CHAPTER 1

Introduction

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1.1 SCOPE AND APPROACH OF SAP 4.6

The Global Change Research Act of 1990 (Public Law 101-606) calls for the periodic assessment of the impacts of global environmental change for the United States. In 2001, a series of sector and regional assessments were conducted by the U.S. Global Change Research Program as part of the First National Assessment of the Potential Consequences of Climate Variability and Change on the United States. Subsequently, the U.S. Climate Change Science Program developed a *Strategic Plan* (CCSP, 2003) calling for the preparation of 21 synthesis and assessment products (SAPs) to inform policy making and adaptive management across a range of climate-sensitive issues. Synthesis and Assessment Product 4.6 examines the effects of global change on human systems. This product addresses Goal 4 of the five strategic goals set forth in the CCSP *Strategic Plan* to "understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes" (CCSP, 2003). The "global changes" assessed in this report include: climate variability and change, evolving patterns of land use within the United States, and changes in the nation's population.

While the mandate for the preparation of this report calls for evaluating the impacts of *global* change, the emphasis is on those impacts associated with climate change. Collectively, global changes are human problems, not simply problems for the natural or the physical world. Hence, this SAP examines the vulnerability of human health and socioeconomic systems to climate change across three foci, including: human health, human settlements, and human welfare. The three topics are fundamentally linked but unique dimensions of global change.

Human health is one of the most basic and direct measures of human welfare. Following past assessments of climate change impacts on human health, SAP 4.6 focuses on human morbidity and mortality associated with extreme weather, vector-, water- and food-borne diseases, and changes in air quality in the United States. However, it should be noted that climate change in other parts of the world could impact human health in the United States. (*e.g.*, by affecting migration into the U.S., the safety of food imported into the U.S., etc.). Adaptation is a key component to evaluating human health vulnerabilities, including consideration of public health interventions (such as prevention, response, and treatment strategies) that could be revised, supplemented, or implemented to protect human health and determine how much adaptation could be achieved.

Settlements are where people live. Humans live in a wide variety of settlements in the United States, ranging from small villages and towns with a handful of people to metropolitan regions with millions of inhabitants. In particular, SAP 4.6 focuses on urban and highly developed population centers in the United States. Because of their high population density, urban areas multiply human health risks, and this is compounded by their relatively high proportions of the very old, the very young, and the poor. In addition, the components of infrastructure that support settlements, such as energy, water supply, transportation, and waste disposal, have varying degrees of vulnerability to climate change.

Welfare is an economic term used to describe the state of well-being of humans on an individual or collective basis. Human welfare is an elusive concept, and there is no single, commonly accepted definition or approach to thinking about welfare. There is, however, a shared understanding that increases in human welfare are associated with improvements in individual and communal conditions in areas such as political power, individual freedom, economic power, social contacts, health and opportunities for leisure and recreation, along with reductions in injury, stress, and loss. The physical environment, with climate as one aspect, is among many factors that can affect human welfare via economic, physical, psychological, and social pathways that influence individual perceptions of quality of life. Some core aspects of quality of life are expressed directly in markets (*e.g.*, income, consumption, personal wealth, etc.). The focus in SAP 4.6 is on non-market effects, although, these aspects of human welfare are often difficult to measure and value (Mendelsohn *et al*., 1999; EPA, 2000).

The other Synthesis and Assessment Products related to CCSP's Goal 4 include reports on climate impacts on sea level rise (SAP 4.1), ecosystem changes (SAP 4.2), agricultural production (SAP 4.3), adaptive options for climate sensitive ecosystems (SAP 4.4), energy use (SAP 4.5), and transportation system impacts along the Gulf Coast (SAP 4.7). Collectively, these reports provide an overview of climate change impacts and adaptations related to a range of human conditions in the United States.

The audience for this report includes research scientists, public health practitioners, resource managers, urban planners, transportation planners, elected officials and other policy makers, and concerned citizens. A recent National Research Council analysis of global change assessments argues that the best assessments have an audience asking for them and a broad range of stakeholders (U.S. National Research Council, 2007). This report clearly identifies the pertinent audience and what decisions it will inform.

Chapters 2–4 describe the impacts of climate change on human systems and outline opportunities for adaptation. SAP 4.6 addresses the questions of how and where climate change may impact U.S. socio-economic systems. The challenge for this project is to derive an assessment of risks associated with health, welfare, and settlements and to develop timely adaptive strategies to address a range of vulnerabilities. Risk assessments evaluate impacts of climate change across an array of characteristics, including: the magnitude of risk (both baseline and incremental risks); the distribution of risks across populations (including minimally impacted individuals as compared to maximally exposed individuals); and the availability, difficulty, irreversibility, and cost of adaptation strategies. While the state of science limits the ability to conduct formal, quantitative risk assessments, it is possible to develop information that is useful for formulating adaptation strategies. Primary goals for adaptation to climate variability and change include the following:

- Avoid maladaptive responses;
- Establish protocols to detect and measure risks and to manage risks proactively when possible;

- Leverage technical and institutional capacity;
- Reduce current vulnerabilities to climate change;
- Develop adaptive capacity to address new climate risks that exceed conventional adaptive responses; and,
- Recognize and respond to impacts that play out across time. (Scheraga and Grambsch, 1998; WHO, 2003; IPCC, 2007b).

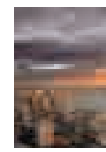
The issue of co-benefits is central in the consideration of adaptation to climate change. Many potential adaptive strategies have co-benefits. Along with helping human populations cope with climate change, adaptive strategies produce additional benefits. For example:

- Creating and implementing early warning systems and emergency response plans for heat waves can also improve those services for other emergency responses while improving all-hazards preparedness; (Glantz, 2004)
- Improving the infrastructure and capacity of combined sewer systems to avoid overflows due to changes in precipitation patterns also has the added benefit of decreasing contaminant flows that cause beach closings and impact the local ecology; (Rose *et al*., 2001)
- A key adaptation technique for settlements in coastal zones is to promote maintenance or reconstruction of coastal wetlands ecosystems, which has the added benefit of creation or protection of coastal habitats (Rose *et al*., 2001); and,
- Promotion of green building practices has added health and welfare benefits as improving natural light in office space and schools has been shown to increase productivity and mental health (Edwards and Torcellini, 2002).

Chapter 2 assesses the potential impacts of climate change on human health in the United States. Timely knowledge of human health impacts may support our public health infrastructure in devising and implementing strategies to prevent, compensate, or respond to these effects. For each of the health endpoints, the assessment addresses a number of topics, including:

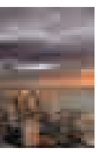
- Reviewing evidence of the current burden associated with the identified health outcome;
- Characterizing the human health impacts of current climate variability and projected climate change (to the extent that the current literature allows);
- Discussing adaptation opportunities and support for effective decision making; and,
- Outlining key knowledge gaps.

Each topic chapter includes research published from 2001 through early 2007 in the United States, or in Canada, Europe, and Australia where results may provide insights for U.S. populations. As such, the health chapter serves as an update to the Health Sector Assessment conducted as part of the First National Assessment in 2001.



Chapter 3 focuses on the climate change impacts and adaptations associated with human settlements in the United States. The IPCC Third and Fourth Assessment Reports (IPCC, 2001; IPCC, 2007c) conclude that settlements are among the human systems that are the most sensitive to climate change. For example, if there are changes in climate extremes there could be serious consequences for human settlements that are vulnerable to droughts and wildfires, coastal and river floods, sea level rise and storm surge, heat waves, land slides, and windstorms. However, specific changes in these conditions in specific places cannot yet be projected with great confidence. Chapter 3 focuses on the interactions between settlement characteristics, climate, and other global stressors with a particular focus on urban areas and other densely developed population centers in the United States.

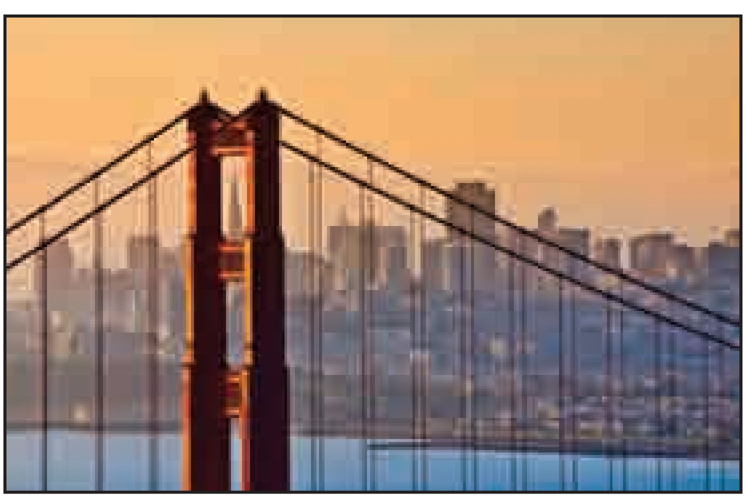
The scale and complexity of these built environments, transportation networks, energy and resource demands, and the interdependence of these systems and their populaces, suggest that urban areas are especially vulnerable to multiplying impacts in response to externally imposed environmental stresses. The collective vulnerability of American urban centers may also be determined by the disproportionate share of urban growth in areas like the Intermountain West or the Gulf Coast. The focus of Chapter 3 is on high density or rapidly growing settlements and the potential for changes over time in the vulnerabilities associated with place-based characteristics (such as their climate regime, elevation, and proximity to coasts and rivers) and spatial characteristics (such as whether development patterns are sprawling or compact).



Chapter 4 focuses on the impacts of climate change on human welfare. To examine the impacts of climate change on human welfare, this chapter reports on two relevant bodies of literature: approaches to welfare that rely on both qualitative assessment and quantitative measures, and economic approaches that monetize, or place money values, on quantitative impacts.

Finally, Chapter 5 revisits the research recommendations and data gaps of previous assessment activities and describes the progress to date and the opportunities going forward. In addition, Chapter 5 reviews the overarching themes derived from Chapters 2–4.

The remainder of this chapter is designed to provide the reader with an overview of the current state of knowledge regarding:



- Changes in climate in the united states;
- Population trends, migration patterns, and the distribution of people across settlements;
- Non-climate stressors and their interactions with climate change to realize complex impacts; and,
- A discussion of the handling of uncertainty in reporting scientific results.

1.2 CLIMATE CHANGE IN THE UNITED STATES: CONTEXT FOR AN ASSESSMENT OF IMPACTS ON HUMAN SYSTEMS

In the following chapters, the authors examine the impacts on human society of global change, especially those associated with climate change. The impact assessments in Chapters 2–4 do not rely on specific emissions or climate change scenarios, but instead rely on the existing scientific literature with respect to our understanding of climate change and its impacts on human health, settlements, and human well-being in the United States. This report does not make quantitative projections of specific impacts in specific locations based on specific projections of climate drivers of these impacts. Instead the report adopts a vulnerability perspective.

A vulnerability approach focuses on estimating *risks or opportunities* associated with possible impacts of climate change, rather than on *estimating quantitatively the impacts* themselves which would require far more detailed information about future conditions. Vulnerabilities are shaped not only by existing exposures, sensitivities, and adaptive capacities but also by responses to risks. In addition, climate change is not the only change confronting human societies: from a vulnerability perspective projected changes in populations, the economy, technology, institutions, infrastructure, and human and social capital are among the factors that also affect vulnerability to climate change. The report reviews historical trends and variability to point to vulnerabilities and then, where possible, determines the likely direction and range of potential climate-related impacts.

In the United States, we are observing the evidence of long-term changes in temperature and precipitation consistent with global warming. Changes in average conditions are being realized through rising temperatures, changes in annual and seasonal precipitation, and rising sea levels. Observations also indicate there are changes in extreme conditions, such as an increased frequency of heavy rainfall (with some increase in flooding), more heat waves, fewer very cold days, and an increase in areas affected by drought. Frequencies of tropical storms and hurricanes vary considerably from year to year and there are limitations in the quality of the data, which make it difficult to discern trends, but evidence suggests some increase in their intensity and duration since the 1970s (Christensen *et al*., 2007).

The following sections provide a brief introduction to climate change as a context for the following chapters on impacts and adaptation. SAP 4.6 does not evaluate climate change projections as they are not used quantitatively in this assessment. The Intergovernmental Panel on Climate Change provides a comprehensive evaluation of climate change science. In their *Summary for Policy Makers* (IPCC, 2007a), the IPCC reports the following observed changes in global climate:

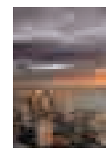
- "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperature, widespread melting of snow and ice, and rising global average sea level."
- "Eleven of the last twelve years rank among the 12 warmest years in the instrumental record of global surface temperatures (since 1850)."
- "Average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80 percent of the heat added to the climate system. Such warming causes sea water to expand, contributing to sea level rise."
- "Mountain glaciers and snow cover have declined on average in both hemispheres."
- "The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapor."

- "Widespread changes in extreme temperatures have been observed over the last 50 years… Hot days, hot nights, and heat waves have become more frequent."
- "There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970." (IPCC, 2007a)

Note that these changes are for the entire globe: changes in the United States may be similar or different from these global changes. The following sections examine U.S. climate trends and historical records related to temperature, precipitation, sea level rise, and changes in hurricanes and other catastrophic events. Information is also drawn from the North American Chapter of the IPCC Fourth Assessment Report and the Climate Change Science Programs Synthesis and Assessment Product 3.3: Weather and Climate Extremes in a Changing Climate. Taken together, this discussion provides a context from which to assess impacts of climate change on human health, human welfare, and human settlements.

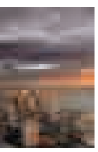
1.2.1 Rising Temperatures

Climate change is already affecting the United States. According to long-term station-based observational records such as the Historical Climatology Network (Karl *et al*., 1990; Easterling *et al*., 1999; Williams *et al*., 2007), temperatures across the continental United States have been rising at a rate of 0.1°F per decade since the early 1900s. Increases in average annual temperatures over the last century now exceed 1°F (Figure 1.1a). The degree of warming has varied by region across the United States, with the West and Alaska



experiencing the greatest degree of warming (U.S. Environmental Protection Agency, 2007). These changes in temperature have led to an increase in the number of frost-free days, with the greatest increases occurring in the West and Southwest (Tebaldi *et al*., 2006). The Intergovernmental Panel on Climate Change, in its most recent assessment report concluded that "Warming of the climate system is unequivocal…" (IPCC, 2007a).

The current generation of global climate models, run with IPCC SRES scenarios of future greenhouse gas emissions, simulates future changes in the earth's climate system that are greater in magnitude and scope than those already observed. According to the IPCC, by the end of the 21st century, annual surface temperature increases are projected to range from 2–3°C near the coasts in the conterminous United States to more than 5°C in northern Alaska. Nationally, annual warming in the United States is projected to exceed 2°C, with projected increases in summertime temperatures ranging between 3 and 5°C (greatest in the Southwest). The largest warming is projected to reach 10°C for winter temperatures in the northernmost parts of Alaska. (IPCC, 2007c). For additional information about the modeling results, see the IPCC Fourth Assessment Working Group I Report, especially Chapter 11: Regional Climate Projections (Christensen *et al*., 2007)



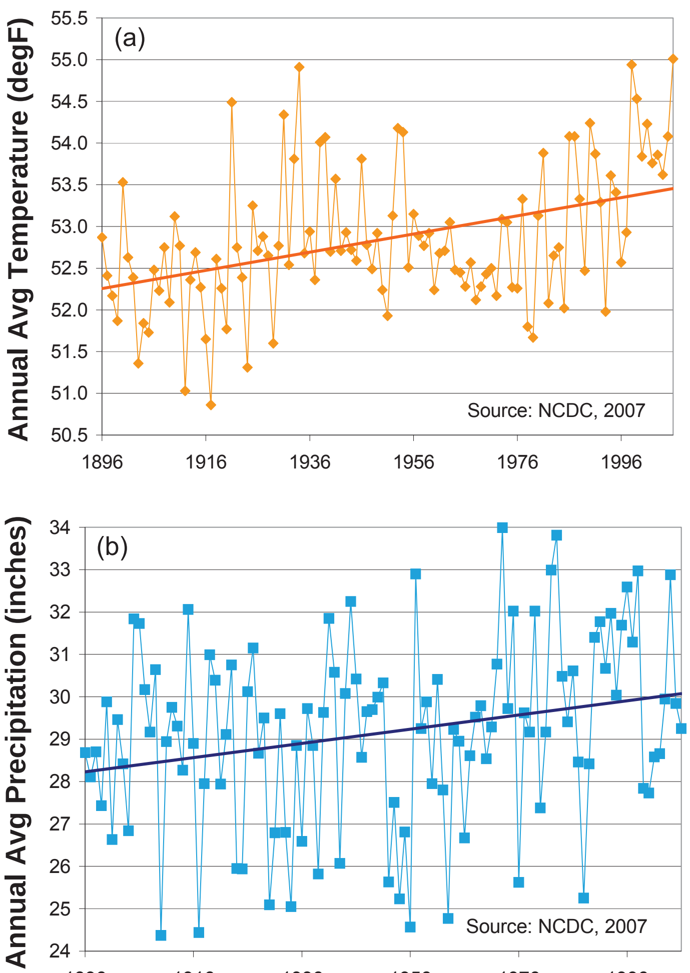


Figure 1.1 Observed trends in annual average (a) temperature (°F) and (b) precipitation (inches) across the continental United States from 1896 to 2006 (Source: NCDC, 2007)

1.2.2 Trends in Precipitation

Shifting precipitation patterns have also been observed. Over the last century, annual precipitation across the continental United States has been increasing by an average of 0.18 inches per decade (Figure 1.1b). Broken down by season, winter precipitation around the coastal areas, including the West, Gulf, and Atlantic coasts, has been increasing by up to 30 percent while precipitation in the central part of the country (the Midwest and the Great Plains) has been decreasing by up to 20 percent. Large-scale spatial patterns in summer precipitation trends are more difficult to identify, as much of summer rainfall comes in the form of small-scale convective precipitation. However, it appears that there have been increases of 20-80 percent in summer rainfall over California and the Pacific Northwest, and decreases on the order of 20 to 40 percent across much of the south. The IPCC reports that rainfall is arriving in more intense events. (IPCC, 2007a).

El Niño events (a periodic warming of the tropical Pacific Ocean between South America and the International Date Line) are associated with increased precipitation and severe storms in some regions, such as the southeast United States and the Great Basin region of the western United States. El Niño events have also been characterized by warmer temperatures and decreased precipitation in other areas, such as the Pacific Northwest, and parts of Alaska. Historically, El Niño events occur about every 3 to 7 years and alternate with the opposite phases of below-average temperatures in the eastern tropical Pacific (La Niña). Since 1976-1977, there has been a tendency toward more prolonged and stronger El Niños (IPCC, 2007a). However, recent analyses of climate simulations indicate no consistent trends in future El Niño amplitude or frequency (Meehl *et al*., 2007).

Global model simulations summarized in the North American Chapter of the IPCC Fourth Assessment Report show moderate increases in precipitation (10 percent or less) over much of the United States over the next 100 years, except for the southwest. However, projected increases in these simulations are partially offset by increases in evaporation, resulting in greater drying in the central part of the United States. Projections for the central, eastern, and western regions of the United States show similar seasonal characteristics (*i.e.*, winter increases, summer decreases), although there is greater consensus for winter increases in the north and summer decreases in the south. However, uncertainty around the projected changes is large (IPCC, 2007b).

1.2.2.1 Changes in Snow Melt and Glacial Retreat

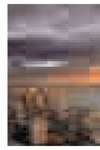
Warmer temperatures are melting mountain glaciers and more winter precipitation in northern states is falling as rain instead of snow (Huntington *et al*., 2004). Snow pack is also melting faster, affecting stream flow in rivers. Over the past 50 years, changes in the timing of snow melt has shifted the schedule of snow-fed stream flow in the western part of the country earlier by 1 to 4 weeks. (Stewart *et al*., 2005). The seasonal "center of stream flow volume" (*i.e.*, the date at which half of the expected winter-spring stream flow has occurred) also appears to be advancing by, on average, one day per decade for streams in the Northeast (Huntington *et al*., 2003).

This trend is projected to continue, with more precipitation falling as rain rather than snow, and snow season length and snow depth are generally projected to decrease in most of the country. Such changes tend to favor increased risk of winter flooding and lower summer soil moisture and streamflows (IPCC, 2007a).

1.2.3 Rising Sea Levels and Erosion of Coastal Zones

Sea levels are rising and the IPCC concluded with high confidence that the rate of sea level rise increased from the 19th to the 20th centuries (IPCC, 2007a). The causes for observed sea level rise over the past century include thermal expansion of seawater as it warms and changes in land ice (e.g., melting of glaciers and snow caps). Over the 20th century, sea level was rising at a rate of about 0.7 inches per decade (1.7 mm/yr ± 0.5 mm). For the period 1993 to 2003, the rate was nearly twice as fast, at 1.2 inches per decade (3.1 mm/yr ± 0.7 mm). However, there is considerably decadal variability in the tide gauge record, so it is unknown whether the higher rate in 1993 to 2003 is due to decadal variability or an increase in the longer-term trend. (Bindoff *et al*., 2007). In the past century, global sea level rose 5–8 inches.

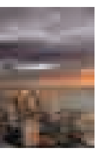
Spatially sea level change varies considerably: in some regions, rates are up to several times the global mean rise, while in other regions sea level is falling. For example, for the mid-Atlantic coast (*i.e.*, from New York to North Carolina), the "effective" or relative sea level rise rates have exceeded the global rate due to a combination of land subsidence and global sea level rise. In this region, relative sea level rise rates ranged between 3 to 4 mm per year (~1ft per century) over the 20th century. In other cases, local sea level rise is less than the global average because the land is still rising (rebounding) from when ice sheets covered the area, depressing the Earth's crust. Local sea levels can actually be falling in some cases (for example, the Pacific Northwest coast) if the land is rising more than the sea is falling (for additional details about sea level rise and its effects on U.S. coasts see Synthesis and Assessment Product 4.1 *Coastal elevations and sensitivity to sea level rise).*



Rising global temperatures are projected to accelerate the rate of sea level rise by further expanding ocean water, melting mountain glaciers, and increasing the rate at which Greenland and Antarctic ice sheets melt or discharge ice into the oceans. Estimates of sea level rise for a global temperature increase between 1.1 and 6.4°C (the IPCC estimate of likely temperature increases by 2100) are about 7 to 23 inches (0.18m to 0.59m), excluding the contribution from accelerated ice discharges from the Greenland and Antarctica ice sheets. Extrapolating the recent acceleration of ice discharges from the polar ice sheets would imply an additional contribution up to 8 inches (20cm). If melting of these ice caps increases, larger values of sea level rise cannot be excluded (IPCC, 2007a).

1.2.4 Changes in Extreme Conditions

The climatic changes described above are often referred to as changes in “average” conditions. Most observations of temperature will tend to be close to the average: days with very hot temperatures happen infrequently. Similarly, only rarely will there be days with extremely heavy precipitation. Climate change could result in a shift of the entire distribution of a meteorological variable so that a relatively small shift in the mean could be accompanied by a relatively large change in the number of relatively rare (according to today’s perspective) events. For example, with an increase in average temperatures, it would be expected there would be an increase in the number of very hot days and a decrease in the number of very cold days. Other, relatively rare, extreme events of concern for human health, welfare, and settlements include hurricanes, floods and droughts.



In general, it is difficult to attribute any individual extreme event to a changing climate. Because extreme events occur infrequently, there is typically limited information to characterize these events and their trends. In addition, extreme events usually require several conditions to exist for the event to occur, so that linking a particular extreme event to a single, specific cause is problematic. For some extreme events, such as extremely hot/cold days or rainfall extremes, there is more of an observational basis for analyzing trends, increasing our understanding and ability to project future changes.

Finally, there are many different aspects to extremes. Frequency is perhaps the most often discussed but changes in other aspects of extremes such as intensity (*e.g.*, warmer hot days), time of occurrence (*e.g.*, earlier snowmelt), duration (*e.g.*, longer droughts), spatial extent, and location are also important when determining impacts on human systems.

Synthesis and Assessment Product 3.3 *Weather and Climate Extremes in a Changing Climate* (CCSP, 2008) has a much more detailed discussion of climate extremes that are only very briefly described here. The interested reader is referred to that report for additional details.

1.2.4.1 Heat and Cold Waves

Extreme temperatures (*e.g.*, temperatures in the upper 90th or 95th percentile of the distribution) often change in parallel with average temperatures. Since 1950, there are more 3-day warm spells (exceeding the 90th percentile) when averaged over all of North America (Peterson *et al*., 2008). While the number of heat waves has increased, the heat waves of the 1930s remain the most severe in the U.S. historical record. Mirroring this shift toward more hot days is a decrease in unusually cold days during the past few decades. There has been a corresponding decrease in frost days and a lengthening of the frost-free season over the past century. The number of frost days decreased by four days per year in the United States during the 1948-1999 period, with the largest decreases, as many as 13 days per year, occurring in the western United States (Easterling, 2002). For the United States, the average length of the frost-free season over the 20th century increased by almost two weeks (Kunkel *et al*., 2004).

Recent studies have found that there is an increased likelihood of more intense, longer-lasting, and more frequent heat waves (Meehl and Tebaldi, 2004, Schar *et al*., 2004, Clark *et al*., 2006). As the climate warms, the number of frost days is expected to decrease (Cubasch *et al*., 2001) particularly along the northwest coast of North America (Meehl *et al*., 2004). SAP 3.3, using a range of greenhouse gas emission scenarios and model simulations, found that hot days, hot nights, and heat waves are very likely to become more frequent, that cold days and cold nights are very likely to become much less frequent, and that the number of days with frost is very likely to decrease (CCSP, 2008). Growing season length is related to frost days, which is projected to increase in a warmer climate in most areas (Tebaldi *et al*., 2006).

1.2.4.2 Heavy Precipitation Events

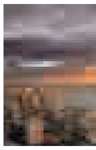
Over the 20th century, periods of heavy downpours became more frequent and more intense and accounted for a larger percentage of total precipitation (Karl and Knight, 1997; Groisman *et al*., 1999, 2001, 2004, 2005; Kunkel *et al*., 1999; Easterling *et al*., 2000; Kunkel, 2003). These heavy rainfall events have increased in frequency by as much as 100 percent across much of the Midwest and Northeast over the past century (Kunkel *et al*., 1999). These findings are consistent with observed warming and associated increases in atmospheric water vapor.

The intensity of precipitation events is projected to increase, particularly in high latitude areas that experience increases in mean precipitation (Meehl *et al*., 2007). In areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but there would be longer periods between rainfall events. Precipitation extremes increase more than does the mean in most tropical and mid- and high-latitude areas. Some studies project widespread increases in extreme precipitation (Christensen *et al*., 2007), with greater risks of not only flooding from intense precipitation, but also droughts from greater temporal variability in precipitation. SAP 3.3 concluded that, over most regions, future precipitation is likely to be less frequent but more intense, and precipitation extremes are very likely to increase (CCSP, 2008).

1.2.4.3 Changes in Flooding

Heavy rainfall clearly can lead to flooding, but assessing whether observed changes in precipitation have lead to similar trends in flooding is difficult for a number of reasons. In particular, there are many human influences on streamflow (*e.g.*, dams, land-use changes, etc.) that confound climatic influences. In some cases, researchers using the same data came to opposite assessments about trends in high streamflows (Lins and Slack, 1999, 2005; Groisman *et al*., 2001, 2004). Short duration extreme precipitation events can lead

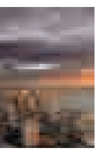
to localized flash flooding, but for large river basins, significant flooding will not occur from these types of episodes alone; excessive precipitation must be sustained for weeks to months for flooding to occur.



1.2.4.4 Changes in Droughts

An extended period with little precipitation is the main cause of drought, but the intensity of a drought can be exacerbated by high temperatures and winds as well as a lack of cloudiness/low humidity, which result in high evaporation rates. Droughts occur on a range of geographic scales and can vary in their duration, in some cases lasting years. The 1930s and the 1950s experienced the most widespread and severe drought conditions (Andreadis *et al*., 2005), although the early 2000s also saw severe droughts in some areas, especially in the western United States (Piechota *et al*., 2004).

Based on observations averaged over the United States, there is no clear overall national trend in droughts (CCSP, 2008). Over the past century, the area affected by severe and extreme drought in the United States each year averaged about 14 percent: by comparison, in 1934 the area affected by drought was as high as 65 percent (CCSP, 2008). In recent years, the drought-affected area ranged between 35 and 40 percent (CCSP, 2008). These trends at the national level however mask important differences in drought conditions at regional scales: one area may be very dry while another is wet. For example, in the Southwest and parts of the interior of the West increased temperatures have led to rising drought trends (Groisman *et al*., 2004; Andreadis and Lettenmaier, 2006).



In the Southwest, the 1950s were the driest period, though droughts in the past 10 years are approaching the 1950s drought (CCSP, 2008). There are also recent regional tendencies toward more severe droughts in parts of Alaska (CCSP, 2008).

Several generations of global climate models, including the most recent, find an increase in summer drying in the mid latitudes in a future, warmer climate (Meehl *et al.*, 2007). This tendency for drying of the mid-continental areas during summer indicates a greater risk of droughts in those regions (CCSP, 2008). Analyses using several coupled global circulation models project an increased frequency of droughts lasting a month or longer in the Northeast (Hayhoe *et al.*, 2007) and greatly reduced annual water availability over the Southwest (Milly *et al.*, 2005). SAP 3.3 concluded that droughts are likely to become more frequent and severe in some regions of the country as higher air temperatures increase the potential for evaporation.

1.2.4.5 Changes in Hurricanes

Assessing changes in hurricanes is difficult: there have been large fluctuations in the number of hurricanes from year to year and from decade to decade. Furthermore, it is only since the 1960s that reliable data can be assembled for assessing trends. In general, there is increasing uncertainty in the data record the further back in time one goes but significant increases in tropical cyclone frequency are likely since 1900 (CCSP, 2008). However, the existing data and an adjusted record of tropical storms indicate no significant linear trends beginning from the mid- to late 1800s to 2005 (CCSP, 2008). Moreover, SAP 3.3 concluded that there is no evidence for a long-term increase in North American mainland land-falling hurricanes.

Evidence suggests that the intensity of Atlantic hurricanes and tropical storms has increased over the past few decades. SAP 3.3 indicates that there is evidence for a human contribution to increased sea surface temperatures in the tropical Atlantic and there is a strong correlation to Atlantic tropical storm frequency, duration, and intensity. However, a confident assessment will require further studies. An increase in extreme wave heights in the Atlantic since the 1970s has been observed that is consistent with more frequent and intense hurricanes (CCSP, 2008).

For North Atlantic hurricanes, SAP 3.3 concludes that it is likely that wind speeds and core rainfall rates will increase (Henderson-Sellers *et al.*, 1998; Knutson and Tuleya, 2004, 2008; Emanuel, 2005). However, SAP 3.3 concluded that "frequency changes are currently too uncertain for confident projection (CCSP, 2008)." SAP 3.3 also found that the spatial distribution of hurricanes will likely change. Storm surge is likely to increase due to projected sea level rise, although the degree to which this will increase has not been adequately studied (CCSP, 2008).

1.3 POPULATION TRENDS AND MIGRATION PATTERNS: A CONTEXT FOR ASSESSING CLIMATE-RELATED IMPACTS

Assessments of climate-related risk must account for the size of the population, including especially sensitive sub-populations and their geographic distribution across the landscape. The following discussion provides a basis for assessing the interactions of global change within the larger context of demographic trends. In particular, the social characteristics of a populace may interact with its spatial distribution to produce a non-linear risk. In such instances, risk assessments are shaped by questions such as:

- Which counties, states, and regions will grow most rapidly?
- How many people will live in at-risk areas, such as coastal zones, flood plains, and arid areas?
- What share of retirees will migrate and where will they move?

1.3.1 Trends in Total U.S. Population

The U.S. population numbered some 280 million individuals in 2000.[1] In 1900, the U.S. population numbered about 76 million people; fifty years later the population had roughly doubled to 151 million people.

1 Information on historical U.S population data and current population estimates and projections can be found at http://www.census.gov/.

Population projections are estimates of the population at future dates. They are based on assumptions about future births, deaths, international migration, and domestic migration and represent plausible scenarios of future population.

In 2000 the IPCC published a set of emission scenarios for use in the Third Assessment Report (Nakicenovic *et al.*, 2000). The SRES scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. The SRES team defined four narrative storylines labeled A1, A2, B1, and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. (Nakicenovic *et al.*, 2000)

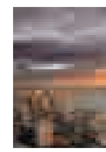
The U.S. Census Bureau periodically releases projections for the resident population of the United States based on Census data. The cohort-component methodology[2] is used in these projections. Alternative assumptions of fertility, life expectancy, and net immigration yield low, middle, and high projections.

Figure 1.2 displays the SRES and Census population projections[3] for the United States. The Census projections span a greater range than the SRES scenarios: by 2100 the low series projection of 282 million is below the current population while the high projection is about 1.2 billion, or about four times the current population. The Census middle series projection is relatively close to the SRES A2 scenario (570 million vs. 628 million in 2100), while the SRES A1/B1 and B2 scenarios fall below the Census middle projection.

1.3.1.1 Aging of the Population

The U.S. population has not only increased by 300 percent over the past century, it has also shifted in its demographic structure. For example, in 1900 less than 4 percent of the U.S. population was 65 years or older; currently about 12 percent of Americans are 65 or older (He *et al.*, 2005). By 2050, the US population aged 65 and older is projected to be about 86 million, or about 21 percent of the total population. Nearly 5 percent of the projected population in 2050, over 20 million people, will be 85 years or older (He *et al.*, 2005). Figure 1.3 displays the projected age distribution for the total resident population of the United States by sex for the middle projection series.

The projected increase in the elderly population is an important variable in projections of



2 See Census website for additional details on the projection methodology.

3 The Census projections are based on the 1990 Census. Preliminary projections based on the 2000 Census for 2000-2050 are available.

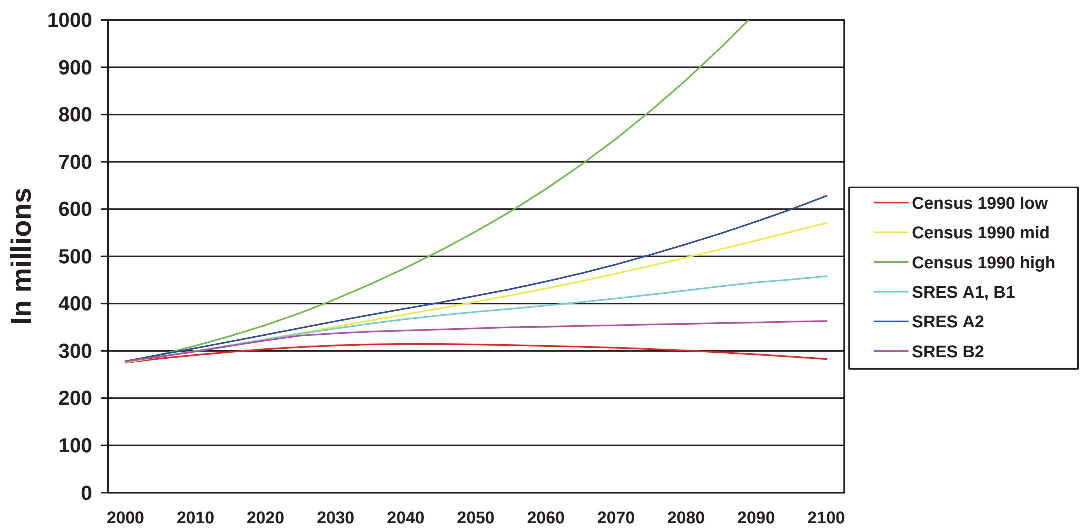


Figure 1.2 U.S. Population Projections 2000–2100

Data source: Census Population Projections http://www.census.gov/population/www/projections/natsum-T1.html
SRES Population Projections: http://sres.ciesin.columbia.edu/tgcia/

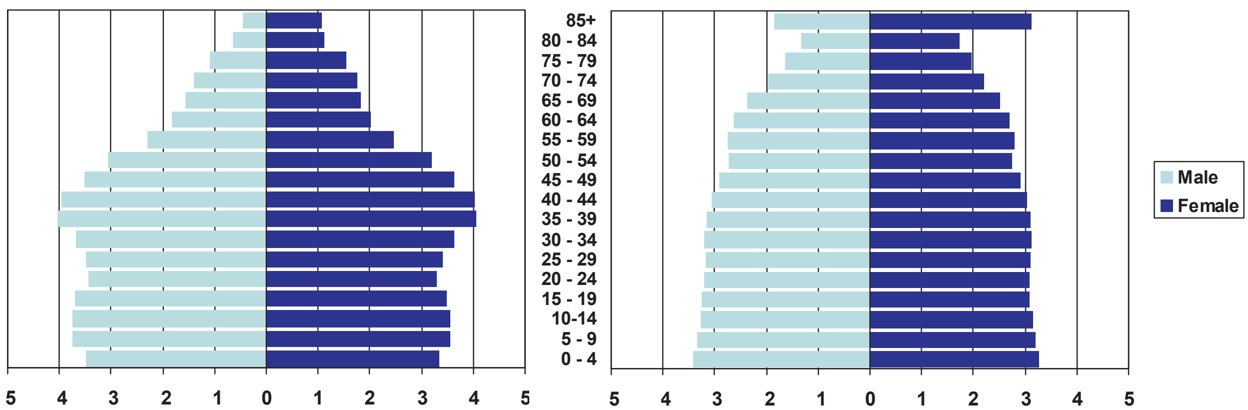
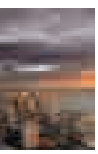


Figure 1.3 Population Pyramids of the U.S. 2000 and 2050 (Interim Projections based on 2000 Census)
Data source: Census Population Projections http://www.census.gov/ipc/www/usinterimproj/



the effects of climate change. The elderly are identified in many health assessments as more vulnerable than younger age groups to a range of health outcomes associated with climate change, including injury resulting from weather extremes such as heat waves, storms, and floods (WHO, 2003; IPCC, 2007b; NAST, 2001). Aging also can be expected to be accompanied by multiple, chronic illnesses that may result in increased vulnerability to infectious disease (NAST, 2001). Chapter two in this report also identifies the elderly as a vulnerable subpopulation.

1.3.2 Migration Patterns

Although numbers produced by population projections are important, the striking relationship between potential future settlement patterns and the areas that may experience significant impacts of climate change is the critical insight. In particular, nearly all trends point to more Americans living in areas that may be especially vulnerable to the effects of climate change (see Figure 1.4). For example, many rapidly growing places in the Mountain West may also experience decreased snow pack during winter and earlier spring melting, leading to lower stream flows, particularly during the high-demand period of summer.

The continued growth of arid states in the West is therefore a critical crossroads for human settlements and climate change. These states are expected to account for one-third of all U.S. population growth over the next 25 years (U.S. Census Bureau, 2005). The combined effects of growing demand for water due to a growing population and changes in water supplies associated with climatic change pose important challenges for these states. For example, a study commissioned by the California Energy Commission estimated that the Sierra Mountain snow pack could be reduced by 12 percent to 47 percent by 2050 (Cayan *et al.*, 2006). At the same time, state projections anticipate an additional 20 million Californians by that date (California Department of Finance, 2007).

Growth in coastal population has kept pace with population growth in other parts of the country, but given the small land area of the coasts, the density of coastal communities has been increasing (Crossett *et al.*, 2004). More than 50 percent of the U.S. population now lives in the coastal zone, and coastal areas are projected to continue to increase in population, with associated increases in population density, over the next several decades. The overlay of this migration pattern with climate change projections has several implications. Perhaps the most obvious is the increased exposure of people and property to the effects of sea level rise and hurricanes (Kunkel *et al.*, 1999). With rapidly growing communities near coastlines, property damages can be expected to increase even without any changes in storm frequency or intensity (Changnon *et al.*, 2003).

1.3.2.1 How Climate Impacts Migration Patterns

It is often said that America is a nation of movers and data collected for both the 1990 and 2000 Census support this notion. While roughly half of the U.S. population had lived in the same house for the previous five years, nearly 10 percent had recently moved from out

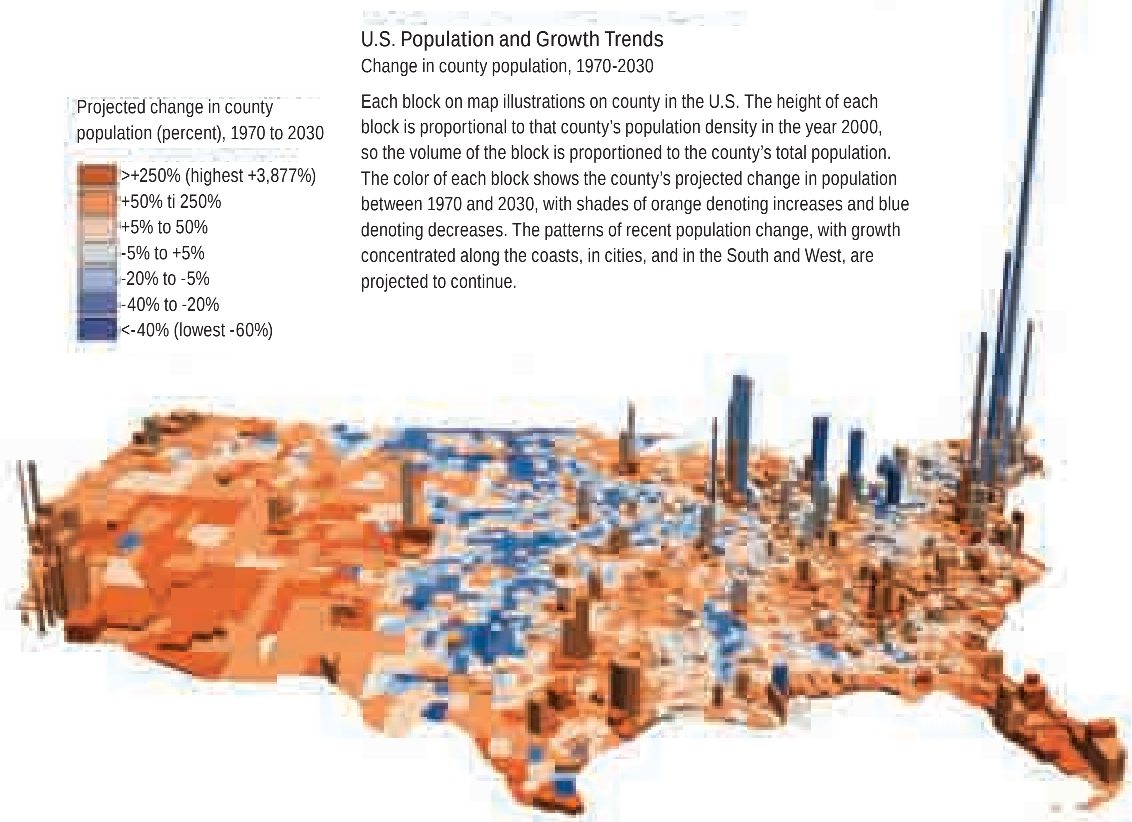
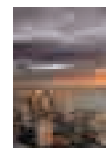


Figure 1.4: U.S. Population and Growth Trends with evidence of more pronounced growth projected along the coasts, in urban centers, and in cities in the South and West (NAST, 2001)



of state.[4] In other words, during the five year period preceding each Census, over 20 million Americans had moved across state lines and half of those moved to different regions.

Although many forces shape domestic migration, climate is a key element of perceived quality of life. In turn, quality of life can be an important factor driving the relocation decisions of households and businesses. The popularity of the Places Rated Almanac and other publications ranking cities' livability illustrates the concept's importance. Additionally, many of the indicators in these reports are based directly on climatic conditions (average winter and summer temperature, precipitation, days of sunshine, humidity, etc.).

A range of studies have attempted to quantify how natural amenities, including a favorable climate, affect migration. While the methods vary[5] the conclusions are similar. In general:

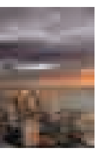
- People move for a variety of reasons other than climate, such as: proximity to family and friends, employment opportunities, lower cost of living, and aesthetics;
- Areas with natural amenities that are close to urban centers have attracted the largest numbers of in-migrants (Serow, 2001);
- Climate's impact on migration varies by income with lower income groups also moving to colder areas in which their wages are likely to compare more favorably to the cost of living (Rebhun and Raveh, 2006);
- For retirees, weather is a far more important rationale cited for moving out of an area than moving to an area (AARP, 2006); and,
- Population growth in rural counties is strongly related to a more favorable climate and other key natural amenities (McGranahan, 1999). In addition, new information technologies may make it possible for some urban dwellers to move to and work from rural regions.

4 http://www.census.gov/Press-Release/www/2002/sumfile3.html

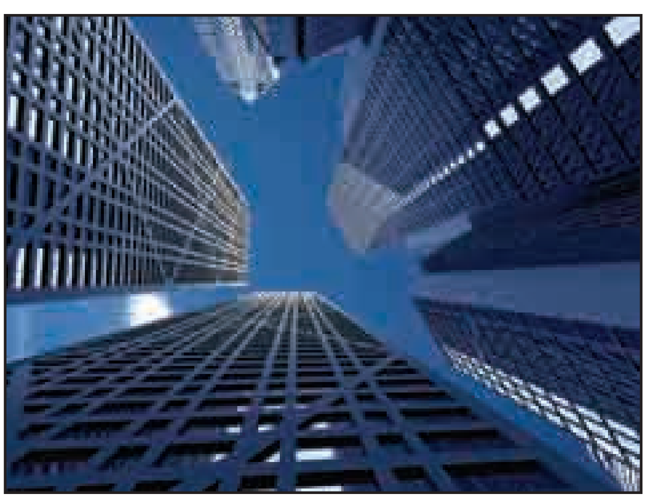
5 Study methodologies include: aggregate studies of population changes alongside regional characteristics, explanatory models developed from individual migration data and individual surveys.

1.4. COMPLEX LINKAGES: THE ROLE OF NON-CLIMATE FACTORS

Climate is only one of a number of global changes that affect human well-being. These non-climate processes and stresses interact with climate change, determining the overall severity of climate impacts. Moreover, climate change impacts can spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages (IPCC, 2007b). Evaluating future climate change impacts therefore requires assumptions, explicit and implicit, about how future socioeconomic conditions will develop. The IPCC (1994) recommends the use of socioeconomic scenarios in impacts assessments to capture these factors in a consistent way.



Socioeconomic scenarios have tended to focus on variables such as population and measures of economic activity (*e.g.,* Gross Domestic Product) that can be quantified using well-established models or methods (for examples of economic models that have been used for long run projections, see Nakicenovic *et al*., 2000; NAST, 2001; Yohe *et al*., 2007). While useful as a starting point, some key socioeconomic factors may not allow this type of quantification: they could however be incorporated through a qualitative, "storyline" approach and thus yield a more fully developed socioeconomic scenario. The UNEP country study program guidance (Tol, 1998) notes the role of formal modeling in filling in (but not defining) socioeconomic scenarios but also emphasizes the role of expert judgment in blending disparate elements into coherent and plausible scenarios. Generally, socioeconomic scenarios have been developed in situations where it is not possible to assign levels of probability to any particular future state of the world and therefore it usually is not appropriate to make confidence statements with respect to a specific socioeconomic scenario (Moss and Schneider, 2000).



Socioeconomic scenarios include non-environmental factors that influence exposures, vulnerability, and impacts. Factors that may be incorporated into a scenario include:

- Population (*e.g.*, demographics, immigration, domestic migration patterns);
- Economic status (income, prices);
- Technology (*e.g.*, pesticides, vaccines, transportation modes, wireless communications);
- Infrastructure (*e.g.*, water treatment plants, sewers, and drinking water systems; public health systems; roads, rails and bridges; flood control structures);
- Human capital and social context and behaviors (*e.g.*, skills and knowledge, social networks, lifestyles, diet); and,
- Institutions (legislative, social, managerial).

These factors are important both for characterizing potential effects of a changing climate on human health, settlements, and welfare, and for evaluating the ability of the United States to adapt to climate change.

1.4.1 Economic Status

The United States is a developed economy with GDP approaching $14 trillion and a per capita income of $38,611 in 2007 (US BEA, 2008). The U.S. economy has large private and public sectors, with strong emphasis on market mechanisms and private ownership (Christensen *et al*., 2007). A nation's economic status clearly is important for determining vulnerability to climate change: wealthy nations have the economic resources to invest in adaptive measures and bear the costs of impacts and adaptation thereby reducing their vulnerability (WHO, 2003; IPCC, 2001). However, with the aging of the population (described in Section 1.3.1.1) the costs of health care are likely to rise over the coming decades (Christensen *et al*., 2007). Moreover, if the trend toward globalization continues through the 21st century, markets, primary factors of production, ownership of assets, and policies and governance will become more international in outlook (Stiglitz, 2002). Unfortunately, there has been little research to understand how these economic trends interact with climate change to affect vulnerability (*i.e.*, whether they facilitate or hinder adaptation to climate change).

1.4.2 Technology

The past half-century has seen stunning levels of technological advancement in the United States, which has done much to improve American standards of living. The availability and access to technology at varying levels, in key sectors such as energy, agriculture, water, transportation, and health is a key component to understanding vulnerability to climate change. Many technological changes, both large and small, have reduced Americans' vulnerability to climate change (NAST, 2001). Improved roads and automobiles, better weather and climate forecasting systems, computers and wireless communication, new drugs and vaccines, better building materials, more efficient energy production–the list is very long–have contributed to America's material well being while reducing vulnerability to climate. Many of the currently deployed adaptive strategies that protect human beings from climate involve technology *(e.g.*, warning systems, air conditioning and heating, pollution controls, building design, storm shelters, vector control, water treatment and sanitation) (WHO, 2003). Continued advances in technology in the 21st century can increase substantially our ability to cope with climate change (IPCC, 2007a; USGCRP, 2001).

However, it will be important to assess risks from proposed technological adaptations to avoid or mitigate adverse effects *(i.e.*, maladaptation) (Patz, 1996; Klein and Tol, 1997). For example, if new pesticides are used to control disease vectors their effects on human populations, insect predators, and insect resistance to pesticides need to be considered (Scheraga and Grambsch, 1998; Gubler *et al.*, 2001).

In addition, technological change can interact in complex ways with other socioeconomic factors *(e.g.*, migration patterns) and affect vulnerability to climate change. For example, advances in transportation technology–electric

streetcars, freight trucks, personal automobiles, and the interstate highway system–have fueled the decentralization of urban regions (Hanson and Giuliano 2004; Garreau 1991; Lang 2003). More recently, the rapid development of new information technologies, such as the internet, have made previously remote locations more accessible for work, recreation, or retirement. Whether these developments increase or decrease vulnerability is unknown, but they do indicate the need for socioeconomic scenarios to better characterize the complex linkages between climate and non-climate factors in order to evaluate vulnerability.

1.4.3 Infrastructure

Communities have reduced, and can further reduce, their vulnerability to adverse climate effects through investments in infrastructure. United States have been modified and intensively managed over the years, partly in response to climate variability (Cohan and Miller, 2001). These investments range from small, privately constructed impoundments, water diversions, and levees to major projects constructed by federal and state governments. Public health infrastructure, such as sanitation facilities, waste water treatment, and laboratory buildings reduce climate change health risks (Grambsch and Menne, 2003). Coastal communities have developed an array of systems to manage erosion and protect against flooding (see SAP 4.1 for an extensive discussion). More generally, infrastructure such as roads, rails, and bridges; water supply systems and drainage; mass transit; and buildings can reduce vulnerability (Grambsch and Menne, 2003).

However, infrastructure can increase vulnerability if its presence encourages people to locate in more vulnerable areas.

For example, increasing the density of people in coastal metropolitan areas, dependent on extensive fixed infrastructure, can increase vulnerability to extreme events such as floods, storm surges, and heat waves (NAST, 2001). In assessments of severe storms, measures of property damage are consistently higher and loss of life lower in the United States when compared with less-developed countries (Cohan and Miller, 2001). This reflects both the high level of development in coastal zones and the effectiveness of warnings and emergency preparedness (Pielke and Pielke, 1997).

Fixed infrastructure itself has the potential to be adversely impacted by climate change, which can increase vulnerability to climate change. For example, flooding can overwhelm sanitation infrastructure and lead to water-related illnesses (Grambsch and Menne, 2003). Much of the transportation infrastructure in the Gulf Coast has been constructed on land at elevations below 16.4 feet. Storm surge, therefore, poses risks of immediate flooding of infrastructure and damage caused by the force of floodwaters (see SAP 4.7 for additional information on the vulnerability of Gulf Coast transportation infrastructure to climate change). Damage to transportation infrastructure can make it more difficult to assist affected populations (Grambsch and Menne, 2003).

1.4.4 Human and Social Capital and Behaviors

While these factors are extremely difficult to quantify, much less project into the future, they are widely perceived to be important in determining vulnerability in a number of different ways. In general, countries with higher levels of human capital (*i.e.*, the knowledge, experience, and expertise of its citizens), are considered to be less vulnerable to climate change. Effective adaptation will require individuals skilled at recognizing, reporting, and responding to climate change effects. Moreover, a number of the adaptive measures described in the literature require knowledgeable, trained, and skilled personnel to implement them. For example, skilled public health managers who understand surveillance and diagnostic information will be needed to mobilize appropriate responses. People trained in the operation, quality control, and maintenance of laboratories; communications equipment; and sanitation, wastewater, and water supply systems are also key (Grambsch and Menne, 2003). Researchers and scientists spanning a broad range of disciplines will be needed to provide a sound basis for adaptive responses.

In addition to a country's human capital, the relationships, exchange of resources, and knowledge, and the levels of trust and conflicts between individuals (*i.e.*, "social capital") are also important for understanding future vulnerability to climate change (Adger, 2003; Lehtonen, 2004; Pelling and High, 2005). Social networks can play an important role in coping and recovery from extreme weather events (Adger, 2003). For example, individuals who were socially isolated were found to be a greater risk of dying from extreme heat (Semenza *et al.*, 1996), as well as people living in neighborhoods without public gathering places and active street life (Klinenberg, 2002).

Individual behaviors and responses to changing conditions also determine vulnerability. For example, fitness, body composition, and level of activity are among the factors that determine the impact extremely hot weather will have on the human body (see Chapter 2 for additional information). Whether this trend continues or not could have important implications for determining vulnerability to climate change. Individual responses and actions to reduce exposures to extreme heat can also substantially ameliorate adverse health impacts (McGeehin and Mirabelli, 2001). Successfully motivating individuals to respond appropriately can therefore decrease vulnerability and reduce health impacts-a key goal of public health efforts (McGeehin and Mirabelli, 2001).

1.4.5 Institutions

The ability to respond to climate change and reduce vulnerability is influenced by social institutions as well as the social factors noted above. Institutions are viewed broadly in the climate change context and include a wide diversity of things such as regulations, rules, and norms that guide behavior. Examples include past development and land use patterns, existing environmental and coastal laws, building codes, and legal rights. Institutions also can determine a decision-maker's access to information and the ways in which the information can be used (Moser *et al.*, 2007).

Well-functioning institutions are essential to a modern society and provide a mechanism for stability in otherwise volatile environments (Moser *et al.*, 2007). Future options for responding to future climate impacts are thus shaped by our past and present institutions and how they evolve over time. In addition, the complex interaction of issues expected with climate change may require new arrangements and collaborations between institutions to address risks effectively, thereby enhancing adaptive capacity (Grambsch and Menne, 2003). A number of institutional changes have been identified that improve adaptive capacity and reduce vulnerability (see Chapter 3 for additional details). While the importance of institutions is clear, there are few scenarios that incorporate an explicit representation of them.

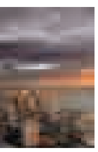
1.4.6 Interacting Effects

The same social and economic systems that bear the stress of climate change also bear the stress of non-climate factors, including: air and water pollution, the influx of immigrants, and an aging and over-burdened infrastructure in rapidly growing metropolitan centers and coastal zones. While non-climate stressors are currently more pronounced than climate impacts, one cannot assume that this trend will

persist. Understanding the impacts of climate change and variability on health and quality of life assumes knowledge of how these dynamics might vary by location and across time and socioeconomic group. The effects of climate change often spread from directly affected areas and sectors to other areas and sectors through complex linkages. The relative importance of climate change depends on the directness of each climate impact and on demographic, social, economic, institutional, and political factors, including the degree of emergency preparedness.

Consider the damage left by Hurricanes Katrina and Rita in 2005. Damage was measured not only in terms of lives and property lost, but also in terms of the devastating impacts on infrastructure, neighborhoods, businesses, schools, and hospitals as well as in the disruption to families and friends in established communities, with lost lives and lost livelihoods, challenges to psychological well-being, and exacerbation of chronic illnesses. While the aftermath of a single hurricane is not the measure of climate change, such an event demonstrates the disruptive power of climate impacts and the resulting tangle of climate and non-climate stressors that complicate efforts to respond and to adapt. The impacts following these hurricanes reveal that socioeconomic factors and failures in human systems may be as damaging as the storms themselves.

Another trend of significance for climate change is the suburbanization of poverty. A recent study noted that by 2005 the number of low income households living in suburban communities had for the first time surpassed the number living in central cities (Berube and Kneebone, 2006). Although the poverty rate in cities was still double the suburban rate, there were 1 million more people living in poverty in America's suburbs. Many of these people live in older inner-ring suburbs developed in the 1950's and 60's. The climate adaptation challenge for these places is captured succinctly by a recent study: "Neither fully urban nor completely suburban, America's older, inner-ring, "first" suburbs have a unique set of challenges—such as concentrations of elderly and immigrant populations as well as outmoded housing and commercial buildings—very different from those of the center city and fast growing newer places. Yet first suburbs exist in a policy blind spot with little in the way of state or federal tools to help them adapt to their new realities" (Puentes and Warren, 2006).



1.5 REPORTING UNCERTAINTY IN SAP 4.6

Uncertainty can be traced to a variety of sources: (1) a misspecification of the cause(s), such as the omission of a causal factor resulting in spurious correlations; (2) mischaracterization of the effect(s), such as a model that predicts cooling rather than warming; (3) absence of or imprecise measurement or calibration (such as devices that fail to detect minute causal agents); (4) fundamental stochastic (chance) processes; (5) ambiguity over the temporal ordering of cause and effect; (6) time delays in cause and effect; and, (7) complexity where cause and effect between certain factors are camouflaged by a context with multiple causes and effects, feedback loops, and considerable noise.

A new perspective on the treatment of uncertainty has emerged from the IPCC Third and Fourth Assessment processes.[6] This new perspective suggests that uncertainties about projections of climate changes, impacts, and responses include two fundamentally different dimensions. One dimension recognizes that most processes and systems being observed are characterized by inherent variability in outcomes: the more variable the process or system, the greater the uncertainty associated with any attempt to project an outcome. A second dimension recognizes limitations in our knowledge about processes and systems.

This report is a summary of the state of the science on the impacts of climate change on human health, human settlements, and human welfare. With this focus, the assessment of uncertainty in this report is based on the literature and the author team's expert judgment. The considerations in determining confidence include the degree of belief within the scientific community that available understanding, models, and analyses are accurate, expressed by

6 SAP 4.6 follows *the Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties*, produced by the IPCC in July 2005. See http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf for more details.

Level of agreement (on a particular finding) ↑

High agreement, limited evidence	High agreement, medium evidence	High agreement, much evidence
Medium agreement, limited evidence	Medium agreement, medium evidence	Medium agreement, much evidence
Low agreement, limited evidence	Low agreement, medium evidence	Low agreement, much evidence

Amount of evidence (number and quality of independent sources) →

Figure 1.5 Considerations in determining confidence

Source: IPCC Guidance Notes on risk and uncertainty (2005) the degree of consensus in the available evidence and its interpretation. This can be thought of using two different dimensions related to consensus. Figure 1.5 represents the qualitatively defined levels of understanding. It considers both the amount of evidence available in support of findings and the degree of consensus among experts on its interpretation.

In this report, each chapter author team assigned likelihood judgments that reflect their assessments of the current consensus of the science and the quality and amount of evidence. This represents their expert judgment that the given likelihood impact statement is true given a specified climatic change. The likelihood terminology and corresponding values used in this report are shown in Table 1.1. As the focus of this report is on impacts, it is important to note that these likelihood statements refer to the impact, not the underlying climatic changes (*i.e.*, the report does not address whether the specific climatic change is likely to occur). Moreover, the authors do not attempt an assessment that takes into account a probabilistic accounting of both the likelihood of the climatic change and the impact. The terms defined in Table 1.1 are intended to be used in a relative sense to summarize judgments of the scientific understanding relevant to an issue, or to express uncertainty in a finding where there is no basis for making more quantitative statements.

The application of this approach to likelihood estimates demonstrates some variability across each of the three core chapters (Chapters 2–4). This variability in reporting uncertainty is based on the degree of richness of their respective knowledge bases. A relatively more extensive and specific application of likelihood and state of the knowledge estimates is possible for health impacts, only a more general approach is warranted for conclusions about human settlements, and uncertainty statements about human welfare conclusions are necessarily the least explicit.

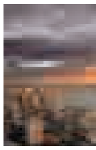


Table 1.1 Description of likelihood: probabilistic assessment of outcome having occurred or occurring in the future based on quantitative analysis or elicitation of expert views.

Likelihood Terminology	Likelihood of the Occurrence/Outcome
Virtually certain	> 99 percent probability
Very likely	> 90 percent probability
Likely	> 66 percent probability
About as likely as not	33 - 66 percent probability
Unlikely	< 33 percent probability
Very unlikely	< 10 percent probability
Exceptionally unlikely	< 1 percent probability

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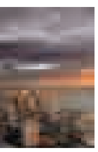

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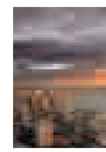

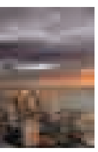

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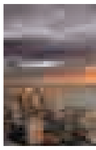

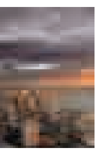

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