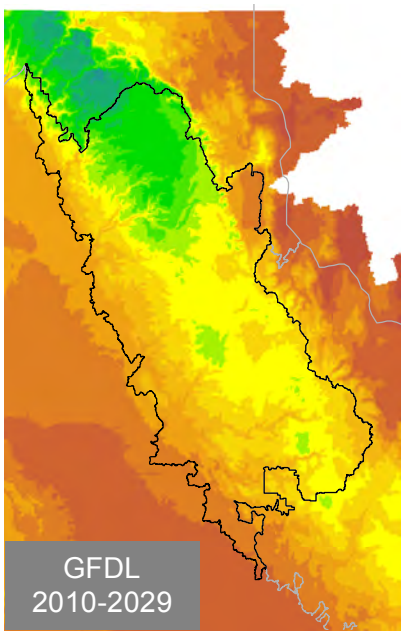
0 - 33	261 - 293
34 - 65	294 - 325
66 - 98	326 - 358
99 - 130	359 - 390
131 - 163	391 - 423
164 - 195	424 - 455
196 - 228	456 - 488
229 - 260	489 - 520

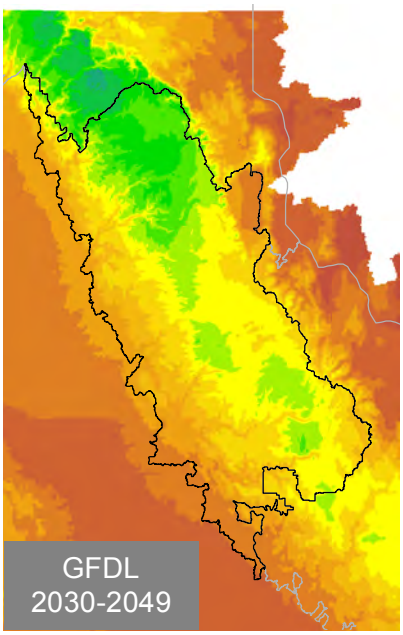
0 100 mi
0 100 km
NORTH

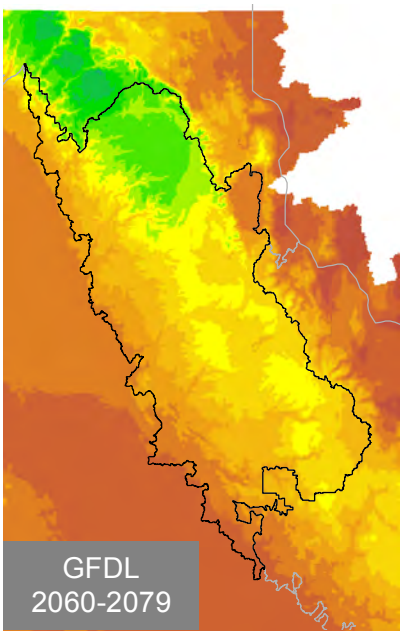
Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

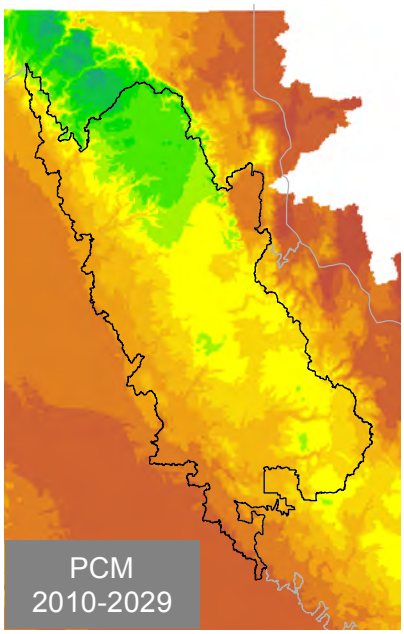
Rev: 2/22/2013

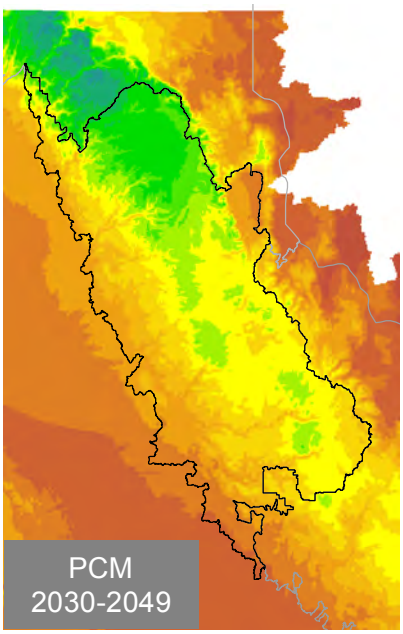


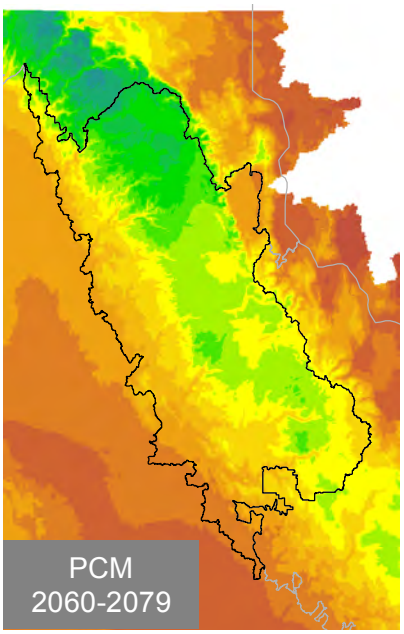












Winter Average Precipitation

Southern Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

0 - 33	261 - 293
34 - 65	294 - 325
66 - 98	326 - 358
99 - 130	359 - 390
131 - 163	391 - 423
164 - 195	424 - 455
196 - 228	456 - 488
229 - 260	489 - 520

0 100 mi
0 100 km

NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

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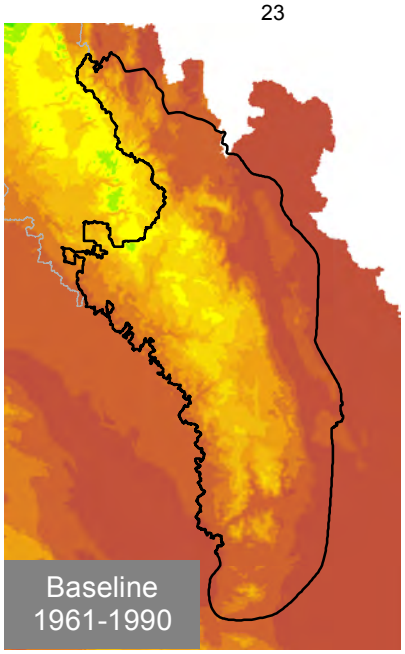
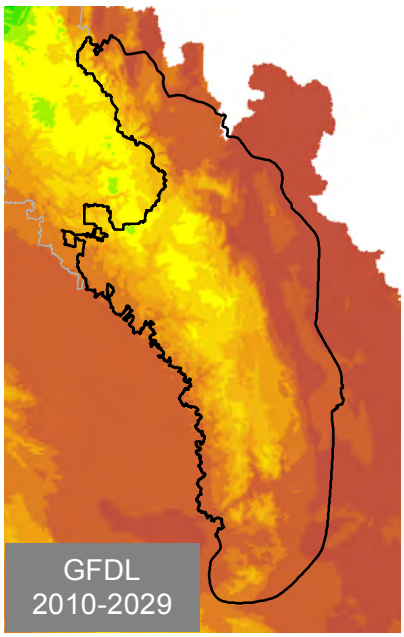
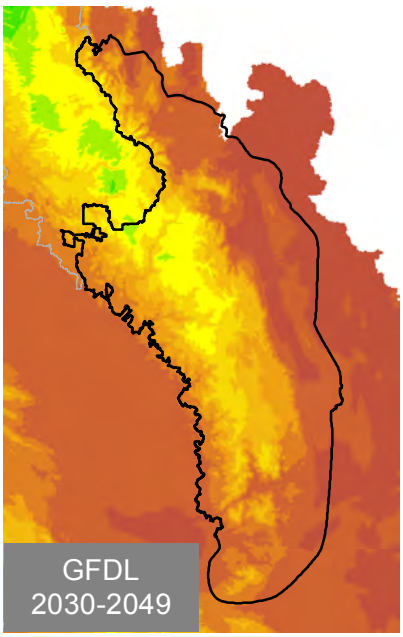
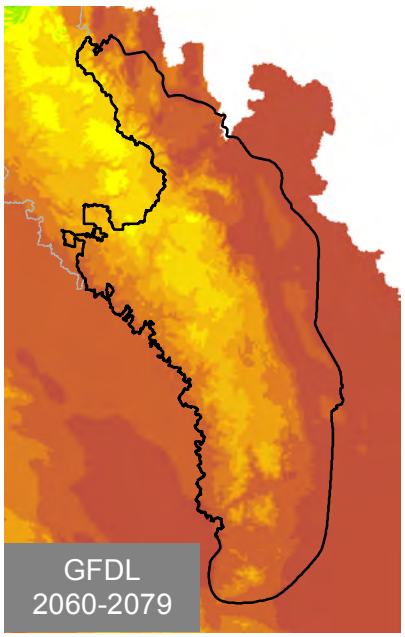
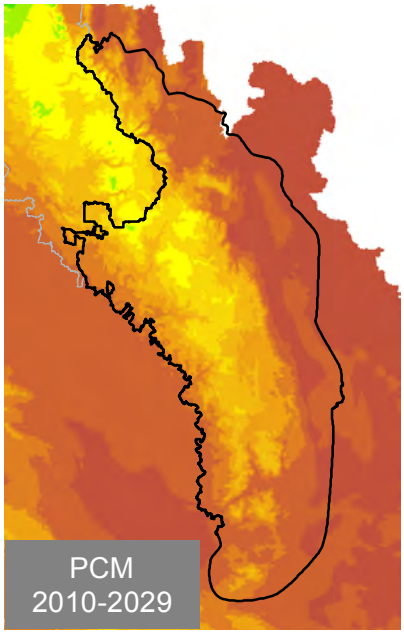
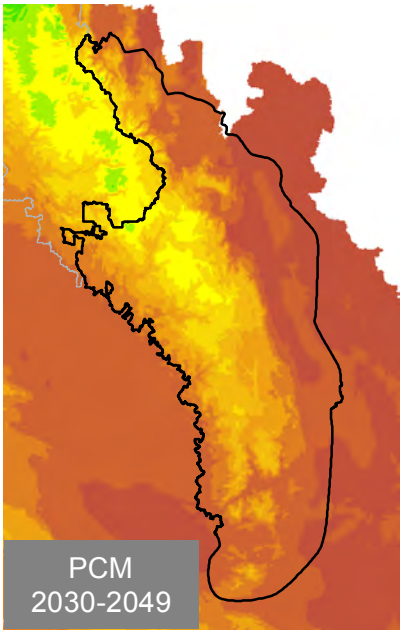


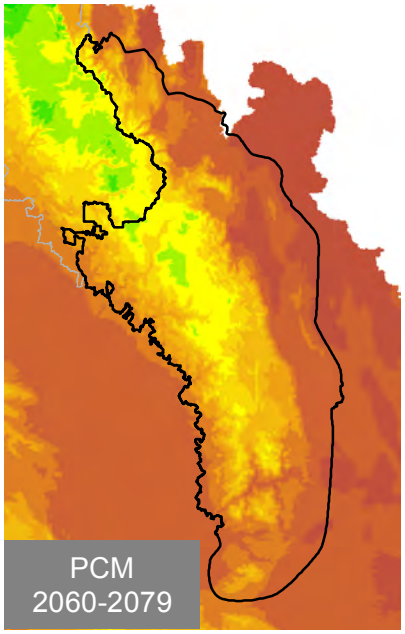












Fall Average Precipitation

Northern Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

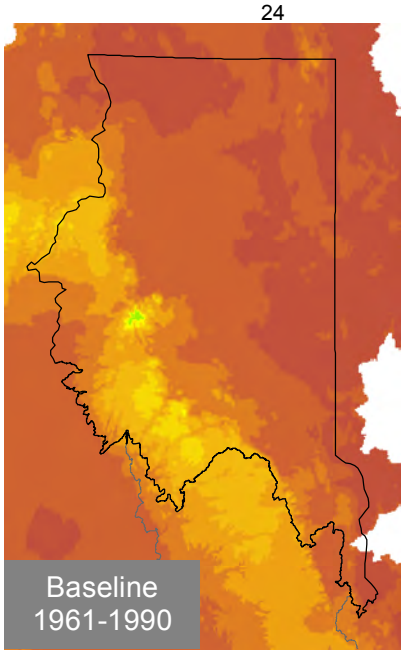
0 - 33	261 - 293
34 - 65	294 - 325
66 - 98	326 - 358
99 - 130	359 - 390
131 - 163	391 - 423
164 - 195	424 - 455
196 - 228	456 - 488
229 - 260	489 - 520

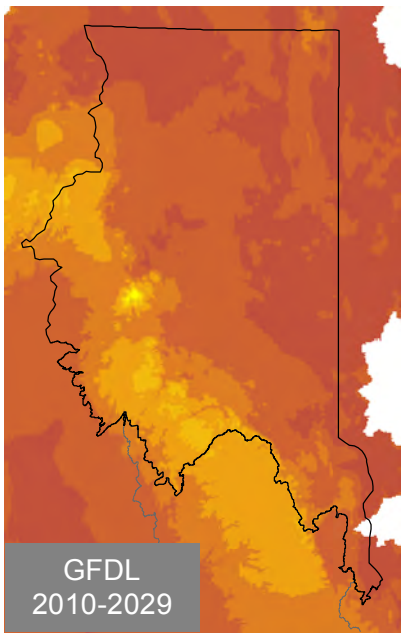
0 100 mi
0 100 km

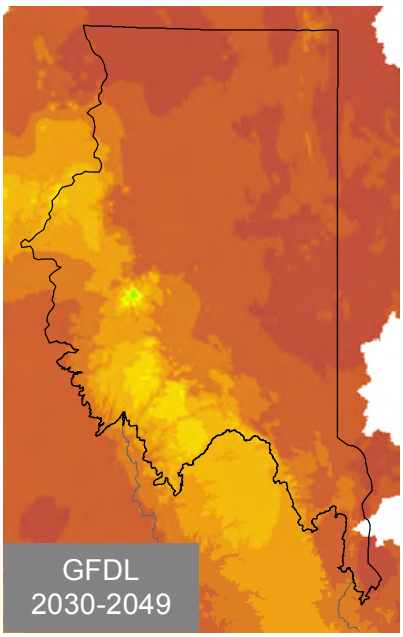
NORTH

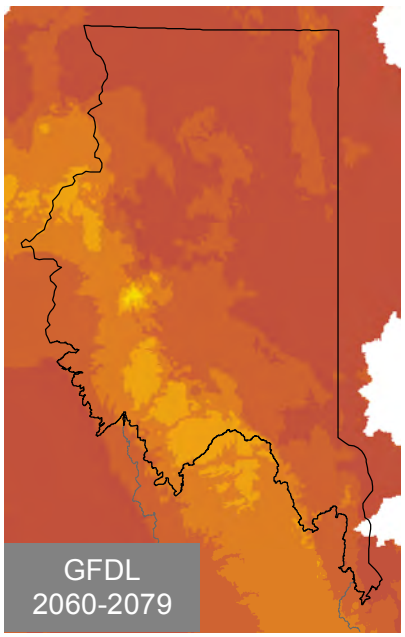
Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

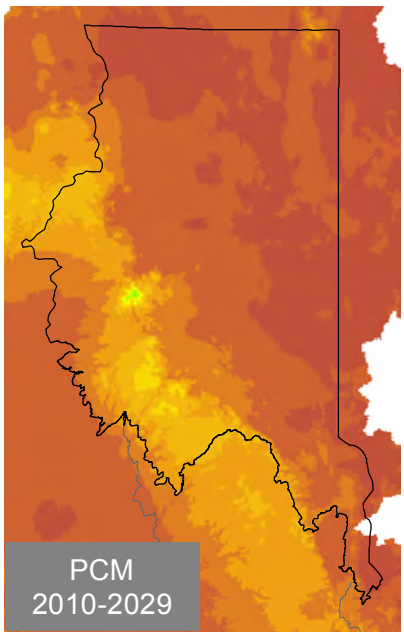
Rev: 2/22/2013

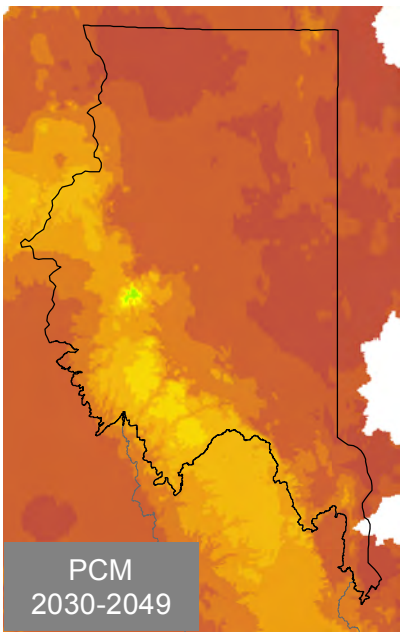


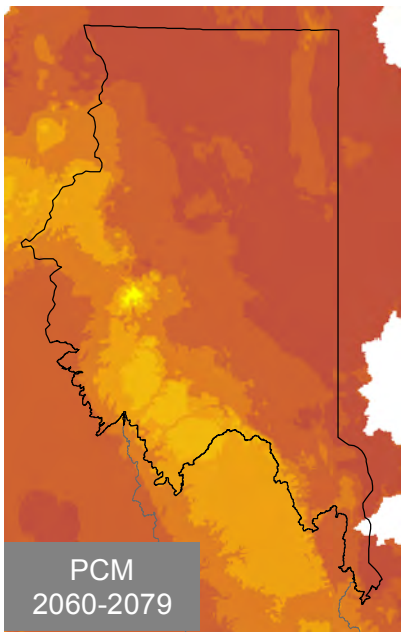












Fall Average Precipitation

Central Region
Sierra Nevada

GEOS INSTITUTE

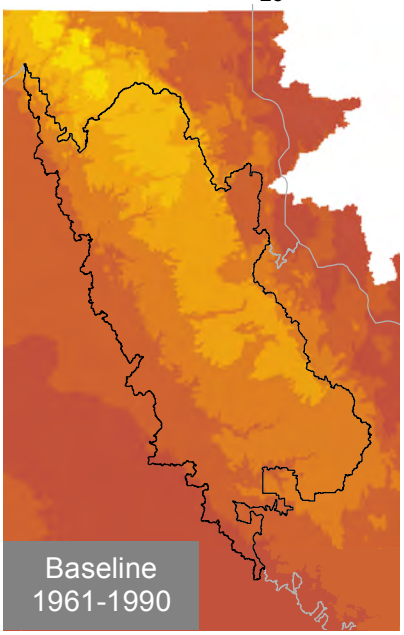
Precipitation in mm

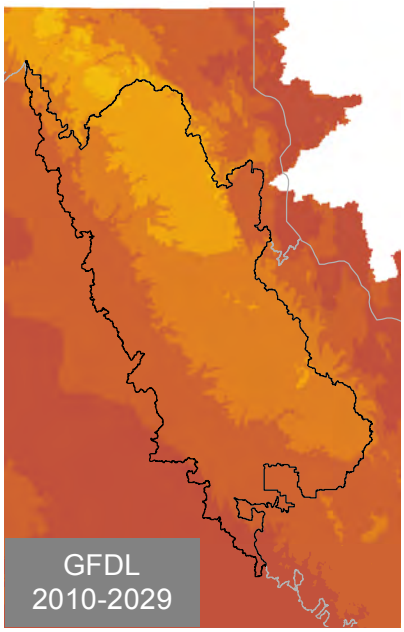
0 - 33	261 - 293
34 - 65	294 - 325
66 - 98	326 - 358
99 - 130	359 - 390
131 - 163	391 - 423
164 - 195	424 - 455
196 - 228	456 - 488
229 - 260	489 - 520

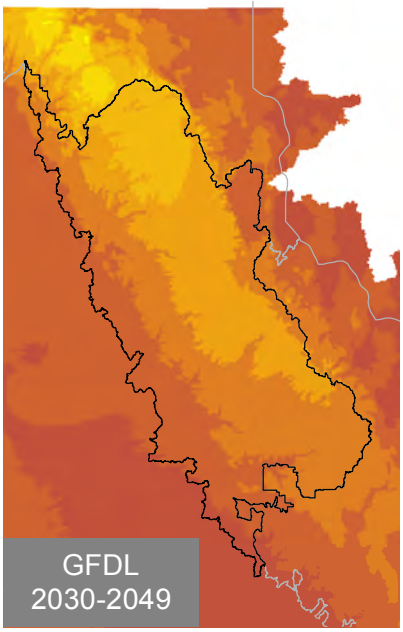
0 100 mi
0 100 km
NORTH

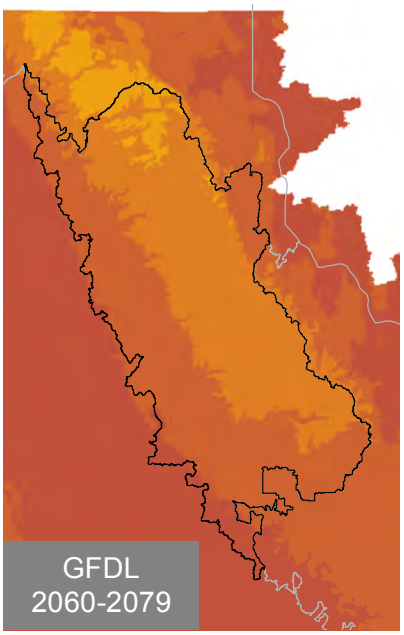
Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
PCM (Washington et al. 2000)[7],
Downscaled following Flint and Flint (2012)[8]

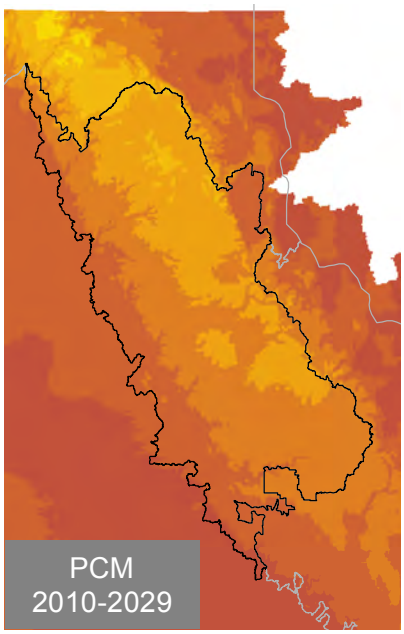
Rev: 2/22/2013

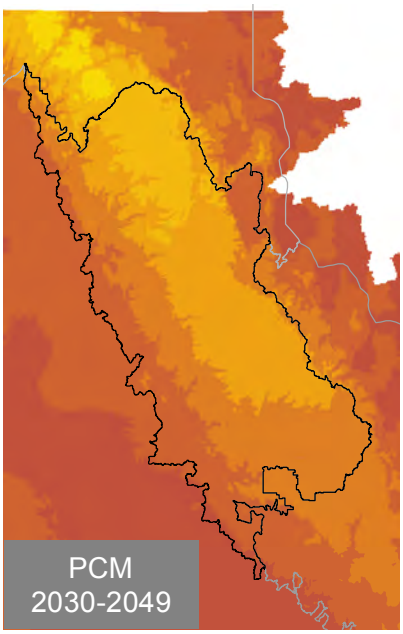


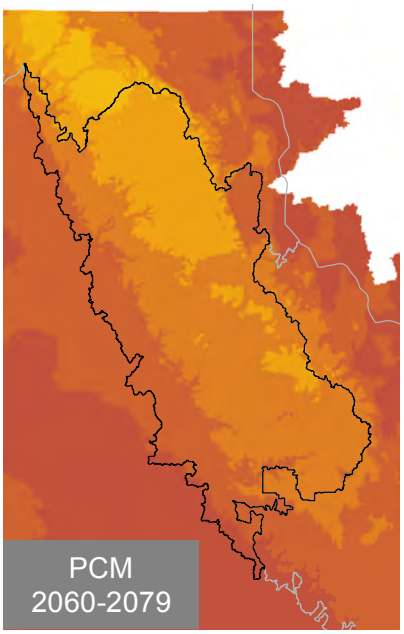












Fall Average Precipitation

Southern Region
Sierra Nevada

GEOS INSTITUTE

Precipitation in mm

0 - 33	261 - 293
34 - 65	294 - 325
66 - 98	326 - 358
99 - 130	359 - 390
131 - 163	391 - 423
164 - 195	424 - 455
196 - 228	456 - 488
229 - 260	489 - 520

0 100 mi
0 100 km

NORTH

Data Sources:
Historic PRISM data (Gibson et al. 2002)[5]
GFDL (Stouffer et al. 2006, Delworth et al. 2006)[6],
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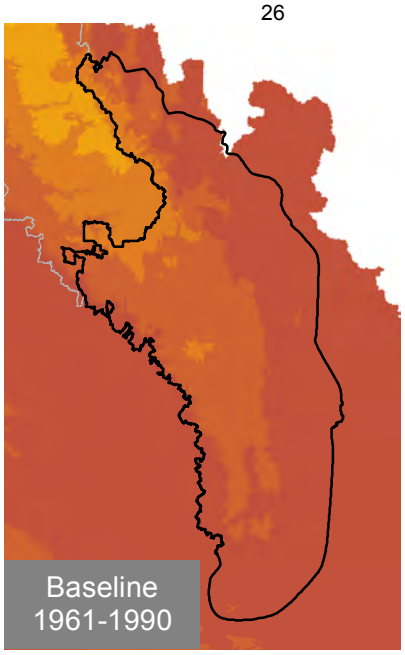
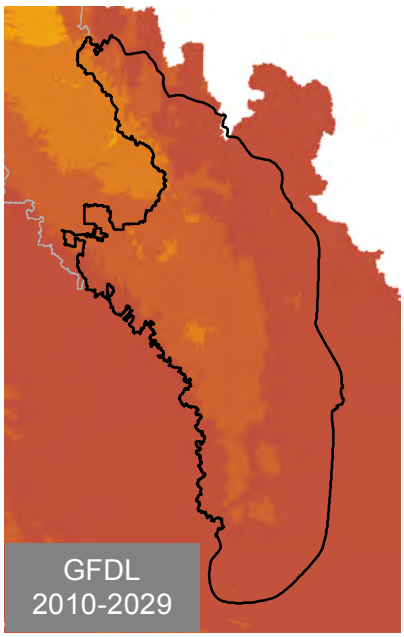
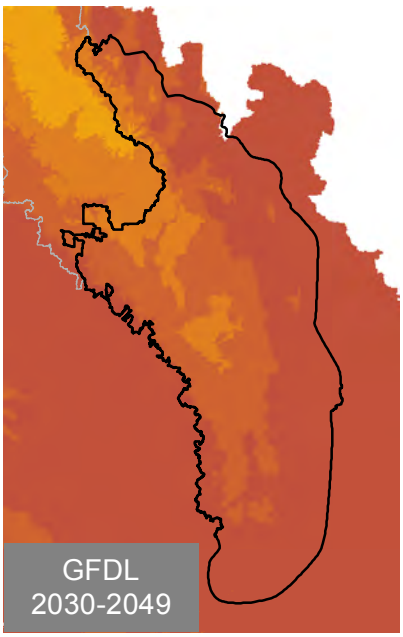
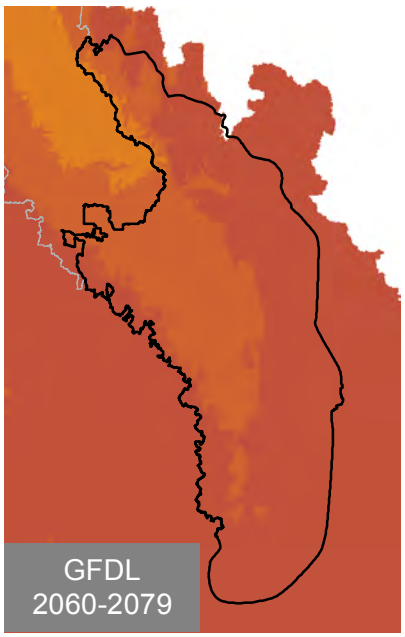
Downscaled following Flint and Flint (2012)[8]

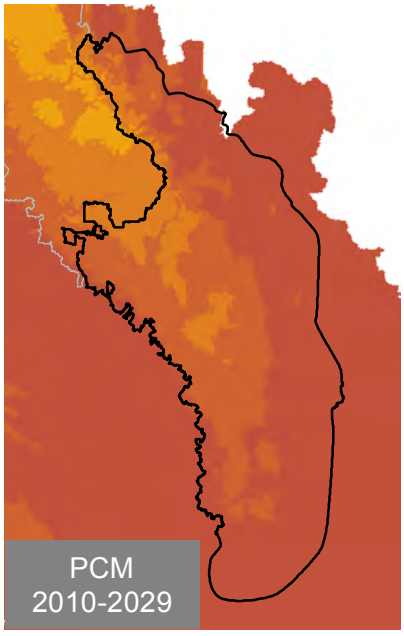
Rev: 2/22/2013

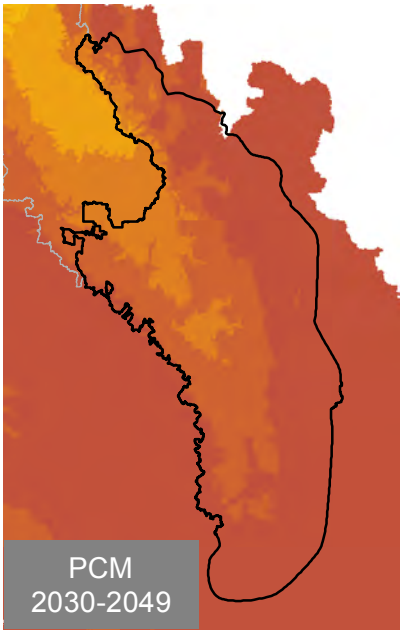


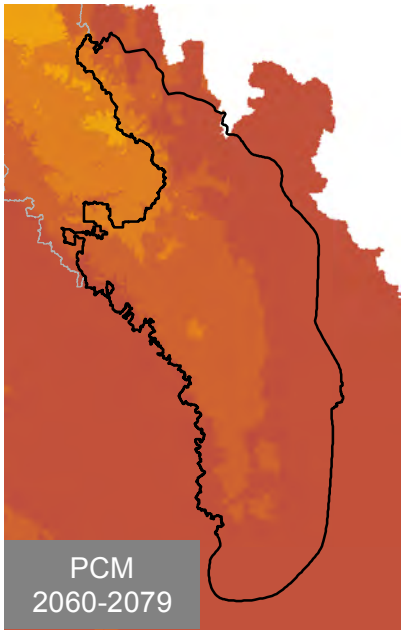












HYDROLOGY

In the Sierra Nevada, surface runoff and hydrology is controlled largely by the snow water equivalent (SWE) of winter snowpack.

Many changes to the hydrology of the Western U.S. have been well documented. These include:

Changes in flow

- 15.8% declines in SWE[9]
- Declines in streamflow[10,11]
  Diminished recharge of subsurface aquifers that support summer baseflows[12]
- Declining summer low flows[13]

Changes in temperature

- Stream temperatures have increased in many areas[14]
- Increased wildfire leads to even more water temperature increase[15]

Changes in storm intensity

- 16% increase in frequency and intensity of very heavy precipitation[16]
- Increased probability of 20-year flood from 1915 to 2003[17]

Changes in seasonal timing

- Rivers and lakes freeze over, on average, 5.8 days later each century[10]
- The ice breakup date is, on average, 6.5 days earlier each century[10]
- Snowmelt and snowmelt-driven runoff also is occurring earlier[18]
- Spring runoff has advanced steadily during the latter half of the twentieth century and now occurs 1 to 3 weeks earlier[7,19]
- Observed streamflow has increased in March and declined in June[11]
- Shifts towards more rainfall, less snowfall[20]

Changes in minimum temperature, declines in SWE, and changes in streamflow timing were all attributed to increased greenhouse gas concentrations in the atmosphere.[18] More extreme downpours are expected to worsen during the coming century.[16,21]

As temperature increase leads to more rain and less snow, the flood risk is expected to increase in the Sierra Nevada.[22] Decreases in snow pack and in the length of the snow season could have serious repercussions to winter recreation and water storage alike.

As temperatures and evapo-transpiration increase, summer low flows are expected to become more severe, with longer and lower low flows.[12]

Basin Characterization Model

Projections of hydrological variables, including average annual/monthly water deficit, snowpack, and runoff, were provided via the Basin Characterization Model (BCM). Below is the abstract from a paper published on the model in 2012. The full paper can be downloaded from the following link: http://climate.calcommons.org/bib/development-and-application-downscaled-hydroclimatic-predictor-variables-use-climate

Citation:
Thorne, J., R. Boynton, L. Flint, A. Flint, and T.-N. Le. 2012. **Development and Application of Downscaled Hydroclimatic Predictor Variables for Use in Climate Vulnerability and Assessment Studies.** California Energy Commission Report #500-2010-010.[23]

Abstract:
This paper outlines the production of 270m grid-scale maps for 14 climate and derivative hydrologic variables for a region that encompasses the State of California and all the streams that flow into it. The paper describes the Basin Characterization Model (BCM), a map-based, mechanistic model used to process the hydrological variables. Three historic and three future time periods of 30 years (1911–1940, 1941–1970, 1971–2000, 2010–2039, 2040–2069, and 2070– 2099) were developed that summarize 180 years of monthly historic and future climate values. These comprise a standardized set of fine-scale climate data that were shared with 14 research groups, including the U.S. National Park Service and several University of California groups as part of this project. The paper presents three analyses done with the outputs from the Basin Characterization Model: trends in hydrologic variables over baseline, the most recent 30-year period; a calibration and validation effort that uses measured discharge values from 139 stream gages and compares those to Basin Characterization Model-derived projections of discharge for the same basins; and an assessment of the trends of specific hydrological variables that links historical trend to projected future change under four future climate projections. Overall, increases in potential evapotranspiration dominate other influences in future hydrologic cycles. Increased potential evapotranspiration drives decreasing runoff even under forecasts with increased precipitation, and drives increased climatic water deficit, which may lead to conversion of dominant vegetation types across large parts of the study region, as well as have implications for rain-fed agriculture. The potential evapotranspiration is driven by air temperatures, and the Basin Characterization Model permits it to be integrated with a water balance model that can be derived for landscapes and summarized by watershed. These results show the utility of using a process-based model with modules representing different hydrological pathways that can be interlinked.

Table 3. Projected average annual runoff, snowpack, and water deficit (and percent change from historic) across the three regions of the Sierra (North, Central, and South), based on output from two different global climate models (GFDL and PCM) under the A2 emissions scenario.

	Historic	2010-29	2030-49	2060-79
Annual Runoff				
North	165mm	-5 to -14%	-5 to -12%	-31 to +10%
Central	386mm	-3 to -10%	-2 to +3%	-31 to +15%
South	140mm	-10 to +1%	-4 to 0%	-41 to +12%
Annual Snowpack				
North	751mm	-39 to -41%	-39 to -59%	-73 to -87%
Central	1153mm	-38 to -40%	-47 to -53%	-64 to -77%
South	2237mm	-58 to -64%	-67 to -70%	-72 to -86%
Annual Water Deficit				
North	500mm	+6 to +13%	+6 to +25%	+25 to +44%
Central	530mm	+6 to +8%	+12 to +21%	+22 to +38%
South	698mm	+6 to +8%	+12 to +16%	+19 to +33%

Annual Average Runoff

Northern Region
Sierra Nevada

GEOS INSTITUTE

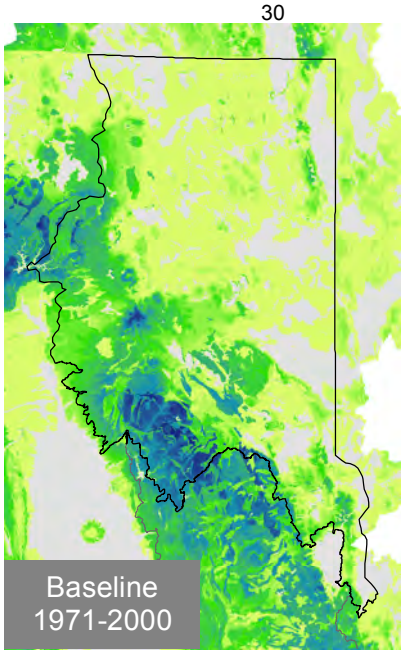
Data Sources:
Thorne et al. 2012[23]

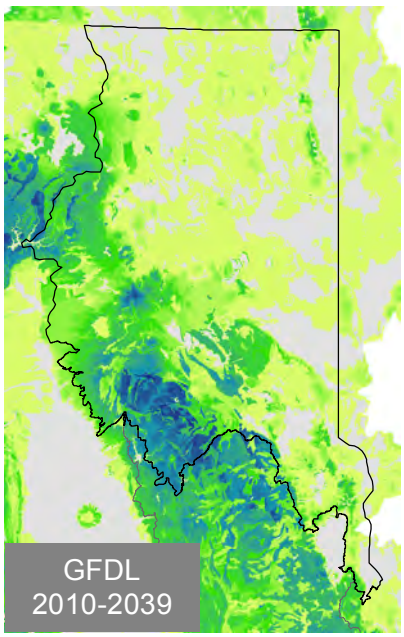
Rev: 2/22/2013

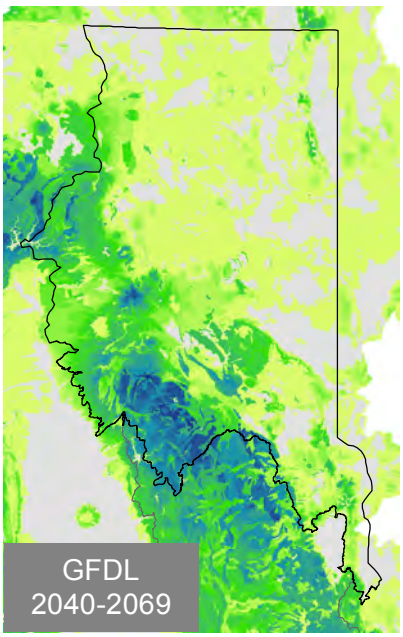
Runoff in mm

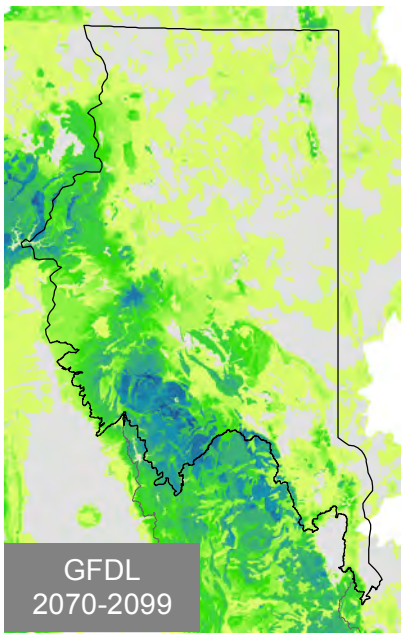
< 0	481 - 600
1 - 48	601 - 720
49 - 96	721 - 960
97 - 144	961 - 1,200
145 - 192	1,201 - 1,440
193 - 240	1,441 - 1,680
241 - 360	1,681 - 2,040
361 - 480	2,041 - 2,400

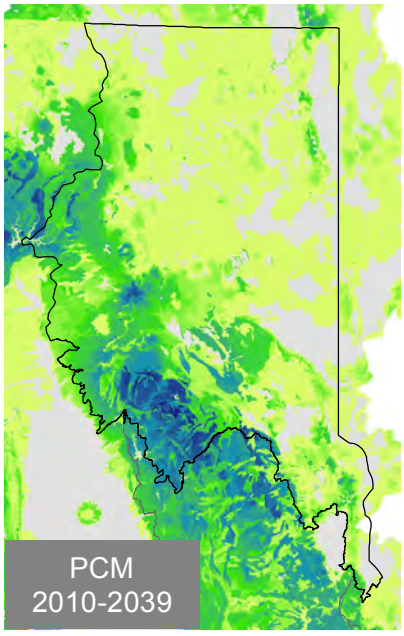
0 100 mi
0 100 km
NORTH

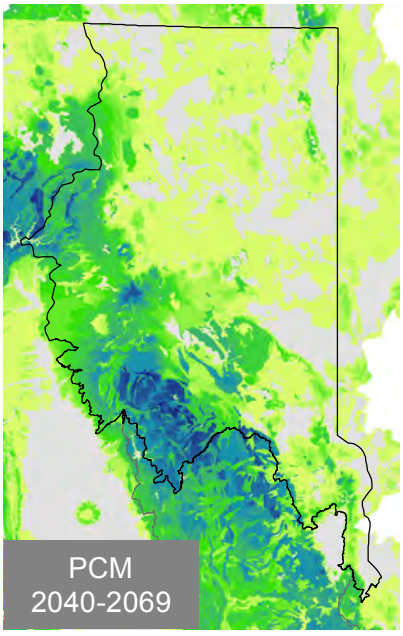


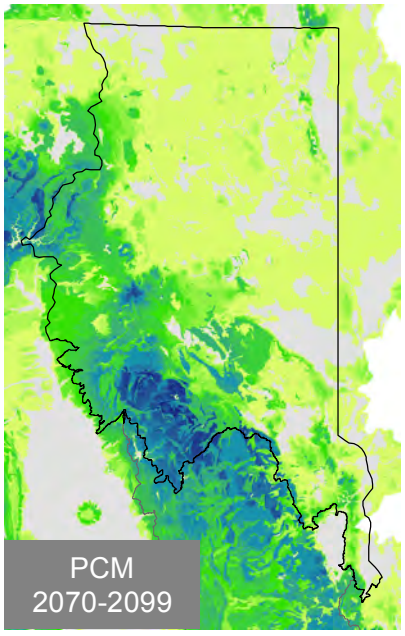












Annual Average Runoff

Central Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Thorne et al. 2012[23]

Rev: 2/22/2013

Runoff in mm

< 0	481 - 600
1 - 48	601 - 720
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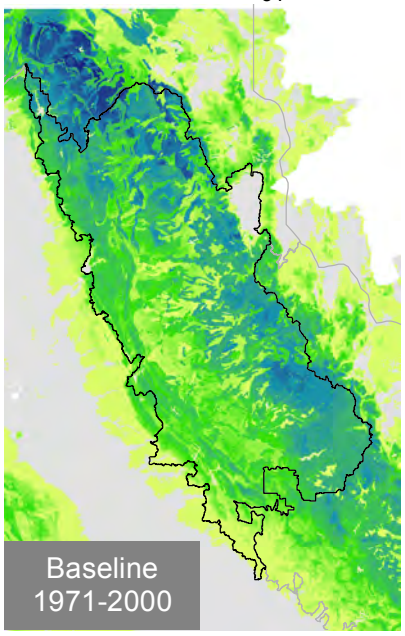
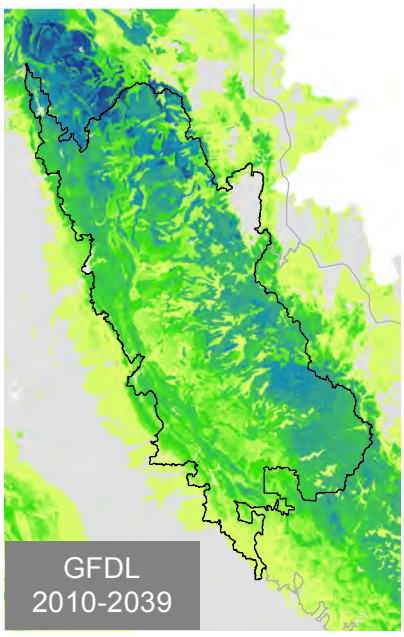
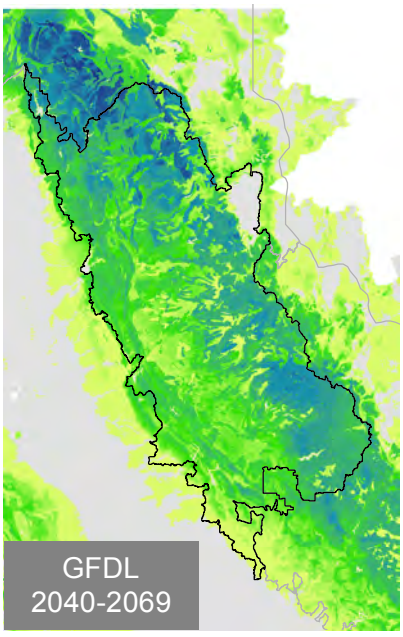
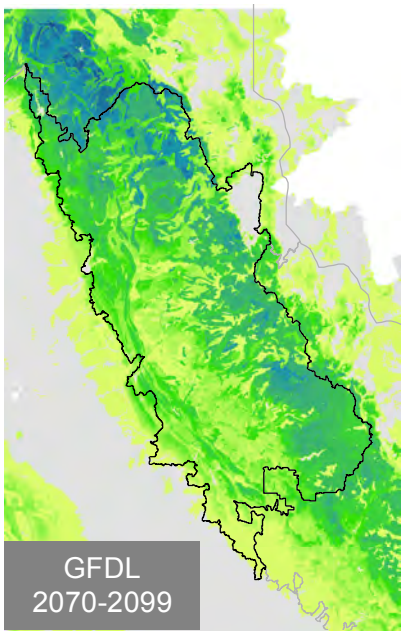
361 - 480	2,041 - 2,400

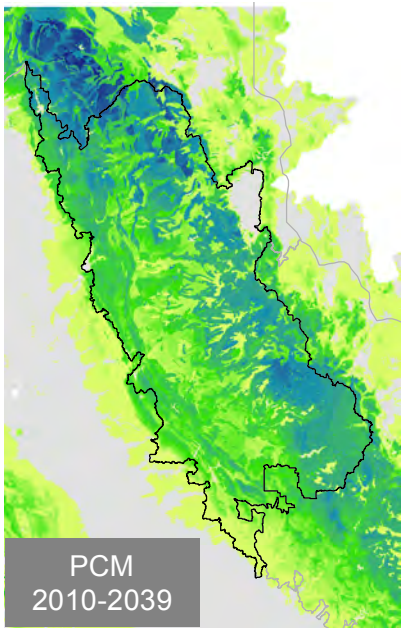
0 100 mi
0 100 km
NORTH

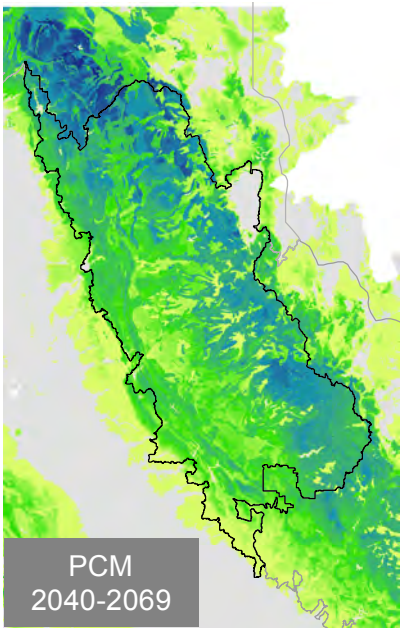


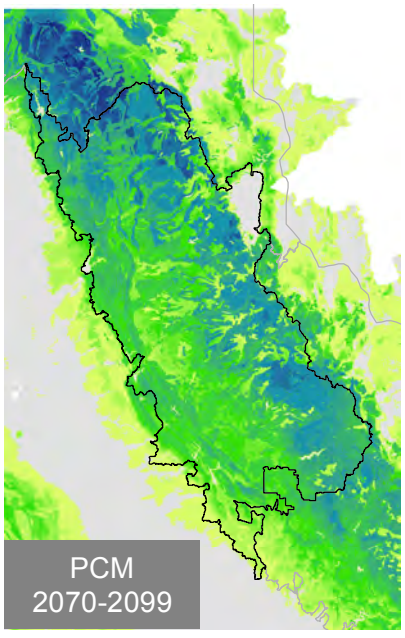












Annual Average Runoff

Southern Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Thorne et al. 2012[23]

Rev: 2/22/2013

Runoff in mm

< 0	481 - 600
1 - 48	601 - 720
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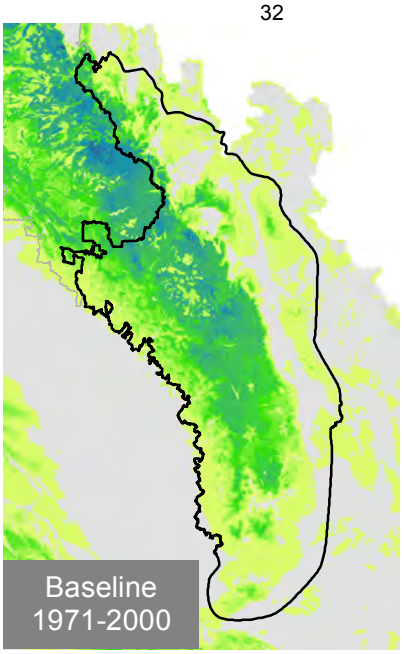
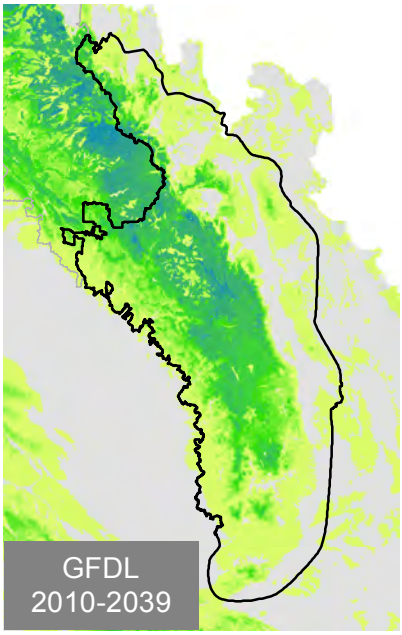
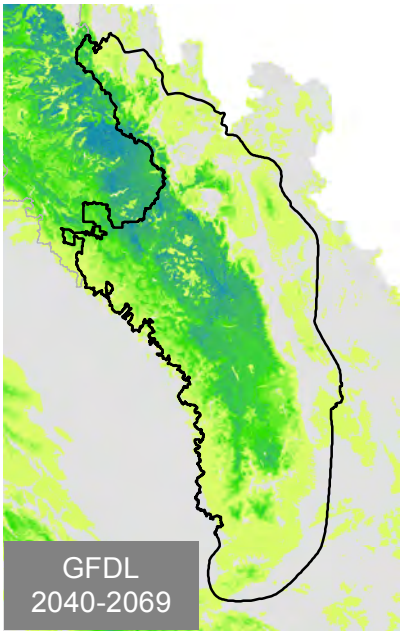
361 - 480	2,041 - 2,400

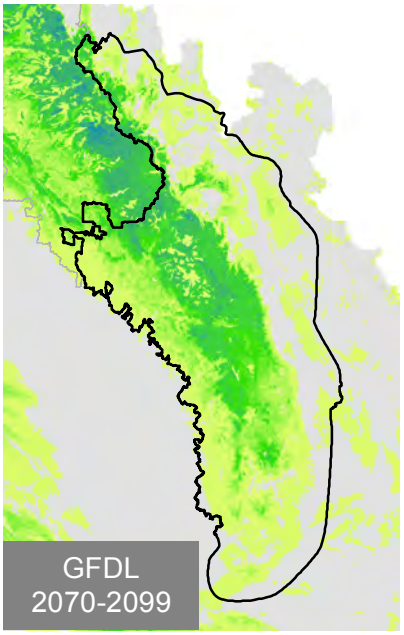
0 100 mi
0 100 km

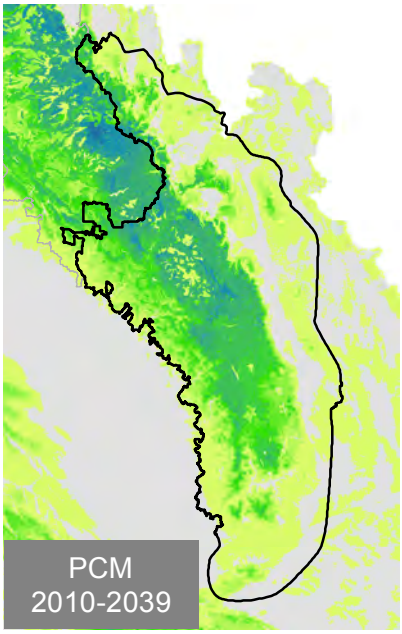
NORTH

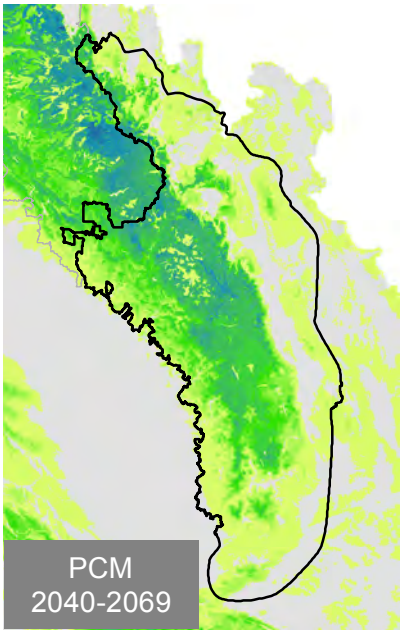


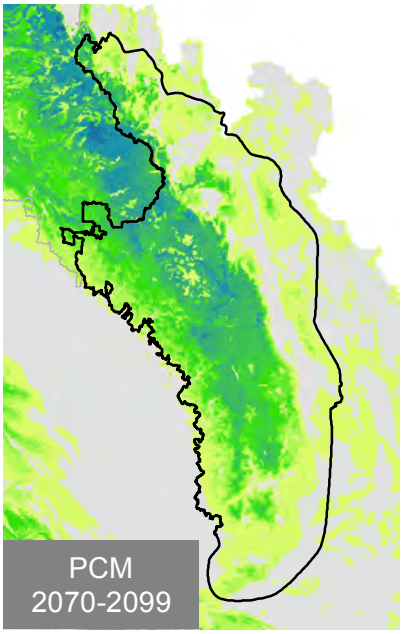












Annual Average Snowpack

Northern Region
Sierra Nevada

GEOS INSTITUTE

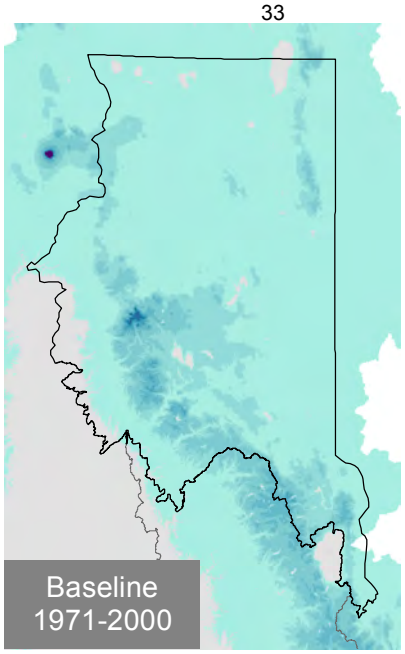
Data Sources:
Thorne et al. 2012[23]

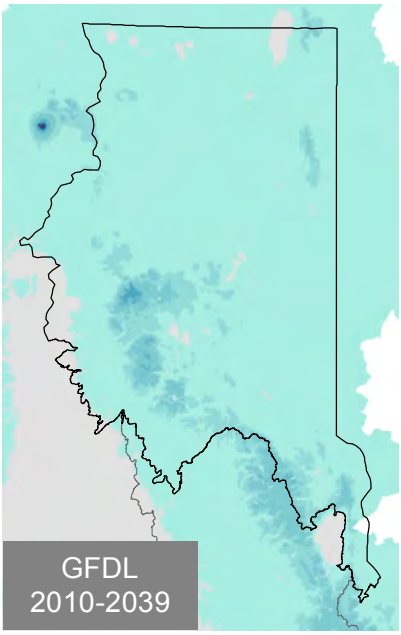
Rev: 2/22/2013

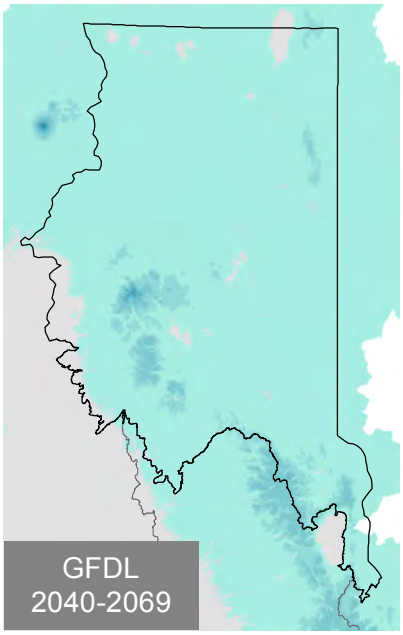
Snowpack in mm

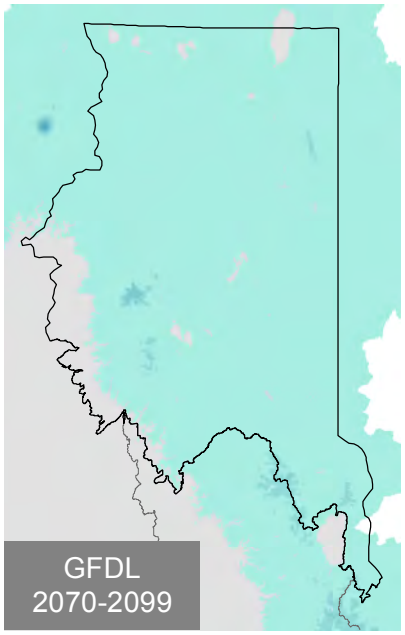
-30,000 - 0	12,501 - 15,000
1 - 1,000	15,001 - 20,000
1,001 - 2,000	20,001 - 25,000
2,001 - 4,000	25,001 - 40,000
4,001 - 6,000	40,001 - 60,000
6,001 - 8,000	60,001 - 85,000
8,001 - 10,000	85,001 - 150,000
10,001 - 12,500	> 150,001

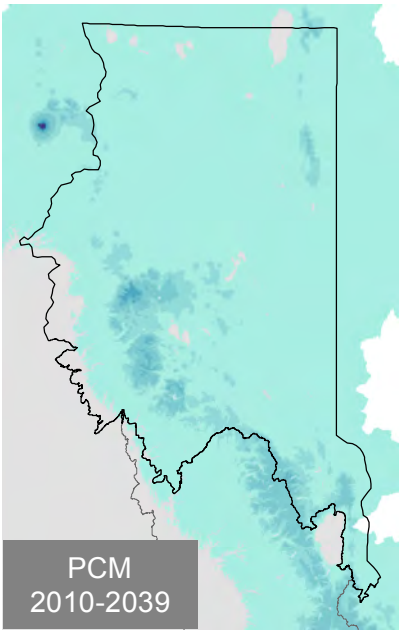
0 100 mi
0 100 km
NORTH

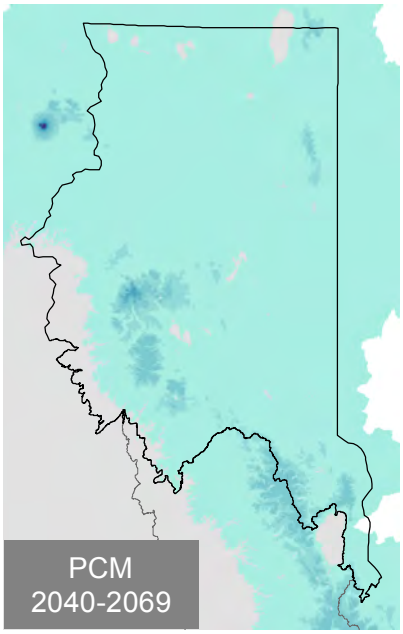


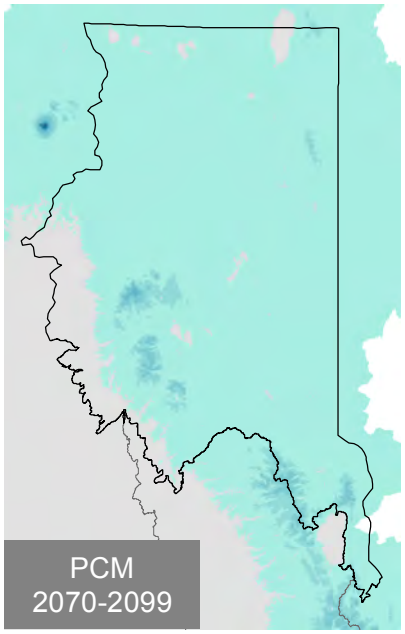












Annual Average Snowpack

Central Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Thorne et al. 2012[23]

Rev: 2/22/2013

Snowpack in mm

-30,000 - 0	12,501 - 15,000
1 - 1,000	15,001 - 20,000
1,001 - 2,000	20,001 - 25,000
2,001 - 4,000	25,001 - 40,000
4,001 - 6,000	40,001 - 60,000
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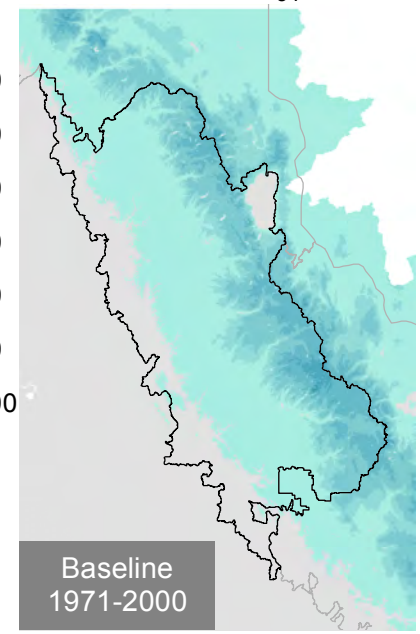
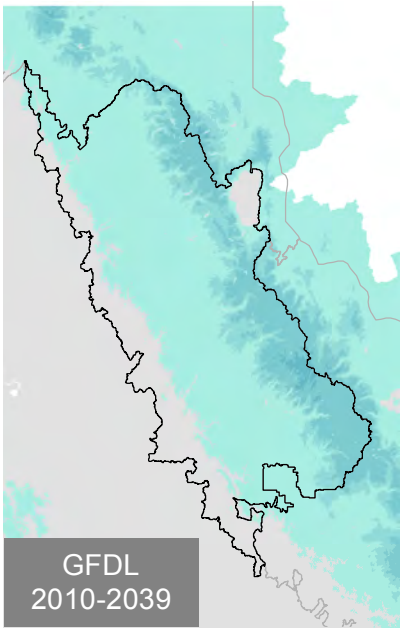
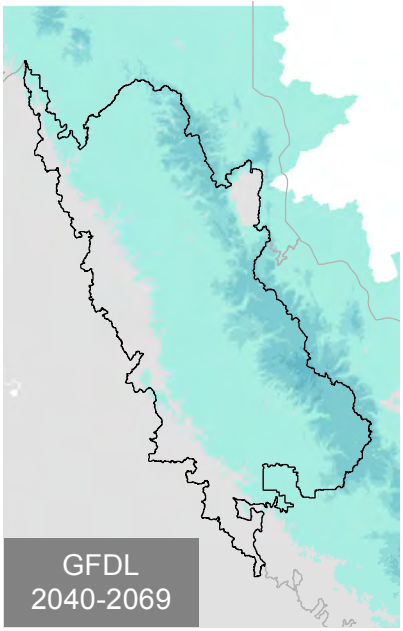
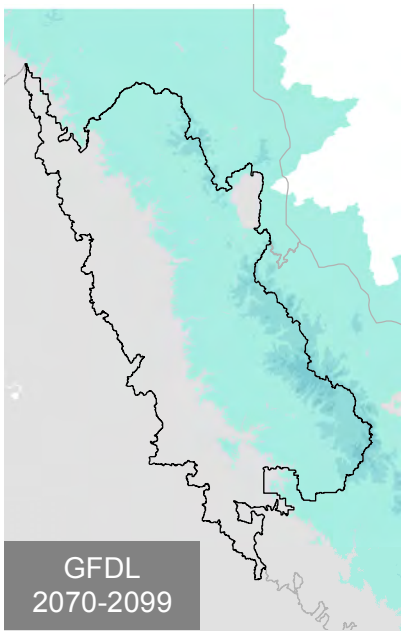
8,001 - 10,000	85,001 - 150,000
10,001 - 12,500	> 150,001

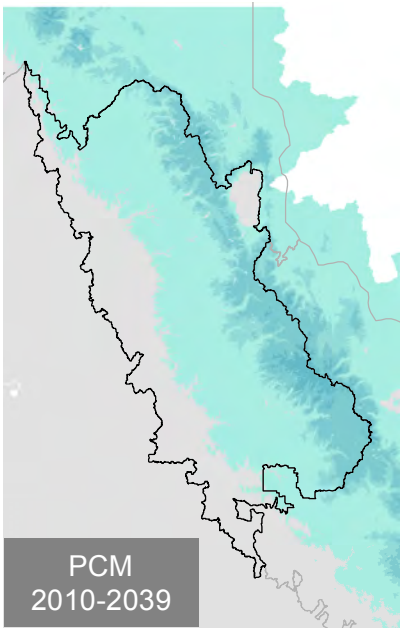
0 100 mi
0 100 km
NORTH

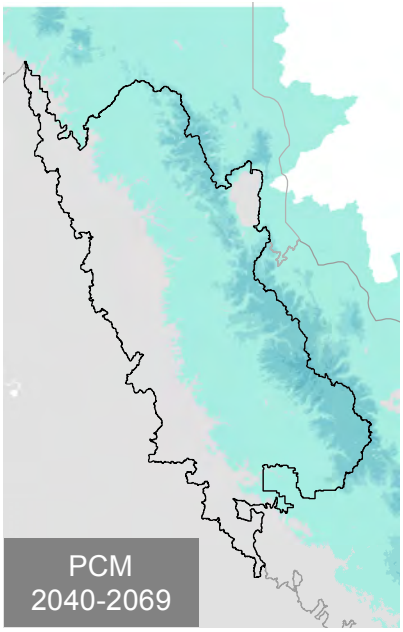


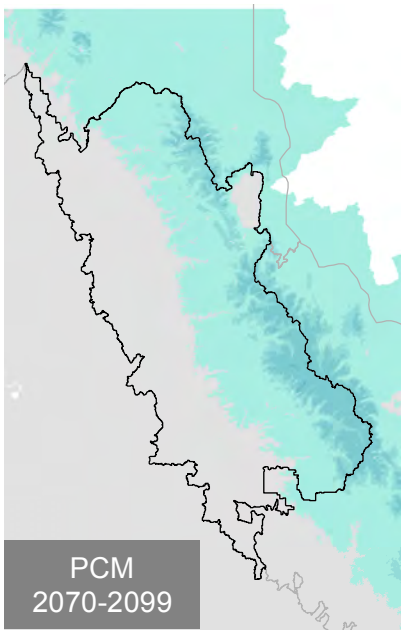












Annual Average Snowpack

Southern Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Thorne et al. 2012[23]

Rev: 2/22/2013

Snowpack in mm

-30,000 - 0	12,501 - 15,000
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1,001 - 2,000	20,001 - 25,000
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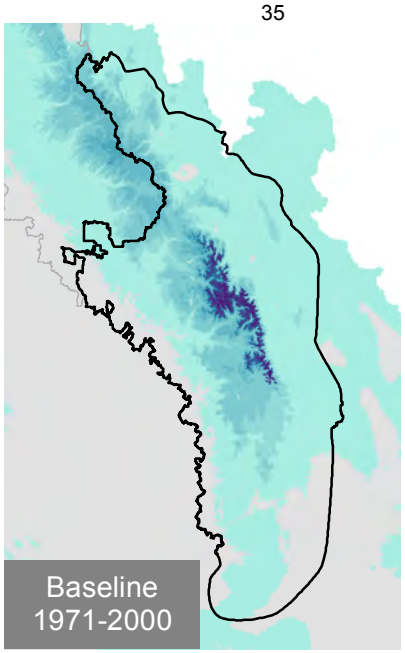
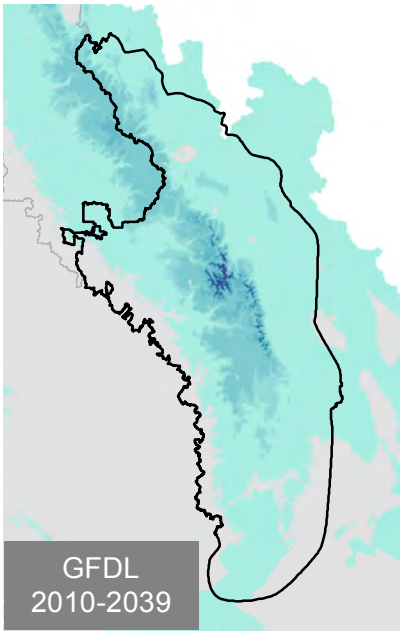
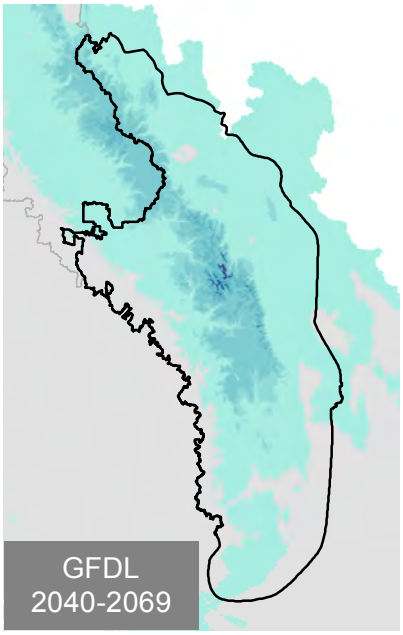
8,001 - 10,000	85,001 - 150,000
10,001 - 12,500	> 150,001

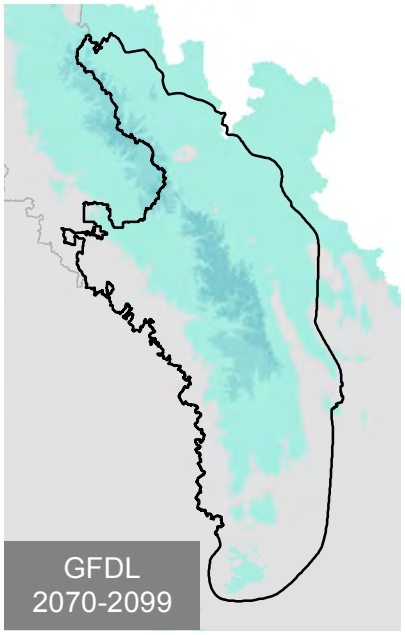
0 100 mi
0 100 km

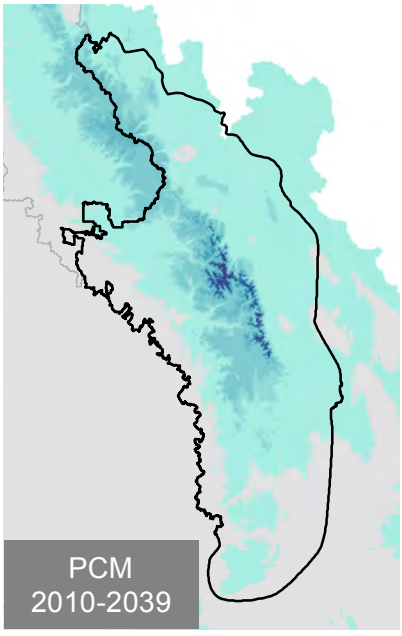
NORTH

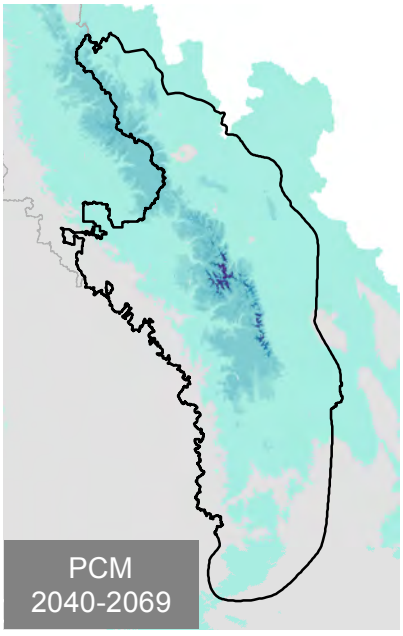


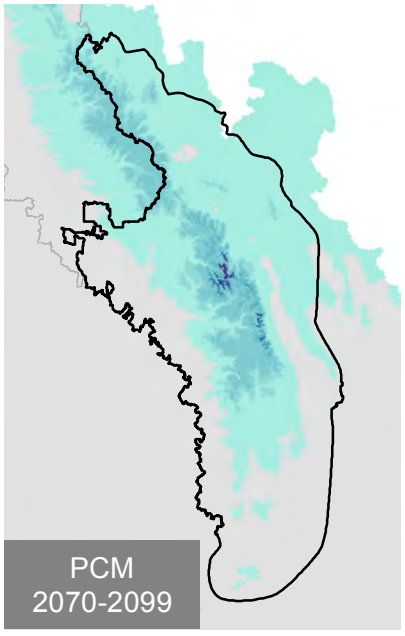












Annual Average Water Deficit

Northern Region
Sierra Nevada

GEOS INSTITUTE

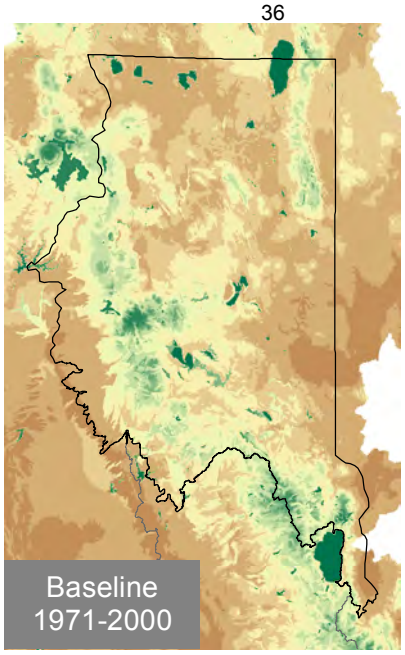
Data Sources:
Thorne et al. 2012[23]

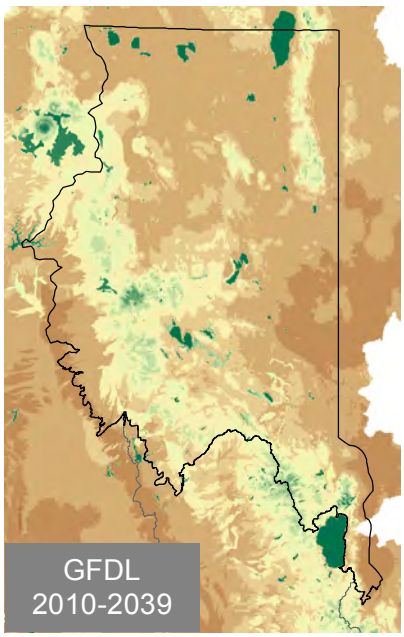
Rev: 2/22/2013

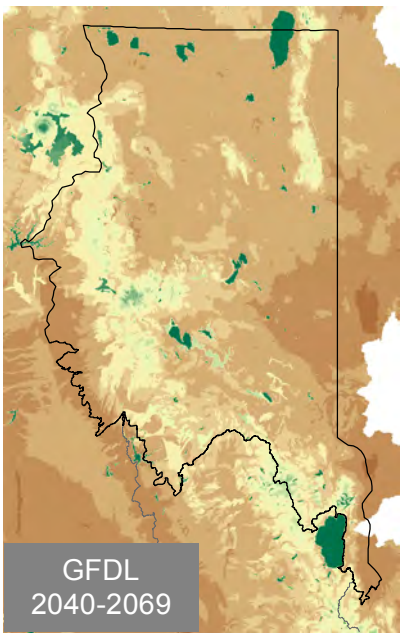
Water Deficit in mm

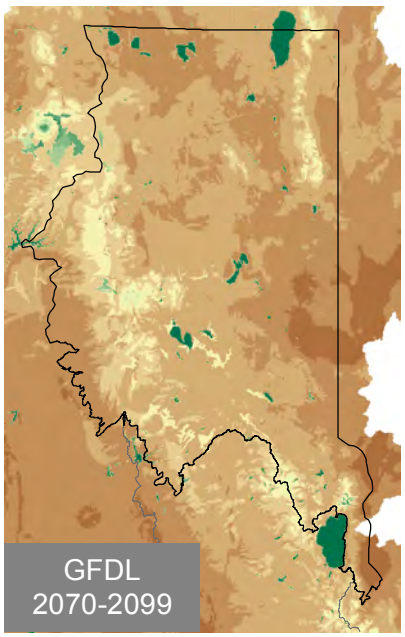
< 0	401 - 500
1 - 40	501 - 600
41 - 80	601 - 800
81 - 120	801 - 1,000
121 - 160	1,001 - 1,200
161 - 200	1,201 - 1,400
201 - 300	1,401 - 1,700
301 - 400	1,701 - 2,000

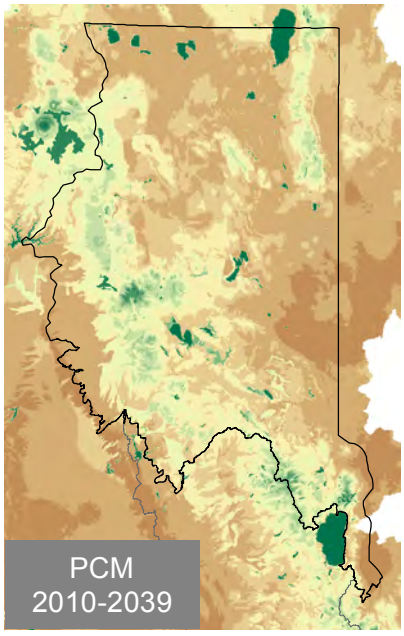
0 100 mi
0 100 km
NORTH

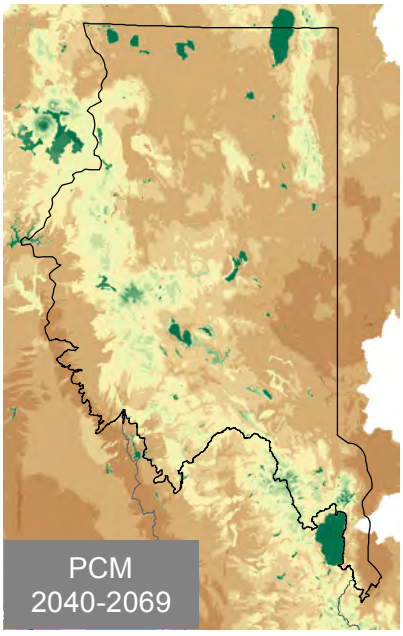


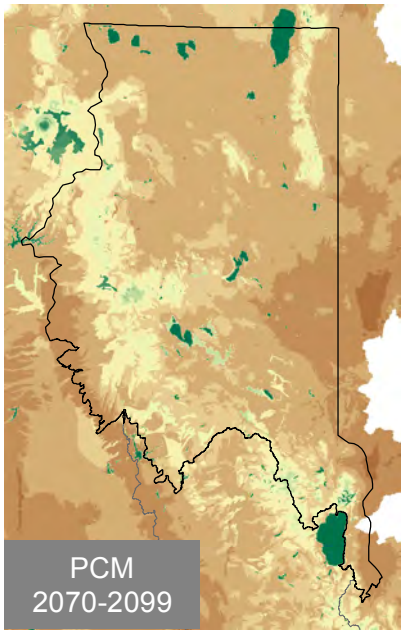












Annual Average Water Deficit

Central Region
Sierra Nevada

GEOS INSTITUTE

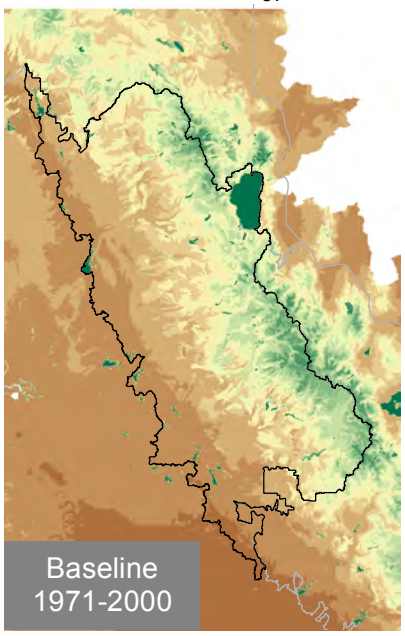
Data Sources:
Thorne et al. 2012[23]

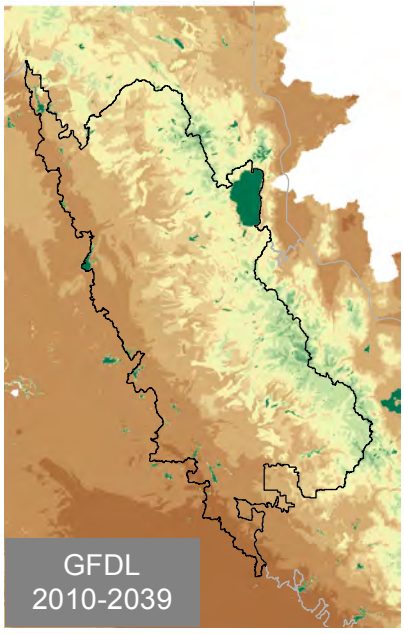
Rev: 2/22/2013

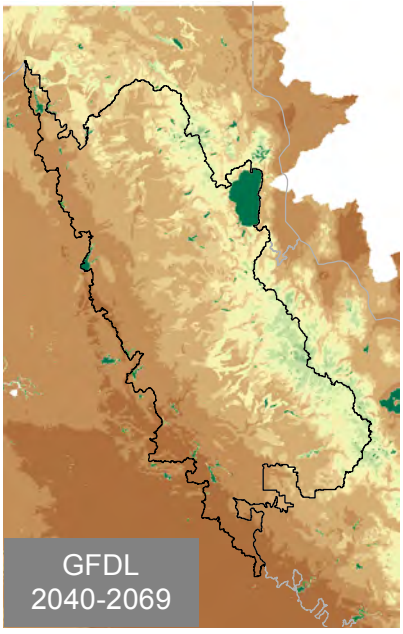
Water Deficit in mm

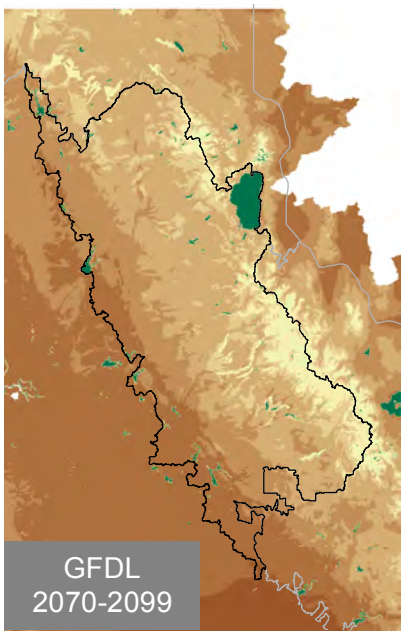
< 0	401 - 500
1 - 40	501 - 600
41 - 80	601 - 800
81 - 120	801 - 1,000
121 - 160	1,001 - 1,200
161 - 200	1,201 - 1,400
201 - 300	1,401 - 1,700
301 - 400	1,701 - 2,000

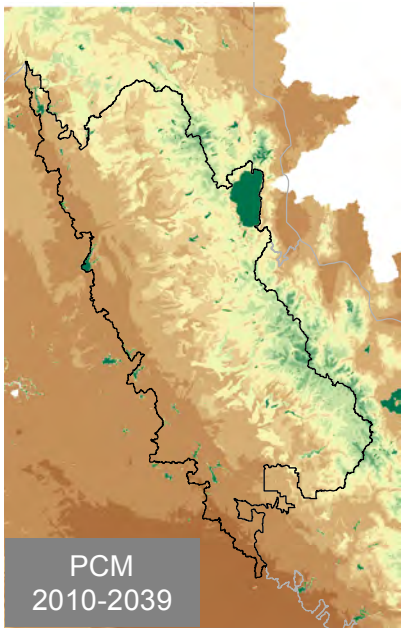
0 100 mi
0 100 km
NORTH

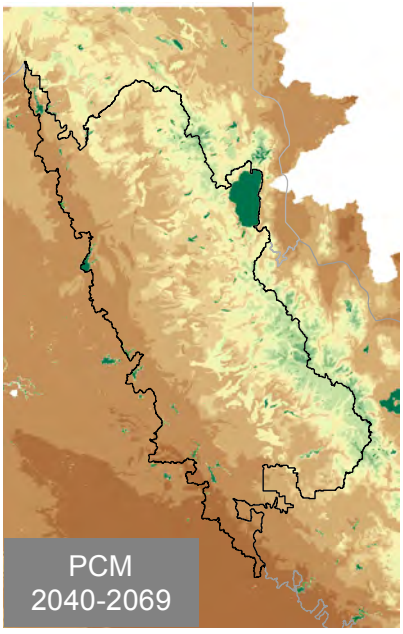


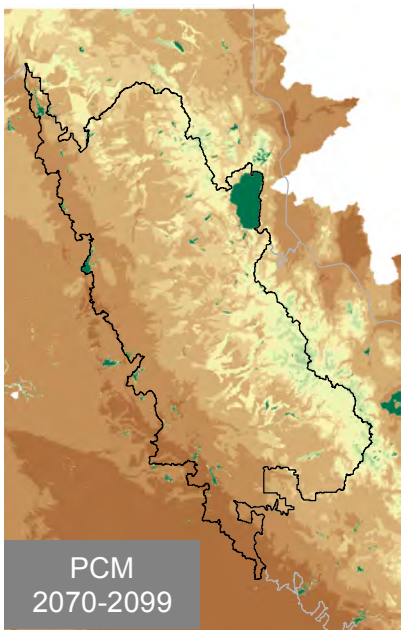












Annual Average Water Deficit

Southern Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Thorne et al. 2012[23]

Rev: 2/22/2013

Water Deficit in mm

< 0	401 - 500
1 - 40	501 - 600
41 - 80	601 - 800
81 - 120	801 - 1,000
121 - 160	1,001 - 1,200
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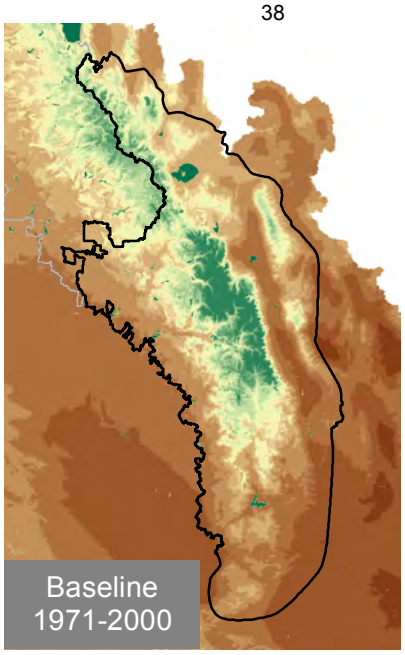
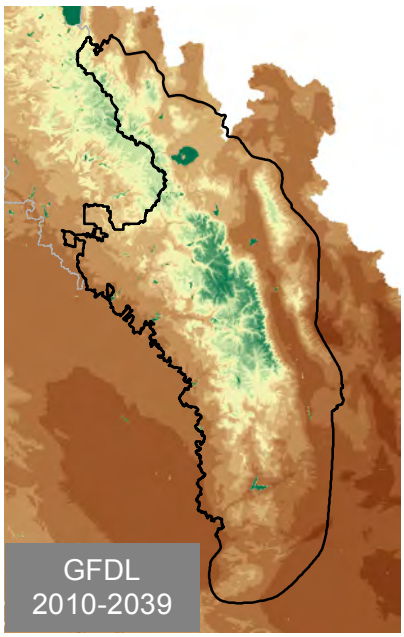
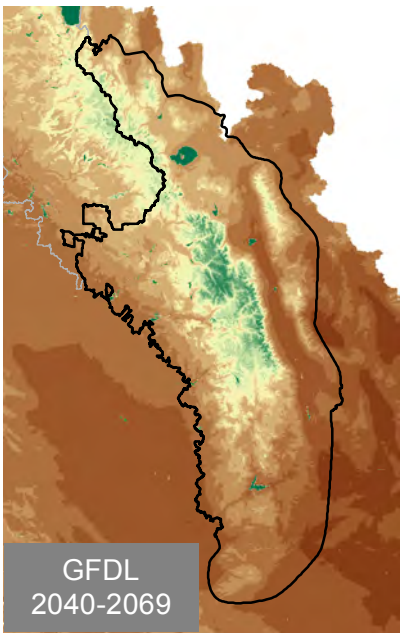
301 - 400	1,701 - 2,000

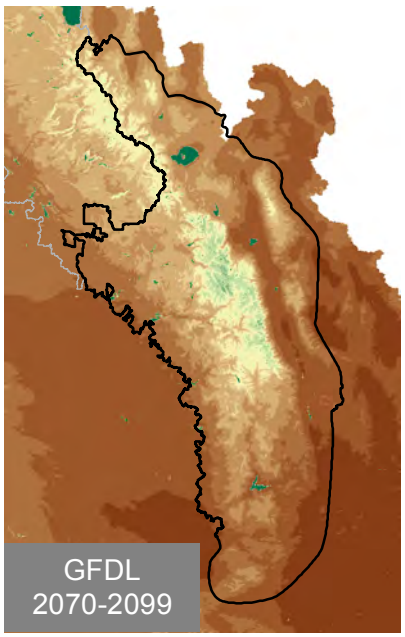
0 100 mi
0 100 km

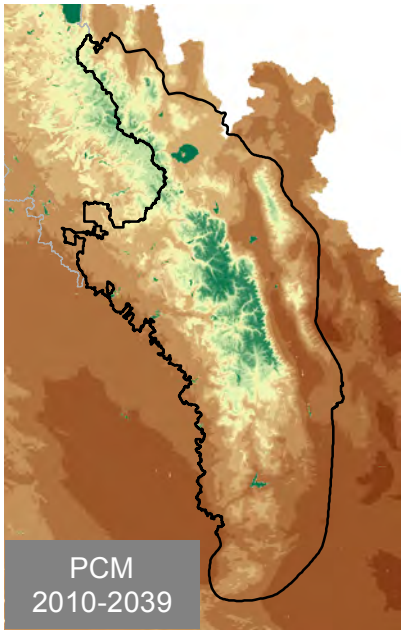
NORTH

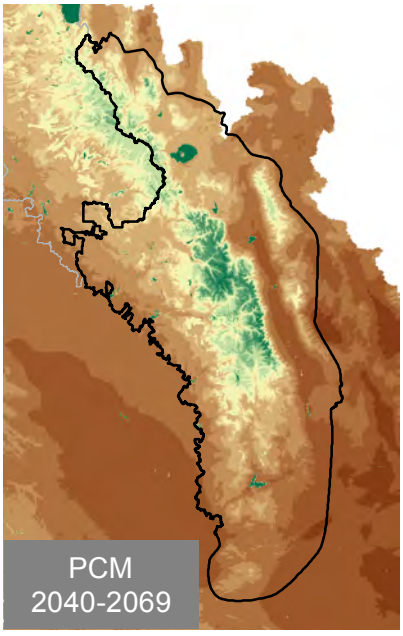


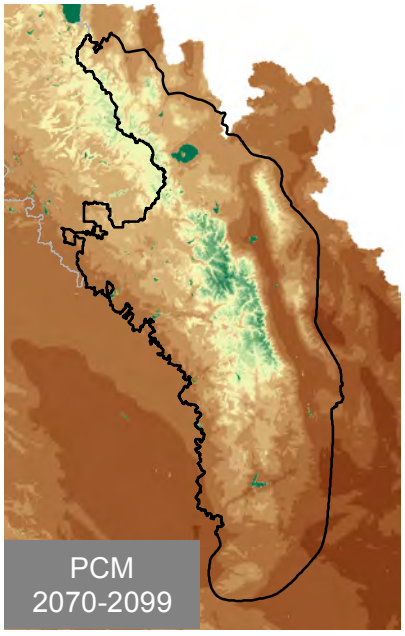












VEGETATION

Vegetation composition throughout the Sierra Nevada has changed over time.[24] Most changes are due to harvest, natural succession, fire, and insect or disease outbreaks, some of which may be linked to climate change. Overall, U.S. forests have become more productive in the last 55 years,[25] likely due to a longer growing season and higher CO_2 levels. Treeline has advanced up slope. As conditions become warmer and drier in the summer, forests in many areas are expected to become less productive due to lower soil moisture during the growing season, temperature stress, insect and disease outbreaks, invasive species prevalence, and wildfire.

MC1 Dynamic Vegetation Model

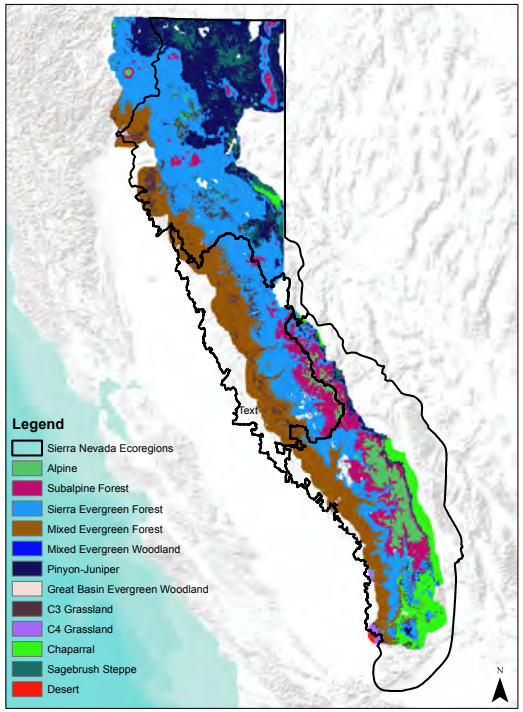
In this section we present the results of the MC1 dynamic vegetation model,[27] mapped by the Conservation Biology Institute. MC1 is a widely used dynamic global vegetation model (DGVM) that simulates vegetation types, ecosystem fluxes of carbon, nitrogen, and water, as well as wildfire occurrence and impacts. MC1 is routinely implemented on spatial data grids of varying resolution (i.e., grid cell sizes ranging from 900 m^2 to 2500 km^2). The MAPSS Team (Mapped Atmosphere-Plant-Soil System) at the USFS Pacific Northwest Research Station used three global climate models (HadCM, MIROC, and CSIRO) to provide input variables to MC1.

The model reads climate data at a monthly time step and calls interacting modules that simulate biogeography, biogeochemistry and fire disturbance.

Most climate models project the future climate at global scales. Managers and decision makers, however, need information about how climate change will impact the local area. The MAPSS Team adjusted global model output to local and regional scales (800 m). This process increases the precision of the projections, but not the accuracy; they are still associated with high uncertainty and variation.

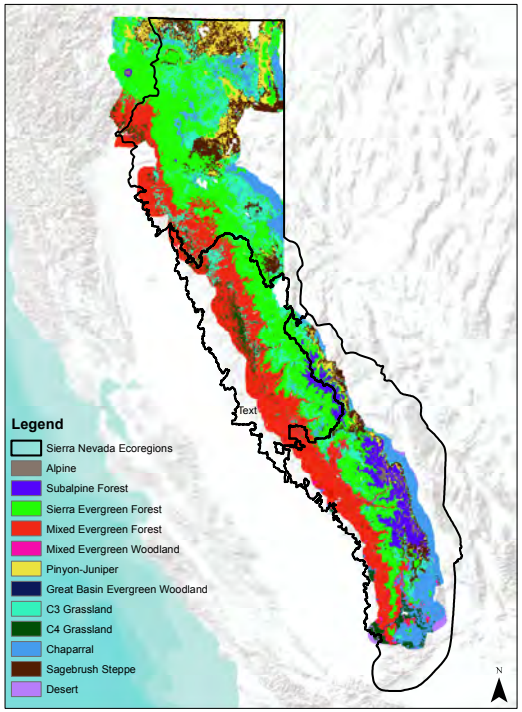
Please see page 13 in the USDA Forest Service report[26] entitled **A Climate Change Primer for Land Managers: An Example from the Sierra Nevada**, by T. L. Morelli, M. C. McGlinchy, and R. P. Neilson (2011) for more details about MC1.

Historic simulated vegetation class (mode), 1986-2005



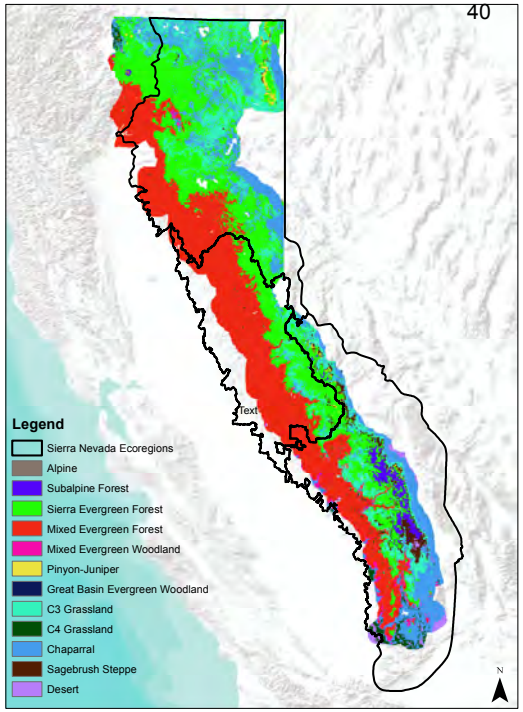
Dataset Credit: Conservation Biology Institute Data Resolution: 800 meter

Simulated vegetation class, 2046-2065, Hadley CM3 A2



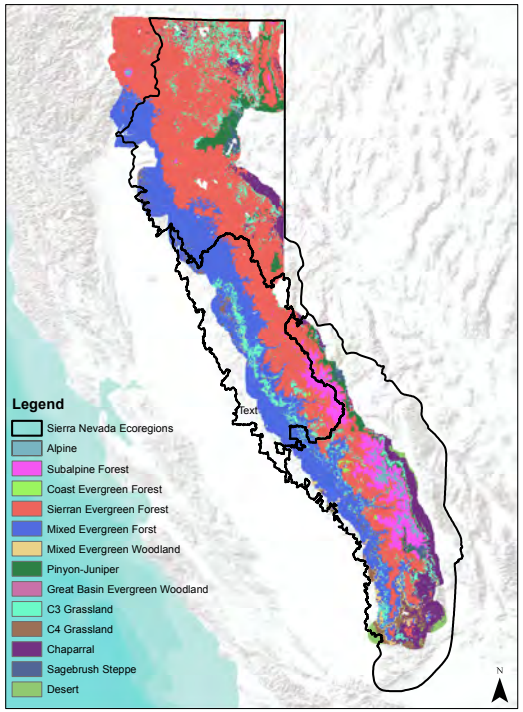
Dataset Credit: Conservation Biology Institute Data Resolution: 800 meter

Simulated vegetation class, 2076-2095, Hadley CM3 A2



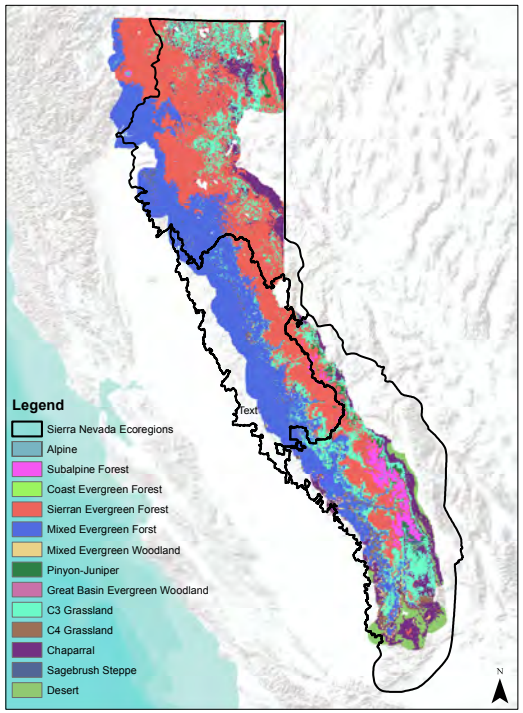
Dataset Credit: Conservation Biology Institute Data Resolution: 800 meter

Simulated vegetation class, 2046-2065, MIROC A2



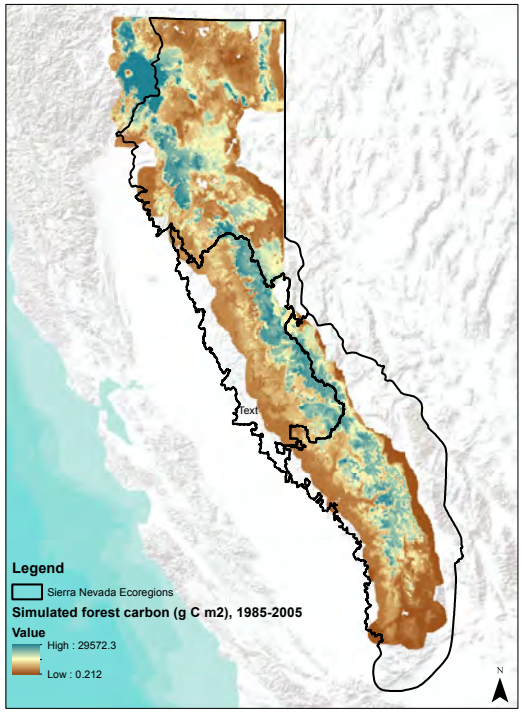
Dataset Credit: Conservation Biology Institute Data Resolution: 800 meter

Simulated vegetation class, 2076-2095, MIROC A2



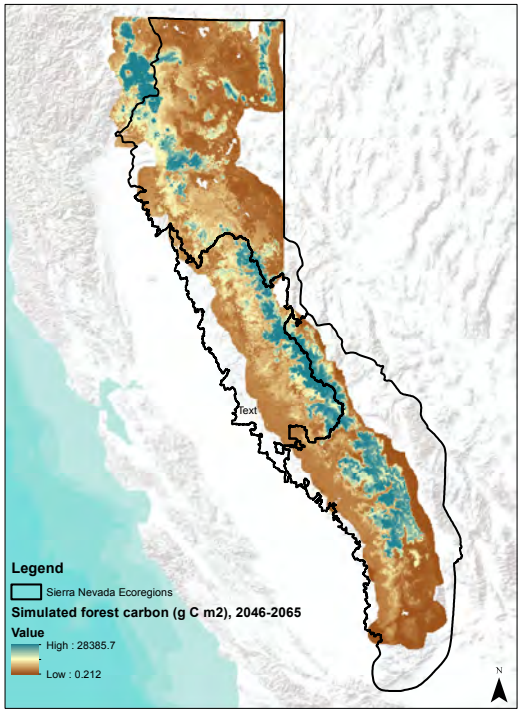
Dataset Credit: Conservation Biology Institute Data Resolution: 800 meter

Historic simulated forest carbon (g C m2), 1985-2005



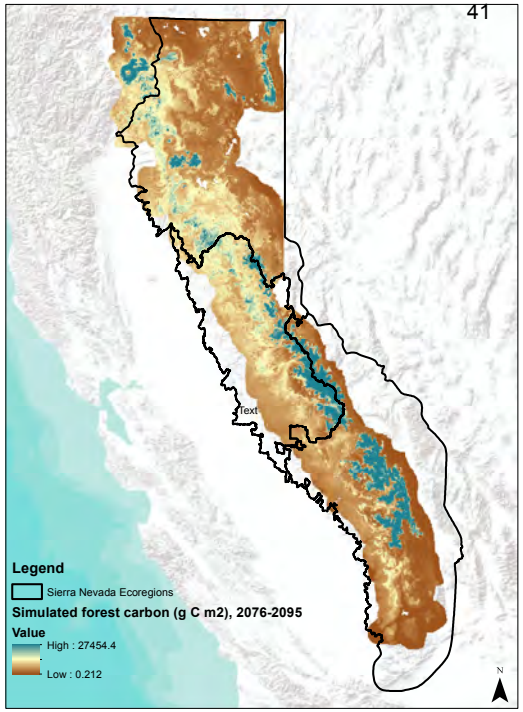
Dataset Credit: Conservation Biology Institute Data Resolution: 800 m

Simulated forest carbon (g C m2), 2046-2065, Hadley CM3 A2



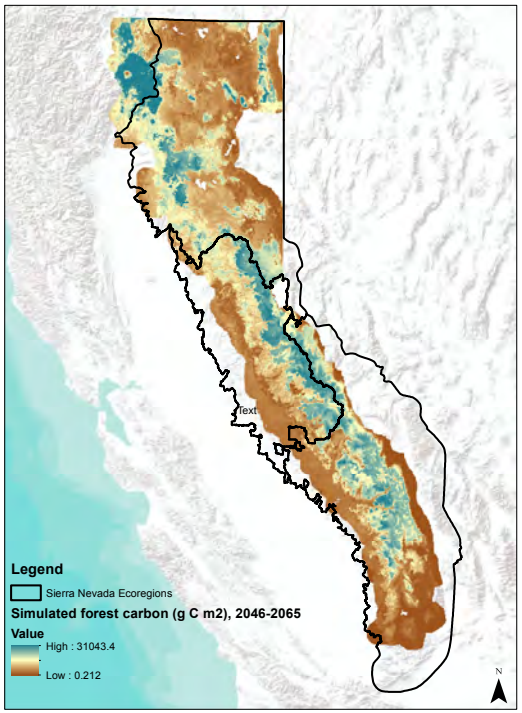
Dataset Credit: Conservation Biology Institute Data Resolution: 800 m

Simulated forest carbon (g C m2), 2076-2095, Hadley CM3 A2



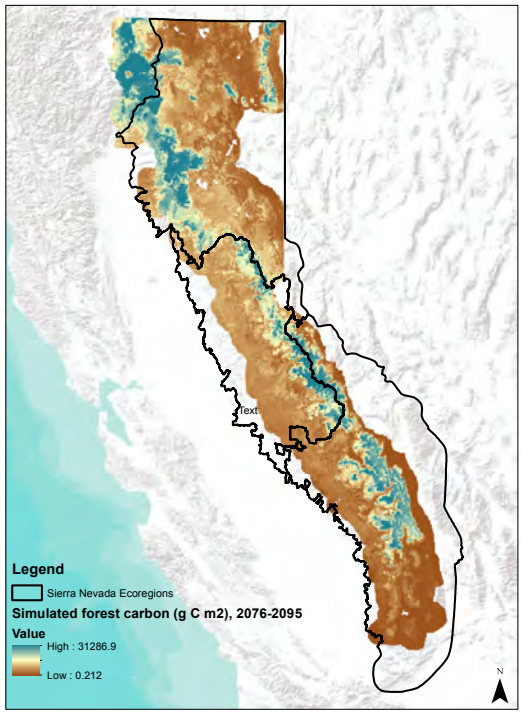
Dataset Credit: Conservation Biology Institute Data Resolution: 800 m

Simulated forest carbon (g C m2), 2046-2065, MIROC A2



Dataset Credit: Conservation Biology Institute Data Resolution: 800 m

Simulated forest carbon (g C m2), 2076-2095, MIROC A2



Dataset Credit: Conservation Biology Institute Data Resolution: 800 m

WILDFIRE

In the western United States, wildfire is driven by a number of natural factors, including fuel availability, temperature, precipitation, wind, humidity, lightning strikes, and anthropogenic factors, including human-caused fire starts. The natural factors are significantly affected by climate.[28] Wildfire is also closely associated with large scale climate patterns such as El Niño.[28]

Years with early arrival of spring account for most of the forest wildfires in the western United States (56% of wildfires and 72% of area burned, as opposed to 11% of wildfires and 4% of area burned occurring in years with a late spring; Figure 3).

Wildfire activity increases during warm years, with relatively little activity in cool years. Since the mid-1980s the incidence wildfire, extent of area burned, and length of season all have increased. The frequency of large wildfires in western U.S. forests today is four times greater than it was in 1970-1986.[29]

The average length of fire season (the time between the first wildfire discovery date and the last wildfire control date) has increased by 78 days (64%) since 1970. The wildfire season is expanding its reach earlier into spring and later into fall.[28]

Fire severity can be expected to increase given warmer and drier conditions.[30] An assessment of climate change and forest fires over North America projected 10-50% increases in seasonal severity rating (SSR) over most of the U.S.,[31] implying increases in area burned and fire severity.

Lightning strikes are also expected to increase with increasing CO_2 in the atmosphere[32], potentially affecting fire frequency.[30]

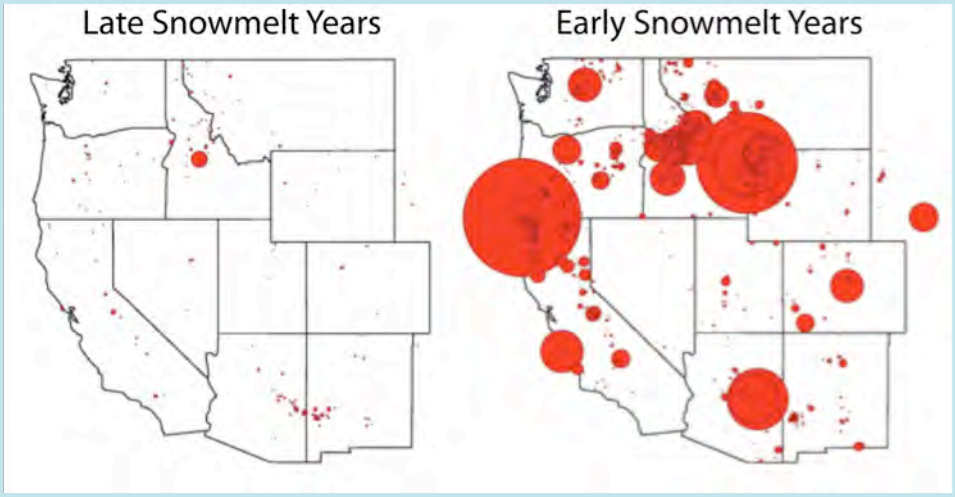


Figure 3. Forest Service, Park Service and Bureau of Indian Affairs large forest wildfires (>1000 acres) for years with early or late spring snowmelt, 1972 - 2003. From *Westerling et al 2006.*[29]

Wildfire and Population Growth Model

In this section, we provide model projections for future changes in wildfire in the Sierra Nevada. Details specific to the model can be found in the following publication. We have included the abstract below.

Citation: Westerling, A. L. B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das, and S. R. Shrestha. **2011. Climate change and growth scenarios for California wildfire.** Climatic Change (2011) 109 (Suppl 1):S445–S463.[33]

Abstract: Large wildfire occurrence and burned area are modeled using hydroclimate and landsurface characteristics under a range of future climate and development scenarios. The range of uncertainty for future wildfire regimes is analyzed over two emissions pathways (the Special Report on Emissions Scenarios [SRES] A2 and B1 scenarios); three global climate models (Centre National de Recherches Météorologiques CM3, Geophysical Fluid Dynamics Laboratory CM2.1 and National Center for Atmospheric Research PCM1); three scenarios for future population growth and development footprint; and two thresholds for defining the wildland-urban interface relative to housing density. Results were assessed for three 30-year time periods centered on 2020, 2050, and 2085, relative to a 30-year reference period centered on 1975. Increases in wildfire burned area are anticipated for most scenarios, although the range of outcomes is large and increases with time. The increase in wildfire burned area associated with the higher emissions pathway (SRES A2) is substantial, with increases statewide ranging from 36% to 74% by 2085, and increases exceeding 100% in much of the forested areas of Northern California in every SRES A2 scenario by 2085.

Table 3. Projected average annual area burned and particulate matter (and percent change from historic) across the three regions of the Sierra (North, Central, and South), based on output from two different global climate models (GFDL and PCM) under the A2 emissions scenario.

	Historic	2005-2034	2035-2064	2070-2099
Particulate Matter				
North	50551674g	+6 to +39%	+37 to +54%	+70 to +125%
Central	90195495g	+8 to +36%	+32 to +66%	+56 to +152%
South	70757340g	+5 to +25%	+17 to +52%	+35 to +85%
Area Burned				
North	41 hectares	+6 to +38%	+36 to +52%	+67 to +117%
Central	71 hectares	+8 to +38%	+33 to +72%	+59 to +169%
South	66 hectares	+4 to +25%	+17 to +53%	+35 to +88%

Annual Average Particulate Matter

Northern Region
Sierra Nevada

GEOS INSTITUTE

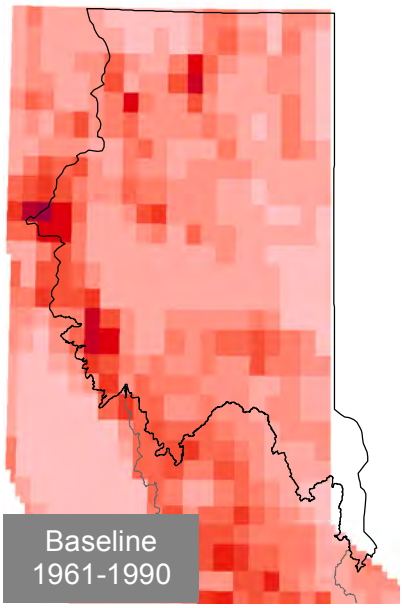
Data Sources:
Westerling et al. 2011[33]

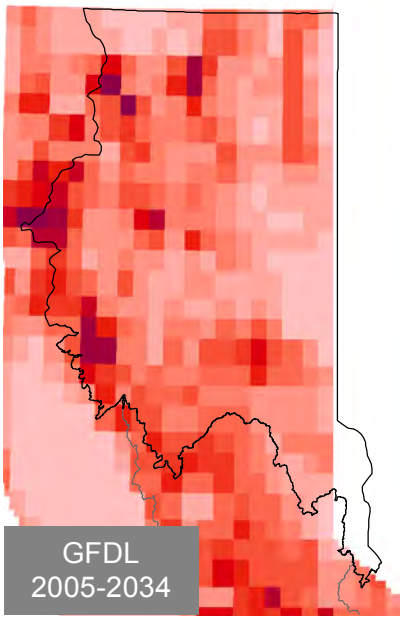
Rev: 2/22/2013

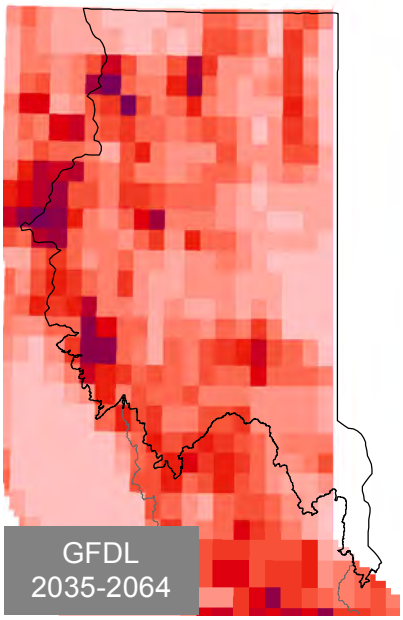
TPM in millions of grams emitted

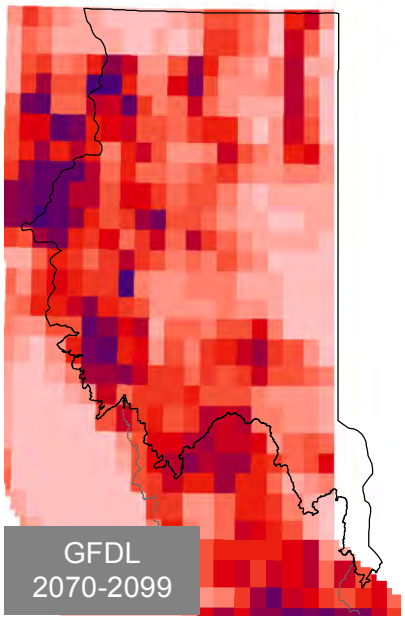
0 - 13.5	169 - 189
13.6 - 40.5	190 - 211
40.6 - 62.1	212 - 235
62.2 - 81.1	236 - 270
81.2 - 103	271 - 324
104 - 124	325 - 419
125 - 146	420 - 559
147 - 168	> 560

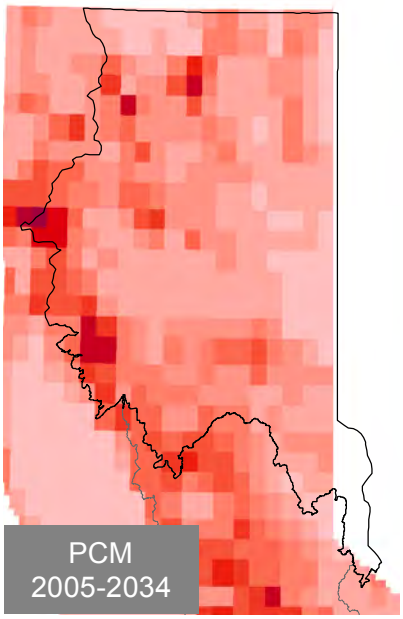
0 100 mi
0 100 km
NORTH

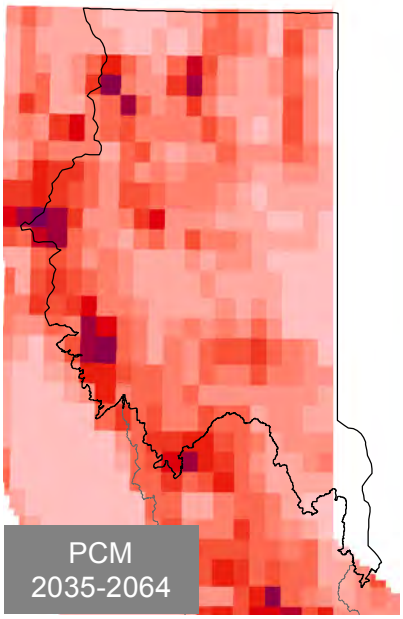


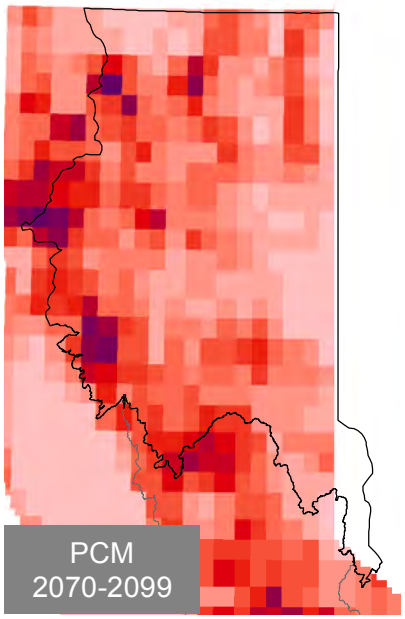












Annual Average Particulate Matter

Central Region
Sierra Nevada

GEOS INSTITUTE

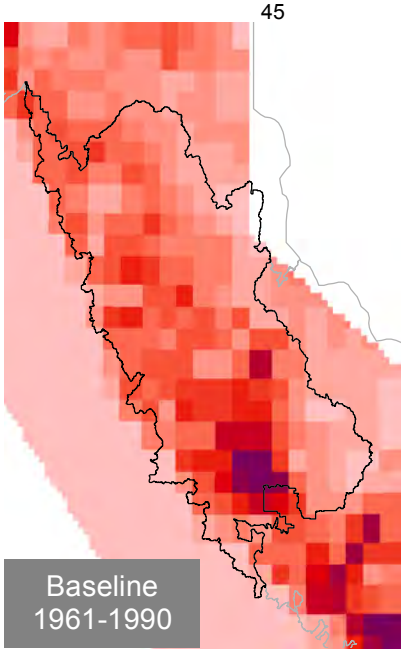
Data Sources:
Westerling et al. 2011[33]

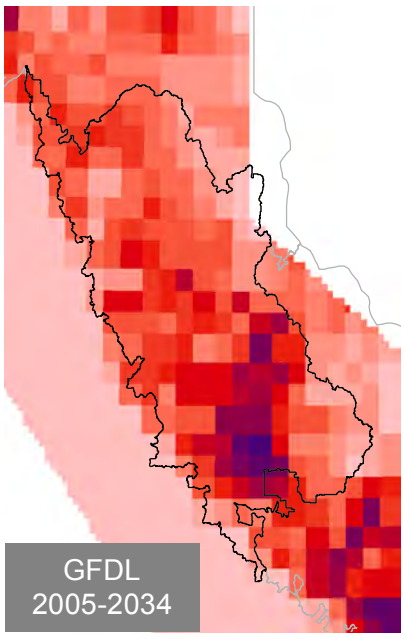
Rev: 2/22/2013

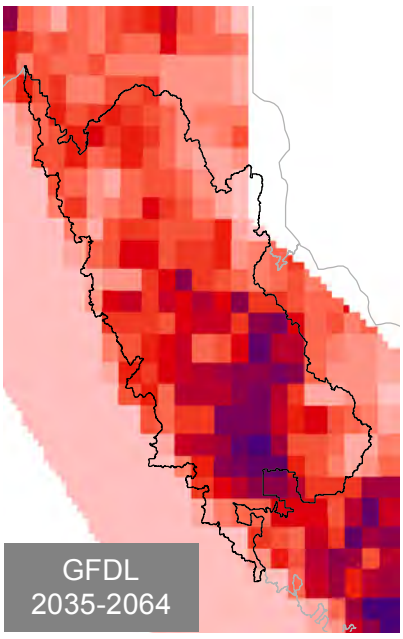
TPM in millions of grams emitted

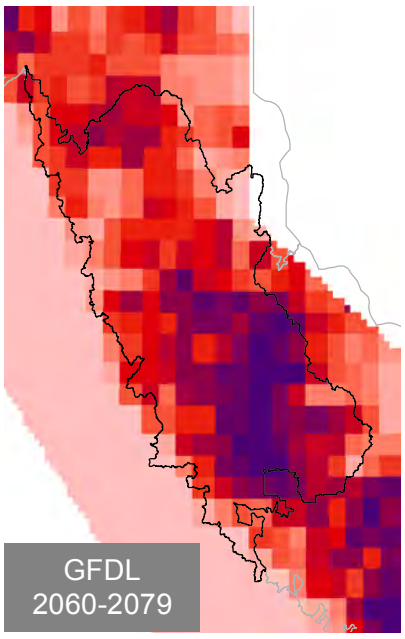
0 - 13.5	169 - 189
13.6 - 40.5	190 - 211
40.6 - 62.1	212 - 235
62.2 - 81.1	236 - 270
81.2 - 103	271 - 324
104 - 124	325 - 419
125 - 146	420 - 559
147 - 168	> 560

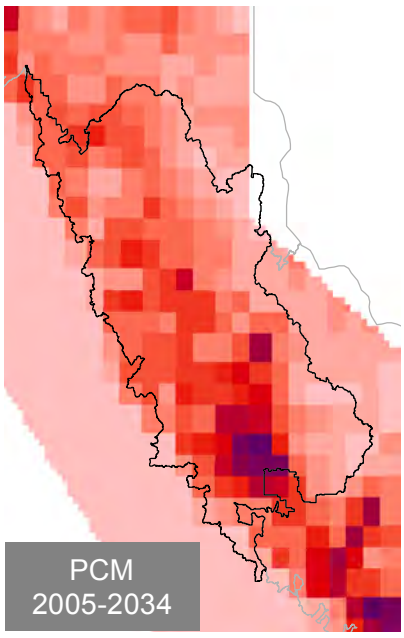
0 100 mi
0 100 km
NORTH

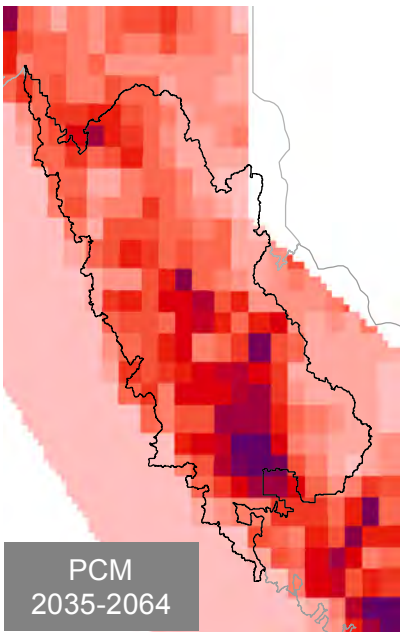


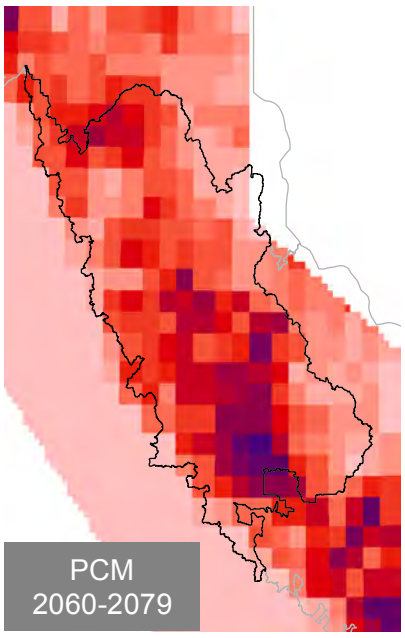












Annual Average Particulate Matter

Southern Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Westerling et al. 2011[33]

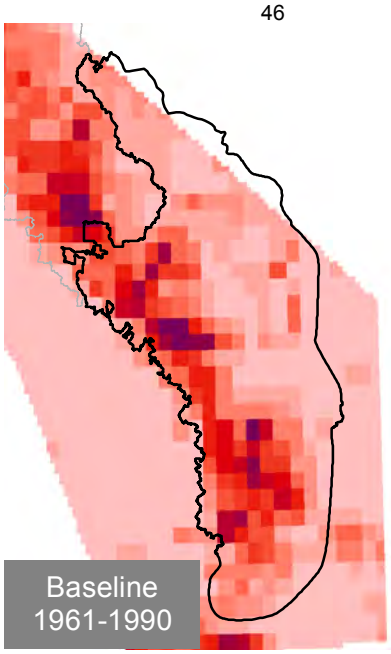
Rev: 2/22/2013

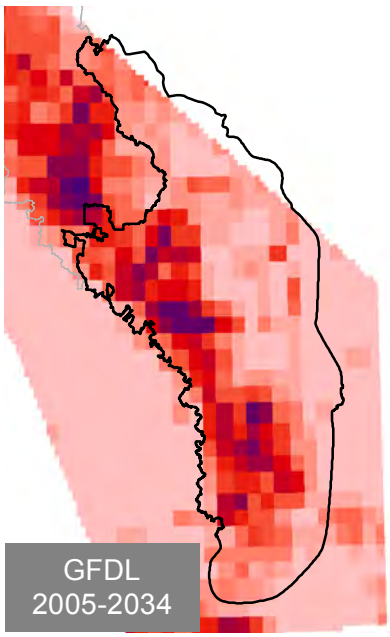
TPM in millions of grams emitted

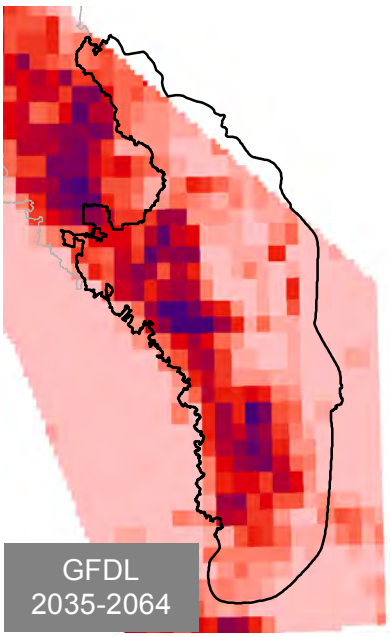
0 - 13.5	169 - 189
13.6 - 40.5	190 - 211
40.6 - 62.1	212 - 235
62.2 - 81.1	236 - 270
81.2 - 103	271 - 324
104 - 124	325 - 419
125 - 146	420 - 559
147 - 168	> 560

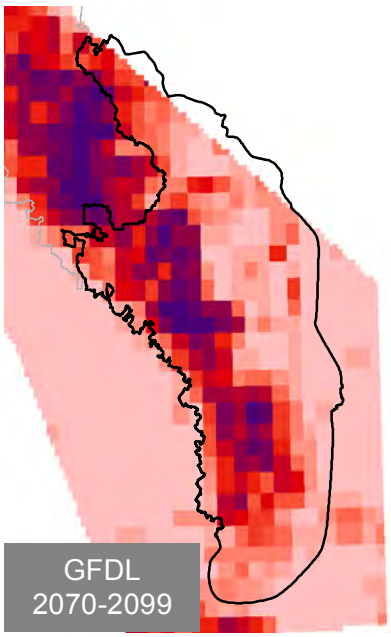
0 100 mi
0 100 km

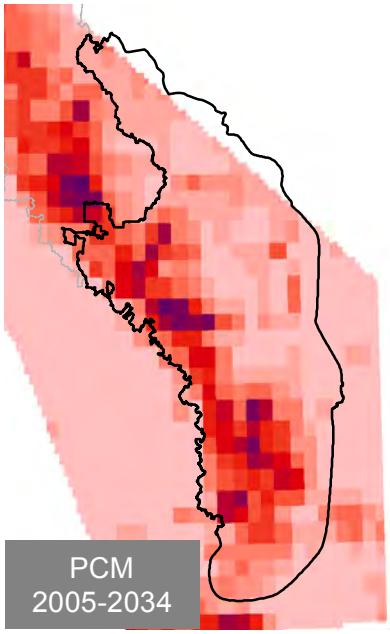
NORTH

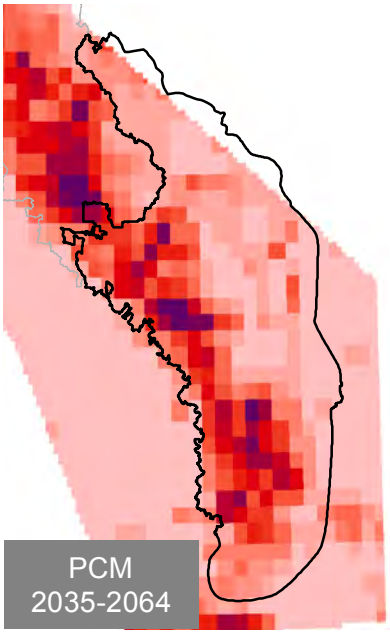


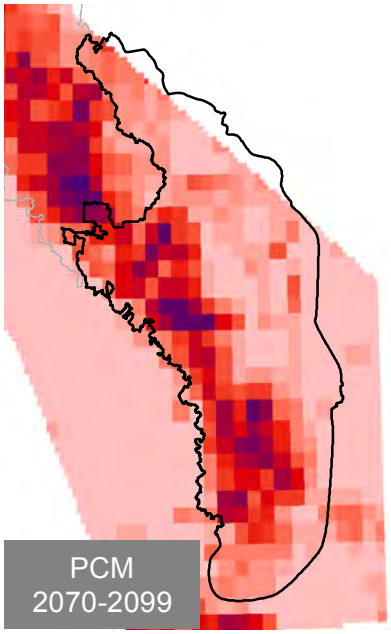












Annual Average Area Burned

Northern Region
Sierra Nevada

GEOS INSTITUTE

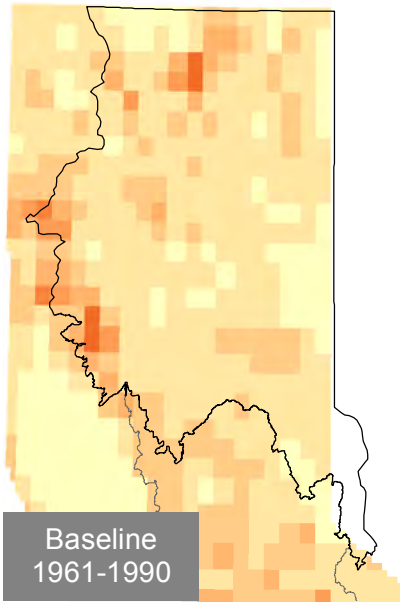
Data Sources:
Westerling et al. 2011[33]

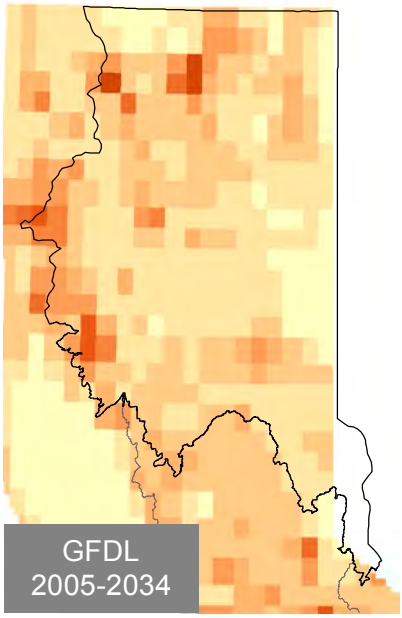
Rev: 2/22/2013

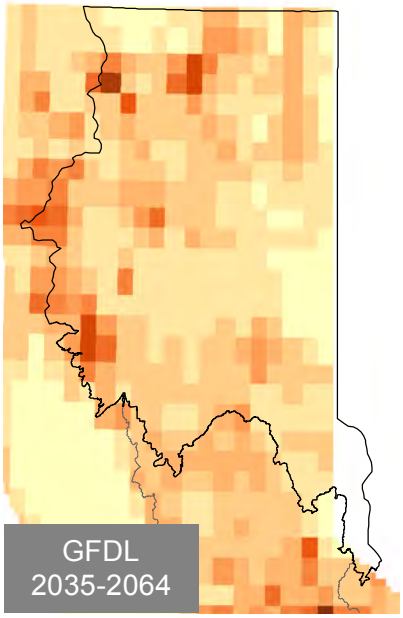
Area Burned in hectares

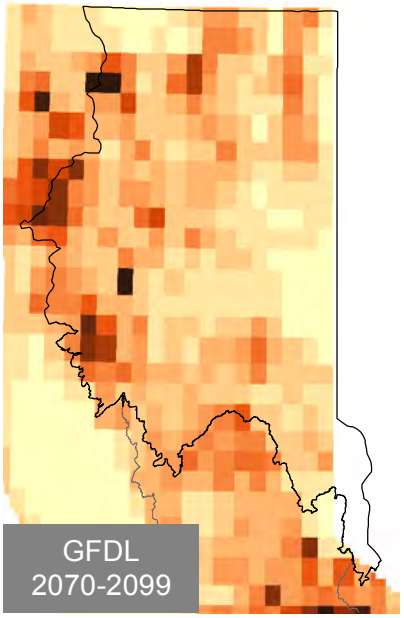
0 - 18	246 - 286
19 - 53	287 - 321
54 - 88	322 - 368
89 - 117	369 - 409
118 - 146	410 - 555
147 - 175	556 - 677
176 - 204	678 - 858
205 - 245	859 - 1,489

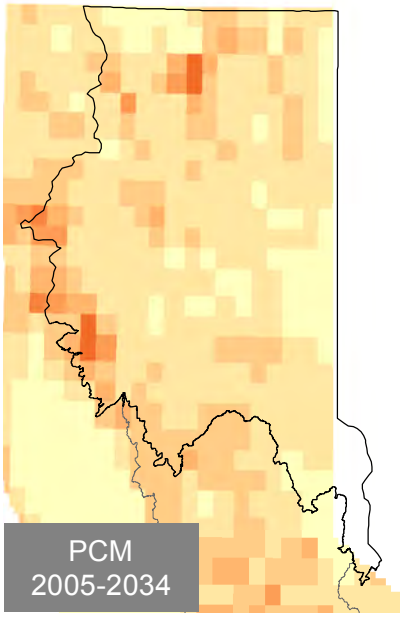
0 100 mi
0 100 km
NORTH

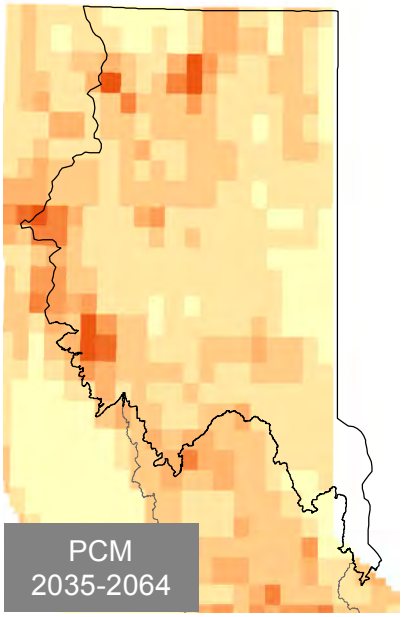


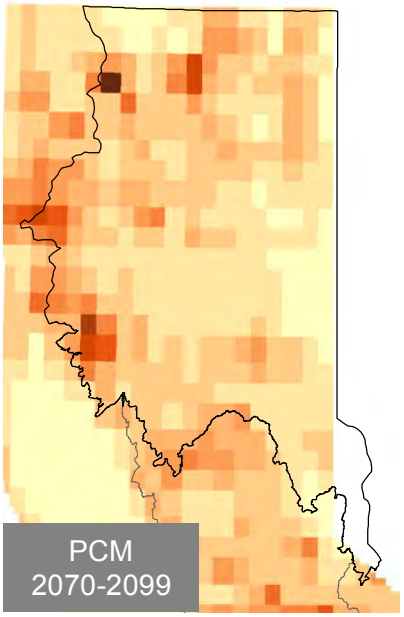












Annual Average Area Burned

Central Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Westerling et al. 2011[33]

Rev: 2/22/2013

Area Burned in hectares

0 - 18	246 - 286
19 - 53	287 - 321
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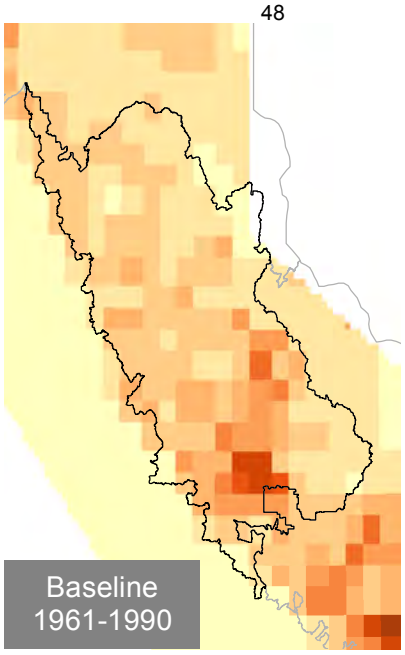
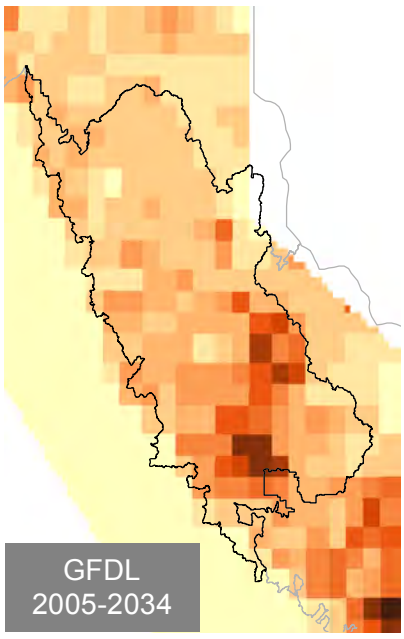
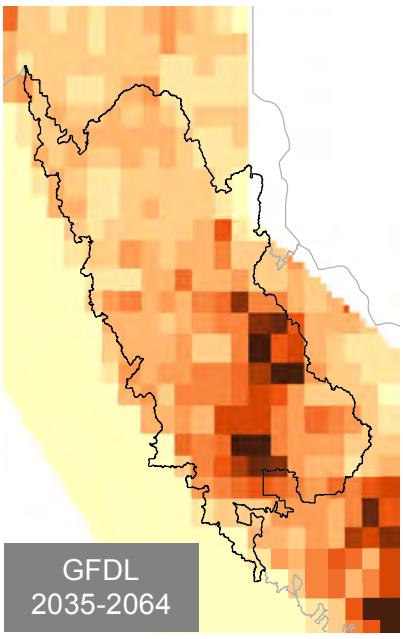
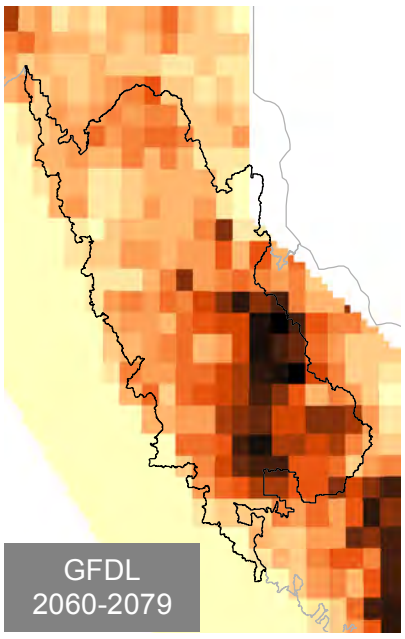
147 - 175	556 - 677
176 - 204	678 - 858
205 - 245	859 - 1,489

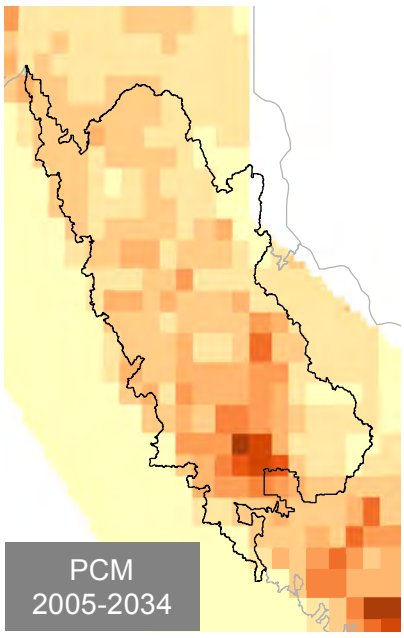
0 100 mi
0 100 km
NORTH

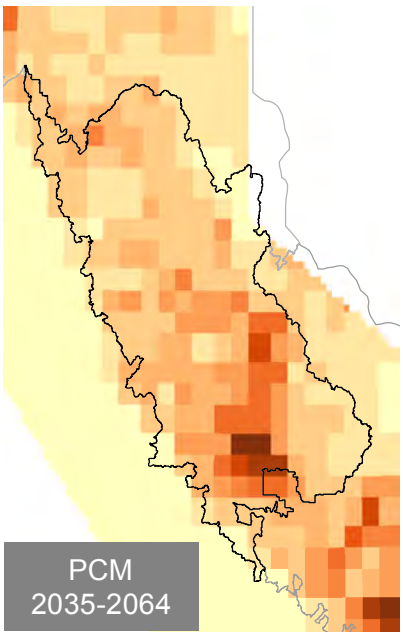


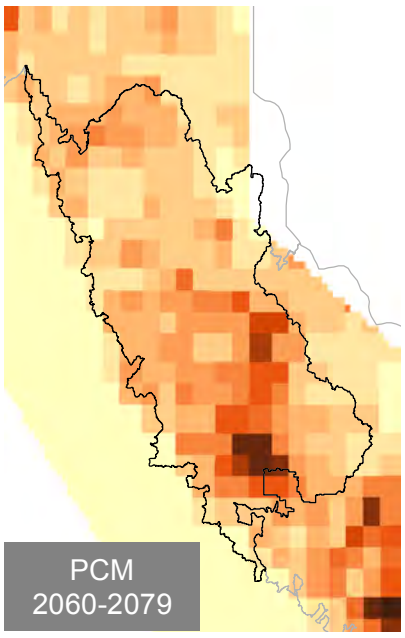












Annual Average Area Burned

Southern Region
Sierra Nevada

GEOS INSTITUTE

Data Sources:
Westerling et al. 2011[33]

Rev: 2/22/2013

Area Burned in hectares

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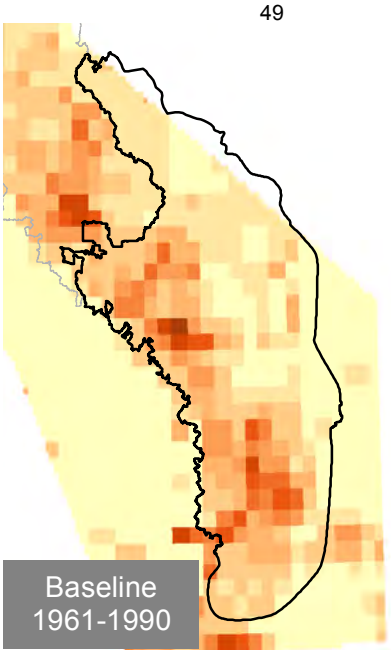
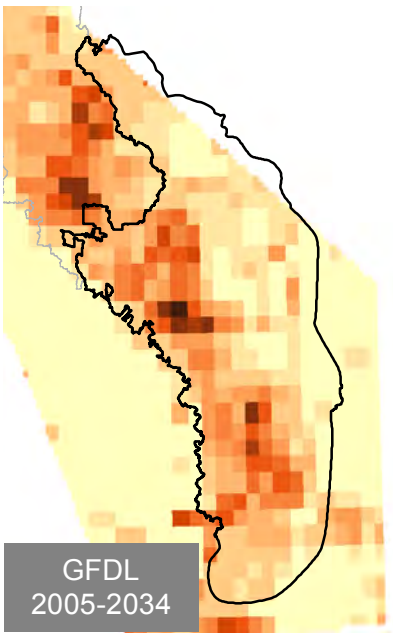
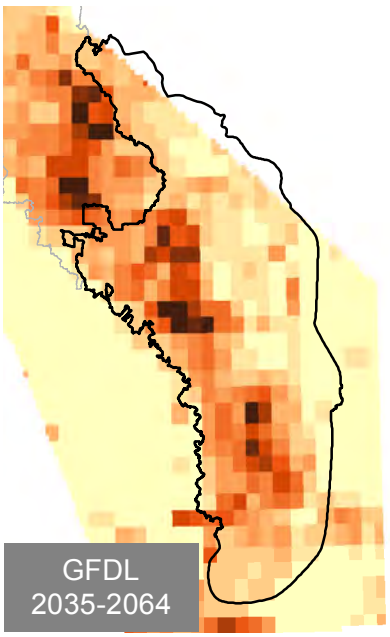
89 - 117	369 - 409
118 - 146	410 - 555
147 - 175	556 - 677
176 - 204	678 - 858
205 - 245	859 - 1,489

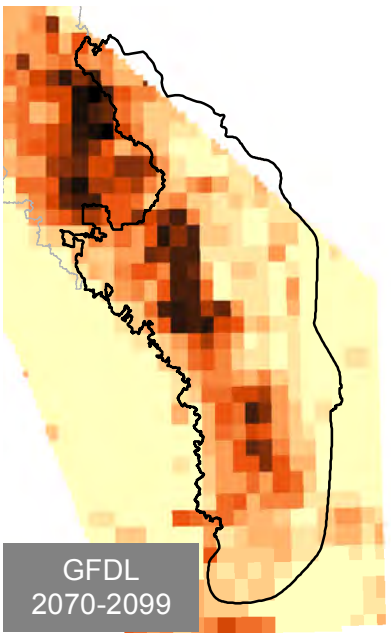
0 100 mi
0 100 km

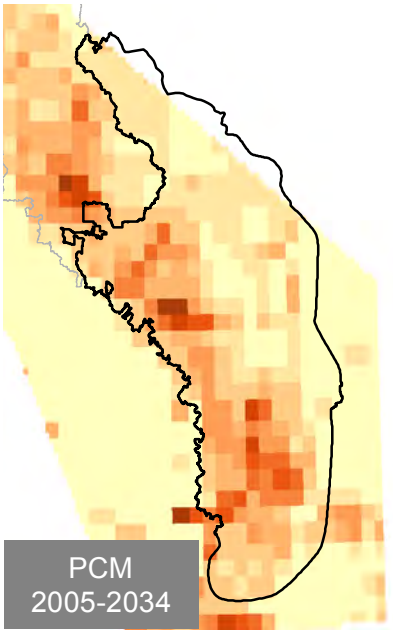
NORTH

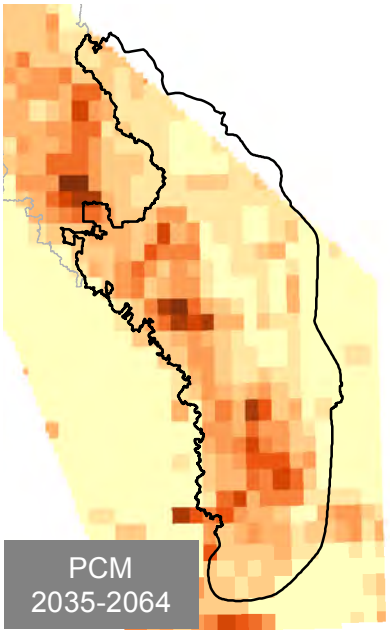


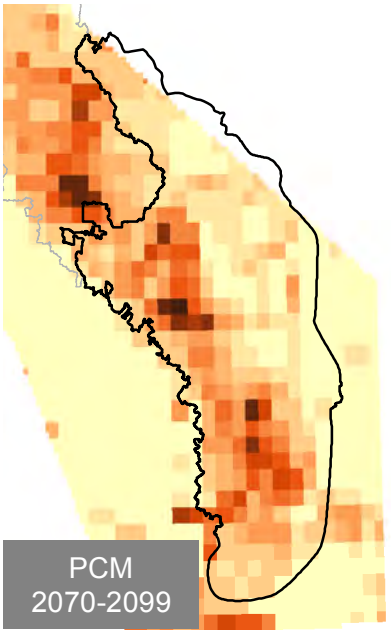












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