



# 1 INTRODUCTION: CLIMATE CHANGE AND HUMAN HEALTH

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# 1 INTRODUCTION: CLIMATE CHANGE AND HUMAN HEALTH



Human health has always been influenced by climate and weather. Changes in climate and climate variability, particularly changes in weather extremes, affect the environment that provides us with clean air, food, water, shelter, and security. Climate change, together with other natural and human-made health stressors, threatens human health and well-being in numerous ways. Some of these health impacts are already being experienced in the United States.

Given that the impacts of climate change are projected to increase over the next century, certain existing health threats will intensify and new health threats may emerge. Connecting our understanding of how climate is changing with an understanding of how those changes may affect human health can inform decisions about mitigating (reducing) the amount of future climate change, suggest priorities for protecting public health, and help identify research needs.

## 1.1 Our Changing Climate

### Observed Climate Change

The fact that the Earth has warmed over the last century is unequivocal. Multiple observations of air and ocean temperatures, sea level, and snow and ice have shown these changes to be unprecedented over decades to millennia. Human influence has been the dominant cause of this observed warming.<sup>1</sup> The 2014 U.S. National Climate Assessment (2014 NCA) found that rising temperatures, the resulting increases in the frequency or intensity of some extreme weather events, rising sea levels, and melting snow and ice are already disrupting people's lives and damaging some sectors of the U.S. economy.<sup>2</sup>

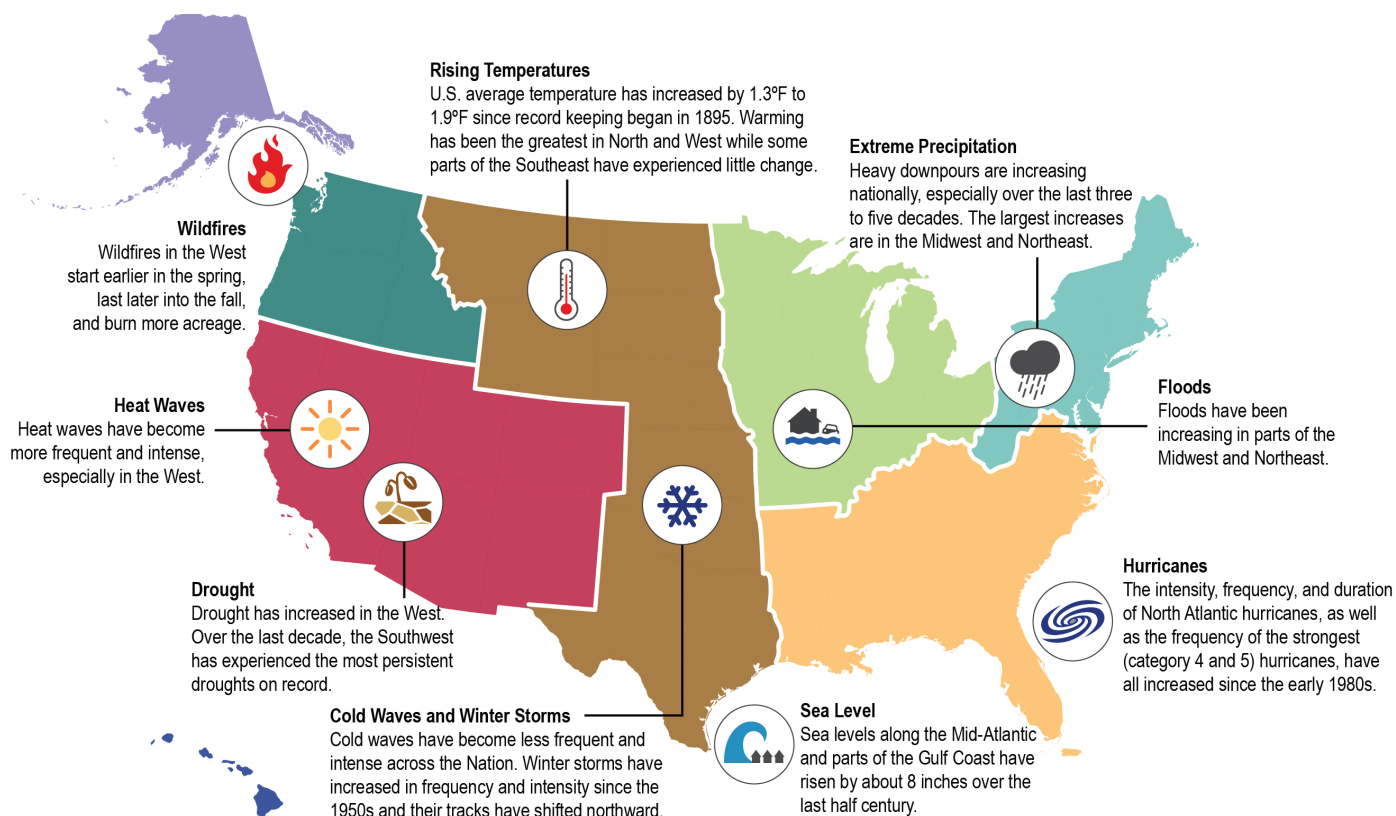
The concepts of climate and weather are often confused. *Weather* is the state of the atmosphere at any given time and place. Weather patterns vary greatly from year to year and from region to region. Familiar aspects of weather include temperature, precipitation, clouds, and wind that people experience throughout the course of a day. Severe weather conditions include hurricanes, tornadoes, blizzards, and droughts. *Climate* is the average weather conditions that persist over

multiple decades or longer. While the weather can change in minutes or hours, identifying a change in climate has required observations over a time period of decades to centuries or longer. Climate change encompasses both increases and decreases in temperature as well as shifts in precipitation, changing risks of certain types of severe weather events, and changes to other features of the climate system.

Observed changes in climate and weather differ at local and regional scales (Figure 1). Some climate and weather changes already observed in the United States include:<sup>2,3</sup>

- U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The first decade of the 2000s (2000–2009) was the warmest on record throughout the United States.

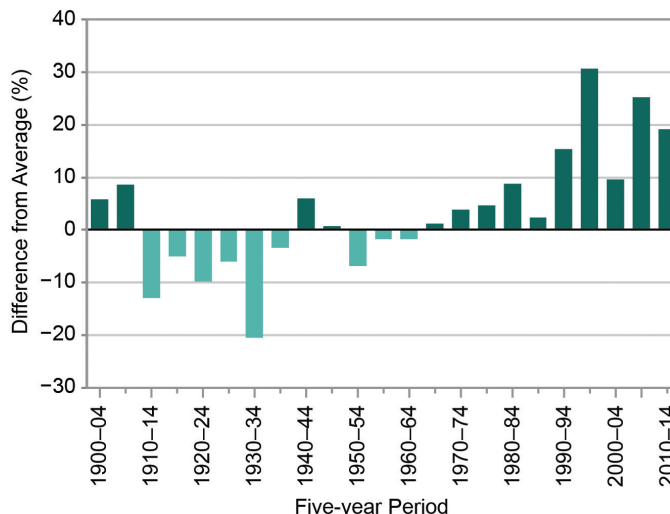
## Major U.S. Climate Trends



**Figure 1:** Major U.S. national and regional climate trends. Shaded areas are the U.S. regions defined in the 2014 NCA.<sup>2, 4</sup>

- Average U.S. precipitation has increased since 1900, but some areas have experienced increases greater than the national average, and some areas have experienced decreases.
- Heavy downpours are increasing nationally, especially over the last three to five decades. The largest increases are in the Midwest and Northeast, where floods have also been increasing. Figure 2 shows how the annual number of heavy downpours, defined as extreme two-day precipitation events, for the contiguous United States has increased, particularly between the 1950s and the 2000s.
- Drought has increased in the West. Over the last decade, the Southwest has experienced the most persistent droughts since record keeping began in 1895.<sup>4</sup> Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas.
- There have been changes in some other types of extreme weather events over the last several decades. Heat waves have become more frequent and intense, especially in the West. Cold waves have become less frequent and intense across the nation.

### Change in Number of Extreme Precipitation Events



**Figure 2:** Time series of 5-year averages of the number of extreme 2-day duration precipitation events, averaged over the United States from 1900 to 2014. The number is expressed as the percent difference from the average for the entire period. This is based on 726 stations that have precipitation data for at least 90% of the days in the period. An event is considered extreme if the precipitation amount exceeds a threshold for a once-per-year recurrence. (Figure source: adapted from Melillo et al. 2014)<sup>2</sup>

- The intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (category 4 and 5) hurricanes, have all increased since the early 1980s. The relative contributions of human and natural causes to these increases remain uncertain.

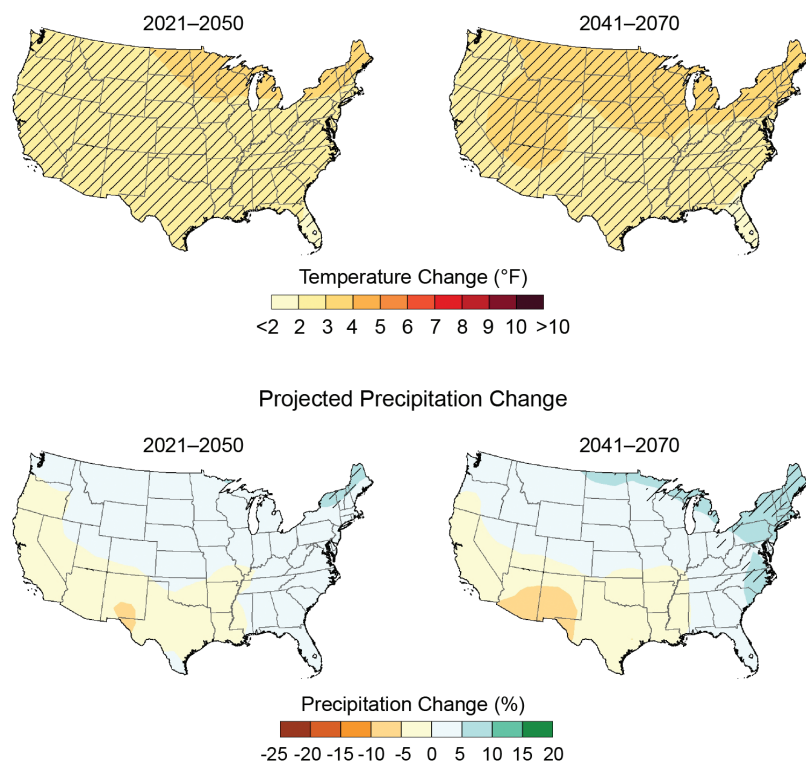
### Projected Climate Change

Projections of future climate conditions are based on results from climate models—sophisticated computer programs that simulate the behavior of the Earth’s climate system. These climate models are used to project how the climate system is expected to change under different possible scenarios. These scenarios describe future changes in atmospheric greenhouse gas concentrations, land use, other human influences on climate, and natural factors. The most recent set of coordinated climate model simulations use a set of scenarios called Representative Concentration Pathways (RCPs), which describe four possible trajectories in greenhouse gas concentrations.<sup>1</sup> Actual future greenhouse gas concentrations, and the resulting amount of future climate change, will still largely be determined by choices society makes about emissions.<sup>2</sup> The RCPs, and the temperature increases associated with these scenarios, are described in more detail in Appendix 1: Technical Support Document and in the 2014 NCA.<sup>3, 5, 6</sup>

Some of the projected changes in climate in the United States as described in the 2014 NCA are listed below:<sup>2, 3</sup>

- Temperatures in the United States are expected to continue to rise. This temperature rise has not been, and will not be, uniform across the country or over time (Figure 3, top panels).
- Increases are also projected for extreme temperature conditions. The temperature of both the hottest day and coldest night of the year are projected to increase (Figure 4, top panels).
- More winter and spring precipitation is projected for the northern United States, and less for the Southwest, over this century (Figure 3, bottom panels).
- Increases in the frequency and intensity of extreme precipitation events are projected for all U.S. areas (Figure 4, bottom panels).
- Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, the southern Great Plains, and the Southeast. Trends in reduced surface and groundwater supplies in many areas are expected to continue, increasing the likelihood of water shortages for many uses.

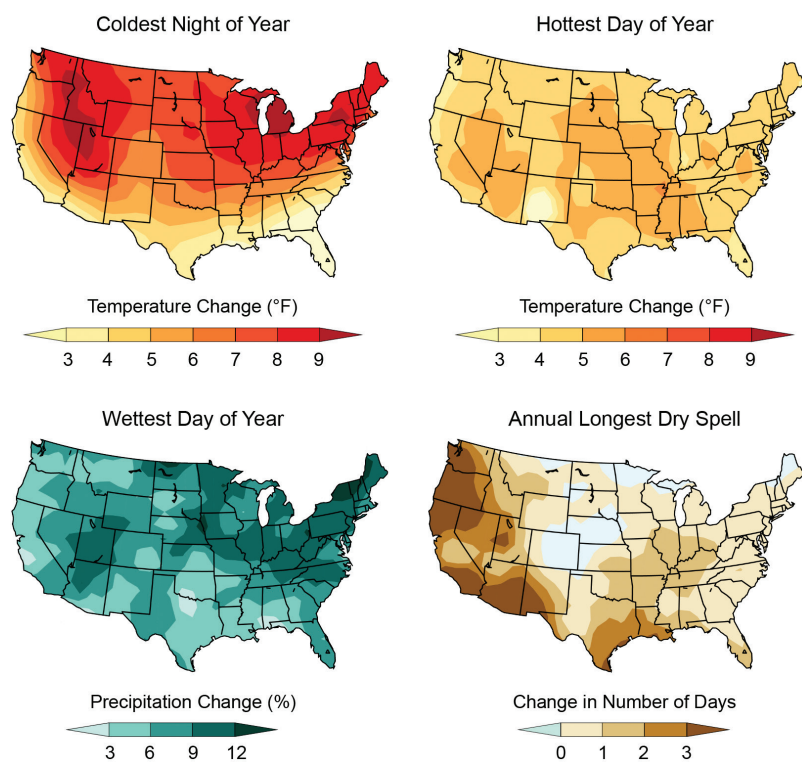
### Projected Changes in Temperature and Precipitation by Mid-Century



**Figure 3:** Projected changes in annual average temperature (top) and precipitation (bottom) for 2021–2050 (left) and 2041–2070 (right) with respect to the average for 1971–2000 for the RCP6.0 scenario. The RCP6.0 pathway projects an average global temperature increase of 5.2°F in 2100 over the 1901–1960 global average temperature (the RCPs are described in more detail in Appendix 1: Technical Support Document). Temperature increases in the United States for this scenario (top panels) are in the 2°F to 3°F range for 2021 to 2050 and 2°F to 4°F for 2041 to 2070. This means that the increase in temperature projected in the United States over the next 50 years under this scenario would be larger than the 1°F to 2°F increase in temperature that has already been observed over the previous century. Precipitation is projected to decrease in the Southwest and increase in the Northeast (bottom panels). These projected changes are statistically significant (95% confidence) in small portions of the Northeast, as indicated by the hatching. (Figure source: adapted from Sun et al. 2015)<sup>54</sup>



## Projected Changes in the Hottest/Coldest and Wettest/Driest Day of the Year



**Figure 4:** Projected changes in several climate variables for 2046–2065 with respect to the 1981–2000 average for the RCP6.0 scenario. These include the coldest night of the year (top left) and the hottest day of the year (top right). By the middle of this century, the coldest night of the year is projected to warm by 6°F to 10°F over most of the country, with slightly smaller changes in the south. The warmest day of the year is projected to be 4°F to 6°F warmer in most areas. Also shown are projections of the wettest day of the year (bottom left) and the annual longest consecutive dry day spell (bottom right). Extreme precipitation is projected to increase, with an average change of 5% to 15% in the precipitation falling on the wettest day of the year. The length of the annual longest dry spell is projected to increase in most areas, but these changes are small: less than two days in most areas. (Figure source: adapted from Sun et al. 2015)<sup>54</sup>

- Heat waves are projected to become more intense, and cold waves less intense, everywhere in the United States.
- Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.

### 1.2 How Does Climate Change Affect Health?

The influences of weather and climate on human health are significant and varied. They range from the clear threats of temperature extremes and severe storms to connections that may seem less obvious. For example, weather and climate affect the survival, distribution, and behavior of mosquitoes, ticks, and rodents that carry diseases like West Nile virus or Lyme disease. Climate and weather can also affect water and food quality in particular areas, with implications for human health. In addition, the effects of global climate change on mental health and well-being are integral parts of the overall climate-related human health impact.

A useful approach to understand how climate change affects health is to consider specific exposure pathways and how they can lead to human disease. The concept of exposure pathways is adapted from its use in chemical risk assessment, and in this context describes the main routes by which climate change affects health (see Figure 5). Exposure pathways differ over time and in different locations, and climate change related exposures can affect different people and different communities to different degrees. While often assessed individually, exposure to multiple climate change threats can occur simultaneously,

resulting in compounding or cascading health impacts. Climate change threats may also accumulate over time, leading to longer-term changes in resilience and health.

Whether or not a person is exposed to a health threat or suffers illness or other adverse health outcomes from that exposure depends on a complex set of vulnerability factors. Vulnerability is the tendency or predisposition to be adversely affected by climate-related health effects, and encompasses three elements: exposure, sensitivity or susceptibility to harm, and the capacity to adapt or to cope (see also Figure 1 in Ch. 9: Populations of Concern). Because multiple disciplines use these terms differently and multiple definitions exist in the literature, the distinctions between them are not always clear.<sup>7</sup> All three of these elements can change over time and are place- and system-specific.<sup>8</sup> In the context of this report, we define the three elements of vulnerability as follows (definitions adapted from IPCC 2014 and NRC 2012)<sup>9,10</sup>

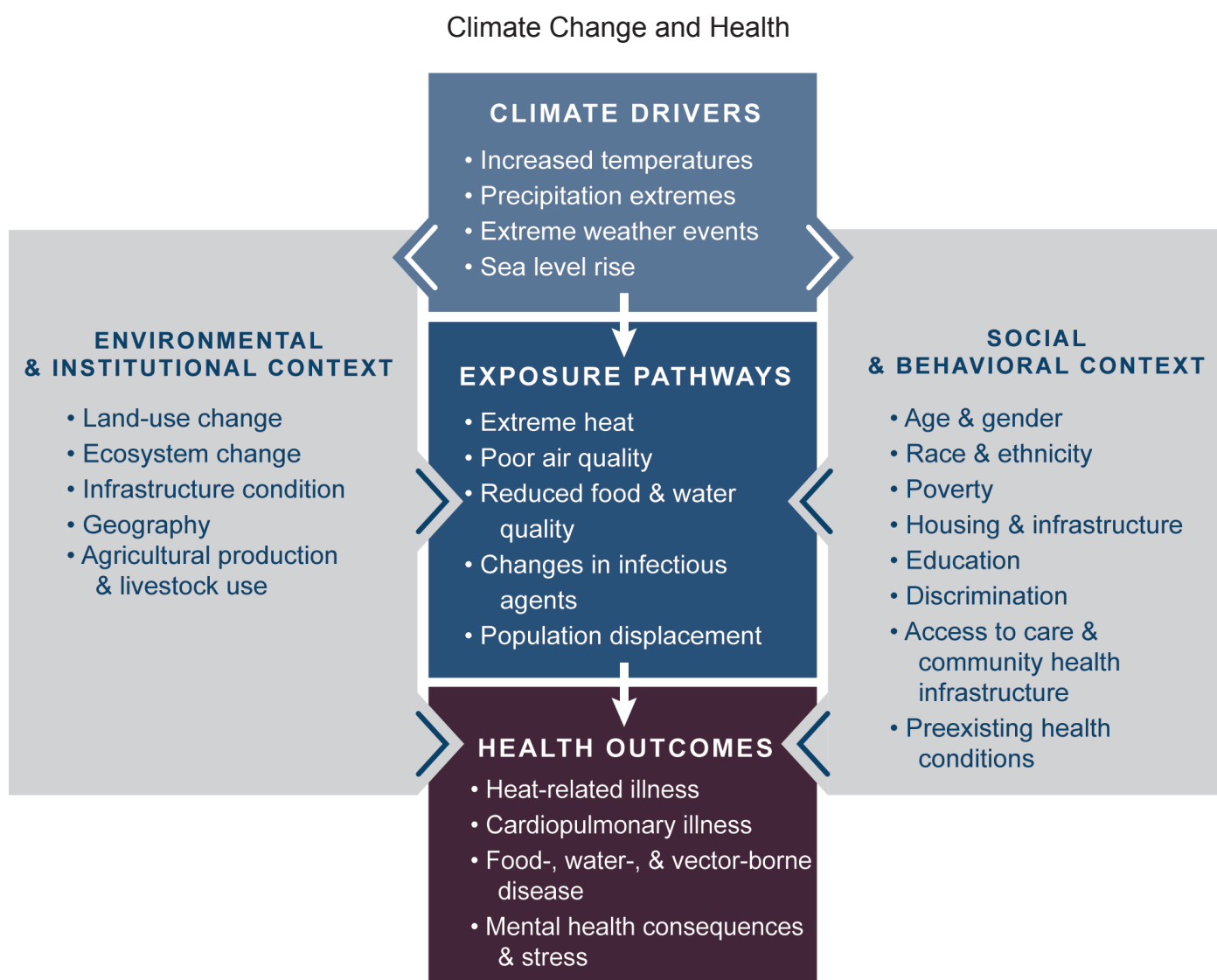
- **Exposure** is contact between a person and one or more biological, psychosocial, chemical, or physical stressors, including stressors affected by climate change. Contact may occur in a single instance or repeatedly over time, and may occur in one location or over a wider geographic area.
- **Sensitivity** is the degree to which people or communities are affected, either adversely or beneficially, by climate variability or change.

- **Adaptive capacity** is the ability of communities, institutions, or people to adjust to potential hazards, to take advantage of opportunities, or to respond to consequences. A related term, *resilience*, is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.

Vulnerability, and the three components of vulnerability, are factors that operate at multiple levels, from the individual and community to the country level, and affect all people to some degree.<sup>8</sup> For an individual, these factors include human behavioral choices and the degree to which that person is vulnerable based on his or her level of exposure, sensitivity, and adaptive capacity. Vulnerability is also influenced by social determinants of health (see Ch. 9 Populations of Concern), including those that affect a person’s adaptive capacity, such as social capital

and social cohesion (for example, the strength of interpersonal networks and social patterns in a community).

At a larger community or societal scale, health outcomes are strongly influenced by adaptive capacity factors, including those related to the natural and built environments (for example, the state of infrastructure), governance and management (health-protective surveillance programs, regulations and enforcement, or community health programs), and institutions (organizations operating at all levels to form a national public health system).<sup>11, 12</sup> For example, water resource, public health, and environmental agencies in the United States provide many public health safeguards, such as monitoring water quality and issuing advisories to reduce risk of exposure and illness if water becomes contaminated. Some aspects of climate change health impacts in the United States may therefore be



**Figure 5:** Conceptual diagram illustrating the exposure pathways by which climate change affects human health. Exposure pathways exist within the context of other factors that positively or negatively influence health outcomes (gray side boxes). Key factors that influence vulnerability for individuals are shown in the right box, and include social determinants of health and behavioral choices. Key factors that influence vulnerability at larger scales, such as natural and built environments, governance and management, and institutions, are shown in the left box. All of these influencing factors can affect an individual’s or a community’s vulnerability through changes in exposure, sensitivity, and adaptive capacity and may also be affected by climate change.

mediated by factors like strong social capital, fully functional governance/management, and institutions that maintain the Nation's generally high level of adaptive capacity. On the other hand, the evidence base regarding the effectiveness of public health interventions in a climate change context is still relatively weak.<sup>13</sup> Current levels of adaptive capacity may not be sufficient to address multiple impacts that occur simultaneously or in close succession, or impacts of climate change that result in unprecedented damages.<sup>2, 12</sup>

The three components of vulnerability (exposure, sensitivity, and adaptive capacity) are associated with social and demographic factors, including level of wealth and education, as well as other characteristics of people and places, such as the condition of infrastructure and extent of ecosystem degradation. For example, poverty can leave people more exposed to climate and weather threats, increase sensitivity because of associations with higher rates of illness and nutritional deficits, and limit people's adaptive capacity. As another example, people living in a city with degraded coastal ecosystems and inadequate water and wastewater infrastructure may be at greater risk of health consequences from severe storms. Figure 5 demonstrates the interactions among climate drivers, health impacts, and other factors that influence people's vulnerability to health impacts.

We are already experiencing changes in the frequency, severity, and even the location of some weather and climate

phenomena, including extreme temperatures, heavy rains and droughts, and some other kinds of severe weather, and these changes are projected to continue. This means that areas already experiencing health-threatening weather and climate phenomena, such as severe heat or hurricanes, are likely to experience worsening impacts, such as even higher temperatures and increased storm intensity, rainfall rates, and storm surge. It also means that some areas will experience new climate-related health threats. For example, areas previously unaffected by toxic algal blooms or waterborne diseases because of cooler water temperatures may face these hazards in the future as increasing water temperatures allow the organisms that

cause these health risks to thrive. Even areas that currently experience these health threats may see a shift in the timing of the seasons that pose the greatest risk to human health.

Climate change can therefore affect human health in two main ways: first, by changing the severity or frequency of health problems that are already affected by climate or weather factors; and second, by creating unprecedented or unanticipated health problems or health threats in places where they have not previously occurred.

### 1.3 Our Changing Health

In order to understand how climate change creates or exacerbates health problems, assessments of climate change health impacts must start with what is known about the current state and observed trends in a wide array of health conditions. In addition, because preexisting health conditions, socioeconomic status, and life stage all contribute to *vulnerability* to climate-related and weather-related health effects, assessments of climate change health impacts should be informed by projected changes in these factors. In cases where people's health or socioeconomic status is getting worse, climate change may accentuate the health burdens associated with those worsening trends. Conversely, in cases where people's health or socioeconomic status is improving, the effect of climate change may be to slow or reduce that improvement. Where the state of scientific understanding allows, the inclusion of projected trends in health and socioeconomic conditions into models of climate change impacts on health can provide useful insights into these interactions between non-climate factors and climate change effects.

#### Demographic and Socioeconomic Trends

The United States is in the midst of several significant demographic changes: the population is aging, growing in number, becoming more ethnically diverse, and demonstrating greater disparities between the wealthy and the poor. Immigration is

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*Current levels of adaptive capacity may not be sufficient to address multiple impacts that occur simultaneously or in close succession, or impacts of climate change that result in unprecedented damages.*

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Storm-damaged home after Hurricane Sandy.



## Terminology

**Incidence:** A measure of the frequency with which an event, such as a new case of illness, occurs in a population over a period of time.

**Morbidity:** A disease or condition that reduces health and the quality of life. The morbidity rate is a measure of the frequency of disease among a defined population during a specified time period.

**Mortality:** Death as a health outcome. The mortality rate is the number of deaths in a defined population during a specified time period.

**Premature (early) mortality or death:** Deaths that occur earlier than a specified age, often the average life expectancy at birth.

**Prevalence:** A measure of the number or proportion of people with a specific disease or condition at a specific point in time.

**Surveillance:** The collection, analysis, interpretation, and dissemination of health data.

having a major influence on both the size and age distribution of the population.<sup>14</sup> Each of these demographic trends has implications for climate change related human health impacts (see Ch. 9: Populations of Concern). Some of these trends and projections are summarized below:

### Trends in population growth

- The total U.S. population has more than doubled since 1950, from 151,325,798 persons in 1950 to 308,745,538 in 2010.<sup>15</sup>
- The Census Bureau projects that the U.S. population will grow to almost 400 million by 2050 (from estimates of about 320 million in 2014).<sup>16</sup>

### Trends in the elderly population

- The nation's older adult population (ages 65 and older) will nearly double in number from 2015 through 2050, from approximately 48 million to 88 million.<sup>17</sup> Of those 88 million older adults, a little under 19 million will be 85 years of age and older.<sup>18</sup>

### Trends in racial and ethnic diversity

- As the United States becomes more diverse, the aggregate minority population is projected to become the majority by 2042.<sup>17</sup> The non-Hispanic or non-Latino White population will increase, but more slowly than other racial groups. Non-Hispanic Whites are projected to become a minority by 2050.<sup>19</sup>

- Projections for 2050 suggest that nearly 19% of the population will be immigrants, compared with 12% in 2005.<sup>19</sup>
- The Hispanic population is projected to nearly double from 12.5% of the U.S. population in 2000 to 24.6% in 2050.<sup>20</sup>

### Trends in economic disparity

- Income inequality rose and then stabilized during the last 30 years, and is projected to resume rising over the next 20 years, though at a somewhat slower overall rate that declines to near zero by 2035.<sup>21</sup> For example, the Gini coefficient, a measure of income inequality, is estimated to have risen by 18% between 1984 and 2000, and is projected to rise by an additional 17% for all workers between 2009 and 2035.<sup>21</sup>
- America's communities of color have disproportionately higher poverty rates and lower income levels. While racial disparities in household wealth were higher in the late 1980s than now, trends in more recent years have been toward greater inequality. The ratio of the median net household worth of White, non-Hispanic versus non-White or Hispanic households increased from 6.0 to 7.8 between 2007 and 2013.<sup>22</sup> In 2009, 25.8% of non-Hispanic Blacks and 25.3% of Hispanics had incomes below the poverty level as compared to 9.4% of non-Hispanic Whites and 12.5% of Asian Americans.<sup>23</sup> In 2014, the median income level for a non-Hispanic Black household was approximately \$35,000, \$25,000 lower than a non-Hispanic White household.<sup>24</sup>

Population growth and migration in the United States may place more people at risk of the health impacts of climate change, especially as more people are located in and around vulnerable areas, such as coastal, low-lying, or flood-prone zones;<sup>25</sup> densely populated urban areas;<sup>26</sup> and drought-stricken or wildfire-prone regions. Increases in racial and ethnic diversity and in the number of persons living near the poverty line may increase the risk of health impacts from climate change. Economic disparity can make it difficult for some populations to respond to dangerous weather conditions, especially when evacuation is necessary or when the aftermath requires rebuilding of homes and businesses not covered by home or property insurance.

### Trends in Health Status

As a nation, trends in the population's health are mixed. Some major indicators of health, such as life expectancy, are consistently improving, while others, such as rate and number of diabetes deaths, are getting worse. Changes in these metrics may differ across populations and over time. For example, though rates of obesity have increased in both children and adults over the last 30 years or more, rates over just the last decade have remained steady for adults but increased among children.<sup>27</sup>



Climate change impacts to human health will act on top of these underlying trends. Some of these underlying health conditions can increase sensitivity to climate change effects such as heat waves and worsening air quality (see Ch. 2: Temperature-Related Death and Illness; Ch. 3: Air Quality Impacts; Ch. 9: Populations of Concern). Understanding the trends in these conditions is therefore important in considering how many people are likely to experience illness when exposed to these climate change effects. Potential climate change related health impacts may reduce the improvements that would otherwise be expected in some indicators of health status and accentuate trends towards poorer health in other health indicators.<sup>1, 28</sup>

Examples of health indicators that have been improving between 2000 and 2013 include the following:

- Life expectancy at birth increased from 76.8 to 78.8 years.<sup>29</sup>
- Death rates per 100,000 people from heart disease and cancer decreased from 257.6 to 169.8 and from 199.6 to 163.2, respectively.<sup>29</sup>
- The percent of people over age 18 who say they smoke decreased from 23.2% to 17.8%.<sup>29</sup>

At the same time, some health trends related to the prevalence of chronic diseases, self-reported ill health, and disease risk factors have been getting worse. For example:



Diabetes increases sensitivity to heat stress.

- The percentage of adult (18 years and older) Americans describing their health as “poor or fair” increased from 8.9% in 2000 to 10.3% in 2012.<sup>29</sup>
- Prevalence of physician-diagnosed diabetes among adults aged 20 and over increased from 5.2% in 1988–1994 to 8.4% in 2009–2012.<sup>29</sup>
- The prevalence of obesity among adults (aged 20–74) increased by almost three-fold from 1960–1962 (13.4% of adults classified as obese) to 2009–2010 (36.1% of adults classified as obese).<sup>30</sup>
- In the past 30 years, obesity has more than doubled in children and quadrupled in adolescents in the United States. The percentage of children aged 6–11 who were obese increased from 7% in 1980 to nearly 18% in 2012. Similarly, the percentage of adolescents aged 12–19 years who were obese increased from 5% to nearly 21% over the same period. In 2012, approximately one-third of American children and adolescents were overweight or obese.<sup>31</sup>

Table 1 shows some examples of underlying health conditions that are associated with increased vulnerability to health effects from climate change related exposures (see Ch. 9: Populations of Concern for more details) and provides information on current status and future trends.

Health status is often associated with demographics and socioeconomic status. Changes in the overall size of the population, racial and ethnic composition, and age distribution affect the health status of the population. Poverty, educational attainment, access to care, and discrimination all contribute to disparities in the incidence and prevalence of a variety of medical conditions (see Ch. 9: Populations of Concern). Some examples of these interactions include:

**Older Adults.** In 2013, the percentage of adults age 75 and older described as persons in fair or poor health totaled 27.6%, as compared to 6.2% for adults age 18 to 44.<sup>29</sup> Among adults age 65 and older, the number in nursing homes or other residential care facilities totaled 1.8 million in 2012, with more than 1 million utilizing home health care.<sup>32</sup>

**Children.** Approximately 9.0% of children in the United States have asthma. Between 2011 and 2013, rates for Black (15.3%) and Hispanic (8.6%) children were higher than the rate for White (7.8%) children.<sup>29</sup> Rates of asthma were also higher in poor children who live below 100% of the poverty level (12.4%).<sup>29</sup>

**Table 1: Current estimates and future trends in chronic health conditions that interact with the health risks associated with climate change.**

Health Conditions	Current Estimates	Future Trends	Possible Influences of Climate Change
<b>Alzheimer's Disease</b>	Approximately 5 million Americans over 65 had Alzheimer's disease in 2013. <sup>33</sup>	Prevalence of Alzheimer's is expected to triple to 13.8 million by 2050. <sup>33</sup>	Persons with cognitive impairments are vulnerable to extreme weather events that require evacuation or other emergency responses.
<b>Asthma</b>	Average asthma prevalence in the U.S. was higher in children (9% in 2014) <sup>29</sup> than in adults (7% in 2013). <sup>34</sup> Since the 1980s, asthma prevalence increased, but rates of asthma deaths and hospital admissions declined. <sup>35, 36</sup>	Stable incidence and increasing prevalence of asthma is projected in the U.S. in coming decades.	Asthma is exacerbated by changes in pollen season and allergenicity and in exposures to air pollutants affected by changes in temperature, humidity, and wind. <sup>28</sup>
<b>Chronic Obstructive Pulmonary Disease (COPD)</b>	In 2012, approximately 6.3% of adults had COPD. Deaths from chronic lung diseases increased by 50% from 1980 to 2010. <sup>37, 38</sup>	Chronic respiratory diseases are the third leading cause of death and are expected to become some of the most costly illnesses in coming decades. <sup>37</sup>	COPD patients are more sensitive than the general population to changes in ambient air quality associated with climate change.
<b>Diabetes</b>	In 2012, approximately 9% of the total U.S. population had diabetes. Approximately 18,400 people younger than age 20 were newly diagnosed with type 1 diabetes in 2008–2009; an additional 5,000 were diagnosed with type 2. <sup>39</sup>	New diabetes cases are projected to increase from about 8 cases per 1,000 in 2008 to about 15 per 1,000 in 2050. If recent increases continue, prevalence is projected to increase to 33% of Americans by 2050. <sup>40</sup>	Diabetes increases sensitivity to heat stress; medication and dietary needs may increase vulnerability during and after extreme weather events.
<b>Cardiovascular Disease</b>	Cardiovascular disease (CVD) is the leading cause of death in the U.S. <sup>41</sup>	By 2030, approximately 41% of the U.S. population is projected to have some form of CVD. <sup>42</sup>	Cardiovascular disease increases sensitivity to heat stress.
<b>Mental Illness</b>	Depression is one of the most common types of mental illness, with approximately 7% of adults reporting a major episode in the past year. Lifetime prevalence is approximately twice as high for women as for men. <sup>43</sup> Lifetime prevalence is more than 15% for anxiety disorders and nearly 4% for bipolar disorder. <sup>44</sup>	By 2050, the total number of U.S. adults with depressive disorder is projected to increase by 35%, from 33.9 million to 45.8 million, with those over age 65 having a 117% increase. <sup>43</sup>	Mental illness may impair responses to extreme events; certain medications increase sensitivity to heat stress.
<b>Obesity</b>	In 2009–2010, approximately 35% of American adults were obese. <sup>31</sup> In 2012, approximately 32% of youth (aged 2–19) were overweight or obese. <sup>45, 46</sup>	By 2030, 51% of the U.S. population is expected to be obese. Projections suggest a 33% increase in obesity and a 130% increase in severe obesity. <sup>47</sup>	Obesity increases sensitivity to high ambient temperatures.
<b>Disability</b>	Approximately 18.7% of the U.S. population has a disability. In 2010, the percent of American adults with a disability was approximately 16.6% for those age 21–64 and 49.8% for persons 65 and older. <sup>48</sup>	The number of older adults with activity limitations is expected to grow from 22 million in 2005 to 38 million in 2030. <sup>49</sup>	Persons with disabilities may find it hard to respond when evacuation is required and when there is no available means of transportation or easy exit from residences

**Non-Hispanic Blacks.** In 2014, the percentage of non-Hispanic Blacks of all ages who were described as persons in fair or poor health totaled 14.3% as compared to 8.7% for Whites. Health risk factors for this population include high rates of smoking, obesity, and hypertension in adults, as well as high infant death rates.<sup>29</sup>

**Hispanics.** The percentage of Hispanics of all ages who were described as persons in fair or poor health totaled 12.7% in 2014. Health disparities for Hispanics include moderately higher rates of smoking in adults, low birth weights, and infant deaths.<sup>29</sup>

The impacts of climate change may worsen these health disparities by exacerbating some of the underlying conditions they create. For example, disparities in life expectancy may be exacerbated by the effects of climate change related heat and air pollution on minority populations that have higher rates of hypertension, smoking, and diabetes. Conversely, public health measures that reduce disparities and overall rates of illness in populations would lessen vulnerability to worsening of health status from climate change effects.

### 1.4 Quantifying Health Impacts

For some changes in exposures to health risks related to climate change, the future rate of a health impact associated with any given environmental exposure can be estimated by multiplying three values: 1) the baseline rate of the health impact, 2) the expected change in exposure, and 3) the exposure–response function. An exposure–response function is an estimate of how the risk of a health impact changes with changes in exposures, and is related to sensitivity, one of the three components of vulnerability. For example, an exposure–response function for extreme heat might be used to quantify the increase in heat-related deaths in a region (the change in health impact) for every 1°F increase in daily ambient temperature (the change in exposure).



The ability to quantify many types of health impacts is dependent on the availability of data on the baseline incidence or prevalence of the health impact, the ability to characterize the future changes in the types of exposures relevant to that health impact, and how well the relationship between these exposures and health impacts is understood. Health impacts with many intervening factors, like infectious diseases, may require different and more complex modeling approaches. Where our understanding of these relationships is strong, some health impacts, even those occurring in unprecedented places or times of the year, may in fact be predictable.



Asthma affects approximately 9% of children in the United States.

Where there is a lack of data or these relationships are poorly understood, health impacts are harder to project. For more information on exposure–response (also called dose–response or concentration–response) functions, see the Exposure–Response section in Appendix 1: Technical Support Document.

Information on trends in underlying health or background rates of health impacts is summarized in Section 1.3, “Our Changing Health.” Data on the incidence and prevalence of health conditions are obtained through a complicated system of state- and city-level surveillance programs, national health surveys, and national collection of data on hospitalizations, emergency room visits, and deaths. For example, data on the incidence of a number of infectious diseases are captured through the National Notifiable Diseases Surveillance System.<sup>50</sup>

This system relies first on the mandatory reporting of specific diseases by health care providers to state, local, territorial, and tribal health departments. These reporting jurisdictions then have the option of voluntarily providing the Centers for Disease Control and Prevention (CDC) with data on a set of nationally notifiable diseases. Because of challenges with getting health care providers to confirm and report specific diagnoses of reportable diseases in their patients, and the lack of requirements for reporting a consistent set of diseases and forwarding data to CDC, incidence of infectious disease is generally believed to be underreported, and actual rates are uncertain.<sup>51</sup>



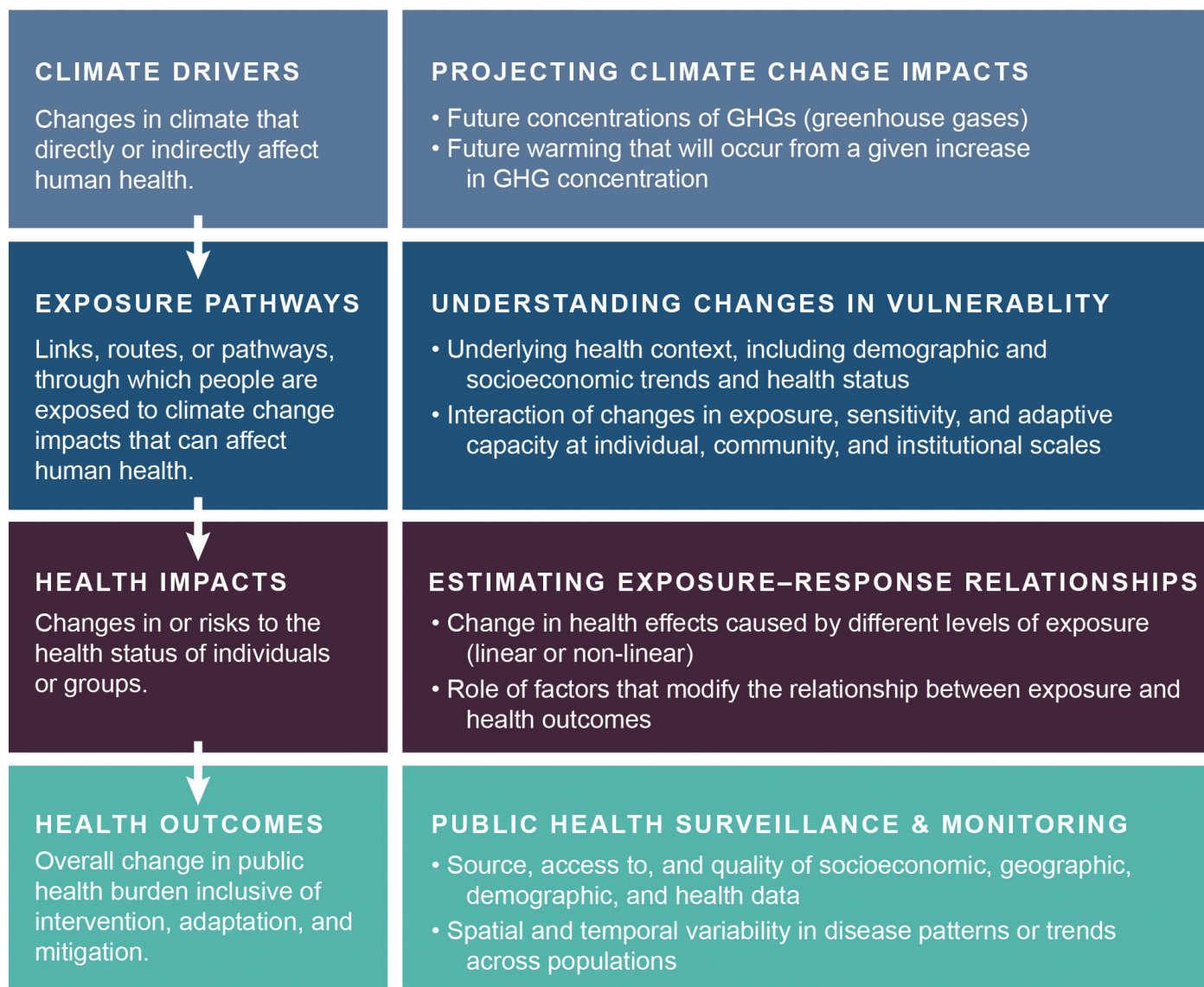
Characterizing certain types of climate change related exposures can be a challenge. Exposures can consist of temperature changes and other weather conditions, inhaling air pollutants and pollens, consuming unsafe food supplies or contaminated water, or experiencing trauma or other mental health consequences from weather disasters. For some health impacts, the ability to understand the relationships between climate-related exposures and health impacts is limited by these difficulties in characterizing exposures or in obtaining accurate data on the occurrence of illnesses. For these health impacts, scientists may not have the capability to project changes in a health outcome (like incidence of diseases), and can only estimate how risks of exposure will change. For example, modeling capabilities allow projections of the impact of rising water temperatures on the concentration of *Vibrio* bacteria, which provides an understanding of geographic changes

in exposure but does not capture how people may be exposed and how many will actually become sick (see Ch. 6: Water-Related Illness). Nonetheless, the ability to project changes in exposure or in intermediate determinants of health impacts may improve understanding of the change in health risks, even if modeling quantitative changes in health impacts is not possible. For example, seasonal temperature and precipitation projections may be combined to assess future changes in ambient pollen concentrations (the exposure that creates risk), even though the potential associated increase in respiratory and allergic diseases (the health impacts) cannot be directly modeled (see Ch. 3: Air Quality Impacts).

### Modeling Approaches Used in this Report

Four chapters within this assessment—Ch. 2: Temperature-Related Death and Illness, Ch. 3: Air Quality Impacts, Ch. 5:

## Sources of Uncertainty



**Figure 6:** Examples of sources of uncertainty in projecting impacts of climate change on human health. The left column illustrates the exposure pathway through which climate change can affect human health. The right column lists examples of key sources of uncertainty surrounding effects of climate change at each stage along the exposure pathway.



Vector-Borne Diseases, and Ch. 6: Water-Related Illness—in-clude new peer-reviewed, quantitative analyses based on modeling. The analyses highlighted in these chapters mainly relied on climate model output from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Due to limited data availability and computational resources, the studies high-ighted in the four chapters analyzed only a subset of the full CMIP5 dataset, with most of the studies including at least one analysis based on RCP6.0, an upper midrange greenhouse gas concentration pathway, to facilitate comparisons across chapters. For example, the air quality analysis examined results from two different RCPs, with a different climate model used for each, while the waterborne analyses examined results from 21 of the CMIP5 models for a single RCP. See the Guide to the Report and Appendix 1: Technical Support Document for more on modeling and scenarios.

Adverse health effects attributed to climate change can have many economic and social consequences, including direct medical costs, work loss, increased care giving, and other lim-itations on everyday activities. Though economic impacts are a crucial component to understanding risk from climate change, and may have important direct and secondary impacts on human health and well-being by reducing resources available for other preventative health measures, economic valuation of the health impacts was not reported in this assessment.

### Uncertainty in Health Impact Assessments

Figure 6 illustrates different sources of uncertainty along the exposure pathway.

Two of the key uncertainties in projecting future global temperatures are 1) uncertainty about future concentrations of greenhouse gases, and 2) uncertainty about how much warming will occur for a given increase in greenhouse gas concentrations. The Intergovernmental Panel on Climate Change’s Fifth Assessment Report found that the most likely response of the climate system to a doubling of carbon dioxide concentra-tions lies between a 1.5°C and 4.5°C (2.7°F to 8.1°F) increase in global average temperature.<sup>1</sup> Future concentrations depend on both future emissions and how long these emissions remain in the atmosphere (which can vary depending on how natural systems process those emissions). To capture these uncertainties, climate modelers often use multiple models, analyze multiple scenarios, and conduct sensitivity analyses to assess the significance of these uncertainties.

Uncertainty in current and future estimates of health or socio-economic status is related to several factors. In general, esti-mates are more uncertain for less-prevalent health conditions

(such as rare cancers versus cardiovascular disease), smaller subpopulations (such as Hispanic subpopulations versus White adults), smaller geographic areas (census tracts versus state or national scale), and time periods further into the future (decades versus seasons or years). Most current estimates of disease prevalence or socioeconomic status have uncertainty expressed as standard errors or confidence intervals that are

derived from sampling methods and sample sizes. When model-ing health impacts using data on health prevalence or socioeco-nomic status, these measures of uncertainty are typically included in the analysis to help establish a range of plausible results. Expert judgment is typ-ically used to assess the overall

effects of uncertainty from estimates of health or socioeco-nomic status when assessing the scientific literature.

The factors related to uncertainty in exposure–response func-tions are similar to those for the projections of health or so-cioeconomic status. Estimates are more uncertain for smaller subpopulations, less-prevalent health conditions, and smaller geographic areas. Because these estimates are based on observations of real populations, their validity when applied to populations in the future is more uncertain the further into the future the application occurs. Uncertainty in the estimates of the exposure–outcome relationship also comes from factors related to the scientific quality of relevant studies, including appropriateness of methods, source of data, and size of study populations. Expert judgment is used to evaluate the validity of an individual study as well as the collected group of rele-vant studies in assessing uncertainty in estimates of exposure–outcome relationships.

### Approach to Reporting Uncertainty in Key Findings

Despite the sources of uncertainty described above, the cur-rent state of the science allows an examination of the likely di-rection of and trends in the health impacts of climate change. Over the past ten years, the models used for climate and health assessments have become more useful and more ac-curate (for example, Melillo et al. 2014).<sup>6, 52, 53</sup> This assessment builds on that improved capability. A more detailed discussion of the approaches to addressing uncertainty from the various sources can be found in the Guide to the Report and Appendix 1: Technical Support Document.

Two kinds of language are used when describing the un-certainty associated with specific statements in this report: confidence language and likelihood language. Confidence in the validity of a finding is expressed qualitatively and is based on the type, amount, quality, strength, and consistency of evidence and the degree of expert agreement on the finding. Likelihood, or the projected probability of an impact occurring,

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*Adverse health effects attributed to climate change can have many economic and social consequences, including direct medical costs, work loss, increased care giving, and other limitations on everyday activities*

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is based on quantitative estimates or measures of uncertainty expressed probabilistically (in other words, based on statistical analysis of observations or model results, or on expert judgment). Whether a Key Finding has a confidence level associated with it or, where findings can be quantified, both a confidence and likelihood level associated with it, involves the expert assessment and consensus of the chapter author teams.

Confidence Level	Likelihood
<b>Very High</b>	<b>Very Likely</b>
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	$\geq 9$ in 10
<b>High</b>	<b>Likely</b>
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	$\geq 2$ in 3
<b>Medium</b>	<b>As Likely As Not</b>
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	$\approx 1$ in 2
<b>Low</b>	<b>Unlikely</b>
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts	$\leq 1$ in 3
	<b>Very Unlikely</b>
	$\leq 1$ in 10

## PHOTO CREDITS

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Pg. 26—Doctor showing girl how to use stethoscope: © John Fedele/Blend Images/Corbis

Pg. 31—Collapsed house after Hurricane Sandy: © iStockPhoto.com/Aneese

Pg. 33—Woman checking blood sugar levels: © Monkey Business Images/Corbis

Pg. 35—Girl suffering from asthma: © Stephen Welstead/LWA/Corbis

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