Arnold Schwarzenegger
Governor

THE FUTURE IS NOW: AN UPDATE ON CLIMATE CHANGE SCIENCE IMPACTS AND RESPONSE OPTIONS FOR CALIFORNIA

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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The Future Is Now: An Update on Climate Change Science Impacts and Response Options for California is a special report conducted by the California Energy Commission's California Climate Change Center. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

This report presents an interim summary of the latest in climate change science and outlines recommended response options for decision makers in California. This document contains four key messages:

- Observed changes in temperature, sea level, precipitation regime, fire frequency, and agricultural and ecological systems reveal that California is already experiencing the measurable effects of climate change.
- Scientific confidence in attributing climate change to human activities has increased since the Fourth Assessment Report (AR4), which was recently made available by the Intergovernmental Panel on Climate Change.
- New scientific studies suggest that the climatic and hydrologic changes already experienced in California are due to human activity.
- Unmitigated climate change will lead to grave consequences for California's economy and ecosystems. Furthermore, it appears that even a scenario that drastically curtails emissions of greenhouse gases may still lead to undesirable trends in warming and sea-level rise.

A rapid two-pronged response to climate that which encompasses both mitigation and adaptation has the potential to promote innovative investment by businesses and protect environmental quality while increasing community preparedness and capacity to cope with change. Conversely, a path of inaction exposes a community's vulnerability to climate variability and is ultimately costly.

Keywords: Climate change, scenario, warming, temperature, precipitation, adaptation, mitigation, sea level, greenhouse gas, vulnerability

Executive Summary

Introduction

Climate change is a critical issue facing California's citizens, ecosystems, and economic vitality. In June 2005, Governor's Schwarzenegger's Executive Order S-3-05 initiated a process that requires biennial updates on the state of climate change science, the expected impacts on the state under different climate change scenarios, and an assessment of whether state efforts to address these impacts are adequate. The biennial reports mainly focus on impacts while this report demonstrates that climate is already changing in California in a way that is consistent with what is expected from climate change. In addition, this report makes a strong case about the need to consider adaptation to deal with the impacts that are already underway and can no longer be avoided. A full-color summary of this document's highlights is also available.

Purpose

Coordination is needed between climate science practitioners and those individuals helping to develop and implement a statewide climate change response strategy. This document, intended for use by the state agencies and Legislature, seeks to:

- Synthesize the most recent findings on climate change science.
- Outline a response strategy that encompasses both mitigation and adaptation.

Project Objectives

- Document how climate change in California is now occurring, has already affected public health, the economy, and natural ecosystems, and is likely to accelerate in the future. (Chapter 2)
- Explain the evidence attributing past and current observations of climate change to direct human causes such as emissions of greenhouse gases. (Chapter 3)
- Examine what would happen to California's climate under hypothetical emissions scenarios, including a scenario of drastically reduced emissions more stringent than any studied previously. (Chapter 4)
- Summarize the most up-to-date scientific understanding of how future climate change will affect California's economy and ecosystems. (Chapter 4)
- Describe the necessity of a two-pronged response strategy that includes both mitigation of emissions and adaptation to that climate change that is already underway. (Chapter 5)

Project Outcomes

The following are some of the most important recent findings taken from the published literature and summarized here:

- The American West is heating faster than the United States taken as a whole.
- Warming and precipitation changes are not occurring uniformly throughout the state. Two examples relating to temperature are the effect of intensive crop irrigation in the Central Valley, which has historically decreased the amount of warming in this region, and the increased warming effect observed in urban areas. For precipitation, changes in snowpack and the timing of spring runoff have already been observed in the Sierra Nevada Mountains over the past century.
- Agricultural productivity, forest composition, timing of ecological events (for example, migration), and wildfire frequency are all arenas that have experienced measurable changes resulting from a changing climate.
- Observed global and regional changes are largely due to human activity.
- A "Policy" scenario was modeled to simulate a drastic reduction in emissions and the stabilization of atmospheric carbon dioxide levels by 2100. Importantly, though it is more stringent than scenarios previously analyzed (such as B1) under the Scenarios Project, the Policy scenario still yields forecasts for detrimental warming and rising sea levels.
- Factors that can aggravate problems caused by climate change include population growth, the presence of poor or vulnerable social groups, and seismic risks in the San Joaquin Delta. In addition, some climate change impacts will overlap and combine in challenging ways.
- A mitigation approach aims to reduce emissions without barring economic progress. An adaptation approach accommodates the unpredictable nature of climate variability and attempts to minimize societal risk to an acceptable level. Both of these approaches are deemed necessary to address climate change. The state is implementing several adaptation programs described in Chapter 5.

Conclusions

Abundant evidence now shows that climate change is not just a future problem, but is already observable now, with measurable impacts for the state's citizens, natural resources, and economic sectors. California's position as a national leader of state-sponsored climate change research provides us a unique perspective on how best to manage for the effects of climate change. Future management decisions should recognize that current emissions have committed the state to some amount of ongoing and irreversible climate change. The consequences of taking no action on adaptation and mitigation would be costly for California and the world.

Recommendations

In 2006, California elected to take decisive action on mitigation via Assembly Bill 32, the Global Warming Solutions Act of 2006 (Núñez, Chapter 488, Statutes of 2006; AB 32), a comprehensive cap on greenhouse emissions. A complementary pathway of adaptation measures is also needed to ensure that potential harm and burden to the economy and environment of California is minimized. The Resources Agency, under the leadership of Secretary Mike Chrisman, has started a new initiative to develop a statewide adaptation strategy that will be updated every other year.

Additional recommendations include:

- Preparing for change via forward-looking, well-designed adaptation plans.
- Understanding connections between climate change and land use decisions, and understanding how climate change affects multiple sectors of the economy.
- Understanding accelerating climate change trends and examining the risks of abrupt climate change.
- Managing climate change efforts via private and public sector channels and promoting cooperation among local and regional stakeholders.

Benefits to California

- California's landmark AB 32 legislation and history of technological innovation make it a current leader in climate change science and action. With planning and foresight, both mitigation and adaptation may offer important opportunities for California businesses.
- Decreasing the human footprint on the environment, reducing vulnerability to climate variability and change, and planning ahead can improve environmental conditions and economic welfare, enhance social justice, and ensure people's quality of life.

1.0 Introduction and Purpose of This Report

California is exemplary in the nation for its commitment to state-funded climate change research, its efforts to understand the climate risks it faces, and its wide range of efforts to confront the challenge. In 1988, the Legislature mandated the preparation of the first state-focused climate change impacts assessment (leading to two high-profile reports, *The Impacts of Global Warming on California* (Energy Commission 1989) and *Climate Change Potential Impacts and Policy Recommendations* (Energy Commission 1991). Other state-focused impacts assessments, initiated and conducted by researchers outside state government, were presented in 1999 (Field et al., 1999), 2002 (USGCRP, 2002), 2003 (Wilson et al., 2003), and 2004 (Hayhoe et al., 2004). In 2003, the state also founded the California Climate Change Center to coordinate climate change research. Together these efforts are steadily building up the necessary knowledge base to inform California state policies on energy, land use, and climate change (see Franco et al., 2008a, for an extended history of the science-policy interaction around climate change in California).

With Governor's Schwarzenegger's June 2005 Executive Order S-3-05, a process was initiated that requires biannual updates on the state of climate change science, expected impacts on the state using several climate change scenarios, and an assessment whether state efforts to minimize and adapt to these impacts are adequate. The first of these "Scenarios Reports" was produced in 2006 (*Our Changing Climate*; CCCC, 2006), and work is underway to develop the scientific basis for the 2008 and future scenarios reports. Figure 1 presents a side-by-side illustration of how science and policy co-evolved in the state.

The present report discusses how climate is already changing in California and makes a strong case about the need to consider adaptation to deal with the impacts that are already underway and can no longer be avoided. It has three main goals:

- To synthesize existing knowledge with new scientific findings in order to keep policy-makers, resource managers, and the public abreast of the rapidly evolving climate change science.
- To dispel any lingering doubts about the human influence on the observed changes in the climate and the natural environment on which Californians depend.
- To underscore the increasingly urgent need for a dual approach to managing California's climate change risks:
    - To reduce greenhouse gas emissions to minimize and slow down global warming.
    - To prepare adaptation plans to deal with the impacts that are already underway and cannot be avoided.
- To minimize harm and take advantage of any opportunities that may arise from climate change.

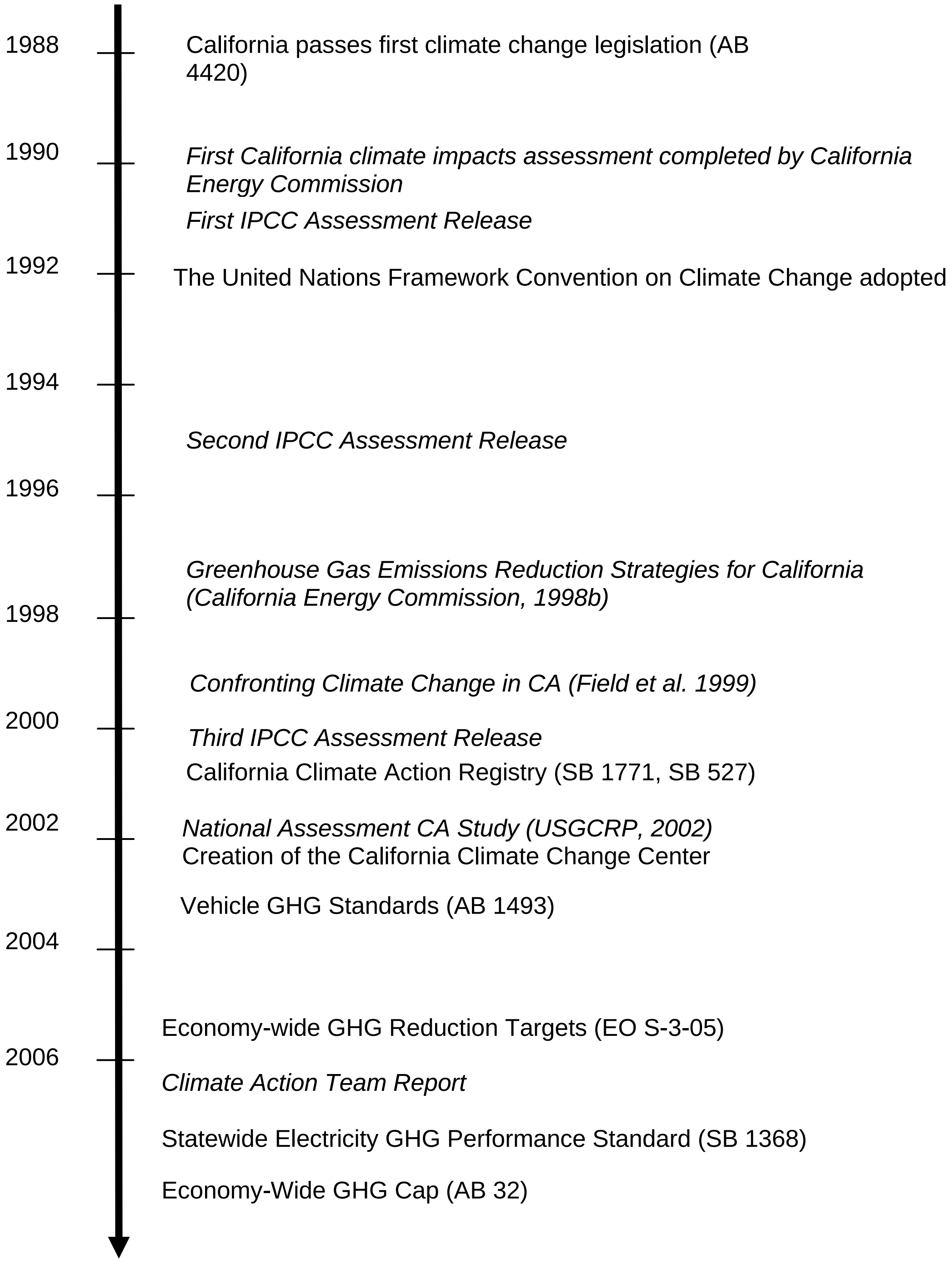

Figure 1. Co-evolution of climate change science and policy in California. Major scientific reports are italicized.

Source: Franco et al. 2008a

1.1. Guide to the Report

Chapter 2 uses primarily local examples of already observed trends in physical parameters and biological changes to illustrate that climate change is not a problem of the future but happening already, here and now, and that many of the observed trends are accelerating. Chapter 3 turns to the question of causality: What is causing these changes? It uses primarily consensus science to illustrate that the majority of climate changes witnessed over the past 50 years can be attributed to human alterations of the atmosphere and land. It also includes, to the extent possible, regional climate change detection and attribution studies of high relevance for California. Chapter 4 then updates previously published projections of climate change and related impacts with new scientific insights that have become available since *Our Changing Climate* in 2006. It focuses on all sectors relevant in California and highlights interconnections between what may happen in California and elsewhere in the nation and world. Finally, C lays the foundation for why mitigation is essential but no longer sufficient to manage the climate change risks California is already and will be facing in the future. It highlights efforts to reduce emissions and of the emerging adaptation planning efforts at the state level.

2.0 Climate Change Is Here, Now: Already Observed Changes and Accelerating Trends

2.1. California's Temperatures Are Already Changing

There is now irrefutable scientific evidence that increasing emissions of greenhouse gases are changing the Earth's climate. The most recent report by the Intergovernmental Panel on Climate Change (IPCC), released in February 2007, states, "Warming of the climate system is unequivocal, as is now evident from observation of increases in average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (Le Treut et al., 2007).

Review of Temperature Impacts

- Overwhelming scientific consensus that greenhouse gas emissions are changing our climate
- The western United States is warming faster than the rest of the United States
- California's annual nighttime temperatures have increased 0.33 °F per decade since 1920
- California's annual daytime temperatures have increased 0.1 °F per decade
- In the Central Valley, irrigation has reduced the expected warming from climate change

The current post-industrial warming trend differs alarmingly from past changes in the Earth's climate because greenhouse gas emissions are higher and warming is occurring faster than at any other time on record within the past 650,000 years. Historical long-term as well as decadal and inter-annual fluctuations in the Earth's climate resulted from natural processes such as plate tectonics, the Earth's rotational orbit in space, solar radiation variability, and volcanism. The current trend derives from an added factor: human activities (see this section). Worldwide, eleven of the last 12 years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850 (Le Treut et al., 2007).

The American West is heating up faster than any other region of the United States (reference from a report from the U.S. Climate Change Science Program, 2008, Saunders et al., 2008). For the last five years, from 2003 through 2007, the global temperature averaged 1°F warmer than its 20th-century average. During the same period, 11 western states averaged 1.7 degrees warmer, 70% more than the world average. This is primarily due to the fact that arid land areas prevalent in American West heat more easily in contrast to the slow-warming oceans. A second explanation may be that atmospheric conditions in the East have produced cloudier and wetter weather, cooling the region relative to the West. Regardless, scientists have shown that the warming trend is more than 99% likely to be outside the normal bounds of climate variation.

In California, average annual temperature has been increasing since 1920 (Figure 2).

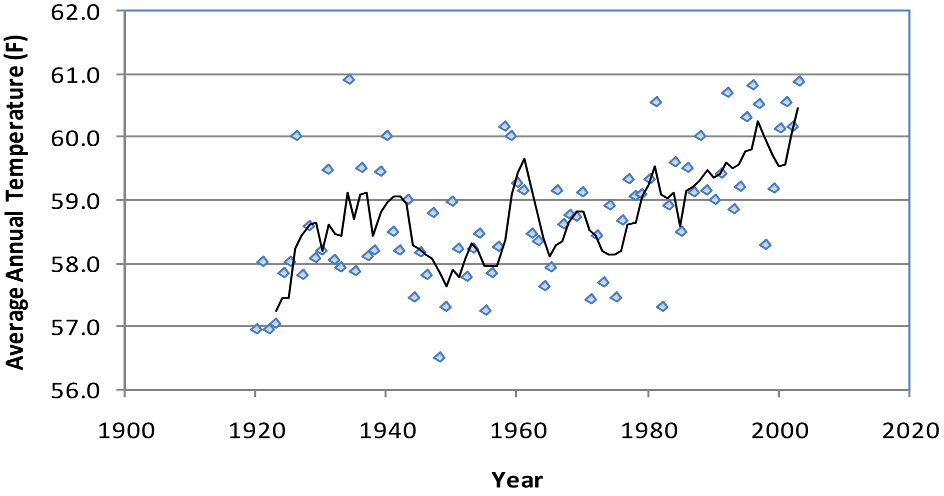

Figure 2. Historical annual average temperature for California. The solid line shows the five-year running average trending upwards. Warming trends due to urbanization have been removed from these long-term climate data.

Source: The National Climatic Data Center, available at http://cdiac.ornl.gov/epubs/ndp/ushcn/state_CA_mon.html.

The warming of California is not geographically uniform. Minimum temperatures (typically nighttime) are increasing almost everywhere in California (Figure 3a) during the summer. On the other hand, maximum daily temperatures are increasing at a slower rate, with some locations (for example, the Central Valley), experiencing a cooling trend (Figure 3b, blue circles). The annual minimum temperature averaged over all of California has increased 0.33°F per decade during the period 1920 to 2003, while the average annual maximum temperature has increased 0.1°F per decade. Measurements taken from other stations in the United States show a similar pattern of stronger nighttime warming (Easterling et al., 1997). The heat wave that affected California in July 2006 was the largest heat wave on record since 1948. This heat wave has been linked to a warming of the ocean especially west of Baja California, which seems to be part of a global pattern of warming of the ocean waters during the last six decades (Gershunov and Cayan, 2008). As explained in the next section, the gradual warming of the oceans is now clearly attributed to increased concentrations of greenhouse gases in the atmosphere.

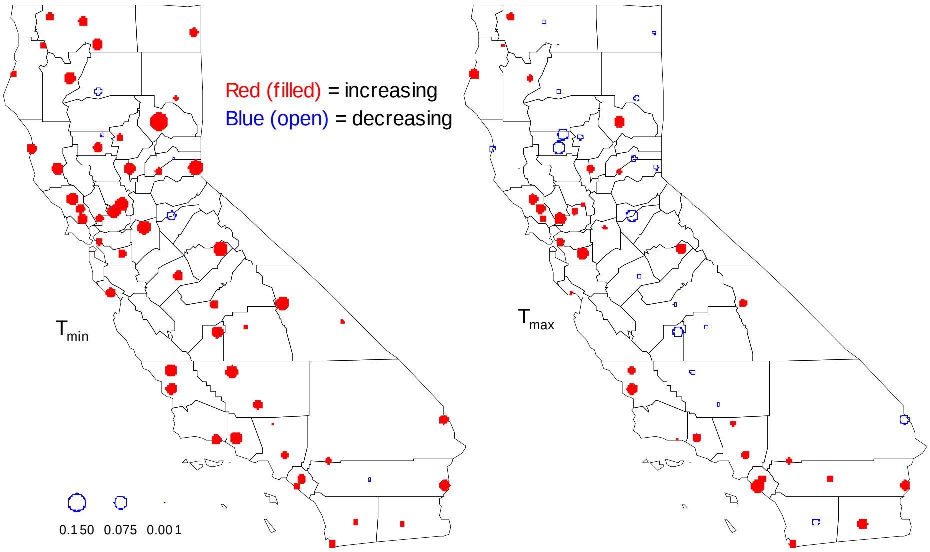

Figure 3. Minimum (a) and maximum (b) daily summer temperature trends at 52 different weather stations in California (1920-2003). Red points indicate warming; blue points indicate cooling. The size of the points is proportional to the rate of change.

Source: California Energy Commission, CEC-500-2005-103-SD.

It appears that intensive irrigated agriculture explains why summer maximum temperatures in the Central Valley have either cooled or have warmed less than other areas of California[1] (Bonfils and Lobell, 2007). Irrigated agriculture in the Central Valley increased between 1920 and 2000, doubling in area by 1979 and eventually stabilizing in the 1980s. During this period of expanding irrigation practices, a large cooling effect of -1.8°F to -3.2°F (relative to non-irrigated areas) has been observed for summertime average daily daytime temperatures in the Valley. The difference in daytime temperatures between irrigated and non-irrigated lands is strongly related to the trend in the amount of irrigated area since 1920 (Figure 4).

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[1] Simulations using regional climate models have also suggested that agricultural irrigation in California has dampened the expected increase of daytime temperatures in the Central Valley (Snyder et al., 2006). The study by Bonfils and Lobell (2008) was the first to experimentally confirm this effect.

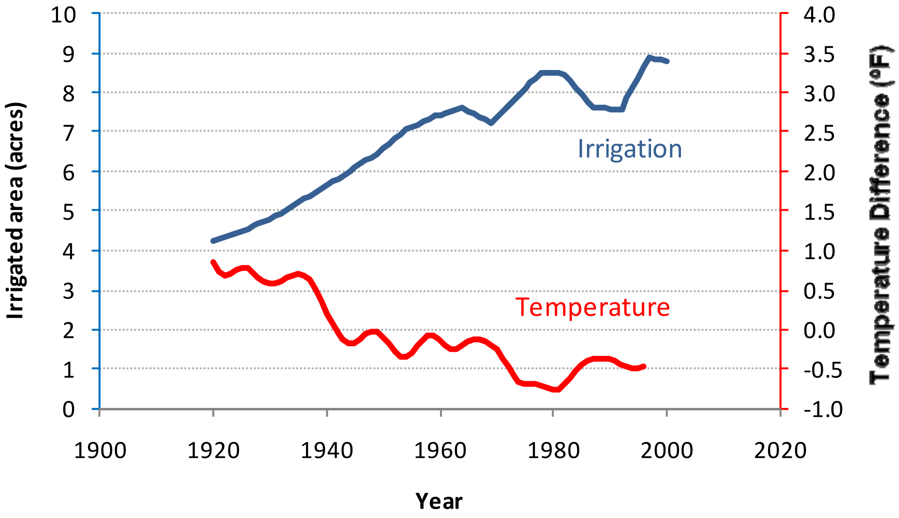


Figure 4. Historical differences in maximum temperature (between irrigated lands and non-irrigated areas, red line) and concurrent changes in irrigated land area in the same region (blue line). Temperature data are June to August months. All data were located in the Central Valley, California.

Source: Adapted from Bonfils and Lobell, 2007.

The empirical evidence from Figure 4 indicates that an increase in agricultural irrigation in the Central Valley has progressively cooled this region, partially masking the warming trend observed in non-irrigated regions. Moist irrigated soil allows for evaporative cooling of the air above, much the same way an evaporative cooler can be used to cool our homes in the dry summer months. A serious concern is that the amount of water available for irrigation is leveling off and is expected to decline in the future, which could prompt an acceleration of warming in the Central Valley.

2.2. Adverse Effects of Climate Change on Public Health

Warming temperatures in the U.S. have given rise to increasingly frequent heat stress events over the last fifty years (NOAA 1999). The largest and most statistically significant trends occurred in some of the most populated areas, in the eastern and western thirds of the United States (Gaffen and Ross, 1998).

Review of Public Health Impacts

- Higher temperatures are correlated with increased heat-related mortality
- Increasing nighttime temperatures make it difficult for the body to cool overnight, increasing the risk of heat related illness
- Persons in socioeconomically depressed areas are at a greater risk for heat-related mortality due to lack of access to in-home air conditioning or neighborhood cooling places, social isolation, and lack of social networks and support systems
- Increased frequency in heat stress events over last fifty years

With climate change, nighttime minimum temperatures have increased significantly (Easterling, 1997; Bonfils et al., 2008), which limits the body's ability to cool overnight during heat waves (English et. al., 2007). Urban areas tend to have higher nighttime temperatures than less developed rural areas since buildings and pavement reemit the heat that they absorbed during the day. In addition, waste heat from vehicles, industry and air conditioners contribute to warmer temperatures in urban areas, exacerbating heat-related illness and mortality and increasing the heat stress vulnerability of millions of Californians living in urban areas (e.g., English et al., 2007; Hayhoe et al., 2004). While the July 2006 heat wave in California did not raise daytime temperatures beyond those of heat waves from the last six decades, the nighttime temperatures experienced during this event were truly unprecedented. Although the authors cannot directly attribute the July 2006 heat wave to climate change, abundant evidence suggests a causal link between climate warming and extreme events. A recent study analyzing this heat wave from a historical perspective concluded that "Generally, there is positive trend in heat wave activity over the entire region that is expressed more strongly and clearly in nighttime rather than daytime temperature extremes. Daytime heat wave activity has been intensifying more rapidly over the elevated interior compared to the lowland valleys." (Gershunov and Cayan, 2008).

There is no uniform definition of a "heat wave"; for example, temperatures that might be considered "normal" in Fresno would constitute an extreme heat event in San Francisco, based on historical precedent. What is considered a "heat wave" locally is the important metric regarding human health, however, because of the temperatures to which the local population is acclimatized. A useful metric at a given climate station is the number of degrees Fahrenheit warmer than 99 percent of the historically recorded temperatures (the 99th percentile). For example, Figure 5a represents this 99th percentile metric at the Firebaugh, California, climate station in the heart of the San Joaquin Valley. To capture the geographical coverage of the heat wave, the authors could add up these hours for all the stations in a given region to generate a composite metric. Figure 5b presents the cumulative degrees for meteorological stations in California and Nevada for the major regional historical heat waves from 1948 to 2006. For the last six major daytime (blue plus-signs) and nighttime (red boxes) heat waves that occurred in "California region," the magnitude of nighttime heat waves has substantially increased over time (Figure 5b).

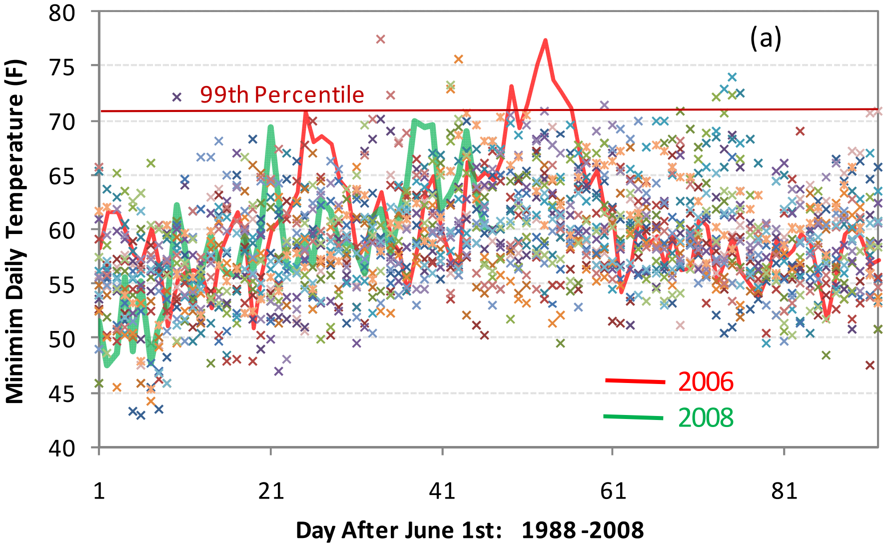


Figure 5a. Ninety-ninth percentile metric comparisons at Firebaugh, California, Climate Station. Red and green lines represent minimum daily summer temperatures each day from June 1 to August 31 (day 1 to day 92) during 2006 and 2008, respectively. The 99th percentile line indicates nights during which the minimum temperature exceeded 99 percent of historically recorded temperatures for that climate station.

Adapted from Gershunov and Cayan, 2008.

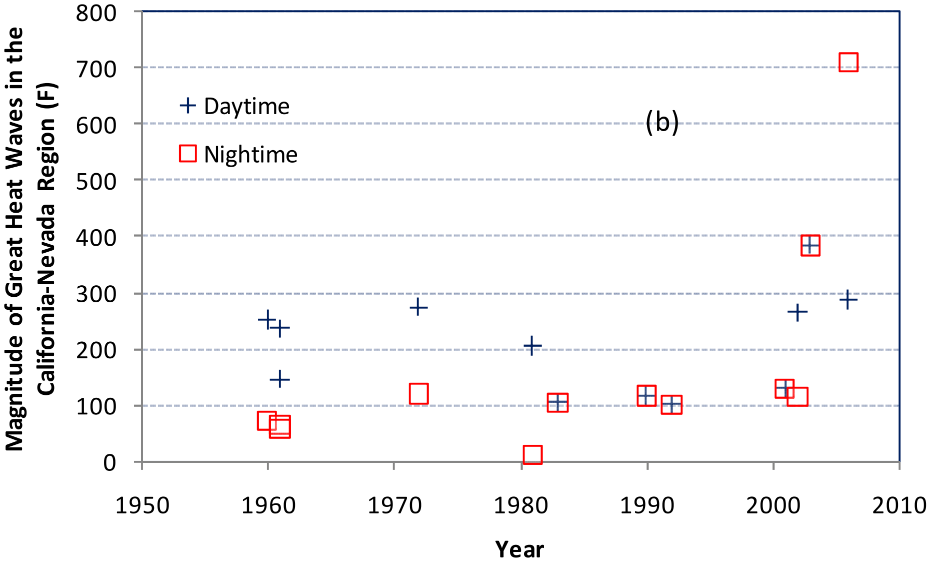


Figure 5b. Overall magnitude of the major heat waves in California and Nevada (˚F) from 1948 to 2006. Blue plus-signs and red boxes represent events dominated by temperatures during the day or night, respectively. The vertical scale represents the summation of degrees F above the 99 percentile for all the stations included in the analysis.

Adapted from Gershunov and Cayan, 2008.

Increases in mortality are commonly observed during heat waves (Basu and Samet, 2002). Heat especially increases the vulnerability of the elderly and of infants as well as persons with cardiovascular, respirator and/or cerebrovascular diseases (English et al., 2007). An analysis of temperatures during summers in several counties in California with no heat waves from 1999 to 2003 found a 3% increase in deaths on any given day for a 10°F increase in the heat index, which is a measure of combined temperature and humidity (Basu et al., 2008).

In the summer of 2006, a heat wave of unusually long duration led to 140 heat-related deaths in California (CDHS, 2007), which excludes potentially heat-related deaths not seen by coroners or medical examiners, who do not typically investigate deaths of persons currently under a doctor's care. During this two-week heat wave, 80% of the reported deaths occurred in seven inland, low-lying areas, such as the Imperial Valley, San Bernardino and the San Joaquin Valley. Sixty-four percent of the heat-related death cases occurred in socioeconomically depressed areas (zip codes where more than 20% of the residents earn less than the Federal Poverty Threshold). A preliminary epidemiological analysis of the July 2006 heat wave and other similar extreme events in California suggest mortality rates higher than the reported 3% increase per 10°F discussed above (Ostro, 2008, personal communication).

The ability to use cooling mechanisms such as air conditioning is one way to combat the negative health effects of rising temperatures. Statewide, older homes (built before 1975), coastal properties, and low-income households are less likely to have air conditioning in the home. The victims of the 2006 heat wave were predominately male (66%), older adults (median age of 66 years), and had a history of chronic disease (73%) (English et al., 2007). Indoor temperatures (only noted in 36 of the recorded 140 cases) averaged 103.5°F, with a range of 85-140°F. None of the decedents was known to have visited a cooling center, and only one individual had an air conditioner running in her home at the time of death.

2.3. The Changing Water Cycle

Declining Snowpack and Earlier Spring Runoff

Review of Water Resources Impacts
• Recorded reductions in the Sierra snowpack • The Sierra snowpack is melting earlier in the spring season • A decrease in spring runoff is creating deficits in reservoir storage during the dry season

Most of California's precipitation falls in the winter as snow in the Sierra Nevada mountain range. Sierra snowpack is extremely important because it acts as a large natural reservoir and provides water for the summer and fall when rainfall is scarce. Over the past century, rising temperatures over the Sierra Nevada have had two major implications: first, more precipitation is falling as rain and less as snow (Mote et al., 2005; Knowles, 2006); and second, snowmelt is occurring earlier in the spring (Hamlet et al., 2007), leading to a shortened winter recreation season and earlier low-flow conditions, with potentially severe implications for fish and other aquatic life and California's all-important water supplies.

One important trend is the decline of total snow accumulation (and water content in the snow) on April 1st (Mote et al., 2005). April 1 is an important date for water managers because it is when they estimate the amount of water stored in the snow and determine how much water will be available to satisfy water demands in the spring and summer.

The amount of water contained in the accumulated snow on April 1 has been declining in low-elevation areas (Figure 6) while snowfall in higher elevations of the southern portion of the Sierra Nevada has been increasing. Lower elevations are more vulnerable to the effects of warming since a small rise in average temperature will create an earlier snowmelt or a shift from snow to precipitation. At high elevations, cooler temperatures provide a buffer that can maintain the snowpack until spring, but this "safety" factor is being eroded by observed warming of the Sierra Nevada. As more snow falls as rain during the winter, and spring snow melt occurs sooner, the risk of flooding increases and water shortages may occur in the summer.

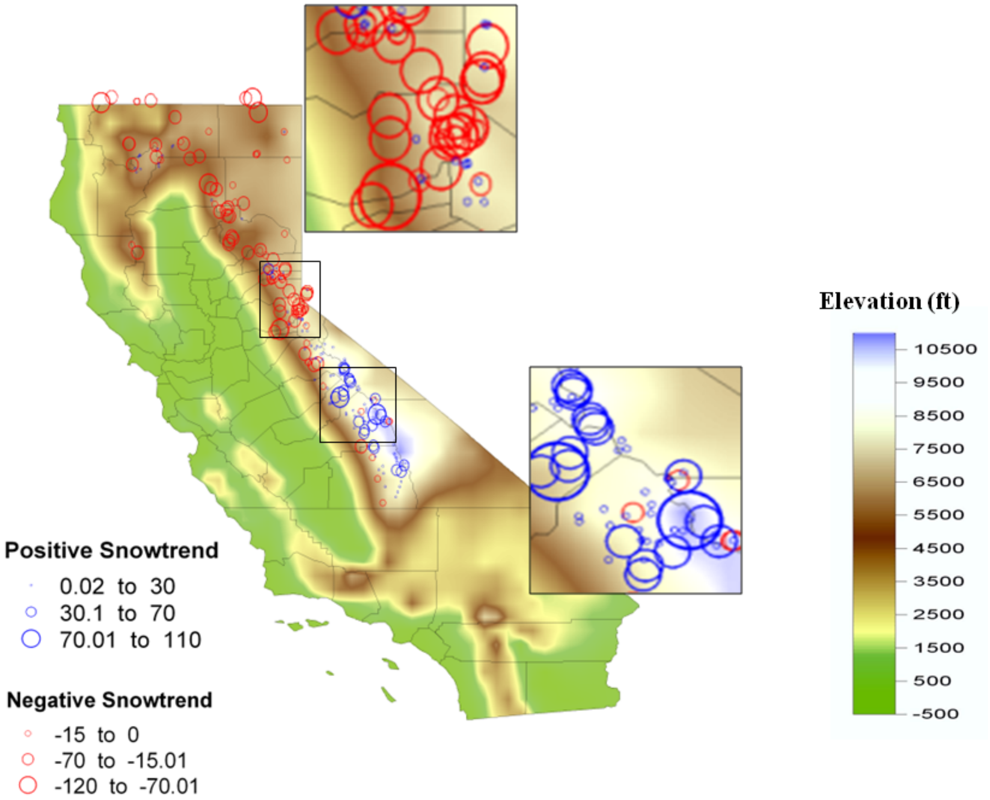


Figure 6. April 1 snow level trends 1950-1997. The red points indicate percent decrease in April 1 snow levels and blue points indicate percentage increase.
Source: Adapted from Mote et al. (2005).

Consistent with the decreasing spring snow levels, California, as well as most of the western United States, is experiencing a related decrease in the fraction of total runoff occurring in the spring (Figure 7). Spring runoff provides a significant portion of the water supply for dry summers and falls in California. Over the past 100 years, the fraction of the annual runoff that occurs during April–July has decreased by 23% for the Sacramento basin and 19% for the San Joaquin basin. This indicates that a greater percentage of the annual runoff is occurring outside the traditional snowmelt season possibly as a result of an earlier onset of snowpack melting. If, as expected, the snowmelt season were to migrate to earlier times in the year as a result of global warming, it would reduce the amount of runoff that could be stored in man-made reservoirs for later use, because runoff would occur during times when flood control requirements mandate release of water from reservoirs to take into account the possibility of strong precipitation events late in the winter (wet) season.

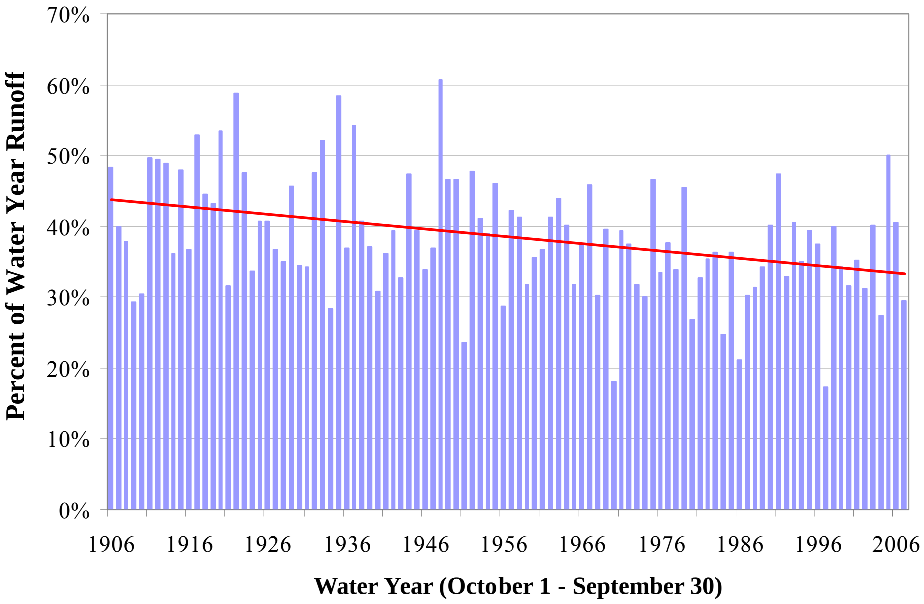


Figure 7. Sacramento River Runoff (April – July) as a percentage of annual runoff. The red linear regression line shows the decreasing historical trend in river runoff.

Source: California Department of Water Resources.

2.4. Growing Stresses in Agriculture

Agriculture is a major sector of California's economy. Statewide agricultural income from sales in 2003 was $27.8 billion, or 13% of the U.S. total (2004). As the nation's leading producer of 74 different crops, California supplies more than half of all domestic fruit and vegetables (CASS, 2004). California is also responsible for more than 90 percent of the nation's production of almonds, apricots, raisin grapes, olives, pistachios, and walnuts (Baldocchi and Wong, 2008; Cavagnaro et al., 2006). Many of these crops are sensitive to multiple facets of climate change, but here the authors focus solely on changes in temperature.

2.5. Decreasing Chill Hours

Review of Agriculture Impacts
• The decreasing trend in wintertime and nighttime chill hours threatens the fruit and nut industry • Recent climatic trends have had mixed effects on crop yields, with orange, lettuce, grape, and walnut yields aided, avocado yields hurt, and most crops little affected by recent climatic trends

Temperature plays a critical role in determining the yield and quality of several economically important crops. Fruit and nut crops, for example, are especially climate-sensitive and require a certain number of hours of cool temperatures (200 to 1200 hours, depending on the crop) during the winter months to properly set fruit. The number of chill hours (time during which temperature drops below 45°F in California's major fruit growing region), however, has been decreasing since 1950 (Baldocchi and Wong, 2008). Failure to meet the minimum requirement of chill hours can cause late or irregular blooming, which decreases fruit quality and reduces economic yield.

The greatest rates of change in chill hours are occurring in the Bay Delta region and the mid-Sacramento Valley (Figure 8).

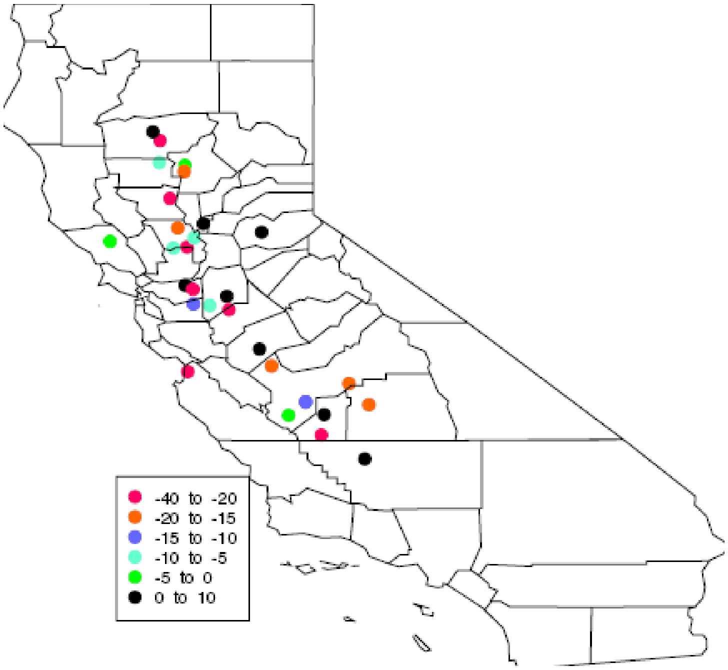


Figure 8. Map of the trends in the change in winter chill hours (hours per year) since 1950.

Source: Baldocchi and Wong, 2008 (data are derived from the California Climate Archive).

Grapes and almonds represent the two of the most valuable food crops in the state. Chill-hour requirements for grapes (depending on variety) are between 100-500 and 400-700 for almonds. If chill hours dropped below the threshold for grapes and almonds it would represent a $3.3 billion dollar loss (2003 value).

While warmer nights have negative impacts on many fruits, nuts, avocados and cotton, it has actually enhanced the production of high-quality wine grapes (Nemani et al., 2001) and oranges (Lobell et al., 2006). Since the early 1950s, winegrape growers in California have seen dramatic increases in premium wine quality and grape yield associated with climate change (Nemani 2001). In the Napa and Sonoma valleys, warmer winter and spring temperatures have resulted in a longer growing season and more favorable growing conditions. However, with the continuation of these warming trends, conditions will be too warm and no longer favorable for the production of certain grape varieties. This creates large financial risks for grape growers who must make significant upfront investments in crops which generally take many years to provide financial paybacks.

2.6. The Disassembly of California's Ecosystems

A number of ecological changes have already occurred in the United States over the past century in concert with increases in average temperature and changes in precipitation patterns (Peñuelas and Filella, 2001; Fields, 2007), Walther et al., 2002; Parmesan and Yohe, 2003, Root et al., 2003, 2005; Parmesan, 2006). Currently, spring is beginning earlier, while the arrival of autumn is being delayed (Menzel et al., 2006). Change in seasonal timing has serious implications for the life cycles and competitive abilities of numerous species (Walther et al., 2002; Visser and Both, 2005; Parmesan, 2006). Examples of different ecological effects in Europe and North America include shifts in phenological spring events such as budburst, egg laying, bird migration and the hatching of caterpillars occurring earlier over the course of the last 30 years (Menzel et al., 2006; Schwartz et al., 2006; van Asch and Visser, 2007). In California, 70% of 23 butterfly species advanced the date of first spring flights by an average 24 days over the period from 1972 to 2002 (Forister and Shapiro, 2003). Climate warming during spring is the only factor that was able to explain this shift in the date of the butterfly's first flight.

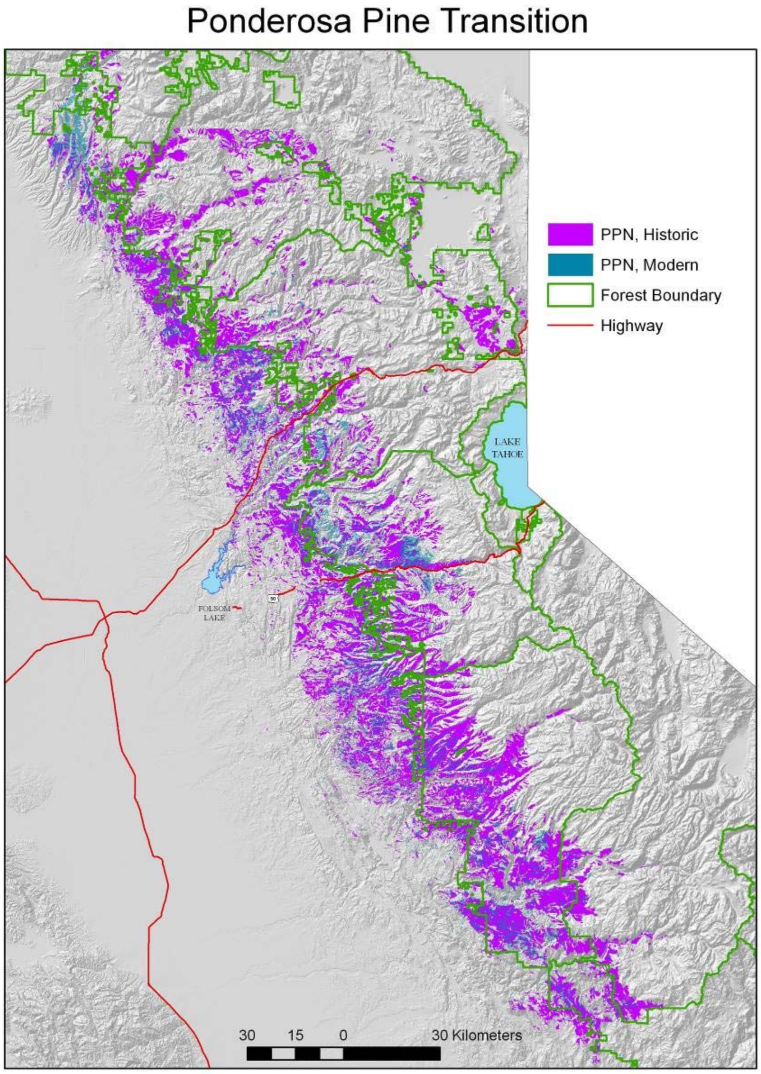
Review of Ecosystem Impacts

- The early arrival of spring and delay of fall has had numerous ecological impacts on species that rely on temperatures to dictate migration and reproduction
- The ecological ranges of Sierra Nevada flora and fauna are shifting north and higher in elevation
- Wildfires have increased in frequency, duration and size due to a longer dry season
- The water of Lake Tahoe is warming in accordance with increasing nighttime temperatures.

2.7. Shifts and Disturbances in Forests and Other Managed Landscapes

Many ecosystems in California, including managed ecosystems such as rangelands, timberlands and agricultural lands, are highly sensitive to the influence of temperature and water availability. Increasing temperatures, changing precipitation patterns, and declining soil moisture trends have shifted the suitable range for many species typically to the north or to higher elevations (Parmesan and Yohe, 2003).

In the 1930s, a U.S. Forest Service team led by A. E. Wieslander surveyed California's vegetation over roughly one-third of the state, producing a rich data set including vegetation type maps, thousands of photographs, and 25,000 herbarium specimens. This historical data has enabled researchers today to assess vegetation changes over the interim (Thorne et al., 2006). In a study of ponderosa pine forest changes between 1934 and 1996 on the western edge of the Sierra Nevada (Placerville Quadrangle), researchers found that the western edge of the forest moved an average of 4.4 miles (7.1 km) eastward and shifted upward by about 637 feet (193 meters), with the previously ponderosa-dominant areas being replaced by non-conifer species (e.g., oaks). Thorne et al. (2006) hypothesized that these changes were at least partially due to anthropogenic climate change. Figure 9 presents more recent results from ongoing research on this topic (Thorne, 2008).

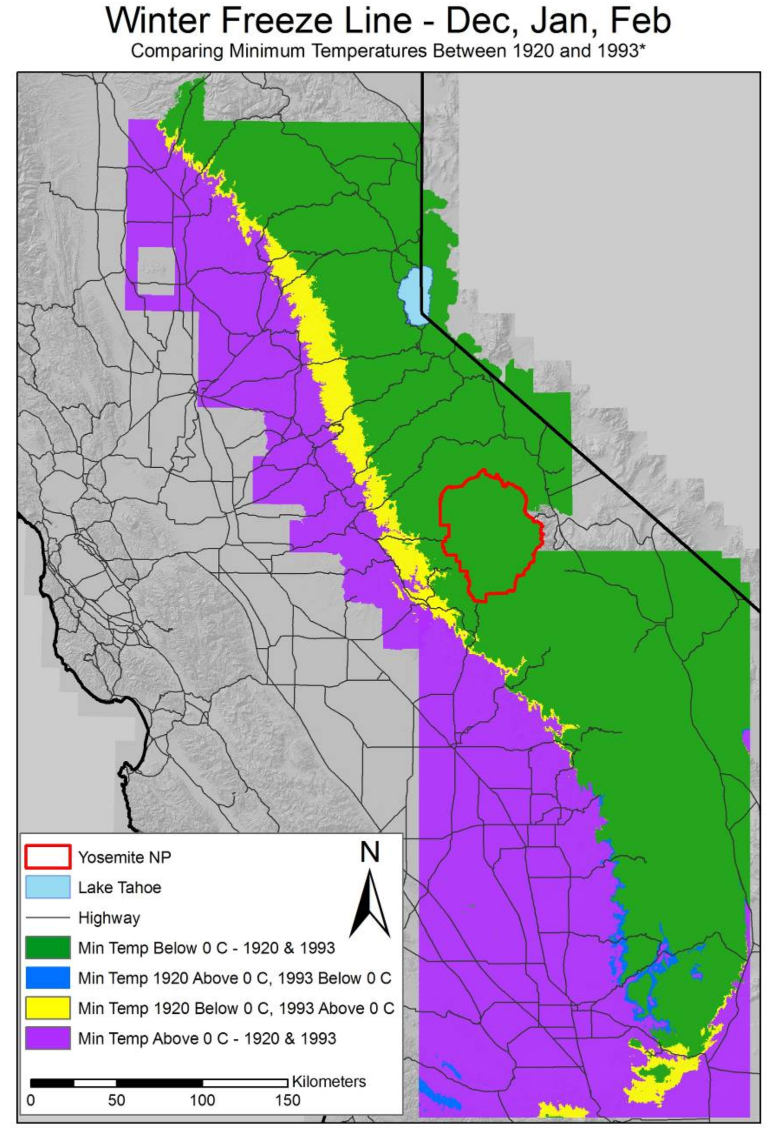


Ponderosa Pine Transition

Figure 9. Upslope retraction of ponderosa pine-dominated woodlands between 1930s and 1996.Note also the downslope retraction of the upper edge, related to fire suppression which provides competitive advantage to Douglas fir and white fir over ponderosa.

PPN Source: Thorne, 2008.

Sierra Nevada warming had already been documented by other scientists and was confirmed by Thorne et al. (2006), who found an increase in monthly minimum temperatures in the middle-elevation Sierra Nevada Mountains over the past 100 years by about 5.4 ºF. In the 1930s, the coldest months still registered with their minimum temperatures below freezing (Figure 10). While unlikely to be responsible for the death of mature pines, which were harvested, the higher temperatures correlate with longer summer drought conditions, which in turn increase drought stress on seedlings. "Drought stress–driven mortality of seedlings following stand removal is the suspected driver of the diminishing range of the Ponderosa Pine Forest" (Thorne et al., 2006, p.3). Corroborating evidence came from the fact that areas potentially affected by other factors such as fire, urbanization, and areas that had converted to grassland with competitive nonnative grasses and pressure from cattle grazing, were removed from the analysis. About 58% of the area had not been affected by these confounding factors, thus suggesting strongly that anthropogenic climate was the key driver behind the observed eastern and upward retreat of ponderosa pine.



*1920 data is the average between 1900-1940; 1993 data is the average between 1980-2006

Figure 10. Change in nighttime frozen areas during the winter quarter, from 1920 to 1993. The yellow sections of the map represent areas that are now no longer frozen at night.

Source: Thorne, 2008.

2.8. Increasing Wildfire Frequency

In recent years, wildfires have increased in frequency, duration and size. The forested area burned in the western United States from 1987 to 2003 is 6.7 times the area burned from 1970 to 1986 (Westerling et al., 2006). Land management is often blamed for the increase in wildfire frequency. A century of fire suppression has lead to increased forest densities and accumulation of fuel wood that can result in more severe fires when this excess buildup of fuel is ignited. Yet climate also plays an important role: Warmer temperatures and longer dry seasons are the main reasons for the increasing trend in forest wildfire risk (Westerling et al., 2006). Reduced winter precipitation and early spring snowmelt deplete the moisture in soils and vegetation, leading to longer growing seasons and drought. These increasingly dry conditions provide more favorable conditions for ignition. In addition, higher temperatures increase evaporative water loss from vegetation, increasing the risk of rapidly spreading and large fires. In the last three decades the wildfire season in the western United States has increased by 78 days, and burn durations of fires >1000 ha in area have increased from 7.5 to 37.1 days, in response to a spring-summer warming of 33.6°F (Westerling 2006). Forests at mid-elevations are at a greater risk for wildfire than lower or higher elevational bands. At high elevations the conditions are less favorable for wildfires because even if the dry season is longer, it is still relatively short and is more protected from the drying effects of the higher temperatures.

2.9. The Warming of Lake Tahoe

The waters of Lake Tahoe are warming at almost twice the rate of the world's oceans (Coats et al., 2006). Analysis of a 33-year data set of more than 7,300 measurements of lake-water temperature collected found that from 1969 to 2002, Lake Tahoe's water temperature increased, on average, 0.027°F per year. Over the 33-year period, the temperature increased about 0.88°F. This is similar to warming reported in other big lakes around the world, including the Great Lakes of North America; Lake Zurich, Switzerland; and Lake Tanganyika, Africa. Tahoe water temperature records are comparable to Tahoe air-temperature records. Nighttime air temperatures rose 3.6°F over the period 1914–2002. The warming of air temperatures is sufficient to account for most of the increase in water temperature.

The lake water warming rate varies with depth. The warming rate is highest at 0 and 38 feet, decreases at depths of 65.6 and 98.4 feet, and increases again at 164 feet. The upward trend in lake temperature is modifying the thermal structure of the lake, and increasing its resistance to stratification and remixing. The continual mixing of lake water is an essential phenomenon that provides oxygen to the deep waters. The most significant effects on the lake ecosystem with continued warming trends will most likely be associated with the increased thermal stability and resistance to mixing (Coats et al., 2006).

2.10. Increasing Rate of Sea-Level Rise

Review of Sea-Level Changes

- Global average sea level rose at an average rate of 0.07 inches per year from 1961 to 2003
- The rate of sea-level rise has accelerated to an average rate of 0.12 inches per year over the decade from 1993-2003
- The combination of higher sea levels and larger precipitation events has increased the frequency of extreme tidal events in the San Joaquin Delta

Sea level has been rising globally since the end of the last glaciation more than 10,000 years ago. Global average sea level rose at an average rate of 0.07 inches per year from 1961 to 2003 and at an accelerated average rate of about 0.12 inches per year during the last decade of this period (1993 to 2003) (IPCC 2007).

Global sea-level rise is primarily the result of thermal expansion of the ocean water (water expands as it heats up) and the melting of land-based ice (which adds water to the ocean basins). These two contributors account for most, but not all of, the observed sea-level rise. For the recent period 1993 to 2003 the small discrepancy between observed sea level rise and the sum of known contributions might be due to as-yet-unquantified human induced processes (for example, groundwater extraction, impoundment in reservoirs, wetland drainage and deforestation) (Bindoff et al., 2007).

Sea-level rise is already affecting much of California's coastal region, including the Southern California coast, the Central California open coast, and the San Francisco Bay and upper estuary. Figure 11 shows relative sea-level height for a north and a south coast tide gauge station in California. During the past century, sea levels along California's coast have risen about seven inches. The rate of sea-level rise observed at the gauges along the California coast is similar to the estimate for global mean sea level.

Bromirski and Flick (submitted) demonstrated that extreme sea-level events in the ocean near San Francisco propagate to the Sacramento/San Joaquin Delta. For this reason, extreme sea-level events (also known as "surge events") observed at San Francisco are associated with extremes within the Delta. According to these authors, since the 1950s, extreme sea water level events have become more frequent in the ocean close to San Francisco. This upward trend in extreme sea-level events "underscores the potential impact of sea level rise on the Delta levees and Bay/Delta ecosystem, and also suggests an increased risk of saltwater intrusion into coastal aquifers." (Bromirski and Flick, submitted). In addition, in the historical record, extremes in storm surge and floods due to high runoff levels in California rivers coincide very frequently. During such instances, the risk of levee failure is enhanced (Bromirski and Flick, submitted).

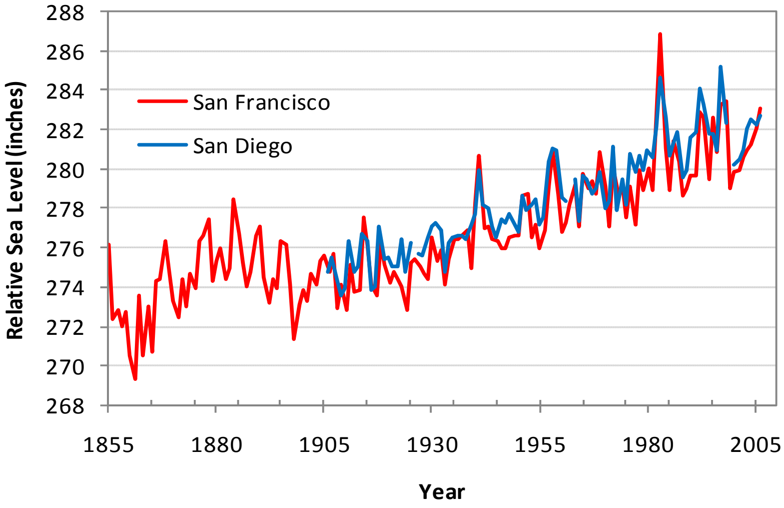


Figure 11. Historical sea-level rise for San Francisco and San Diego.

Data Source: NOAA, 2008[2].

2.11. Conclusions

In this section, the authors have provided examples of recent research that documents observed changes in California's regional climate, as well as climate-driven changes in physical and biological, both natural and managed, systems. Two conclusions emerge from these studies: first, the impacts of climate change, often still perceived as problems that might manifest in the distant future and in distant places, are actually evident in California at this time. Second, with only a relatively small temperature increase over the past few decades, the magnitude of impacts on physical and ecological systems is surprisingly large, especially for essential resources such as snowpack and water supplies. Moreover, in the last few decades, these changes have begun to accelerate. As the next section will document, there is now overwhelming evidence that the observed climate changes are driven by human activities. Even if these activities could be curtailed dramatically, climatic and related environmental changes would continue to impact California for the foreseeable future. This conclusion alone suggests that California will need to pursue a two-pronged approach to managing its climate change risks—the ones already evident and those coming in the future, and the authors will return to this issue in Section 4. Below, the authors provide evidence for the clear human influence on changes in the global and regional climate.

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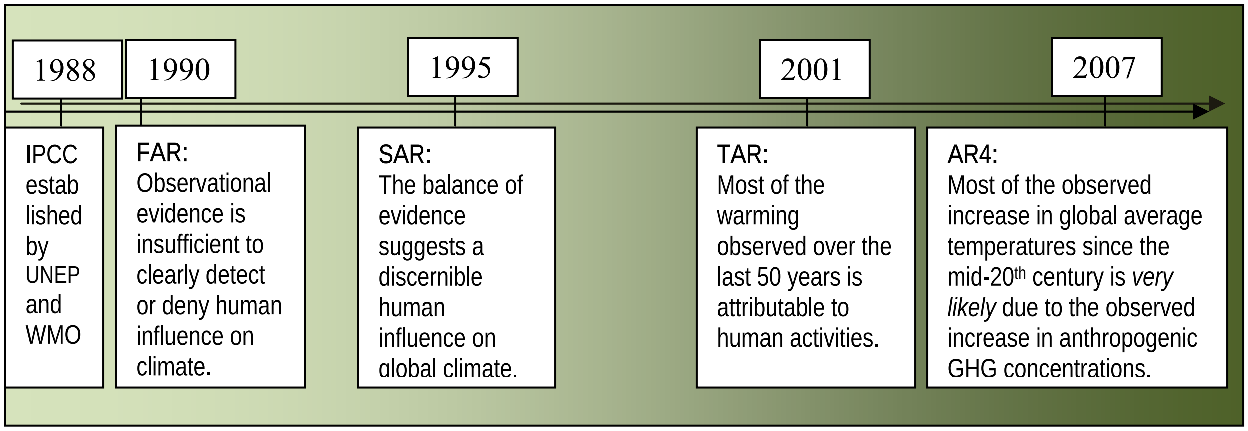
[2] http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

3.0 Detecting the Human Fingerprint on Our Changing Climate: The Scientific Verdict Is In

Over the course of four IPCC assessment reports from 1990 to 2007, the conclusions regarding whether human activities can be held responsible for the changes observed in global and regional climates have become stronger. While the IPCC's first assessment could only state that the observational evidence was insufficient to either clearly detect or deny a human influence on the global climate (IPCC, 1990), in its most recent assessment, the IPCC essentially eradicated any remaining doubt over human responsibility for the observed impacts over the last half of the 20th century (Figure 12; Solomon et al., 2007).



IPCC established by UNEP and WMO

FAR:
Observational evidence is insufficient to clearly detect or deny human influence on climate.

SAR:
The balance of evidence suggests a discernible human influence on global climate.

TAR:
Most of the warming observed over the last 50 years is attributable to human activities.

AR4:
Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.

Figure 12. Growing scientific confidence regarding human contribution to climate change. Since the founding of the Intergovernmental Panel on Climate Change in 1988, the scientific community has conducted four global climate change assessments. Each time, the conclusions regarding human attribution became stronger. In its latest assessment, the IPCC concluded with a greater than 90% likelihood that human use of fossil fuels, land use changes, and agriculture have caused most of the changes observed since the middle of the 20th century.

It clearly showed that the steep increase over the past 250 years in emissions and atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, along with several other powerful heat-trapping gases, was primarily due to fossil fuel use, land use changes and agriculture (see also Appendix 1). Moreover, considering all types of emissions (gases and aerosols) and activities, the IPCC stated with very high confidence[3] that "the global average net effect of human activities since 1750 has been one of warming" (IPCC, 2007, p.3). Greenhouse gas concentrations alone would have warmed temperatures even more were it not for the cooling effect of certain natural and anthropogenic (that is, from human sources, such as aerosols) that reflect solar radiation back to space. Agricultural irrigation in different parts of the world may have also reduced some regional warming (Lobell, 2006). Based on longer and

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[3] "Very high confidence" means that there is a 9 out of 10 chance that the scientific judgment is correct.

improved data records, an expanded range of observations, improved simulations of many aspects of the climate and new attribution studies, the IPCC arrived at its strongest conclusion yet regarding the "human fingerprint" on the global climate when it stated,

"Most of the observed increase in global average temperatures since the mid-20th century is very likely[4] due to the observed increase in anthropogenic greenhouse gas concentrations. […] Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns." (IPCC, 2007, 10)

How have scientists come to such a strong conclusion about human causation, that is, how can observed changes be attributed to human as opposed to natural causes? This section provides evidence from studies of global and—to the extent possible—regional (including Californian) climate and other environmental variables that show a clear human influence.

3.1. Human Attribution Studies: How IS IT Known?

The process of understanding the causes and impacts of climate variability and change involves, first, the detection of change, and second, the attribution of that change to a particular cause or set of causes. Both are challenging, and a variety of methods and data sets are typically used to determine connections between cause and effect (Appendix 1).

3.2. Detection

The task of detection is to discern a real trend in any climatic variable away from a long-term average that is, showing with statistical significance that the observed change is indeed a notable deviation from the long-term average (Houghton et al., 1996, pp.4-5). Given the "noise" of natural variability in climate observations (or computer simulations), detecting a real change often requires longer data records[5], and confidence grows typically with the length of the records. If an observed change or trend is larger than internal variability alone is likely to produce by chance, that change is said to be "detected" (Hegerl et al., 2007, p.667).

3.3. Attribution

By contrast, the task of attribution is to establish the most likely cause(s) of the observed change or trend, typically by testing alternative explanations for example, the observed trend is due to

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[4] "Very likely" indicates a greater than 90% likelihood of an outcome or result occurring, based on expert judgment.

[5] In modern climate studies, it is common to use a baseline of 30 years, for example, 1961-1990 or 1971-2000, and determine the average value of the variable of interest.

natural vs. anthropogenic forcings[6], or drivers of climate change). Unequivocal attribution to a cause would only be possible in a completely controlled experiment. Since this is impossible, scientists instead use model-based climate simulations as "laboratories" to test alternative explanations. Attribution then, in practical terms, means that scientists test two principal hypotheses:

- An observed change is consistent with the estimated or expected response of the climate system to the actual combination of natural and anthropogenic forcing.
- An observed change is inconsistent with an alternative, physically plausible (but not actually realized) climate change as a result of a different set of forcings.

If an observed change meets both criteria, and especially if multiple observed changes withstand this type of testing, confidence in the causal linkage between a forcing or combination of forcings increases (Hegerl et al., 2007, p.668). In some cases (such as global temperature change), such attribution studies can be done quantitatively, using computer simulations and illustrating statistical significance. In other cases, the human fingerprint on observed trends is not yet apparent, that is, statistically significant, and scientific confidence lower, though the observed change may still be physically consistent with expected change and therefore important (see Appendix 1 for more detail).

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[6] "Forcing" is formally defined as the change in net (downward minus upward) irradiance (in W/m^2) at the tropopause due to an external driver of climate change such as carbon dioxide concentration (Forster et al., 2007: p.133).

3.4. Evidence of Human Influence on Global and Continental Climate

In general, scientific confidence in detection and attribution is higher the more closely causally linked a climate variable is to radiative forcing, that is, temperature changes are more directly linked than precipitation changes to radiative changes, although latitudinal changes in average precipitation have now also been detected and attributed to human causation (Zhang et al., 2007)). Confidence also tends to be stronger for larger (global and continental) than for smaller (regional and local) scales, because more sampling data available over large regions raises the signal-to-noise ratio, that is, improves our ability to detect a trend ("signal") out from natural variability ("noise").

The strong overall conclusion of human contribution to climatic changes observed since the middle of the 20th century thus rests predominantly on global and continental fingerprints, with smaller-scale changes (such as those found for the western United States or California, see below) confirming and adding weight to the overall findings, but being associated with somewhat greater uncertainty.

Extreme Events: Acts of God or …?

One question many people have is whether any given individual extreme event such as a heat wave, a drought, a hurricane, or a record-breaking flood is the result of global warming. Differently put: are extreme events still purely "natural" (or, as some would have it, "acts of God") or are they caused by anthropogenic climate change, that is, by human emissions of greenhouse gases?

Stanford University scientist Stephen H. Schneider perhaps best captured the answer in this very complex area of research by saying, "Humans are loading the die." Human emissions of heat-trapping gases change the composition of the atmosphere, which increases average temperatures and affects temperature extremes. Climate models project—in general—more frequent abnormally hot days and nights and more heat waves with global warming. They also project that cold days and nights are very likely to become much less frequent, as will the number of days with below-zero temperatures. Sea surface temperatures will also increase, which are correlated with more intense hurricanes. Furthermore, "droughts are likely to become more frequent and severe in some regions as higher air temperatures increase the potential for evaporation. Over most regions, precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase," thereby increasing the risk of flooding (CCSP, 2008, p.81). In short, anthropogenic forcing is changing the climate such that the risk of many extreme events is increasing. But is it possible to say that any *single* extreme event is due to human influence on the climate? The simple answer at this time is: No.

One of the principal reasons is that extreme events have always occurred on Earth. They are part of any region's typical climate. While there is often a seasonality to when they happen, their exact timing, occurrence, and magnitude is very difficult to predict, and typically only on very short notice, for example, in snow-dominated regions, spring meltwater runoff combined with rainfall makes flooding more likely in later winter and spring; tropical storms are most common to affect the North American continent from June to November). Typically the more "extreme" an event is, the less common or frequent it is, hence even with a relatively long historical record, there may only be a relatively small number of events in the data base that researchers can use to understand and predict them. Extreme events, however, are typically caused by a combination of factors—some of which may be influenced by human forcings on the climate, others not. This is the second principal reason why it is impossible to say whether any individual event was caused by humans.

Figure 13 shows temperature changes over the last 100 years at global and continental scales, both as model-reproduced actual trends and modeled trends with and without human forcing. It is the signature illustration of how observed changes over the past 50-60 years cannot be explained without accounting for the human contribution to radiative forcing. This has led the IPCC to conclude that it is *extremely likely* (>95%) that anthropogenic temperature change has been detected and that it is *extremely unlikely* (<5%) that natural forces alone could have produced these changes.

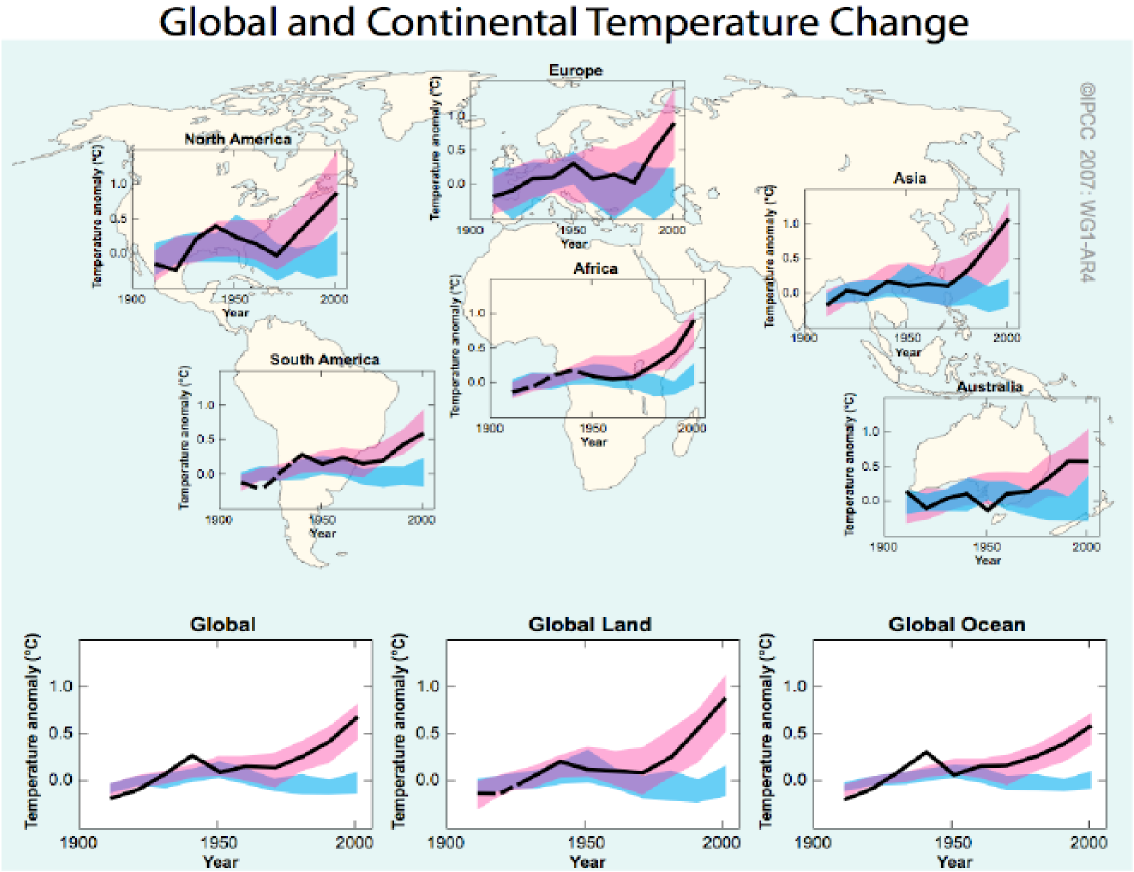

Figure 13: Global and continental temperature change. For each continent, simulated reproduction of observed temperatures are shown in black, modeled temperatures driven only by natural forcings in blue, and modeled temperatures driven by both natural and anthropogenic forcings in pink. For all but Antarctica (where the observational basis is too small), natural and anthropogenic forcings are needed to reproduce observed temperature changes over the past 100 years. The fit of modeled (pink) and observed (black) temperatures on global and continental scales increases over time as the anthropogenic forcing becomes ever more dominant.

Source: Solomon et al., 2007, p.11.

Figure 14 provides a simplified overview of additional observed climatic changes; the length of each bar corresponds to the estimated likelihood that the observed changes have been caused by human forcing (Hegerl et al., 2007, pp.729-732).

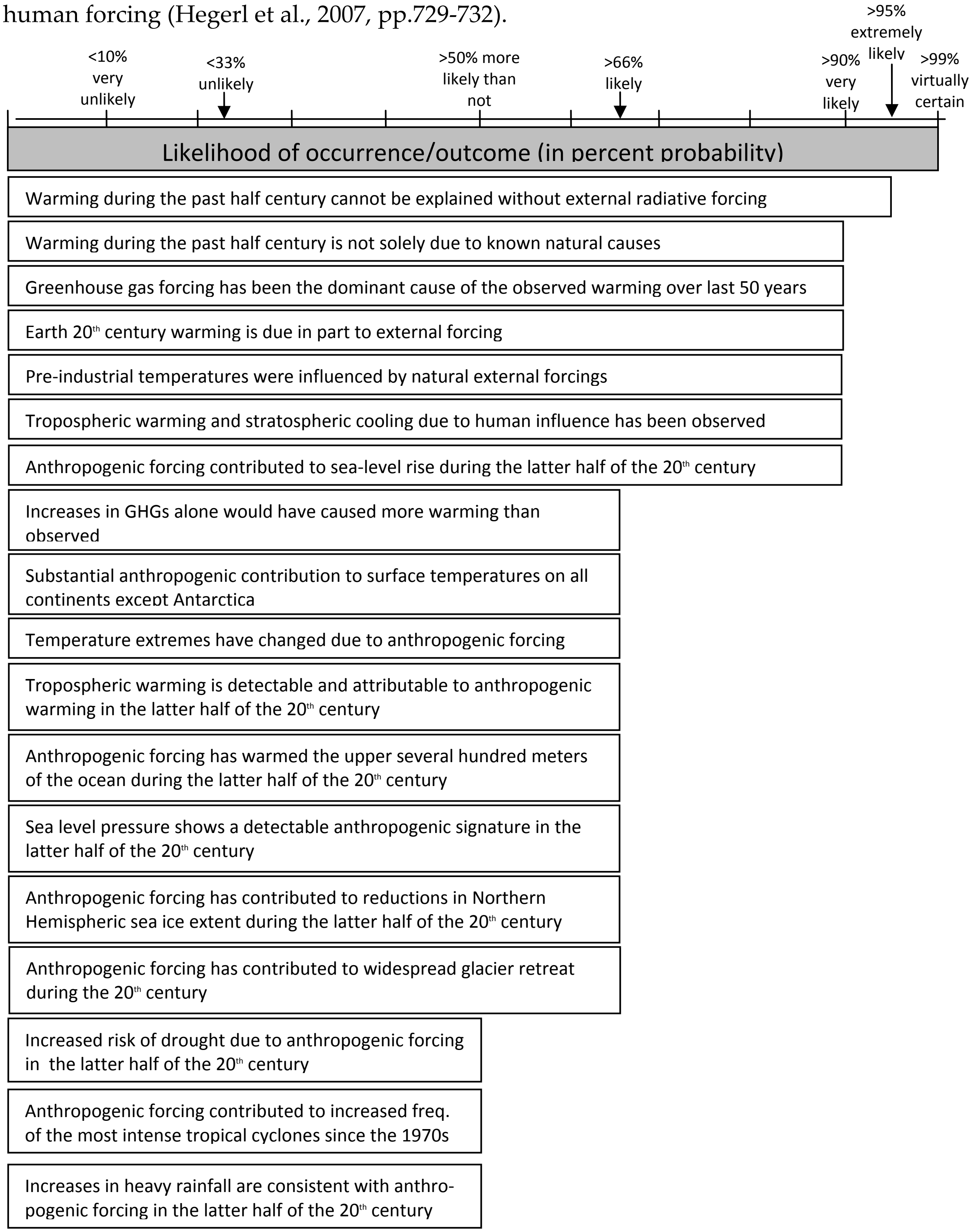

Figure 14: Selected detected climate changes attributable to human forcing likelihood of occurrence or outcome of each of the identified changes is given in standard IPCC language and probabilities. Some changes are detected at global scales, others at continental scales.

Source: Based on information provided by Hegerl et al., 2007, pp.729-732.

The scale at which these changes have been detected range from global to hemispheric to continental. Many additional ones, such as the declining number of frost days, increasing temperatures of extreme hot nights, cold nights and cold days, the increased risk of heat waves, wind pattern changes that affect extratropical storm tracks and temperature patterns in both hemispheres, shifts in precipitation patterns over land, and changes in the extent and quality of snow have been observed and are consistent with the changes noted in Figure 12.

In addition to the geophysical changes in climate discussed above, the IPCC's Working Group II also assessed climate change-driven ecological and societal impacts. It concluded that

> "A global assessment of data since 1970 has shown it is likely [66-90% probability] that anthropogenic warming has had a discernible influence on many physical and biological systems." (Parry et al., 2007, p.9)

Limited data sets from relatively few systems and locations are an important reason for the more tentative tone in this conclusion. Attribution studies of impacts observed in physical and biological systems also have to contend with relatively greater climate variability at regional and local scales, and the concurrent non-climatic influences such as land use change, pollution, and invasive species. Until recently, scientists expressed nonetheless high confidence that anthropogenic warming of the last few decades has discernibly influenced a wide range of systems (Rosenzweig et al., 2007). More recently, a global study explicitly tested for the first time whether observed physical and ecological changes can be attributed to human forcing. It came to a stronger conclusion, stating that "anthropogenic climate change is having a significant impact on physical and biological systems globally and in some continents" (Rosenzweig et al., 2008, p.353, emphasis added).

Scientists have detected changes in numerous physical and ecological systems and are beginning to identify impacts in human systems as well. These higher order impacts are more difficult to detect and attribute to anthropogenic climate change. In particular in systems managed by humans (such as agriculture, water resources, forestry) or directly impacting humans (such as human health, tourism and recreation), efforts undertaken to cope with extremes and variability or adapt to longer-term change may mask the direct impact that climate change and related physical and ecological responses may have. Table 1 (based on Rosenzweig et al., 2007) lists the most important observed changes that are largely driven by anthropogenic climate change (see Appendix 1 for more detail on each of these observed changes).

Table 1: Observed changes in physical, biological and managed or human systems in response to anthropogenic climate warming

Changes in Physical Systems	• *Arctic sea ice* extent is continuing to decline • *Mountain glaciers* are receding on all continents, at high and low latitudes • *Land-based ice caps* are melting at increasing rates • *Northern Hemisphere permafrost* is thawing • Extent of *snow cover in the Northern Hemisphere* is decreasing, especially at lower elevations • Annual duration of *lake and river ice cover* in the mid- and high latitudes of the Northern Hemisphere has been shortened and become more variable • Changes in *surface and groundwater* in many systems, but uniform global trends are not detectable due to complex influences on water systems • In snow-driven catchments, *earlier peak runoff* in spring • Some evidence of *the most catastrophic floods increasing in frequency* • In some regions *more severe droughts and more heavy rainfall events* • *Increased rate of global sea-level rise*, greater rates and extent of coastal erosion, wetland loss, and increases in wave height, storm surges, and inland flooding extent. • Overall, *extension of the growing season* by up to two weeks in the latter half of the 20th century
Changes in Biological Systems	• *Terrestrial plant and animal ranges* are shifting poleward and to higher elevations • Similar observations in *marine ecosystems* in response to warmer water and sea surface temperatures, stratification, changes in salinity and upwelling • Within the ranges of some terrestrial and marine species, *populations* are increasing in some areas and declining in others • Many *phenological life cycle events* (e.g., blooming, migration, insect emergence, leaf unfolding, coloring and fall, fruit ripening, breeding) are occurring earlier in spring and/or later in fall • *Species interactions* are becoming decoupled from each other as individual species react differently to warming • *Productivity (or biomass) increases* due to warmer temperatures, a longer growing season, and higher CO_2 levels • Climate change driven range contraction, loss of suitable habitat, favorable conditions for invasive competitors, or spread of deadly diseases has contributed to *local extirpation and global extinction of some species.*
Changes in Managed and Human Systems	• Changing *energy demand* for cooling and heating, with summer increases in peak demand typically more pronounced • Some evidence for *shifts in skiing and winter recreation*; otherwise still difficult to detect the impact of climate change in tourism and outdoor recreation • *Widespread adaptive responses in agriculture* such as crop switching, later sowing dates, diversification of livelihoods, tree planting, cooling and irrigation technology changes • *Northward shift of some disease vectors* and *changes in the seasonal pattern of allergens*, but no documented increase in incidence of climate-driven human health problems, except for *excess heat-related mortality* • When normalized by population and growth in overall wealth, *no significant upward trend* had been identified *in economic losses from floods and storms*.[7]

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[7] Normalization by population and economic growth does not account for all changes that have occurred over time in risk-prone areas. Other changes, for example, in building codes, emergency response, warning systems, land use and so on also affect what is at risk and how much. Currently there is no universally accepted approach to normalization (see discussion in CCSP (2008).

Considering the available global data base of all the physical and biological changes observed, Rosenzweig et al. (2007) found that 94% of statistically significant observed changes in physical systems, and 90% of significant observed changes in biological systems are consistent with the warming trend observed in the regions in which they occurred.

3.5. Evidence of Human Influence on Western United States and California's Climate

It is more difficult at smaller-than-continental scales and for observational records of less than 50 years to reliably simulate and attribute observed temperature changes and related impacts. At these smaller scales, climate variability is relatively larger and the distinction of natural and anthropogenic forcing of climate is more challenging. Non-climatic processes such as land-use change, human management practices, pollution, population growth and urbanization, and other anthropogenic factors interact with climatic changes to produce the observed changes. The added complexity at these smaller scales, however, helps improve our understanding of causal links, and climatic and ecological changes observed locally add to the overall global picture described above. And as Rosenzweig et al. (2007, p.115) observe, "[T]hese [human] factors are very unlikely to explain the coherent response that has been found across the diverse range of systems and across the broad geographical regions considered."

Observed temperature extremes over North America., including in the Western United States, have clearly been attributed to human influence, as have been the increases in extreme precipitation events (via the greenhouse gas-induced increases in atmospheric water content) (CCSP, 2008, pp.81-116; Burkholder and Karoly, 2007). More specifically, there are a number of new regional climate change detection and attribution studies (beyond those previously cited in *Our Changing Climate* (California Climate Change Center, 2006) that are of high relevance for the Western United States and California. These illustrate—even at the regional and local level—the overall consistency with the global picture: temperature increases and related climate changes are affecting natural systems in the expected direction.

As described above, it is essential both for a reliable projection of future climate and for the design of appropriate response options to accurately characterize (detection) current climate trends above and beyond natural variability (caused, for example, by El Niño or the Pacific Decadal Oscillation), and to understand what forces caused these changes (attribution). Below the authors highlight several studies that are relevant to California, the first two of which are considered detection studies, while the latter two constitute attribution studies.

3.6. Detection Study 1: Warming Over the Sierra Nevada and Retreat of the Ponderosa Pine Forest

The Wieslander data set spanning the period 1934 to 1996 has provided critical documentation of vegetation-range changes in the Sierra Nevada Mountains. Sierra Nevada warming had already been documented by other scientists and was confirmed by Thorne et al. (2006), who found an increase in monthly minimum temperatures in the middle-elevation Sierra Nevada over the past 100 years by about 3°C (5.4°F). In the 1930s, the coldest months still registered with their minimum temperatures below freezing. While unlikely to be responsible for the death of mature pines, which were harvested, the higher temperatures correlate with longer summer drought conditions, which in turn increase drought stress on seedlings. "Drought stress–driven mortality of seedlings following stand removal is the suspected driver of the diminishing range of the Ponderosa Pine Forest" (Thorne et al., 2006, p.3). Corroborating evidence came from the fact that areas potentially affected by other factors such as fire, urbanization, and areas that had converted to grassland with competitive non-native grasses and pressure from cattle grazing, were removed from the analysis. About 58% of the area had not been affected by these confounding factors, suggesting strongly that anthropogenic climate was the key driver behind the observed eastern and upward retreat of ponderosa pine.

3.7. Detection Study 2: Migratory Songbirds in California

California is home to dozens of migratory bird species and throughway for millions of birds along the Pacific Flyway. For these birds, "Time is of the essence […]: it is critical for departures with favorable weather conditions, intersecting adequate resources to fuel further flight, and for spring migrants, ensuring that arrival on the breeding grounds is coincident with the flush of spring insects to feed offspring" (MacMynowsky and Root, 2007, p. 1). Importantly, to obtain a comprehensive picture of the vulnerability of migratory birds to climate change, species responses to shifts in climate should be studied in all destination regions that the birds cover over the course of an annual migratory cycle. However, even significant changes in any of the critical habitats along the migratory route can disrupt the life cycle of the species and affect its reproductive success.

In a study analyzing spring and fall phenology of migratory songbirds moving through Central and Northern California, MacMynowski and Root (2007) found that all those species that are sensitive to changes in climate (so-called"climate associates") changed their migratory arrival in spring (most of them now come earlier), whereas none of the species that are insensitive to changes in climate shifted their arrival dates. They found that climate-sensitive migratory birds tend to arrive earlier in spring in association with warmer local temperatures, positive NAO indices, and stronger ENSO indices. Fall phenological changes were also apparent, with a majority of climate associates arriving earlier, but a statistically significant correlation with regional climate warming was not detected. The analysis of data from multiple sites, correlated with climate data from multiple scales, and using multiple indices of migratory behavior, however, adds more "evidence that changes in western North American land ecosystems are already detectable with warming of less than a degree Celsius over the past century" (MacMynowski and Root, 2007, p.2).

3.8. Attribution Study 1: Human-Caused Warming Over California

A number of external factors influence California's climate including solar variability, volcanic eruptions, aerosols, greenhouse gases released from human activities, and land-use changes (especially urbanization and irrigation). Bonfils and colleagues (2007,2008) used eight observational data sets to estimate temperature trends during the last five decades of the 20th century (1950–1999) and over a longer period (1914–1999).

Bonfils et al. (2007, 2008) noted, first of all, that trends among these different datasets were quite consistent, giving confidence that the trends are not simply artifacts of location or measurement. The researchers then compared these observed data trends to trends from a suite of control simulations of natural climate variability alone (without additional external forcing). These comparisons showed for most data sets that the observed increases in annual mean surface temperature were outside the "noise" of natural variability. "The most robust results are large positive trends in mean and maximum daily temperatures in late winter/early spring, as well as increases in minimum daily temperatures from January to September. These trends are inconsistent with model-based estimates of natural internal climate variability, and thus cannot be explained without invoking one or more external forcing agents" (Bonfils et al., 2007, p.2). In particular, warming of California's winters over the second half of the 20th century is associated with human-induced changes in large-scale atmospheric circulation, whereas the lack of a detectable increase in summertime maximum temperature arises from a cooling associated with large-scale irrigation, particularly in the Central Valley (Bonfils et al., 2008). This cooling may have counteracted the warming induced by increasing greenhouse gases and urbanization effects lowering summertime average daily daytime temperatures by as much as –0.14°C to –0.25°C (-.252 to -.45°F) per decade for an estimated total of –1.8°C to –3.2°C (-3.24 to -5.76°F) cooling since the introduction of widespread irrigation (Bonfils and Lobell, 2007). To the extent irrigated areas are not further expanded or may shrink in the future, this cooling effect may be increasingly overpowered by global warming (Bonfils and Lobell, 2007; see also Kueppers et al., 2007; Weare and Du, 2007).

3.9. Attribution Study 2: Changes in the Hydrological Cycle in the Western United States

Previous studies already documented significant shifts in the hydrological cycle over the Western United States, including more winter precipitation falling as rain rather than as snow, the snow line retreating upward, earlier snow melt and associated increases in spring and decreases in summer river flow. One recent study went beyond these well established findings to demonstrate with statistical significance, “that the majority of the observed low-frequency changes in the hydrological cycle (river flow, temperature, and snow pack) over the western United States from 1950 to 1999 are due to human caused climate changes from greenhouse gases and aerosols” (Barnett et al., 2008, p.1080). Using a high-resolution hydrologic model with climate inputs derived from several global climate models, the researchers showed that “up to 60% using the model with the best ability to reproduce regional climate of the climate-related trends of river flow, winter air temperature, and snow pack between 1950 and 1999 are human-induced” (ibid.). These results were robust across climate models and using different hydrological variables and methods.

3.10. Conclusions

Evidence for long-term climatic changes and related responses in physical and ecological systems above and beyond the “noise” of natural variability is now available from every continent. Scientists’ ability to attribute these observed changes to anthropogenic forcing by greenhouse gas emissions and aerosols is increasing steadily. While end-to-end models that relate ecological changes directly to human causes are not yet available (Zwiers and Hegerl, 2008), the indirect attribution of ecological changes to climatic changes and these, in turn, to greenhouse gas emissions has led to the strong conclusion that most of the climatic changes observed over the latter half of the 20th century are due to human activities and that many related physical and ecological responses bear clear evidence of human influence—at local to global scales.

This conclusion challenges the fundamental belief held still by many that human actions are too small to exert a global influence on the Earth’s life support systems. While adjusting basic assumptions to the facts of the matter, and recognizing that many of the observed changes are predominantly negative for the systems involved, Californians must realize what the world might look like if the human imprint on its climate and natural and managed ecosystems were not rapidly minimized. The potential impacts of climate change without concerted efforts to reduce anthropogenic emissions and land use changes are discussed in the next section.

4.0 Projected Impacts of Climate Change in California Updating "Our Changing Climate": What More Have Californian's Learned?

In July 2006, the California Climate Change Center (CCCC) published a non-technical document called *Our Changing Climate: Assessing the Risks to California*, (California Climate Change Center, 2006) representing the culmination of a major research effort by the CCCC[8] (Cayan et al., 2008a). This outreach publication summarized the latest "state of the science" on the climate change impacts facing California over the next century. Today, as climate change research continues to move forward, new details can be added toward understanding how California's environment, economy, and societal well-being will be affected by climate change. The following section provides, sector by sector, a brief encapsulated review of the existing knowledge on future impacts, taken largely from *Our Changing Climate*, then presents and interprets research findings that have emerged since 2006. The newest findings reinforce the idea that climate change will have significant impacts for both the natural and managed systems on which California depends.

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[8] The "2006 Scenarios Report" involved a series of assessments conducted over the course of two years. According to Executive Order S-E-05, such assessments are to be produced every two years. *Our Changing Climate* was preceded by another technical document comprehensively assessing climate change impacts on California (Hayhoe et al., 2004), which has been widely cited in the scientific community.

“Scenarios” Terminology

The Special Report on Emissions Scenarios (SRES) approach used by the Intergovernmental Panel on Climate Change (IPCC) acknowledges that future levels of carbon dioxide (CO_2) in the atmosphere will depend upon human activities. Policy and development outcomes will affect emissions from carbon-based fossil fuel burning and other human activities driving climate change. Importantly, the SRES scenarios do not assume *explicit* climate change or emission-reducing policies. Three scenarios are referenced in this section. One **lower-emissions scenario (called “B1”)** projects future decreases in CO_2 concentrations following significant “decarbonization” of the economy. If CO_2 emissions continue unabated, **high emissions** ensue, under a scenario called “**A1fi**” (for fossil fuel-intensive). The **“A2”** scenario describes a **medium-high emissions** scenario (Figure 15). The impacts discussed below include some of these scenarios to frame the range of plausible futures. Three caveats should be noted. First, it is important to recognize differences between weather and climate; while weather occurs at a point in time, climate represents a longer time period. Even with sophisticated computer modeling, then, scenarios-based climate models are not intended to provide specific or detailed forecasts as one might request for tomorrow’s temperature. Rather, they usually present a range of plausible futures and the impacts associated with each, based on our best available knowledge. Second, because of limitations in our scientific understanding and our imperfect ability to reproduce these complex interactions in computer models, the projections produced by the IPCC do not fully account for potential reinforcing feedbacks (e.g., the loss of sea ice over Greenland or Antarctica, and some unaccounted-for changes in the carbon cycle) as warming increases (IPCC 2007a). Third, when assessing future impacts resulting from climate change, modeling to date does not account for other societal pressures that may increase or decrease the ultimate severity of impacts. Multiple stressors including demographic changes, pollution, land use changes, political discord, and economic factors, are not included in these projections, but nevertheless will influence impacts. The descriptions of impacts below, then, must be considered an incomplete picture of the future, but one that emphasizes the climatic stresses different regions and economic sectors may experience under different emissions scenarios.

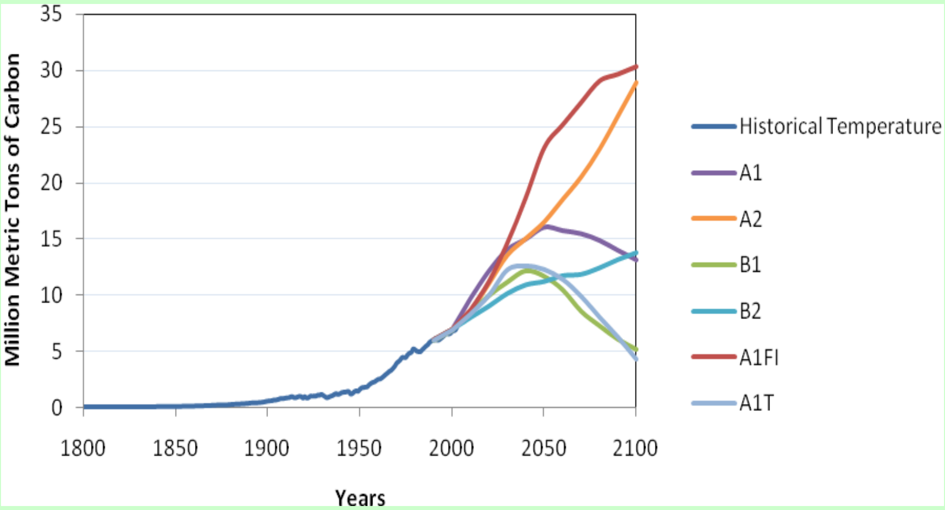

Figure 15. CO_2 emissions under three IPCC scenarios.

Data Source: Marland et al. 2008 and IPCC

In addition to the IPCC SRES scenarios, the authors present preliminary estimates for changes in temperature and sea-level rise over this century under a scenario that assumes the implementation of policies to limit global average temperature increase to less than 2°C (3.6°F) above pre-industrial temperatures (referred to as the "policy scenario" in this document). Since the atmosphere has already warmed by about 1.4 ºF, this scenario assumes that the additional warming in this century will not surpass 2.2 º F. The policy scenario is characterized by emission reductions in the industrialized nations of about 30 percent below 1990 levels by 2020, about 80 percent by 2050, and extremely low emissions by the end of this century[9] The policy scenario also assumes eventual reductions from the developing world so that overall global emissions by 2050 are reduced by 50 percent with more drastic reductions after 2050. This scenario is presented and discussed in a report prepared by the United Nations Development Programme (UNDP, 2008).

4.1. California's Warmer Future: Temperature Projections

Review of Temperature Impacts

- Increasing temperatures (between 3 and 5.5°F for B1, and between 8 and 10.5°F for A1fi)
- Some models predict more warming in the summer and less in the winter
- Warmer nights

As outlined in *Our Changing Climate*, hotter temperatures are expected throughout the state, with an increase of 3-5.5°F under the lower emissions scenario (B1) and 8-10.5°F under the higher emissions scenario (A1fi), and intermediate temperature increases under the A2 emissions scenario by the end of the century (average for the period 2070-2099) (Hayhoe et al., 2004).

Within the past year, carbon emissions accounting has revealed that emissions are rising more rapidly than those predicted by even the most "aggressive" scenario (A1fi) (Raupach et al., 2007). In future IPCC reports, scenarios such as A2 and A1fi will represent "middle-of-the-road" scenarios and new higher emissions scenarios will be used (Moss et al., 2007). Thus, future projections of temperature increases for the state are likely to increase (IPCC 2007a) if no global actions are adopted to reduce emissions.

Temperatures will vary locally and by the time of day. Urban areas can exacerbate the "heat island" effect, especially by raising nighttime temperatures. In areas like the Central Valley, for instance, future warming will be governed in part by future rates of irrigation (known to mask warming effects, see Chapter 2) (LaDochy, Medina, and Patzert, 2007). The Hadley Centre (U.K.) model (HadCM3) predicts greater summertime warming relative to wintertime warming, whereas one of the U.S. National Center for Atmospheric Research models (Parallel Climate Model) shows less seasonality of temperature increases (Hayhoe et al., 2004). Researchers report

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[9] This document, titled *Human Development Report 2007/2008. Fighting Climate Change: Human Solidarity in a Divided World*, can be accessed at http://hdr.undp.org/en/reports/global/hdr2007-2008/

that, under climate change, nights (typically representing minimum temperatures) are projected to warm slightly more relative to daytime temperatures (Lobell et al., 2007).

Figure 16 presents preliminary projections of annual average temperature for California for the A2 and B1 global emission scenarios. The left portion of the graph also shows the observed temperatures in the last several decades as reported in Chapter 2. The main message from this figure is that lower emissions (B1) results in less warming at the end of this century than higher emissions would. Each global emission scenario is represented by a solid color line, which is the smoothed average of outputs from different climate models, all using the same emissions scenario (represented by the similarly colored lines underlying each of the ensemble averages). While, of course, there is only one realization of past temperatures (temperatures in the historical record), there are three estimated sets of temperatures each for the A2 and B1 scenarios. This is due to the fact that different climate models produce alternative views on how temperatures would evolve in the future.

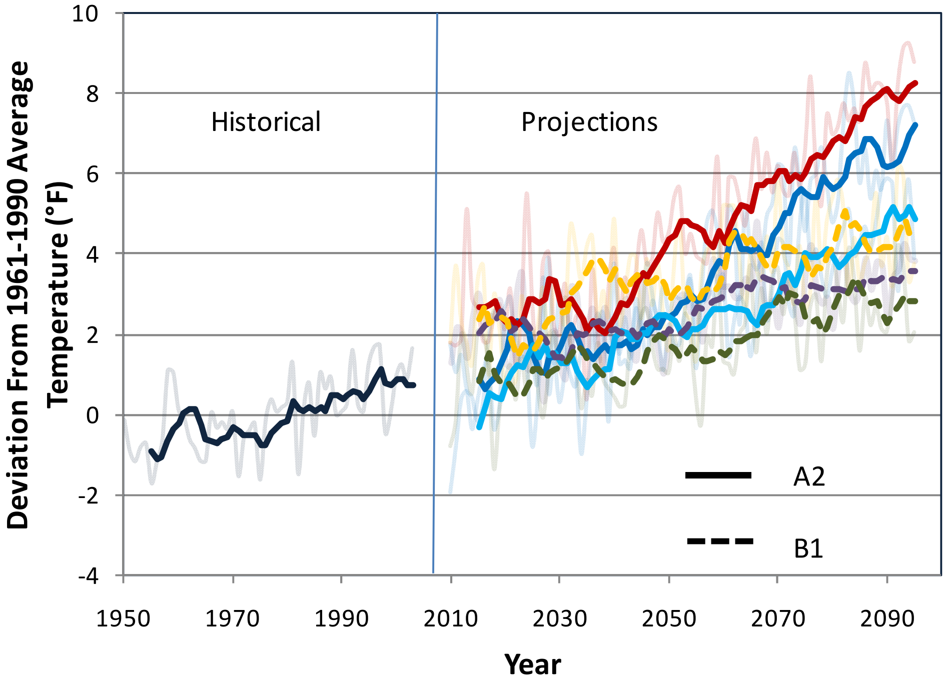

Figure 16. Historical and projected annual average temperatures for California. The soft lines represent annual average temperatures while the thick lines are the smoothed time series of annual average temperatures using 6-year running averages to more clearly detect overall trends. The projections for the A2 and B1 global emission scenarios are represented with solid and dashed lines, respectively.

Figure 17 shows changes in global average temperature around 2100 under the B1 and the "policy" scenarios. It is clear from this figure that even with a strong policy scenario, with global emissions lower than in the B1 scenario, temperatures might still rise dangerously high.

However, the risk of crossing dangerous temperature thresholds is lower in the policy case than in the B1 case.

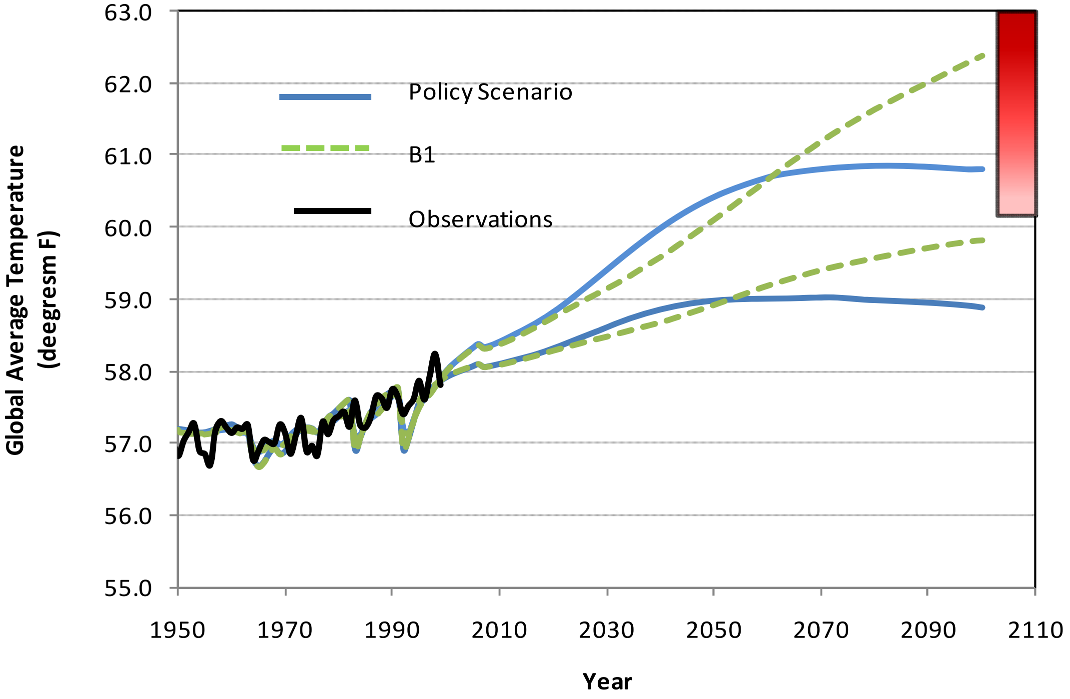

Figure 17. Global average temperature projections for 2100 for the B1 and "policy" scenarios at the end of this century.
Data Source: (Meinshausen et al., 2008 and personal communication)

4.2. Public Health: Stark Challenges for Vulnerable Populations

Review of Public Health Impacts
• Demographic shifts may lead to increased social vulnerability to stresses and shocks, including worsening climate extremes • Disproportionate suffering by the aged, the infirm, the socially isolated, racial minorities, low-income residents, and outdoor laborers • Increased transmission of mosquito-borne diseases such as West Nile Virus and encephalitis

As *Our Changing Climate* reported, the degree to which climate change impacts public health depends strongly on the groups experiencing the climate-related stress (English et al., 2007). One recent finding is that "social vulnerability"—a measure of how exposed to hazards and how well equipped society is to handle stresses and shocks—in California is predicted to increase in future decades due simply to demographic shifts (Cutter and Finch, 2008). A recent study of all counties in the United States concluded that counties in California's Central Valley, Orange County, and San Francisco were either currently rated (in 2000), or predicted to be (by 2010), among the highest in the country in social vulnerability, as measured by demographic factors such as socio-economic status, race, age, and gender. Social vulnerability suggests the potential for greater harm to the affected public in the event of natural disasters, although the metric is used only comparatively (across localities) rather than in an absolute sense (Cutter and Finch, 2008). For the noted communities that are more vulnerable to natural hazards, the impacts of climate variability and extremes (e.g., droughts, heat events) will involve added societal burdens. Residents in the communities of concern may find it increasingly difficult to cope with climate-related stresses and may well require additional public resources or actions to prevent or alleviate potential harm.

4.3. Water Resources: Summertime Scarcity and Changes in Snowfall

Review of Water Resources Impacts

- Decreased snowpack by the end of the century (20 to 40% under different emissions scenarios)
- Increased risk of winter flooding
- Earlier timing of meltwater runoff and greater vulnerability to summer shortfalls
- Decreased hydropower generation (under dry warming)
- Decreased quality of winter recreation

Water resource management under a changing climate could emerge as California's greatest future challenge. Satisfying the water needs for the state's industrial, urban, agricultural, energy, and environmental uses will be harder for two reasons: the decreasing reliability of surface water storage (Jain et al., 2005, Medellín-Azuara et al., 2008, Vicuna et al., 2007) and anticipated population growth (PPIC, 2006). Ongoing modeling efforts are attempting to understand how the state can best manage flows under climate change (Anderson et al., 2008). A dry warming scenario, by a recent estimate, would raise statewide water scarcity and total operation costs by at least $500 million per year by 2085 (Medellín-Azuara et al., 2008). The actual costs may be two to three times higher because these authors assume perfect water markets and do not consider all the potential costs associated with climate change, such as flood protection or recovery costs in the event of floods.

California's management of groundwater will be critical in the next century because surface water supplies appear to be less able to accommodate the water needs of the state's growing population and economy. Currently about half of California's water supply for human consumption or use comes from groundwater (Franco, 2005). Questions researchers hope to answer in the near future include whether Central Valley growers can safely pump groundwater from aquifers to irrigate their crops (Purkey et al., 2004). Additionally, more information is needed regarding the reliability and management of groundwater recharge, i.e., the natural penetration of surface water to deeper storage layers underground. Groundwater recharge would be especially valuable if the greater winter flows expected under climate change could essentially be "banked" underground for later use (i.e., in times of water shortage) (Earman and Dettinger, 2008). Researchers at U.C. Davis and U.S. Geological Survey (USGS) are modeling groundwater behavior and dynamics under climate change (LaBolle et al., 2003, Niswonger and Fogg, 2008). Ensuring proper protection of groundwater quality is also a high priority for future research.

California's prominent Sierra Nevada range controls some precipitation patterns such as higher rain totals on the windward side. In mountainous areas, certain rain effects, such as the quantity of aerosols in the air, are not yet well understood. Aerosols (e.g., soot and dust) are tiny airborne particles that travel in the air for days to weeks. Recent research has shown that these particles can inhibit cloud formation which typically occurs when air rises over mountains. In the presence of aerosols, fewer clouds form and less rain falls on the windward side of the Sierra, compared to pristine conditions (Rosenfeld and Gavati, 2006; Givati and Rosenfeld, 2004). Motivating this research is the idea that decreasing the pollution that produces aerosols might help mitigate the problem of reduced precipitation over the Sierra.

4.4. Increased Risks and Costs for Agriculture

Review of Agriculture Impacts

- Decreased productivity of almonds, cotton, and dairy products
- Increased pest range and viability
- Crop stress due to high temperatures, decreased chill hours reduces quality of cherries, almonds, apples, and walnuts
- Irrigation water shortages; Greater evaporative demand by crops

California's agricultural yields are sensitive to climate and management practices. In addition, management practices are also likely to be influenced by changes in climate. Changes are expected for maximum and minimum temperatures, growing season length, chill hour accumulation for fruits and nuts (see Chapter 2), precipitation regime, and atmospheric CO_2 levels (CO_2 serves as a fertilizer to fuel growth). A recent study modeled one consequence of warmer temperatures, namely the projected decline in accumulated chill hours that leads to decreased fruit and nut quality[10] (Figure 18) (Baldocchi and Wong, 2008).

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[10] This study used the National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamic Laboratory (GFDL) model (Stouffer, 2006) and the A2 scenario.

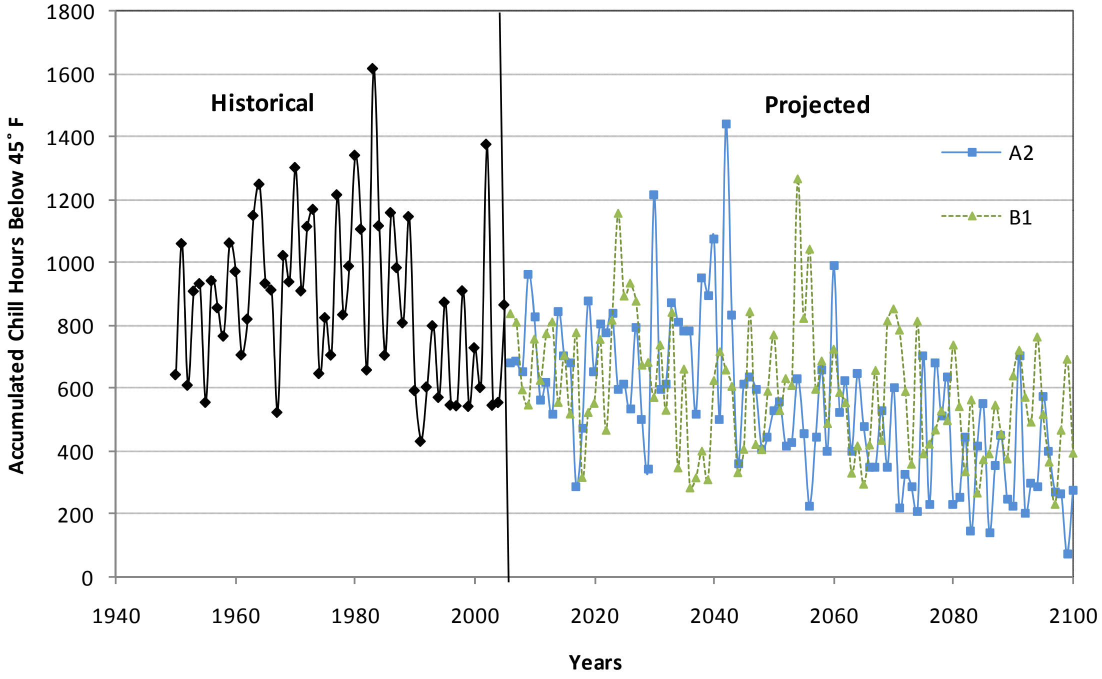

Figure 18. Historical data (black) and projected decrease in annual accumulated chill hours for the city of Davis, California. Future projections utilized scenarios B1 (green diamonds) and A2 (blue squares).

Source: Adapted from Baldocchi and Wong (2008).

Recent research has revealed serious vulnerabilities of growers in the Sacramento-San Joaquin Delta to negative impacts from climate change. The Delta contains an array of carbon-rich peat soils and marshlands which have supported high agricultural productivity (including crops such as corn, grain and hay, alfalfa, tomatoes, asparagus, fruit, safflower, pears, and wine grapes) for over a century following the establishment of levees separating the water from the land. However, cutting off the land from flood waters has barred replacement of sediments, leading to dramatic land subsidence as previously flooded, low-oxygen soils have been drained and aerated, losing significant amounts of organic carbon in the process. Certain parts of the central and western Delta currently sit more than 10 feet below sea level (Lund et al., 2007). As steady sea-rise (a major consequence of climate change) is projected to increase flood elevations, the aging levees are slowly but surely losing their protective function. Together, land subsidence and rising sea levels have rendered the region behind the levees increasingly vulnerable to flooding (Zhu et al., 2007), with particular susceptibility noted for the western and central Delta (Lund et al., 2007). And, as soils become more saline, especially in the western, central and southern areas of the Delta, economic impacts would be felt by growers, bringing into question the future ability of those regions to sustain irrigated agriculture (Mount et al., 2006, Schoups et al., 2005).

The snowmelt that passes through the Delta supplies water to farms throughout the Central Valley. In fact, it is estimated that 3.6 million acres of farmland depend on water from the Delta

(Vicuna, Hanemann and Dale, 2006). A recent study analyzed costs to farmers south of the Delta stemming from a hypothetical breaching of the Delta levees assuming that such an event would affect water supplies (Vicuna, Hanemann, and Dale, 2006). In effect, they found that different climatic conditions affected the size of the economic burden from the levee breach. Three hypothetical scenarios[11] were treated in this economic analysis. In the first scenario, a time of drought preceded the levee failure, which led to $2 billion in net farm revenue losses. In the second scenario, a period of high rainfall preceded the levee failure, resulting in net revenue losses of $0.7 billion. Finally, a levee failure followed by drought was found to place the greatest squeeze on water supplies, inflicting more strain on growers and increasing farm revenue losses to $2.6 billion due to limited water supplies (Vicuna, Hanemann, and Dale, 2006). Such an analysis illustrates how economic impacts are highly sensitive to the specific climatic conditions (including the frequency and specific sequence of changes and extreme events) that California might encounter in the future. Advances in technology, such as irrigation efficiency, can lessen the severity of impacts to agriculture (Purkey et al., 2008).

4.5. Changing Landscapes: Forests and Aquatic Ecosystems

Review of Ecosystem Impacts

- Coverage of certain tree species, especially pines, will shrink and/or relocate, including high-altitude alpine and sub-alpine forests
- Key changes in competition are likely to occur among species, such as a gain in broad-leaved species at the expense of needle-leaved species
- Number of large wildfires increase by 12–53% statewide depending on emissions scenario, with larger increases in Northern California

In addition to providing recreational opportunities and economic revenue, the state's forests and aquatic ecosystems harbor wildlife, help sustain biodiversity, promote clean water, and sequester carbon. The species that inhabit these ecosystems represent a cultural and ecological heritage for California. Under pressure from climate change, however, these ecosystems, including the distinctive species associated with these places, will necessarily respond and change.

While *Our Changing Climate* highlighted the relocation of certain high-altitude evergreen species further upslope in response to warming, additional research in the interim has indicated that pines might feature a much wider array of responses, including changes in stand density, decreased growth, increased mortality, susceptibility to disease, and complex interactions with other species (Millar, Westfall, and Delany, 2007).

California possesses tremendous biodiversity, including approximately 1300 "endemic" species—native species that occur nowhere else in the world. Conserving this biodiversity is an important goal. An ongoing project based at U.C. Santa Barbara is developing a species-specific demographic computer model called "BioMove" to determine how climate change will affect the geographic ranges of some 300 California plant species, including 89 endemics. Users of the

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[11] Note that for all three hypothetical scenarios, the Geophysical Fluid Dynamics Laboratory (GFDL) model was applied, using the A2 emissions scenario.

model can select a species for which historical data exist, then vary factors such as dispersal (i.e., the distance that seeds can travel), competition against other plants (e.g., those already occupying territory, or new invaders), and disturbance (e.g., wildfire frequency). By adjusting these values, users can estimate the relative importance of these factors in assessing the eventual range of the target species under different climate change scenarios. At this stage of development, BioMove's target species include the iconic Joshua tree (Mojave Desert), the valuable sugar pine (Sierra Nevada), and the endemic blue oak (Central Valley). Animal species will be added in the future. As the model is finalized, it will help managers prioritize research areas that can best assess extinction threats and protect biodiversity. For example, understanding dispersal patterns of the Joshua tree may be critical, as model simulations suggest that long-range dispersal could offset negative impacts from a warmer climate, increased competition from invasive grasses, and increased fire disturbance (Conservation International et al., 2008).

Oak woodlands are a distinctive and visually evocative landscape in the state. Earlier work suggested that climate change, including changes in temperature and precipitation, would shift the area suitable for oaks (their so-called "climate envelope") northward. A new study modeled the controls on California oak regeneration as affected by climate change. Successful regeneration of oaks was linked to whether the area had "reserved" status, suggesting that species dispersal is an important determinant of regenerative ability (Zavaleta, Hulvey, and Fulfrost, 2007). The critical role of dispersal was similarly highlighted in a much broader study that modeled ranges for over 500 endemic plant species 80 years from the present. These researchers observed decreases in biodiversity under a higher-emissions scenario (a loss of about 1 species per acre), but found that increasing the species' dispersal ability buffered against species losses. At a lower emissions scenario (B1) and high dispersal capability, biodiversity actually increased in many areas of the state[12] (Loarie et al., 2008).

Salmon, spawning along the Sacramento, American, and Feather Rivers, are an important part of Northern California's economy and a cultural icon to fishermen and naturalists. In 2008, unusually low populations of California's wild salmon forced a curtailment of the entire fishing season, resulting in estimated losses of $255 million and 2,263 jobs, according to the Department of Fish and Game (Weiser, 2008). The complex reasons for these unusual low salmon runs are not yet fully understood, although in the Sacramento basin, temperature change or water withdrawals could have played a role.

Although more locally specific research on the impacts of climate change on salmon is still needed for California, research conducted in the Puget Sound area of Washington state shows that the modeled population of salmon will be negatively impacted by climate change, largely due to the reduction in snowpack and hence runoff during important stages in the salmon's life cycle, as well as to increases in water temperature (Battin et al., 2007). In a relevant study, two global climate models (both using the "A2" emissions scenario) were used to test how future

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[12] Note that differences in model results stemmed from the different ways these models forecast future precipitation patterns, an area which deserves future research emphasis.

climate would affect in-stream habitat for spawning salmon with a separate modeling component that addressed salmon population dynamics. Both models produced a strong negative effect of climate change on salmon population: a 40% decline by 2050 (Geophysical Fluid Dynamics Laboratory model, based in Princeton, New Jersey), versus a 20% decline (Hadley Center model). The two primary reasons for this substantial decline were the climate change-induced reduction in suitable cold-water habitat and reduced stream flows for salmon spawning, incubation, and rearing, plus the increased damage to salmon eggs from increased winter runoff scouring streambeds (Battin et al., 2007). These findings suggest that climate change impacts to California salmon should be a high priority for future research.

4.6. Sea-Level Rise: Greater Than Previously Thought?

Review of Sea Level Impacts

- Sea level likely to increase by up to 35 inches by 2100, depending on the magnitude of climate warming
- Most severe impacts result from the coincidence of sea-level rise with storm surge, tides, and other climatic fluctuations (like El Niño)

California is vulnerable to significant economic costs resulting from loss of, or damage to, coastal property and infrastructure as sea levels rise. Additional impacts include erosion of recreational area (such as beaches), inundation of wildlife habitat, and salinization of inland water supplies. Estimates of future global sea-level rise have recently been revised upwards. Estimates by Rahmstorf (2007) suggest global sea-level rise could increase by over 4 feet by 2100, depending on the warming scenario employed (Figure 19), as opposed to the very modest 0.6 to 1.9 feet (7.12 to 23.4 inches) projected in the most recent assessment of the IPCC (2007). However, a recent paper in the journal *Science* asserts that artificial water reservoirs (dams) around the world have had a significant impact on sea-level rise, reducing the magnitude of global sea level rise by about 30 millimeters (1.2 inches) during the last half of the 20th century (Chao, Wu and Li, 2008). In other words, if there had been no dams retaining water on land, global sea level rise would have been 30 mm (1.18 inches) higher than they actually are, suggesting that warming of the oceans and/or water additions to the oceans from land-based ice must have been greater than previously assumed.

Figure 19 shows global average sea level changes over the 21st century for the B1 and "Policy" scenarios. The projected increases are larger than previously reported due to recent improvements in sea-level rise science, though still not accounting for the possibility of rapid ice loss from Greenland and Antarctica. There is almost no difference in the expected range of increase in sea level (about 8 inches higher by 2050 and about 18 inches higher by 2100 above the 1961–1990 average) between the two scenarios. This suggests that even stringent emissions reductions and resulting lower temperature increases—while critically important in limiting other dangers to human health, water resources, food supplies and ecosystems—cannot prevent substantial sea-level rise because ocean waters store heat effectively and will expand for centuries, long after air temperatures have been stabilized. Adaptation is the only way to deal with the long-lasting threat of sea-level rise to coastal areas.

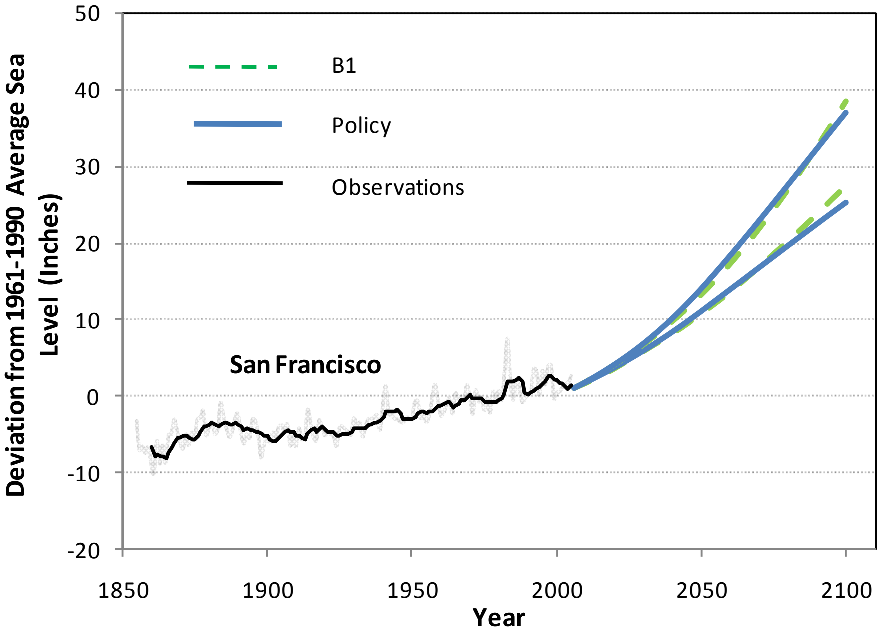

Figure 19. Observed sea levels in San Francisco and projected global levels for the B1 and "Policy" scenario.

Source: Dan Cayan (forthcoming PIER report)

A striking feature of Figure 19 is the amount of sea level rise even for the policy scenario. This again emphasizes the need for the development of adaptation strategies. Another consideration is the fact that given the residence time of carbon dioxide and other long-lived greenhouse gases, sea level rise will continue for many centuries and, for this reason, only planning for expected sea levels expected by 2100,which would be a good start, may not be enough in the long run. Recently a group of researchers from France has estimated non-linear melting behaviors of Greenland. According to the researchers, the ice sheets in Greenland could completely melt in an irreversible way if a cumulative amount of 2,480 gigatonnes of carbon dioxide (GtC) are released to the atmosphere, which is a plausible scenario if California continues to follow or exceed the emissions under the A1Fi emission scenarios (Charbit et al., 2008). A melting of Greenland ice would result in a catastrophic rise of sea level in the order of 23 feet (7 meters). Cumulative total emissions of 2,150 GtC, on the other hand, would result in only partial melting of the Greenland ice sheet, causing significantly less impacts and damages in coastal regions around the world. The question of what level of emissions would allow a crossing of the warming threshold that would lead to irreversible melting is not yet scientifically settled and requires further attention.

Future changes in storminess (frequency, intensity and paths) strength are of particular concern because storms can generate extreme sea levels (short-term) increases in that can cause rapid shifts and economic damage. These extreme events are defined operationally as those where water levels exceed a given threshold. The climate models project two important trends: higher sea level extremes resulting from increasing storm intensity and more frequent extreme events. As shown in Figure 20, a sea-level threshold that was previously crossed only once out of 10,000 measurements at Fort Point, California historical record is projected to be exceeded for more than 20 hours per year by the end of the century (Cayan et al., 2008b). Researchers also are projecting a trend of longer-lasting extreme events (Bromirski and Flick, submitted). One mechanism behind these trends relates to changes in the water cycle discussed above: increased winter rainfall (tied to warmer temperatures and decreased snowfall) and earlier spring runoff creates more discharge into San Francisco Bay from storm water, also elevating water levels (Bromirski and Flick, submitted).

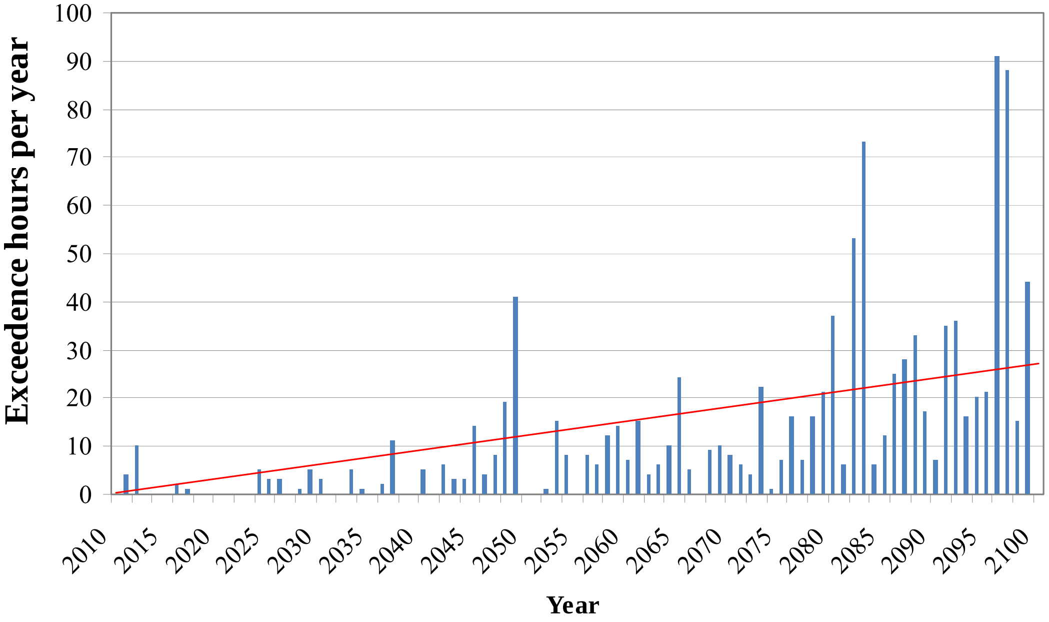

Figure 20: Projected sea level exceedence hours per year at Fort Point, San Francisco (SFO), over the next century. The GFDL model (A2 emissions scenario) was used. The figure illustrates the hours per year when sea level will exceed the threshold of 56.4 inches (historical 99.99th percentile). The red line indicates the increasing linear trend.

Source: Adapted from Cayan et al. (2008b).

Under the former projections for sea-level rise, experts calculated that California needed to invest hundreds of millions of dollars to protect vulnerable coastal areas against damage. For instance, an analysis by Neumann and others from 2003 extrapolated from a subset of seven locations throughout the state to conclude that a sea-level rise of 39 inches would cost the state an estimated $0.4 to $0.6 billion for coastal protection (beach nourishment and armoring of our coasts) state-wide as measured in year 2000 dollars (Neumann et al., 2003). Consistent with the old predictions, the San Francisco Bay Conservation and Development Commission (http://www.bcdc.ca.gov/) assembled maps of areas which would be inundated by the encroaching sea. However, economic impact assessments conducted using past projections now are seen as under-estimates of the magnitude of both costs and adaptive actions needed by state and local decision makers.

How do the new sea-level rise figures translate to economic impacts for California coastal communities? The state can focus on certain urban locales as indicators of coastal regions: San Francisco Bay Area and San Diego are economically important, low-elevation locales that are vulnerable to flooding and coastal erosion. Newer maps are now available for San Francisco Bay (Figure 21).

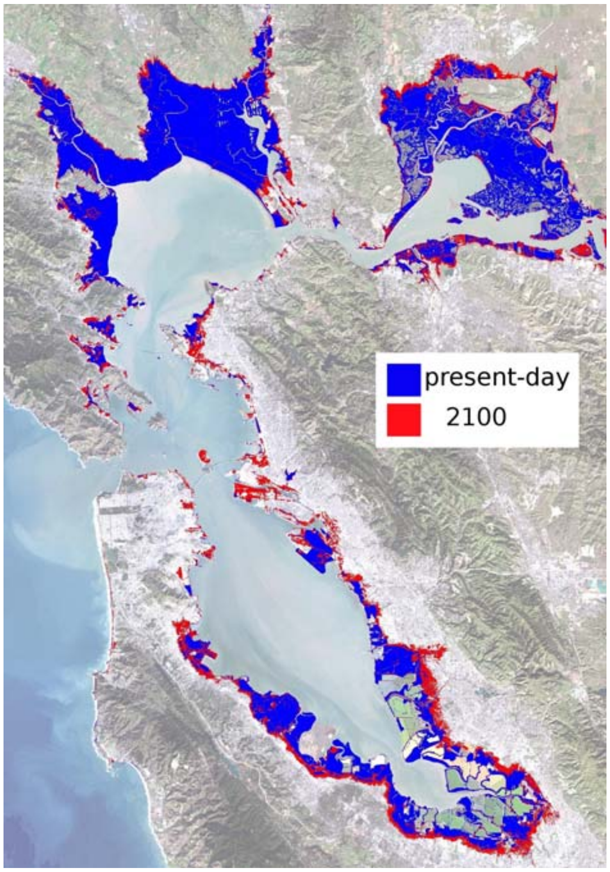

Figure 21. Areas inundated or at risk of inundation by average yearly Bay high-water levels, for both present-day (blue) and projected 2100 (red) conditions. The projected sea level rise by 2100 used in this analysis is 140cm (55 inches).

Source: Bay Conservation and Development Commission

A recent county-level analysis for San Diego and La Jolla estimates a one-time cost of protecting San Diego's coastline ranging from $24 million to $47.5 million for activities such as sea wall construction, beach nourishment and halting new building in heavily disturbed areas (San Diego Foundation, 2008). Figure 22 shows updated inundation maps for La Jolla.

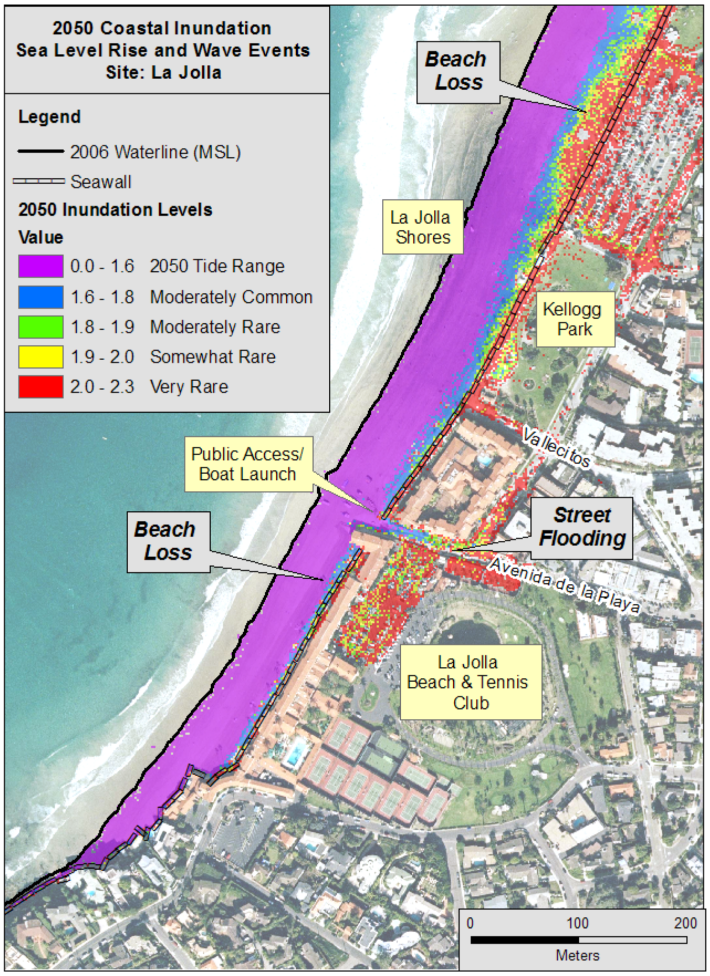

Figure 22. SLR, La Jolla "Regions of inundation at La Jolla Shores for sea level rise and various wave event scenarios in year 2050. Tidal fluctuations alone (purple) appear to inundate sandy beach and access road. Adding run-up from moderately common wave events (blue) floods majority of sandy beach. Very rare wave events (red) flood sandy beach, some surface streets, the heavily-used Kellogg Park, and parts of the La Jolla Beach and Tennis Club."

(Source: San Diego Foundation, 2008)

4.7. Growing Energy Demands

Under climate warming, higher costs from increased demand for cooling in the summer are expected to outweigh the decreases in heating costs in the cooler seasons (Franco and Sanstad, 2008b). Hotter temperatures in California will mean more energy (typically measured in "cooling-degree days") needed to cool homes and businesses both during heat waves and on a daily basis, during the daytime peak of the diurnal temperature cycle (Franco and Sanstad, 2008b). A high-emissions warming scenario such as A1fi results in a tripling, and the B1 scenario results in a doubling, in the statewide number of cooling degree days compared to historical values (Miller et al., 2008). During future heat waves, historically cooler coastal cities (e.g., San Francisco and Los Angeles) are projected to experience greater relative increases in temperature, such that areas that never before relied air conditioning will experience new cooling demands (Miller et al., 2008). A confounding concern is that similar to other western states, California expects to see extensive population growth, especially in the southern and central part of the state, where the climate is already hot enough to require air conditioning. Will California have enough electricity reserves to prevent shortages and blackouts? Unfortunately, decreased hydropower supplies are a likely consequence of climate change if precipitation decreases, although uncertainties in the precipitation projections hinder more precise predictions for hydropower (Vicuna and Dracup, 2007). The state's electrical capacity, while growing, is unlikely to be able to accommodate the dual pressures of increased cooling demand and increased population. The work by Miller and others (2008) suggests that summer electricity shortages may occur as early as 2020, with particular shortage vulnerabilities noted for Southern California.

4.8. Climate Change in a Multi-Stressor World

Climate change will impact many sectors simultaneously, yet different systems will vary in both their sensitivities and their responses to the coming changes. Moreover, any climate-related impacts will interact with non-climatic stresses. The resulting combined effects could be larger or smaller than any single projected impact occurring in isolation. One example may be a multi-year drought, followed by wildfire, followed by flooding. Another may be a number of severe coastal storms during an El Niño occurring at a time of economic recession. If compounding impacts lead to increased vulnerability to future climate change, there will be a growing need for broad-based management and adaptation plans. Cooperation and collaborative management among multiple agencies will be required to develop appropriate response strategies. Example cases where critical climate change impacts interact with non-climatic stressors and affect multiple sectors simultaneously are discussed below.

4.9. Growing Water and Energy Management Challenges in Southern California

Population growth promises to compound water management challenges under climate change. By 2030, the population of California is expected to grow by 14 million overall (California Department of Finance; Public Policy Institute of California, 2006). Most of this growth will occur in Southern California, resulting in a geographic disconnect between demand and supply. Dry Southern California imports water from the wetter north, yet the population in Southern California is growing faster than elsewhere in the state (PPIC, 2006). In addition, energy demand for cooling in Southern California is also expected to outpace that of Northern California due to both higher temperatures and intense development pressures in the southern half of the state. Finally, an aging and increasingly immigrant population in the southern part of the state is contributing to growing social vulnerability there compared to other regions of the state (Cutter and Finch, 2008).

4.10. Growing Wildfire Risk

Climate change can increase wildfire risks by elevating temperatures (a noted corollary) and by either increasing the vegetative fuel load (in wetter years) or drying out vegetation (in drier years). It is important to highlight that the existing projection is for 12-53 %[13] increases in the frequency of large wildfires in California by the end of the century, using the B1 and A2 scenarios, respectively. Under a higher-emissions scenario like A2, the value of structures lost to fire is projected to increase by 32-36 %, or by 6-11 % under the B1 scenario (Westerling and Bryant, 2008). Recent work has focused heavily on fire patterns within the wildland-urban interface, where more development and urbanization in fire-prone areas add to the climate-related increase in fire risk. Researchers are addressing issues such as land use planning measures (e.g., building density, buffers) that can minimize fire spread (Spyratos, Bourgeron, and Ghil, 2007) as well as the effect of increased urbanization in Southern California on both future vegetation distribution and urban fire risk (Syphard, Clarke, and Franklin, 2007). Future research will continue to probe the possible ways human activities can mediate California's vulnerability to wildfire and which actions can be taken to mitigate those risks.

Wildfire affects a host of economic and environmental issues, including air pollution, visibility, and human health (from smoke and aerosols), ecosystem dynamics, wildlife habitat, timber production, hydrologic cycling, and flooding and soil erosion risks (from loss of forest cover). This range of impacts illustrates how climate change and non-climatic stressors interact to create impacts that span multiple sectors. The resulting economic damages and costs are enormous (e.g., private property damages, tourism and recreation, evacuation, and fire suppression). By a 1996 state estimate, air quality degradation alone adds up to $15,000 per acre burned to economic costs of wildfire, depending on the type of area burned and the location of the air basin (Department of Forestry and Fire Protection, 1996). California's Department of Forestry and Fire Protection also reported that during the 2007 wildfire season, fire suppression costs totaled nearly $300 million, over 3,000 structures were destroyed, and damages totaled roughly $250 million. To minimize negative economic impacts, further studies are needed to analyze both costs and benefits of long-term investments to reduce the severity of fire, such as the use of prescribed fire treatments or strategies to reduce fuel loads.

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[13] These estimates are supplied by the Department of Forestry and Fire Protection (2007), available on-line at http://www.fire.ca.gov/communications/downloads/fact_sheets/2007Summary.pdf

4.11. Growing Vulnerability of the Sacramento-San Joaquin Delta

The confluence of the Sacramento and San Joaquin rivers that forms the Delta also represents an amalgamation of many issues impacted by climate change. The Delta provides local services for users from diverse sectors: agriculture, recreation, urban land use, and wildlife habitat, all of which depend upon water. As much of the land is below sea level, increased flood risk and salt water intrusion are both serious concerns; these can stem from sea level rise, an earthquake, levee failure from structural weakness with increasing age, or some combination of these processes. At least a portion of the drinking water supply for two-thirds of California's population passes through the Delta on its way to other areas. Thus, if the Delta's water system is compromised, this will affect potable water supplies for Central Valley users, customers in the Bay Area (in Silicon Valley and counties such as Contra Costa, Napa, and Solano), as well as the Metropolitan Water District of Southern California via the California Aqueduct. Research has shown that the impacts of climate change combined with a levee failure increases costs for the agricultural sector (Vicuna, Hanemann, and Dale, 2006). Meanwhile, the mountain snowmelt that supplies water to the area is expected to decrease with warming. The likelihood of decreased flows during the summertime, when demand is high, also creates problems concerning water quality standards for human uses and wildlife.

The Delta region currently accommodates considerable power and fuel infrastructure (e.g., electricity transmission lines, gas lines) plus corridors for transportation and shipping. If levees are compromised by flooding or seismic activity, the resulting consequences could be costly (Mount, Twiss, and Adams, 2006), reaching up to $40 billion cumulatively by one estimate (Lund et al., 2007). Such costs are expected to increase as urbanization of the Delta, especially in the periphery, is a major driver of change and is expected to accelerate in coming decades. As more land is converted from agricultural use to urban uses, more pressure will be focused to meet increasing demands for transportation and other urban infrastructure.

4.12. Keeping the Eye on the Ball: A Global Perspective

California clearly does not operate in isolation from the global community. For example, California's CO_2 emissions, while sizeable, are only a part of the whole. Thus, California has an important responsibility to reduce its own carbon footprint as well as to engage with partners elsewhere to support their carbon emission reduction efforts. This approach is critical because the global total of greenhouse gas emissions will ultimately affect California. Just a couple of examples are given here to illustrate the climate connectivity shared among different regions of the world.

4.13. Global Teleconnections of Air Quality

More than at any previous time in our history, human-generated air-quality problems have not just local or regional, but global reach. The atmosphere is capable of moving pollutants relatively rapidly—in a matter of days—in the west-east direction. Pollution arising from areas at a similar latitude to (west of) California are therefore able to affect California's air quality. Specifically, particulate pollutants from combustion known as black carbon are increasingly being transported across the Pacific Ocean, from Asia to California. In fact, the majority of black carbon passing over the West Coast of North America (measured in a spring month) originates on the Asian continent (Hadley et al., 2007), adding to the locally generated black carbon. Black carbon absorbs sunlight, which affects the rate of snowmelt (by darkening otherwise highly reflective snow), and contributes to climatic warming of the atmosphere (Reddy and Boucher, 2007). In addition to these important effects, an increase in black carbon pollution from combustion, whether locally or remotely sourced, causes health concerns, including respiratory symptoms as well as cardiovascular effects (Jansen et al., 2005).

4.14. Inter- and Intrastate Water Movement

Natural precipitation varies throughout California, and the state has engineered a massive system of infrastructure, such as aqueducts, to move water from areas of abundance to places of relative scarcity. Flexibility is also an important feature in allocating water supply regionally among western states. In future decades, some areas in the western United States, especially the southwest, may experience greater drought, necessitating more interaction in regional water markets (Seager et al., 2007). In the southern part of the state, water supplies from the Colorado River may decrease in the future. A recent comprehensive modeling study projected an 8-11 % decrease in runoff by 2100 for the Colorado River Basin depending on the emissions scenario. This study also found that water shortages for the basin became more frequent (Christensen and Lettenmaier, 2007). This reduction in water availability will require that all states within the Colorado River watershed collaborate to share the diminishing water resources fairly. Much of the West, like California, is considering some use of groundwater sources to supplement shrinking water supplies. However, groundwater access and rights among multiple regional players is subject to debate, as is currently playing out in the area surrounding Las Vegas, which is experiencing tremendous population and development growth (Deacon et al., 2007). Both the physical and social trends require a better understanding of the full implications for resource management at the regional scale.

4.15. Conclusions

The emerging projections of climate change impacts offer several sobering conclusions. In areas such as sea-level rise and carbon emissions, recent scientific progress suggests that impacts are likely be more severe than previously anticipated. Moreover, climate change impacts will not occur in isolation from other global environmental and societal changes, but will compound underlying environmental and economic stresses that are already occurring in California from development and urbanization. In addition, impacts that may occur in distant places can impact California through physical teleconnections (e.g., in the case of air pollution) or via societal and economic interactions (e.g., market interactions in an increasingly globalized world).

This section has focused on the ways in which changes in climate are projected to affect the environment and society over the 21st century. However, what will actually occur depends greatly on efforts to reduce emissions and to minimize future negative impacts. In short, human decisions are key to determining the true severity of future impacts. As will be discussed in the following section, California has already demonstrated, through legislative and other civic action, the enormous potential for positive change. Mitigation of emissions to slow down climate change and efforts in adaptation to deal with the impacts of change will help minimize the harmful impacts of climate change and provide valuable co-benefits. Efforts in both arenas currently underway in the state are discussed in the next section.

5.0 Managing California's Climate Risks: Need for a Two-Pronged Strategy

5.1. A Compelling Case: Why California—and the World—Must Mitigate Climate Change and Adapt to Its Impacts

Climate change risks are no longer a matter of the future or of places far away. As a growing number of studies of changes already observed in California's climate and ecosystems makes clear: climate change is already evident in the state, and it is happening now (see Chapter 2). Science is able to show that these local changes are consistent with a collective picture of physical and biological changes across the globe, which—in the vast majority of cases—are driven by anthropogenic climate warming and cannot be explained by natural changes alone (see Chapter 3). While modified by local climate variability and other human impacts such as pollution and land use change, the irrefutable conclusion is that humans affect the global environment in ways never thought possible before. If heat-trapping greenhouse gases are not curtailed and the related impacts are not reduced, the state faces tremendous impacts on its natural resource base, its ecological treasures, and the lives, livelihoods, and well-being of its citizens (see Chapter 4).

These three arguments—each detailed in the previous three sections—serve as a strong basis for action. Clearly they have motivated the mitigation efforts already underway in the state (see further discussion below, especially of the implementation of AB32). Yet there are several other reasons why California must complement its mitigation efforts with planning for adaptation to ongoing and future impacts of climate change. These reasons add urgency to the need for

10 Reasons Why California Must Adapt

1— California's climate and ecosystems are already changing, demanding management changes.
2— Observed global and regional changes are largely due to human activity.
3— Without swift and concerted action, climate change will produce severe and costly consequences for California and the world.
4— Current greenhouse gas emissions commit the state for decades to centuries to further warming and climate change impacts that must be managed.
5 — While mitigation is critical for long-term reduction of global warming, it will not help manage the impacts to which past emissions have committed California.
6— Land use changes are equally long-lasting and interact with climate change and response options.
7— Changes in the atmosphere, climate and other natural systems are accelerating, increasing the risk of abrupt and dramatic changes for which society is currently entirely unprepared.
8— Adaptation may offer important opportunities for California businesses.
9— Decreasing the human footprint on the environment, reducing vulnerability to climate variability and change, and planning ahead can improve environmental conditions and economic welfare, enhance social justice, and ensure people's quality of life.
10 — Well thought out adaptation plans, implemented over time, are less risky, less costly, and allow Californians to *create* their future, rather than being compelled later to just *cope* with it.

stepped up mitigation efforts and for adaptation to the problem while also pointing to the opportunities involved (see Textbox "10 Reasons to Mitigate and Adapt").

Dealing with the emissions that are the principal causes of global warming is different than dealing with other types of pollution. Many of the already emitted greenhouse gases—primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), but also halocarbons—are so-called "long-lived" greenhouse gases because they remain in the atmosphere for decades to centuries. To illustrate this point, consider the fact that about half of all the CO_2 added to the atmosphere today will still reside in the atmosphere 50 years from now, about a third will remain after 100 years, and about a fifth will still be there 1000 years hence (Hansen et al., 2007; Archer, Kheshgi and Maier-Reimer, 1997). Related studies show that if CO_2 emissions had been completely stopped in 2000, 25 years later the atmospheric concentration would only be reduced by 25 parts per million (ppm) and only by 40 ppm by 2100, i.e., getting back to 1975 levels (Friedlingstein and Solomon, 2005, p.10834).

This means that the warming experienced to date is mostly due to emissions released into the atmosphere decades ago, while more is yet to come. Current emissions are committing California and the world to decades if not hundreds of years of further warming, and some changes—such as sea-level rise—will go on for millennia because the oceans store heat even more effectively than the air (Meehl et al., 2005; Wigley, 2005; Friendlichstein and Solomon, 2005). So even if no more emissions were released from now on (which is practically impossible), warming would still continue because plants and oceans can absorb carbon dioxide only slowly, and their capacity to do so appears to be slowing (Canadell et al., 2007; Raupach et al., 2007). In short, the longer the reduction of emissions is delayed, the longer the world commits itself to additional warming and more changes in the environment. Moreover, the faster our climate changes, the more difficult and costly adaptation will be.

Similarly, land use changes (e.g., converting forests to grasslands, agricultural areas to urban areas) are long-term commitments, which change the reflectivity of the surface, and diminish the ability of ecosystems to absorb carbon dioxide, adapt effectively to climatic changes or maintain local climate conditions. Such land use changes are responsible for about one quarter of the anthropogenic forcing, and present similarly long-term commitments to additional impacts.

Furthermore, it is unlikely that future impacts are simply linear extensions of past trends. Emissions, greenhouse gas concentrations in the atmosphere, global temperature increases, sea ice losses, sea-level rise and other changes all are accelerating (Solomon et al., 2007). Evidence from the geologic past suggests that very abrupt climatic and environmental changes can happen (dramatic shifts far outside interdecadal variability over the course of just a few years) (Steffensen et al., 2008), and that these abrupt changes are more likely the more a system is pushed out of its dynamic equilibrium (as reflected in the range of natural variability). This is currently occurring with the climate as a result of anthropogenic forcing and there is considerable concern in the scientific community that abrupt changes—imaginable, but not predictable at present—may occur again (e.g., NRC, 2002; Schellenhuber et al., 2006; Lenton et al., 2008; McCracken, Moore and Topping, 2008). The social and economic costs of such abrupt changes have not been assessed but may be beyond the capacity of many countries and communities to absorb without major suffering (Schellenhuber et al., 2006; Holdren, 2008).

Reducing greenhouse gas emissions, on the other hand, by launching already existing and developing additional new technologies offers significant economic opportunities. Achieving the level of emission reductions recommended by many scientists and discussed in various policy circles (e.g., 80% reduction below 2000 emissions levels by 2050 as, for example, targeted in AB32) requires an almost complete "retooling" of society. Priority areas will include:

- Novel ways to meet our mobility needs through new modes of transportation using alternative, low- to zero-emission fuels.
- Alternative energy production systems involving virtually no net emissions of heat-trapping gases over the entire life cycle of the system.
- Significant reductions in energy demand/consumption through a mix of technological and behavioral changes.
- Denser and mixed, integrated land use, renewal of the existing building stock and a widespread, green revolution in building design.
- Changes in agricultural production technologies and the food distribution system.
- Changes in the design, production and consumption of other materials and appliances across all sectors of society.

Beyond these high-priority changes, every sector of society will need to be involved and contribute to the overall goal of climate stabilization. If climatic changes unfolded even more rapidly than currently observed or anticipated, such social and technological changes would need to be implemented very quickly, incurring dramatic economic costs. If, on the other hand, technological and policy changes were set in motion and pursued persistently over the course of several decades, innovation and stock turn-over could instead be a driver of a worldwide "sustainability revolution." Estimated impacts on the global economy over the next 50 years range from a few percentage points reduction in global GDP to several percentage points growth over what would be expected otherwise, without consideration of mitigation actions (IPCC, 2007c). Clearly, policy proposals must also consider equity, justice, and many other welfare concerns. But as national and international climate change policy will be put in place over the coming years, the global market for energy efficiency and zero-emission technologies will grow exponentially, and California's industry and overall economy could benefit tremendously.

In fact, California, a proving ground for technological and policy innovation, has benefited from similar pioneering thinking in the IT sector in the past. From appliance efficiency improvements to air quality regulations, to vehicle emission standards, the state has proven again and again that when California leads, other states follow (Rabe, in press; Kosloff, Trexler and Nelson, 2004; McKinstry, 2004). The resulting policy patchwork across the nation has repeatedly been an important driver of federal environmental and public health policies. Given the size of the California economy and market, technological and policy changes also have global ramifications. This puts a great responsibility and opportunity to act before California's political and business leaders.

In addition to the opportunities emerging with technological innovation and the remaking of the infrastructure and functioning of society, the larger sustainability challenge also beckons. In fact, it is the integrated approach of decreasing the total human impact on the environment, reducing social vulnerability to climate variability and change, and planning ahead for the unavoidable impacts of climate change that can improve environmental conditions and economic welfare, enhance social justice, and ensure quality of life (e.g., Holdren, 2008; Bizikova, Robinson, and Cohen, 2007; Eriksen and O'Brien, 2007; Yohe et al., 2007). As many of the changes observed in ecological and social systems to date are the result of both anthropogenic climate change and other human impacts on the environment, reducing any additional stressors will give these natural systems the best chance at adapting to additional climate changes expected in the future.

Finally, if California acts now together with other states and nations to reduce climate change risks through stringent mitigation and adaptation to the impacts that cannot be avoided, the world community has a chance to create its future, rather than being compelled later to just cope with it. While generations of humans before could not imagine affecting a system as large as the entire planet, the collective and cumulative impact of the human species has become that powerful. The challenge now is to redirect that powerful impact toward reducing and managing climate change risks and steer the world toward sustainability.

5.2. The Two-Pronged Approach to Reduce Climate Risks: Mitigation and Adaptation

Until fairly recently, the almost exclusive focus in climate policy has been on reducing greenhouse gas emissions from energy use and other forcings (such as large-scale deforestation) that cause global warming. Together, these efforts are commonly known as "mitigation." More recently, the climate policy discussion—internationally, at the federal level, and in California—has been expanded to now also include a concern with adaptation (e.g., Pielke et al., 2007), i.e., with the wide range of efforts needed to plan for and deal with the impacts of climate change to avoid or minimize harm and take advantage of any potential opportunities climate change may involve.

According to Moser and Luers (2008, pp. S309-S310),

> "Society's and the environment's ability to cope with climate impacts depends in important ways on the pace and magnitude of global climate change, thus continuing to require substantial mitigation efforts. However, because society is already facing risks associated with climate variability at present, the first signs of change are already being observed, and further impacts over the next 30 years are unavoidable due to the emissions already released into the atmosphere, adaptation is increasingly recognized as a complementary necessity to mitigation."

Managing California's climate risks then means reducing the drivers of change on the front end of the problem and minimizing the impacts on the back end, with the overall goal of ensuring public safety and welfare, continued economic vitality of the state's climate-sensitive sectors, and a rich and functional natural environment on which people and the economy depend.

California's ability to manage climate risks with such a dual approach, i.e., its response capacity, depends on a set of factors that apply to both mitigation and adaptation (e.g., Yohe and Tol, 2002; Smith, Klein and Huq, 2003; Brooks, Adger and Kelly, 2005; Pelling and High, 2005; Gallopín, 2006; Smit and Wandel, 2006; Adger et al., 2007):

- A strong economic resource base.
- Appropriate technologies.
- Adequate infrastructure.
- Institutional support and strong governance mechanisms.
- Highly educated and skilled workforce.
- Widespread public awareness and adequate information/knowledge to support decisions.
- Natural resources and functioning ecosystems.
- Equity in access to the above resources and institutions.

In fact, these factors have helped California invest in technological innovation, become a world leader in various technologies and market sectors, and create the image of a forward-thinking culture. They have also helped Californians cope with the challenges associated with historical climate variability.

In the future, as California increases its efforts in mitigation and adaptation (see below), it can bank on the existing strengths that increase the state's response capacity but must also strengthen that capacity where it may be insufficient, especially in light of rapidly unfolding climate impacts in the state. Moreover, the capacity to act does not automatically translate into action. Preliminary studies for California (e.g., Moser and Luers, 2008; Moser and Tribbia, 2006/2007; Tribbia and Moser, 2008) and elsewhere (e.g., Adger and Vincent, 2005; O'Brien et al.,

2006) suggest that communities, businesses and local and state agencies face considerable challenges and barriers in beginning to plan for climate change. Thus, there is a significant need for the state to not just build capacity but also help remove the barriers in the way of using it and implementing mitigation and adaptation plans.

5.3. California's Emerging Efforts in Adaptation Planning

As argued above, to minimize the potential harm from climate change and take advantage of potential opportunities, California must pursue a two-pronged strategy, where one is not exclusive of, but complementary to, the other. Importantly, mitigation and adaptation should be considered in concert as sometimes they can be mutually reinforcing (e.g., increasing or maintaining tree cover in urban areas to provide shade and to capture carbon), and other times undermine each other (e.g., more air conditioning to provide cooling against increased heat will consume more energy and increase CO_2 emissions) (Klein et al., 2007; Füssel, 2007). Here the authors focus on the meaning of adaptation and the emerging efforts at the state level to plan and prepare for adaptation to climate change impacts.

5.4. Adaptation, Coping Range, and Climate Extremes

Because adaptation is a relatively new concept in California state policy, it is helpful to first clarify what is meant by this term and what it involves. At the most general level, "Adaptation […] usually refers to a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (Smit and Wandel, 2006, p.282).

It is difficult to state in general what adaptation involves in any one situation because it is highly context specific. There are key dimensions, however, that apply to all contexts (adapted from Füssel, 2007, pp.266-267):

- *Climate sensitivity*—Adaptation is only relevant if the system or decision at hand is sensitive to climate and changes in it.
- *Climate hazards*—Adaptation can be to changes in average climate conditions, climate variability, or climatic extremes.
- *Predictability vs. uncertainty of climatic changes*—Adaptation is generally easier, all else being equal, if the climatic change is well understood and can be predicted with considerable confidence than if there is significant uncertainty associated with climate change projections.

- *Non-climatic context of adaptation*—Adaptation does not occur in a vacuum, but in a context of multiple stresses and place-specific environmental, socioeconomic, political, institutional, and cultural conditions that deeply affect what types of adaptation measures are relevant, effective and feasible.
- *Purposefulness*—Adaptation can be autonomous (happening spontaneously, without concerted effort) or planned (occurring with the express purpose of addressing climate change risks).
- *Timing*—Planned adaptation can be reactive (i.e., after some impacts have occurred) or proactive or anticipatory (i.e., before some impacts have occurred).
- *Planning horizon*—planned adaptation may aim to affect systems over the next few months or for many decades to come.
- *Measures*—Adaptation can involve technological, economic, organizational, legal/policy/regulatory, informational, educational, behavioral, or research measures.
- *Actors involved*—Typically, a wide range of actors should be involved in adaptation planning and policy development and implementation, from several levels of governance and from the public and private sectors.

Societies are already adapted to some range of variability in the local climate. For example, in California, state agencies—and in some instances private sector parties—built reservoirs and levees to protect against common winter and springtime floods and periods of summer drought; snowmaking equipment was put in place in part to compensate for insufficient snowfall in winter tourism locations in the Sierra; emergency warning and response systems as well as building codes were established for coastal storms, floods and other hazards; insurance mechanisms were established to deal with wildfires and agricultural losses from frost. Together, such structural, technological, monetary, institutional and other mechanisms have helped individuals and the state's economy deal with the vagaries of nature; they have built its "coping capacity" (e.g., Adger, 2003; Brooks et al., 2005; Pelling and High, 2005; Tompkins and Adger, 2005).

As climate change accelerates against a backdrop of other changes in society and the environment, three possible conditions would require additional adaptation efforts beyond those already in place:

Case 1: Along with average changes in climate, climate variability increases (e.g., more frequent and/or more intense extreme events) but society's coping capacity remains unchanged; consequently, more and more extreme events will fall outside the normal coping range and cause damages to people, property, infrastructure and ecosystems.

Case 2: Even if climate variability were not to change markedly with average changes in climate, societal coping capacity might decline for unrelated reasons; this means that even historically common extreme events can cause more damage because society is less well-prepared, protected, or able to recover.

Case 3: Average climate and climate variability change rather dramatically, and some efforts are made to increase society's coping capacity, but they are incommensurate with the shifts in climate; this means that society is drastically underprepared to deal with the major climatic changes unfolding.

Many researchers have observed that, "Climate extremes expose existing human and natural system vulnerabilities" (CCSP, 2008, p.28). In fact, "[c]hanges in extreme events are one of the most significant ways socioeconomic and natural systems are likely to experience climate change" (ibid). While such extremes may have positive or negative impacts, the most severe of these extreme events are outside society's coping range and hence produce negative impacts.

5.5. The Goal of Adaptation: Not "Free from Risk" but "Well-Managed Risk"

Adaptation to climate change does not mean preventing all adverse impacts. Since neither the climate nor society is entirely predictable or controllable, "perfect" adaptation with no adverse consequences of climate variability ever is impossible. Rather, the goal of adaptation is to create the conditions in which society and managed ecosystems are largely able to absorb the impacts from climate variability and change, such that any residual impacts beyond their coping capacity remains within (socially defined) acceptable limits of risk. For example, when people build in a floodplain, they are typically made aware of the fact that in their desired location they face a given flooding risk (e.g., in any given year there is a 1 in 100 chance to be flooded). Since this is a high level of risk, people are typically required to purchase flood insurance and make various structural changes to their homes. As climate changes and increases the frequency or magnitude of flooding and people experience floods repeatedly, they may choose or be required to relocate out of the floodplain. Insurance, elevation of homes, and relocation are all forms of adaptive adjustments to live with climate variability and change.

Ultimately, then, the goal of adaptation is to enhance the long-term resilience of society and of socio-ecological systems, i.e., their capacity to withstand and bounce back from disturbances and impacts, and—if necessary—to learn and transform themselves while continuing or regaining the ability to provide essential functions, services, amenities, or qualities (e.g., Walker and Salt, 2006). Importantly, "the resilience perspective shifts policies from those that aspire to control change in systems assumed to be stable, to managing the capacity of social–ecological systems to cope with, adapt to, and shape change" (Folke 2006, p. 254).

5.6. Adaptation Needs Assessments

How then can communities, industries, business sectors, and resource managers assess how much adaptation is needed to attain resilience in the face of change? Researchers have approached this question from the two obvious sides of the problem: the amount of climate change that may occur and the system's ability to cope, adapt, and change. For several decades, the scientific traditions using either of these approaches have been working quite separately; in recent years, the two approaches are increasingly viewed as complementary, and both are necessary (Burton et al., 2005; Füssel, 2007).

The first, sometimes called the *hazards-based approach*, begins with the change in climate (typically, model-based climate change projections), and aims to ascertain the incremental impacts of climate change. Any impacts beyond the historical norm would require adaptation, and their magnitude suggests how much. Consideration of non-climatic factors is typically limited. This approach—traditionally, the approach used in California's climate change (impacts) research—is critical for identifying climate change risks, but is limited for the development or assessment of different adaptation options. From this perspective, adaptation depends primarily on the magnitude of the expected change in climate. Consequently, if somewhat simplified, the most important information needed to guide adaptation actions are projections of climate change. More specifically, and pointing to future research needs (see below), the projected changes in climate, including in extremes, must be translated into changes in risk to inform adaptation planning decisions (CCSP 2008, p.29).

The *vulnerability-based approach*, on the other hand, is strongly focused on the socioeconomic factors that determine a system's ability to cope with climate change. Typically, such an assessment explicitly examines past experience with climatic variability and extremes and considers non-climatic factors and changes that affect a system's vulnerability and coping range. Vulnerability is the starting point, i.e., the initial context in which climate along with multiple other stressors combine to influence which impacts a system or community might experience. The key factors affecting vulnerability are:

- The geographic or functional *exposure* to a risk (e.g., projected temperature extremes, sea-level rise, or reduction in water supply for a specified sector; one's location vis-à-vis a specified climate hazard; one's dependence on a particular resource; the number of people at risk of experiencing a particular hazard).
- The degree of *sensitivity* to that risk (e.g., older people are more susceptible than younger people to extreme heat; coastal communities with seawalls may be less sensitive to sea-level rise than those without).
- The *ability to respond* (coping and adaptive capacity) (e.g., the availability of insurance; tight social networks; strong emergency response capacity; flexible institutions; economic resources).

Combining these three factors, it becomes apparent then why "a system can be sensitive to change but not be vulnerable, such as some aspects of agriculture in North America, because of the rich adaptive capacity; or relatively insensitive but highly vulnerable" (CCSP, 2008, p.21).

The vulnerability-based approach is most useful for identifying priority areas for action, and for assessing adaptation options and their relative effectiveness in the practical context of other stresses and demands on resources. Importantly, "[i]n practice, adaptations tend to be on-going processes, reflecting many factors or stresses, rather than discrete measures to address climate change specifically" or exclusively (Adger et al., 2007, p.720). Adaptation planning, from this perspective then, does require more than climate change information; substantial input from the social, economic, engineering, and ecological sciences on all factors affecting vulnerability and response options is needed. Table 2 places the characteristics and pros and cons of these two approaches to assessing adaptation needs side by side.

Table 2: Comparison of hazards- and vulnerability-based approaches to adaptation

Hazards-based approach	Vulnerability-based approach
Focus: • Incremental impacts of climate change	Focus: • Social factors determining the exposure, sensitivity and ability to cope with climate hazards
Starting point: • Model-based climate change projections	Starting point: • Experience with managing climate risks in the past
Benefits: • Critical for identifying climate change risks and raising awareness of climate change problems • Useful for identifying research priorities • Useful in long-term decisions, especially where projections are quite reliable already • Particularly useful if sufficient data and resources are available to develop high-resolution projections	Benefits: • Involve stakeholders often from the start to link climate and adaptation to their activities • Can produce useful results even in the absence of useful climate change projections or where climatic and other stressors are deeply intertwined • Useful for identifying priority areas for action • Useful for assessing the relative effectiveness of different interventions
Drawbacks: • Consideration of non-climatic factors is limited, especially the non-technical aspects and policy context of adaptation • Strong reliance on model-based climate and impacts projections (possibly not available at relevant spatial scales) • Long timeframe of projections are of little relevance to management today • Insufficient consideration of current climate risks • Insufficient consideration of key uncertainties and their implications for designing robust adaptation options	Drawbacks: • Greater reliance on expert judgment • Limited comparability across regions, sectors, contexts • Wide range of methodologies produce different results • Requires non-climatic data which are also often unavailable, unreliable, or difficult to integrate
Common in: • IPCC impacts assessment guidelines; • UNEP adaptation assessment handbook; • California climate (impacts) research to date*	Common in: • UNDP-GEF Adaptation Policy Framework • Many local vulnerability and adaptation assessments

Source: Information compiled and adapted from Füssel (2007).

*** The California Energy Commission's California Climate Change Center has begun studies using the vulnerability-based approach, and this effort will be enhanced in the future.**

Ideally then, California's adaptation planning will draw on both approaches to chart the way forward (Smit et al., 1999; McCarthy et al., 2001):

- Model-driven climate projections to better understand what risks the state must adapt to ("adapt to what?").
- On-the-ground social scientific assessments of vulnerability ("who/what must adapt?").
- Assessments of adaptive capacities, adaptation options, costs, ancillary positive and negative consequences, and barriers to action ("how to adapt?").
- Over time, assessments of the selected adaptive actions' outcomes ("how good is it?").

It is quite possible that many measures employed to adapt to climate change will have ancillary benefits, e.g., because they aim at reducing vulnerability to climate variability and extremes or because they improve environmental or social conditions more generally. On the other hand, policy- and decision-makers must be careful to avoid negative consequences of adaptation, e.g., in terms of social justice, unintended environmental consequences, or other impacts on sectors and communities (see examples discussed in Moser et al., 2008). Moreover, "actions that lessen the risk from small or moderate events in the short-term, such as construction of levees, can lead to increases in vulnerability to larger extremes in the long-term, because perceived safety induces increased development" (CCSP, 2008, p.28).

Another important inference of the projected increase in the frequency of extreme events is that there is less time between events available for recovery. This, in turn, increases the risk of such maladaptations—i.e., actions that may meet an immediate need but may have negative social and environmental consequences and increase vulnerability in the long-term, rather than reduce it. The higher frequency of extreme events will also alter "the feasibility and effectiveness of adaptation measures" (CCSP, 2008, p.29).

5.7. Adaptation Planning in California

Climate change impacts will need to be managed by involving both private and public sector decision-makers, climate science experts, vulnerability and adaptation analysts, and all affected stakeholders. Actions will need to be coordinated across relevant sectors and levels of government, as climate change impacts and many response efforts are not neatly confined in space (see Chapter 4). Clearly, because climate change impacts will manifest in specific ways at the local level, local governments, businesses and individuals will play a prominent part in minimizing risks and taking advantage – where possible – of potential opportunities. In many instances, however, it is unrealistic to assume local decision-makers can manage all the impacts by themselves. Often, state- and federal-level leadership and guidance will be needed, as will financial and technical resources (Tribbia and Moser, 2008). In addition, many impacts occurring in different places or having cross-regional and cross-sectoral linkages will best be managed through a coordinated effort at a higher level.

The State of California has recognized the need for adaptation and in early 2008 began coordinated efforts to develop adaptation plans and strategies across state agencies. This effort is linked institutionally to California's mitigation efforts through a subcommittee of the Climate

Action Team, which coordinates the implementation of AB 32 and the strategic planning of deeper emissions cuts. The goal is to establish an adaptation planning process in each of the relevant state agencies (see textbox for more information) and to develop an initial state adaptation plan by the first or second quarter of 2009. This plan is only the first step in the state's ongoing adaptation efforts, which will need to be maintained for as long as climate change impacts are felt in the state.

The California Adaptation Strategy (CAS), with the help of sector-focused working groups and in coordination with key state agency stakeholders, will

- Synthesize information on anticipated climate change impacts for California policy-makers and resource managers.
- Provide strategies to promote resiliency to these impacts.
- Develop implementation plans for short and long term actions.

The CAS process will be guided by peer-reviewed scientific information gathered from scientists, agencies, cities, states, and countries around the world.

For more information on California's Adaptation Strategy (CAS):

http://www.climatechange.ca.gov/adaptation

5.7.1. Research in Support of Adaptation Planning

California is strongly committed to climate change research that will support the state's adaptation efforts. Since 2001 the California Energy Commission's Public Interest Energy Research (PIER) Program has been funding research climate change research. With the adoption of a long-term PIER climate change research plan in 2003, this effort has been substantially enhanced. Since 2003 PIER has been funding research on 1) climate monitoring, analysis, and modeling; 2) improving greenhouse gas inventory methods; 3) identifying options to reduce emissions, and 4) impacts and adaptation studies. In this document the authors discuss only the fourth area of research but more information about the other areas can be found in numerous other sources, including: Franco et al, 2008a; the California Climate Change Center (Center) website, at http://calclimate.berkeley.edu/; and a brochure describing the activities of the center (Energy Comission, in preparation).

The rest of this section briefly describes several PIER studies designed to support adaptation in California and concludes with a brief description of other relevant research and decision support efforts currently underway.

5.8. Adaptation Studies Supported by Local, State, and Federal Agencies

Federal agencies such as National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and the National Science Foundation (NSF) are funding studies on adaptation for the water sector. For example, NOAA will continue to fund the follow-up phase of the INFORM project that is described below. Both NOAA and US EPA have contracts with the Stockholm Environmental Institute (SEI) to apply the Water Evaluation and Planning (WEAP) model – a water resources planning tool with a GIS-based interface that allows supply, demand, water quality, and ecological issues to be integrated into analyses of water allocations – for adaptation studies at the water district level. NSF funded RAND Corporation for a study of adaptation in the water sector in Southern California (Groves et al, 2008). US DOE has an on-going project with The Nature Conservancy and others for a study on potential ecological effects from climate change in a region in the Sierra Nevada, including a preliminary identification of adaptation strategies (Gonzalez et al., 2007).

At the state level, several agencies have in-house efforts, such as the San Francisco Bay Conservation and Development Commission (BCDC), which is also working with PIER and the Pacific Institute to estimate potential impacts to the San Francisco Bay and the identification of adaptation measures. DWR is preparing an update of its State Water Plan with a substantial amount of work being done by DWR staff and a team formed by SEI and RAND on impacts and adaptation issues. The California Department of Public Health has released its first report on impacts and adaptation options titled *Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies – Report No. 1: Heat-Related Illness and Mortality Information for the Public Health Network in California*.

At the local level, counties and cities such as the county of San Diego have prepared preliminary impacts and adaptation plans (San Diego Foundation, 2008), but they are requesting additional scientific information to refine these plans.

5.9. PIER-Supported Studies

The majority of PIER-supported research in the past falls within the hazards-based approach to assess adaptation needs. Here the authors highlight several relevant efforts before turning to the emerging efforts in vulnerability-based adaptation research.

5.10. Development of Climate Projections for California

Substantial effort has been invested to develop methods to focus the output from global climate models specifically to the California region. The grid cells of global climate models (typically from 150 kilometers (90 miles) to 300 kilometers) are too coarse to properly capture the diverse climatic conditions in California (see Figure 23). California impacts and adaptation studies require a much finer geographical resolution. A number of models are being developed that can simulate climate at grid resolutions of approximately 12 km (7.5 miles) (Kanamaru and Kanamitsu, 2007), which are better able to model ambient ground-level temperatures and precipitation. The statistical techniques used to generate these projections, however, cannot provide complex meteorological and hydrological information such as three-dimensional temperature and wind fields that would be needed for more detailed impacts and adaptation studies. For this reason, enhancements to and validation of regional climate models (similar to the sophisticated models used for weather forecasting) are underway or have been completed. These models are now ready for the creation of probabilistic climate projections for California at a resolution that will be adequate for local and regional impacts and adaptation studies. These scenarios will be ready in the third or last quarter of 2009.

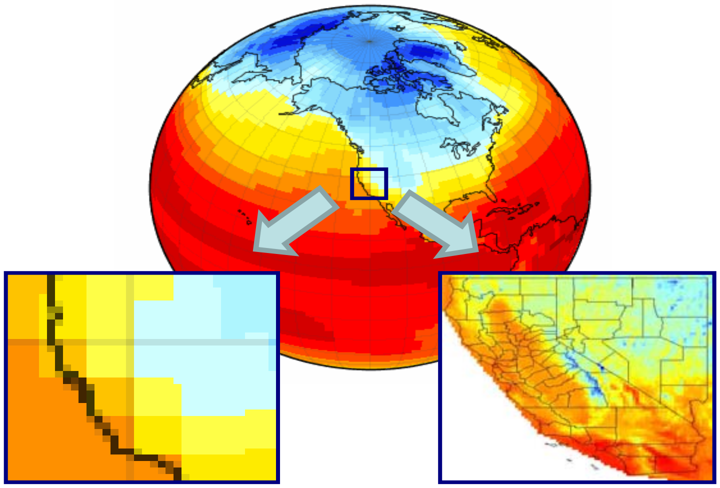

Figure 23. Temperature distribution for California from a global climate model and downscaled results for California. The global temperature distribution is an example for a given month in a given year for a typical global climate model. The map on the left shows how downscaling provides fine-scale (about 7.5 miles) resolution.[14]

Source: Authors

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[14] Mary Tyree from Scripps Institution of Oceanography provided the data, and Franco and Pittiglio (Energy Commission) generated the maps.

5.11. Development of Tools for Impacts and Adaptation Studies

An ongoing and acute need for improved tools and models to understand the effects of climate change on California's resources has led to the continued support of development of several new predictive and analytical tools and the preparation and refinement of several others. For example, researchers at UC Davis enhanced its California Value Integrated Network (CALVIN) model to improve the representation of groundwater resources after a preliminary study suggested that water storage in underground aquifers could ameliorate some of the negative impacts of climate change on water availability (Lund, 2003). Researchers at UC Santa Barbara, Stanford, UC Davis, and Conservation International have developed a new dynamic ecological model for California that addresses some limitations of existing ecological models such as incomplete assessment of barriers (e.g., urban areas) to the dispersal of fauna and flora (Conservation International et al., 2008). A coastal evolution model is under development at the University of Florida and Scripps Institute of Oceanography to improve estimations of coastal responses to accelerating sea-level rise.

5.12. Effect of Aerosols on Precipitation Levels and Regional Climate

Aerosols (fine particles suspended in air) may be reducing precipitation levels over the Sierra Nevada mountains (Lynn et al., 2007; Rosenfeld and Gavati, 2006) and affecting the regional climate (Jacobson, 2004). The reported precipitation reductions are on the order of 15 percent, representing a substantial loss of water resources that otherwise could have been used for environmental purposes, to provide water to cities and farms, and to produce hydroelectricity. Several studies using numerical models, satellite data, and field measurements using research aircraft have facilitated the accumulation of evidence that appears to confirm the negative role of aerosols on the amount of precipitation in the Sierra Nevada (Rosenfeld et al., 2007), with similar findings reported in other parts of the world where the topography influences the generation of rain and snow (Woodley, 2008). Further studies are being planned to identify the types of sources (e.g., cars, natural gas combustion) responsible for generating the detrimental aerosols. If climate change results in a drying of the West, including California, actions to reduce the aerosols that are affecting precipitation levels in California could become an extremely important adaptation tool.

5.13. Adaptation to Present Climate Variability as a Parallel for Climate Change

As discussed earlier, climate change not only will result in changes in average climate conditions but will also increase climate variability (deviations from "normal" conditions). For example, more frequent heat waves, flooding events, and forest fires are expected for California in this century. Common sense suggests that improving the ability to manage current climate variability may also be useful in a changing climate. The following example details a strategy for water management that provides an example for this type of adaptation.

Researchers associated with the Hydrologic Research Center (HRC) published a paper in 2001 (Yao and Georgakakos, 2001) that demonstrated that probabilistic climate forecasts in combination with a modern decision support system could substantially improve the management of the Shasta Reservoir. According to the study, this new management system would be more efficient, resulting in more water available for consumptive use and electric power generation while still providing other needed services such as recreation and flood protection (Carpenter and Georgakakos 2001). This new management system would replace the existing operating rules, which are very conservative and are based on historical hydrological conditions.

A second paper by HRC researchers suggested that negative impacts from climate change on the services provided by the Shasta Reservoir could also be substantially ameliorated (Yao and Georgakakos 2001). Given the importance of these findings, the National Oceanic Atmospheric Administration (NOAA), CALFED (a consortium of state and federal agencies), and the PIER Program together funded a demonstration project known as the Integrated Forecast and Management (INFORM) system for the coordinated management of five major reservoirs in Northern California, including Shasta. After system development, INFORM entered a demonstration phase involving participation by all the agencies responsible for the operation of these reservoirs (e.g., California Department of Water Resources, U.S. Bureau of Reclamation). INFORM system was run on a near-real-time basis during this phase, during which appropriate management decisions were suggested by the system while the water managers continued to operate the reservoirs using existing operating rules. A retrospective evaluation conducted months after the management decisions were made indicated that the INFORM system was superior to the traditional operating rules (i.e., it would have been superior to follow the forecasting information and decision support provided by INFORM). Given the success of the INFORM study, the participating agencies, along with DWR, plan to fund further enhancements to INFORM to extend the geographical coverage area and carry out additional demonstrations to capture different hydrologic conditions (O'Hagan, Personal communication). DWR and other agencies are seriously considering using INFORM to "re-operate" the five reservoirs included in INFORM.

The existing INFORM system is in the process of being evaluated using one or two climate scenarios to estimate how and if the system might alleviate some of the expected negative impacts of climate change and increased climate variability on water resources.

5.14. Vulnerability-Based Adaptation

To complement the state’s existing strengths in the hazards-based approach to assessing adaptation needs, the state has recognized the need to foster a greater focus on vulnerability-based adaptation studies. Only one such study on the barriers to adaptation faced in California’s coastal sector has been funded to date (Moser and Tribbia, 2006/07; Tribbia and Moser, 2008), but several proposals are under review for future funding. Moreover, this type of research will be emphasized increasingly in the future along with a stepped-up effort to build California’s decision support capacity for climate change adaptation decisions, as will be evident in the Energy Commission’s revised strategic research plan available later in 2008. Social science studies designed to identify barriers for adaptation have also started. Barriers include any regulatory, legal, socio-economic, cultural, and economic barriers for the implementation of adaptation measures.

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Appendix 1: Detection of Climatic and Related Environmental Changes and Attribution to Anthropogenic Causes

Growing Scientific Confidence over Time

In 1990, at the time of the IPCC's first assessment, scientists concluded that the observational evidence was insufficient to either clearly detect or deny a human influence on the global climate (IPCC, 1990). By the time of the second IPCC assessment report in 1995, the consensus view had strengthened, but many uncertainties remained when scientists carefully stated that, "The balance of evidence suggests a discernible human influence on global climate" (IPCC, 1996, p.4). In 2001, at the time of the Third Assessment Report, the scientific community had advanced significantly concluding that, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (IPCC, 2001, p.10). Finally, in its most recent assessment in 2007, the IPCC essentially eradicated any remaining doubt over human responsibility for the observed impacts over the last half of the 20th century.

Regarding the emissions of heat-trapping greenhouse gases in the atmosphere, the IPCC observed,

> "Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentrations are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture." (Solomon et al., 2007, p.2)

Moreover, considering all types of emissions (gases and aerosols) and activities, the IPCC stated with *very high confidence*[15] that "the global average net effect of human activities since 1750 has been one of warming" (IPCC, 2007, p.3) and that greenhouse gas concentrations alone would have warmed temperatures even more were it not for the cooling effect of natural and anthropogenic aerosols. Based on longer and improved data records, an expanded range of observations, improved simulations of many aspects of the climate and new attribution studies, the IPCC arrived at its strongest conclusion yet regarding the "human fingerprint" on the global climate when it stated,

> "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.[16] […] Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns." (IPCC, 2007, 10)

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[15] "Very high confidence" means that there is a 9 out of 10 chance that the scientific judgment is correct.

[16] "Very likely" indicates a greater than 90% likelihood of an outcome or result occurring, based on expert judgment.

How have scientists come to such a strong conclusion about human causation, i.e., how can observed changes be attributed to human as opposed to natural causes. This section provides evidence from studies of global and – to the extent possible – regional climate variables that show a clear human influence.

Human Attribution Studies: How Do We Know?

The process of understanding the causes and impacts of climate variability and change involves, first, the *detection* of change, and second, the *attribution* of that change to a particular cause or set of causes. Both are challenging, and a variety of methods and data sets are typically used to determine connections between cause and effect.

One fundamental challenge lies in the fact that the climate system is inherently variable, i.e., dynamic processes in the atmosphere cause temperatures, atmospheric pressure, precipitation patterns, sea levels and so on to vary from place to place and from month to month, year to year, decade to decade, and even over much longer timeframes. In addition, there are external "forcings," i.e. perturbation in the radiative energy budget of the Earth's climate system, which also lead to changes in climate variables such as temperature or precipitation. Such perturbations or forcings may be natural or human in source, including variations in solar radiation, aerosols from volcanic eruptions, or greenhouse gases and aerosols produced from human activities. In an effort to detect and explain observed changes, it is essential then to understand three critical components:

- The natural dynamics and resulting internal variability of the climate system
- The magnitude of any external forcings, both natural and anthropogenic
- The response or sensitivity of the climate system to that forcing

Scientific understanding of each of these components has improved significantly over the past 20 years, leading to the growing confidence in human causation mentioned above. Clearly, additional uncertainties remain and knowledge is likely to improve further by the time of the next IPCC assessment.

Detection

The task of *detection* is to discern a real trend in any climatic variable away from a long-term average, i.e., showing with statistical significance that the observed change is indeed a notable deviation from the long-term average (Houghton et al., 1996, pp.4-5).[17] Given the "noise" of natural variability in climate observations (or computer simulations), detecting a real change often requires longer data records, and confidence grows typically with the length of the records. If an observed change or trend is larger than internal variability alone is likely to produce by chance, that change is said to be 'detected' (Hegerl et al., 2007, p.667).

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[17] In modern climate studies, it is common to use a baseline of 30 years (e.g., 1961-1990 or 1971-2000) and determine the average value of the variable of interest.

Detection can be difficult when the observational record is too short to conclude anything with statistical significance, when the climate system's response to a forcing is small relative to natural variability, or when the climate system responds in some areas in one direction (e.g., precipitation increases in one region) but in the opposite direction elsewhere (precipitation decreases in another region), thus canceling each other out on a global average. It is therefore important to carefully analyze climate records at those spatio-temporal scales at which the climate system is expected to respond, filter out, as much as possible, internal variability, use the longest possible data records, look for patterns of variation in time and space (so-called 'fingerprints') that are consistent with physical understanding of the climate system, and identify changes in several indicators so as to combine various lines of corroborating evidence into a consistent and physically plausible picture (Hegerl et al., 2007, pp.667-668).

Attribution

By contrast, the task of *attribution* is to establish the most likely cause(s) of the observed change or trend, typically by testing alternative explanations (e.g., the observed trend is due to natural forcing vs. anthropogenic forcing). Unequivocal attribution to a cause would only be possible in a completely controlled experiment. Given that there is only one Earth, however, and no alternative planet with similar baseline conditions but without humans, a "natural" comparison between changes observed on Earth and elsewhere is impossible. Differently put, the Earth is undergoing at present a global experiment as a result of human activities without a "control run."

In the absence of a second Earth, scientists instead use model-based climate simulations as "laboratories" to test alternative explanations. Attribution then, in practical terms, means that scientists combine their best current understanding of the climate system and of natural and anthropogenic forcings, with their by now quite sophisticated ability to reproduce these dynamics in powerful super-computer models to test two principal hypotheses:

- An observed change is consistent with the estimated or expected response of the climate system to the actual combination of natural and anthropogenic forcing; and
- An observed change is inconsistent with an alternative, physically plausible (but not actually realized) climate change as a result of a different set of forcings.

If an observed change meets both criteria, and especially if multiple observed changes withstand this type of testing, confidence in the causal linkage between a forcing or combination of forcings increases (Hegerl et al., 2007, p.668). In some cases (such as global temperature change), such attribution studies can be done quantitatively, using computer simulations and illustrating statistical significance. In other cases, the human fingerprint on observed trends is not yet apparent (i.e., statistically significant) and scientific confidence lower, though the observed change may still be physically consistent with expected change and therefore important.

Attribution studies, like detection studies, are constrained by our knowledge of internal climate variability over the course of decades or longer, uncertainties in models, uncertainties in climate forcings and in our understanding of the responses to a given level of forcing. Multiple simulations (ensembles) from a single model, systematic comparison between simulations of the same observed modes of variability from different models, comparisons of simulated and observed variability, and comparisons of proxy records with simulations of climate variability over the last millennium have all helped to increase confidence in our ability to attribute changes to specific (combinations of) causes. Moreover, the improved observational basis (longer data records, more records, different kinds of indicators of change), more insights from paleoclimatological studies, increased modeling capacity (using different models, faster computers enabling work at higher temporal and spatial resolution), better theoretical understanding, and the use of different analytical techniques, have allowed scientists to repeatedly test their detection and attribution claims. In fact, "detection of an anthropogenic contribution to the observed warming [in the 20th century] is a result that is robust to a wide range of model uncertainty, forcing uncertainties, and analysis techniques" (Hegerl et al., 2007, p.687).

Uncertainties remain in the estimates of radiative forcing of some substances (e.g., aerosols) and in the magnitude of interdecadal variability of solar forcing, in the understanding of forcing at smaller space and time-scales, and in the attribution of surface pressure, precipitation changes, and higher-order impacts (such as some observed ecological responses).

Detection and Attribution of Environmental and Societal Impacts of Climate Change

The IPCC assessed more than the climatic changes discussed so far. Working Group II in its assessment of ecological and societal impacts, similarly concluded that,

> "A global assessment of data since 1970 has shown it is likely [66-90% probability] that anthropogenic warming has had a discernible influence on many physical and biological systems." (Parry et al., 2007, p.9)

This conclusion is based on four sets of evidence:

- The IPCC Working Group I conclusion – based on its extensive detection and attribution work – that most of the observed increase in globally averaged temperature since the middle of the 20th century is very likely due to observed increases in anthropogenic forcing.
- Based on 75 studies providing more than 29,000 data series, 89% of those that show any change exhibit responses from physical and biological systems that are consistent with the expected response to warming.
- There is strong spatial agreement between regions of significant warming and the locations where significant physical or biological response has been observed. Natural variability of the climate or the observed system is very unlikely to have solely caused the observed changes.

- Several modeling efforts were undertaken, akin to those in physical climate attribution studies, that linked physical and biological system responses to anthropogenic warming and then compared system response driven solely by climatic changes due to natural forcing.”Models with combined natural and anthropogenic forcings simulate observed responses significantly better than models with natural forcing only” (Parry et al., 2007: p.9)

Limited data sets from relatively few systems and locations are an important reason for the more tentative tone in these conclusions. Attribution studies of impacts observed in physical and biological systems also have to contend with relatively greater climate variability at regional and local scales, and the concurrent non-climatic influences such as land use change, pollution, and invasive species. Until recently, scientists expressed nonetheless high confidence that anthropogenic warming of the last few decades has *discernibly* influenced a wide range of systems (Rosenzweig et al., 2007, emphasis added, from which the following summary points about observed changes is extracted). More recently, a global study explicitly tested for the first time whether observed physical and ecological changes can be attributed to human forcing. It came to a stronger conclusion, stating that, “anthropogenic climate change is having a *significant* impact on physical and biological systems globally and in some continents” (Rosenzweig et al., 2008, p.353, emphasis added).

Changes in Physical Systems

- *Arctic sea ice* extent is continuing to decline, and at increasing rates especially in the last few years; impacts on ice-dependent species (e.g., nutritional stress) and human activities (e.g., travel on ice; navigation of increasingly open Arctic waters) are already documented
- *Mountain glaciers* are receding on all continents, at high and low latitudes, leading to changing runoff, and hazard conditions (e.g., debris flows, rock fall, glacial lake outbursts, crustal uplift); *land-based ice caps* are also melting, causing freshening on ocean waters (and related ecological changes in the marine food web), and increased iceberg calving.
- *Northern Hemisphere permafrost* is thawing, leading to temporary lake expansion, eventual surface water drainage and disappearance, weakening of the mechanical stability of the ground, formation of thermokarst, ground subsidence, slope instability, increased coastal erosion, and subsequent structural impacts on buildings and infrastructure
- The extent of *snow cover in the Northern Hemisphere* is decreasing, especially at lower elevations; spring peak flows of meltwater are occurring earlier
- The annual duration of *lake and river ice cover* in the mid- and high latitudes of the Northern Hemisphere has been shortened and become more variable; some evidence for a reduction in ice-jam floods exists from Europe; other chemical and ecological changes are only beginning to be documented.

- Changes in *surface and groundwater* have been observed in many systems, and some have been linked with statistical significance to trends in temperature and precipitation, but because of different trends in regional climate change, climate variability, and the complexity of non-climatic influences on surface and groundwater, uniform global trends have not been identified. One globally coherent, if not uniform, picture is emerging regarding changes in river runoff, with increases in higher latitudes and decreases in some lower, drier latitudes. Moreover, in snow-driven catchments, there is a consistent finding of earlier peak runoff in spring
- Documented trends in floods are ambiguous with some basins showing increases, others decreases, and yet others no statistically significant trends. There is some evidence of the most catastrophic floods to increase in frequency in recent years. There is also a documented trend in some regions toward more severe droughts and more heavy rainfall events, indicating an intensification of the hydrological cycle.
- Changes in coastal processes and systems are widely evident. While clearly influenced by human activities along the coast and upstream in coastal catchments (destruction of mangroves, corals, pavement, hard protection measures, etc.), coastal erosion is occurring and possibly increasing along most of the world's coasts. Similarly, coastal wetland losses are increasing particularly where other human influences do not allow for wetlands to migrate inland and upland. Regionally, there have also been documented increases in wave height increases, coastal storm surges, flood heights and inland flooding extent, partly driven by sea-level rise and changes in storm climatology, but also land subsidence and other influences on coastal hydrology.

Changes in Biological Systems

- *Terrestrial plant and animal ranges* are shifting poleward and to higher elevations; areas where snow and ice have recently receded are quickly being colonized by plants and animals. Similar observations are made in *marine ecosystems*, where plankton, pelagic organisms, and populations of higher organisms are responding to warmer water and sea surface temperatures, stratification, changes in salinity and upwelling.
- Within the ranges of some terrestrial and marine species, *populations* are increasing in some areas and declining in others. Warm-water species, for example, are becoming more prevalent in their habitat and increasing their range.
- The timing of many *phenological life cycle events* (e.g., blooming, migration, insect emergence, leaf unfolding, coloring and fall, fruit ripening, breeding) is shifting earlier in spring and/or later in fall.
- *Species interactions* are becoming decoupled from each other as individual species react more readily than others to warming or respond in different directions. Some are changing their migratory patterns; in other cases trophic relationships and interactions are changing. Where species lose their habitat (e.g., ice), new interactions are established in alternative habitat, if available and suitable in principle.

- There are also documented *productivity (or biomass) increases* due to warmer temperatures, a longer growing season, and higher CO_2 levels (and where other factors, such as nutrient availability, were not restrictive).
- While the causes of extinctions/extirpations are typically multifactorial, climate change can play a significant part in the process, e.g., through range contraction and loss of sufficient suitable habitat, warmer temperatures and higher CO2 concentrations creating more favorable conditions for invasive competitors, or climate-driven spread of deadly diseases.

While differences among individual regions and species are apparent, the mid- and high Northern Hemisphere latitudes show a clear trend toward extension of the growing season by up to two weeks in the latter half of the 20th century, driving many of the changes observed in biological systems. A more complete assessment of these changes, i.e., higher-order impacts of the primary, climate-driven responses mentioned above, is constrained by lack of data, lack of understanding of functional interactions, and the interactive nature of many of the observed changes. For example, changes in population size of one species interact with phenological changes among species in a particular region, together producing shifts in species interactions, yet they themselves may also be directly affected by climatic changes. Moreover, "non-climate synergistic factors can significantly limit migration and acclimatization capacities" of individual species (Rosenzweig et al., 2007, p.104).

Changes in Managed and Human Systems

In general then, higher order impacts are difficult to detect and attribute to anthropogenic climate change. In particular in systems managed by humans (such as agriculture, water resources, forestry) or directly impacting humans (such as human health, tourism and recreation), efforts undertaken to cope with extremes and variability or adapt to longer-term change may mask the direct impact climate change and related physical and ecological responses may have.

- Extreme heat periods and milder winters have affected *energy demand* for cooling and heating, with summer increases in peak demand typically more pronounced.
- While it has been shown that people's destination choices regarding *tourism and outdoor recreation* are highly climate sensitive, it is difficult to isolate the role climate changes to date have played in vacation or recreation behavior, although some evidence for shifts in skiing and winter recreation has been documented.
- In *agriculture* – a sector already sensitive to climate variability – switching crops, later sowing dates, diversification of livelihoods, tree planting, cooling and irrigation technology employment or changes have all been observed as adaptive responses to observed climate changes.
- The northward shift of some disease vectors and changes in the seasonal pattern of allergens is well documented but a greater incidence of related *human health* problems is

not, due to the complexity of the disease and health care systems. Excess mortality due to extreme heat events, however, is documented on several continents.

- While statistically significant upward trends in extreme floods or storms are not yet available, *economic and insurance losses* from such events have grown tremendously. The dominant reason for these growing losses is the increase of insured and uninsured property, structures, and value in high-risk areas. When normalized by population and growth in overall wealth, no significant upward trend has been identified – at least not prior to the hurricane seasons of 2004 and 2005 in the US. Significant adaptations (e.g., early warning systems, building code and land use changes, various protection measures) have been observed in many countries.