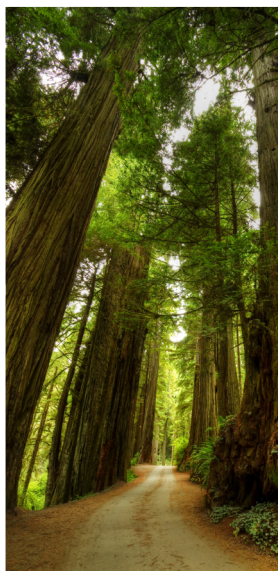


August 2013



# Indicators of Climate Change in California

*Report Summary*



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# INDICATORS OF CLIMATE CHANGE\*

## CLIMATE CHANGE DRIVERS

- Greenhouse gas emissions (*updated*)
- Atmospheric greenhouse gas concentrations (*updated*)
- Atmospheric black carbon concentrations (*new*)
- Acidification of coastal waters (*new*)

## CHANGES IN CLIMATE

- Annual air temperature (*updated*)
- Extreme heat events (*updated*)
- Winter chill (*updated information*)
- Freezing level elevation (*new*)
- Annual precipitation (*updated*)

## IMPACTS OF CLIMATE CHANGE

### *Impacts on physical systems*

- Annual Sierra Nevada snowmelt runoff (*updated*)
- Snow-water content (*updated*)
- Glacier change (*updated information*)
- Sea level rise (*updated*)
- Lake water temperature (*updated*)
- Delta water temperature (*updated*)
- Coastal ocean temperature (*updated*)
- Oxygen concentrations, California Current (*no update*)

### *Impacts on biological systems*

#### *Impacts on humans*

- Mosquito-borne diseases (*updated information*)
- Heat-related mortality and morbidity (*updated information*)
- Exposure to urban heat islands (*new*)

#### *Impacts on vegetation*

- Tree mortality (*updated information*)
- Large wildfires (*updated information*)
- Forest vegetation patterns (*no update*)
- Subalpine forest density (*new*)
- Vegetation distribution shifts (*new*)
- Alpine and subalpine plant changes (*no update*)
- Wine grape bloom (*updated information*)

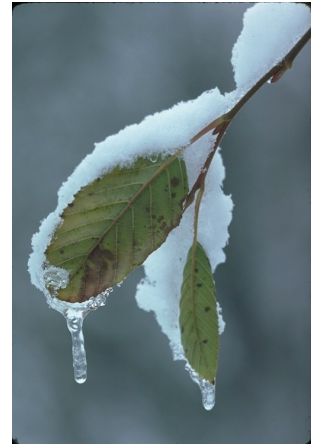
#### *Impacts on animals*

- Migratory bird arrivals (*no update*)
- Small mammal range shifts (*no update*)
- Spring flight of Central Valley butterflies (*updated*)
- Effects of ocean acidification on marine organisms (*new*)
- Copepod populations (*updated*)
- Sacramento fall run Chinook salmon abundance (*new*)
- Cassin's auklet breeding success (*updated*)
- Shearwater and auklet populations off Southern California (*new*)
- Sea lion pup mortality and coastal strandings (*new*)

\* The status of each indicator relative to the 2009 report is shown in parentheses as follows: **Updated:** Both graph and narrative are updated. **Updated information:** New information is presented, but the graph is unchanged. **No update:** 2009 graph and narrative are unchanged. **New:** Indicator did not appear in the 2009 report.

## INTRODUCTION

Climate change poses an immediate and growing threat to California's environment, public health and economic vitality. The state has been a pioneer and a leader in efforts to track and reduce greenhouse gas emissions, and in preparing for the unavoidable impacts of climate change—both of which are supported by state-sponsored research to better understand climate change and its impacts.



## TRACKING CLIMATE CHANGE AND ITS IMPACTS

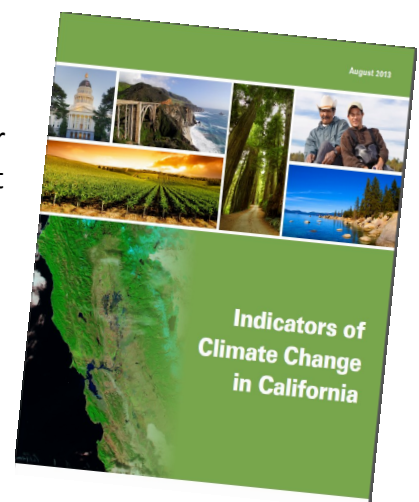


This document summarizes the technical report, *Indicators of Climate Change in California*. The report compiles indicators that characterize the multiple facets of climate change, specifically:

- human-induced (anthropogenic) drivers of climate change
- changes to the state's climate
- impacts of climate change on physical and biological systems

**Environmental indicators** convey scientific information on the status of, and trends in, environmental conditions. They help the state track, evaluate and report on the climate change issues it is working to address, as well as the outcomes of these efforts. Taken collectively, the indicators help portray the interrelationships among climate and other physical and biological elements of the environment.

Many indicators reveal already discernible impacts of climate change, highlighting the urgency for the state, local government and others to undertake mitigation and adaptation strategies.



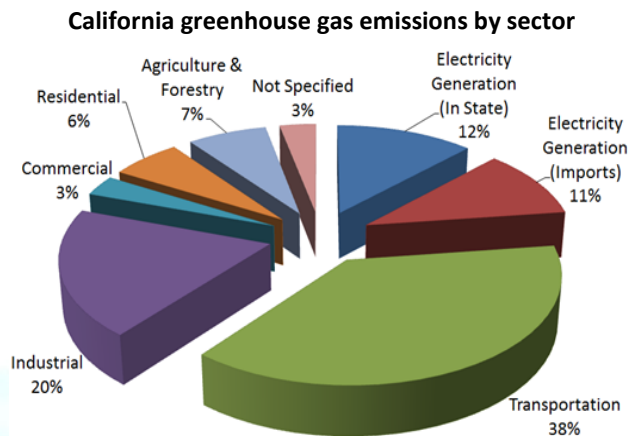
The full report can be downloaded from:  
<http://www.oehha.ca.gov/multimedia/epic/index.html>.

# CLIMATE CHANGE DRIVERS

Climate scientists attribute most of the warming since the 1950's to increasing levels of greenhouse gases (GHG) in the atmosphere. These gases warm the Earth's surface by trapping heat. Examples include carbon dioxide, methane, nitrous oxide, halocarbons and ozone.

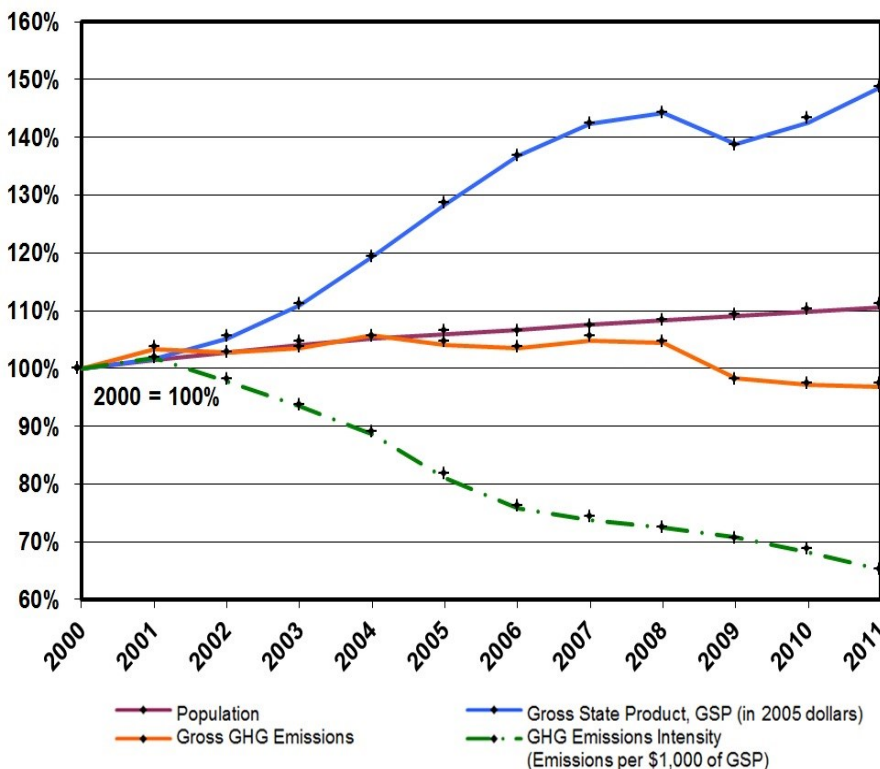
In California, emissions from transportation, electrical power generation and the industrial sector account for over 80 percent of GHG emissions. The transportation sector alone is responsible for more than one-third of all such emissions in the state.

In addition to greenhouse gases, other air pollutants can influence climate. Recent attention has focused on short-lived climate pollutants which, unlike carbon dioxide, are removed from the atmosphere within a few days to a few decades. Reducing emissions of these pollutants will quickly lower their concentrations in the atmosphere, helping slow the rate of warming over the next several decades.



Source: ARB, 2012

**Trends in California Population, Economy, Greenhouse Gas Emissions and Emissions Intensity: 2000—2011 (Relative to 2000)**



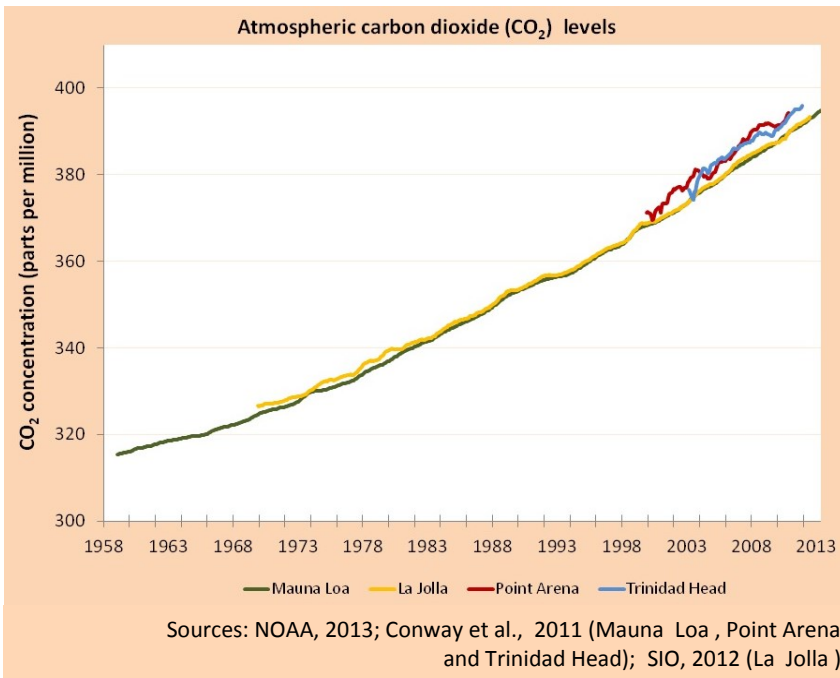
Source: ARB, 2013

California emissions of greenhouse gases (GHG) have seen an overall increase between 1990 and 2010. Since 2008, however, emissions decreased by more than 7 percent.

Since 2000, despite a 49 percent increase in economic output (as measured by the gross state product or GSP), and a 10 percent increase in population, GHG emissions per \$1,000 GSP—also known as emissions intensity—have declined.

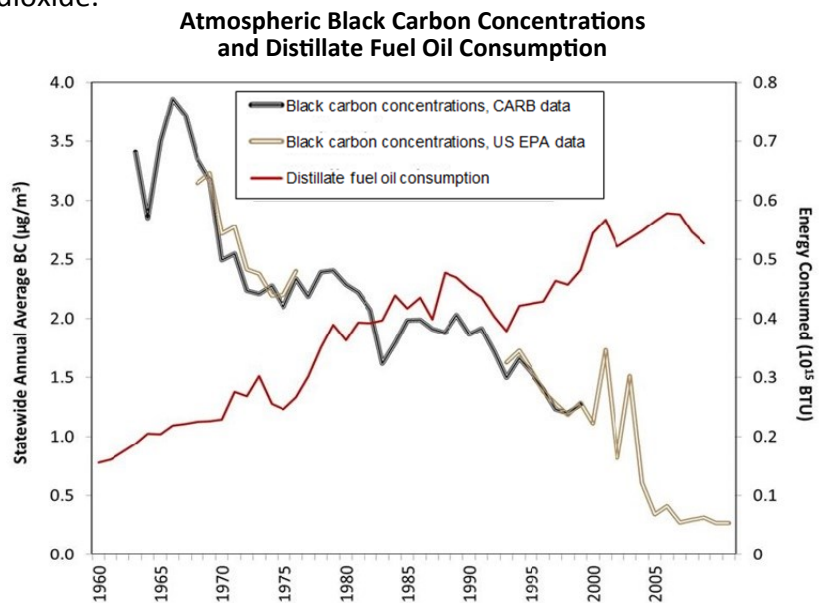


Of the greenhouse gases, carbon dioxide (CO<sub>2</sub>) is the largest and most important anthropogenic driver of climate change.



Rising atmospheric CO<sub>2</sub> levels, first documented in 1958 at Mauna Loa, Hawaii, have been observed at three California sites. About half of CO<sub>2</sub> emissions are removed by various processes within 30 years, another 30 percent within a few centuries; the rest may remain in the atmosphere for thousands of years. On May 9, 2013, the mean concentration at Mauna Loa reached a new milestone, topping 400 parts per million.

Recent studies have shown black carbon, one of the short-lived climate pollutants, to be a powerful contributor to global warming, second to carbon dioxide. A component of soot, black carbon's major sources are diesel vehicles, residential wood burning and wildfires. In California, atmospheric concentrations of black carbon have dropped significantly over the past several decades in spite of increasing diesel fuel consumption. Air pollution controls to reduce diesel emissions to protect human health and environmental quality have played a significant role in these reductions.



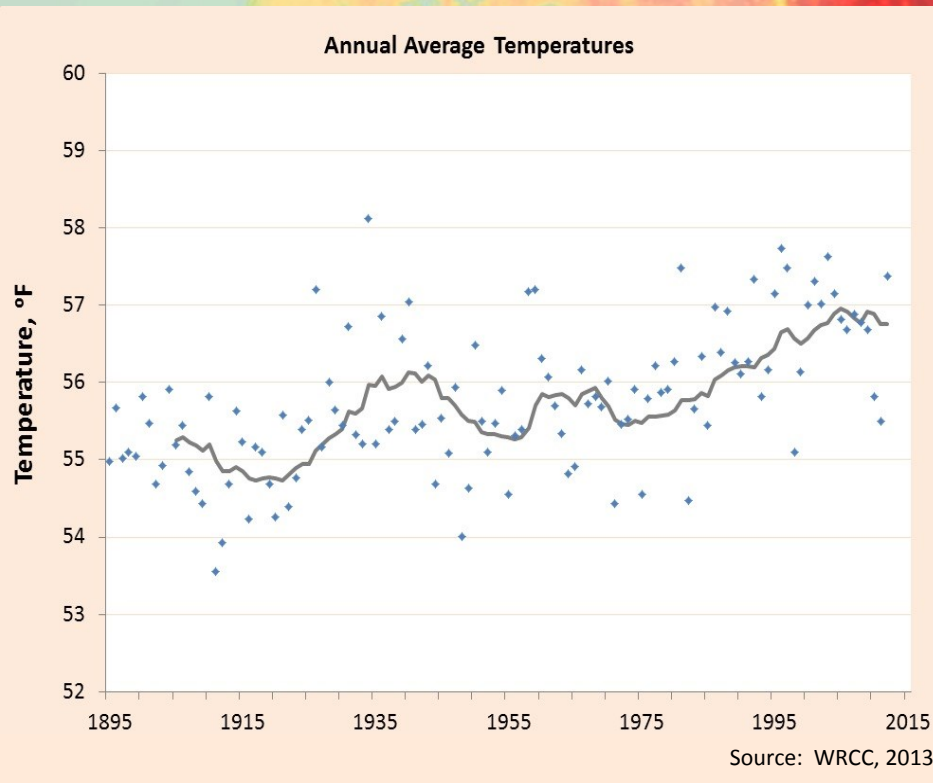
Source: Ramanathan, et al., 2013

As atmospheric CO<sub>2</sub> levels increase, so do CO<sub>2</sub> levels in the ocean, changing the chemistry of the water—a process called ocean acidification. The ocean absorbs nearly one quarter of the CO<sub>2</sub> released into the atmosphere by human activities every year. Seawater acidity is measured by pH – an increase in acidity lowers the pH of the water. Acidification of seawater causes decreased calcification in animals with shells, including plankton, mollusks and corals. Along the West Coast, acidification is occurring as evidenced by seawater CO<sub>2</sub> and pH levels measured at Monterey Bay.

# CHANGES IN CLIMATE

Climate is generally defined as “average weather.” It is usually described in terms of averages and measures of variability in temperature, precipitation and wind over a period of time. Global observations provide unequivocal evidence that the climate is warming.

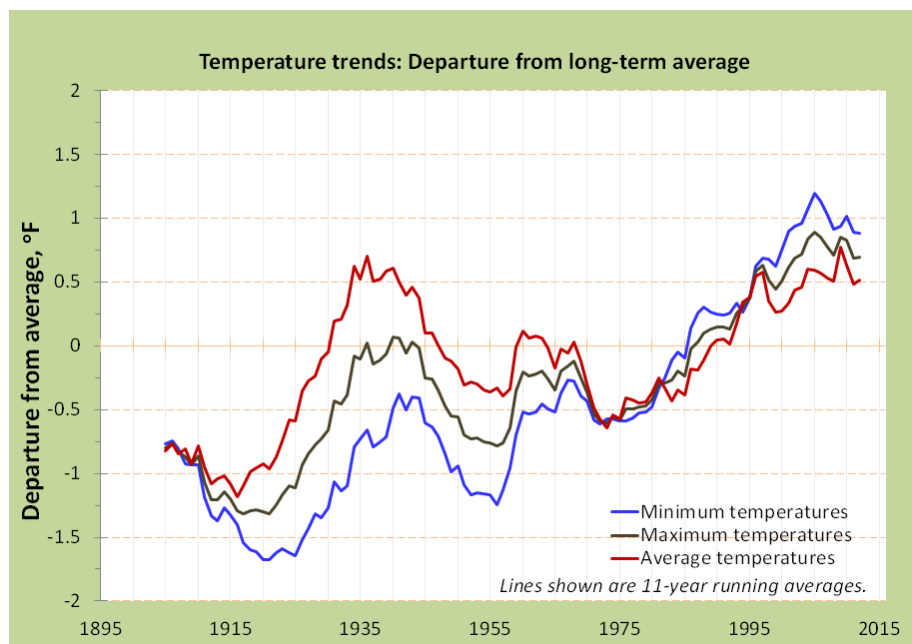
Temperature is a direct indicator of climate change, and is an important factor affecting agriculture, forestry, water supply and human and ecosystem health.



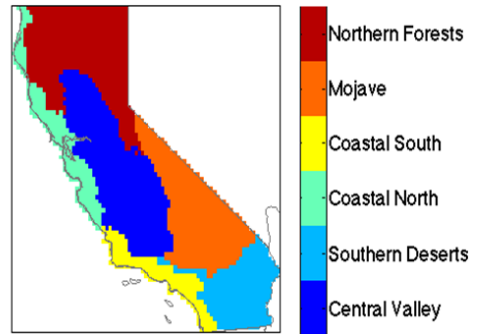
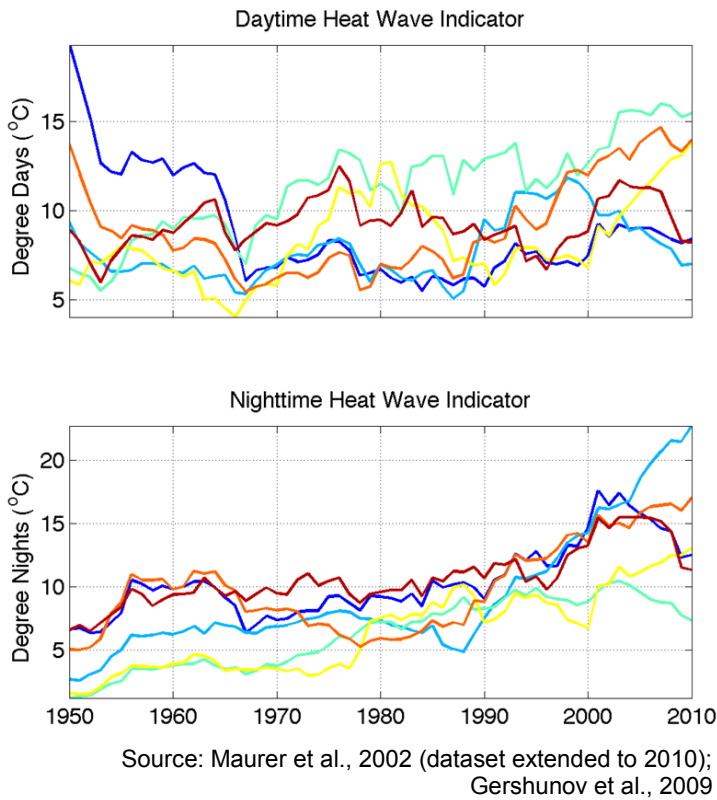
Since 1895, annual average temperatures have increased by about 1.5 degrees Fahrenheit (°F) across California.

Parts of the Central Valley and Southern California have experienced the greatest warming.

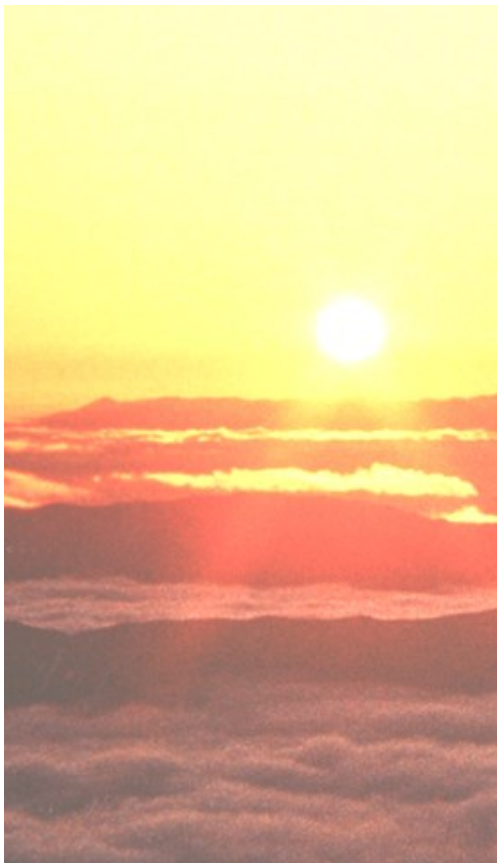
Over the past century, minimum, average and maximum temperatures have all been increasing. The graph shows how much these temperatures have deviated (“departed”) from long-term average temperatures each year. Minimum temperatures—which correspond to nighttime lows—have been increasing at a faster rate than both maximum (daytime highs) and average temperatures since the mid-1970s.



Summertime heat waves are increasing across the state. The graphs below show heat wave trends based on the frequency, intensity and regional extent of heat patterns during July and August.



Except for the Central Valley (where agricultural irrigation likely had a cooling effect), daytime heat waves during the summer are increasing, especially in the Coastal North and Mojave regions. Nighttime heat waves are increasing in all regions. Extreme heat events can result in heat-related deaths and illnesses, decreased agricultural production, increased irrigation requirements, and greater electricity demands.



Other indicators of **changes in climate** show that:

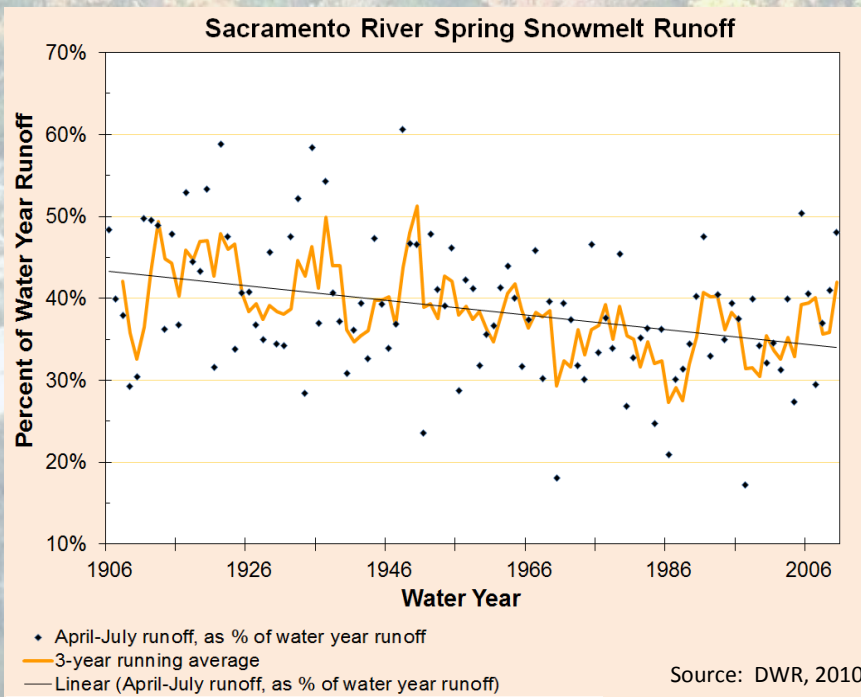
- During winter, the warming trend is reflected in decreasing “winter chill” in fruit-growing regions of the state. Many fruit trees require a certain number of hours below a temperature threshold to produce flowers and fruit.
- Over the past 20 years, the altitude in the atmosphere at which temperatures drop below freezing has risen by about 150 meters (500 feet). This indicates warming conditions at higher elevations.
- Precipitation varies considerably from year-to-year, and periods of consecutive dry or wet years are evident. Overall, statewide and regional trends show little change over the past century.



# IMPACTS OF CLIMATE CHANGE ON PHYSICAL SYSTEMS

Climate is a key factor affecting snow, ice and frozen ground, streams, rivers, lakes and the ocean. Regional climate change, particularly warming temperatures, have affected these natural physical systems.

From October to March, snow accumulates in the Sierra Nevada. This snowpack stores much of the year's water supply. Spring warming releases the water as snowmelt runoff. Over the past century, spring runoff to the Sacramento River has decreased by 9 percent.



Lower runoff volumes from April to July may indicate: (1) warmer winters, during which precipitation falls as rain instead of snow; and (2) earlier springtime warming.

Reduced runoff means less water to meet the state's domestic, agricultural, hydroelectric power generation, recreation and other needs. Cold water fish habitat, alpine forest growth and wildfire conditions are also impacted.

Glaciers are important indicators of climate change. They respond to the combination of winter snowfall and spring and summer temperatures. Like spring snowmelt, the melting of

glaciers supplies water to sustain flora and fauna during the warmer months. Glacier shrinkage results in earlier peak runoff and drier summer conditions—changes with ecological impacts—and contributes to sea level rise.

## Goddard Glacier

1908



G. K. Gilbert

2004



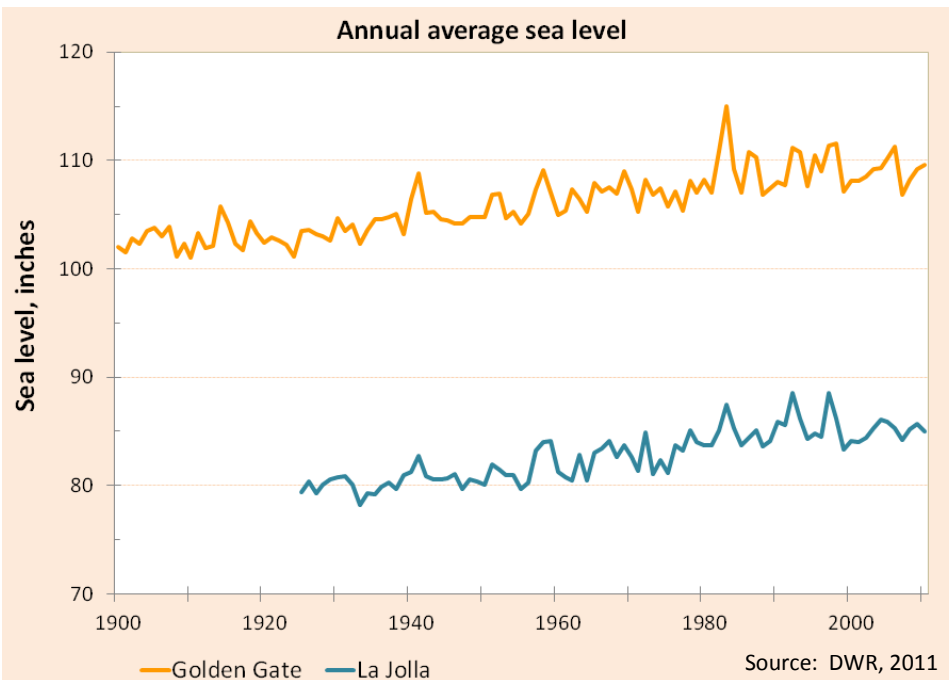
H. Basagic

With warming temperatures over the past century, the surface area of glaciers in the Sierra Nevada has been decreasing. Losses have ranged from 20 to 70 percent. For example, Goddard Glacier (left), has decreased by about 50 percent. With few exceptions, alpine glaciers have been receding globally.



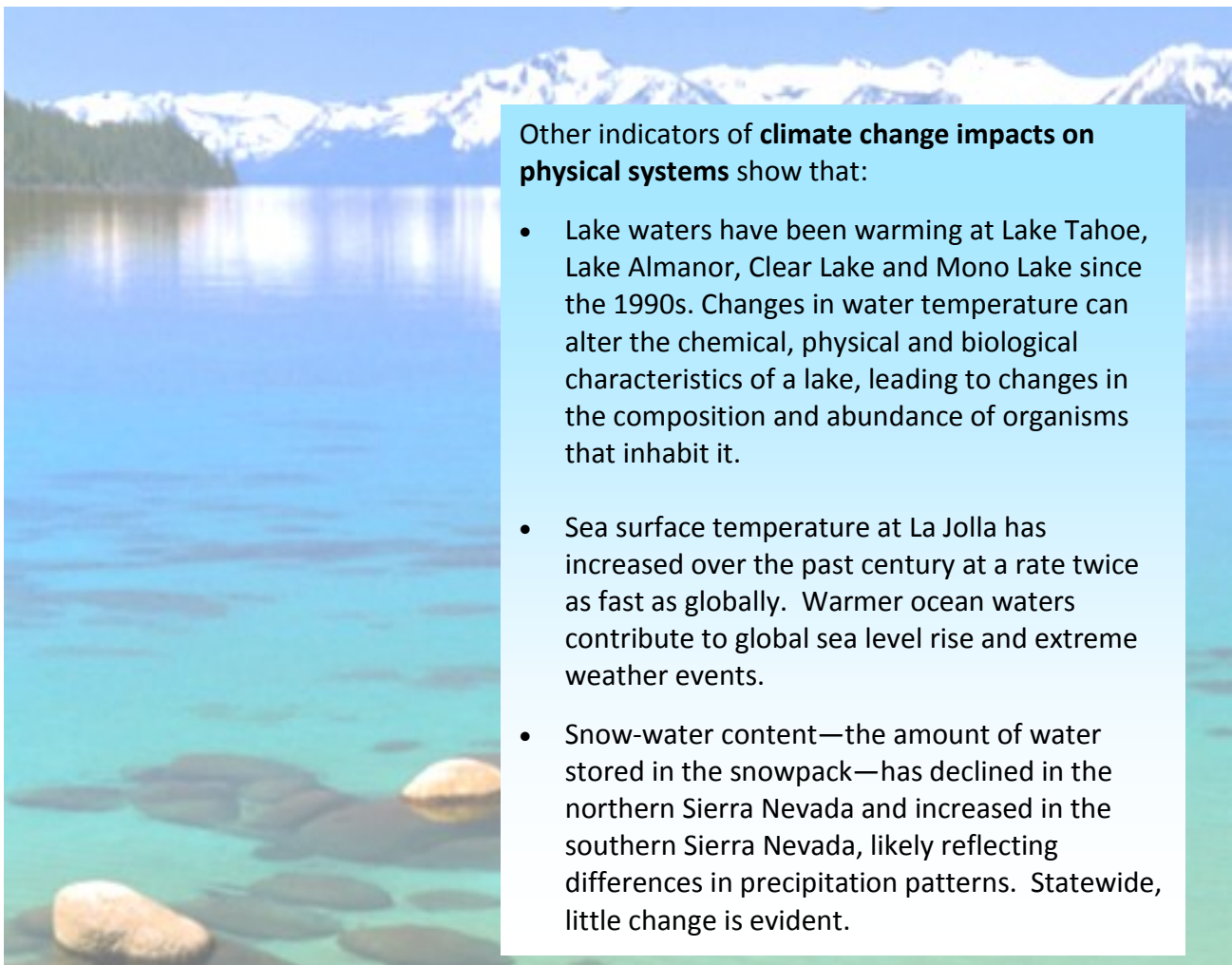
Sea level provides a physical measure of possible oceanic response to climate change. The rise in global sea level is attributed to thermal expansion of ocean water and the melting of

mountain glaciers and polar ice sheets.



Over the last century, sea levels have risen by an average of 7 inches along the California coast. Levels at the Golden Gate in San Francisco and at La Jolla near San Diego have increased by about 8 and 6 inches, respectively.

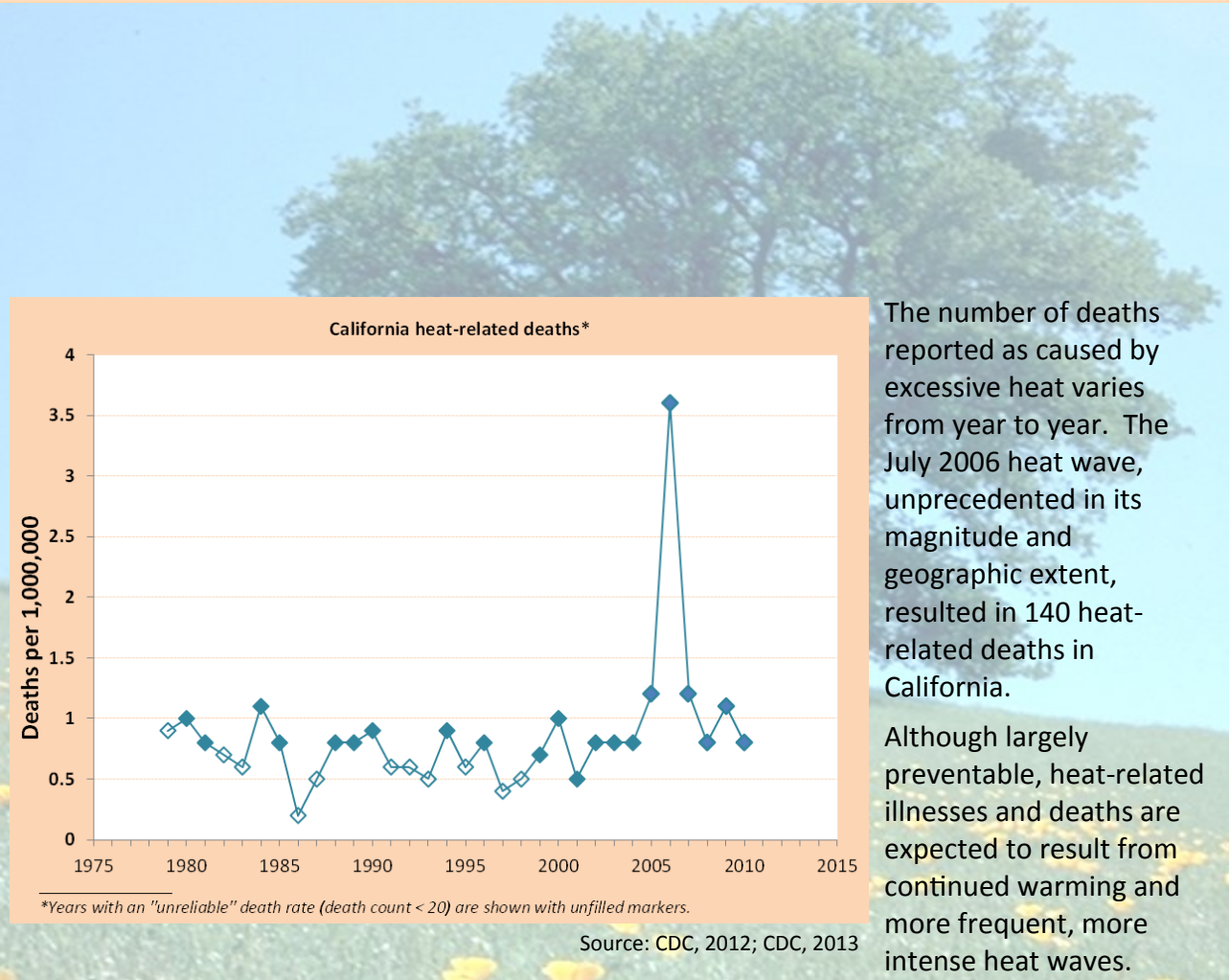
Sea level rise could lead to flooding of low-lying areas, loss of coastal wetlands, erosion of cliffs and beaches, saltwater contamination of groundwater aquifers and impacts on roads, sewage treatment plants and other coastal infrastructure.



**Other indicators of climate change impacts on physical systems show that:**

- Lake waters have been warming at Lake Tahoe, Lake Almanor, Clear Lake and Mono Lake since the 1990s. Changes in water temperature can alter the chemical, physical and biological characteristics of a lake, leading to changes in the composition and abundance of organisms that inhabit it.
- Sea surface temperature at La Jolla has increased over the past century at a rate twice as fast as globally. Warmer ocean waters contribute to global sea level rise and extreme weather events.
- Snow-water content—the amount of water stored in the snowpack—has declined in the northern Sierra Nevada and increased in the southern Sierra Nevada, likely reflecting differences in precipitation patterns. Statewide, little change is evident.

# IMPACTS OF CLIMATE CHANGE ON BIOLOGICAL SYSTEMS



The number of deaths reported as caused by excessive heat varies from year to year. The July 2006 heat wave, unprecedented in its magnitude and geographic extent, resulted in 140 heat-related deaths in California.

Although largely preventable, heat-related illnesses and deaths are expected to result from continued warming and more frequent, more intense heat waves.

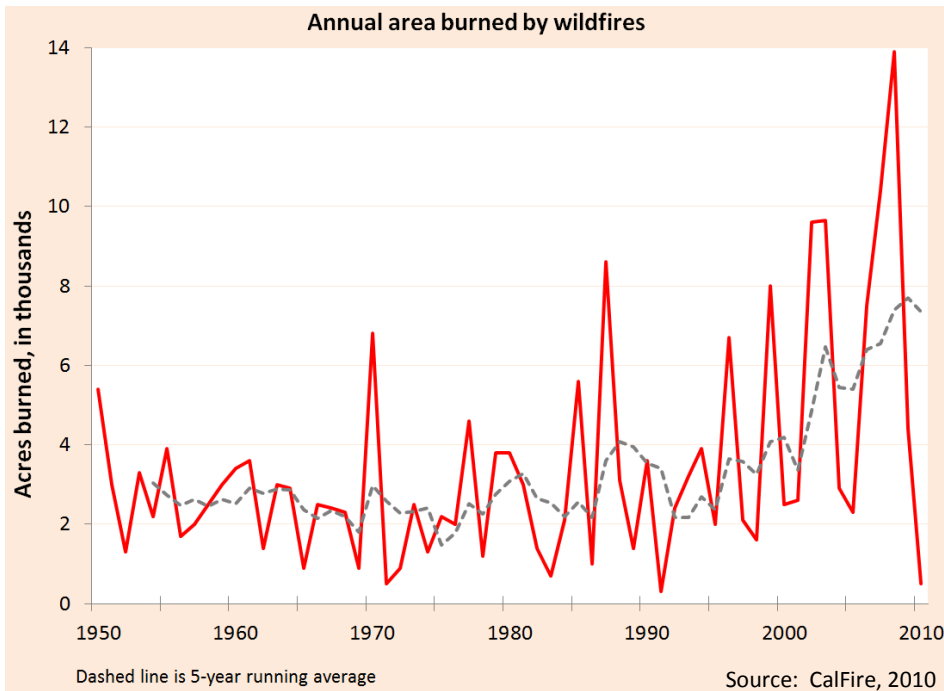


Ocean conditions—including currents, winds and temperature—strongly influence marine populations. The following population changes may be related to ocean warming and changes in the distribution and abundance of prey:

- A dramatic decline in fall-run Chinook salmon abundance in the Central California region since 2004.
- More variable Cassin's auklet breeding success on the Southeast Farallon Islands off the California coast, with unprecedented reproductive failures in 2005 and 2006, and record high productivity in 2010.
- Significant declines in sooty shearwater and Cassin's auklet populations at sea in Southern California over the past 24 years.
- Increased California sea lion pup mortality and stranding of yearling pups.



The area burned by wildfires each year is highly variable, ranging from 31,000 acres in 1963 to 1.4 million acres in 2008, making it difficult to determine long-term trends. However, the data suggest a trend toward increasing acres burned statewide since 2000.



The three largest fire years since 1950 have occurred in the past decade (2003, 2007 and 2008), and the annual average since 2000 (598,000 acres) is almost twice that for the 1950-2000 period (264,000 acres).

#### Other indicators of **climate change impacts on biological systems** show that:

- In Southern California, dominant plant species across the north slope of Deep Canyon in the Santa Rosa Mountains have moved upward by an average of about 65 meters (213 feet) over the past 30 years.
- Today's subalpine forests in the Sierra Nevada are much denser, consisting of more small-diameter trees, than 70 years ago.
- The lower edge of the conifer-dominated forests in the Sierra Nevada has been retreating upslope over the past 60 years.
- Central Valley butterflies have been appearing earlier in the spring over the past four decades.
- About half of the small mammal species surveyed in Yosemite National Park showed a change in the elevation at which they can be found today, compared to earlier in the century. Most of these changes involved movement to higher elevations.



## EMERGING ISSUES

Possible climate-related changes and impacts in California that are plausibly—but not yet established to be—influenced by climate change are referred to here as *emerging issues*. These may, in the future, be tracked as indicators of climate change once sufficient data become available.

The following are examples of environmental changes that have been hypothesized to occur or to intensify due to climate change:

- The growth, geographic distribution and toxicity of harmful algal blooms may be impacted by warmer ocean temperatures, increases in carbon dioxide in seawater, and alteration of marine wind and water circulation patterns.
- Anecdotal evidence suggests that Central Valley winters are less foggy than they were a few decades ago. Valley fog promotes colder temperatures during the winter—a critical factor for fruit production in agricultural regions.
- In recent decades, billions of coniferous trees have been killed by native bark beetles in Western US forests, and several of the current outbreaks are among the largest and most severe in recorded history. Increasing temperature, precipitation shifts and extreme weather events appear to be factors driving at least some of the current bark beetle outbreaks.
- In the coming decades, it is likely that California will be faced with increased impacts from extreme events including droughts and floods.

## ACKNOWLEDGMENTS

The Office of Environmental Health Hazard Assessment is grateful to the Cal/EPA Office of the Secretary and to the technical staff and researchers who contributed their ideas, data, findings and other information for inclusion in *Indicators of Climate Change in California*.

(A full list of these contributors can be found in the technical report.)

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