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Climate Change in California: Scenarios for Adaptation

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Supported with funding from Next Ten, Pacific Gas and Electric Company, and The Nature Conservancy

This report is part of a larger PPIC study, *Preparing California for a Changing Climate.* Other reports in this collection are available at http://www.ppic.org/main/publication.asp?i=755.

November 2008

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Summary

There is now growing momentum worldwide to address climate change by reducing emissions of greenhouse gases. However, because of the inertia in geophysical systems, even with aggressive global action to reduce emissions, the climate will continue to change for decades because of previous decades' emissions. As a result, no matter what emissions-reducing steps are taken, society has to focus on enhancing its capacity to cope with the unavoidable impacts that we are already experiencing and will continue to experience over the next few decades. In this report, we provide an overview of climate change scenarios for California and explore how these might be used in state and regional planning efforts in the future.

By mid-century, the average annual temperature of the state is projected to rise by roughly 2 to 4° F (~1 to 2 °C), with summer temperatures rising most rapidly. Total precipitation in the state is not expected to change; however, warming temperatures are projected to decrease the amount of precipitation falling as snow and increase the amount falling as rain, with significant implications for the accumulation of snow in the Sierra Nevada and timing of snowpack melting. Sea level is expected to rise at least one foot and up to three feet by the end of the century. Over the shorter term the changes in extreme events such as heat waves, flooding and wildfires will likely be the biggest climate challenges Californians face. Understanding how these events are changing and the implications of these changes for social and ecological systems is of critical importance for adaptation planning.

Given the climate changes ahead, resource managers, regional planners, and government agencies will need to consider climate risks in their planning. The range of climate projections presented in the literature has been helpful for characterizing the risks that society faces from climate. However, the literature provides less guidance on how to interpret these projections for on-the-ground adaptation planning. The best approach for drawing useful information from the suite of climate projections will likely vary by sector, depending largely on the planning horizon for the sector and the lifetime of planning decisions. One important near-term strategy across sectors is to identify and pursue actions that strengthen the ability to cope with today's climate variability, while incorporating short-term projections for changes in climate extremes. For medium and long-term adaptation strategies (those that make adjustment for projections 30 or more years into the future) such as habitat protection or infrastructure investment, it is critical to consider the consequences of the full range of climate projections, the nature of underlying uncertainty, and the requisite planning horizon for minimizing impacts.

Introduction

Californians are well acquainted with climate-related hazards such as floods, wildfires, heat waves, and droughts. Over time, the state's communities and economy have developed strategies to manage climate stresses and to thrive within the state's diverse climatic zones. However, the rapidly changing climate is now threatening to exceed the limits of society's traditional strategies for managing climate conditions and coping with climate extremes. Extended droughts have strained the region's water management systems, severe heat waves have led to the loss of lives and revenues, and extreme floods such as those during the El Niño years of 1987, 1992 and 1997 have caused extensive economic damages to private and public property while exposing the costly consequences of management, planning, and development decisions. While none of these extreme events can be directly attributed to human-induced climate change, their devastating consequences highlight California's vulnerabilities to climate variability and change. Among other impacts, extreme events are projected to become more frequent and intense as the climate continues to change (Meehl et al., 2007).

There is now growing momentum worldwide to address climate change by reducing emissions of greenhouse gases. However, because of the inertia in social and geophysical systems, even with aggressive global action to reduce emissions, the climate will continue to change for decades because of previous decades' emissions. Scientific research suggests that if actions could be taken to immediately stop the rise in atmospheric greenhouse gas concentrations, the inertia of the climate system is such that 0.9°F (0.5°C) or more of additional global average warming would still occur (Meehl et al., 2005, Wigley 2005, Meehl et al., 2007). As a result, no matter what emissions-reducing steps are taken, society has to focus on enhancing its capacity to cope with the unavoidable impacts that we are already experiencing and will continue to experience over the next few decades. Over the longer term, emissions reduction choices made now will determine the severity of climate change and its impacts and will affect the degree of adaptation required in the future.

A central planning question is: For what climate changes should managers and individuals prepare? Climate scientists have developed a range of potential climate change scenarios based on different assumptions about future greenhouse gas emissions and different assumptions about how the climate will respond to rising concentrations of greenhouse gases in the atmosphere. The range of projections presented in the literature has been helpful in characterizing the risks that society faces. However, the literature provides less guidance on how to interpret these projections for on-the-ground adaptation planning.

In this report, we provide an overview of climate change scenarios for California and explore how these might be used in state and regional planning efforts in the future.

1. California's Changing Climate

In recent decades, California and the western United States have experienced clear signs of a changing climate. For example, with rising winter and spring temperatures, spring snow levels in lower- and mid-elevation mountain areas have dropped, snowpack is melting one to four weeks earlier, and flowers are blooming one to two weeks earlier (Cayan et al., 2006b). Over this century, California's climate is expected to change considerably. Not only does this mean further increases in average temperatures, but also changes in rain and snow (precipitation) patterns, rising sea levels, and changes in the frequency and/or severity of extreme events such as heat waves, droughts, and fires.

Climate projections depend in large part on two factors: (1) how much and how quickly greenhouse gases are emitted into the atmosphere; and, (2) how the climate, oceans, and terrestrial systems respond to rising atmospheric concentrations of these gases. Scientists have developed a range of potential scenarios for future greenhouse gas emissions based on different assumptions about socioeconomic development. These scenarios represent the first source of uncertainty noted above. The second source of uncertainty is represented by the behavior of different climate models, which project different levels of temperature increase and different patterns of precipitation change for the same emissions scenario. Figure 1 summarizes many impacts on California that are projected for different levels of temperature increase. On the left side of the figure, arrows denote the temperature increase projected by the end of the century under three different emissions scenarios. The length of each arrow represents the range of projections in different climate models for each emissions scenario. See the Appendix for further information.

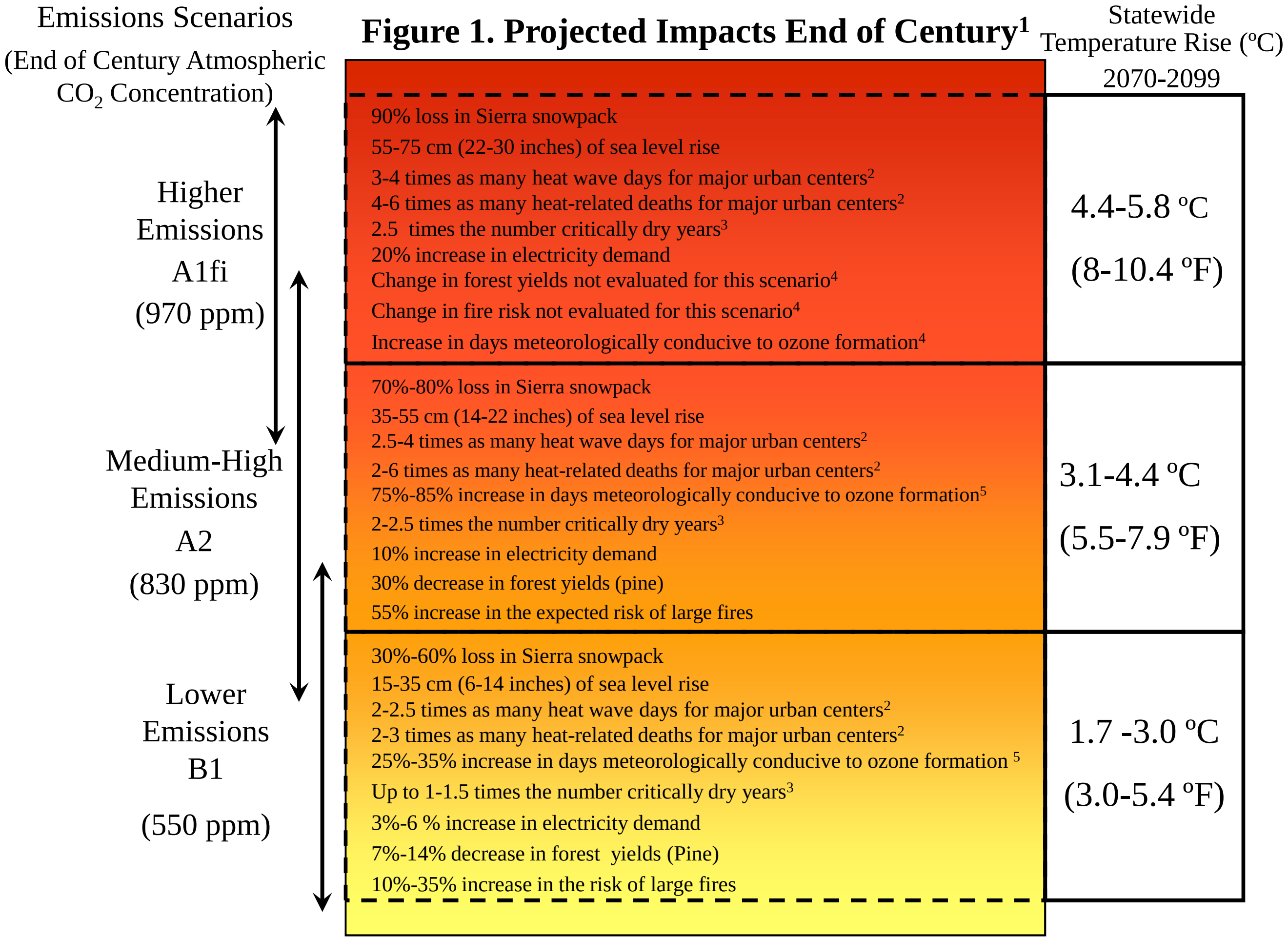

Figure 1. Projected Impacts End of Century[1]

Emissions Scenarios (End of Century Atmospheric CO$_2$ Concentration)		Statewide Temperature Rise (°C) 2070-2099
Higher Emissions A1fi (970 ppm)	90% loss in Sierra snowpack 55-75 cm (22-30 inches) of sea level rise 3-4 times as many heat wave days for major urban centers[2] 4-6 times as many heat-related deaths for major urban centers[2] 2.5 times the number critically dry years[3] 20% increase in electricity demand Change in forest yields not evaluated for this scenario[4] Change in fire risk not evaluated for this scenario[4] Increase in days meteorologically conducive to ozone formation[4]	4.4-5.8 °C (8-10.4 °F)
Medium-High Emissions A2 (830 ppm)	70%-80% loss in Sierra snowpack 35-55 cm (14-22 inches) of sea level rise 2.5-4 times as many heat wave days for major urban centers[2] 2-6 times as many heat-related deaths for major urban centers[2] 75%-85% increase in days meteorologically conducive to ozone formation[5] 2-2.5 times the number critically dry years[3] 10% increase in electricity demand 30% decrease in forest yields (pine) 55% increase in the expected risk of large fires	3.1-4.4 °C (5.5-7.9 °F)
Lower Emissions B1 (550 ppm)	30%-60% loss in Sierra snowpack 15-35 cm (6-14 inches) of sea level rise 2-2.5 times as many heat wave days for major urban centers[2] 2-3 times as many heat-related deaths for major urban centers[2] 25%-35% increase in days meteorologically conducive to ozone formation [5] Up to 1-1.5 times the number critically dry years[3] 3%-6 % increase in electricity demand 7%-14% decrease in forest yields (Pine) 10%-35% increase in the risk of large fires	1.7 -3.0 °C (3.0-5.4 °F)

[1]The projected warming ranges presented here are for 2070–2099, relative to 1971–2000. [2] Los Angeles, San Bernardino/Riverside, San Francisco, Sacramento, and Fresno. [3]Measures for the San Joaquin and Sacramento basins. [4] Impacts expected to be more severe as temperatures rise. However, the higher range of projected warming was not assessed for the project. [5] For high ozone locations in Los Angeles (Riverside) and the San Joaquin Valley (Visalia).

Figure 1. Projected Climate Impacts, Late 21st Century

Source: Adapted from California Climate Change Center, 2006.

Notes: Arrows on left correspond to temperature projections for three emissions scenarios in a range of climate models. Atmospheric concentrations (in parts per million (ppm)) for the year 2100 under each scenario are also provided.

Temperature

By mid-century, the average annual temperature of the state is projected to rise ~2 to 4° F (~1 to 2 °C),[1] regardless of the emissions scenario evaluated (Cayan et al., 2006b). Studies indicate that by the end of the century, if global greenhouse gas emissions proceed at a medium to high rate, temperatures in California are expected to rise 4.5 to 10.5°F (2.5 to 4.5°C). In contrast, a lower emissions rate would keep the projected warming to 3 to 5.6°F (1.5 to 2.7°C) (see Figure 1). The divergence of projections for higher and lower emissions scenarios by the end of the century is an indication of the long-term benefits of mitigation policy. But through mid-century, arguably a timeframe more relevant for adaptation policy, this divergence is far more modest, providing a narrower range of possible outcomes. In the discussion that follows, we focus on mid-century projections where available. Further discussion of projections for the end of the century can be found in many of the references cited here.

The rise in average annual temperature affects seasonal temperatures very differently. Spring and winter temperatures have increased more than the annual average over the second half of the 20th century, while summer temperatures have increased more slowly (Cayan et al., 2006b). In contrast, studies project that this pattern will reverse in the future, with summer temperatures rising most rapidly (Cayan et al., 2006b). Rising summer temperatures are particularly of concern in terms of impacts on agriculture, energy demand, public health, and many ecosystems. By mid-century, Northern California summer temperatures are projected to rise 3 to 6.1°F (1.7 to 3.4°C) for a higher emissions scenario, and 2 to 4.7°F (1.1 to 2.6°C) for a lower emissions scenario. Southern California summer temperatures over the same period are projected to rise by slightly less: 2.3 to 5.6°F (1.3 to 3.1°C) and 1.4 to 4.1°F (0.8 to 2.3°C), respectively. Inland temperatures are also projected to rise faster than coastal temperatures, due to the stabilizing influence of the ocean.

Precipitation

In general, projections of precipitation change exhibit far more variation across different climate models than projections of temperature increase, and the same is true in California. Precipitation is influenced by local or regional geographical variations, proximity to features such as mountains or bodies of water, and temperature differences across regions. All of these interacting influences are more difficult to include accurately in models, and precipitation often varies widely at scales below the grid-box scale of global climate models. Scientists have devised downscaling techniques to produce projections at scales finer than the model grid (see Appendix). Nevertheless, uncertainty regarding projections of precipitation remains higher than for temperature.

There is no clear trend in projections for California over this century, but the most prevalent pattern across the range of available projections is little change in overall precipitation, with a tendency toward slightly greater winter and slightly lower spring precipitation. This ensemble also includes several projections that project drier conditions in California. No model projections suggest a change in the Mediterranean seasonal pattern of precipitation California currently experiences, with most precipitation falling between November and April (Cayan et al., 2006b).

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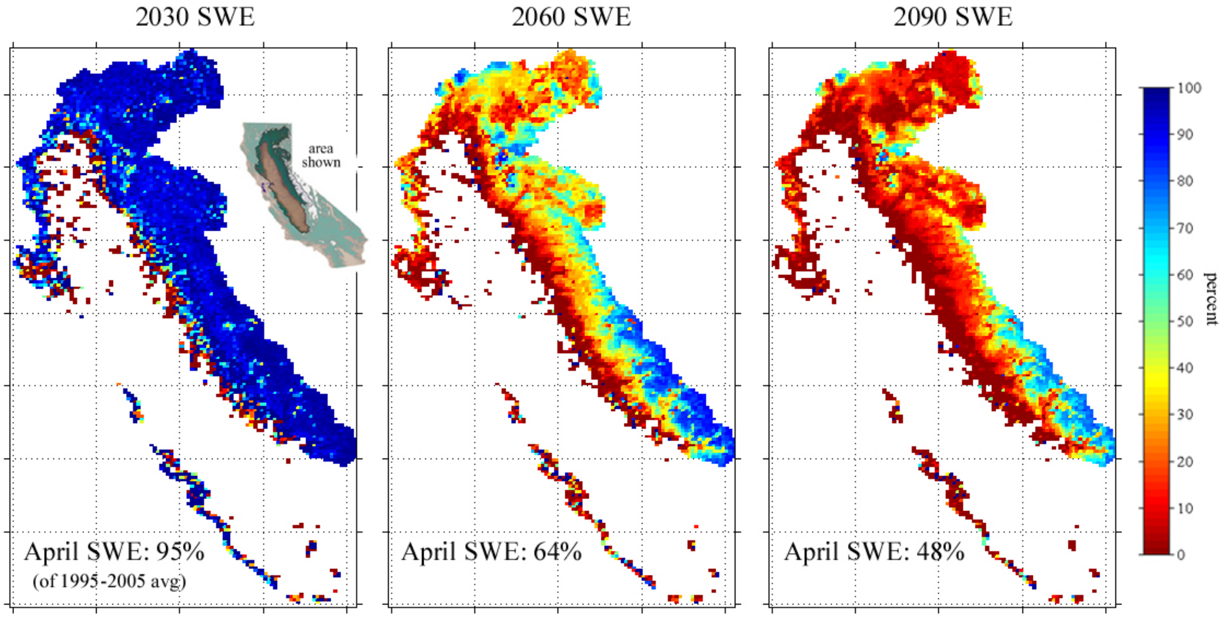
[1] These projections are relative 1961-1990 averages.

While overall precipitation changes are uncertain, warming temperatures are projected to decrease the amount of precipitation falling as snow and increase the amount falling as rain. This pattern is expected to continue to drive the already observed decrease in snow accumulation in the Sierra Nevada, and lead to earlier spring melting of snowpack. In California, the higher elevations of the Sierra Nevada are in the southern portion of the range, so these effects are expected to be largest in the central and northern parts of the state (Cayan et al., 2006b). By mid-century the amount of water stored as snow on April 1 is projected to decrease by 12 to 27 percent under a less sensitive model (less warming for a given emissions scenario; see Appendix), and 37 to 42 percent under a more sensitive model, with much larger decreases later in the century (Cayan et al., 2006b). The most significant losses are projected to be at lower elevations (< 2000 to 3000 ft). Figure 2 shows the spatial distribution of projected snowpack losses in 2030, 2060, and 2090, compared to the 1995 to 2005 average, for a less sensitive model with lower projected temperature increase than other models. This model also projects decreases in total precipitation levels.


2030 SWE

2060 SWE

2090 SWE

Figure 2. Springtime snow water equivalent (SWE) under projected temperature increases

Source: Knowles and Cayan, 2002.

Notes: Projected temperature increases: 0.6°C (2020 to 2039), 1.6°C (2050 to 2069), and 2.1°C (2080 to 2099), expressed as a percentage of average present conditions.

Sea Level Rise

Warming temperatures are contributing to global sea level rise in two ways. First, water expands when it warms, and a warming atmosphere is causing the ocean to warm as well. Second, warmer temperatures are also melting continental ice sheets and glaciers, adding water to the ocean that previously has been stored in these reservoirs of ice. In California, records suggest an observed rate of sea level rise of 3.9 to 7.9 inches (in) (10 to 20 centimeters (cm)) per century, which is similar to the global estimate (Cayan et al., 2006a). The rate of global sea level rise has accelerated in recent years (Bindoff et al., 2007), and while a similar trend has not been observed in California, projections suggest the potential for substantially greater sea level rise over this century.

The magnitude of future sea level rise is dependent on the level of future warming and remaining uncertainties in the response of the system to warming. While sea level rise due to the expansion of warming water and some components of melting ice can be reliably projected (with some uncertainty), an important component of the future rate of melting of the large ice sheets in Greenland and Antarctica cannot be satisfactorily quantified with current modeling tools—specifically, the rate of discharge of ice from these ice sheets into the surrounding oceans, which has accelerated in recent years. Without including this component, global sea level is projected to rise 9 to 20 in (23 to 51 cm) in this century for the higher emissions scenario discussed above, and 7 to 15 in (18 to 38 cm) for the lower scenario (Meehl et al., 2007). Assuming that recently observed ice discharge rates were to scale linearly with global temperature increase would add 4 to 8 in (10 to 20 cm) to the upper bounds of the projected sea level rise for this century, but whether this is a realistic assumption is uncertain (Meehl et al., 2007). Another recent analysis based on an observed linear relationship between temperature increase and the rate of sea level rise over the 20th century suggests a larger range (across emissions scenarios) of 8 to 16 in (~20 to 40 cm) by mid century and 20 to 55 in (50 to 140 cm) by the end of the century (Rahmstorf, 2007).

While these projections are uncertain, they signify that sea level rise greater than 1 m cannot be ruled out under strong warming scenarios. Furthermore, research indicates that warming over this century has the potential to destabilize the Greenland Ice Sheet, increasing the magnitude and rate of global sea level rise and eventually contributing 6.6 to 23 ft (2 to 7 m) of sea level rise, although complete melting could take many centuries. Studies suggest this process could be initiated by sustained global average warming of 3.6 to 8.1°F (2 to 4.5°C) (Meehl et al., 2007), well within the range of temperature increase expected by late in this century under high emissions scenarios, although it is unclear for how long this warming must be sustained.

Extreme Events

While changes in average temperature, precipitation, and sea level will very likely occur gradually, the frequency and intensity of extreme events such as heat waves, droughts, and floods can change substantially with even small average changes. This implies that changes in extreme events are among the most immediate climate challenges faced by California. Understanding how these events are changing is of critical importance for adaptation planning. Studies indicate the potential for an increase in the frequency of heavy precipitation events in Northern California, even if overall precipitation does not change (Cayan et al., 2006b). Rising average temperature will lead to more frequent periods of extreme heat and the potential for temperatures above the range of historical experience. For example, statewide, the number of days per year above the "climatological" (1961 to 1990) 90th percentile temperature (meaning only 10 percent of daily temperatures exceed this level) is projected to increase from a current average of around 6 weeks per year to an average of 15 to 19 weeks per year under the same higher emissions scenario, and to an average of 10 to 12 weeks per year under the lower emissions scenario (Dreschler et al., 2006). Additionally, the length of individual events is expected to increase (from a few days to as much as a few weeks). The amount by which this threshold is exceeded is expected to increase considerably, with significant implications for public health, fire risk, air quality, agricultural production, and natural ecosystems.

California is already experiencing increasing occurrence of extremes in coastal sea levels. This pattern is not consistent along the entire coast. For example, their occurrence has decreased slightly at Crescent City, but this is due to tectonic activity causing coastal uplift along parts of the northern California coast (Cayan et al., 2006a). In San Francisco, the occurrence of extremes has increased twentyfold since 1915, and in La Jolla, thirtyfold since 1933. These two latter locations are more tectonically stable. The frequency and duration of sea level extremes is expected to increase as sea level rises, with the potential to exceed coastal and San Francisco Bay-Delta flood defenses designed for historical conditions (Cayan et al., 2006a). In addition, climate change increases the potential for more intense storms, further threatening coastal and floodplain areas.

Climate change also has the potential to cause large-scale changes in the climate system that would affect California, such as shifts in the El Niño-Southern Oscillation cycle, but as yet there is no consensus regarding the effects of climate change (Meehl et al., 2007).

2. Managing Climate Risks

California's vital resources and natural landscapes are already under increasing stress due to California's rapidly growing population, which is expected to grow from 35 million today to nearly 60 million by 2050 (California Department of Finance 2007). Continued climate changes will put further pressures on these systems and have widespread consequences for California's society, economy, and environment. Of particular concern are potential impacts on California's water supply, human health, coastal, energy and natural ecosystems, which are highly sensitive to changes in temperature, sea level, and water availability (California Climate Change Center 2006, Hayhoe et al., 2004, Wilkinson 2002, CEC 1989).

Given the changes ahead, resource managers, regional planners, and government agencies will need to consider climate risks in their planning. Although Californians are well accustomed to planning under uncertainty, with floods, and wildfires all being familiar risks to the state, climate change poses a new challenge for risk management. On the scientific side, challenges include making existing projections of climate change available in a form and at a scale that decisionmakers can use, and continuing to improve the projections themselves. The *Preparing California for a Changing Climate* study as a whole is an attempt at the former. One example of the latter is the current effort to develop a regional climate model for California that can generate more detailed projections for the state and supplement the statistical downscaling methods described above. On the decisionmaking side, further work is needed to better incorporate climate information, given the uncertainties and wide range of potential impacts.

Policy makers and resource managers generally assess the risk of specific events (e.g. floods or droughts) by determining the frequency of events of specific magnitudes in the past. For example, a flood event might be determined to be a 1-in-100 year event based on the frequency of such an event in the past. This approach assumes that the past climate is an effective indicator of future conditions. But the climate is changing and will continue to change for the foreseeable future, and this approach is no longer sufficient. The uncertainty in future projections makes it impossible to generate the same frequency profiles for future conditions; climate projections cannot replace historical data within the same decision making frameworks. In other words, defining a 1-in-100 year event becomes less meaningful when we know that conditions will not be constant over the next 100 years. As a result, mainstreaming future climate risks into regional planning and resource management can no longer rely on the traditional "frequentist" probability approach of using the past to predict the future, but rather needs to develop modeling tools and methods to incorporate expert judgment (also called "Bayesian," or subjective probability). Two paths forward in achieving this goal are more formal assessment of expert opinion regarding the relative likelihoods of different pathways for future emissions and therefore climate impacts, and focusing (at least for the near-term) on strategies that build resilience to current variability and the impacts that are deemed most likely to occur regardless of future emissions.

The "explosion of uncertainties" (Schneider 2002) embedded in climate projections take three forms: (1) natural variability, (2) incomplete understanding of earth system processes (e.g., climate sensitivity—see Appendix), and (3) human actions with regard to greenhouse gas emissions. While the first two of these types of uncertainties can be reasonably quantified, it is much more problematic to quantify the uncertainty around future emissions scenarios (Dessai and Hulme 2004). As a result, to date, global emissions scenario developers have avoided quantifying the relative likelihood of different emissions scenarios. However, over time society can update understanding of what global emissions path the world is following (Raupach et al., 2007) and which scenarios are likely to reflect reality given trends in the driving forces of emissions. As a result, the uncertainty range associated with future emissions can be narrowed over time.

Guidelines for drawing useful information from the suite of climate projections will likely vary by sector, depending largely on the planning horizon for the sector and the lifetime of planning decisions. Over the near-term (10 to 30 years), an effective strategy is likely to be identifying and pursuing actions that strengthen the ability to cope with today's climate variability, while also accounting for the most likely climate impacts over that time period. As mentioned above, one of the largest near-term climate challenges California is likely to face is the potential for more intense and/or more frequent extreme events than those seen historically, since extreme events can change substantially with small average changes. Such an approach will build resilience while new information continues to come in regarding the trajectory of future climate change, reducing the probability of maladaptations—actions that actually lower the capacity to cope with future conditions when those future conditions materialize. That said, there are certain decisions that require a longer planning horizon (> 30 years) to avoid severe impacts. These include habitat protection for threatened or endangered species and infrastructure investment for new development. In these cases, considering the full range of climate projections over the next century is important.

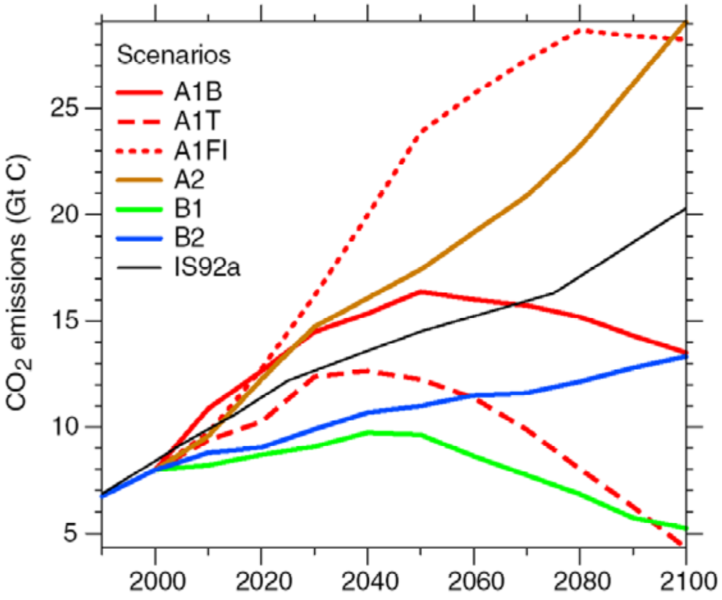
Appendix: Projecting Climate

Climate projections depend in large part on two factors: (1) how much and how quickly greenhouse gases are emitted into the atmosphere; and, (2) how the climate responds to rising atmospheric concentrations of these gases.

Emissions Scenarios

The Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (SRES) developed a set of future emissions scenarios based on different assumptions about global development paths (Nakicenovic et al., 2000). Each is presented as a possible "baseline" scenario without explicit policy intervention, although some scenarios are more likely to reflect expected "business as usual" trends than others. The range of the emissions scenarios are presented in Figure 3. These scenarios begin to diverge from historical emissions data in 1990 (and from each other in 2000). An acceleration in global emissions since 2000 has led to annual emissions in 2005 equal to or higher than the upper limit of this range of scenarios (Raupach et al., 2007). It remains to be seen whether this short-term trend will continue.

Figure 3: Range of IPCC Emissions Scenarios



CO_2 emissions for the range of IPCC emissions scenarios over the 21st century. Each scenario represents a possible baseline scenario without explicit policy intervention. The impact projections for California that are discussed in this chapter are based on the A1FI (high), A2 (medium-high), and B1 (lower) emissions scenarios.

Figure 3. Range of IPCC Emissions Scenarios

Source: Cubash et al., 2001

The highest emissions scenario (A1FI) represents a world of rapid fossil-fuel-intensive economic growth, global population that peaks mid-century then declines, and the introduction of new and more efficient technologies towards the end of the century. In this scenario, CO_2 emissions continue to climb until the end of the century, reaching ~25 Gt per year, about four times the present rate of emissions, by mid-century. By the end of the century, CO_2 concentrations would reach more than triple their pre-industrial level.

The lowest emissions scenario of the IPCC set (B1) characterizes a world with population growth similar to the highest emissions scenarios, but with rapid changes toward a service and information economy and with the introduction of clean and resource-efficient technologies. By the end of the century, this scenario has CO_2 emissions dropping below the current-day levels and CO_2 concentration doubling relative to its pre-industrial level. These two scenarios, in addition to the medium-high A2 emissions scenario, were used in the impact projections for California that are discussed in this report.

Climate Sensitivity

Climate sensitivity is a measure of the extent to which temperatures will rise as a result of increasing atmospheric concentrations of greenhouse gases. Climate sensitivity depends on how various Earth system processes respond to warming, which can lead to "feedbacks" that either amplify or dampen warming. For example, as temperatures rise, the atmosphere can hold more water vapor, which traps heat and raises temperatures further—a positive feedback. However, the clouds created by this water vapor could either enhance warming by absorbing and radiating outgoing infrared radiation from Earth's surface (another positive feedback) or dampen warming by reflecting more incoming shortwave radiation from the Sun back to space before it reaches Earth's surface (a negative feedback).

Climate sensitivity is often expressed as the long-term temperature increase associated with a doubling of CO_2 concentrations in the atmosphere. The IPCC reports a likely range for climate sensitivity of 3.6°F to 8.1°F (2°C to 4.5°C) (Meehl et al., 2007). However, recent scientific assessments conclude that, although not extremely likely, it is still possible that climate sensitivity could be greater than 4.5ºC (e.g., Stainforth et al., 2005; Hegerl et al., 2006; Meehl et al., 2007).

The Projections

Different climate models exhibit different climate sensitivities, and therefore the global temperature increase they predict differs, even for the same emissions scenario. Over the next few decades, the projected changes in temperature are roughly similar across the IPCC emission scenarios due to the inertia of the climate system (Meehl et al., 2007). But by the second half of the century, different emissions scenarios yield very different temperature projections. For the high-emissions scenario described above, models project further global average warming of 4.3 to 11.5°F (2.4 to 6.4°C) by the end of the century. For the lower-emissions scenario described above, models project further warming of 2 to 5.2°F (1.1 to 2.9°C) by the end of the century. The difference between these ranges is an indication of the influence of different trajectories for future greenhouse gas emissions on projected climate change. The ranges themselves represent uncertainties associated with the response of the climate system—the climate sensitivity, and how the uptake of carbon dioxide by the ocean and by land ecosystems will be altered by changing temperature and atmospheric greenhouse gas concentrations.

A significant fraction of current greenhouse gas emissions is taken out of the atmosphere by oceanic processes and living plants. The strength of these “sinks” is expected to decrease over time, leaving a greater fraction of emissions in the atmosphere to drive further warming. Recent research indicates that this weakening is already occurring (Canadell et al., 2007). Some studies suggest that the uptake by land ecosystems could flip to a source of additional emissions with climate change, primarily due to increased release of carbon stored in soils that would exceed the carbon taken out of the atmosphere by living plants (Denman et al., 2007).

Downscaling

Most global climate models are currently limited to representing the Earth’s surface with “grid boxes” of roughly 200 kilometers (km) (125 miles) or more on a side. Climatically important phenomena, such as clouds, occur on much smaller scales. In addition, some areas, including California, have complex landscapes that cannot be adequately represented at this coarse scale. Many model simulations of the current climate have identified biases in some regions. As discussed above, projections for precipitation, for example, are hindered by this lack of spatial detail. Scientists use a variety of tools to correct these biases and “downscale” results from global models to a regional scale. Dynamical downscaling techniques employ a regional climate model running at a finer resolution than global models. However, these exercises are computationally intensive, limiting their feasibility for long-term projections. Much of the downscaling conducted to date in California has used statistical techniques to downscale global climate model projections and correct for biases (Cayan et al., 2006b).

Statistical downscaling as applied in California links observed climate patterns with the patterns represented in global climate model simulations of the same historical period. Distributions of temperature and precipitation for each calendar month are assembled for both observed and simulated data for the period 1950 to 1999. Then, future climate model projections are downscaled using these linkages. For example, if a climate model projects that the precipitation in January of 2050 will be equal to the median value of the model-simulated historical distribution of January precipitation, then precipitation for that month will be set to the median value of the observed distribution of January precipitation (Cayan et al., 2006b).

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