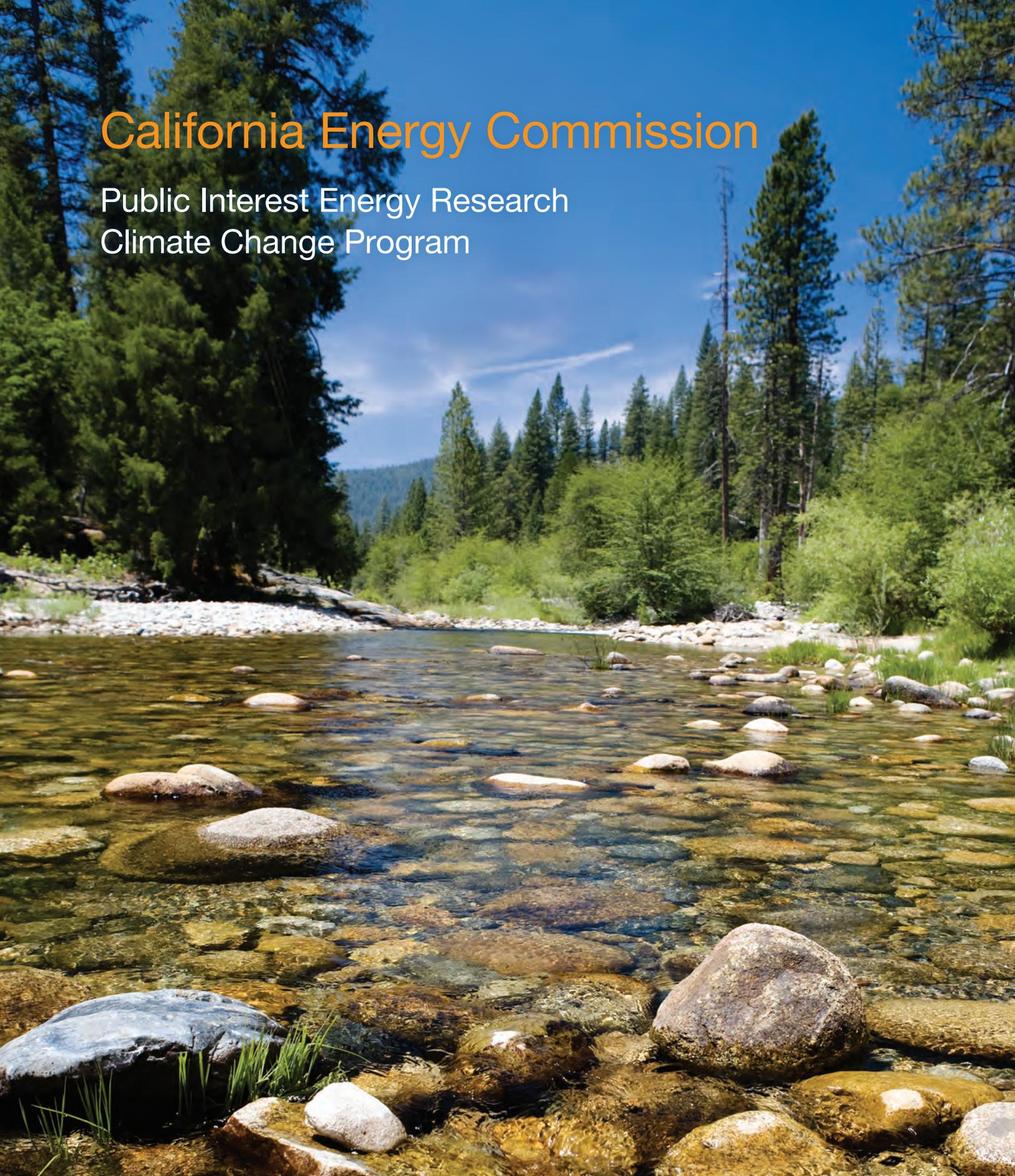


California Energy Commission

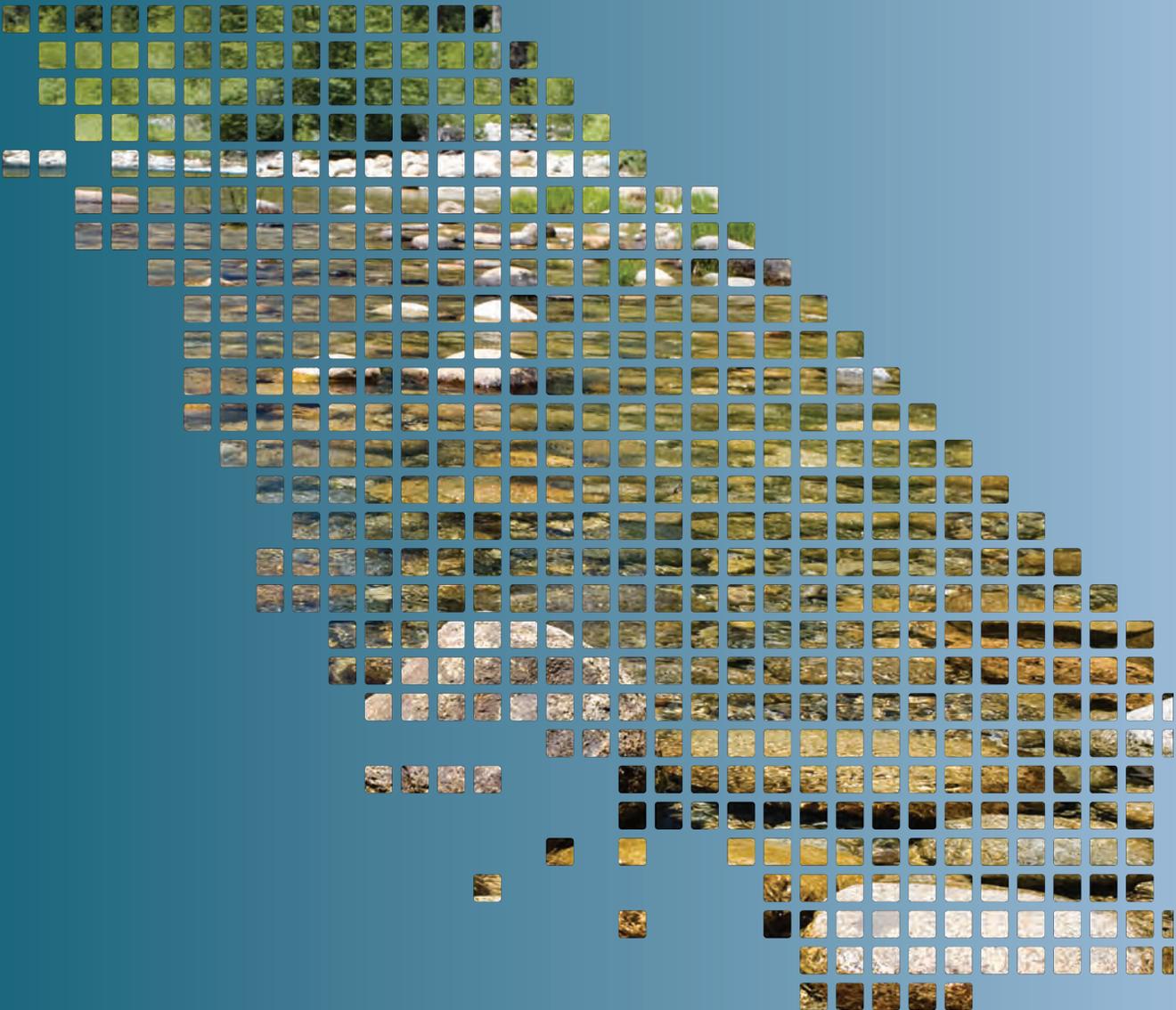
Public Interest Energy Research
Climate Change Program



California Climate Change Center
www.climatechange.ca.gov/research



The California Climate Change Center was the first state-funded climate change research program in the nation. Its goal is to enhance national and international studies, generating new information that can be used to shape California's climate change policy.



Shaping California's Climate Change Policy

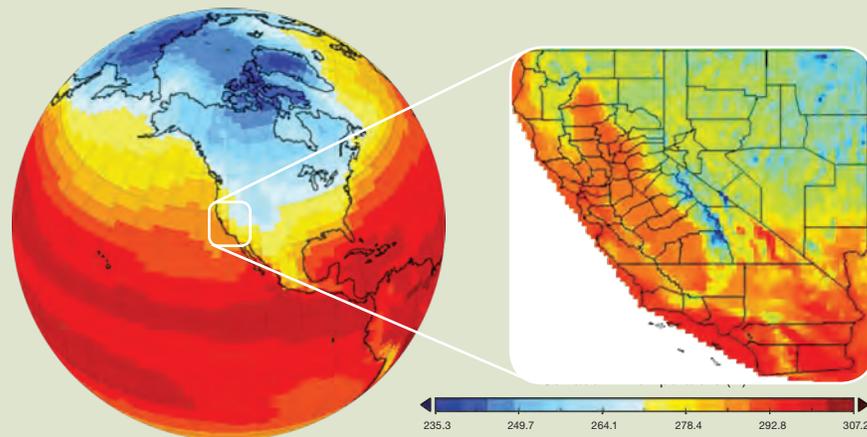
Climate change is one of the most important long-term issues facing California. With wide-ranging impacts expected on the state's natural resources, public health, energy, air quality, agriculture, economy, environment, and infrastructure, the lives of all Californians will be affected by climate change in the decades ahead.

Although climate change is a global problem, it poses special risks to California. For example:

- Over the past century, the West (including California) has warmed more than any other region in the United States apart from Alaska.
- The state's water resources, already scarce, are highly vulnerable to changes in temperature and precipitation. The Sierra Nevada snowpack, which provides most of the state's drinking water, is currently shrinking as a result of climate warming already in progress.
- The risk of large wildfires in the state could increase substantially.
- California's diverse landscape hosts more plant and animal species than any other state. Climate change will affect many of these species directly, as well as exacerbating existing environmental stressors such as land-use change, invasive species, and reductions in air and water quality.

To address these risks effectively, California requires detailed, state-specific information on how climate may change and the potential impacts associated with these changes. The California Climate Change Center is the main source of policy-relevant research on climate change in California. Created in 2003 as part of the California Energy Commission's Public Interest Energy Research (PIER) program, this virtual research center—operated in partnership with U.C. San Diego and U.C. Berkeley—provides information on emissions, impacts, adaptation, and mitigation strategies.

The Center was the first state-funded climate change research program in the nation. Its goal is to enhance national and international studies, generating new information that can be used to shape California's climate change policy. The Center also works very closely with state and local agencies to make sure its scientific results are relevant to their climate change activities.



Research funded by the Center has downscaled information from coarse-resolution global climate models to enable more detailed projections of future climate change in California.

The Center funds research in four areas:

- 1. Climate monitoring, analysis, and modeling:** This area of work targets the “how” and “why” of climate processes and climate change in California. This research includes developing the modeling capabilities to estimate how climate will change in the future, as well as integrating past data into the development of future climate projections for the state.
- 2. Improving inventory methods:** Some of the methods used to estimate greenhouse gas emissions, especially for methane, nitrous oxide, and other non-carbon-dioxide (CO₂) greenhouse gases, have significant uncertainties. Work in this area includes improving key methodologies to improve emission estimates and track emissions trends in California.
- 3. Options to reduce greenhouse gas emissions:** Research in this area identifies promising options to reduce net greenhouse gas emissions, and weighs the relative costs and benefits of each option.
- 4. Impacts and adaptation:** This area of work focuses on studying the potential impacts of climate change on different sectors of the economy, such as energy, water, and human health. As many of these impacts may be unavoidable, this research also involves investigating options to ameliorate these impacts.

The Center works with many of California's prestigious research institutions, and has to date produced more than 150 peer-reviewed reports—with many published in prominent scientific journals such as *Science* and the *Proceedings of the National Academy of Sciences*.

This brochure provides an overview of the Center's work and achievements in each of these areas.

Climate Monitoring, Analysis, and Modeling

To estimate future changes in California's climate, scientists first must understand both past and current climate behavior, and what factors are driving climate change.

Monitoring

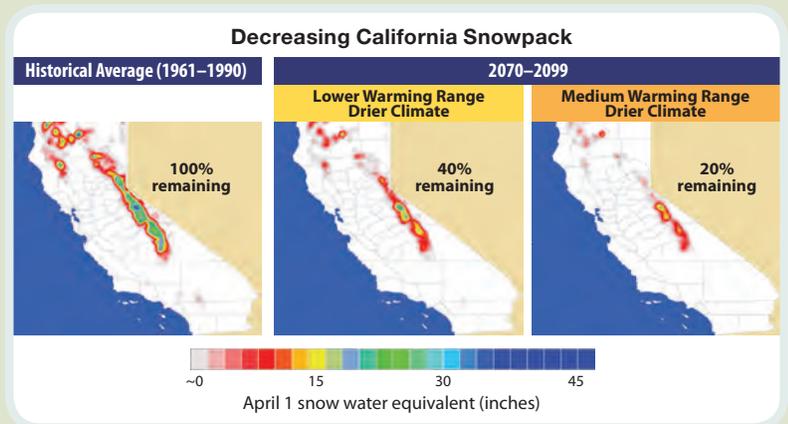
California's current network of temperature and precipitation stations provides only a partial picture of how climate is changing in the state—with data especially scarce for high elevations, where warming is expected to be greatest. Collecting data from monitoring stations in mountains and other remote locations can be particularly expensive. With the Center's support, however, researchers have developed and field-tested small, low-cost monitoring systems that transmit data wirelessly to a Web-accessible database. These new systems are operating now in Yosemite National Park and the Santa Margarita Ecological Reserve (50 miles north of San Diego), and will be used to expand the climate monitoring network into areas that previously lacked coverage. The Center also maintains the California Climate Archive, which contains meteorological and hydrological data for the state for the last 100 years. With extensive records from individual stations and networks, the archive provides a historical context of present and past climate conditions.

Analysis

By studying climate and related data collected over the past century, researchers can determine the extent that climate has already changed in California, as well as how much of that alteration is due to human versus natural causes.

Historical data can reveal important trends affecting California today. For example, a study funded by the Center documented a regional trend from 1949–2001 toward less snowfall and more winter rain in the Sierra Nevada. California's mountain snowpack serves a vital function by storing wintertime precipitation until it is needed during the warmer and drier spring and summer months, so the discovery of this trend brings to light a serious risk to the state's water resources.

Another Center-funded study documented for the first time how changes in climate are affecting the frequency and severity of forest fires in the western United States. The study found that the longer, warmer summers occurring in the West since 1986 have led to a four-fold increase in the number of major wildfires compared with the average over the past two decades (1970–1986).



Changes in California's historical (1961–1990) and projected (2070–2099) snowpack

Source: California Climate Change Center



Electronic data loggers collect climate data in remote locations and transmit it wirelessly to a central database.

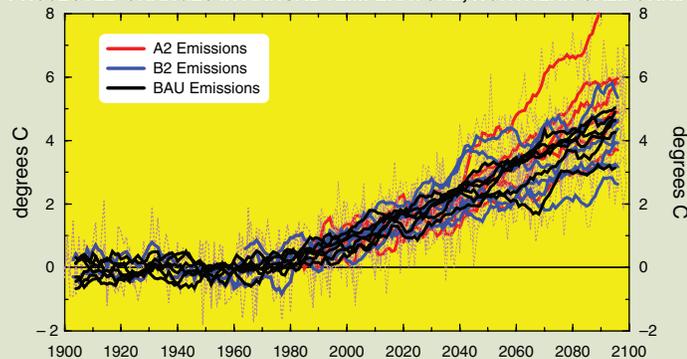
Source: Douglas Alden, Scripps Institution of Oceanography.



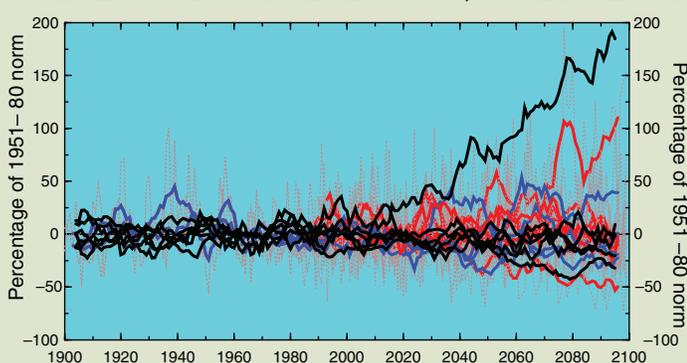
Twentieth Century Glacier Change in the Sierra Nevada, California — A comparison of Lyell Glacier, Yosemite National Park in 1903 (top) taken by G.K. Gilbert, and 2003 (bottom) taken by Hassan Basagic

Source: Geography Department, Portland State University

PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA



PROJECTED CHANGES IN ANNUAL PRECIPITATION, NORTHERN CALIFORNIA



Ensembles of historical and future temperature and precipitation projections from six coupled ocean-atmosphere general-circulation models, each forced by historical scenarios, and then in the 21st century—by three scenarios developed by the Intergovernmental Panel on Climate Change. Projections are for grid cells from each model centered over northern California.

Source: California Climate Change Center

Other studies are examining the effects of atmospheric aerosols from pollution on precipitation over the Sierra Nevada mountains. Combining data from research aircraft, satellites, and stream flow measurements in Sierra Nevada rivers, the researchers discovered that airborne pollution is reducing the amount of precipitation in mountains downwind of major urban areas. This finding suggests that reducing urban aerosol pollution could counteract some of the expected impacts of climate change on the Sierra Nevada snowpack, and help protect the state's water resources.

Finally, two new studies have determined that increased concentrations of greenhouse gases represent the most likely cause for observed trends of increased temperatures and shorter winter seasons in California. In simple terms, the climate change signal is already detectable in our state.

Modeling

Building on the understanding gained from monitoring and analyzing California's past and present climate, researchers can develop regional-scale models to explore how the state's climate may change in the future.

One of the Center's most important modeling projects is the generation of regional climate change scenarios to inform research and decision making. The scenarios show the likelihood and severity of changes to weather and climate in California, including precipitation, average temperature, extreme heat days, and sea levels. The development of these scenarios involves creating and testing regional-scale climate models for California, which are informed by the California-specific climate data and analyses described above. For example, researchers at Scripps Institution of Oceanography enhanced their Regional Spectral Model, allowing them to simulate weather conditions in California for the past 57 years with unprecedented level of detail. Researchers have conducted extensive testing of this and other regional climate models for California. These highly computationally demanding models are now better able to project how climate may change in California. The Center expects the resulting climate scenarios to be available in the second quarter of 2010. Modeling outputs will be available at resolutions of grids with sizes of 10 by 10 kilometers (about 6.25 by 6.25 miles)—a much finer scale than those of global climate models (100 to 200 miles).

Models can also help researchers understand the reasons for past and current climate changes. A Center-funded study used regional climate models to estimate the cooling effect of irrigation, which is widespread in the Central Valley. The researchers found that irrigation appears to have been masking a portion of the warming caused by greenhouse gas emissions. If agricultural irrigation follows expected trends and does not increase, it will not be able to counterbalance the additional warming that is expected to occur in the years ahead. For this reason, the Central Valley may experience more pronounced warming in the near future.

Inventory Methods

To reduce its contribution to climate change, California must first understand from where its emissions are coming. The state performs periodic greenhouse gas inventories to identify and quantify its sources and sinks of greenhouse gases. However, while these inventories are conducted using the latest protocols, they still contain data gaps and uncertainties. The Center funds research to address these issues, allowing the state to more accurately track emissions trends and better inform efforts to reduce emissions. Current research focuses on compiling energy balances for California and developing new, improved methods to estimate non-CO₂ emissions.

California's Energy Balances

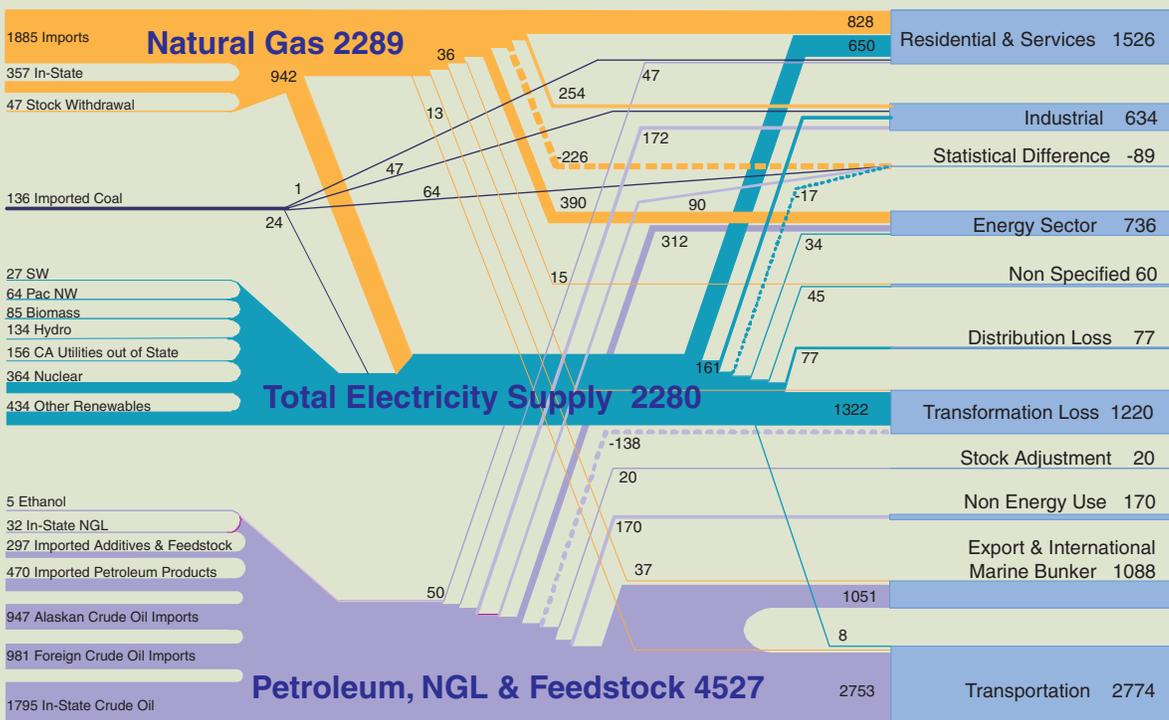
Energy production and use is the single largest human-generated source of greenhouse gas emissions in California. With support from the Center, Lawrence Berkeley National Laboratory has assembled a comprehensive database on energy production, transformation, and consumption in California from 1990 to the present, providing the foundation needed for accurate inventories and analysis of California's emissions. The California Energy Balances (CALEB) database allows researchers and policy makers to accurately track trends in energy use and energy-related greenhouse gas emissions in the state. The Air Resources Board used CALEB as the main source of energy data for its updated California greenhouse gas emissions inventory.

Estimating Non-CO₂ Greenhouse Gas Emissions

While emitted in smaller quantities than CO₂, other powerful greenhouse gases such as methane and nitrous oxide also contribute to climate change. Some key sources of these gases remain less well-quantified than those of CO₂, and contribute to uncertainty in greenhouse gas inventories. To help fill these information gaps, the Center supports a number of studies that improve the accuracy and efficiency with which researchers can estimate emissions from these sources.

For example, the Center is funding development of a sophisticated, field-calibrated model to accurately estimate manure-related greenhouse gas emissions from dairy farms. The project is further improving the accuracy of these estimates by developing a geographic information system to support regional simulations for California dairies. The Center also supports the advancement of methods to estimate methane emissions from landfills, which represent the largest human-caused methane source in California and the nation. Landfill methane recovery is also one of the most cost-effective measures for reducing greenhouse gases, so reducing uncertainties in this area is vitally important for effective policy making. To help address this need, the Center is funding a project to create a detailed landfill emission model and incorporate the results into an improved methane inventory methodology. The model is based on field data from individual landfills, and accounts for variation across different climates and landfill types, including different cover materials used to control emissions. It also accounts for oxidation in landfill cover soils, an area of major uncertainty.

CALEB Database — California Energy Flows in 2000, trillion Btu



This graphic shows how energy is produced, transmitted, and consumed in California, based on data in the California Energy Balances (CALEB) database.

The California Air Resources Board used CALEB to estimate carbon dioxide emissions for its official greenhouse gas emissions inventory.

Source: Lawrence Berkeley National Laboratory using data from U.S. Energy Information Administration and California Energy Commission.



Options to Reduce Greenhouse Gas Emissions

Historically, greenhouse gas emission reduction strategies (also known as mitigation) have focused on increasing energy efficiency and renewable sources of energy, along with reducing fossil fuel consumption. To broaden the range of options, since 2003 the Center has focused on non-CO₂ greenhouse gases, carbon sequestration, and reducing emissions in other sectors of the economy.

Carbon Sequestration

Carbon sequestration—the removal and storage of CO₂ that otherwise would be released to the atmosphere—may play an important role in slowing the increase of CO₂ concentrations in the atmosphere. The Center has helped fund a number of studies on carbon sequestration, including the development of an online geographic information system, known as the West Coast Carbon Atlas, which identifies locations and estimated capacities of potential sites for CO₂ sequestration in six western states and one Canadian province. The U.S. Department of Energy provided most of the funds for this effort. The Center also funded the development of cost curves to determine sequestration potential of forest, range, and agricultural lands in California. The study will help stakeholders estimate the value of emissions reductions that might be available at various price points for different classes of sequestration projects.

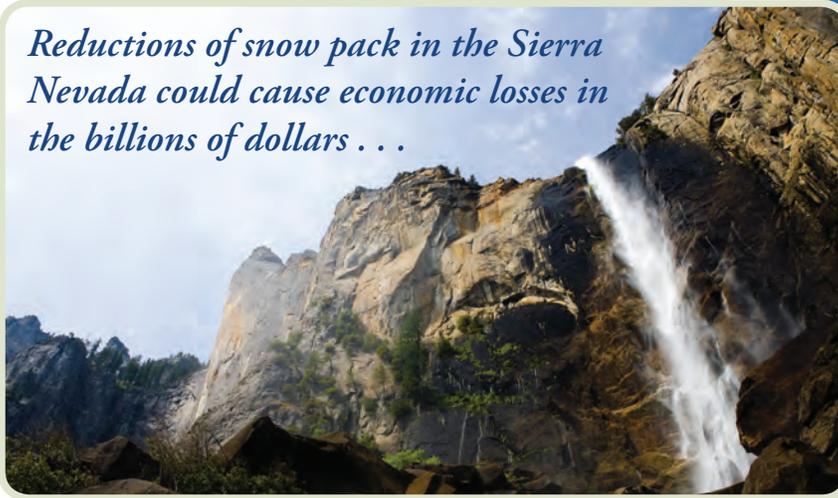
Non-CO₂ Greenhouse Gases

The Center funded an exploratory study to estimate the costs and benefits of 59 mitigation options for sources of non-CO₂ greenhouse gases, including natural gas and petroleum systems, landfills, manure management systems, electric power systems, refrigeration and air conditioning systems, and other sources. The analysis produced a set of cost curves, showing the estimated cost per metric ton of reducing a given quantity of greenhouse gases under various scenarios.

Long-term Options to Reduce Greenhouse Gas Emissions in California

The Center is investigating promising options to move California onto a path of significant greenhouse gas emissions reductions by 2050, to meet the goal adopted by the Governor on June 1, 2005. To pursue this plan, the Center is developing a new technology-rich model that will simulate the energy system in California as a region in a larger national and global model. Finally, the Center is exploring the potential for aggressive and extremely long-term energy efficiency programs as an important tool to reduce emissions in our state. This work is being closely coordinated with the work on energy technologies being undertaken at PIER and at other research programs.

Reductions of snow pack in the Sierra Nevada could cause economic losses in the billions of dollars . . .



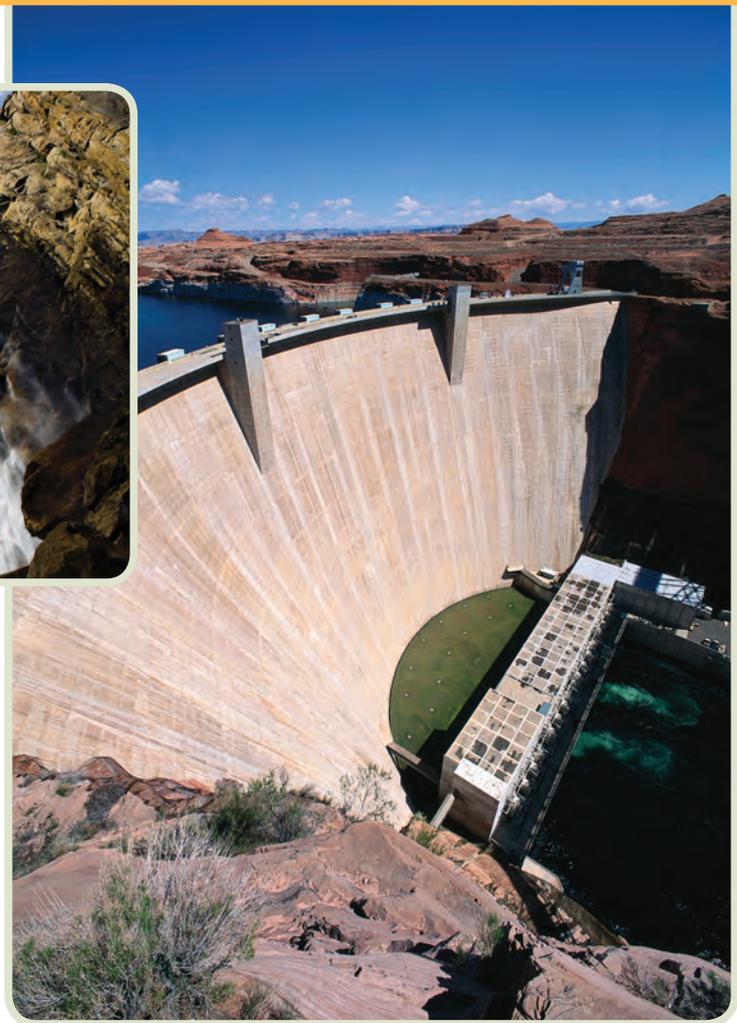
Impact and Adaptation Studies

The research areas described above focus on understanding climate change in California as well as its underlying causes. In addition to addressing those concerns, California needs to begin preparing for the expected impacts of climate change. A number of studies indicate that some level of warming is inevitable even if emissions are drastically reduced, due to the long life of greenhouse gases in the atmosphere and the slow release of stored heat from the oceans. The diversity of ecosystems and the scarcity of water in California make the state especially vulnerable to changes in climate. To prepare for the challenges ahead, planners need better information about the risks to vulnerable systems and what can be done to help them adapt to climate change.

The Center's research in this area identifies potential impacts in California and effective coping or adaptation strategies. The Center is conducting research in the following areas: energy, water resources, public health, coastal resources, forests, ecosystems, and agriculture. All of these studies are conducted in very close cooperation and coordination with the relevant federal, state, and local agencies.

Energy

The Center so far has conducted research on how climate change would change energy demand and hydropower generation. Electricity demand is expected to increase, with more pronounced impacts on peak electricity demand in the summer when, traditionally, our electricity system is stressed to satisfy demand. This negative impact would be exacerbated by a diminished capability to generate electricity from hydropower due to reduced snow pack storage. On the positive side, energy demand for space heating would go down.



Water Resources

Agriculture, electric power, industry, households, and natural systems in California all depend on reliable supplies of water. State decision makers need a better understanding of how water quality and supplies will be affected by climate change and other dynamic conditions (such as population growth). Managers must be able to identify which regions and sectors of the economy will be most affected and what steps can be taken to adapt to these challenges. The Center has published high-impact reports on the potential reductions of snow pack in the Sierra Nevada due to warming temperatures, with potential resulting economic losses in the billions of dollars by the end of this century. Center-affiliated researchers at UC Davis, UC Berkeley, and Scripps have substantially improved our scientific understanding of potential impacts. The Department of Water Resources (DWR) has used and will continue to use these study findings in the preparation of its State Water Plan. The Center is now investigating coping strategies for climate change, such as the feasibility of using underground aquifers to store water and the use of modern probabilistic hydrological forecasts and decision support systems to improve the management of water reservoirs in California. The Center, in collaboration with DWR, is investigating these options based on the promising results of preliminary studies.

Public Health and Welfare

Climate change carries a number of risks to health and safety, including shifts in the ranges of vector-borne diseases; increases in extreme weather-related events such as heat waves, flooding, and landslides; more frequent or intense wildfires; and impacts on important services and infrastructure, such as electricity supply. The Center funds research to identify risks, pinpoint the most vulnerable segments of the population, and develop strategies to reduce risk. A major effort in this area of work

Climate change will alter the fundamental character, production, and distribution of the ecosystems upon which the economy of California has been built.



More than 100 years of excluding fire has led to a heavy build-up of fuels such as dead vegetation, dense brush, and dense tree stands, with a potential for larger, more intense fires and more rapid spread than before the fire-exclusion era.

Source: U.S. Geological Survey

entails estimating the potential impacts of higher temperatures on human morbidity and mortality. The Center has also funded the development of sophisticated models to project the future risk of wildfires in the state. The modeling studies suggest that large wildfires could become more frequent over this century, although the risk will vary widely across the state and will be strongly influenced by changes in precipitation.

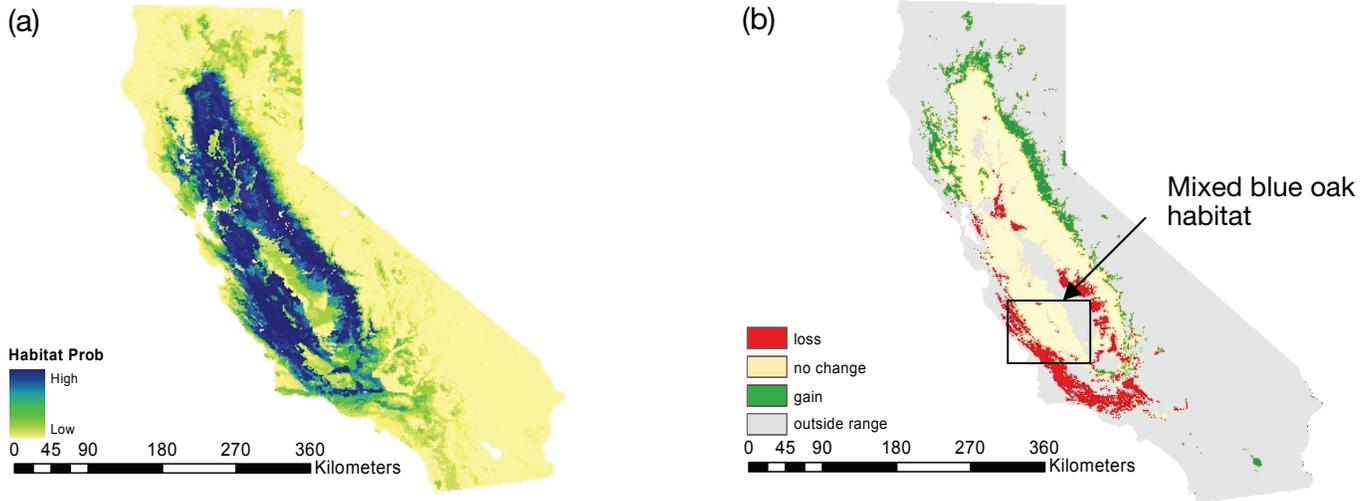
Agriculture and Forestry

Crops and natural vegetation are sensitive to changes in temperature, precipitation, and extreme weather events. The Center supports research to identify vulnerable species and early signs of stress, predict their response under a range of climate scenarios, and determine how farmers and resource managers can best prepare for these changes. Modeling studies funded by the Center show positive as well as negative effects of climate change and increasing CO₂ concentrations on crop production. While the growing season may be extended in a warmer climate, citrus fruit and olive production may decline due to reductions in winter chill periods. Other Center-funded studies show that pests such as the olive fly, Mediterranean fruit fly, and pink bollworm (which attacks cotton) would expand their range. The Center is currently engaged in preliminary studies designed to explore coping and adaptation strategies, with case studies for specific regions in California.

Ecological Changes

In addition to its effects on society and the economy, climate change is expected to have wide-ranging impacts on California's unique and rich array of ecosystems, affecting valuable ecosystem services upon which humans depend. The Center funds research in this area as well, including the first detailed analysis of changes in songbird migration timing through central and northern California. Using observational and banding data at multiple sites, the research team found that 13 species arrived earlier in spring, with 77 percent of those earlier arrivals being likely or highly likely to be associated with climate change. Other studies suggest that already detectable changes in vegetation patterns are also most likely due to a warming climate. A preliminary study suggests that the combined effect of warming and urbanization may decimate important ecosystems in California. To examine this phenomenon, the Center has developed a new dynamic ecological model for California (involving scientists from UC Santa Barbara, UC Davis, Conservation International, and Stanford University), which is being used to estimate how ecosystems would respond to changing climatic conditions. The Center is also collecting ecological data, re-sampling sites that were sampled for flora and fauna early in the 20th century to test the Center's ecological model and other promising models. Evaluating the models with historical data will increase our level of confidence in model predictions.

Urban and suburban expansion, agriculture and grazing threaten the persistence of blue oak woodlands. Climate change may exacerbate these current threats and must be considered when developing management strategies to help protect this unique community type endemic to California.



The Wilson's warbler is one of several bird species in California whose timing of spring migration appears to be affected by climate change.



California Climate Change Research Conference

Since 2004, the California Energy Commission, the California Environmental Protection Agency, the California Natural Resources Agency, and a range of cosponsors have held an annual conference to share timely results from PIER-sponsored and other research. The conference helps foster cross-disciplinary discussion, provides networking opportunities among institutions, and encourages collaboration among researchers interested in regional climate change topics relevant to California.

Conference presentations reflect state-of-the art information on climate change science, yet are tailored to present technical concepts in an easy-to-understand manner. These popular conferences have been attended by policy makers, scientists, experts from academia, state and federal agencies, national laboratories, and members of the public. Participation in the conference has grown significantly over the years and now provides opportunities for interested practitioners to participate online.

Information on past conferences, including downloadable presentation materials, may be found at:

www.climatechange.ca.gov/events/research.html



Past keynote speakers at California Climate Change Research Conferences have included such notable figures as Rajendra K. Pachauri (left) chairman of the Intergovernmental Panel on Climate Change, and James E. Hansen, director of the NASA Goddard Institute for Space Studies.

Public Outreach and Education

Biennial Science Reports

California Executive Order S-3-05 called on the California Environmental Protection Agency (CalEPA) to prepare biennial science reports on the potential impacts of climate change on certain sectors of the California economy. CalEPA entrusted the Center to lead this effort.

Our Changing Climate: Assessing the Risks to California

Our Changing Climate summarizes the findings of the Center's 2006 first biennial science report, which analyzed a range of likely impacts on California from projected increases in temperature.

The Future is Now: An Update on Climate Change Science, Impacts, and Response Options for California

The Future is Now suggests that California must use a two-pronged approach to manage its climate risks, complementing its greenhouse gas emission reduction efforts with the development of adaptation plans to help the state deal with impacts that are already underway and can no longer be avoided.

All of these documents are available at:
www.climatechange.ca.gov/research/

California Climate Change Research Bibliography

The Center maintains a searchable online research bibliography on climate change publications relevant to California. Available online at:

www.climatechange.ca.gov/bibliography/index.php

For More Information

Center Website:

www.climatechange.ca.gov/research/

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