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Overview of the California climate change scenarios project

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Abstract In response to an Executive Order by California Governor Schwarzenegger, an evaluation of the implications to California of possible climate changes was undertaken using a scenario-based approach. The "Scenarios Project" investigated projected impacts of climate change on six sectors in the California region. The investigation considered the early, middle and later portions of the twenty-first century, guided by a set of IPCC Fourth Assessment global climate model runs forced by higher and lower greenhouse gas emission scenarios. Each of these climate simulations produce substantial impacts in California that would require adaptations from present practices or status. The most severe impacts could be avoided, however, if emissions can be held near the lower end of global greenhouse gas emissions scenarios.

It is increasingly apparent that the rising atmospheric concentration of greenhouse gases (GHGs), resulting from human activities, is changing the climate in ways that pose serious risks to California's health, economy, and environment. Furthermore, the more GHGs accumulate in the Earth's atmosphere, the more the climate is likely to change and the greater the risks that Earth's system processes and society will face (IPCC 2007). If actions are not taken soon, substantial impacts are likely to happen sooner and grow to larger magnitudes.

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Recently a number of U.S. local and regional efforts have begun to join the international community to address the increasing risks of climate change and have set policies to reduce GHG emissions. Amongst these actions, California has begun to consider the need to manage climate change through a combination of mitigation and adaptation strategies.

California has been a leader in both supporting research on the science of climate change as well as in identifying solutions for reducing GHG emissions. In 2002, the California Legislature passed the first law to regulate GHG emissions from passenger vehicles. In the following year, the state established the California Climate Change Center, which is one of the first and perhaps the only state-sponsored research institution in the nation dedicated to regional climate change research. On June 1, 2005, Governor Arnold Schwarzenegger signed Executive Order S-3-05, which called for specific emission reductions and a periodic update on the state of climate change science and the emerging understanding of potential impacts on climate-sensitive sectors including the state's water supply, public health, agriculture, coastal areas, and forestry. In response to this Executive Order, the California Energy Commission (Energy Commission) and the California Environmental Protection Agency (Cal/EPA) commissioned an assessment of the potential impacts of climate change on key state resources ("the Scenarios Project"). This special issue presents the results of the Scenarios Project.

The Scenarios Project was conceived in early summer 2005 out of discussions among State administrators and scientists from various California Universities, federal and state agencies, and non-governmental organizations. The project was directed by a team of state government staff and non-governmental scientists, including those from the California Climate Change Center (the "Center"), an effort engaged to study long-term climate issues in California. The political, scientific and organizational landscape that led up to this effort is described in this volume by Franco et al. The Scenarios Project builds upon previous efforts to assess potential climate change impacts in California (e.g., Field et al. 1999; Barnett et al. 2004; Hayhoe et al. 2004). Explicitly, it extends the work of Hayhoe et al. 2004, which compared the projected impact of climate change in California under differing emissions scenarios. The Scenarios Project drew upon experts within and outside of the Center to produce a collection of reports on the projected impacts of climate change under multiple scenarios across six different sectors: coasts, water resources, agriculture, public health, forestry, and electricity production and demand. These reports are posted electronically on a State of California web page: http://www.climatechange.ca.gov/climate_action_team/reports/index.html. The articles in this special issue are based upon these reports.

The climate projections for the Scenarios Project are from three global climate models (PCM, GFDL, HadCM3) for three greenhouse gas emissions scenarios – a lower emissions (SRES B1), a medium-high emissions (SRES A2), and a higher emissions scenario (SRES A1fi). As described by Cayan et al. (in this issue), these projections contain increases in temperature that range from about +2°C to about +6°C by the end of the century, but contain relatively little change in precipitation. Statistical techniques were used to downscale these climate projections to incorporate in sector-specific assessments. These global climate models and emission scenarios bracket the potential climate outcomes expected from the full range of models and scenarios available from the IPCC. And as noted by Bonfils et al. (in this issue), the observed regional warming over the twentieth century during winters and springs in California lies on the outside edge of trends that could be attributed to estimated natural variability, and, therefore, the findings suggest that the warming over the twentieth century is associated with human-induced changes.

Sea level rise due to climate change is a priority concern for California which has one of the longest coasts in North America. Cayan et al. (in this issue) show that projected sea level rise increases in proportion to the amount of global warming and that the problems created by sea level rise are greatly aggravated by higher frequency sea level phenomena.

Concerning California's water resources, hydrologic model calculations (Cayan et al., in this issue) indicate that by the end of this century, spring snowpack could decrease by at least 32%. Lower snowpack levels translate in more critically dry years defined here as the amount of unimpaired runoff from April to July (the relative dry season in California). This results in a reduced ability of the major water reservoirs to deliver water to agricultural users. However, at the end, the implications for water resources depend largely on what happens to precipitation and management. Medellín-Azuara et al. (in this issue) examine economically operational changes and adaptations for California's water supply system for a dry form of climate warming with year 2050 water demands and land use, and they describe the economical mix of adaptation, technologies, policies and operational changes needed to keep water supply impacts to modest levels. Anderson et al. (in this issue) present an analysis of historical data for trends related to climate change (snowpack, runoff, operations of water projects, water quality and water levels, and evapotranspiration), and preliminary results from modeling studies of projected climate change conditions. They demonstrate the first steps in incorporating climate change into the planning and management process for the State Water Project and the federal Central Valley Project, and they also provide directions on moving towards probability/risk assessment. Finally, Purkey et al. (in this issue) use an integrated hydrology/water resource systems tool to investigate climate change impact and adaptations in the water sector and demonstrate how water management adaptation in the water resources sector has the potential to mitigate the impacts of climate change (particularly in the agricultural sector).

Electricity generation in hydroelectric facilities represents a major source of energy in California. Currently, hydropower generation contributes about 15% of California's in-state electricity productions. As expected, the two studies addressing this issue (Medellín-Azuara et al. and Anderson et al., in this issue) report reductions in hydropower generation for relatively low elevation units that are associated with relatively large reservoirs that partially offset the trend to an early melting of the snow. Medium and high elevation units mostly rely on the snowpack to store water to produce electricity. Vicuña et al. (in this issue) performed an initial study for the high elevation units operated by the Sacramento Municipal Utility District. The main conclusion of this study is that electricity generation would be reduced in response to lower precipitation levels but the existing reservoirs system would be able to compensate for earlier runoff from climate warming by storing enough water to allow generation of electricity in the hot summer months when it is most needed. Franco and Sanstad et al. (in this issue) demonstrate that annual and peak electricity demands would increase with increasing warming driven mostly by demand for air conditioning.

In regards to agriculture, Baldocchi et al. (in this issue) show a decrease of chill-hours in the last 50 years with a continuation of this trend to the end of this century. This represents a serious threat to the future viability of many species of fruit trees in the state. Gutierrez et al. (in this issue) suggest that climate change most likely alter the abundance and types of many pests. Pink bollworm, a common pest of cotton crops, is currently a problem only in southern dessert valleys because it cannot survive winter frosts elsewhere in the state. However, if winter temperatures rise, the pink bollworm's range would expand northward affecting important cotton growing regions in the Central Valley.

Ecosystems, especially forests and natural landscapes, one of California's most precious resources, could undergo substantial changes in extent and character. Several papers in this Special Issue study the impact of climate change on these resources and wildfires. Battles et al. (in this issue) estimated 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. Lenihan et al. (in this issue) used the MC1 Dynamic Vegetation Model to simulate the response of vegetation distribution and ecosystem productivity to observed historical climate and to project responses to the climate scenarios described above. 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. Westerling et al. (in this issue) investigate the forest fire issue further focusing on "large fires" defined as fires that exceed 500 acres. Their calculations indicate that the risk of large wildfires statewide could rise almost 35% by mid-century and 55% by the end of this century under a medium-high emission scenarios. Fried et al. (in this issue) demonstrate that subtle shifts in fire behavior induced by climate change are of sufficient magnitude to generate an appreciable increase in fires, and they conclude that relatively modest increases in firefighting resources might be sufficient to compensate for the impact of climate change on wildland fire outcomes. Finally, Moritz et al. (in this issue) evaluate the policy, planning and management changes that should be made, regardless of the many uncertainties in predicting future fire regimes, and they offer recommendations as "no regrets" actions that will be beneficial, regardless of what climate changes do actually occur.

Air quality and public health is a key concern associated with the prospect of increasing temperatures. Using an air quality model to evaluate possible climate change influences on key air quality measures in California air basins, Kleeman (in this issue) finds that global changes in temperature and humidity will lead to increased ozone concentrations and possible rises in PM2.5 concentrations in California. Similarly, Motallebi et al. (in this issue) evaluate the response of the current California on-road mobile source fleet to possible future temperature changes, and they find that emissions of reactive organic gases, carbon monoxide, methane, and carbon dioxide are expected to increase for all of the scenarios.

This Scenarios Project does not provide *forecasts*, but rather explores a range of *possible futures* of climate for the state. However, a key generalization from these assessments can be made: the magnitude of impacts increases with the magnitude of global warming, and some severe impacts that are expected with greater temperature rises can likely be avoided if the rate of increase of GHG concentrations is reduced. To help frame the choices California and the world face, in this assessment the projected impacts across sectors were grouped into three warming ranges – a lower warming range (3 to 5.4°F), a medium warming range (5.5 to 7.9°F), and a higher warming range (8 to 10.4°F). These warming ranges were defined, for illustrative purposes only, by dividing the total projected temperature rise evenly into three ranges. Future updates to the Scenarios Project will consider attaching probabilities to different climate scenarios, probably under the assumption that there will be no further climate policy intervention, even though it seems quite possible that climate change mitigation will become a priority (Schneider 2002).

If the world follows the higher emissions (A1fi) scenario California can expect substantial impacts on its economy, ecosystems, and the health of its citizens. On the other hand, if global emissions follow the lower emissions (B1) scenario, temperatures would likely not rise above the lower warming range and many of the most severe impacts could be avoided. However, if the actual climate sensitivity to GHGs reaches the level of the more sensitive global climate models employed here, an even lower emissions path than the B1 scenario may be required to avoid the medium and higher warming range.

How much would GHG emissions have to be reduced to stay at or below the lower emissions pathway (B1) and ensure against temperatures rising to the medium and higher warming ranges presented in this study? The California Governor's Executive Order S-3-05 calls for an 80% reduction in GHG emissions below 1990 levels by 2050. If the industrialized world were to follow California's lead, and assuming the industrializing nations followed the B1 pathway, global emissions might remain below the lower emissions scenario (B1), increasing the likelihood of avoiding the more severe impacts by preventing temperatures from rising to the medium warming range. This estimate of the impact of an 80% reduction by the industrialized world has on global emissions depends crucially on the development patterns of the developing world. The SRES B1 scenario assumes development proceeds with a "high level of environmental and social consciousness" with a transition to "alternative energy systems" (Nakic′enovic′ et al. 2000). Emission reductions targets such as the one set by the Governor's Executive Order could spur the innovation necessary to lead the world to a transition to alternative energy systems.

However, even if global emissions stay below the lower emissions scenario (B1), some impacts from climate change are inevitable. Evidence indicates that even if actions could be taken to immediately curtail GHG emissions, the potency of GHGs that have already built up, their long atmospheric lifetimes, and the inertia of the Earth's climate system could result in average global temperatures rising an additional 0.6°C (1.1°F) (Wigley 2005; Meehl et al. 2005). As a result, some impacts from climate change, in California and across the globe, are now unavoidable. Consequently, adaptation is an essential complementary strategy to manage some of the projected impacts of climate change.

As explained by Moser and Luers (in this issue), there are many opportunities for California to increase its capacity to cope with the projected changes. However, these can be costly and require time and planning. Furthermore, there are critical limits to adaptation, especially in addressing the threats of abrupt climate changes or in dealing with those impacts on natural, unmanaged species and ecosystems, which may not be able to keep up with the increasingly rapid and severe climate changes expected if emissions go unabated. In addition, managing the impacts of climate change may be particularly challenging when different kinds of changes are experienced together. For example, how would California manage in years where it was subjected simultaneously to an extreme heat wave, an energy blackout, and widespread wildfires, during an extended drought? While at present we are unable to quantify the probability and all of the consequences of such an event, in preparing for change we must consider the potential compounding effects of multiple impacts.

Finally, the ability to cope and adapt is differentiated across populations, economic sectors, and regions within the state (Moser and Luers (in this issue)). As a result, without appropriate mitigating actions, climate change will likely aggravate existing equity issues within California and the rest of the United States. The most vulnerable populations to the health impacts of climate change appear to be children, elderly people, and the poor – the same groups that already face the greatest health and environmental risks.

An important part of developing and implementing effective mitigative and adaptative strategies for managing climate change will likely be a continuous communication between the scientific and the policy communities. The Scenarios Project, as described by Franco et al. (in this issue), is an outgrowth of such a dialogue that has developed over the last few years in California. The papers in this special issue of Climatic Change begin to characterize the range of impacts that might be expected in California from the changing climate. While none of these papers are policy prescriptive, they are all policy relevant, as they were framed to both highlight the role of mitigation in minimizing climate risks and to begin to define the needs for adaptation. The dialogue between scientists, managers and policy makers in California is still just beginning but the science and the relationships developed as part of this Scenarios Project has been an important step in further opening theses lines of communication.

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