

# Chapter 15

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## Human Health

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## Executive Summary

Global climate models project changes in precipitation patterns, drought, flooding, and sea-level rise, and an increase in the frequency, duration, and intensity of extreme heat events throughout the Southwest. The challenge for the protection of public health is to characterize how these climate events may influence health and to establish plans for mitigating and responding to the health impacts. However, the effects of climate change on health vary across the region, by population, and by disease system, making it difficult to establish broad yet concise health promotion messages that are useful for developing adaptation and mitigation plans.

Techniques are increasingly available to quantify the health effects resulting from climate change and to move forward into predictions that are of sufficient resolution to

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**Chapter citation:** Brown, H. E., A. C. Comrie, D. M. Drechsler, C. M. Barker, R. Basu, T. Brown, A. Gershunov, A. M. Kilpatrick, W. K. Reisen, and D. M. Ruddell. 2013. "Human Health." In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 312–339. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

establish policy guidelines. Strides are being made in assigning cost to both the positive and negative effects on health of proposed climate-mitigation strategies or the lack thereof. As a result, more tools are available for cities and states to develop mitigation and adaptation plans that are specifically tailored to their populations.

For this assessment, we identify six key messages that relate to climate change and health in the Southwest:

- Climate change will exacerbate heat-related morbidity and mortality. (high confidence)
- Climate change will increase particulate matter levels from wildfires with subsequent effects on respiratory health. (medium-high confidence)
- Climate change will influence vector-borne disease prevalence, but the direction of the effects (increased or decreased incidence) will be location- and disease-specific. (medium-high confidence)
- Disadvantaged populations are expected to bear a greater burden from climate change as a result of their current reduced access to medical care and limited resources for adaptation strategies. (high confidence)
- Certain climate-change mitigation strategies have costs and benefits relevant to public health. Considering health costs (positive and negative) will more accurately represent the costs and benefits of the mitigation strategies. (medium-high confidence)
- Mitigation and adaptation plans tailored to the specific vulnerabilities of cities and states will lessen the impacts of climate change. (medium-high confidence)

## 15.1 Introduction

Summer season average temperatures in the Southwest United States are projected to be up to 9°F (approximately 5°C) higher than the present by the end of the twenty-first century (see Chapters 6 and 7 for details on climate change predictions in the Southwest). Global climate models also forecast changes in precipitation patterns, drought, flooding, and sea-level rise, and an increase in the frequency, duration, and intensity of extreme heat events throughout the Southwest. These climate changes will vary across the region, however, they are sufficient to threaten human health and well-being (Kunkel, Pielke, and Changnon 1999; Parmesan, Root, and Willig 2000; Baker et al. 2002; Christensen et al. 2004; Meehl and Tebaldi 2004; Harlan et al. 2006; Ruddell et al. 2010).

Unaddressed, there is a reasonable probability that climate change will have a negative impact on health in some Southwest human populations. There is uncertainty as to the timing, magnitude, and locations of these negative impacts. Population demographics, geographical differences, and socioeconomic factors that influence vulnerability also contribute to the uncertainty (Ebi et al. 2009). The complexity of interactions between these factors will require analysis and planning from multiple perspectives, including federal, state, tribal, and local governments, academia, the private sector and nongovernmental organizations (Frumkin et al. 2008).

This chapter focuses on those health effects related to climate change that will likely disproportionately affect the Southwest. It begins with a discussion of climate-related

health issues of current concern in the Southwest followed by a brief review of the mechanisms in which climate change influences health. While the health impacts expected from climate change can be estimated at a qualitative level, it is difficult to quantify the effects. Thus, the qualitative discussion as to how climate-change will influence health outcomes and the growing body of quantitative literature that has reported observed or predicted climate-change-related outcomes are discussed separately. Since few studies relevant to this assessment have been performed in Southwest states other than California, in some cases the conclusions presented are based on extrapolation of those findings to the rest of the Southwest. The chapter closes with a discussion of key uncertainties and highlights several key points for public health planning for climate change.

## 15.2 Current Climate-Related Health Concerns in the Southwest

Climate, even without considering climate change, influences the health of residents in the Southwest in several ways. First, the topographical and climate variability of the Southwest, with its extreme geographical and climatic conditions, is greater than that in any other region of the United States. In addition, several health concerns exist only or primarily in the Southwest. Finally, there is variation in the vulnerability (i.e., the sensitivity, resiliency, and adaptive capacity) of individuals and groups of people within the region (Patz et al. 2005; Bell 2011).

Climate-related exposures can be the direct cause of morbidity (illness) or mortality (death), such as death from hyperthermia. Climate-related exposures can also be a contributing cause of health problems by exacerbating an already existing medical condition—such as heart disease—or can exert indirect effects, as by inducing changes in the ranges of vectors (organisms such as mosquitoes that transmit disease from one host to another) that can introduce health effects to populations who have no previous history of infection. In this section, we discuss health issues related to air quality, heat extremes, wildfires, and the ecology that disproportionately affect the Southwest. These illnesses connote a considerable health burden in this region.

### *Air quality*

Air-pollution exposure is associated with mortality and morbidity (EPA 2006, 2009). The U.S. Environmental Protection Agency (EPA) sets health-based National Ambient Air Quality Standards (NAAQS) for ozone, for particulate matter smaller than 2.5 microns in diameter (PM<sub>2.5</sub>)<sup>i</sup> and smaller than 10 microns in diameter (PM<sub>10</sub>), and for four other environmental pollutants (Figure 15.1). Ozone and PM<sub>2.5</sub> are considered the greatest threats to human health. Climate is not a factor in setting these standards, since they are based solely on health effects attributable to air-pollutant exposure (Figure 15.2).

The Clean Air Act requires that all states attain the NAAQS. If a state is not in attainment, it must develop state implementation plans (SIPs) that outline how attainment will be reached by a specified date. Currently, all or parts of forty-eight counties in the Southwest do not attain the 8-hour ozone standard (EPA 2011a). Thirty-six of these counties are in California (which has fifty-eight counties total), eight are in Colorado (with sixty-four counties), two are in Arizona (sixteen counties), and two are in Utah (twenty-nine counties). All or part of thirty-eight counties in the Southwest do not attain

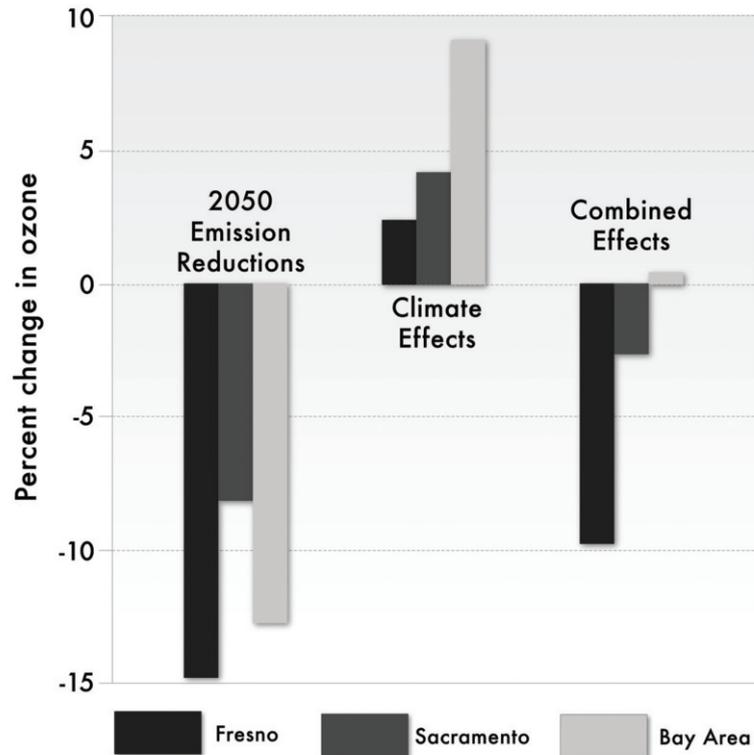


**Figure 15.1 Hazy view of Los Angeles.** The visible smog translates into poor air quality with negative consequences for cardiorespiratory health. Photo courtesy of David Illiff. License: CC\_BY\_SA 3.0.

the PM<sub>2.5</sub> NAAQS (EPA 2011b) including twenty-nine in California, two in Arizona, and seven in Utah. These counties encompass the major metropolitan areas of each state and consequently are home to significant fractions of each state's population.

**OZONE.** Ozone is a form of oxygen that forms naturally in the stratospheric portion of the atmosphere, where it absorbs most of the sun's UV radiation. In the lower atmosphere ozone is considered an ambient air pollutant, produced through chemical reactions between nitrogen oxides and hydrocarbons typically emitted by the burning of fossil fuels. The health effects of ozone were most recently assessed as part of the 2008 review of the ozone NAAQS (EPA 2006). The EPA concluded that short-term ozone exposure is associated with acute reductions in lung function, increased respiratory symptoms (such as shortness of breath, pain on deep breath and coughing, airway inflammation, and hyperresponsiveness), and increased respiratory hospital admissions and emergency department visits. Some literature suggests an association between ozone and cardiovascular morbidity, as well as mortality in people who have chronic cardiopulmonary disease. Long-term ozone exposure has not been clearly linked with health outcomes, except for structural changes in the airways of chronically exposed animals. People who are physically active outdoors, such as children, outdoor workers, and recreational and professional athletes, are at greatest risk of adverse health effects from ozone exposure.

**PARTICULATE MATTER.** The most recent assessment of the health effects of PM<sub>2.5</sub> is part of the ongoing review of the PM NAAQS (EPA 2009). The EPA concluded that both daily and long-term exposures to PM<sub>2.5</sub> are associated with mortality for cardiovascular causes, particularly in the elderly who have pre-existing cardiovascular disease. In comparison, the relationship of long-term and short-term PM<sub>2.5</sub> exposure to illness and death (other than that from cardiovascular causes) has not been as consistently demonstrated. PM<sub>2.5</sub> exposure is associated with hospitalizations and emergency department visits for exacerbation of pre-existing cardiopulmonary disease, mainly in the elderly. Reduced lung function growth,<sup>ii</sup> increased respiratory symptoms, and asthma exacerbation have been noted in children. Several studies report an increased risk of mortality and respiratory infections in infants exposed to elevated PM<sub>2.5</sub> concentrations.



**Figure 15.2 Projected ozone response to climate in three urban areas of California, 2050.**

A recent EPA-funded study at the University of California, Berkeley evaluated the effects of variables associated with anticipated changes in climate and ozone precursor emissions for cities in California's Central Valley (Fresno and Sacramento) and San Francisco Bay Area. In the set of bars at left, expected reductions (due to existing and projected control measures) in ozone precursor emissions in 2050 would reduce ozone levels, assuming no change in climate. In the middle set of bars, changes in climate variables (such as higher temperatures) and expected increases in nitrogen oxide and hydrocarbon emissions lead to higher regional ozone concentrations. When these two effects are combined on the right, the benefits of the emissions reductions are partially or completely offset by climate-related increases in ozone, especially in the San Francisco Bay Area. Thus, climate change will make ozone standards more difficult to attain and maintain, and will increase control costs. Adapted with permission from American Geophysics Union (Steiner et al. 2006; California Air Resources Board, <http://www.arb.ca.gov/>).

### *Heat extremes*

Heat stress is the leading weather-related cause of death in the United States (CDC 2006; Kalkstein and Sheridan 2007; Sherwood and Huber 2010). Based on death certificates, an estimated 400 deaths each year are directly attributed to heat-related causes (CDC 2006), with the largest number occurring in Arizona (CDC 2005). However, both heat mortality and morbidity are believed to be significantly underreported (CDC 2006). Moreover, heat exposure can cause morbidity directly and also through exacerbation of preexisting chronic disease, particularly of the circulatory system (reviewed in Drechsler 2009).

Heat waves (periods of abnormally elevated temperature) can considerably increase the number of cases of direct and indirect heat-related mortality and morbidity (Semenza et al. 1996; Smoyer 1998; Naughton et al. 2002; Weisskopf et al. 2002; Knowlton et al. 2009; Ostro et al. 2009). The specific temperature associated with a heat wave varies by location because it is defined in relation to local normal conditions (see also Chapters 5 and 7 for more detailed discussions about heat waves in the Southwest).

### *Wildfires*

The high frequency of wildfires in the Southwest presents several health concerns. Wildfire smoke can lead to PM<sub>2.5</sub> levels that greatly exceed national standards (Phuleria et al. 2005; Wu, Winer, and Delfino, 2006), contributing to adverse health effects. Other health concerns related to wildfires include death and burn injuries through direct contact with the fire or from indirect effects such as evacuation and dislocation, physical loss of home or other property, and increased risk of mudslides during subsequent rainstorms. Whether or not health effects derive from a specific wildfire depends on many factors, including the proximity of the fire to a population; the size, intensity, and duration of the fire; and whether the smoke plume moves across a populated area.

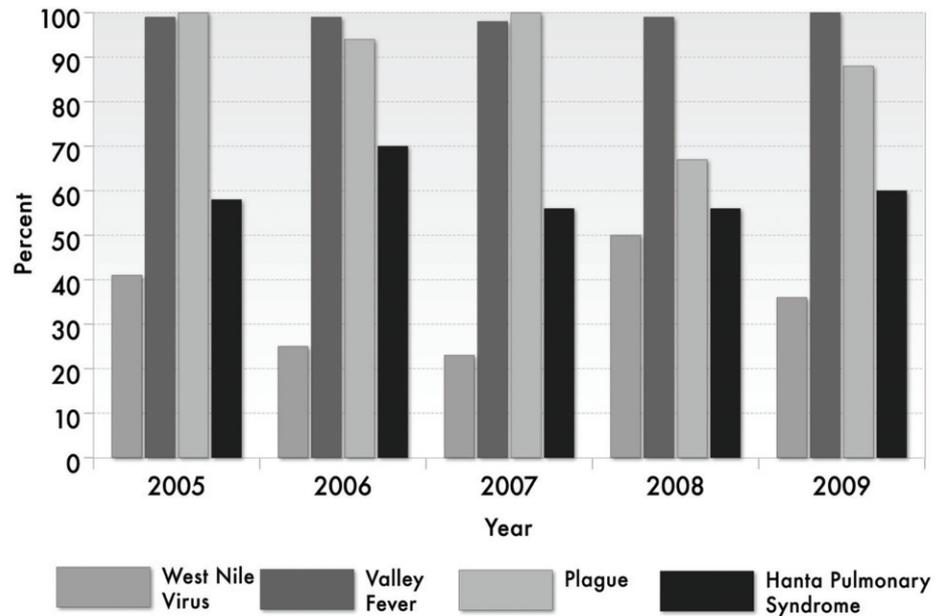
### *Permissive ecology*

Climate affects the seasonality, geographic distribution, and transmission frequency of infectious illnesses through the regulation of permissive habitat for pathogen establishment. Many of the climate-related infectious illnesses that occur in the United States (e.g., West Nile virus, influenza, food- and water-borne pathogens) also affect the Southwest. These illnesses contribute considerably to U.S. morbidity and mortality. For example, food-borne illnesses affect 25% of the U.S. population and cause some 76 million cases annually (Mead et al. 1999).

Certain infectious diseases are more prevalent or are almost exclusively found in the Southwest. The Centers for Disease Control and Prevention (CDC) reports that from 2005 to 2009, most cases of valley fever (99.1% of 44,029 cases nationwide), plague (93% of 43 cases), and Hanta pulmonary syndrome (61% of 136 cases) occurred in the six Southwestern states (Figure 15.3) (Hall-Baker et al. 2009; Hall-Baker et al. 2010; Hall-Baker et al. 2011; McNabb et al. 2007; McNabb et al. 2008).

## 15.3 Climate Change and Potential Health Implications

Climate change is expected to increase injury and death related to extreme events, to alter the distribution of infectious diseases, and to exacerbate current climate-related health issues (Frumkin et al. 2008). These changes in climate have varying effects depending on location, event, population susceptibility, and disease. Here we discuss the changes in climate and the way in which they influence human health outcomes. The focus is on health effects that affect the Southwest disproportionately compared to other parts of the United States. The 2006 California heat wave is presented as a “case study” because it had the characteristics of future heat waves predicted for the Southwest.



**Figure 15.3 Incidence of selected diseases in the Southwest as a percent of total for the United States.** The proportion of the total cases in the United States of West Nile virus, valley fever, plague, and Hanta pulmonary syndrome reported annually from the Southwest to the CDC shows consistency from year to year. Data from cases reported to the CDC.

### *Emissions and air pollution*

Rising temperature will accelerate atmospheric chemical reactions, tending to increase concentrations of ozone and possibly PM<sub>2.5</sub> (Steiner et al. 2006; Jacobson 2008; Kleeman 2008; Mahmud et al. 2008; Millstein and Harley 2009). However, other meteorological characteristics, such as relative humidity, wind speed, and mixing height<sup>3</sup> also interact with temperature and influence pollutant concentrations (Steiner et al. 2006; Jacobson 2008; Kleeman 2008; Mahmud et al. 2008; Millstein and Harley 2009). Changes in ozone and PM<sub>2.5</sub> levels are unlikely to be uniform across an air basin. There remain many uncertainties in our current understanding of the influence of meteorological parameters on air quality. In addition, current strategies for modeling ozone cannot yet factor in the reduction of air pollution that is expected from regulations and control strategies that will be adopted to meet NAAQS attainment requirements. Thus, current knowledge is inadequate to project future health impacts. However, without implementation of new air-pollution-control strategies, the concentrations of these pollutants could increase with climate change, and consequently contribute to increased air pollution-related health effects (Knowlton et al. 2004; Peng et al. 2011).

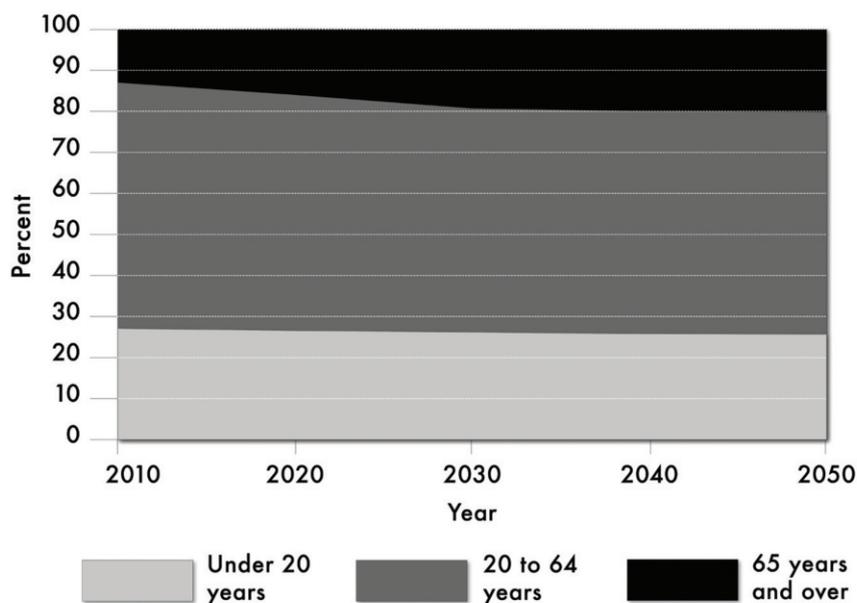
### *Increases in extreme events*

Increased climate extremes (heat waves and winter cold) and their direct effects, along with indirect effects related to vector populations, are expected to have an overall negative effect on human health (McMichael 2001). In particular, future heat waves are

expected to be more humid (Gershunov, Cayan and Iacobellis 2009), with higher overnight low temperatures. Heat waves are expected to increase more in coastal areas compared to inland (Guirguis and Gershunov forthcoming; see also Chapter 7). In addition to rising temperatures in the Southwest, climate models predict that the frequency, intensity, spatial extent, and duration of heat waves will continue increasing through the remainder of this century (Gershunov, Cayan, and Iacobellis 2009; Climate Action Team 2010; see also Chapters 6 and 7).

**HEAT-RELATED MORTALITY AND MORBIDITY.** Heat stress (the physiological response to excessive heat) can lead to morbidity and mortality and is the primary health-related threat to human health and well-being related to climate change both nationally and within the Southwest (Sherwood and Huber 2010). Heat stress is greater when elevated temperatures continue for several days (Kalkstein et al. 1996; Ruddell et al. 2011) or when conditions are hot and more humid. Humid heat poses a greater physiological stress than dry heat because it reduces the body's ability to cool itself through evaporation (Gagge 1981; Horvath 1981). Increases in daily mortality have been observed to vary by community and the intensity, duration, and timing of the heat event (Anderson and Bell 2011).

Increased physiological stress due to global temperature rise; more frequent, humid, intense, and longer lasting heat waves; and intensification of heat stress by urban heat islands will likely increase heat-related morbidity and mortality in the Southwest (Oke 1982; Brazel et al. 2000; Meehl and Tebaldi 2004; Rosenzweig et al. 2005; IPCC 2007; see also discussion in Chapter 7). This trend will be exacerbated by a projected demographic shift toward an older population (Figure 15.4) (Basu, Dominici and Samet 2005; Basu and Ostro 2008; Sheridan et al. 2011). Basu and Malig (2011) found that higher temperatures were associated with significant reductions in life expectancy and did not only affect extremely frail individuals.



**Figure 15.4 U.S. census population predictions by age.** Predictions that are stratified by age show an increase over the coming decades in the proportion of the 65-and-older population. The decadal estimates were generated using 2000 U.S. Census data. Source: Vincent and Velkoff (2010).

Outcomes of an unprecedented ten-day humid heat wave in California during late July 2006 are instructive for considering future climate-change-related mortality and emergency room (ER) visits. Studies showed that excess mortality related to the heat wave was at least three times greater than what was reported by coroners and that a greater proportion of deaths occurred in the elderly (Ostro et al. 2009). Knowlton et al. (2009) and Gershunov et al. (2011) confirmed that there were proportionally more ER visits in the cooler coastal areas than in the hotter inland regions, likely because populations living in the cooler parts of the state are less physiologically adapted to heat exposure, have less air conditioning, and are less knowledgeable about protective behaviors. Ownership and usage of air conditioners has been shown to reduce the adverse effects of increased temperature on some chronic health outcomes (Ostro et al. 2010).

Collectively, these studies suggest that: (1) mortality to which heat is a contributing cause will continue to exceed that in which heat is the underlying cause; (2) absolute risks of heat-related mortality will continue to be high in hotter areas, although coastal areas may see greater increases in risk over time with climate change; (3) relatedly, changes in risk of heat-related mortality and morbidity will likely be greater in areas that currently have relatively low peak temperatures (for example coastal or high-altitude areas), and consequently are less adapted to heat than areas that currently have frequent periods of high temperature; and (4) an aging population will increase the size of the at-risk population.

**WILDFIRES.** Climate change is expected to increase wildfire frequency and size (Westering et al. 2006, 2009; Flannigan et al. 2009), which in turn will increase the contribution of wildfire smoke to ambient PM<sub>2.5</sub> levels. Forest flammability will increase because of projected changes in the patterns of precipitation and drought, and their attendant effects on vegetation stressors such as insects, disease, soil-moisture loss, and tree mortality (Figure 15.5). These changes, along with human factors and land management practices (such as livestock grazing, wildfire suppression, and increased human presence) are expected to increase the number of wildfires, their contribution to ambient air pollution levels, and related health effects (see Chapter 8, Section 8.4.2).

Studies in the Southwest (Shusterman, Kaplan, and Canabarro 1993; Lipsett et al. 1994; Vedal and Dutton 2006) have found no significant relationship between wildfire smoke (measured as PM<sub>2.5</sub>) and mortality during fire periods. Fire-related deaths were principally related to burns, even in individuals who also had smoke-inhalation injury (Shusterman, Kaplan, and Canabarro 1993). In the Southwest, fire smoke exposure has been associated with respiratory and eye symptoms (Sutherland et al. 2005; Künzli et al. 2006). ER visits and unscheduled physician's visits increase during wildfire periods (Duclos, Sanderson, and Lipsett 1990; Shusterman, Kaplan, and Canabarro 1993; Lipsett et al. 1994; Vedal 2003; Künzli et al. 2006). Künzli and others (2006) also found that non-asthmatic children were more affected than asthmatic children, probably because asthmatic children were more likely to take preventive actions, including remaining indoors, reducing physical activity, using air conditioning, and wearing masks when outdoors. This is the first published study that showed a benefit from adopting these actions. Delfino and colleagues (2009) reported a 34% increase in asthma hospital admissions during the 2003 Southern California wildfires that increased PM<sub>2.5</sub> by an average of 70 micrograms (one millionth of a gram) per cubic meter. The greatest increase in



**Figure 15.5**  
**2010 Wildfire in**  
**Great Sand**  
**Dunes National**  
**Park, Colorado.**

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Research.

risk was for people over 65 years of age and for children up to four years of age. Risk of asthma admissions for school-age children was not statistically significant. The greatest increases in risk for hospital admissions were for acute bronchitis and pneumonia, particularly among the elderly, with no significant change in risk for cardiovascular effects or disease. Together these studies suggest that people with acute or chronic respiratory disease at the time of wildfire smoke exposure are the individuals most at-risk.

**VALLEY FEVER.** The majority of valley fever (coccidioidomycosis) cases in the United States occur in the Southwest (99.1% or 43,634 cases from 2005 to 2009), almost exclusively in Arizona and California (Hall-Baker et al. 2009; Hall-Baker et al. 2010; Hall-Baker et al. 2011; McNabb et al. 2007; McNabb et al. 2008), and mainly affecting people over age 65 (CDC 2003). Potential infection occurs when a dry spell desiccates the soil-dwelling fungus and subsequent soil disruption releases the spores, which are then inhaled. It is hypothesized that moisture in the soil preceding a dry spell promotes fungal growth (Kolivras et al. 2001; Comrie 2005; Comrie and Glueck 2007; Tamerius and Comrie 2011). Changes in extreme climatic events are expected to influence the growth and airborne release of this fungus.

Investigations into the relationship of weather patterns and valley fever found a weak correlation (4% of variance explained) between disease incidence and preceding precipitation for California (Zender and Talamantes 2006) while a substantially stronger correlation was found in two Arizona counties (69% of variance in Maricopa and 54% in Pima Counties explained; Tamerius and Comrie 2011). These disparities are likely related to the complexity of the relationships between climate factors and the fungus, as well as human susceptibility, habitat availability, model and variable selection, and data quality. This complexity impedes precise predictions of how climate change will influence the future incidence of valley fever.

### *Long-term warming trend*

The warming climate is expected to increase the length of the freeze-free season (the time between the last frost of spring and first autumn frost). These changes are in turn expected to influence many vector-borne diseases. The life cycles of vectors and their hosts are influenced by temperature and other climate factors (Gage et al. 2008), which in turn influence the time between vector infection to disease transmission (Reisen et al. 1993; Reisen, Fang and Martinez 2006). Warm temperatures increase the rate at which vector populations grow, speed vector reproductive cycles (Reisen 1995), shorten the time between exposure and infectivity (Reisen et al. 1993; Gubler et al. 2001; Gage et al. 2008; Reisen, Fang and Martinez 2006), and increase vector-host contact rates (Patz et al. 2003).

Vector ranges may change over time, depending on whether or not future local climate is suitable for a given vector (Box 15.1). Thus, previously unexposed populations may become exposed, while some currently exposed populations may no longer be exposed (Lafferty 2009). Understanding the effect of climate on vectors, hosts, and pathogens can help us estimate the geographic extent and intensity of disease risk. Research is continuing to improve our understanding of the association between disease incidence and climate, which brings us closer to predicting the future disease risk.

#### **Box 15.1**

### *Entomologic Risk*

Entomologic risk is a term used in describing the distribution of insects with respect to insect-borne disease. It is a helpful topic here as it highlights how a vector can exist in the absence of the occurrence of disease. For example, the dengue and yellow fever vector, *Aedes aegypti*, occurs in Tucson, Arizona (first noted in 1946, but more

recently since 1994 [Merrill, Ramberg, and Hagedorn 2005]), but neither dengue nor yellow fever are known to occur. This notion can be expanded to other health concerns: behavioral adaptation to heat can reduce the possibility of heat-related illness in spite of increasing heat events.

**MOSQUITO-BORNE DISEASES.** Mosquitos are a vector for the transmission of pathogens worldwide. Their abundance varies over time and space due to variations in temperature and the water available for their larvae (Barker, Eldridge, and Reisen 2010; Morin and Comrie 2010). Abundance of vertebrate hosts and the extent of suitable habitat can also be influenced by climate. Certain peridomestic birds (species that live around human habitation) are effective hosts for viruses such as West Nile virus (Reisen, Fang, and Martinez 2005; Kilpatrick 2011). Models that incorporate the interaction of vectors, hosts, and pathogens in a manner to also be explicit with respect to time and spaces are exceedingly complex. Quantifying these interactions, which are influenced

by climate in multiple ways, creates a challenge for predicting with precision the future health consequences of these diseases.

Long-term warming trends are expected to have several effects on mosquito-borne diseases. Longer-living vectors will increase the likelihood that a mosquito will obtain a potentially infectious blood meal, survive the pathogen's incubation period, and become infectious (Gubler et al. 2001; Cook, McMeniman, and O'Neill 2008). More days with temperatures exceeding minimum thresholds will increase vector-host contacts and decrease the period of time it takes for a mosquito to become able to transmit infection after ingesting an infecting blood meal (Kilpatrick et al. 2008; Hartley et al. 2012). Above certain maximum temperature thresholds, however, the mortality of adult female mosquitoes increases by around 1% per day for each 1.8°F (1°C) increase in temperature (Reeves et al. 1994). This reduced survival may be compensated for by increased mosquito biting rate and viral replication (Delatte et al. 2009; Hartley et al. 2012). These thresholds vary by vector species and their location, making uniform predictions, such as country-wide predictions about changes in generic mosquito-borne disease risk, inappropriate.

**PLAGUE.** Plague is a flea-borne bacterial disease maintained in rodents, with occasional spill-over to humans and companion animals. Ninety-three percent (40 cases) of all U.S. plague cases reported between 2005 and 2009 were from the six Southwestern states (Hall-Baker et al. 2009; Hall-Baker et al. 2010; Hall-Baker et al. 2011; McNabb et al. 2007; McNabb et al. 2008).

Most plague outbreaks occur when temperatures are between 75°F and 80°F (24°C and 27°C) and cease at higher temperatures (Brooks 1917; Davis 1953; Cavanaugh and Marshall 1972; Cavanaugh and Williams 1980; Gage et al. 2008; Brown et al. 2010). Global climate cycles, such as the Pacific Decadal Oscillation, as well as local meteorology, influence year-to-year differences in human plague cases (Parmenter et al. 1999; Ensore et al. 2002; Ben Ari et al. 2008). To date, these findings rely on retrospective analyses of climate and disease incidence without predicting future risk associated with climate change.

## 15.4 Observed and Predicted Effects on Health from Climate Change

Though the publication of research investigating the association between climate and health is growing, statistical models capable of predicting future health impacts are limited (Ebi et al. 2009). The World Health Organization estimated that global warming caused 140,000 excess deaths in 2004 compared to 1970 (WHO 2010). Climate change alters the distribution of physical exposures, which in turn changes the distribution of vulnerable populations and increases the likelihood of adverse impacts to those populations. As discussed in the previous section, climate change is expected to exacerbate several current health concerns, and alter the distribution of vulnerabilities by age, geographical, and socioeconomic factors on a local level (Ebi et al. 2009). This section summarizes recent findings that show already observed climate-change-related health effects or provide quantitative predictions of impacts.

### *Air quality*

The health impacts of PM<sub>2.5</sub> and ozone exposure are proportional to their concentrations in the ambient air, which is influenced by emissions, atmospheric chemistry, and emissions-reduction regulations driven by the National Ambient Air Quality Standards (NAAQS). NAAQS are reevaluated approximately every five years, and are revised if new information suggests that the existing NAAQS are inadequate. Overall, concentrations of these two pollutants and the number of air basins in the Southwest that do not attain the NAAQS have declined due to emissions-reduction regulations. However, several parts of the Southwest, particularly portions of California, do not attain the ozone and/or PM<sub>2.5</sub> NAAQS (EPA 2001a, 2001b).

Some greenhouse-gas-reduction regulations provide co-benefits—multiple and ancillary health benefits of a program, policy, or intervention—by reducing emissions of other chemicals, such as hydrocarbons and nitrogen oxides that combine to form ozone<sup>iv</sup> and PM<sub>2.5</sub> (CARB 2008). Energy demand is projected to increase in the future due to a growing population and a warmer climate, which could increase emissions of ozone precursors and PM<sub>2.5</sub> from some sectors (Climate Action Team 2010). Land use planning and policy changes will also affect emissions, particularly those from the transportation sector. Increases and decreases in emissions from various sectors, along with new emissions-reduction regulations and control technologies, will determine future attainment of the NAAQS. Overall, climate change is likely to make it harder to achieve and maintain attainment with the NAAQS.

**ASTHMA AND ALLERGIES.** As climate warms, data show earlier and longer spring bloom for many plant species, which has led to a general increase in plant biomass and pollen generation, triggering allergies and asthma cases (Weber 2012). A recent EPA review (EPA 2008) of the likely influence of climate change on bioallergens (pollens and molds) concluded that: pollen production is likely to increase in most parts of the United States; earlier flowering is likely to occur for numerous species of plants; changes in the distribution of pollen-producing species are likely, including the possibility of extinction of some species; intercontinental dispersal of bioallergens is possible (Figure 15.6), facilitating the introduction of new aeroallergens into the United States and increases in allergen content, and thus, potency of some aeroallergens are possible. Concomitant exposure to ozone and allergens may also lead to greater allergic responses than exposure to allergens alone (Molfino et al. 1991; Holz et al. 2002; Chen et al. 2004).

### *Heat-related mortality and morbidity*

U.S. heat-related deaths declined between 1964 and 1998 (Davis et al. 2003), likely due to more air conditioning, improved medical care, and better public awareness programs, as well as other infrastructural and biophysical adaptations. However, heat-related mortality and morbidity still occur throughout the Southwest region, particularly associated with intense heat waves. Based on historical data, without additional adaptations, mortality and morbidity will increase as the climate warms (Karl, Melillo and Peterson 2009).

A few studies, all focused on California, have quantitatively estimated future heat-related mortality (Hayhoe et al. 2004; Drechsler et al. 2006; Ostro, Rauch, and Green 2011;



**Figure 15.6 Dust storm on Interstate 10 near Phoenix, July 8, 2007.** Photo courtesy of Los Cuatro Ojos blog (<http://loscuatroojos.com/2007/07/28/dust-storms-over-phoenix-looks-worse-than-it-is/>).

Sheridan et al. 2011). Sheridan and colleagues (2011) suggest that by the 2090s, heat waves lasting two weeks or longer will occur about once per year throughout the state and that ten-day or longer heat waves could increase nearly ten times under a higher emissions scenario. Without new adaptations, most of California's urban areas could see significantly higher heat-related mortality by the 2090s, with a significant portion of the increase attributable to California's aging population (Table 15.1). Projected heat-related mortality is not uniform statewide, ranging from a 1.9-fold increase in San Francisco to a 7.5-fold increase in San Diego, compared to present. Incorporation of adaptations into the modeling only partially mitigated these increases. Ostro, Rauch, and Green (2011) estimated that heat-related mortality in California could increase up to three times by the mid-twenty-first century, with about a third of the increase offset by a 20% increase in air conditioning prevalence.

### *Vector-borne disease*

The IPCC's Fourth Assessment Report (2007) states that physical changes in the climate system will alter the "spatial distribution of some infectious diseases," such as dengue fever, malaria, and West Nile virus (WNV). In 2007, California declared a State of Emergency "due to the increasing risk of West Nile virus transmission" (CDPH 2007). The complexity of these systems makes forecasting the effects of climate change on disease outcomes difficult. However, researchers are increasingly able to generate future climate predictions.

**Table 15.1** Estimated future heat-related mortality in nine metropolitan statistical areas of California

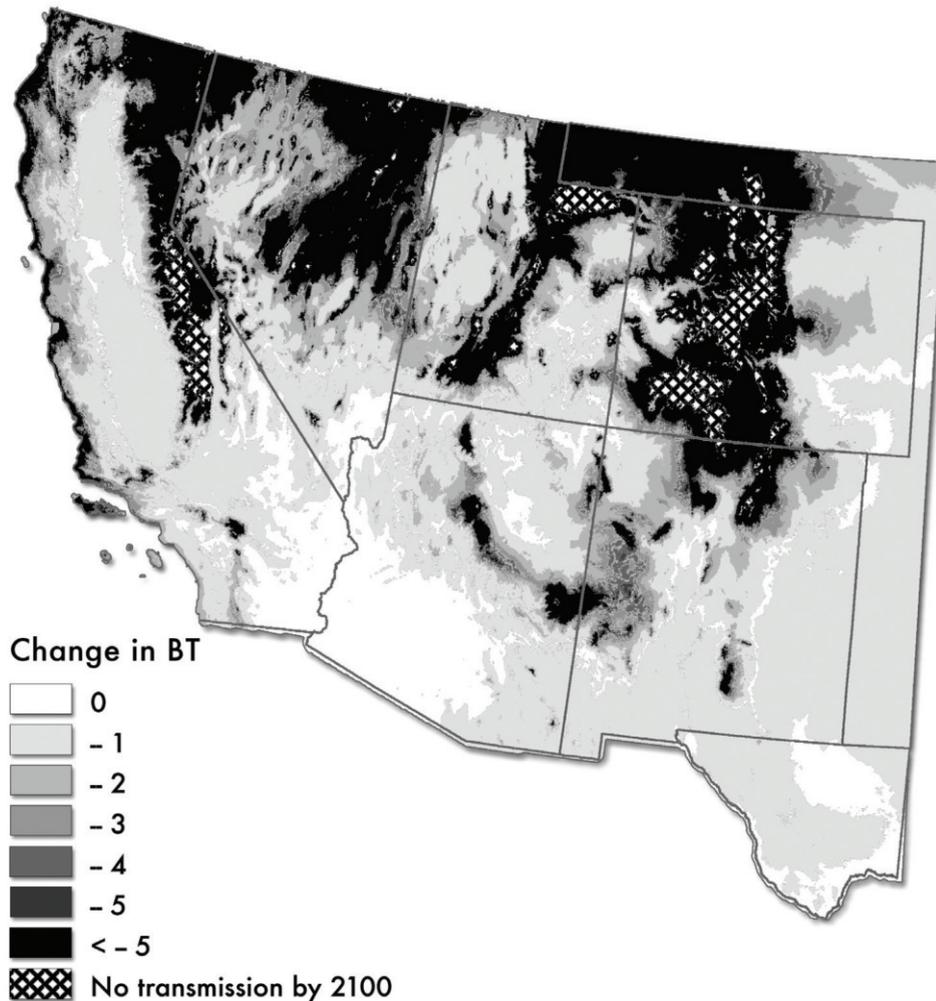
Urban Area	Mean Annual Heat-Related Mortality (Age 65 and older)		
	20th Century	2090s – Medium Growth	2090s – No growth
Fresno	15	192 – 266	26 – 36
Los Angeles	165	1,501 – 2,997	368 – 732
Oakland	49	413 – 726	85 – 149
Orange County	44	395 – 742	105 – 194
Riverside	60	741 – 1,063	113 – 162
Sacramento	27	275 – 440	55 – 88
San Diego	68	750 – 1,865	207 – 511
San Francisco	53	161 – 247	71 – 110
San Jose	27	256 – 411	44 – 69
<b>TOTAL</b>	<b>508</b>	<b>4,684 – 8,757</b>	<b>1,074 – 2,051</b>

Source: Sheridan et al. (2011).

WEST NILE VIRUS. Recent models that focus on the physiological responses of mosquitoes to changes in climate allow us to estimate WNV transmission using future temperature predictions (Figure 15.7). Comparisons of the Southern San Joaquin Valley to the otherwise comparable (in terms of vegetation, land use, rainfall, and human population) but 5.4°F–9°F (3°C–5°C) warmer Coachella Valley of California illustrates the likely influence of a warming climate on arboviruses (viruses spread by arthropod vectors) such as WNV (Reisen, Fang, and Martinez 2006). The transmission season in Coachella starts almost a month earlier than in the San Joaquin Valley and may persist through winter. However, above high temperature thresholds, the maximal intensity of pathogen transmission from mosquito to host may not differ markedly. WNV may be transmitted throughout the winter at very southern latitudes (Tesh et al. 2004; Reisen et al. 2006), whereas at more northern latitudes or high elevations temperatures drop below virus developmental thresholds for extended periods and vector populations enter diapause (a period in which growth or development is suspended), which interrupts virus transmission (Reisen, Smith, and Lothrop 1995; Reisen, Meyer and Milby 1986).

Warming trends apparently allow non-diapausing (not becoming dormant) portions of *Culex* mosquito population to persist through the winter (Reisen et al. 2010), especially in urban environments (Andreadis, Armstrong, and Bajwa 2010). Overall, it is likely that shorter winters will allow transmission of some arboviruses like WNV to continue

throughout the year. Highly efficient transmission of WNV is already evident during the summer, and little change is expected with warming trends. However, warming in the currently cooler and densely populated areas along the California coast and in the foothills of the Sierra Nevada and Rocky Mountains will increase risk of transmission of WNV and other mosquito-borne pathogens into new areas.



**Figure 15.7 Model-based estimates of changes in WNV transmission potential during June, based on expected shortening of the incubation period in mosquitoes.** Shown is the decrease in the average number of mosquito bites necessary to get from infection to transmission (BT) for WNV by 2100, based on future temperatures derived for mean scenarios used by Dettinger (2005). Parts of the region with cooler climates show a progressive decrease in BT during June by 2100, increasing the risk of transmission, whereas areas with extremely warm or extremely dry desert climates show no change in BT from current estimates. Source: PRISM Climate Group, Oregon State University, <http://www.prism.oregonstate.edu>.

## 15.5 Uncertainties

Quantitative estimates of future health impacts of climate change are difficult and uncertain for several reasons. These include: a dearth of adequate health data and sufficiently downscaled climate data; incomplete understanding of how non-climate-related factors modify risk; incomplete understanding of the relationships between climate, health, and disease processes; and the influence of physiological, behavioral, and societal adaptations. In addition, range shifts for infectious diseases or new introductions are difficult to predict. The Southwest has many large population centers located near earthquake faults and in coastal areas that can be struck by tsunamis. Although not the product of climate change, the Southwest has experienced major earthquakes that inflicted crippling damage to infrastructure in its major population centers, and it continues to be at risk of further earthquakes. A major seismic event preceding or overlapping extreme climate events would further complicate planning and execution of adaptation plans. These issues increase uncertainty for planning adaptive capacity and interventions.

### *Availability of high-quality health data*

Deficiencies in health data quality limit our ability to characterize the relationship of climate change and health and to develop predictive models for climate-related health impacts. Multi-year data sets of consistent quality and from multiple locations, with high spatial and temporal resolution, are needed to assess how risk changes over time and to estimate future impacts on a regional basis (Frumkin et al. 2008; Ebi et al. 2009; English et al. 2009). Data on the spatial distribution of vector-borne and fungal diseases, the organisms that transmit them, and their seasonal abundance are needed to estimate future infectious disease impacts (Bush et al. 2011).

### *Climate data*

Uncertainties in climate modeling are discussed in Chapters 6 and 7 of this report. Adequately downscaled climate projections are needed to quantify health effects at the local level (Ebi et al. 2009).

### *Disease complexity*

Diseases are physiologically complex, and many factors interact with or modify disease (Box 15.2). For example, humans have extensive physiological and behavioral capabilities that allow them to adapt to the usual temperature conditions where they live. The use of physiological, societal, and behavioral data in predictive modeling is limited by data availability and by our understanding of the interactions. These limitations are further confounded by our ability to interpret how physiology, society, and behavior will change with climate change. Failure to incorporate these factors increases uncertainty in predicting health outcomes (Randolph 2009) and may lead to spurious attribution of risk (Campbell-Lendrum and Woodruff 2006). A recent review on climate and human health over millennia suggests that modern societies may be less flexible and thus vulnerable (McMichael 2012). The complexities of human behavior and adequate characterization of the entities involved in disease transmission create uncertainty in estimating future climate-related health outcomes.

**Box 15.2*****Linking Data with Models: Lessons from Mosquito-borne Disease***

A key challenge in predicting the impacts of climate change on disease is determining the net impact of a multitude of individual effects, including some that offset others. The difficulty is to predict the net impact of all these climate influences acting simultaneously. Mathematical models provide a powerful method for this integration.

For example, a strong empirical test of the impacts of global warming on mosquito-borne disease transmission would require data (preferably weekly or monthly) on temperature, rainfall, mosquito abundance, infection prevalence in

mosquitoes, and infection prevalence in humans (ideally age-structured), in addition to human density and vector control efforts over the time period in question. Since substantial year-to-year variation in climate is ubiquitous, a minimum time series of a decade is likely needed to successfully disentangle the influence of the myriad influences that control incidence of mosquito-borne disease in humans. Unfortunately, such datasets are rare or non-existent for even the most important human infectious diseases.

***New disease introduction***

Predicting where new pathogens will emerge is difficult. Certain socio-economic, environmental, and ecological factors are common in areas where infectious diseases tend to emerge, which may help identify risk areas (Jones et al. 2008). Global travel and trade have already contributed to emergence of pathogens in new areas (Gubler 2002; Tatem, Hay, and Rogers 2006; Randolph and Rogers 2010). Climate- and habitat-based models can identify habitat suitable for the species of interest and identify theoretical geographic distributions. However, the emergence of new pathogens in an area is more complicated, requiring suitable hosts and environmental conditions to facilitate arrival, establishment, and spread (Randolph and Rogers 2010).

**15.6 Public Health Planning for Climate Change**

Current climate-related human health effects, combined with forecasts for a warming climate and an increase in the vulnerable population, demand development and implementation of mitigation and adaptation strategies (Bollen et al. 2009; Jack and Kinney 2010). Immediate improvements to health would result from strengthening public health infrastructure to respond to climate-induced threats (Costello et al. 2011). The initial challenge is to assess linkages between climate and human health at city, state, and regional levels, and develop mitigation and adaptation plans for each spatial scale (Frumkin et al. 2008). Only certain states and cities in the Southwest currently have action plans (e.g., Boulder, Colorado; Phoenix, Arizona; California; Colorado; and New Mexico—for examples see ACCAG 2006, City of Boulder 2002, and NMCCAG 2006), with most focusing on reduction in anthropogenic waste heat (heat produced by human activities for which there is no useful application, such as the heat generated to cool a

structure), air quality improvement, promotion of active lifestyles, and efficient use of natural resources.

Barriers to developing climate action plans include reduced tax revenue due to the 2007 financial downturn, along with competing budget priorities that have reduced the public funding available for long-term investment in mitigations to reduce human vulnerability to climate change. Several of the Southwest states (Arizona, California, Nevada) have been particularly affected by the ongoing recession (Heinberg 2011), including large reductions in the workforce of many local health departments (NACCHO 2010). Institutional barriers can limit development of partnerships between public, private, and non-profit groups to address climate change concerns (Harlan and Ruddell 2011), leading to lack of coordination, inefficient use of resources, or continued neglect of the most vulnerable and disenfranchised. Moreover, little is known about the cost-effectiveness of many climate change mitigation actions (Kalkstein et al. 1996; Kalkstein and Sheridan 2007). Together these factors provide challenges to action plan development. A recent publication provides a framework for identifying and organizing barriers to managing the risk and impacts of climate change (Ekstrom, Moser, and Torn 2011).

### *Adaptation*

The health sector is more involved in adapting to climate change than mitigating it (Frumkin et al. 2008). Surveillance (for temperature-related morbidity and mortality, adverse effects related to air pollution and wildfire smoke exposure, and vector-borne diseases) is a key adaptation strategy that must be coordinated with first-alert systems and emergency services. For example, Los Angeles County has established an automated, near-real-time surveillance system to detect health changes in incidence of increased morbidity and mortality related to environmental stresses (LACDPH 2006). Public communications to both policy makers and the public should clearly emphasize that (a) climate change is already upon us, (b) it will be bad for human health, (c) the consequences will be worse if no adaptation or mitigation measures are taken, and (d) there are actions we can take individually and as a society that will simultaneously reduce the consequences of climate change and improve health (Maibach et al. 2011). To be effective, the framing of climate-change communication should be sensitive to concerns of various segments of the population. Public education campaigns, in multiple languages, should emphasize protective behaviors to reduce risk and provide care for vulnerable individuals and groups (Naughton et al. 2002; Weisskopf et al. 2002; Drechsler 2009). Access to cooling centers and other services to prevent climate-related morbidity and mortality are needed, particularly for the elderly, infirm, and economically disadvantaged. Vector-control programs and occupational safety standards for outdoor workers should be reviewed and strengthened. The federal block grant LIHEAP program<sup>5</sup> provides reduced energy rates during the cooling season for low-income residents of Arizona, Nevada, and New Mexico. Reduced energy rates are available only during the heating season in California, Utah, and Colorado. The influence of climate change on emissions and atmospheric chemistry will need to be included in future planning efforts to reduce emissions and attain the health-based NAAQS.

### Co-benefits

Though the health sector usually focuses on adaptation to climate change, evidence is increasing that certain mitigation policies also provide ancillary health benefits. Quantifying the economic benefits to health may provide additional support for the implementation of these mitigation policies and help reduce the future public health impacts of climate change. For example, many actions that reduce greenhouse gas emissions also reduce emissions of PM<sub>2.5</sub> and ozone precursors. Community designs that promote walking and bicycling to reduce emissions from vehicles also can help improve the health of individuals (Frumkin et al. 2008). An emerging body of research demonstrates a large potential source of health co-benefits from different mitigation strategies is the physical activity component of active transport (Woodcock et al. 2009; Grabow et al. 2011; Maizlish et al. 2011; Rabl and de Nazelle 2012). Health consequences of the mitigation activities themselves should be incorporated into cost-benefit analyses of mitigation strategies (Haines et al. 2009; Costello et al. 2011).

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## Endnotes

- i The smaller size of PM<sub>2.5</sub> particulates allows them to lodge deeply in the lungs.
- ii This is a smaller amount of growth in lung function during the child's growth period. Both the growth rate and the attained lung function at adulthood seem to be smaller in children growing up in high PM<sub>2.5</sub> areas.
- iii Mixing height is the level of the inversion layer. It is like an atmospheric ceiling that limits the volume of air into which air pollution can mix. High air pollution is associated with a low mixing height/inversion layer, while a high mixing height is associated with better air quality.
- iv Ozone forms in the atmosphere as the result of reactions involving sunlight and two classes of directly emitted precursors. One group of precursors includes various oxides of nitrogen, such as nitric oxide and nitrogen dioxide, and the other group includes volatile organic compounds (also called reactive organic gases), such as hydrocarbons.
- v Low Income Home Energy Assistance Program (LIHEAP), <http://www.liheap.ncat.org>.