Chapter 5
California and Climate Changes

Rupa Basu

Abstract Epidemiologic studies of temperature and adverse health outcomes in California are their incipient stage, as the majority of the research has been conducted in the past 5 years. Exposure has been defined primarily as apparent temperature, a combination of temperature and humidity, a measure that has been calculated from meteorologic monitors supplied by the California Irrigation Management System and the United States Environmental Protection Agency. The various outcomes that have been studied include mortality and morbidity, such as hospitalizations, emergency room visits, and in one study, preterm delivery. Air pollutants have often been examined as potential confounders or effect modifiers. The results have shown a positive association between temperature and various health outcomes and have identified increased risk for infants, young children, the elderly, and Blacks and for some specific cardiovascular and respiratory diseases. Identifying vulnerable subgroups for local regions will be essential to decreasing heat-related mortality and morbidity.

Keywords Temperature and mortality studies • Temperature and hospitalizations • Increased mortality • Morbidity • Vulnerable subgroups • Mortality displacement • California

According to the Intergovernmental Panel on Climate Change [1], global warming impacts are likely to result in increased deaths, cardiorespiratory diseases, and injury due to heat waves, among other public health impacts. This chapter summarizes

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K.E. Pinkerton and W.N. Rom (eds.), *Global Climate Change and Public Health*, Respiratory Medicine 7, DOI 10.1007/978-1-4614-8417-2_5,

epidemiologic studies of temperature and adverse health outcomes, focusing primarily on California. The health outcomes discussed include mortality and morbidity, such as hospital visits, emergency room visits, and preterm delivery.

Summary of Epidemiologic Studies of Temperature and Mortality

Temperature and Mortality Studies in the United States Including California

Previous studies of heat waves or elevated temperature and mortality have been documented worldwide and summarized in two recent epidemiologic review articles [2, 3].

A few investigators examining temperature and mortality in the United States have included cities or counties in California as a part of their analyses.

Among the first studies of temperature and cardiorespiratory mortality was conducted by Basu et al. [4] using National Morbidity and Mortality Air Pollution Study (NMMAPS) data from 20 metropolitan areas in the United States. The investigators reported a positive association between temperature and mortality in the summer for all regions and mostly null or negative associations during all other seasons. The Southwest region consisting of Phoenix, AZ; San Diego, CA; Santa Ana, CA; Los Angeles, CA; and San Bernardino, CA, had the highest regional effect with an odds ratio (OR) of 1.15 (95 % confidence interval (CI): 1.07, 1.24) per 10° Fahrenheit (°F) increase in mean daily temperature, adjusted for dew point temperature to account for humidity. In this study, the time-stratified case-crossover approach using logistic regression models (Fig. 5.1) and the time-series analysis using Poisson regression models produced virtually identical results. Since this study was based on 1 year of data in 1992, more studies of multiple areas over a longer time period are warranted.

Recently, other investigators have expanded the NMMAPS data to include more metropolitan areas throughout the United States [5, 6]. Barnett [5] included 107 cities in their analysis to compare findings between the summers of 1987 and 2000. He reported an elevated risk in 1987 for temperature and cardiovascular mortality that was no longer observed in 2000. Similar to the Basu et al. [4] study, regional analyses showed that southern California had among the greatest effects in 1987 but also had the largest decline in 2000. The author attributes the diminished effect partially to the increased availability of air conditioning (AC). However, racial disparities have been reported for access to AC in the United States [7], and thus, AC use is not a viable solution to mitigate heat-related health impacts equally for everyone that may be affected. Furthermore, prolonged and widespread AC use can lead to power brownouts and blackouts. In another investigation of 95 NMMAPS cities from 1987 to 2000, the potential effect modification by ozone on the

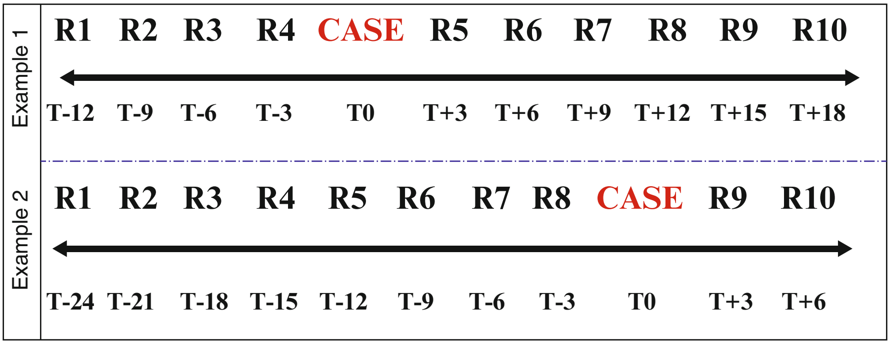

Fig. 5.1 Schematic diagram of time-stratified case-crossover design. CASE, case period; R1-R10, referent periods 1–10 every third day in the same month and year; T0, time that case occurred (death date); T−24 … T+18, time that referent periods occurred

temperature and cardiovascular mortality association was assessed during the summer months [6]. A synergistic effect between ozone and temperature in most regions, including Southern California, was observed.

In another case-crossover study of temperature and mortality in 50 US cities using data from 1989 to 2000, investigators explored extreme temperatures, using various cutoff values for temperature [8]. In their analysis of over six million observations, mortality was found to increase with extreme heat (5.74 %, 95 % CI: 3.38, 8.15). Although no estimates were provided for California specifically, Los Angeles and San Diego were included in the overall analysis. The largest effects were generally observed in cities with milder summers, less AC, and higher population density. In another case-only study using the same data, Medina-Ramón et al. [9] found that older subjects, diabetics, Blacks, and those dying outside a hospital were more susceptible to the effects of extreme heat.

Temperature and Mortality Studies in California

California is unique since 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, lending them the potential for more exposure to heat, air pollution, smoke, as well as vector-borne diseases. AC use is not a surrogate for socioeconomic status, as it may be in other parts of the country. Many homes in coastal areas do not have AC installed because predominantly cool temperatures minimize the need, although coastal homes tend to be more expensive and, thus, consist of a wealthier population. 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.

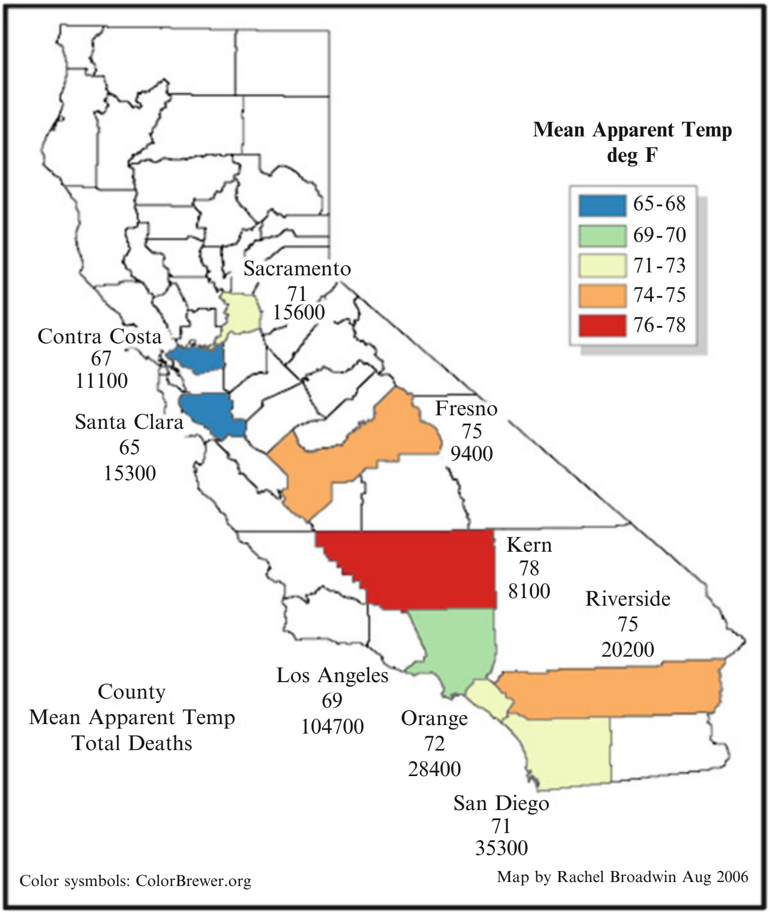

Fig. 5.2 Mean apparent temperature for nine California counties, May to September 1999–2003 (from Rupa Basu, PhD, MPH, Oral presentation entitled "An Epidemiologic Study of Temperature and Mortality in California: Implications for Climate Change." California Energy Commission, Sacramento, September 15, 2006 with permission)

Investigators have estimated the impact of temperature on mortality in California [10–12]. Temperature and mortality data from nine counties in California were analyzed including Contra Costa, Fresno, Kern, Los Angeles, Orange, Riverside, Sacramento, San Diego, and Santa Clara, which comprise approximately 65 % of the State's population, and include regions in northern and southern California and inland and coastal regions (Fig. 5.2). To focus on heat effects, data were limited to the warm season from May 1 to September 30, 1999–2003. Air pollutants were accounted for in the analyses as potential confounders or effect modifiers. County-specific estimates were obtained followed by an overall combined estimate using the random effects model in meta-analyses [13].

In the first epidemiologic study of temperature and mortality in California, the primary goal was to establish methods to examine the association independent from air pollutants [11]. A total of 248,019 deaths were included. Same-day lag was found to have the best data fit and also the highest risk estimates, demonstrating the acute effect of temperature on mortality. Each 10 °F increase in same-day mean apparent temperature corresponded to a 2.3 % increase in mortality (95 % CI: 1.0, 3.6) in the time-stratified case-crossover analysis for all nine counties combined, with similar results produced in the time-series analysis. No air pollutant examined was found to be a significant confounder or effect modifier. Regional differences within California were found between coastal and inland areas, and thus, region-specific policies are warranted. An association between temperature and California was observed in a relatively mild climate without focusing on extremes in apparent temperature or heat waves. The findings from this study are comparable to temperature and mortality in other regions in the United States using the same methods [14].

Vulnerable Subgroups

In a second time-stratified case-crossover study examining temperature and mortality in California, vulnerable subgroups were identified [12]. A total of 231,676 non-accidental deaths were included to evaluate several disease categories and subgroups including cardiovascular, respiratory, cerebrovascular, and diabetes. Effect modification by race/ethnic group, age, sex, and education level was also considered. Each 10 °F increase in mean daily apparent temperature corresponded to a 2.6 % (95 % CI: 1.3, 3.9) increase in cardiovascular disease mortality, with elevated risk especially found for ischemic heart disease. Acute myocardial infarction (MI) and congestive heart failure also had elevated risks, although respiratory disease mortality did not. High risks were also found for persons at least 65 years of age (2.2 %, 95 % CI: 0.04, 4.0), infants 1 year of age and under (4.9 %, 95 % CI: −1.8, 11.6), and Black non-Hispanic racial/ethnic group (4.9 %, 95 % CI: 2.0, 7.9). No differences were found by gender or education level. Thus, persons at risk for cardiovascular disease, the elderly, infants, and Blacks among others should be targeted to prevent mortality associated with high apparent temperature.

Mortality Displacement

In a time-series study, the potential effect of mortality displacement in the relationship between apparent temperature and mortality was explored [10]. Mortality displacement, also known as harvesting, refers to the phenomenon in which a specific exposure, such as temperature, impacts already frail individuals whose deaths may have only been brought forward by a few days. Significant associations were observed for the same day (excess risk, 4.3 % per 10 °F increase in apparent temperature, 95 % CI: 3.4, 5.2) continuing up to a maximum of 4 days following apparent temperature exposure for non-accidental mortality (Fig. 5.3). Similar patterns of

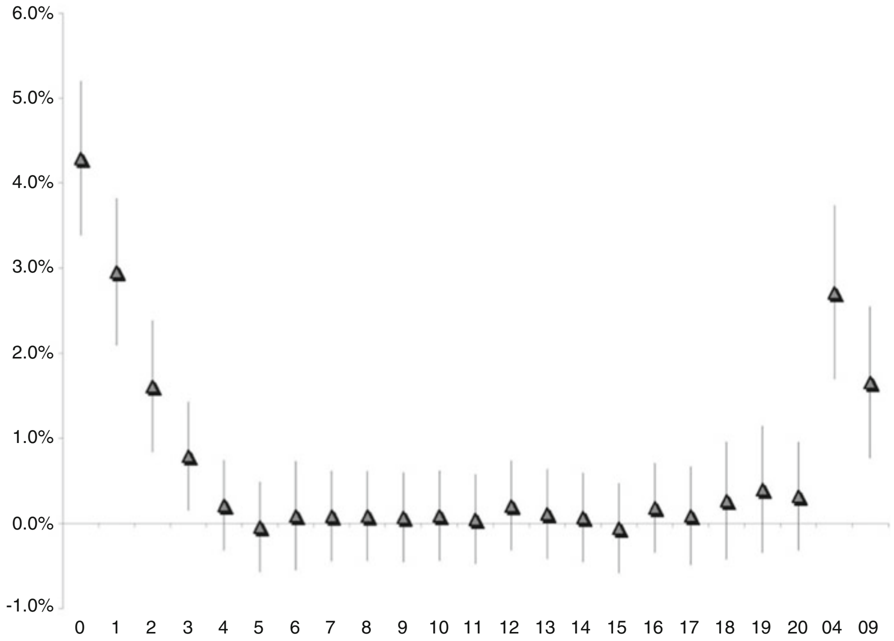

Fig. 5.3 Estimated percent change (95 % CI) associated with a 10 °F increase in mean apparent temperature and non-accidental mortality in 13 counties in California, May to September, 1999–2005

risk were found for mortality from cardiovascular diseases and respiratory diseases among children 0–18 years of age and among those 50 years and older. Since no significantly negative effects were observed in the following single or cumulative days, evidence of mortality displacement was not found. Thus, the effect of temperature on mortality in California appears to be an event that occurs within 3 days following exposure, with the most significant impact occurring on the same day, and appears to have a broad impact on the general population.

Heat Waves and Mortality

Two studies were recently conducted focusing on the Phoenix metropolitan area in Arizona [15, 16]. One study focused on heat-related deaths occurring from June to September 2000 to 2005 [15]. Per °F, a 6 % (1.00, 1.13) increase in mortality risk was observed. Most deaths occurring outdoors affected children under 5 years of age, while the majority of indoor deaths occurred among the elderly at least 65 years of age. Other investigators examined heat-related medical dispatches in Phoenix from 2001 through 2006 and found that maximum daytime temperature and elevated comfort indices, a measurement of temperature and relative humidity, were associated with the greatest risk [16].

The estimates provided in the previous section discussing studies conducted in California were based on background apparent temperature, including both heat wave and non-heat wave periods. Thus, they do not capture the worst-case scenario, as would be observed during heat wave periods only. Ostro et al. [17] investigated the July 2006 heat wave in California from July 14 to August 1, 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 multifactorial nature of mortality [2]. Furthermore, no systematic definition for heat-related deaths currently exists in the United States or California specifically. Daily data were collected for mortality, relative humidity, ambient temperature, and ozone 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 °F change in apparent temperature, which is more than 3 times larger than the effect estimated for the full warm season and corresponds to a number of deaths 2 or 3 times greater than the coroner estimates. The studies summarized provide a quantification of heat-related effects in California using epidemiologic methods. The first three studies described methodology, vulnerable subgroups, and potential mortality displacement of the apparent temperature-mortality association, while the last study focused on mortality during the 2006 heat wave.

Summary of Epidemiologic Studies of Temperature and Morbidity

Temperature and Hospitalizations/Emergency Room Visits

Using the same nine counties as the mortality analyses, temperature and hospitalizations from various causes were evaluated [18]. The study population consisted of 597,735 individuals who were admitted to a hospital with selected diagnoses and lived within 10 km of a temperature monitor in an effort to refine exposure assessment. A 10 °F increase in mean apparent temperature was associated with a 3.5 % (95 % CI: 1.5, 5.6) increase in several disease-specific outcomes, such as ischemic stroke, all respiratory diseases (2.0 %, 95 % CI: 0.7, 3.2), pneumonia (3.7 %, 95 % CI: 1.7, 3.7), dehydration (10.8 %, 95 % CI: 8.3, 13.6), diabetes (3.1 %, 95 % CI: 0.4, 5.9), and acute renal failure (7.4 %, 95 % CI: 4.0, 10.9). There was little evidence that the temperature effects found were due to confounding by either $PM_{2.5}$ or ozone. In a follow-up study using data provided by a housing survey [19], the impact of AC use was investigated on the apparent temperature-hospitalization associations. [20] Although ownership and usage of ACs significantly reduced the effects of temperature on several health outcomes, even after controlling for potential confounding by family income and other socioeconomic factors, the associations between temperature and the health outcomes remained robust.

In a recently published time-stratified case-crossover study of over 1.2 million ER visits in 16 climate zones [19] in California, the study population consisted of cases who resided within 10 km of a temperature monitor in the same climate zone [21]. Significant positive associations for same-day apparent temperature and ischemic heart disease (% excess risk per 10 °F: 1.7; 95 % CI: 0.2, 3.3), ischemic stroke (2.8; 0.9, 4.7), cardiac dysrhythmia (2.8; 0.9, 4.9), hypotension (12.7; 8.3, 17.4), diabetes (4.3; 2.8, 5.9), intestinal infection (6.1; 3.3, 9.0), dehydration (25.6; 21.9, 29.4), acute renal failure (15.9; 12.7, 19.3), and heat illness (393.3; 331.2, 464.5). Statistically significant negative associations were found for aneurysm, hemorrhagic stroke, and hypertension. These estimates all remained relatively unchanged after adjusting for air pollutants, with the exception of pneumonia and all respiratory diseases, which were confounded by nitrogen dioxide and carbon monoxide. Risks often varied by age or racial/ethnic group. Thus, risk prevention strategies for morbidity during heat exposure require an immediate response and should consider those who are at greatest risk for cardiovascular disease, as well as the elderly, children, and minority race/ethnic groups.

Heat Waves and Morbidity

In a study examining the effects of the 2006 California heat wave on morbidity, Knowlton et al. [22] aggregated county-level hospitalizations and emergency department (ED) visits for all causes and for some specific causes for six geographic regions of California. Excess morbidity and rate ratios (RRs) during the heat wave (July 15 to 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. ED visits for heat-related causes were found to be increased (RR 6.30, 95 % CI: 5.67, 7.01). The greatest risk was found in the Central Coast, children (0–4 years) and the elderly (≥65 years of age). Acute renal failure, cardiovascular diseases, diabetes, electrolyte imbalance, and nephritis also had significantly increased risk. Some regions with relatively mild temperatures were found to be at increased risk, suggesting the influential roles of population acclimatization and biological adaption.

Temperature and Adverse Birth Outcomes

In the first large-scaled study of temperature and preterm delivery in the United States, Basu et al. [23] examined approximately 60,000 births spanning 16 counties in California from May through September 1999–2006. The investigators identified cases of preterm delivery from a state registry of births, which were combined with temperature and air pollution monitoring data based on residential zip code. Apparent temperature was significantly associated with preterm birth for all mothers, regardless of maternal race/ethnic group, age, education, or infant sex. Per 10 °F increase in weekly average (lag06) apparent temperature, an 8.6 % (95 % CI: 6.0, 11.3) increase in preterm delivery was found. Greater associations were observed for younger mothers, African-Americans, and Asians. These associations were found to be independent of air pollutants. Since this study was the first to report positive associations between temperature during the warm season and preterm delivery, more large-scaled studies of temperature and other adverse birth outcomes are warranted to establish associations in various locales.

El Niño Events

El Niño refers to a temporary change in the climate of the Pacific Ocean, in the region around the equator. The changes in weather are observed in both the ocean and the atmosphere, generally in the Northern Hemisphere during the winter. Typically, the ocean surface warms up by a few degrees Celsius, causing thunderstorms to move eastward, as well as other marked effects on the world's climate.

Investigators have examined existing trends in weather and hospitalizations for several cardiovascular outcomes (MI, angina pectoris, congestive heart failure) and stroke during both normal weather patterns and during El Niño events in three regions of California: Los Angeles, Sacramento, and San Francisco from 1983 to 1998 [24]. Although they found minimal changes in hospitalizations due to weather in Los Angeles, a 5 °F decrease in maximum temperature or a 5 °F increase in minimum temperature was associated with significant increases (6–13 %) in hospitalizations for all outcomes studied among those 70 years of age and older in San Francisco. Similar patterns were observed for men 70 years of age and older in Sacramento: 6–11 % increase for MI and 10–18 % increase for stroke. El Niño events were found to be significantly associated with increased hospitalizations particularly for angina pectoris in San Francisco and Sacramento, but not in Los Angeles.

The same investigators also studied women over the same time period to examine the association between weather and viral pneumonia [25]. A 5 °F decrease in minimum temperature resulted in significant increases (30–50 %) in hospitalizations in San Francisco and Los Angeles, whereas a 5 °F decrease in maximum temperature difference produced significant increases (25–40 %) in hospitalizations in Sacramento. The associations were found to be independent of season. El Niño events were associated with hospitalizations only in Sacramento, with significant decreases for girls and increases for women.

An understanding of the changing patterns of hospital admissions during periods of weather changes is beneficial for evaluating population vulnerability and developing public health response.

Projections for Climate and Mortality

A few investigators have projected the effects of climate change and mortality, specifically for California. Using various climate models, greater increases in summer temperatures compared to winter temperatures are predicted. Based on the higher A1 emission scenarios, heat waves and extreme heat in Los Angeles are expected to be 6–8 times more frequent, with heat-related excess mortality increasing 5–8 times by the year 2100 [26]. The projections were slightly lower for the lower B2 emission scenarios. Other investigators also predicted a significant increase in heat events with longer duration and greater frequency over the twenty-first century, particularly for coastal areas of California [27]. By the 2090s, annual mortality could rise to a total of 4,684–8,757 deaths per year in California depending upon the scenario used from the General Circulation Model. The elderly over 65 years and urban centers are likely to face the greatest impact. A similar prediction was made in another study, with the central estimate of annual mortality ranging from 2,100 to 4,300 for the year 2025 and from 6,700 to 11,300 for 2050 [28]. Estimates using the low B1 emissions scenario are roughly half of these values. A 10 % and 20 % increase in AC use would generate reductions of 16 % and 33 % in the years 2025 and 2050, respectively. A national US estimate of annual incidence of heat-related mortality was found to be 3,700–3,800 from all causes, 3,500 from cardiovascular disease, and 21,000–27,000 from non-accidental deaths from May through September 2048 to 2052 relative to 1999–2003 using the A1 emissions scenario [29].

Biologic Mechanisms

Since heat-related mortality and morbidity have multiple etiologies, a clear biologic mechanism or cause is unknown. Susceptible individuals may not be able to thermoregulate efficiently. When body temperatures rise, the body generally shifts blood flow from the vital organs to the skin's surface in an effort to cool down [30]. Thus, thermoregulation may be inadequate when too much blood is diverted from the vital organs [31]. Increased blood viscosity, elevated cholesterol levels associated with higher temperatures, and a higher sweating threshold have also been reported in susceptible subgroups [32]. Another possible explanation for preterm delivery may be increased dehydration with heat exposure, which could decrease uterine blood flow and increase pituitary secretion of antidiuretic hormone and oxytocin to induce labor [33].

Conclusions

Public health impacts of climate change in California are expected to be broad, including direct impacts from increased temperature and extreme weather events. Most of the epidemiologic studies of temperature and mortality or morbidity that have been published have been conducted over the past decade. Prior to that, most research had focused on case reports following heat waves, rather than using background apparent temperature as a measure of exposure. However, the topic is still in its nascent phase, and relatively very little research has focused on the Southwest or on California specifically.

Several important research questions remain regarding the relationship between temperature, heat waves, and subsequent human morbidity and mortality. More information from public health research is needed to provide the National Weather Service the best measure of heat warning (e.g., heat index) that is predictive of morbidity and mortality. Recommendations need to be developed based on the characteristics that comprise the most effective heat warning systems in the United States and abroad and how to develop such systems locally. Although individuals may know about heat warning systems, they may not be aware of what actions need to be taken or perceive themselves as being at increased risk [34]. Identifying comorbidities in vulnerable subgroups such as the elderly and children, as well as communicating to them precautionary efforts that can be taken, is crucial. Expansion of personal heat exposure assessment studies, using methods described previously by Basu and Samet [35], would be informative for identifying individual high-risk characteristics, as well as for understanding the biological mechanism between heat exposure and associated morbidity and mortality. Furthermore, no research has been conducted analyzing the characteristics of air masses (humidity, stagnation, period of occurrence, length) in relation to morbidity and mortality. Thus, the associations between temperature and adverse health outcomes need to be further investigated across all temperature exposure levels. Since heat waves are expected to occur more frequently with longer duration, the focus of epidemiologic studies should be on the higher end of temperature exposure, as they are expected to have the greatest public health impact in the future [1].

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