Regional Assessment of Climate Impacts on California under Alternative Emissions Pathways – Key Findings and Implications for Stabilisation

Katharine Hayhoe

ATMOS Research & Consulting
809 West Colfax Avenue
South Bend, Indiana 46601 USA
Tel: (574) 288-1507
Fax: (419) 715-6765
Email: hayhoe@atmosresearch.com

Christopher Field

Department of Global Ecology
Carnegie Institution of Washington
260 Panama Street
Stanford, California 94305 USA

Peter Frumhoff

Union of Concerned Scientists
Two Brattle Square
Cambridge, Massachusetts 02238 USA

Stephen Schneider

Department of Biological Sciences and Institute for International Studies
Stanford University
Stanford, California 94305 USA

Amy Luers

Union of Concerned Scientists
2397 Shattuck Ave
Berkeley, California 94704 USA

Key words: regional climate impact assessments, emission pathways

Regional Assessment of Climate Impacts on California under Alternative Emissions Pathways – Key Findings and Implications for Stabilisation

Regional estimates of climate change impacts and their relationship to temperature and other indicators of change provide essential input to decisions regarding "acceptable" levels of global mean temperature change, long-term stabilisation levels, and emissions pathways. Here, we present an assessment of regional impacts for California based on projections by two climate models (HadCM3 and PCM) for the SRES higher and lower emissions scenarios (A1fi and B1). Temperature increases under the higher scenario are nearly double those of the lower scenario by 2100, with proportional impacts on human health, ecosystems, water resources, and agriculture. Further analyses of this type for other sectors and world regions will increase confidence in and understanding of potential impacts under given scenarios. For this reason, our experience and lessons learned during the analysis are summarised here to encourage application to other regions and sectors.

1. Introduction

Evaluating the potential impacts of climate change at the local to regional scale is essential to assessment of regional vulnerabilities. Comparing potential impacts under alternative scenarios of future greenhouse gas concentrations provides a means of quantifying the degree to which several alternative emission pathways could mitigate impacts.

Based on a comprehensive analysis of projected impacts for California under the SRES A1fi (higher) and B1 (lower) emission scenarios [1,2], we argue that the magnitude of future climate change depends substantially upon the greenhouse gas emission pathways we choose. Although not directly linked to climate policy-based stabilisation levels, the scenarios examined bracket a large part of the range of IPCC non-intervention emissions futures with atmospheric concentrations of CO_2 reaching 550 ppm (B1) and 970 ppm (A1fi) by 2100.

The majority of impacts seen under the A1fi scenario are substantially greater than those under the B1 scenario, suggesting that climate change and many of its impacts scale with the quantity and timing of greenhouse gas emissions. However, even under the lower B1 scenario, many ecological, water, agricultural and health-related impacts may exceed socially or politically acceptable thresholds. The UNFCCC requires its more than 190 signatories to stabilise greenhouse gas concentrations at levels that will prevent "dangerous anthropogenic interference with the climate system," [3] suggesting that some of the results reported in [2] or here for California might well be interpreted by decisionmakers and stakeholders as requiring a response under the UNFCCC. In addition, the enormous uncertainties in impacts and the potential for severe risk in several key areas (e.g., wild fire, El Niño-driven winter storms) is sufficiently large so as to compound the societal challenge of specifying a level of change that should be avoided. Whether to postpone decisions in favour of waiting for further research findings or to implement precautionary steps via policy decisions is the value choice faced by decisionmakers aware of the potentially large impacts of climate change such as those presented here.

Disaggregation of impacts by sector allows for a broad picture of the degree to which increases in temperature and other indicators of climate change may affect California and other world regions. Here, we first summarise the projected impacts for California under a higher vs. a lower emissions scenario as first presented by [2]. We then discuss the rationale behind our analysis, identify key scientific, methodological and resource-related issues to consider, and present an overview of the process in hope that our experiences will prove useful to others. Finally, we examine the implications of our findings for evaluating a given temperature or stabilisation target aimed at preventing long-term and serious impacts at the regional and global level.

2. Key Climate Change Impacts on California

California is one of the largest economies in the world, and is characterized by its diverse range of climate zones, limited water supply, and substantial economic dependence on climate-sensitive industries such as agriculture. As such, it provides a challenging test case to evaluate impacts of regional-scale climate change under alternative emissions pathways. Using two state-of-the-art climate models (HadCM3 and PCM), the higher and lower SRES emissions scenarios (A1fi and B1), and two well-documented statistical downscaling methods [4,5], the potential impact of climate change on temperature-sensitive sectors in California was evaluated, with initial results presented in [2]. This is the first study to use projections from multiple climate models and the full range of SRES scenarios to examine climate change impacts at the regional level. For this reason, we not only summarise the main findings of this study (this section) but also present a brief summary of the lessons learned during this experience in support of future assessments (next section).

Annual temperature increases over California nearly double from the lower B1 to the higher A1fi emission scenario by 2100. Heat waves and associated impacts on a range of temperature-sensitive sectors are substantially greater under the higher scenario, with some inter-scenario differences apparent by mid-century. Downscaled monthly mean temperature projections show consistent spatial patterns across California, with lesser warming along the southwest coast and increasing warming to the north and northeast. Statewide, the range in projected average temperature increases is higher than previously reported [6,7], particularly for summer temperature increases which equal or exceed increases in winter temperatures in all cases. The extent to which these results are model-dependent will be better understood as more such analyses are conducted around the world using a variety of models and for a large number of sectors and regions.

For many of California's urban areas, the duration, intensity and number of heat wave events is projected to increase linearly with average summer temperatures, particularly in inland areas. By 2070-2099, extreme heat waves that occurred once or twice per decade during the historical period are projected to make up one quarter to one half of annual heat waves for inland cities such as Sacramento, Fresno, and the inland suburbs of Los Angeles under B1 and one half to three quarters of the heat waves experienced each year under A1fi [8]. Under these scenarios, heat-related mortality is also projected to increase, with the largest increases in acclimatized morality rates (100% to 1000%) expected for coastal cities such as San Francisco and Los Angeles that are relatively unaccustomed to extreme heat.

Rising temperatures over California, exacerbated in most cases by decreasing winter precipitation, produce substantial reductions in snowpack in the Sierra Nevada Mountains, with cascading impacts on California streamflow, water storage and supply. Under even the lowest emissions scenario, snowpack is projected to decrease 25-40% before mid-century and 30-70% before 2100, with peak runoff shifting 1-3 weeks earlier. Under the higher scenario, snowpack decreases before 2100 are on the order of 70-90%. The response of snowpack to temperature varies by elevation, with lower levels being more sensitive to local temperature changes on the order of 2.5^{o}C or less (displaying a logarithmic relationship between temperature increases and snowpack amount) while snowpack at higher elevations decreases most sharply for temperature changes greater than 2.5^{o}C (exponential). In addition to snowpack losses, the proportion of years projected to be dry or critical increases from 32% in the historical period to 50-64% by the end of the century. Under both scenarios, these changes have the potential to disrupt the current highly-regulated California water system by reducing the value of rights to mid- and late-season natural streamflow while boosting the value of rights to stored water.

The combination of decreased water availability and rising temperatures also threatens some of California's $30 billion agricultural industry. Perennial crops such as oranges, grapes and other fruit may be more vulnerable to climate change because there are few options for short-term adaptation, and long-term adaptation such as switching to new cultivars or shifting the location of orchards is expensive. Citrus is sensitive to high temperatures during particular growth phases, and high temperatures can also affect wine grape quality. According to both PCM and HadCM3 projections, Central Valley regions may already experience impaired grape quality before mid-century, while California's major grape-growing regions with the sole exception of the Cool Coastal areas are projected to be either marginal or impaired before 2100 under both the lower B1 and higher A1fi scenario. Response to temperature increases varies by region, with the quality of grape-growing regions currently at the lower end of the temperature range improving before declining, while other regions (Napa, Sonoma and the Central Valley) display a logarithmic dependency and thus higher sensitivity to smaller-scale temperature changes on the order of 2^{o}C or less. Once more, this suggests that a B1-like scenario may be insufficient to prevent some serious repercussions on California's agricultural industry, though it is less severe than for A1fi and does not consider of the effects of CO_2 fertilization.

The distribution of California's diverse vegetation types is also projected to change substantially. Reductions in the extent of alpine/subalpine forest and the displacement of evergreen conifer forest by mixed evergreen forest are driven primarily by temperature, becoming pronounced under A1fi by the end of the century. Other vegetation more sensitive to precipitation and fire frequency (grass, shrubland) do not exhibit consistent inter-scenario differences. There is a clear link between climate and fire in California, where fires occur during the dry summer season and area burned is generally higher following a wet El Niño winter [9]. Little projected change in summer rainfall coupled with warmer temperatures, an expanding population, and increasing human settlement in previously wild areas make it likely that the economic costs and damages due to wildfire will increase in the future. Numerous factors interact to determine the net effect of climate on fire – climate change may cause fire hazard conditions to increase in one area but decrease in another, while changes in the number of rare but extreme fires that cause the most damage [10] could be different again. Hence, it is not possible to quantify the response of fire risk to temperature increases over California although based on the above reasoning we believe it is likely that fire risk will increase.

Finally, California is also highly vulnerable to El Niño events, as demonstrated by the severe winter storms and floods that have devastated the California coast in recent years. During El Niño events, some of the most significant increases in heavy rainfall events have been observed, as well as several of the largest floods on record [11]. Several studies have found that storm characteristics have been changing over the last century, creating a greater flood risk during the last half of the 21st century and particularly during the 1990s [12,13]. It is uncertain whether these trends are likely to continue, although some observational evidence suggests that the shift may be linked to increasing global temperatures [14,15]. However, it is clear that severe winter storms combined with long-term sea level rise due to climate change would expose the coast to severe flooding and erosion, damage to coastal structures and real estate, and salinity intrusion into vulnerable coastal aquifers.

Overall, extreme heat and related impacts on a range of temperature-sensitive sectors were found to be substantially greater under the higher emissions scenario, with some inter-scenario differences apparent by mid-century. Inter-scenario differences for other sectors more sensitive to non-temperature-related drivers were not as distinct, obscuring the response of these sectors to a given temperature or CO_2 stabilisation target.

3. Key Considerations for Regional Assessments

Regional assessments of potential climate change impacts provide critical information for deliberations on CO_2 stabilisation and temperature targets with the goal of preventing "dangerous anthropogenic interference" with the climate system. However, producing a consistent, comprehensive impact assessment that captures the dynamic relationships between climate, human population, economics, natural resources, and ecosystems in a specific region is a challenging task. Confidence in understanding climate impacts would be improved through greater participation in sector-specific regional assessments from other experts and world regions. As we hope our experiences will prove useful to others, this section reviews the key scientific, methodological, resource, and communication-related issues that were considered in designing the aforementioned assessment and our further work in California. Scientific issues taken into account included the following:

- Consideration of multiple and consistent socioeconomic futures in order to accurately capture the possible range of future projections
- Use of multiple, reasonably credible and tested climate models with varying regional responses to climate change to look for robust conclusions despite model dependence
- Resolution of appropriate spatial and temporal scales of climate forcings and change that captured regional to local-scale influences on climate
- Consistent representation of the uncertainty involved in socioeconomic and climate change projections, in a manner that was easily understood and assimilated into estimates of impacts and their relationship to temperature or other indices of change
- Recognition of the multiple nature, interactions, and need for consistency between drivers of change, including climate, socio-economic development, human decisions, and policy
- Inclusion of the principal connections between multiple scales and sectors which together determine the net response of a region to future climate change

Resources were also identified that were crucial to the success of this assessment. Most significant was the relevant scientific expertise – here taking the form of a multi-disciplinary team of nineteen scientists, most based in California. Areas of expertise included climate modelling and downscaling; regional hydrology and extremes; ecology and agriculture; dynamic vegetation modeling; the economics of water management, supply and demand; and human health and welfare and the social dimensions of climate change. The team leader's first task was to ensure uniformity of underlying assumptions by providing team members with the latest socio-economic projections and climate simulations in the format required for analysis in each sector. The benefits of a integrated team with regional expertise was key to the conduct of the project, allowing a credible search for robust analyses based on previously-evaluated methodologies to be re-applied to a consistent and identical set of socio-economic assumptions and resulting climate projections. Other resources essential to a thorough regional assessment include up-to-date climate model projections for a range of socio-economic and stabilisation scenarios, downscaling methods, region-specific impact models, and adequate computer facilities. Although the question of both physical and intellectual resources often pose a challenge for scientists from developing nations (see discussion in [16]), a number of these resources already exist and are freely available[1].

[1] Monthly output from 7 AOGCMs for the SRES mid-range scenarios is available on the IPCC-DDC website (ipcc-ddc.cru.uea.ac.uk). The latest IPCC AR4 Working Group 1 simulations from 5 AOGCMs (including stabilisation scenarios, fixed percentage CO_2 increases, and various SRES scenarios) in addition to a large library of PCM and CCSM simulations are available on the Earth System Grid portal (www.earthsystemgrid.org).

In terms of methodological issues and communication, [17] recommends that regional assessments should not be merely a collection of independently-conducted studies or a means for scientists to inform regional specialists and stakeholders. Rather, the purpose may be better served through an iterative learning process whereby an interdisciplinary team of scientists engages decision-makers and stakeholders in multi-lateral discussions of human response to future change, the limits of adaptation, and the need for mitigation.

There are many scientific as well as societal advantages to engaging those whose welfare and livelihoods are threatened by climate change. Decision-making at the local to state level based on the latest information has a greater likelihood of preparing for possible impacts, thereby increasing the potential for successful adaptation and/or mitigation. Such communication requires awareness of the needs and cultures of different stakeholders, decision-makers, and the media as dissemination of results does not always occur via the standard formats with which most scientists are familiar. In California, outreach efforts based on these findings have resulted in significant dialogues being generated between the author team, representatives of non-profit organizations, and key stakeholder groups including state legislatures, private industry, labor unions, and public utilities. Roundtable discussions allowed stakeholders to ask scientists questions about climate change, and scientists to explore values and perspectives on related issues. These dialogues have helped shape further research plans on more targeted questions about potential impacts and adaptive capacity of specific sectors and populations, as well as creating opportunities for a large body of informed California scientists and stakeholders to speak to the implications of climate change for their region.

These scientific and methodological considerations highlight the philosophical underpinnings of the California analysis in order to make our underlying assumptions transparent to others pursing the same course. The greater the number of replicates and similar evaluations, the higher our collective ability to assess the robustness of the projected impacts on both a regional and global level for a given emissions pathway or stabilisation target.

4. Relationship to GHG Stabilisation Levels and Temperature Change

Estimates of the relationship between impacts and temperature or other such drivers provide crucial decision-making information to identify “acceptable” levels of global mean temperature change, long-term stabilisation levels, and preceding emissions pathways. The U.K. and the European Union have endorsed targets limiting CO_2 stabilisation target to 550ppm or below or global mean temperature change to 2^oC, respectively [18,19]. It is not yet clear whether these targets are sufficient to prevent “dangerous anthropogenic interference”. Indeed, Mastrandrea & Schneider [20] estimate a 20% risk of exceeding dangerous thresholds of change (as represented by IPCC Working Group 2) for a 2^oC warming, a risk that increases steadily with temperature. The SRES B1 scenario reaches (although does not yet stabilise at) 550 ppmv by 2100. As such, it may serve as a useful proxy to evaluate potential impacts on California under the targets assumed above.

The risk of significant impacts is already relatively high under the B1 scenario. Regional temperature changes of $2\text{-}3.5^oC$ may already represent unacceptable stress on water supply (through reduction of Sierra snow pack and shifts in peak streamflow to earlier in the year) and human health (in terms of heat-related mortality), as well as on some perennial cash crops in certain regions currently at their upper temperature limits. These impacts intensify for larger increases in temperature, with near-complete loss of Sierra Nevada snow pack (70-97%) and severely impaired grape growing conditions for all but the cool coastal regions for a local warming of $5\text{-}6^oC$. If future analyses for other regions bear out these findings, consideration of emission pathways leading to a stabilisation level lower than 550ppm target may be warranted.

It is also essential to note that many impacts are moderated or even controlled by climate influences other than temperature (e.g., precipitation, cloudiness, or humidity), socio-economic development, and human decisions, with climate change acting as an exacerbating factor, not necessarily the primary driver. For California, for example, ecosystem and vegetation shifts, coastal impacts from sea level rise and El Niño-driven winter storms, wildfire extent and damages, and the net impact of climate change on the water supply system are not primarily driven by temperature. Precipitation and changes in atmospheric circulation patterns, socio-economic change, human choices and behaviour all play roles of equal or greater importance. Hence, it is difficult to determine with high confidence how the vulnerability of these systems would scale with temperature and hence resolve emission targets for impacts whose relationship to temperature is only part of the story. Instead, a multi-dimensional threshold incorporating several key drivers (e.g., temperature, precipitation, population, settlement patterns, water demand) would be more suitable than temperature as simultaneous changes in multiple factors could push a system over the limits of acceptable change, whereas changes in temperature alone may not.

5. Conclusions

Assessing the potential impacts of climate change on the local to regional-scale level is essential to identifying the vulnerabilities these systems may display under future change. Through considering a range of potential socio-economic futures and climate projections, estimates of the response of key sectors to a given level of change can be obtained. Value judgments regarding the tolerability of these impacts can then be made, enabling the establishment, evaluation and revision of emission targets aimed at avoiding unacceptable levels of change. Through a recent study for California, the degree to which key sectors' vulnerabilities and their relationship to temperature change can be quantified was estimated. Large and consistent increases in temperature and extreme heat were seen to drive significant impacts on temperature-sensitive sectors under both lower and higher emissions scenarios, with the most severe impacts occurring under the higher A1fi scenario. These findings support the conclusion that climate change and many of its impacts scale with the quantity and timing of emissions. As such, they represent a point of departure for assessing the outcome of changes in emission trajectories driven by climate-specific policies, and the extent to which lower emissions can reduce the likelihood and thus risks of "dangerous anthropogenic interference with the climate system" as the UNFCCC requires.

References

[1] Nakićenović, N. et al. 2000. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, UK

[2] Hayhoe, K., D. Cayan, C. Field, P. Frumhoff, E. Maurer, N. Miller, S. Moser, S. Schneider, K. Nicholas Cahill, E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. Kalkstein, J. Lenihan, C. Lunch, R. Neilson, S. Sheridan & J. Verville. 2004. Emission Scenarios, Climate Change and Impacts on California. Proc. Natl. Ac. Sci., 101, 12422-12427.

[3] United Nations (1990) United Nations Framework Convention on Climate Change.

[4] Wood, A., E. Maurer, A. Kumar & D. Lettenmaier 2002. Long-range experimental hydrologic forecasting for the eastern United States, J. Geophys. Res., 107, art. no. 4429.

[5] Dettinger, M., Cayan, D., Meyer, M. & A. Jeton. 2004. Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American River basins, Sierra Nevada, California, 1900-2099. Clim. Change 62:283-317.

[6] Wilkinson, R., Clarke, K., Goodchild, M., Reichman, J., & Dozier, J. 2002. The Potential Consequences of Climate Variability and Change for California: The California Regional Assessment, United States GCRP.

[7] Wilson, T., L. Williams, J. Smith & R. Medelsohn. 2003. Global Climate Change and California: Potential Implications for Ecosystems, Health, and the Economy. Prepared for California Energy Commission by Electric Power Research Institute. Available at http://www.energy.ca.gov/pier/reports/500-03-058cf.html

[8] Hayhoe, K., Kalkstein, L., Moser, S. & Miller, N. 2004. Rising Heat and Risks to Human Health: Technical Appendix. A report of the Union of Concerned Scientists, available online at: www.climatechoices.org

[9] Westerling, A.L. and T.W. Swetnam. 2003. Interannual to Decadal Drought and Wildfire in the Western United States. EOS, 84, 545, 554-555.

[10] Fried, J.S., M.S. Torn & E. Mills. 2004. The impact of climate change on wildfire severity: A regional forecast for Northern California. Climatic Change, 64, 169-191.

[11] Cayan, D., T. Barnett & L. Riddle. 1997. The 1997-1998 El Nino – Increased potential for winter storms, flooding and coastal impacts in California. Available online at: meteora.ucsd.edu/elnino/ENSO.html

[12] Westerling, A. 2001. Climate variability and large storm surge on the Pacific coast of the United States. Presented at the 81st Annual Meeting of the American Meteorological Society, January, 2001.

[13] Bromirski, P.D., R.E. Flick & D.R. Cayan. 2003. Storminess Variability along the California Coast. J. Clim. 16, 982-993.

[14] Trenberth, K. & T. Hoar. 1997. El Nino and climate change. Geophys. Res. Lett., 24 (23): 3057-3060.

[15] Tsonis, A., A. Hunt & J. Elsner. 2003. On the relation between ENSO and global climate change, Met. & Atmos. Phys., 84, 229-242.

[16] Jones, P., J. Amador, M. Campos, K. Hayhoe, M. Marin, J. Romero & A. Fischlin, 2004. Generating climate change scenarios at high resolution for impact studies and adaptation: Focus on developing countries, Proceedings of the International Workshop on Adaptation to Climate Change, Sustainable Livelihoods and Biological Diversity, in press.

[17] Cash, D. & S. Moser. 2000. Linking global and local scales: designing dynamic assessment and management processes. Global Env. Change, 10, 109-120.

[18] DEFRA. 2003. The Energy White Paper. Available online at: www.dti.gov.uk/energy/whitepaper/index.shtml

[19] European Environment Agency. 2004. Impacts of Europe's Changing Climate. Available online at: reports.eea.eu.int/climate_report_2_2004/en

[20] Mastrandrea, M and S, Schneider, 2001. Integrated Assessment of Abrupt Climatic Changes, Clim. Policy 1, 433-449.