

## PRIMER ON CLIMATE SCIENCE

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The notion that **carbon dioxide** ( $\text{CO}_2$ ) and other greenhouse gases (GHG) emissions could accumulate in the Earth's atmosphere and increase global surface temperatures was first proposed in the nineteenth century. Indeed, in 1896, Swedish physicist and chemist Svante Arrhenius created a greenhouse law for  $\text{CO}_2$  that is still in use today: the increase of  $\text{CO}_2$  emissions leads to global warming (Walter 2010). However, the idea was considered unlikely at the time and was mostly forgotten until rising global temperatures in the middle of the twentieth century sparked renewed interest in the hypothesis.

In the late 1950s, Charles Keeling began measuring the atmospheric concentration of  $\text{CO}_2$  at Mauna Loa Observatory in Hawaii, a remote observatory that is minimally affected by local  $\text{CO}_2$  sources and thus reflects average global atmospheric  $\text{CO}_2$  levels. Over time, repeated measurements at Mauna Loa showed a consistent upward trend in the concentration of atmospheric  $\text{CO}_2$ . Indeed, this atmospheric concentration has increased more than 42 percent since the Industrial Revolution (Siegenthaler and Oeschger 1987). This increase is consistent with the quantity of  $\text{CO}_2$  emitted into the atmosphere by humans through the burning of fossil fuels such as oil, coal, and natural gas. As of 2008, approximately 10 billion tons of anthropogenic carbon had been released into the atmosphere, and the total mass of anthropogenic emissions was increasing annually by approximately 2 percent (Le Quéré et al. 2009).

## KEY CONCEPTS

- There is a strong consensus among climate scientists that global temperatures are increasing as a result of human activities.
- Weather, natural climate variability, and long-term climate change are distinct phenomena.
- The Earth is in an energy balance, which means that the amount of energy that enters the Earth's atmosphere is equal to the amount of energy that leaves the atmosphere.
- Three primary factors affect the Earth's energy balance: variability of solar intensity, reflectivity of the Earth's surface or atmosphere, and concentration of greenhouse gases.
- Natural solar radiation cycles affect the amount of solar energy reaching the Earth's surface, but they cannot account for the average global temperature increases we are experiencing.
- The greenhouse effect is a natural process that traps energy in the Earth's system, causing average global temperatures to be warmer than they would be otherwise.

## KEY CONCEPTS (CONTINUED)

- Human activities have increased the concentration of greenhouse gases in the atmosphere, which have augmented the greenhouse effect and increased average global temperatures.
- Direct and indirect observations indicate with certainty that the global climate is changing.
- Average global temperatures have increased by approximately 0.85°C since 1880.
- In addition to increasing temperatures, observations over the past century have indicated that snow and sea ice cover is decreasing, the average global sea level is rising, and precipitation patterns are changing.
- Climate models make projections of future climate change.
- Climate models strongly suggest that the increasing global temperatures and climate change in the past century are due to anthropogenic emissions of greenhouse gases.
- Average global temperatures are expected to increase between approximately 0.8°C to 4.9°C by the end of this century.
- Temperatures will increase most over land and high-latitude regions.
- There will likely be an increase in extreme heat events associated with climate change.
- Most areas will see an increase in the amount of precipitation, and rainfall events may become more intense.

## Scientific Consensus

As a result of increasingly complex mathematical models of climatological processes and the development of techniques to study past climates, there is now strong agreement among climate scientists that the altered composition of the atmosphere due to emissions of CO<sub>2</sub> and other GHG from human activities is causing an increase in mean global temperatures. An analysis of 11,944 peer-reviewed global warming studies published between 1991 and 2011 found that 97.7 percent of the studies stated that humans are causing global warming (Oreskes 2004; Cook et al. 2013). The science that has shaped this consensus is synthesized by the Intergovernmental Panel on Climate Change (IPCC), a nonpartisan intergovernmental organization that was created in 1988 and was jointly awarded the Nobel Peace Prize in 2007. The IPCC performs periodic assessments on the status of climate change science, potential impacts, and mitigation and adaptation.

The IPCC reports reflect the evolving state of the science. The IPCC (1990) stated that “the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.” In the Third Assessment (IPCC 2001), the panel concluded there was new evidence that human activities were responsible for the majority of the observed temperature increases. The Fourth Assessment Report (IPCC 2007) collectively determined with “very high confidence” (very low uncertainty) that human activities have increased global temperatures over the past fifty years. Over five hundred scientists and two thousand reviewers voluntarily contributed to the report. The recently completed Fifth Assessment (IPCC 2013) issued the strongest statement that observed warming in the past fifty years was “unequivocal.” The strength of this scientific consensus is similar to the evidence linking smoking to carcinogens and cancer (Shwed and Bearman 2010).

This book looks at the climatological processes that modulate human health. This chapter, however, focuses on the physical processes associated with climate change to provide a foundation for subsequent discussions.

In particular, we discuss how greenhouse gases alter Earth's energy balance and describe recent climate trends and projections of future climate change. In addition, we present multiple converging lines of evidence that support that the climate is changing and the changes are primarily caused by human activities.

## Weather, Climate Variability, Climate Change, and Scientific Theory

It is important to distinguish short-term weather changes, natural **climate variability**, and long-term climate change. People are intricately familiar with short-term weather changes in atmospheric conditions from their everyday experiences. However, it is exceedingly difficult to sense changes to climate because of its relatively slow progression and because it is masked by weather fluctuations. Confusion about these concepts can lead to incorrect interpretations and conclusions regarding climate change.

We commonly experience *weather*, the state of the atmosphere at any given moment in time, through changes in temperature, humidity, precipitation, cloudiness, and wind. Although weather changes from moment to moment, weather events such as storms may last for several hours or several days. Locations around the world tend to experience relatively unique weather patterns based on their latitude and their proximity to large water bodies and significant terrain (e.g., mountains). Collectively these features and the general circulation of the Earth's atmosphere and oceans shape a location's climate. *Climate* can be defined as the long-term average weather patterns for a specific region. More colloquially, Robert Heinlein (1973) stated, "Climate is what on an average we may expect; weather is what we actually get." J. Marshall Shepherd, former president of the American Meteorological Society, similarly stated, "Weather is your mood and climate is your personality." An operational climate definition commonly averages weather conditions over a period of thirty to fifty years.

*Climate change* also has a precise definition: systematic change in the long-term state of the atmosphere over multiple decades or longer. In the scientific literature, climate change may refer to a combination of human-induced and natural climatic changes or only human-induced changes. Formal statistical tests measure the probability that observed changes are outside the range of natural variability. The results are probabilistic statements about the likelihood that climate change is occurring. For example, there is at least a 99 percent chance that average global temperatures have significantly increased from 1950 to present (IPCC 2013). There is less than a 1 percent chance that we would randomly observe a similar increase

in global temperatures over the same time period. Thus, scientific statements avoid using strict statements such as “I do [do not] believe” in climate change. The most robust climate changes exhibit the same trend regardless of the choice of multidecadal aggregation period (e.g., 1950–1989, 1970–2009). Due to natural climate variability, there will be periods where temperatures do not appreciably change. However, the trend over the entire period of 1950 to the present is unequivocal. Similarly, reliable studies consider globally averaged trends instead of deliberately selecting the small subset of stations where temperatures did not change.

Superimposed on long-term trends in climate is natural climate variability. Natural climate variability is often associated with oscillations in the Earth system that occur at the scale of months to decades. The El Niño Southern Oscillation (ENSO) is the best-known and important driver of year-to-year climate variability (Trenberth 1997). ENSO is associated with a two- to seven-year oscillation in sea surface temperatures (SST) in the eastern tropical Pacific, with warmer SST during El Niño. Conversely, during a La Niña event, eastern tropical Pacific SST are cooler than normal. Shifts in SST in this region have dramatic effects on the large-scale atmospheric circulation patterns around the world and can influence temperature and precipitation conditions. For example, in the eastern part of South Africa, El Niño events are frequently accompanied by drier-than-normal summers, while La Niña is associated with a slightly greater chance of above-average precipitation. However, the distribution, magnitude, and timing of the effects of ENSO vary from event to event (McPhaden, Zebiak, and Glantz 2006; Zebiak et al. 2015). Other analogous ocean-atmosphere climate variability features vary over longer periods. For example, the Pacific Decadal Oscillation alters weather throughout the Pacific Ocean and Pacific Rim, while the North Atlantic Oscillation influences eastern North America, the Atlantic and Europe (Vuille and Garreaud 2011). The Northern and Southern annular mode, respectively, alter weather in North America/Eurasia and Antarctica.

The contention by some that climate change is “just” a theory reflects common confusion about the meaning of the term *theory*. When used colloquially, a theory is defined as an educated guess. Scientifically, however, a theory is a well-substantiated, evidence-based explanation of some aspect of the natural world. By definition, scientific theories begin as hypotheses. Over the course of repeated verification by experimental testing and observation, some hypotheses are so well supported by scientific evidence that they are accepted as theories. Climate change is one such evidence-based theory of science. Other examples are the germ theory of disease and the atomic theory of matter (American Association for the Advancement of Science 2006).

### CLINICAL CORRELATES 1.1 HEAT WAVES AND THE ELDERLY

During the 2003 heat wave in Europe, a majority of the seventy thousand excess deaths were among older adults (over age sixty-five) who remained alone in their homes despite warnings to seek cooler environments (Ledrans et al. 2004; Robine et al. 2008). Older adults are particularly vulnerable to heat waves because their mobility, hearing, vision, or cognition may be compromised, making it difficult or impossible for them to process or adhere to warnings. Cardiovascular, renal, and pulmonary diseases co-morbidities, which disproportionately affect the elderly, compound cognitive and mobility issues and thus increase their vulnerability during heat waves. Primary care physicians can begin to incorporate heat vulnerability in their preventative health screening as a way to raise awareness among this population of the early warning signs of heat stress.

**Elderly populations are particularly vulnerable to heat stress, a factor that should be incorporated into routine care.**

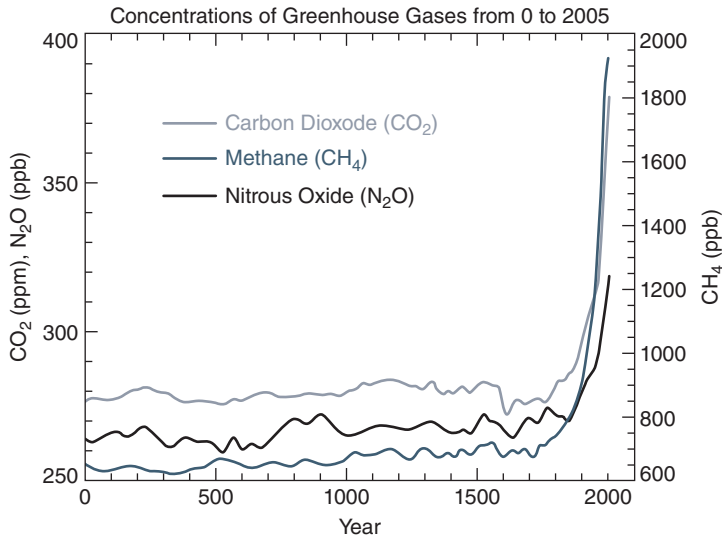
## Energy Balance

A basic understanding of Earth's energy balance is required to understand the theory of climate change. Our planet's temperature is dependent on how solar energy is transferred within the Earth system. The global temperature remains relatively constant because the total energy entering Earth is balanced by the energy that is released back into space. Specifically, solar energy is transmitted to Earth, and a proportion of the energy is naturally reflected back to space. However, some solar energy that enters the Earth system is absorbed by the atmosphere, oceans, and land surfaces, which causes the planet to warm. In turn, the Earth system releases (transmits) energy back into space, which precludes the accumulation of energy in the Earth system and sustains relatively constant global temperatures.

Several factors can cause the Earth's energy balance to change over time. This section discusses changes in the concentration of GHG, the greenhouse effect, GHG global warming potential, and changes in the amount of solar energy reaching Earth. Each of these factors is discussed further below.

## Greenhouse Gases

We review the main GHG whose atmospheric levels have increased as a result of human activities to concentrations not seen in hundreds of thousands of years. In order of their contribution to climate change these are



**Figure 1.1** Atmospheric CO<sub>2</sub> Levels, 1958–2015

Source: NOAA (2015).

Note: Rapid increases in CO<sub>2</sub> concentrations accompanied the Industrial Revolution.

CO<sub>2</sub>, methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and fluorinated gases: hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

The most important greenhouse gas is CO<sub>2</sub> (figure 1.1). CO<sub>2</sub> is naturally emitted to and absorbed from the atmosphere through plant photosynthesis and animal respiration, volcanic eruptions, and ocean-atmospheric interactions. Although the cycle of CO<sub>2</sub> is a natural process, humans have been discharging increasing amounts of CO<sub>2</sub> through the burning of fossil fuels (oil, coal, and natural gas) for energy and transportation, solid waste, trees, and wood products. We have also been increasing atmospheric CO<sub>2</sub> through land use changes such as deforestation (Environmental Protection Agency [EPA] 2013). Human activities such as fossil fuel use and land use change have emitted so much CO<sub>2</sub> into the atmosphere that natural CO<sub>2</sub> sinks (sources of CO<sub>2</sub> absorption such as oceans and plants) cannot absorb the excess CO<sub>2</sub> (EPA 2013). Indeed, since the eighteenth century, atmospheric CO<sub>2</sub> concentrations have increased by 40 percent from approximately 280 parts per million by volume (ppmv) to 398 ppmv in 2014. The current CO<sub>2</sub> level has not occurred for over 850,000 years (National Research Council 2010) and is not a result of natural CO<sub>2</sub> variation in the atmosphere.

Methane (CH<sub>4</sub>), an important GHG, is emitted into the atmosphere through several processes. CH<sub>4</sub> is naturally emitted from wetlands and other natural areas through the decomposition of organic materials, and it is naturally removed from the atmosphere through soil and chemical reactions. Humans emit CH<sub>4</sub> through the production and use of fossil

fuels and commercial livestock where it is produced from the creation and decomposition of manure in holding tanks and lagoons. The processing and decomposition of human solid waste in landfills and treatment facilities also produce  $\text{CH}_4$ . Atmospheric  $\text{CH}_4$  levels have not been as high as they are now for 650,000 years (Environmental Protection Agency 2013).

For the 11,500 years before the Industrial Revolution, atmospheric nitrous oxide ( $\text{N}_2\text{O}$ ) levels remained virtually constant. This gas is naturally released into the atmosphere through the breakdown of nitrogen by bacteria in the soil and ocean waters (denitrification). It is removed from the atmosphere through absorption by bacteria or decomposition by ultraviolet light radiation or other chemical reactions. Human causes of increased  $\text{N}_2\text{O}$  emissions stem from agriculture (e.g., synthetic fertilizers and livestock excrement), industry (e.g., nitric acid fertilizers and other synthetic products), and the combustion of solid waste and fossil fuels (Environmental Protection Agency 2013). After  $\text{CO}_2$  and  $\text{CH}_4$ , increased atmospheric  $\text{N}_2\text{O}$  is the third largest contributor to the greenhouse effect and the largest contributor to depletion of Earth's ozone layer.

The final GHG we discuss are fluorinated gases: hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride emitted from industrial sources. They are used as refrigerants (air conditioning for buildings and vehicles), solvents, aerosol propellants, and fire repellants. Their use as refrigerants is the primary form of their emissions. HFCs were designed to take the place of chlorofluorocarbons and hydrochlorocarbons which are being phased out internationally because they degrade the stratospheric ozone layer. However, HFCs are extremely potent GHGs. Perfluorocarbons are produced as the by-product of industrial sources such as aluminum production and the semiconductor manufacturing. Sulfur hexafluoride is produced through the transmission of electricity through electrical transmission equipment.

## The Greenhouse Effect

The most discussed driver of change in Earth's energy balance is the greenhouse effect: the ability of greenhouse gases to trap heat in the atmosphere. In particular, when the planet releases or reflects energy into the atmosphere as infrared radiation (i.e., heat), GHGs absorb that radiation and prevent or slow down the loss of energy to space. GHGs essentially act like a blanket that keeps the planet warm. The natural greenhouse effect dramatically captures more of the sun's energy and raises the Earth's average temperature by  $33^\circ\text{C}$ . Although the natural greenhouse effect is beneficial, scientists are concerned about human actions' increasing the concentration of GHGs in the atmosphere since this will intensify the greenhouse effect.

Since the start of the Industrial Revolution in approximately 1750, human activities have added substantial quantities of GHGs to the atmosphere, thereby increasing the greenhouse effect and raising Earth's surface temperature (Environmental Protection Agency 2013). Ground-based observations observed an enhanced greenhouse effect of 2.6 Watts per meter squared (energy per area) per decade from 1986 to 2000 (Wacker et al. 2011; Wild 2012). Satellites provide a complementary record to ground-based observations of the enhanced greenhouse effect. Since 1970, less heat emitted by the Earth's surface has escaped to space, which strongly suggests more heat is being absorbed by GHGs and transferred back toward the Earth's surface (Harries et al. 2001; Feldman et al. 2015).

## Greenhouse Gas Global Warming Potential

Based on its chemical structure, each GHG has a particular potential to absorb energy emitted from the Earth's surface and atmosphere, termed its global warming potential (GWP). GWPs are calculated based on the average length of time a GHG remains in the atmosphere and the amount of the heat energy it absorbs. GHGs that have a higher GWP absorb more energy and contribute more toward global warming than GHG with lower GWPs. Because changes in the atmospheric concentration of  $\text{CO}_2$  typically occur over long periods of time (hundreds of years), the GWP of  $\text{CO}_2$  is used as a baseline value against which other GHGs are compared. For instance, while  $\text{CO}_2$  has a GWP of 1,  $\text{CH}_4$  has a GWP of 21. This means that 1 pound of  $\text{CH}_4$  is equivalent to 21 pounds of  $\text{CO}_2$ , and  $\text{CH}_4$  has the potential to cause 21 times as much warming as  $\text{CO}_2$  over 100 years.  $\text{N}_2\text{O}$  has a GWP of 300, HFCs 140 to 11,700, perfluorocarbons 6,500 to 9,200, and sulfur hexafluoride to 23,900 (Environmental Protection Agency 2013). Although many molecules have a greater GWP than  $\text{CO}_2$ , the abundance of  $\text{CO}_2$  in the atmosphere and the rate that it is increasing makes it the most important GHG.

## Residence Time of GHG and Climate Change Commitment

The residence time, or amount of time individual GHGs remain in the atmosphere, varies substantially. For instance,  $\text{CO}_2$  remains in the atmosphere for 50 to 200 years, methane ( $\text{CH}_4$ ) for about approximately 12 years, and nitrous oxide ( $\text{N}_2\text{O}$ ) for about 120 years. For the fluorinated gases, HFCs can remain in the atmosphere in the range of 1 to 270 years, perfluorocarbons for 800 to 50,000 years, and sulfur hexafluoride for 3,200 years (Environmental Protection Agency 2013). In addition to long residence times of the GHG, it takes decades for energy in the Earth's system to equilibrate



to increased GHG levels. Ocean and land temperatures will continue to increase even if all GHG emissions from human activities abruptly stopped. In other words, society is committed to additional climate changes from GHG that have already been emitted.

### **CLINICAL CORRELATES 1.2 INNOVATIONS IN EMERGENCY READINESS IN THE ERA OF HEAT WAVES**

Epidemiological research shows that mortality in many places increases as the temperature rises (Bassil et al. 2011). Models have used temperature and humidity, as well as the time and rate of onset of these variables, to forecast when clinically significant **heat waves** may occur. These models allow for initiation of time-sensitive warnings to be released to the public. However, there is significant variability in the ways communities are affected; factors such as age, architecture, socioeconomics, prevalence of chronic disease, and relative isolation all play a part. Thus, each community has a different threshold at which heat-related illness becomes clinically apparent. Emergency medical systems (Leonardi et al. 2006), medical help lines, and emergency departments (Claessens et al. 2006) are at the forefront of detecting and treating heat-related illnesses. Research has shown that reliance on these organizations increases with rising temperatures, and the public's reliance on these institutions could therefore be an accurate indicator of the appearance of clinically relevant heat-related disease. More research is needed to determine whether real-time surveillance data generated from these clinical settings could assist public health officials in deciding when to issue heat warnings to a community. Early warnings can help to ease the toll of health-related illness, and prevention may ease the burden of such events on the health care system.

**Real-time data indicate clinically significant heat waves and could be used to generate public warnings and emergency system preparedness.**

## **Solar Radiation Cycles**

Short-term solar cycles such as sunspots marginally alter the solar energy that the Earth receives. Over the past thirty years, short-term solar cycles increased the energy in the Earth system ( $0.017 \text{ W/m}^2$  per decade), but this is notably less than the greenhouse gas contribution ( $0.30 \text{ W/m}^2$  per decade) (IPCC 2013). Since 1750, there has been a slight increase in the total emitted solar energy  $0.05 \text{ W/m}^2$  solar energy.

In addition to short-term solar cycles, gradual long-term solar cycles (10,000 to 100,000 years) also modulate the amount of solar energy reaching Earth. These cycles, referred to as Milankovitch cycles, affect the distance, orientation, and axis of the Earth relative to the sun. Indeed, the timing of the ice ages generally corresponds to periods of the Milankovitch cycles

when the Earth is receiving less solar energy (Hays, Imbrie, and Shackleton 1976). Based on these predictable solar cycles, the Earth should be in the midst of a gradual cooling trend lasting 23,000 years instead of rapidly warming (Imbrie and Imbrie 1980).

## Summary

In summary, there is a strong and consistent physical mechanism linking GHG to observed changes to the Earth's energy balance. GHGs absorb thermal radiation emitted by the Earth's surface and reemit this energy, further warming the Earth's surface. Human activities such as burning fossil fuels, synthesizing fertilizer and artificial coolants, and agricultural activities rapidly increased atmospheric GHG concentrations. The world is already committed to future climate changes due to the properties of GHG and the Earth's system.

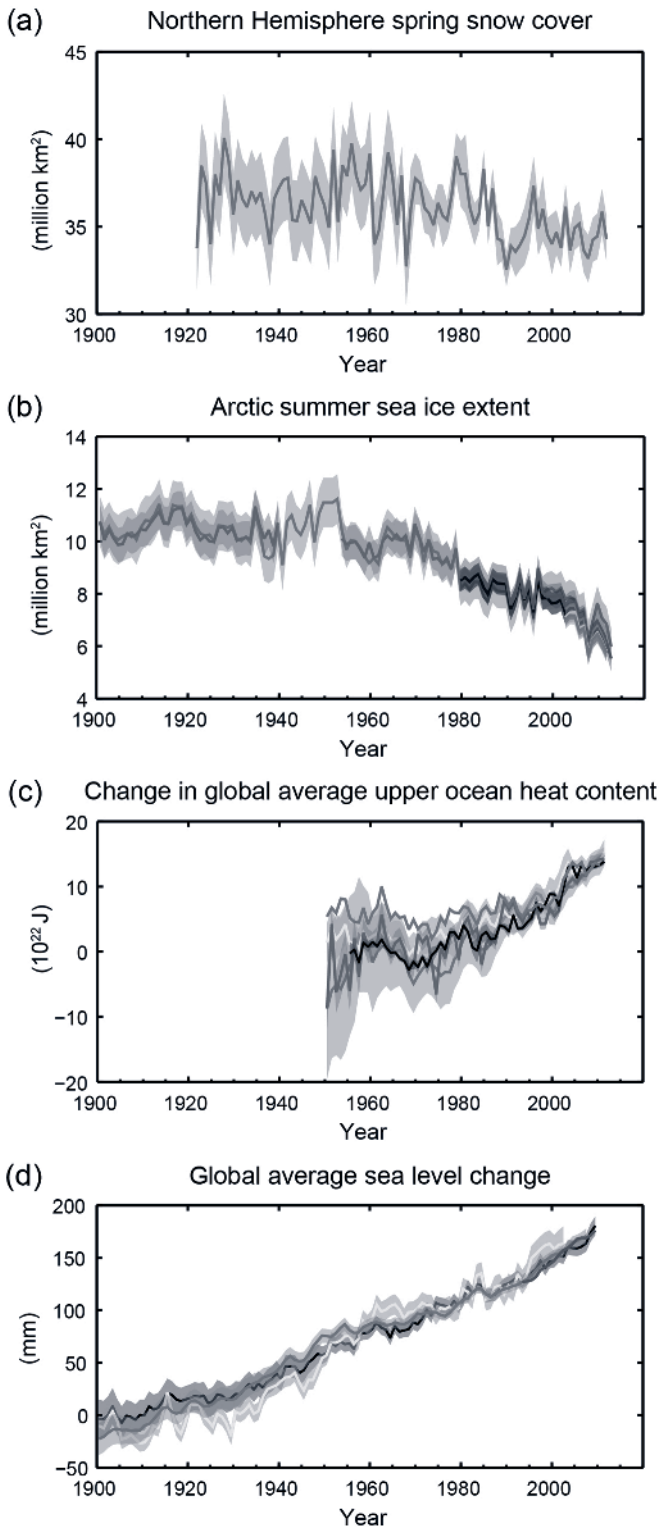
## Evidence of a Changing Climate

This section focuses on climatic changes that are virtually certain (99 to 100 percent probability), very likely (90 to 100 percent probability), or likely (66 to 100 percent probability) (Mastrandrea et al. 2010). There is no doubt that the climate on Earth is changing. We know this from direct observations of increasing average air and ocean temperatures, melting snow and ice, and rising average sea levels (figure 1.2). Here we examine the evidence for climate change since the first measurements were recorded in 1959 at Mauna Loa Observatory and paleoclimate records that provide physical evidence of a changing climate prior to the nineteenth century.

## Temperature

Earth's surface temperatures are typically lowest near the poles and increase toward the equator. The warmer temperatures in the tropics are due to a greater amount of solar energy reaching the surface in these regions. The temperature differentials generate large-scale atmospheric circulation patterns that redistribute energy from tropical to higher-latitude regions. However, local factors such as land cover, water bodies, and terrain can modulate regional and local temperature conditions.

Global surface temperatures have been increasing since the early twentieth century. Indeed, global temperatures increased by 0.85°C (1.8°F) from 1880 to 2012 (IPCC 2013). The rate of warming since 1957 is 0.13°C (0.27°F) per decade, almost twice as fast as it had been during the previous century (Hansen et al. 2010), and all of the top ten warmest years since 1850 have occurred since 1998 (Blunden and Arndt 2013). Stated another way, no

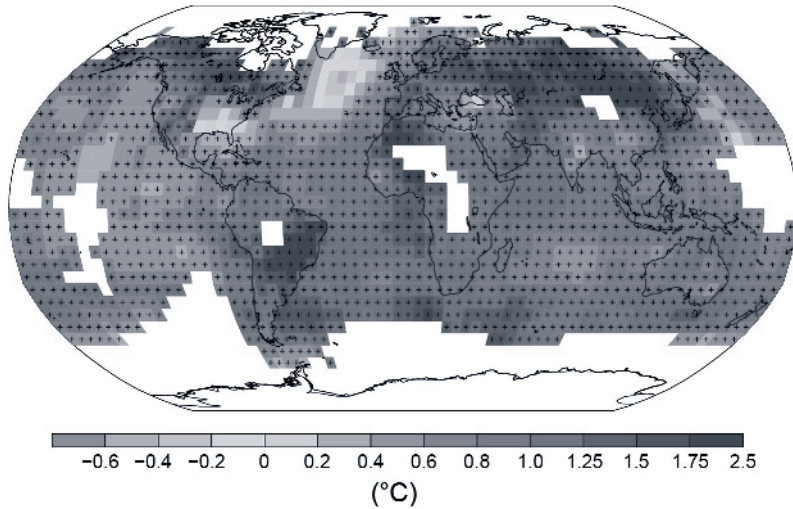


**Figure 1.2** Observed Changes in the Earth System Related to Climate Change

*Note:* Consistent with warming temperatures, the extent of Northern Hemisphere snow cover (a) from March to April and Arctic summer sea ice extent (b) from July to September are significantly decreasing. The upper ocean (0–700 meters) is also strongly warming (c), as summarized by standardized observational data sets, and (d) global average sea levels are increasing. Each line corresponds to a different data set. The lighter shading captures observational uncertainty.

*Source:* IPCC (2013).

## Observed change in surface temperature 1901–2012



**Figure 1.3** Decadal Rate of Observed Temperature Changes, 1901–2012

*Note:* Map of the observed surface temperature change from 1901 to 2012.

*Source:* IPCC (2013).

person under the age of thirty has experienced a cooler-than-normal month based on global average temperatures (NOAA National Climatic Data Center 2015).

Although nearly the entire globe has experienced increasing temperatures over the past century (IPCC 2013), there is significant geographic variation with respect to the magnitude of these increases (figure 1.3). Observed temperature changes have been greatest in polar regions of the Northern Hemisphere, and air temperatures over land have increased faster than over oceans (Hansen et al. 2010). The ocean's ability to store more heat energy modulates temperature increases compared to the land surface.

Precise temperature and systematic observations did not exist prior to the late nineteenth century. Fortunately, a variety of natural records indirectly measured historic conditions. Tree rings, ocean lake microorganisms, and pollen are mechanistically linked and well associated with temperature, moisture, and other physical environmental properties of the past. Although each proxy record has its limitations, all peer-reviewed proxies exhibit the same trend.

## Diurnal Temperature Cycles

Superimposed on the upward trend of global temperatures are seasonal and diurnal temperature cycles. The increase in diurnal temperatures is not straightforward. Over the past century, nighttime temperatures have

increased more rapidly than daytime temperatures, resulting in a decrease in the daily temperature range (DTR; Vose, Easterling, and Gleason 2005). However, this pattern varies strongly across the world, with some regions experiencing increases in DTR and others decreases. For example, DTR has been increasing in western and eastern Europe since the 1970s (Makowski, Wild, and Ohmura 2008), whereas it significantly decreased across China from 1961 to 2008 (Zhou and Ren 2011). Local and regional trends in diurnal temperature patterns can also be modified by land surface changes due to urbanization, deforestation, and other processes. Further complicating this picture is that the global decreasing trend in DTR has flattened out since the 1990s as maximum temperatures are now increasing at rates commensurate with minimum temperatures (Vose, Easterling, and Gleason 2005).

## Seasonal Temperature Cycles

In general, the timing of the warmest and the coolest times of the year have not been affected by global climate change. However, the onset of many biologically important seasonal events now occurs at a different time of the year from the past. For example, the length of the frost season is declining in many temperate regions, with later onsets and earlier cessations than was typical in the past. Remember that recent temperature increases have not been distributed evenly across the world or across seasons and geography. For instance, early summertime temperatures in the Southeast and central United States have been consistently cooler over the past fifty years (Portmann, Solomon, and Hegerl 2009).

## Urban Heat Island

Warming is becoming a major problem in urban areas through a phenomenon known as the **urban heat island** (UHI) effect: a built environment that is hotter than the surrounding rural areas (Oke 1982). UHI is a result of several distinct processes. The first of these is “waste” heat released from vehicles, power plants, air-conditioning units, and other anthropogenic sources in urban regions. Second, urban areas typically absorb more radiation than rural areas. Urban streets and tall buildings composed of asphalt, concrete, and metal reflect less solar radiation than vegetated areas. Third, urban areas alter the hydrological cycle, which also changes the local temperature. Urban surfaces and storm water infrastructure move water out of the city. Thus, urban areas retain less water that can be evaporated to moderate surface temperatures. UHI effects cause increases in energy consumption (e.g., using air-conditioning units for extended periods), elevated levels of ground-level ozone, and deterioration of the living environment in urban areas.

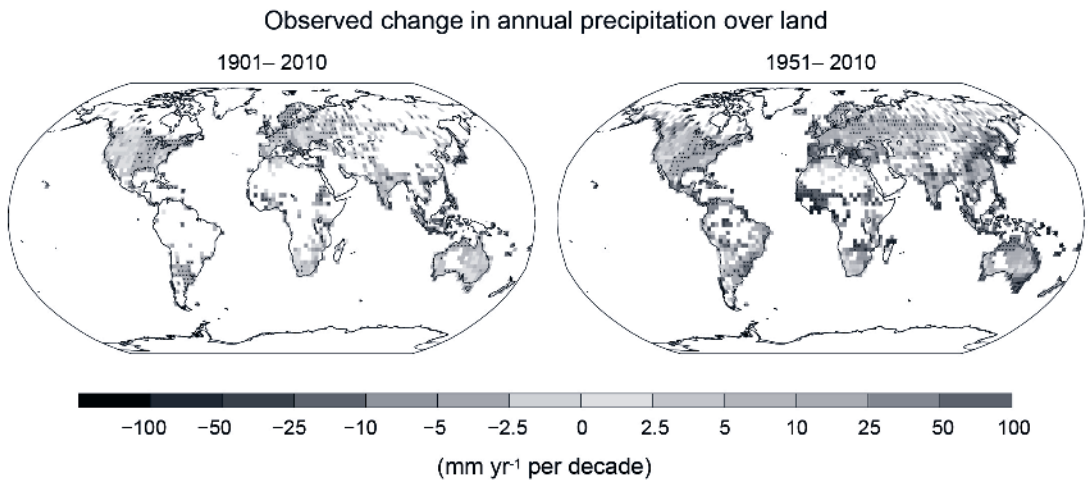
It is important to note that while UHI effects are changing the climate at the microlevel, they are of little importance to rising temperatures at the global level with less than a  $0.006^{\circ}\text{C}$  impact on land temperatures and no impact on ocean temperatures (Solomon et al. 2007). However, UHI is a massive global problem as approximately 3 billion people live in urban areas and are directly affected by it (Rizwan, Dennis, and Liu 2008). Outdoor extreme heat increases will likely be more pronounced in large, sprawling cities with an enhanced UHI (Kalnay and Cai 2003; Stone, Hess, and Frumkin 2010). Furthermore, many of the contributors to UHI also contribute to climate change, including greenhouse gas emissions from vehicles, industrial sources, and air-conditioning units. UHI may become a more serious problem in the future as the planet continues to urbanize (Rosenzweig et al. 2011).

## Hydrological Cycle

Most readers will be familiar with the hydrological cycle from their everyday experiences. Precipitation—rainfall and other solid forms of water that fall from the atmosphere to Earth’s surface—occurs when the atmosphere absorbs more water vapor than it can hold. The majority of Earth’s water makes its way back into the atmosphere either directly through surface evaporation or indirectly through plant transpiration. Much of the remaining liquid water runs off the land surface to a water body such as lakes, rivers, or oceans. Additional waters percolate into groundwater systems. Water may also be temporarily stored on the surface as ice or snow. Glaciers, snowpack, and groundwater are natural reservoirs that can trap water for extended periods of time.

There have been distinct geographical changes in total annual precipitation over the past century (figure 4.1). Total precipitation significantly decreased in the Mediterranean and West Africa. Drier-than-normal conditions may increase the frequency of wildfires, challenge hydropower generation, lower agriculture yields, and impair transportation on waterways. In contrast, precipitation significantly increased in the midlatitudes of both hemispheres (IPCC 2013). There is also some evidence for precipitation increases in polar areas of the Northern Hemisphere, although the strength of the conclusions is limited by patchy observations. There are inconsistent precipitation trends in the tropics and Southern Hemisphere polar regions due to uncertainties in early records.

Changes to the types and seasonal phase of precipitation may have an adverse impact on societal and ecosystem functioning. The frequency of and intensity of heavy precipitation events likely have increased over North America and Europe since 1950. This relationship is well grounded



**Figure 1.4** Observed Precipitation, 1901–2010 and 1951–2010 (Rates per Decade)

Source: IPCC (2013).

in physical theory since the amount of water the atmosphere can hold increases by approximately 7 percent for each additional degree Celsius of warming (Allan and Soden 2008). Furthermore, consistent with observed temperature increases, there is a trend toward fewer snowfall and more liquid rainfall events. This transition was recorded in North America, Europe, and South and East Asia (Takeuchi, Endo, and Murakami 2008; Kunkel et al. 2009). Satellite and ground-based observations support a significant decrease in snow cover extent (very high confidence) and depth (medium confidence) in spring and early summer (Brown and Mote 2009; Brown and Robinson 2011). In addition, the area, volume, and mass of almost all glaciers are decreasing across the globe (Arendt et al. 2012). Globally, 1 billion people live in watersheds with rivers fed by glacier or snowmelt. Ice loss is geographically concentrated in polar regions and high-altitude mountains such as the Andes and Himalayas.

### Sea Ice Extent, Sea Level, and Ocean Acidification

Since 1978, satellite data have allowed us to observe overall Arctic sea ice shrinkage (Solomon et al. 2007). From 1979 to 2012, annual mean Arctic sea ice area had very likely decreased in the range of 3.5 to 4.1 percent per decade. On the other side of the world, Antarctic sea ice area slightly increased 1.2 to 1.8 percent. The rapid decrease of Arctic and increase of Antarctic sea ice are not contradictory findings since each pole is governed by different processes. Antarctic sea ice may be expanding due to climate change–related melting of land glaciers or increased rainfall (Zhang 2007). Strengthening wind patterns may also be responsible for observed changes

(Holland and Kwok 2012). Scientists are highly confident that there are significant regional differences in sea ice extent in Antarctica, with some regions showing increases in sea ice areas and other regions showing decreases (IPCC 2013).

For approximately the past two thousand years, average sea level changed very little. However, since the start of the twentieth century, the sea level has been rising at an accelerating pace (Environmental Protection Agency 2013). For instance, since 1961, global sea level rose at an average rate of 1.8 millimeters per year. But since 1993, that rate has accelerated to 3.1 millimeters per year (Solomon et al. 2007). Although the melting of sea ice does not directly lead to an increase in sea levels, melting glaciers, ice caps, and polar ice sheets have been contributing to **sea level rise** (Solomon et al. 2007). Equally important, the thermal expansion of ocean water is increasing the volume of water in the oceans. Specifically, as average global temperatures increase, the oceans are storing more heat. This results in increasing sea surface temperatures, which causes ocean water to thermally expand, contributing to sea level rise.

In addition to increasing sea levels, seawater chemistry has also been altered as the oceans have absorbed increasing amounts of carbon from the atmosphere. Today the oceans are about 26 percent more acidic than they were forty years ago (IPCC 2013). Tiny microscopic creatures on which the marine food chain depends are significantly affected by the calcium chemistry of ocean waters. Increased seawater acidity has also decreased the ability of these creatures to form shells (Rodolfo-Metalpa et al. 2011).

## Summary

Global surface and ocean temperatures and sea levels are significantly increasing, and the rate of change continues to accelerate. Surface temperatures may be further magnified by the UHI. In turn, increased temperatures alter the timing of the seasons and length of the frost season. Increased temperatures are altering the amount, timing, and phases of precipitation and storage of liquid water. In the latter half of the twentieth century, annual precipitation increased in many midlatitude and polar regions. In North America and Europe, extreme precipitation events are becoming more intense and frequent. In North America, Europe, and South and Southeast Asia, there are fewer snowfall and more liquid precipitation events. Globally almost all glaciers are shrinking. Arctic sea ice area or extent has rapidly decreased. Thus, nonrandom climate changes are already detectable and are starting to challenge biological systems and societal well-being.



### CLINICAL CORRELATES 1.3 POVERTY AND EXTREME HEAT EVENTS

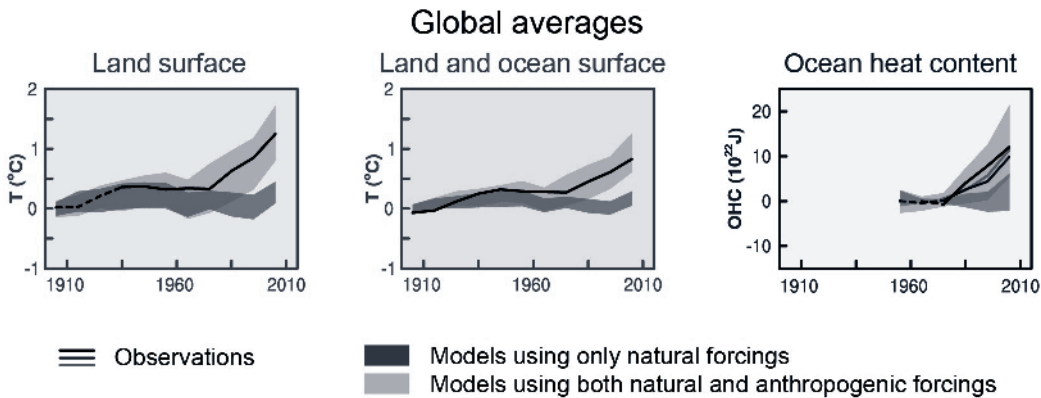
Poverty is an independent risk factor for illness related to heat. It is associated with a decreased likelihood of access to medical care. It is also associated with decreased access to protective measures, such as air-conditioning (Balbus and Malina 2009), which is then compounded by the urban microclimate that escalates heat events through heat island effects (Harlan et al. 2013). The heat island effect, caused by nighttime radiation of heat from buildings, industrial heat production, and a lack of green spaces, elevates both daytime and nighttime temperatures in city neighborhoods (Smargiassi, Goldberg, and Kosatsky 2009). This effect is evident in analysis of morbidity and mortality from heat events in Phoenix, Arizona (Uejio et al. 2011; Harlan et al. 2013) and Chicago in 1995 (Semenza et al. 1996) when a disproportionate number of deaths occurred among inner-city poor. These figures highlight the need for the medical community to increase health care access and address environmental health disparities.

**More resources are needed to address environmental disparities and provide protective measures against heat-related illness in urban areas.**

## Climate Models

How do scientists draw informed conclusions from the evidence of climatic change outlined thus far and make reasonable predictions about future change? If there were multiple Earths, a randomized trial could be conducted to determine exactly how elevated greenhouse gas levels alter the climate compared to a control Earth. Of course, we have only one planet Earth. The next-best study design is to build mathematical computer models that simulate the Earth's system and conduct trials within that model system. A climate model contains realistic representations of and interactions between the oceans, atmosphere, land surface, and cryosphere.

The backbone of climate models consists of physical equations and principles that govern the transfer of energy and mass. Climate models with increasing GHG levels over time accurately reproduce increasing temperatures, sea ice dynamics, and changing patterns of extreme weather (IPCC 2013). These models also provide additional evidence that observed climate change is caused by human activities. Detection and attribution studies attempt to determine if climate models can reproduce observed changes without elevated GHG levels (figure 1.5). Observed climate changes are outside the range of those expected by natural variability such as short-term solar radiation changes, volcanic eruptions, and other confounding processes. Only climate models with elevated greenhouse gas levels and reduced stratospheric ozone can reproduce observed climatic changes.



**Figure 1.5** Detection and Attribution Study Results

*Note:* Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere, and the ocean. Only climate models that account for human impacts on the atmosphere can reproduce observed temperature and heat content changes.

*Source:* IPCC (2013)

More than half of the observed changes in average global surface temperature from 1951 to 2010 are due to human activities based on the modeling results.

## Climate Projections, Uncertainty, and Climate Feedbacks

Future climate projections are uncertain for multiple reasons. The largest contributors to uncertainty are societal choices, natural climate variability, and scientific uncertainty. The relative contribution of societal versus scientific uncertainty for climate change varies over time and region (Hawkins and Sutton 2009, 2011). *Societal choices* broadly refers to demographic, economic growth and distribution, technological, and public policy changes. Projecting future societal actions and behaviors is notoriously difficult. For instance, a high population growth rate would increase emitted carbon 12.4 gigatons per year by 2100 over a low growth rate (O'Neill et al. 2010). To put this in perspective, 31.6 gigatons of carbon were emitted in 2012. Climate change and health impact studies work with climate projections over multiple years, and ideally decades, to minimize the influence of natural climate variability.

Scientific uncertainty in climate models is introduced by the modeling techniques and incomplete knowledge of some Earth system processes. Climate modeling techniques use simplified representations of processes smaller than approximately 100 to 300 kilometers. For example, North American summer precipitation changes are more uncertain than temperature changes. Climate models have difficulty resolving clouds, water vapor,

and aerosols, which are key components of convective summer precipitation. Similarly, climate projections may be more uncertain in areas with topography, near coastlines, or with large inland water bodies due to their simplified representation in global climate models (GCMs).

Scientific uncertainty also surrounds the ability of climate models to reproduce **climate feedback**. A feedback is defined as a forcing in the climate system that is both a cause and effect of itself and either acts to amplify (positive feedback) or dampen the initial forcing (negative feedback). For example, increasing surface temperatures cause highly reflective snow and ice to melt, thereby exposing dark soil and rock with lower reflectivity. This increases the solar radiation absorbed by Earth's surface, resulting in additional temperature increases and melting. Human-induced global climate change is unprecedented, so many important feedbacks have not been directly observed. Each GCM represents climate change feedbacks in subtle to moderately different ways. Climate sensitivity is defined as the average-rate global temperature increase for a doubling of CO<sub>2</sub> concentrations relative to preindustrial periods. The climate sensitivity depends on the representation of climate feedbacks and carbon reservoirs.

Major climate feedbacks are related to changes in the distribution of clouds, atmospheric temperature structure (changes to the relationship between temperature and altitude), vegetation type and coverage, the atmospheric concentration and distribution of water vapor, and modification of the carbon and sulfur cycles. There remains considerable uncertainty regarding feedback mechanisms, in particular those associated with clouds and the capacity of terrestrial surfaces and the ocean to absorb CO<sub>2</sub>. (The following section provides more information on key feedbacks.)

Robustly projecting the climate change disease burden should account for societal and scientific uncertainty. Climate models provide plausible projections of future conditions based on future GHG emissions trajectories or **representative concentration pathways** (RCPs). Climate projections that use multiple RCP essentially represent some of the societal uncertainty. Using a suite of projections from ten or more climate models will capture a range of scientific uncertainty.

Rather than issue a precise forecast, scientists use scenarios to generate a plausible range of RCPs. The RCPs are bounded on the upper end by rapid GHG emission growth (RCP 8.5 Watts per meter squared, i.e., energy per area) and on the lower end by aggressive limits on GHG emissions (RCP 2.6) (Moss et al. 2010). The middle pathways suggest that GHGs stabilize at different levels (RCP 4.5, 6.0) by the end of the century.

The RCPs were recently updated in the 2013 IPCC assessment. The RCPs replace the *Special Report on Emission Scenarios* (SRES) used in the third and fourth IPCC assessments (IPCC 2001, 2007). The report describes four “scenario families” that reflect distinct and realistic demographic, technological, and economic paths, enabling projections of global GHG emissions (Nakicenovic and Swart 2000). Among the key scenarios are A1F1, A1B, and B1. A1F1 describes a world characterized by intense economic growth, a decrease in global economic disparity, low to decreasing population growth, rapid introduction of efficient technology, and a reliance on fossil energy sources. The A1B scenario is equivalent with the exception that societies use a balance of fossil and nonfossil energy resources. In scenario B1, the demographic changes are identical to those in A1F1 and A1B; however, service and information economies rapidly become predominant, clean and efficient technologies are introduced, and significant decreases in material consumption are observed.

There may be some confusion surrounding the transitions in nomenclature. To help interpret the previous literature, RCP 8.5 is analogous to the A1F1, RCP 6.0 to A1B, and RCP 4.5 to B1. The lowest RCP (2.6) is new and did not have a *Special Report on Emissions Scenarios* analogue.

## Cloud Feedbacks

Feedbacks associated with clouds are still incompletely understood, and it is essential to understand their effects to improve predictions of future climatic conditions. Increasing temperatures will cause changes in the distribution and types of clouds occurring across Earth. Clouds are involved in both positive and negative feedback mechanisms by reflecting short-wave radiation back into space and by absorbing and reradiating outgoing long-wave radiation back to the surface, although different types of clouds have different radiative properties (Zelinka et al. 2013). The cumulative effect of feedback related to cloud cover is impeded by our inability to predict how the type, distribution, and characteristics of clouds will change as temperatures increase (Zelinka et al. 2013).

## Carbon Reservoirs

Another source of uncertainty regarding future climate change concerns the ability of natural carbon reservoirs such as oceans and terrestrial plants to continue to uptake carbon at current rates. Slightly less than half of the total CO<sub>2</sub> emissions are currently absorbed by land and ocean reservoirs (Le Quéré et al. 2009). There is evidence, however, that the rate of carbon uptake by carbon reservoirs will decline as they become increasingly saturated with CO<sub>2</sub>. Furthermore, physical characteristics of the reservoirs are

modulated by increasing temperatures and anthropogenic activity (e.g., land cover change). The mechanisms underlying the uptake of carbon by land and ocean reservoirs are complex, and it remains uncertain how carbon reservoirs will absorb CO<sub>2</sub> in the future.

## Summary

Climate models are multifaceted tools that complement observations and theory. Retrospectively, they show that natural climatic and solar variability cannot explain observed temperature increases. However, accounting for increased GHG produces similar changes to what scientists have observed. Prospectively, these models provide a range of plausible future climatic conditions. Future climate projections differ based on the magnitude and timing of climate feedbacks, natural variability, and substantial uncertainty surrounding human behavior. Nonetheless, the models continue to improve and increasingly capture the complexity of Earth's systems. The latest generation of global climate models includes the carbon cycle and dynamic vegetation.

### CLINICAL CORRELATES 1.4 INTEGRATIVE APPROACHES TO HEAT RESILIENCE

Air-conditioning has become the mainstay approach to buffer the deleterious health effects of extreme heat events. Unfortunately, it places major strains on energy supplies and contributes substantially to CO<sub>2</sub> emissions, which in turn increase global surface temperatures. Eighty-percent of energy for air-conditioning comes from fossil fuels, and according to estimates, total world air-conditioning consumes roughly 1 trillion kilowatt hours annually, more than twice the total energy consumption of the entire continent of Africa (Dahl 2013). Given the medical necessity of cooling in the future, it is important to realize that the developing world contains thirty-eight of the largest fifty cities on the planet, the warmest of which are in the developing world (Sivak 2009). Thus, to curb the health effects of heat stress among vulnerable populations, city planners and engineers must creatively use energy-saving technologies as well as integrate traditional technologies that have a small energy footprint. These designs include passive cooling systems—evaporative cooling (“Evaporative Cooling” 2012), night flushing (“Night-Purge Ventilation” 2012), and passive downdraft evaporative cooling (Kamal 2011)—exterior heat sinks, and modification of existing structures with awnings, reflective paint, and landscaping that maximizes shade. Health care organizations should model appropriate building codes and use of indoor climate control.

**Air-conditioning is both a cause of and cure for heat-related illness. Health care organizations should model green behavior in regard to indoor climate control.**

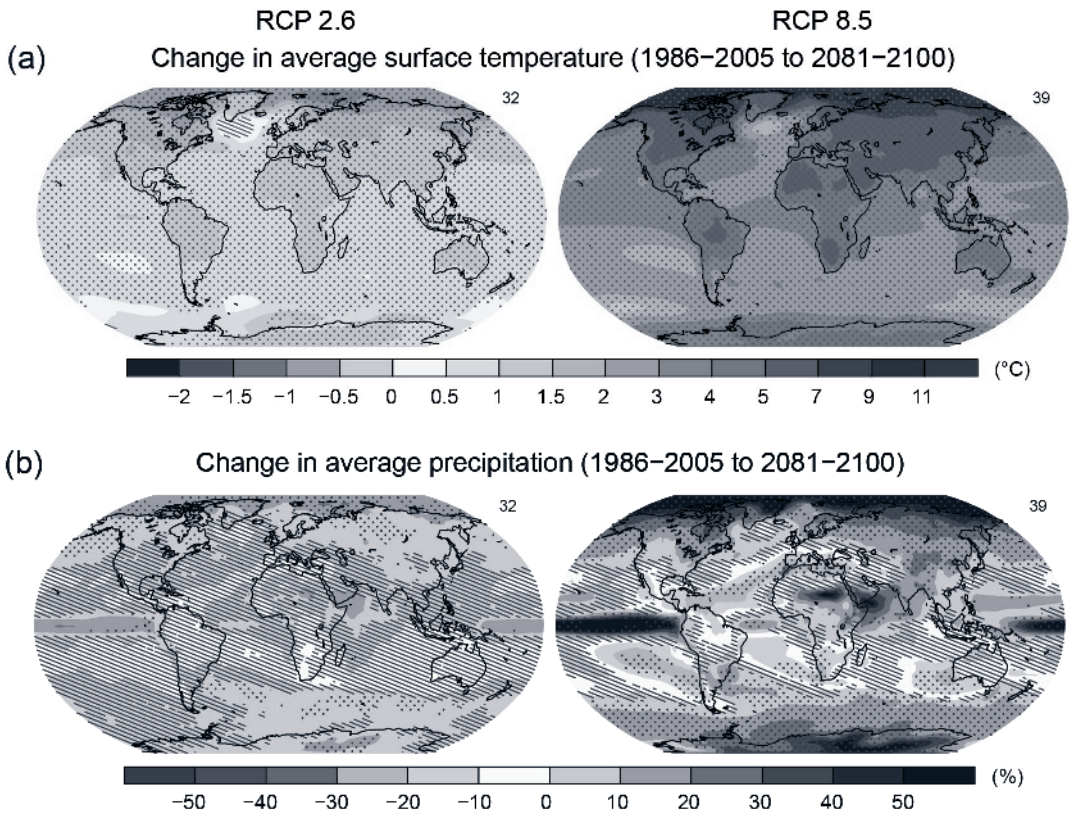
## Projected Future Climate Changes

Climate models are the primary tool to project long-term changes for the end of this century. Due to societal and scientific uncertainty, scientists cannot state which RCP and climate models are most likely to happen and which climate model provides the most accurate projections. This section focuses on projected temperature, hydrological cycle, and cryosphere changes. The estimates of future changes are based on the average, or an ensemble of multiple climate model projections, since the ensemble projection is typically more accurate than any individual climate model projection (Pierce et al. 2009).

### Increasing Temperatures

There is significant uncertainty regarding the magnitude of future temperature increases due to our incomplete understanding of societal and physical processes. Taking this uncertainty into account, global mean surface air temperatures are expected to increase from 1986–2005 averages by approximately 0.3°C to 0.7°C by the period 2016 to 2030, and 0.8°C to 4.9°C by the period 2081 to 2100 (Kharin et al. 2013). However, mean temperature increases over land will be double the global mean increase (figure 1.6). This will be even greater in high latitudes of the Northern Hemisphere. Although mean surface temperatures over the ocean will generally not increase as rapidly as surface temperatures over land, large changes will be observed over the Arctic and the southern oceans, where the reduction of sea ice will be associated with temperature increases of approximately 2°C to 11°C by the period 2081 to 2100 (IPCC 2013). Stated another way, by the middle of this century, average annual temperatures will be higher than the hottest observed annual temperatures from 1860 to 2005 over most of the world (Mora et al. 2013).

Seasonal variation of climate will continue to evolve with anthropogenic climate change. In high and middle latitudes, the number of frost days could decrease by up to ninety days in some regions of North America and Western Europe by 2081 to 2100, and the poleward extent of permafrost areas will be reduced (Sillmann et al. 2013). The seasonal modification of temperature and precipitation will modify the seasonal and spatial range of many plants and animals, including disease vectors such as mosquitoes and allergenic plant species. The DTR will continue to decrease across much of the world, especially in high and low latitudes, due to increased cloud coverage. Many middle-latitude locations will experience increases or no change in DTR in the coming century (Kharin et al. 2013).



**Figure 1.6** Projected Changes in Average Surface Temperature Difference for 2081–2100 versus 1986–2005 for Different RCP

Source: IPCC (2013).

Note: The average change is the mean of thirty-two climate model projections for RCP 2.6 and thirty-nine models for RCP 8.5. The figure also conveys uncertainty. In the dotted areas, the average projected changes is notably larger (two standard deviations) than natural variability. There is less confidence in the areas with hatching.

## Extreme Heat Events

Extreme heat events (EHE) can be defined as periods with notably greater-than-normal surface temperatures and moisture for a specific time of year (Robinson and Dewy 1990). EHE generally occur when very hot and humid air moves into an area where people are not adapted to extreme conditions. The longer that air masses linger over a region, the greater the potential is for harm to society and the environment. Many heat metrics suggest EHE are already becoming more intense, longer lasting, frequent, and geographically widespread (IPCC 2013), a trend that is likely to continue into the future. By the end of this century, extreme heat events will be even hotter and more humid, more likely to last weeks instead of days, and more frequent.

Scientists cannot directly link individual weather events to climate change. However, they can determine the extent to which climate change is

increasing the odds of an extreme event such as EHE compared to normal conditions. For example, climate change has at least doubled the probability (Stott, Stone, and Allen 2004) that an EHE event of the same magnitude of the historic European heat event of 2003 linked to seventy thousand excess deaths (Robine et al. 2008) will occur in the coming years.

## Hydrological Cycle

Climate change is expected to amplify important interactions between energy in Earth's system and the intensity of the hydrological cycle. With increasing temperatures, average total global precipitation will almost certainly increase by 2050 (IPCC 2013). The rate of annual precipitation increases ranges from 1 to 3 percent per degree average annual temperature increase for all scenarios except RCP 2.5. However, there will be substantial geographical variability in projected changes. At high latitudes, precipitation is very likely to increase since warmer air holds more moisture combined with the increased transfer of tropical moisture into the region.

In the midlatitudes, there are distinct total annual precipitation trends for drylands and deserts versus relatively wet and semitropical regions. Under the high RCP 8.5 scenario, dry areas are projected to desiccate further, while precipitation is expected to increase in relatively wet midlatitude locations. Summertime monsoon precipitation will likely increase in Southeast Asia, southern India, southern regions of the West Africa, and northern Australia, whereas summertime precipitation will likely decrease in southern Africa, Mexico, and Central America (IPCC 2013). In dry regions, climate warming will accelerate land surface drying as heat goes into the evaporation of moisture and increase the frequency and severity of droughts.

The frequency and intensity of average daily precipitation events will likely increase across most midlatitude and wet tropical locations. The difference in total annual versus daily precipitation may seem incongruous for drylands and deserts; however, both trends can coexist. These regions may receive fewer precipitation events that are not compensated by the increase in relative rare extreme precipitation events. More intense precipitation will transport more pollutants, toxins, and pathogens into water bodies. Increasing atmospheric water vapor may also contribute to the greenhouse effect, further increasing the amount of energy in the system.

## Sea Ice Extent, Sea Level, Ocean Acidification, Glacial Extent, and Snow Cover

The geographical extent of Arctic sea ice will continue to decrease by the end of this century under all RCP. Sea ice extent will decrease in all seasons. During the Arctic sea ice nadir in September, projected decreases range



**Table 1.1** Projected Changes in Global Mean Sea Level Rise Relative to 1986–2005 for Four Representative Concentration Pathways (in meters)

Scenario	2046–2065		2081–2100	
	Mean	Likely Range	Mean	Likely Range
RCP 2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
RCP 4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
RCP 6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
RCP 8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

*Note:* The estimates are based on twenty-one global climate models. Rapid ice sheet changes and altered societal practices such as increasing water storage are not considered in these estimates.

from 43 to 94 percent relative to 1985 to 2006. Similarly, the apex of sea ice extent in February will also be reduced 8 to 34 percent relative to 1985 to 2006 (IPCC 2013).

Since 1870, the global sea level has risen by eight inches due to the thermal expansion of water and melting polar ice and glaciers. In the next century, future sea level rise is expected to rise at a faster rate than it has been rising for approximately the past fifty years. Various scenarios estimate different levels of sea level rise (table 1.1). Sea level rise will vary by coastal regions. Major factors that affect local and regional sea levels will be subsiding coastal land and the changing gravitational pull of large glaciers (EPA 2013; Slangen et al. 2014). With rising sea levels, we face shore erosion, loss of dry land, coastal flooding, and human population displacement. There will also be significant damage to wetlands and coastal ecosystems (EPA 2013). Logically, increased carbon emissions and subsequent absorption by the ocean will continue to increase ocean acidity. All global climate models and scenarios reflect further **ocean acidification** (IPCC 2013).

It is virtually certain that the global permafrost area will decrease in response to rising temperatures and less snow cover. Furthermore, the proportion of North America covered by snow in the spring will likely continue to decrease (Brutel-Vuilmet, Ménégoz, and Krinner 2013). Climate models do not explicitly capture local processes like glacier dynamics. Nonetheless, based on projected temperature changes, glacier area, volume, and mass are reasonably expected to continue to recede. Springtime glacier runoff is also expected to decrease.

## Conclusion

We are already witnessing climate change impacts on public health, society, and ecosystems (Kovats, Campbell-Lendrum, and Matthies 2005). There is no doubt that since about 1950, the oceans and atmosphere have been warming,

sea levels have been rising, and snow and ice cover have been decreasing. Observations, modeling experiments, and scientific theory implicate human activities as the largest driver of changes to the Earth's energy balance. The physical mechanism linking GHG concentrations to warming is physically sound and consistent over hundreds of thousands of years. Projecting the magnitude and geographical distribution of future climatic conditions is difficult due to uncertainty with regard to societal and physical processes. In general, there tends to be more agreement surrounding projected temperature changes and much less confidence in hydrological cycle projections.

### DISCUSSION QUESTIONS

1. How have the conclusions of scientific assessments (e.g., Intergovernmental Panel on Climate Change) on whether climate change is occurring and what processes are responsible for these changes been updated over time?
2. What is the difference between natural climate variability and long-term climate change?
3. Why is it so difficult for an individual to observe long-term climate change?
4. If society somehow suddenly stopped emitting greenhouse gases, would existing greenhouse gases in the atmosphere continue to alter the climate? If so, for how long?
5. Some proposed public policies to mitigate or limit greenhouse gas emissions focus on methane, nitrous oxide, and fluorinated gases instead of carbon dioxide. What is the scientific rationale for these proposals? Discuss the relative merits and limitations of such a policy.
6. In what regions are temperatures increasing the most rapidly? Most slowly? Why?
7. What are the most important causes of sea level increases that have already happened?
8. What are the different types of evidence that support that the climate is changing?
9. What are the primary causes of uncertainty in climate model projections?
10. What are representative concentration pathways (RCPs), and why are they used?

### KEY TERMS

**Carbon dioxide:** A colorless, odorless gas naturally occurring in our atmosphere. Over the last 150 years, global levels of this “greenhouse” gas have increased secondary to combustion of carbon-based fuels, significantly contributing to global warming. It is also a major cause of ocean acidification since it dissolves in water to form carbonic acid.

- Climate feedback:** Processes that change as a result of a change in forcing and cause additional climate change, for example, the “ice-albedo feedback” (as the atmosphere warms, sea ice will melt).
- Climate variability:** Long-term averages and variations in weather measured over a period of several decades. The Earth’s climate system includes the land surface, atmosphere, oceans, and ice.
- Heat wave:** A prolonged period of excessively hot temperature that may be exacerbated by humidity and solar radiation. Human morbidity and mortality are known to increase during heat waves.
- Ocean acidification:** The ongoing decrease in the pH of the Earth’s oceans, caused by the uptake of carbon dioxide from the atmosphere.
- Representative concentration pathways:** Four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. They represent differing predictions of future effects of climate change.
- Sea level rise:** A major consequence of global warming, affecting long-term coastal morphology as well as sea-level cities of the planet. Expected changes include a general shoreline retreat and increased flooding risk.
- Urban heat island:** A city or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities.

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