SCENARIOS OF CLIMATE CHANGE IN CALIFORNIA: AN OVERVIEW

A Report From:
California Climate Change Center

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Arnold Schwarzenegger, *Governor*

February 2006
CEC-500-2005-186-SF

Acknowledgements

The authors would like to acknowledge the contributions from each one of the researchers that prepared the papers from which this overview is based. Without their valiant efforts this paper would not have been possible. We also thank Mary Tyree, of Scripps Institution of Oceanography for very rapidly and pleasantly archiving, processing, and dispensing data; and Edward Vine, with the University of California Office of the President, for managing the peer review process. Funding for the research and preparation of this report was provided by the California Environmental Protection Agency (Cal/EPA), the California Energy Commission (Energy Commission), California Air Resources Board, California Integrated Waste Management Board, and State Water Resources Control Board. In addition, Amy Luers wishes to express her appreciation for a grant received from the Robert & Patricia Switzer Foundation, which made her contribution possible.

We acknowledge the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and Climate Simulation Panel for organizing the model data analysis activity, and the IPCC WG1 TSU for technical support. The IPCC Data Archive at Lawrence Livermore National Laboratory is supported by the Office of Science, U.S. Department of Energy. In particular, we thank the NOAA Geophysical Fluids Dynamics Laboratory global modeling group, the NCAR/DOE Parallel Climate Modeling group, and the U.K. Met Office Climate Impacts LINK Project for very responsive model output and consultation

We are grateful to Chris Field, of the Carnegie Institution of Washington; Peter Frumhoff, of Union of Concerned Scientists; and Stephen Schneider from Stanford University for their review of a draft version of this paper. We thank the reviewers for their extremely valuable comments; however, we remain responsible for the content of this paper and for any errors or omissions that may have escaped our attention.

Finally, we would like to express our appreciation to California Environmental Protection Agency (Cal/EPA) and the California Energy Commission (Energy Commission) for their leadership on climate change issues; and to Eileen Tutt, Assistant Secretary for Climate Change Activities, in particular, for entrusting the research group with this study. In the California Energy Commission, we wish to express our thanks to Kelly Birkinshaw and Martha Krebs for supporting our activities and allowing one of the authors, Guido Franco, to focus most of his energy on the work that has culminated with this paper.

Preface

The 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, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

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

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5.0 Climate Change Scenarios

5.1. Emission Scenarios

The Intergovernmental Panel on Climate Change's (IPCC's) *Special Report on Emissions Scenarios* (SRES) developed a set of possible future emissions scenarios based on different assumptions about global development paths (Nakicenovic et al. 2000). This report contrasts the results from recent analyses for California of three SRES emissions scenarios—a lower emissions scenario (B1), a medium-high emissions scenario (A2), and a higher emissions scenario (A1fi) (Figure 1):

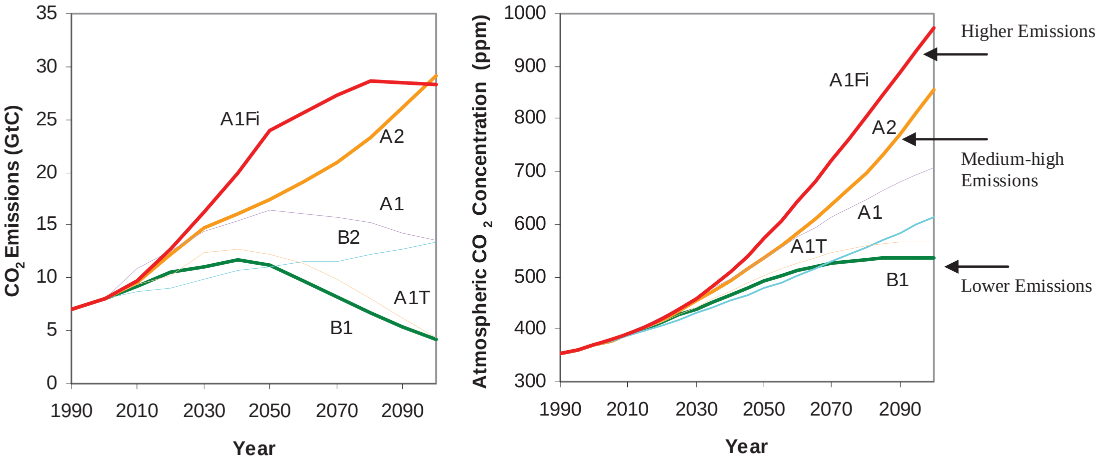

Figure 1. IPCC SRES Emission Scenarios

Six IPCC SRES Emissions Scenarios are presented here. The bold lines represent the three scenarios used in the analysis presented here (B1, A2, A1fi), the other lines represent IPCC scenarios not used in this study, yet presented here to illustrate how the trajectories selected for this study fit within the family of curves developed by the IPCC (Nakicenovic et al. 2000). The trajectories in this figure do not exactly match those in official IPCC documents (Nakicenovic et al. 2000) because the results we report here are based on revised emissions projections subsequently made available by IPCC; these are available at http://sres.ciesin.columbia.edu/. In addition, the authors used a new version of MAGICC available from www.cgd.ucar.edu/cas/wigley/magicc/index.html. However, the differences between this figure and similar figures provided by the IPCC are minor, and do not affect the discussion in this paper.

- The lower emissions scenario (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. The B1 scenario has CO_2 emissions peaking just below 10 gigatonnes per year (Gt/yr) in mid-century before dropping below the current-day level of 7 Gt/yr by 2100. Under the B1 scenario, the CO_2 concentration would double, relative to its pre-industrial level, by the end of this century.
- The medium-high emissions scenario (A2) projects continuous population growth, with slower economic growth and technological change than in the other scenarios. For the medium-high emissions scenario (A2), CO_2 emissions continue to climb throughout the century, reaching almost 30 Gt/yr, about four times the present rate of emissions. By the end of the century CO_2 concentration would reach more than triple its pre-industrial level.
- The higher 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. The higher emissions scenario (A1fi) rises faster than the A2 scenario, reaching about 25 Gt/yr, more than three times the present rate of emissions, by 2050. The A1fi scenario concludes the century with approximately the same annual emissions as the A2 scenario. However, the A2 and A1fi scenarios differ in two ways that have important implications for the projected changes. First, the emissions pathways of A1fi and A2 diverge by mid-century, with A1fi rising rapidly and then flattening out toward the end of the century. Second, the total cumulative emissions in the A1fi scenario are almost 20% higher at the end of century than in the A2 scenario.

To capture a range of uncertainty among climate models, this chapter reports on projections from three state-of-the-art global climate models (GCMs) that capture a range of climate sensitivities:

- The Parallel Climate Model (PCM1) from the National Center for Atmospheric Research (NCAR) and the U.S. Department of Energy (DOE) groups (Washington et al. 2000), a low-sensitivity model, with a climate sensitivity of approximately 1.8°C (3.2°F)[1]
- The Geophysical Fluids Dynamic Laboratory (GFDL) CM2.1 (NOAA Geophysical Dynamics Laboratory, Princeton New Jersey) model (Delworth et al. 2005), a medium-sensitivity model with climate sensitivity of approximately 3°C (5.4°F)
- The U.K. Met Office Hadley Centre Climate Model, version 3 (HadCM3) (Pope et al. 2000), with a slightly higher climate sensitivity of 3.3°C (5.9°F)

Each of the three GCMs produced a reasonably good simulation of key features of California's observed climate and representations of tropical Pacific ENSO variability.

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[1] *Climate sensitivity* is defined as the change in temperature resulting from a doubling of CO_2 concentration above pre-industrial levels.

The models were also chosen for having available simulation datasets at monthly and daily time scales in order to carry out the impact studies undertaken in the scenarios analysis.

Global climate models calculate weather, ocean, and land surface variables over a discrete global grid too coarse to adequately depict the complex structure of temperature and precipitation that characterizes the California setting. The results presented here rely principally on a statistical technique using properties of observed data (Wood et al. 2002), that was employed to correct model biases and "downscale" the model data to a finer level of detail—a grid of approximately 12 kilometers (km) (7 miles). This downscaling technique, which was employed in previous climate change assessments, was used to satisfy study requirements for impact studies, including modeling the water and energy balance. To derive land surface hydrological variables consistent with the downscaled forcing data, a macroscale, distributed, physically based hydrologic model—the variable infiltration capacity (VIC) model (Liang et al. 1994; Liang et al. 1996)—was used.

5.2. Climate Projections

5.2.1. Temperature

Temperatures in California are projected to rise significantly over the twenty-first century. As shown in Table 1 and Figure 2, magnitudes of the warming vary because of the uncertainties in the climate sensitivity, as expressed by differences between models and in the emission scenarios. The rises (2000 to 2100) vary from approximately 1.7°C–3.0°C (3.0°F–5.4°F) in the lower range of projected warming, 3.1°C–4.3°C (5.5°F–7.8°F) in the medium range, and 4.4°C–5.8°C (8.0°F–10.4°F) in the higher range (Cayan et al. 2006a). To comprehend the magnitude of these projected temperature changes, over the next century the lower range of projected temperature rise is slightly larger than the difference in annual mean temperature between Monterey and Salinas, and the upper range of project warming is greater than the temperature difference between San Francisco and San Jose, respectively.[2]

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[2] The difference in annual mean temperatures between Monterey (65.3ºF or 18.5ºC) and Salinas (67.8ºF or 19.9ºC) is 2.5ºF (1.4ºC) and the difference between San Francisco Mission Dolores (63.6ºF or 17.6ºC) and San Jose (71.0ºF or 22ºC) is 7.4ºF (4.4ºC).

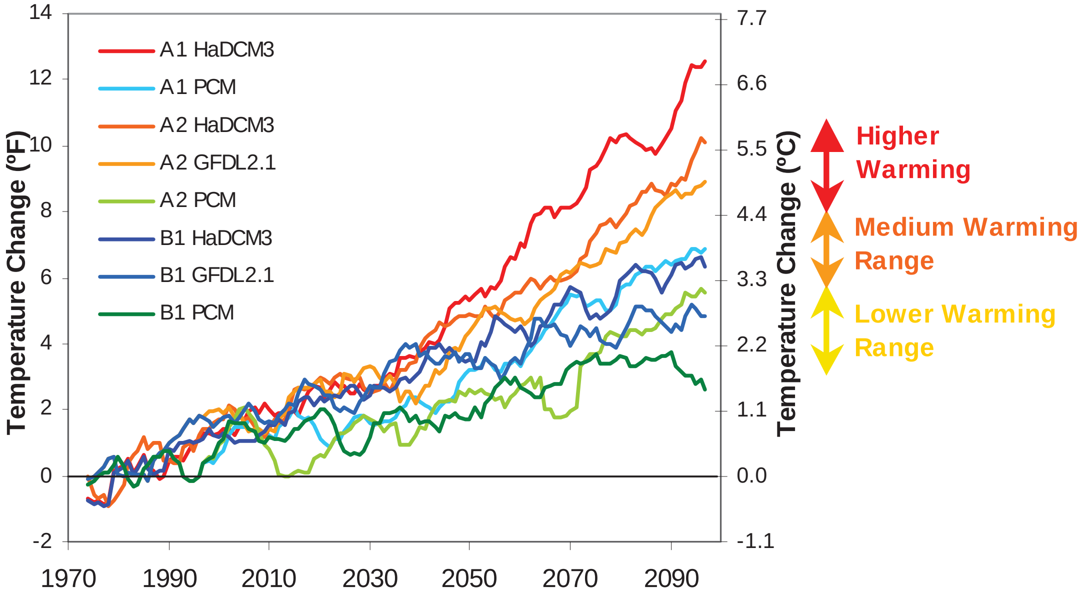


Figure 2. Change in California annual mean temperature

Change in California annual mean temperature (7-year running mean) (°F/°C) by year, from 1970–2099, relative to 1961–1990 average.

An important aspect of the model results is that all of the GHG scenario simulation, (except the low-emission scenario simulated by the low response model) exhibit higher warming in summer than in winter. In the medium-high emission (A2) scenario with the low sensitivity and medium sensitivity models, temperature increases by the end of the twenty-first century are 1.5°C–3.5°C (2.7°F–6.3°F), greater in summer than in winter (Cayan et al. 2006a). This result has important implications for impacts such as ecosystems, agriculture, water and energy demand, and the occurrence of heat waves, which have public health consequences.

5.2.2. Precipitation

There is no clear trend in precipitation projections for California over the next century. However, from the recent IPCC model projections—including several models that were not selected for the present study—there are considerable differences, from wetter to drier, between models and between emissions scenarios. The center of this distribution of simulations yields relatively little change, with a tendency for a slight decrease in precipitation, as is the case for the GFDL and the HadCM3 simulations (Cayan et al. 2006a).

Table 1. Potential warming ranges for California

	GCMs	Lower °C (°F)	Medium °C (°F)	Higher °C (°F)
Projected End of Century Range of Warming[*]		1.7°C–3°C (3.0°F–5.4°F)	3.1°C–4.4°C (5.5°F–7.8°F)	4.4°C–5.8°C (8.0°F–10.4°F)
Lower GHG Emissions B1	PCM	1.7 (3.0)		
	GFDL	2.2 (4.0)		
	HadCM3		3.1 (5.6)	
Medium-High GHG Emissions A2	PCM	2.6 (4.7)		
	GFDL		3.9 (7.0)	
	HadCM3			4.5 (8.1)
Higher GHG Emissions A1fi	PCM		3.3 (6.0)	
	HadCM3			5.8 (10.4)

[*] The temperature ranges were defined here for illustration only. The division was made simply by dividing evenly (low, medium, high) range of change in California's average annual temperatures as projected by the three GCM and emissions scenarios reported on in this summary (1.7°C–5.8°C (3.0°F–10.4°F)). The projected warming ranges presented here are for 2070–2099 relative to 1971–2000. However, some of the impacts summarized in this report used a different historical climatological baseline of 1961–1990. The difference between the 1961–1990 and 1971–2000 baselines leads to a small difference in projected temperature rise for the different scenarios and models. The difference in baselines amounts to approximately a 0.2°C (0.36°F) difference in the full range of projected end-of-century temperature rise.

There is no evidence from the projections indicating that the Mediterranean seasonal precipitation regime in California will change. All of the simulations examined here indicate that the very dominant portion of precipitation continues to be derived during winter from North Pacific storms. Summer precipitation changes only incrementally, and actually decreases in some of the simulations, so there is little evidence for a stronger monsoon influence. For the scenarios reported here, each of the model runs is characterized by large interannual to decadal fluctuations of precipitation, but not much change in annual precipitation over the 2000–2100 period. Little change in variability over the period of the model runs is evident in the simulations. The frequency of warm tropical events (El Niños) remains about the same as was exhibited in the historical simulations. As in observations, GCM El Niño events are related to anomalous precipitation patterns near the California region (Cayan et al. 2006a).

9.0 Forests and Natural Landscapes

Climate changes and increased CO_2 concentrations are expected to alter the extent and character of forests and other ecosystems (Field et al. 1999; McCarty et al. 2001; Aber et al. 2001). The distribution of species is expected to shift; the risk of climate-related disturbance such as wildfires, disease, and drought is expected to rise; and forest productivity is projected to increase or decrease—depending on species and region. In California, these ecological changes could have significant implications for both market (e.g., timber industry, fire suppression and damages costs, public health) and non-market (e.g., ecosystem services) values.

9.1. Natural Landscapes

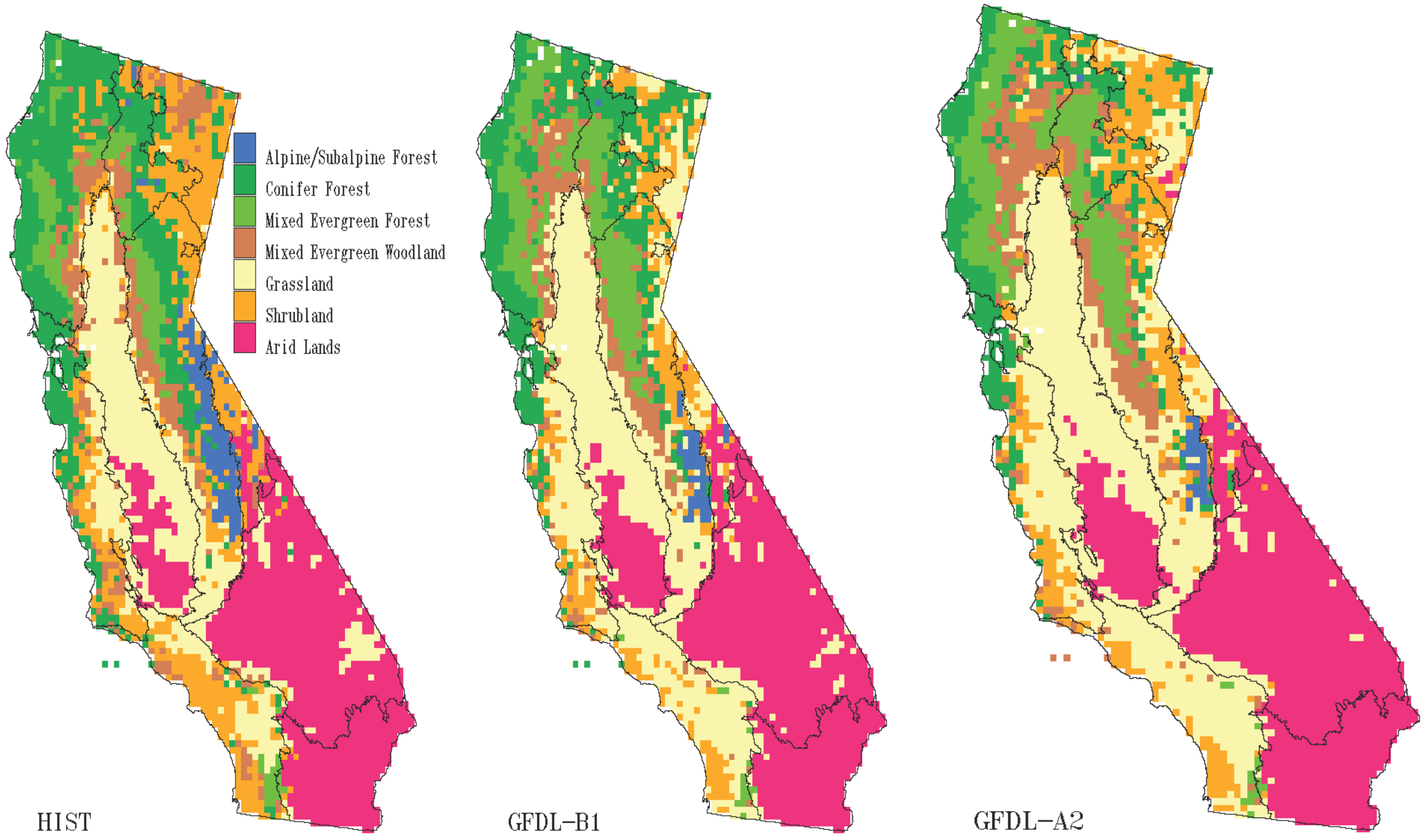
Lenihan et al. (2006) used the MC1 Dynamic Vegetation Model to simulate the response of vegetation distribution and ecosystem productivity to observed historical climate and to project the response to several scenarios of potential future climate change for California (Lenihan et al. 2006; Hayhoe et al. 2004). MC1 simulates lifeform mixtures and vegetation types; ecosystem fluxes of carbon, nitrogen, and water; and fire disturbance. The MC1 projections indicate that the ecosystems most susceptible to temperature rise are the alpine and subalpine forest cover. In addition, changes in fire frequency are expected to contribute to an increase in the expanse of grasslands, largely at the expense of woodland and shrubland ecosystems (Figure 9).

9.2. Wildfires

Fire is an important natural disturbance within many California ecosystems that promotes vegetation and wildlife diversity, releases nutrients and eliminates heavy fuel accumulations that can lead to catastrophic burns. The changing climate could alter fire regimes in ways that could have social, economic, and ecological consequences (McKenzie et al. 2004; Fried et al. 2004; Brown et al. 2004).

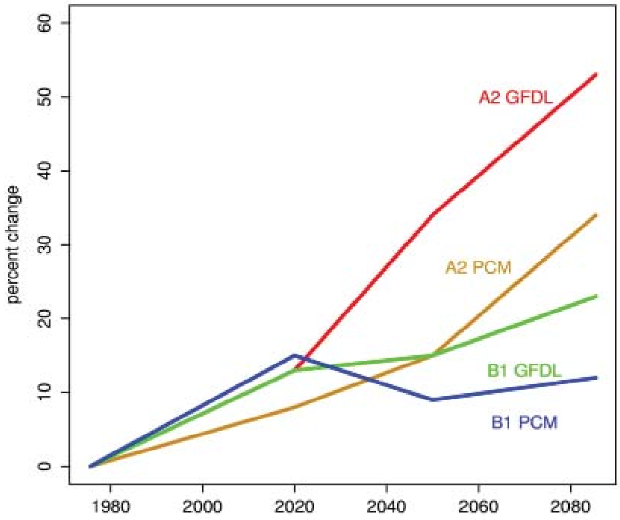
Westerling and Bryant (2006) estimated future statewide wildfire risk from a statistical model based on temperature, precipitation, and simulated hydrologic variables. These are conservative estimates because they do not include effects of extreme fire weather, but implications are nonetheless quite alarming. Projections made for the probabilities of “large fires”—defined as fires that exceed an arbitrary threshold of 200 hectares (approximately 500 acres)—indicate that the risk of large wildfires statewide would rise almost 35% by mid-century and 55% by the end of the century under a medium-high emissions scenario, almost twice that expected under lower emissions scenarios (Figure 10). Estimates of increased damage costs from the increases in fire season severity (Westerling and Bryant 2006) are on the order of 30% above current average annual damage costs.

A second study explored, through a case study in Amador and El Dorado Counties, the effects of projected climate change on fire behavior, fire suppression effort, and wildfire outcomes (Fried et al. 2006). Climate and site-specific data were used in California Department of Forestry and Fire Protection (CDF) standard models to predict wildfire behavior attributes such as rate of spread and burning intensity. The predicted wildfire



(Lenihan et al. 2006)

Figure 9. Vegetation distribution under historical conditions and multiple climate change scenarios at end of century



(Source: Westerling and Bryant 2006)

Figure 10. Percent change in the expected minimum number of large fires per year in California

outcomes were aggregated using the California Fire Economics Simulator version 2 (Fried and Gilless 1999), a stochastic computer model developed for CDF's fire protection planning program. The study found an increase in the projected area burned (10%–20%) and number of escaped fires (10%–40%) by the end of century, under the drier climate scenarios (GFDL). However, the less dry model showed little change.

Neither of these approaches for modeling the effects of climate change on wildfires considers the effects of the potential changes in wind conditions that may result from a changing climate, because the winds produced by GCMs are too coarse to be useful over most of the complex terrain in the California region. However, the strength and direction of winds can greatly influence fire behavior (Fried et al. 2004). Although initial studies suggest that future climate change may decrease early fall Santa Ana Wind conditions in some regions (Miller and Schlegel 2006), further research is needed to more thoroughly characterize potential changes in wind conditions and their possible effects on wildfires in the state.

9.3. Pests and Pathogens

Pests and disease have historically had a significant effect on California forests. The changing climate may exacerbate these effects, by expanding the range and frequency of pest outbreaks. For example, the introduced pathogen, pine pitch canker (*Fusarium subglutinans* f. sp. *pini*), once limited to coastal areas of California has expanded to the El Dorado National Forest in the Sierra Nevada. Rising winter temperature in the Sierra Nevada would make conditions more favorable for pitch canker, and could result in increased disease severity and economic loss (Battles et al. 2006).

9.4. Forest Productivity

Past studies project increases in forest productivity with continued climatic change (Mendelsohn 2003; Lenihan et al. 2003). However increasing evidence suggests that given the uncertainties concerning how trees will respond to elevated CO_2 concentrations (Körner et al. 2006), and the increased risk and susceptibility to catastrophic loss, the implications for the forest productivity and the timber industry may be less optimistic.

The recent assessment by Battles et al. (2006) of the expected impacts of climate change on the California forest sector used an industry standard planning tool to forecast 30-year tree growth and timber yields for forest stands in El Dorado County under a high and medium level of projected warming. Conifer tree growth was reduced under all climate change scenarios. In the medium level of projected warming, productivity in mature mixed-species stands was reduced by 20% by the end of the century. The reductions in yield were more severe (30%) for pine plantations.[9] Projections further indicate that the reduced growth rates could lead to substantial decreases in tree survival rates.

9.5. Potential Strategies for Reducing Impacts on Wildfire Risk and Forestry

Existing fire management strategies will be severely challenged by the interacting effects of expected changes in population and land use, and the projected changes in wildfire frequency and severity resulting from climate change. However, there are actions that can be taken in the near-term to improve our ability to live within California's fire-prone landscapes, while maintaining the functioning and structure of the ecosystems upon which we depend. For example, Moritz and Stephens (2006) suggest: (1) the adoption of a risk-based framework for fire management; (2) the reintroduction of fire to fire-prone ecosystems; (3) the creation of flexible policies that differentiate between the diverse ecosystems in California; and (4) a reevaluation of building and land use planning in the wildland-urban interface.

Battles et al. (2006) point to a number of strategies to offset declining forest yields. For example, silvicultural treatments could be designed to compensate growth losses to climate change with improvements in stand conditions. Planting mixtures of species, maintaining several age classes, reducing tree density, and pruning trees at strategic intervals are examples of cultural practices that could improve timber yields. Retaining a mixture of species and ages in the mixed conifer forests may alleviate some of the risks associated with the projected climatic changes. Single-species stands are at most risk. Spatially mixed forests limit the spread of both pathogens and insects. Decreasing tree densities reduce fuel loads and competition, and promote structures that are more resilient to catastrophic events like fire and epidemics.

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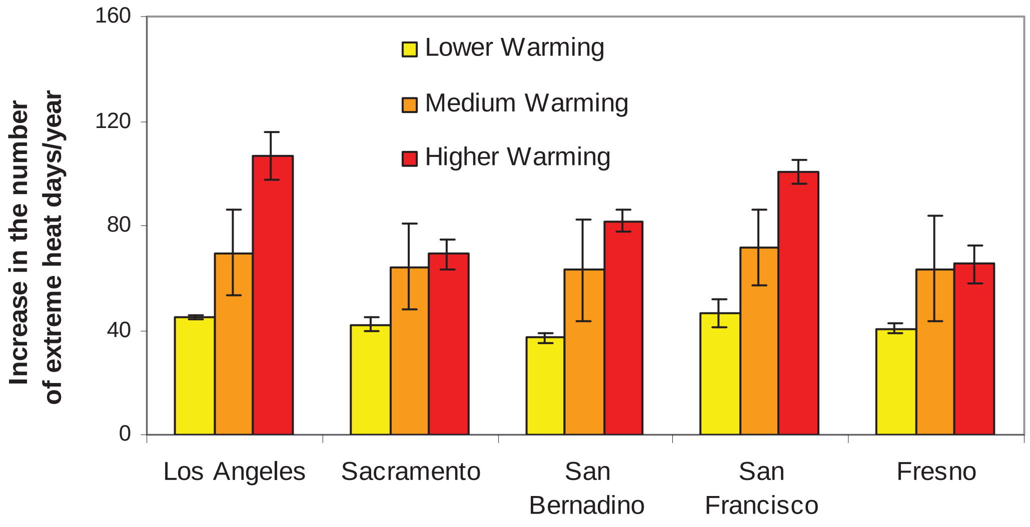
[9] The projections do not consider possible changes in vegetation distribution over the time period. However, Lenihan et al. (2006) analysis suggests that the composition for the study site considered in this study is expected to change very little over the next century.

10.0 Public Health

Climate change will affect the health of Californians by increasing the frequency, duration, and intensity of conditions conducive to air pollution formation, oppressive heat, and wildfires. The primary concern is not the change in average climate, but rather the projected increase in extreme conditions that are responsible for the most serious health consequences. In addition, climate change has the potential to influence asthma symptoms and the incidence of infectious disease.

10.1. Heat-related Deaths

Analyses of various climate change scenarios indicate that the future will have a greater number of extremely hot days and fewer extremely cold days, which may lead to two to six times as many heat-related deaths for the five cities studied (Drechsler et al. 2006). For the higher range of projected warming, the number of days over 31°C (90°F) in Los Angeles and over 35°C (95°F) in Sacramento will increase by up to 100 days by the end of the century—a striking increase over historical rates of occurrence, and almost twice the increase projected under the low-temperature path (Drechsler et al. 2006) (Figure 11).



(Source: Drechsler et al. 2006)

Figure 11. Projected increase in the number of extreme heat days relative to 1961–1990. *Extreme heat* is defined as the average temperature that is exceeded less than 10% of the days during the historical period (1961–1990), or approximately 36 days a year.

Individuals likely to be most affected include the elderly, the already ill, and the economically disadvantaged (CDC 2005a,b; Kilbourne 2002; Kaiser et al. 2001). Other identified risk factors for temperature-related health effects include social isolation, not leaving the home daily, and for heat-related death, living on the upper floors of multi-story buildings (Naughton et al. 2002). The number of deaths attributed to heat have declined over the past 30 years in the United States, primarily due to the increasing number of households with central air conditioning, which appears to be the strongest protective factor (Davis et al. 2003; Donaldson et al. 2003). Kilbourne (2002) suggested that municipal housing codes be modified to require functional air conditioners in rental housing, in addition to existing requirements for heat. The U.S. Department of Commerce expects that air conditioning will be universal in the United States by 2050 (McGheehin and Mirabelli 2001), which will increase demand for electricity for residential cooling—especially on peak demand summer days in the future. In 2100, California will need at least 10% more electricity, compared to today's total generation capacity, for air conditioning alone on peak demand summer days (Miller et al. 2005). Ongoing studies are investigating the contribution of air pollution increases to deaths attributed to heat and refining the air conditioning demand estimates.

10.2. Air Pollution-related Death and Disease

Californians experience the worst air quality in the nation, with over 90% living in areas that violate either the state ambient air quality standard for ozone or particulate matter (PM) (CARB 2005a). The annual health impacts of these standard violations include 8800 premature deaths (3000–15,000 probable range), or 4% of all death; 9500 (4600–14,000) hospitalizations and emergency room visits; 2,800,000 (2,400,000–3,200,000) lost work days; and 4,700,000 (1,200,000–8,600,000) school absence days (CARB and OEHHA 2002, 2005; CARB 2005b). An annual value of $2.2 billion ($1.5–2.8 billion) is associated with hospitalizations and the treatment of major and minor illnesses related to air pollution exposure in California (CARB 2005b). In addition, the value of premature deaths resulting from exposure to air pollution in excess of the state's PM and ozone standards is $69 billion ($34–133 billion) (CARB 2005b). Current motor vehicle and industry control programs cost about $10 billion per year.[10] Ozone (from the precursors methane and nitrogen oxides, NO_X) and PM (especially elemental carbon), and to a lesser extent carbon monoxide and volatile organic compounds (VOCs), contribute to climate change (IPCC 2001).

Two recent reports from the National Research Council of the National Academies note that higher temperatures lead to increased emissions and formation of air pollution (NRC 2001, 2004). Maximum ozone levels are about double the current air quality standards and climate change will slow progress toward attainment by increasing emissions, accelerating chemical processes, and increasing summertime stagnation episodes. Model estimates of the effect of altered climate applied to current (2005) pollutant emission patterns show that temperature alone may alter emissions. For the medium-high emissions scenario, summer-time on-road VOC emissions from motor vehicles for the 2005 baseline are estimated to increase by 4% to 5% using temperature

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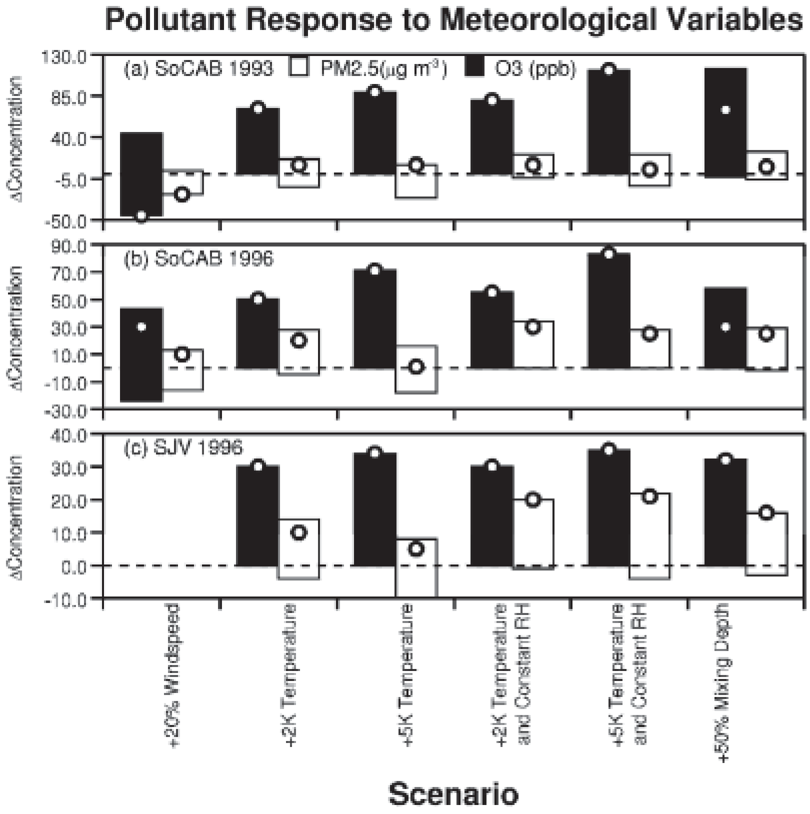
[10] The nationwide annual cost for air pollution control in 2000 was estimated to be $44 billion in 1986 dollars (USEPA 1991). Between 1986 and 2000, nationwide control costs grew about 3.85% annually. Assuming that control costs continued to grow at the same rate from 2000 to 2004, the annual control cost in 2004 is estimated to be about $53 billion in 1986 dollars. Using the Consumer Price Index (CPI), the nationwide annual cost of air pollution control is estimated to be $88 billion in 2004 dollars (the 2005 CPI is not yet available). Assuming California accounts for 12% of this expenditure (proportional to its population), the annual cost of air pollution control for California is about $10 billion.

projections for mid-century and by 13% to 16% for end-of-century temperature projections (Drechsler et al. 2006). These estimates also suggest small decreases in NO_X (Drechsler et al. 2006). Estimates for the low-emissions scenario are similar for mid-century and less than half for 2100. The medium-high emissions scenario results in a positive feedback loop for GHG emissions from on-road motor vehicles, with 4% to 5% increase in methane and 8% to 9% increases in CO_2 by 2100. These emissions estimates are strictly a test of sensitivity to temperature, as they do not take into account future changes in motorist behavior (e.g., increased air conditioning usage or increased miles driven), future growth in the number of vehicles or changes in the fleet mix, future emission controls, or possible technological advances in vehicle design. Constable et al. (1999) estimate that a doubled CO_2 atmosphere will result in a doubling of national biogenic VOC emissions. While California power plants are well controlled, higher temperatures lead to increased NO_X emissions (3% per ˚F, or 1.8% per ˚C) due to increased air conditioning usage (Drechsler et al. 2006).

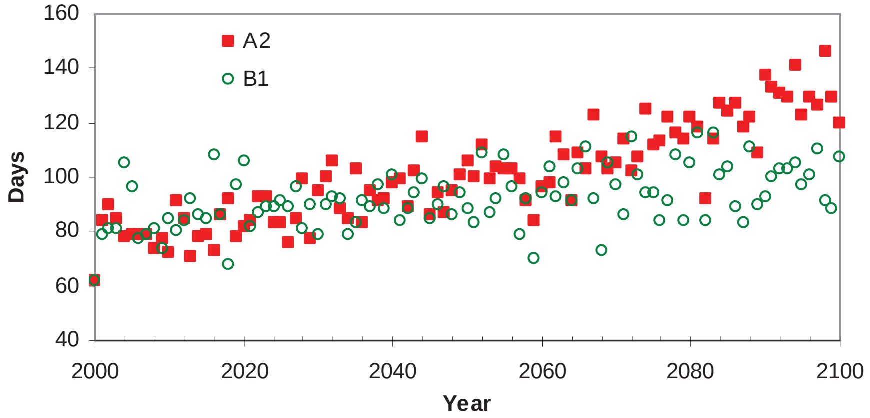
A sensitivity study of three air pollution episodes in the South Coast Air Basin and San Joaquin Valley (Kleeman and Cayan 2006) found that increased temperatures favor the formation of ozone but discourage the formation of ammonium nitrate (a major component of PM). The decrease in PM caused by increased temperatures will be offset by other factors, most notably the increase in background ozone concentrations. The IPCC (2001) estimates that global background ozone concentrations could increase to 40–80 ppb by the year 2100 (up to double the current background value), largely due to emissions outside of California. Background ozone strongly contributes to the nighttime formation of particulate nitrate through the production of N_2O_5 in the upper atmosphere during the evening hours. A preliminary study by Kleeman and Cayan (2006) suggests that if global background ozone levels double, there would be an increase in $PM_{2.5}$ concentrations in California (Figure 12), despite the corresponding increase in temperature. Increased humidity also favors the formation of ozone and ammonium nitrate. Increased wind speed reduces ozone and PM concentrations by enhancing dilution of precursor emissions. Increased mixing depth also reduces PM concentrations, but leads to an increase in surface ozone concentrations because less NO_X is available to titrate the ozone that is produced aloft and mixed to the surface. The converse would be true for lowered wind speeds and mixing heights.

Statistically downscaled climate data from two simulations of one global climate model (GFDL) using two global emissions scenarios (a medium-high (A2) and a lower (B1) scenario), indicates that the number of days meteorologically conducive to pollutant formation could rise by 75% to 85% in the high ozone areas of Los Angeles (Riverside) (Figure 13) and the San Joaquin Valley (Visalia, the high ozone area downwind of Fresno) by the end of the century under a medium-high emissions scenario, but only 25% to 35% under the lower emissions path (Kleeman and Cayan 2006). In addition, global background ozone (primarily formed from the GHG methane and NO_X from fuel combustion) is projected to increase by 4-10 ppb (low scenario) to more than 20 ppb (high scenario) at 2100 (Prather et al. 2003). If background ozone increases by the amount projected for the high scenario, the state 8-hour-average ozone air quality standard of 70 ppb would be impossible to attain in much of California, even with near-zero local emissions. The future trend for PM is not as clear, because increasing temperatures reduce some particle types while others show no change or increase slightly. Rainy days, wildfires, global dust storms, humidity, and other factors also affect PM, and are the subject of ongoing study (Kleeman and Cayan 2006).



(Source: Kleeman and Cayan 2006)

Figure 12. Summary of pollutant response to meteorological perturbations when background ozone concentrations are doubled to 60 ppb during pollution episodes that occurred in: (a) Southern California on September 9, 1993; (b) Southern California on September 25, 1996; and (c) the San Joaquin Valley on January 6, 1996. The bars represent the range of concentration change at any location in the modeling domain in response to the indicated perturbation. The circles represent the concentration change at the location of the maximum concentration for each pollutant.



(Source: Kleeman and Cayan 2006)

Figure 13. Projected days at Riverside meteorologically conducive to exceedances of the 1-hour California ambient air quality standard for ozone of 0.09 ppm.

10.2.1. Wildfires

Wildfires affect public safety and have the potential to significantly impact public health through their smoke. For example, a survey of 26% of all tribal households on the Hoopa Valley National Indian Reservation in northern California showed a 52% increase in medical visits for respiratory problems during a large fire in 1999, compared to the same period of 1998. More than 60% of those surveyed reported an increase in respiratory symptoms during the smoke episode, and 20% continued to report increased respiratory symptoms two weeks after the smoke cleared (Mott et al. 2002). The projected increases in fire season severity could lead (Westerling and Bryant 2006) to more "bad air" days. However, quantitative estimation of the impacts of future wildfire events is extremely difficult. The impacts of any fire are unique to that event, and are influenced not only by the magnitude, intensity, and duration of the fire, but also the proximity of the smoke plume to a population.

10.3. Asthma

Another concern of climate change is the effect on asthma prevalence and attacks. This impact is difficult to predict for several reasons. The most common asthma triggers are dust mites and molds, both of which are higher indoors than outdoors. Both require a relatively humid environment for survival. Consequently, if the climate becomes drier, or drought periods increase, these triggers will become less important. However, both will respond to higher humidity with increased growth, and these triggers may become more significant. Many asthmatics are allergic to various plant pollens. Plants and trees typically have pollination seasons that last a few weeks per year. To the extent that pollen seasons lengthen or become more intense in response to climate change, increased asthma exacerbation could result.

10.4. Infectious Disease

Climate change also has the potential to influence the incidence of infectious disease spread by mosquitoes, ticks, fleas, rodents, and food (Colwell and Patz 1998). More study is needed, because research to date has focused on short-term changes in weather patterns (primarily in ambient temperature and rainfall), rather than long-term changes.

10.5. Potential Strategies for Reducing Public Health Impacts

Some of the public health impacts can be reduced through adaptation measures, but costs are significant and special attention will need to be given to those most vulnerable to the health effects. For example, building climate change considerations into efforts to attain the health-based air quality standards will be necessary in the long-term if the standards are to be met. In addition, heat emergency action plans can help reduce those affected by extreme heat waves (Bernard and McGeehin 2004). Chicago and Milwaukee have developed effective heat emergency plans that could serve as models for California. In both cities, heat-related death rates were considerably lower during the 1999 heat wave, during which the action plans developed in response to the 1995 heat wave were activated (Naughton et al. 2002; Weisskopf et al. 2002). However, Bernard and McGeehin (2004) reviewed heat emergency plans from 18 cities, and found that many plans were inadequate, and that many other at-risk cities had no heat emergency action plans. These findings point to the urgency of developing heat emergency action plans for California before the need arises, and the inclusion of objective criteria for assessing the effectiveness of the plans.