Draft CEC PIER-EA Discussion Paper

Public Health Impacts from Climate Change

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Disclaimer

The purpose of this paper is to inform discussions among CEC staff, other state agency staff, non-governmental representatives, representatives of academia and other stakeholders regarding the state of the research on public health impacts of climate change in California. In particular, this discussion paper will identify gaps in our understanding and recommendations for future research initiatives with the end goal of supporting informed and systematic planning for climate change. Note that this discussion paper is not a research proposal and does not include recommendations regarding specific research projects.

1.0 Description of Research Topic

According to the Intergovernmental Panel on Climate Change (IPCC), global warming impacts are likely to result in increased deaths, disease and injury due to heat waves, floods, storms, fires and droughts, increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone related to climate change, and altered spatial distribution of some infectious disease vectors, among other impacts (IPCC, 2007). Climate change will have major impacts on public health in California. Although Assembly Bill 32 (AB 32) stipulates immediate reduction in greenhouse gases, California will experience human health consequences of global warming before such reductions can take effect. The public health effects of climate change in California have been extensively reviewed recently for the CEC (DEHS, 2005). This paper will focus on current gaps in research initiatives.

2.0 Summary of PIER Program Research and Accomplishments to Date

El Nino Events

Investigators examined existing trends in weather and health during both normal weather and El Niño events in three geographical regions in California: Sacramento/Yolo, San Francisco/San Mateo, and Los Angeles/Orange County (Ebi and Kelsh, 2003). They found that the weather-health associations varied by geographic region. For viral pneumonia, hospitalizations in the San Francisco and Los Angeles areas increased significantly (30%-50%) with a decrease in minimum temperature. Sacramento area hospitalizations increased significantly (25%-40%) with a decrease in maximum temperature difference. In the Sacramento area, El Niño events were associated with viral pneumonia hospitalizations, showing significant decreases for girls and increases for women. These weather-health associations were independent of season.

For cardiovascular diseases and stroke, weather variables had the strongest effect on hospitalizations in San Francisco. Changes in both maximum and minimum temperature were associated with significant increases in hospitalizations for all types of cardiovascular disease for men and women 70 years of age and older. These increases were most pronounced in men with angina and women with acute myocardial infarction (MI). Men and women aged 55 to 69 years had increased hospitalizations for congestive heart failure. The hospitalization patterns in Sacramento were generally similar to those in San Francisco, but with weaker associations. Decreasing maximum and increasing minimum temperatures affected hospitalizations in a number of age-disease categories. In general, the health effects of temperature variables were weakest in the Los Angeles area, with fewer weather-health associations observed.

El Niño events were significantly associated with cardiovascular disease hospitalizations for both men and women in the San Francisco area. In Sacramento, El Niño events increased hospitalizations for acute MI and angina, notably in women. In Los Angeles, El Niño events had little health impact.

In short, a single temperature variable failed to explain all of the associations among viral pneumonia, cardiovascular disease, and stroke hospitalizations, and specific weather factors varied across the geographic regions. The study findings underscore the complexities of the association between climate and health effects, suggesting that a model based on either the inland region or one of the coastal regions would not be predictive of the other regions in California.

The investigation was designed to generate rather than test hypotheses about associations between weather and human health. The consistency of results across disease categories suggests some common mechanism for physiological responses to changes in weather. Data were not available to understand differences in age groups with respect to behaviors, exposures, and other factors that influence health. An improved understanding of the mechanisms underlying these relationships is needed to assess possible public health interventions.

Temperature and Mortality/Morbidity

To date, temperature and mortality studies have been conducted in nine California counties (Basu et al., 2008; Basu and Ostro, 2008). The nine California counties that were analyzed include: Contra Costa, Fresno, Kern, Los Angeles, Orange, Riverside, Sacramento, San Diego, and Santa Clara, and encompass approximately 65% of the State's population. Data were obtained from the National Climatic Data Center (NCDC)—temperature and relative humidity; the California Department of Health Services (CDHS)—mortality; and the California Air Resources Board (ARB)—particulate matter, ozone, carbon monoxide, and nitrogen dioxide. By examining apparent temperature, the effects of temperature and humidity were both considered. Daily data were limited to the warm season from May 1 to September 30, 1999 to 2003 to focus on heat effects. Modern statistical methods, including time-series analysis and time-stratified case-crossover analysis were used, while adjusting for day of the week effects in both analyses. County-specific estimates were obtained followed by an estimate for all counties in the analysis using the random effects model in meta-analyses.

In the first epidemiologic study of temperature and mortality, the primary goal was to establish methods to examine the association independent from air pollution. A total of 248,019 deaths were included. Same-day lag was found to have the strongest fit to the data and also the highest risk estimates. Each 10 degree Fahrenheit increase in same-day mean apparent temperature corresponded to a 2.3% increase in mortality (95% confidence interval (CI): 1.0–3.6%) in the case-crossover analysis for all 9 counties combined, with nearly identical results produced from the time-series analysis. No air pollutant examined was found to be a significant confounder or effect modifier. Thus, even without extremes in apparent temperature, we observed an association between temperature and mortality in California that was independent of air pollution.

In a second study examining temperature and mortality, the primary goal was to identify vulnerable subgroups in California (Basu and Ostro, 2008). A total of 231,676 non-accidental deaths were included to evaluate several disease categories and subgroups, including cardiovascular, respiratory, cerebrovascular, and diabetes. Other variables that were considered included race/ethnicity, age, gender, and education level. Each 10 degree Fahrenheit increase in mean daily apparent temperature corresponded to a 2.6% (95% CI: 1.3–3.9%) increase for cardiovascular mortality, with the most significant risk found for ischemic heart disease. Elevated risks were also found for persons at least 65 years of age (2.2%; 95% CI: 0.04–4.0%), infants one year of age and under (4.9%; 95% CI: −1.8–11.6%), and Black racial/ethnic group (4.9%; 95% CI: 2.0–7.9%). No differences were found by gender or education level. Thus, this study suggests that measures to prevent mortality associated with ambient temperature should be targeted primarily at persons with cardiovascular disease, the elderly, infants, and Blacks racial/ethnic groups.

Following the California heat wave in July 2006, county coroners reported that high ambient temperatures caused 142 deaths. However, heat-wave deaths are likely to be underreported due to a lack of a clear case definition and the multi-factorial nature of mortality. It is useful to provide a comparison of the mortality impact per degree during heat waves versus normal high temperatures outside of heat waves. Daily data were collected for mortality, relative humidity, ambient temperature and ozone pollution in seven California counties known to be impacted by the July 2006 heat wave. The combined meta-analytic results suggested a 9% (95% CI: 1.6–16.3%) increase in daily mortality per 10 degree Fahrenheit change in apparent temperature. This estimate is almost 3 times larger than the effect estimated for the full warm season, and 2 or 3 times greater than coroner estimates.

The studies summarized provide a quantification of heat-related effects in California using epidemiologic methods. The first studies described methodology and vulnerable subgroups of the temperature-mortality association, while another study analyzed the effect of temperature and mortality during the 2006 heat wave.

3.0 Non-PIER Accomplishments in this Area and Opportunities for Collaboration

Temperature and Mortality/Morbidity

Previous studies of heat waves and elevated temperature have been summarized in a review paper (Basu and Samet, 2002a). Since then, several epidemiologic studies of ambient temperature and mortality have been published throughout the world. Many investigators reported an elevated association after establishing a cut-off point for temperature, or temperature and humidity (Hajat et al., 2005; Hales et al., 2000). Investigators using data from 50 U.S. cities also reported elevated cardiovascular risks, specifically cardiac arrest and myocardial infraction, from exposure to cold or hot extreme ambient temperatures (Medina-Ramon, 2006). Other investigators found mortality from coronary heart disease, cerebrovascular, and especially, respiratory diseases to be associated with ambient temperature (Revich et al., 2008). Apart from a few recent epidemiologic studies (Basu et al., 2005; Filleul et al., 2006; Hales et al., 2000; O'Neill et al., 2005), air pollutants have not been considered as confounders and/or as effect modifiers of the temperature-mortality association, and the results of these studies varied by region and provided conflicting results.

In a study examining the effects of the 2006 California heat wave on morbidity, Knowlton et al. (2008) aggregated county-level hospitalizations and emergency department (ED) visits for all causes and for ten cause groups into six geographic regions of California. Excess morbidity and rate ratios (RRs) during the heat wave (July 15–August 1, 2006) were calculated and compared to a referent period (July 8–14 and August 12–22, 2006). During the heat wave, 16,166 excess ED visits and 1,182 excess hospitalizations occurred statewide. ED visits for heat-related causes increased across the state (RR 6.30; 95% CI: 5.67–7.01), especially in the Central Coast, which includes San Francisco. The study documented that the 2006 California heat wave had a substantial effect on morbidity, including regions with relatively modest absolute temperatures, and suggested that population acclimatization and adaptive capacity influenced risk.

California Department of Public Health staff (Margolis et al., 2008), in collaboration with scientists from Scripps Institution of Oceanography, have initiated a statewide integrated assessment of the historical and changing spatial and temporal patterns of diseases/health outcomes as they relate to climate and specific meteorological conditions, with a focus on identification of underlying community and population vulnerabilities. The project will focus first on temperature and humidity-related health impacts. The goal of the project is to reduce, or prepare for, the additional burden of disease associated with a changing climate. In California, the climatological and meteorological changes, and the associated health risks will not be distributed uniformly across the State. For California's public health officials (including State and local governments, the medical community, and local service agencies) to provide guidance on prevention of climate-change related excess morbidity and mortality, and to adequately respond during weather-related emergencies, a better understanding of what to expect is needed—both with respect to the climatological and meteorological changes, and with respect to the health impacts of those changes. Temporal patterns in health risks—such as those that occur year-to-year or season-to-season—and spatial patterns—such as differences in region-to-region, community-to-community, or census-tract-to-census tract patterns—may exist or change over time for a variety of reasons (often interconnected) that need to be defined. For example, there may be changes in underlying population characteristics, land-use patterns (e.g., development, housing density, irrigation, and agricultural uses), as well as day-to-day weather or longer-term shifts in climate. Thus, the project includes a component dedicated to the translation of the scientific results into public health adaptive strategies and risk mitigation actions.

4.0 Research Underway/Committed to via PIER Process

In an on-going study, temperature and hospitalizations from various causes are being evaluated using the same nine counties as the mortality analyses. The study population will consist of 597,735 individuals who were admitted to a hospital with selected diagnoses and lived within 10 kilometers of a temperature monitor. Heat-related diseases, such as heat stroke and dehydration, as well as ischemic heart disease, respiratory disease, and intestinal infectious disease will be evaluated, in addition to all respiratory and cardiovascular hospitalizations. Furthermore, these health endpoints will be evaluated by age, gender, and race/ethnicity. ED visits (available since 2005) will also be investigated to address morbidity associated with ambient temperature in California. Further study will also be conducted on vulnerable subgroups, particularly infants and young children, who have been identified as being at higher risk of mortality and morbidity from heat exposure.

5.0 Gaps in Research/Knowledge Relevant to California

Heat Waves and Morbidity/Mortality

Several important research questions remain regarding the relationship between temperature, heat waves, and human morbidity and mortality in California. Although some estimates of excess morbidity and mortality have been calculated, these estimates need to be elucidated by age, gender, race/ethnicity, geographic region and socio-economic status. Among vulnerable populations, such as the elderly and children, further research needs to be preformed to identify other factors in these subgroups (e.g., co-morbidities) which make them particularly at risk. Further, no research has been conducted analyzing the characteristics of air masses (humidity, stagnation, when they occur, length, etc.) in relation to morbidity and mortality. Little information is available to the National Weather Service from public health research to inform the best measure of heat warning (e.g., heat index) that can be used that is most predictive of morbidity and mortality. Recommendations need to be developed on what characteristics are the most effective heat-warning systems in the U.S. and abroad, and how to develop such systems in California.

With regard to mortality studies, the effect of harvesting—the phenomena that some deaths would have occurred regardless of temperature exposure—has not been fully explained.

Modeling/Scenario Analysis

More modeling studies are needed to better characterize the temperature and mortality/morbidity associations in California. In previous research, temperature has been described as having a linear relationship with mortality or morbidity in the warm season, or as having a threshold effect (i.e., having a linear association after establishing a specific temperature cut-off value). To readily compare across epidemiologic studies, a consistent modeling strategy should be employed. The effects that are observed during general ambient temperature exposure may not convey the actual risk for the higher end of the dose-response curve, as might be observed during a heat wave or other extreme event. Alternatively, scenario analysis or the expected effect estimate and corresponding number of deaths from actual heat waves that have occurred could be used. In scenario analysis, various projections are obtained based on climate and population changes. Thus, the temperature-mortality/morbidity associations need to be further investigated across all temperature exposure levels, while focusing on the higher end of exposure, since it may have the greatest public health impact, and is more likely to occur in the future.

Surveillance

Monitoring of key environmental and health indicators that reflect trends in the effects of climate change on human health is essential to prevent illness and help predict the magnitude of future effects and mitigation strategies. The Council of State and Territorial Epidemiologists have convened a State Environmental Health Indicators Subgroup on Climate Change, which has been charged with developing these measures. Such indicators will need validation and testing, and appropriate resources for wide implementation.

Air Quality and Disease

Levels of ground-level ozone and particulate matter are expected to increase due to global warming in California. There is a need for disease modeling under different global warming scenarios to predict the excess number of cases of respiratory illness, such as asthma and bronchitis (such as Knowlton et al., 2004), along with an analysis of the economic burden of such increases in terms of excess hospitalizations, ED and patient visits, and increased medication usage. Ecologic shifts predicted to occur due to global warming would result in increased pollens and ragweed in California. Detailed analyses are needed to quantify the increased disease burden due to allergies and specify where in the state we would see concentrations of this illness. The Natural Resources Defense Council recently conducted an analysis which estimated that 110 million Americans live in areas with both ragweed and ozone problems (Knowlton et al., 2007).

Wildfires

Climate change has been linked to an increased risk of wildfires in California, and wildfires themselves contribute tons of greenhouse gas emissions to the atmosphere. Projected warmer springs and summers, resulting in earlier snowmelt, coupled with projected reductions in precipitation and snowpack, will result in longer fire seasons in Western U.S. forests (Westerling et al., 2006).

The massive wildfires that occurred in Southern California in the fall of 2006 affected approximately 20 million people living in Los Angeles, San Diego, and surrounding areas. Large increases in respiratory emergency room visits were noted in local public health surveillance during and after these wildfire events (SDADIC, 2007). Future research should examine the types of health conditions and priority interventions of sensitive populations during wildfire events, such as those with pre-existing respiratory or cardiovascular disease, smokers, elderly, and children. There is also a need for more refined exposure assessment methodologies of wildfire smoke, including rapid deployment of inexpensive portable passive particle monitors and better analytic use of satellite imagery. More research is needed in developing recommendations for vulnerable populations in fire prone areas, such as use of anti-inflammatory medications at first sign of symptoms among chronic obstructive pulmonary disease (COPD) and asthma sufferers, and increased coverage of pneumonia and flu vaccinations among the elderly. Several states including Oregon, Montana, and Idaho, use a Wildfire Air Quality Index to alert populations of health impacts of wildfires. Analysis and recommendations are needed as to whether development of a similar system in California could better target health messages to vulnerable populations to save lives.

Extreme Events (e.g., flooding, droughts, sea-level rise)

California is currently in a drought, after the driest spring on record. Extreme variability in rainfall patterns, and more rapid spring snow melt are predicted in California, which makes the risk of flooding and repeated drought-flooding cycles more likely. Heavy rainfall after a long drought has been associated with waterborne disease outbreaks—such as *cryptosporidiosis*, *giardiasis*, and *cyclosporidiosis*—while droughts after heavy rainfalls can affect population dynamics of animal reservoirs of human disease (as described further below). Droughts also reduce water quality, and subsequent flooding can cause sewer overflows and microbial contamination (Tibbets, 2007). In addition, the IPCC and the 2006 California Climate Action Team Report have projected that mean sea level will rise between 100 and 900 millimeters (12 and 36 inches) by the year 2100; reducing 100 year surge-induced flood events to once in every 10 years. Research priorities in this area include: regional analysis of drinking water system vulnerability to contamination, especially in areas that are in flood plains, along the coast, and near potential levee breaks; analysis of which populations in California would be most vulnerable to water-borne disease outbreaks (e.g. elderly, immunosuppressed populations) and sea-level rise; analysis of capacities of local and state public health departments for rapid surveillance and response during water contamination events, similar to the Milwaukee 1993 cryptosporidiosis outbreak; and analysis/future scenario modeling of impacts on drinking water quality of continued droughts and reduced snow pack melt.

Vector-Borne Disease

Similar to increased water-borne disease risk following flooding after a drought, the same weather conditions can affect rodent, tick, and mosquito populations. In California, three vector-borne diseases of concern that climate change may impact are human Hantavirus Cardiopulmonary Syndrome (HCPS), Lyme disease, and West Nile virus.

The Deer Mouse, *Peromyscus maniculatus*, is the main small rodent reservoir for Hantavirus, and is ubiquitous throughout California in undeveloped areas. During heavy precipitation periods, food supplies increase, resulting in rodent population growth. It has been hypothesized that the 1992–1993 El Niño weather patterns were associated with an outbreak of HCPS in the southwestern United States (Engelthaler et al., 1999), though this suggestion remains under discussion by Hantavirus researchers (Boone et al., 2002). Although HCPS infections have remained rare in California, more common flooding or heavy precipitation cycles could increase infected deer mice populations.

Lyme disease is the most common vector-borne disease in the United States today. The number of cases has been increasing nationwide, but the majority of cases occur in the northeast United States. In California, the adult or sub-adult (nymph) western black-legged tick transmits the Lyme disease agent, Borrelia burgdorferi, to humans, and risk of acquiring Lyme disease is highly correlated with exposure to *Ixodes pacificus* nymph habitats (Eisen et al., 2006.). Climate change may impact the distribution of the vector tick, as wet, humid areas become drier and less suitable as *Ixodes pacificus* habitat. Conversely, other areas may become wetter, allowing for the vector tick to exist where it previously did not. Abundance of small mammal reservoirs may similarly be affected as described for Hantavirus above.

California had a total of 380 West Nile virus (WNV) human symptomatic cases in 2007, compared to 278 in 2006, and 880 in 2005 (CDPH, 2008). Like the related Saint Louis encephalitis virus (SLE), endemic to California, WNV development within the mosquito increases as a linear function of temperature, when temperatures are above 14.7 degrees Celsius (Reeves et al., 1994). Above-average summer temperatures in California and other temperate regions of the United States are related to WNV epidemic conditions (Reisen, 2006; Epstein, 2001). SLE and perhaps WNV activity appears to be greatest during La Niña conditions of drought and hot summer temperatures. Though increased rainfall may temporarily provide increased mosquito breeding sites, in fact, rainfall has little effect on SLE or WNV transmission, since urban mosquitoes breeding in municipal water systems may benefit from below-normal rainfall. The 2006–2008 WNV seasons saw drier rural areas than in previous years, an abundance of urban mosquito breeding sites augmented by unmaintained swimming pools in foreclosed homes, resulting in more intense urban WNV transmission than in previous years (CDPH, 2007). In the California Mosquito-borne Virus Surveillance and Response Plan,[1] average daily temperature in the previous half month is used prospectively to forecast risk during the coming season. It should be noted that an increase in summer rainfall could make California more at risk for the introduction and establishment of exotic vectors, such as *Aedes aegypti* and *Aedes albopictus* – the principal mosquito vectors for other flaviviruses, such as dengue and yellow fever.

Research questions that need to be addressed regarding vector-borne disease and climate change include identifying the climatic conditions, including El Niño events, which are the most conducive for increase in deer mouse populations, and identifying which geographic regions and populations are most vulnerable in terms of contact with the disease reservoir for HCPS. Research is also needed on how temperature increase and changes in land use in California affect the probability of increased interactions between humans, deer populations, tick vectors, and mice reservoirs. Finally, daily/seasonal data on degree days and moisture need to be analyzed to determine their usefulness for predicting and monitoring mosquito populations and WNV transmission.

Health Behaviors/Communication

Research must be conducted to identify which policies/incentives (e.g., gas taxes) could be implemented to change behaviors and social norms, in communities to encourage more walking, bicycling, and use of public transport. These behavior changes also result in public health co-benefits, including reduction of obesity and reduction of cardio-vascular disease risk. The utility of walkability audits, and the incorporation of health impact assessments into land use planning or environmental impact reports of developments also should be explored.

[1] See www.westnile.ca.gov.

There is a paucity of research on the most effective outreach and communication plans/strategies that will cause behavior change to reduce human health risks associated with climate change. These plans need to be appropriately tailored to target the most vulnerable communities (e.g., racial/ethnic minorities, elderly, etc.) (Andrulis et al., 2007).

Alternative Energy Sources

In discussions of the need to switch to alternative energy sources from a coal- and oil–based portfolio, there is a need for a cost-benefit analysis of various energy sources for California to include public health impacts that can be incurred both inside and outside of California. For example, an analysis of the increased use of nuclear power should include the health impacts of uranium mining.

6.0 Conclusions and Prioritized Recommendations

6.1 Conclusion

Public health impacts of climate change on California are expected to be broad, including: direct effects of increased temperature and extreme weather events; increased air pollution and pollen, resulting in more respiratory disease and allergies; increased wildfires with associated air pollution and respiratory impacts; and increased risk of vector-borne disease. With regard to heat waves, most of the epidemiologic studies that have been published have been conducted over the past decade. Prior to that, most research has focused on case reports following heat waves, rather than using background ambient temperature as a measure of exposure. However, the topic is still in its incipient phase, and very little research has focused on California.

Vulnerable subgroups must be identified and studied further by region of the State with regard to all the health outcomes reviewed. California is unique in that temperature and humidity tend to be relatively mild, while pollutant levels are generally high with distinct sources and patterns of exposure. Furthermore, people spend more time outdoors throughout the year in California, leading to the potential for more exposure to heat, air pollution, smoke, and vector-borne disease. Air conditioning use is not a surrogate for socioeconomic status, as it may be in other parts of the country. Many homes in coastal areas don't have air conditioning installed because they have not been needed, although coastal homes tend to be more expensive. Thus, people living in coastal areas may be more impacted by a heat wave since they do not have air conditioning in their homes and are not acclimatized to high ambient temperatures. In a study conducted by Basu et al. (2008), a slightly higher but significant mortality effect estimate was found for coastal areas compared to inland areas of California, pointing to some evidence for acclimatization.

6.2 Prioritized Recommendations

Key research needs have been identified in Section 5.0 of this paper. The priority should first be on studies that use data that are available for public use and also on studies that can obtain data efficiently. Thus, temperature and mortality/morbidity, modeling, surveillance, and air pollution effects should be addressed first. Other research areas that have received recent attention are wildfires, extreme events, and vector-borne diseases, but methods must be developed to study these outcomes in more detail. Individual data collection would also be useful, particularly to establish health behaviors (e.g., time-activity diaries, as was done by Basu and Samet [2002b]). With climate change and public health on the research forefront, these issues should be investigated, as well as others that may arise with the progress of the proposed studies.

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