2 The Climate System

OVERVIEW

In order to understand the problem and then be able to manage it effectively, it is imperative to have an understanding of the complex theory and science behind climate change. Although much of the existing literature refers to the issue as *global warming*—the term used predominantly in the past—scientists have largely transitioned to the term *climate change* because of the multifaceted nature of the phenomenon. This book utilizes the current terminology. As background, the term global warming tends to imply that the only consequence is that the earth's atmosphere is slowly getting warmer, unfortunately causing many to minimize the significance of the issue. When the media reports that scientists predict that the earth's atmosphere is warming, some people expect to hear that the temperature will get tens of degrees warmer. Some may have visions of sitting in a hot, steamy sauna—a vision that for those who live in extremely cold climates, such as Siberia or the Yukon, may be very welcome indeed! Therefore, when climatologists predict a temperature rise of 1.1°C–6.4°C, the public may be inclined to ask what the urgency about the issue really is. After all, it is just a few degrees, right?

Wrong.

Look at it this way: During the earth's last ice age, the earth was only about 4°C–6°C *cooler* than it is today. Although that may seem like an insignificant temperature difference, it was enough to blanket huge areas of the earth with thick layers of ice. It had such an enormous impact on ecosystems that it even rendered some species extinct, such as the mammoth and mastodon.

Thus, although a few degrees may seem trivial, the earth's climate is so sensitive that those few degrees can make a significant difference. In addition, although some climate change is natural, scientists have now proven that humans are causing the bulk of the recent changes and rises in temperature, and although those few degrees may not seem like much, it is unfortunately enough to serve as a tipping point—a big enough influence on the climate that, once reached, it will set into motion permanent changes with global ramifications. When the climate changes, it affects the entire earth systems. Many components of the earth's physical system operate on a global scale, such as the hydrologic, carbon, nitrogen, and phosphorus cycles. The earth's various biogeochemical cycles are always changing and represent the continual interactions between the biosphere (life), the lithosphere (land), the hydrosphere (water), and the atmosphere (air). Various substances move endlessly throughout these four spheres. Of the four spheres, the atmosphere transports elements the most rapidly, and climate change will negatively affect these spheres if left unchecked.

This chapter is the first of the three parts that lays the foundation needed to understand how the climate system works as a whole and what climate change is capable of and why. It looks at the climate as a global system and the fact that harmful environmental practices at one location can negatively affect other locations. It then examines the effect that human activities have on the earth's natural carbon cycle—commonly referred to as the human-enhanced carbon cycle. From there, it focuses on global circulation patterns of the atmosphere and oceans and their role in climate change, specifically the consequences of the disruption of the Great Ocean Conveyor Belt—a major circulation pattern responsible for Western Europe's mild climate and possibly for abrupt climate change. Finally, it presents current research information about the effects of sea-level rise and the consequences of a warming world.

INTRODUCTION

Climate change is one of today's most urgent topics. Despite all the controversy and hype the entire climate change topic has generated, there now exists an overwhelming body of scientific evidence that the problem is real, that its effects are being felt right now on a global scale, that some geographic areas are more vulnerable than others, and that it will take the concerted effort of every person working toward the same goals to put a halt to the rise in both temperature and atmospheric greenhouse gases. The fact is that even if all necessary steps are taken right now to stop the increase in greenhouse gases entering the earth's atmosphere, the effects of climate change will still be present for centuries to come. The complicated process has already been set into irreversible motion. The critical key to understanding the effects of climate change is to be knowledgeable about how to control and mitigate the causes of climate change now in order to minimize future damage to the environment and the life living in it. An unhealthy environment affects all forms of life on earth, and through understanding first the causes and effects—the science behind climate change—it will be possible to empower the world's populations to solve the problem through political leadership, realistic sociological mind-sets, and proper economic measures. The scientific consensus is that people's behavior is largely responsible for today's climate change problem. Another factor that makes this a volatile and controversial issue is that it is not just confined to the realms of the scientific community, nor does it have just one simple, predefined solution—it has multifaceted dimensions involving economic, sociological, political, psychological, and personal issues, making this a topic affecting the future outcome of every person's life on earth now and in the future. To make the problem even more sensitive, it is projected that those who will suffer the worst effects are not even those who have caused the bulk of the problem—the undeveloped nations will take the brunt of what the developed nations have largely caused.

The scientific community has many theories about climate change. The topic is extremely challenging in nature because there are so many factors involved in it, making it difficult to pinpoint its exact causes and solutions across the board. The earth's climate is extremely complicated, and climatologists are conducting daily research in order to improve their understanding of all the interrelated components.

In 2014, about 40 billion tons of carbon was pumped into the atmosphere (Plait, 2014). Studies show that concentrations of carbon dioxide (CO_2) have increased by about one-third since 1900. During this same time period, experts say the earth had warmed rapidly. For this reason, a connection has been made that humans are contributing significantly to climate change. Even scientists who are skeptical about the climate change issue recognize that there is much more CO_2 in the atmosphere than ever before.

Although it is certainly true that the atmosphere is warming up, that is only one part of what is going on. As the earth's atmosphere continues to warm, it is setting off an avalanche of other mechanisms that will do even greater harm to the earth's natural ecosystems. Glaciers and ice caps are melting, sea levels are rising, and ocean circulation patterns are changing, which then change the traditional heat distributions around the globe. Seasons are shifting and storms are becoming more intense, leading to severe weather events. Droughts are causing desertification, crops are dying, and disease is spreading. Some ecosystems are shifting where they still can; others are beginning to fail. In short, humans are changing the earth's climate—and not for the better.

DEVELOPMENT

In order to understand climate change management issues, it is necessary to have a good understanding and working knowledge of the basic scientific theory behind climate change: how the earth's atmosphere works, how it interacts with the earth's surface, what causes climate change, how it affects the various earth systems, and why it is an issue that must be addressed today. In practical land management, principally overseen by the world's government agencies and appropriated entities, much of the knowledge relied on in order to manage the land and make appropriate policy decisions to properly provide for present and future management capabilities and expertise is current research, largely provided by the world's principal research institutions—chiefly governmental, academic, and private—such as the National Aeronautics and Space Administration (NASA), numerous universities worldwide, and esteemed organizations such as the Pew Center on Global Climate Change, respectively. Therefore, Chapters 2 through 4, while merely touching on some of the most prominent key issues, provide an overview of the recent scientific research and work that has been done on the climate change issue, laying the basic groundwork, to promote an understanding of the complex, interwoven issues and key concepts of the climate change problem, thereby creating a firm foundation for why this issue is critical to both the society and the environment's future, as well as why politics, sociology, and economics play such a critical role in its management. Consulting the references listed at the conclusions of each chapter will also provide a greater depth of detail in each subissue presented. This research has been crucial toward enabling managers to gain an understanding of all the individual facets of the problem in order to be able to put proper and effective policy in place to provide efficient land stewardship practices for both the present and the future. It is crucial that you, the reader, understand the scientific concepts behind the complex climate change issue in order to gain an appreciation for the immense challenge that land managers, urban planners, financial analysts, engineers, and other professionals concerned with sustainability face today. In planning for future climate change situations based on a plethora of interactive scenarios where each has the ability to change the long-term outcome, making effective management decisions one of the most challenging tasks of this century—a task that will affect many future generations. Chapters 2, 3, and 4 provide a brief but comprehensive introduction to climate change science and present the key scientific concepts behind it. Only through understanding the depth of the scientific principles and processes involved is it possible to grasp the interwoven complexity of the issue and gain an appreciation for why informed climate management practices are critical for the future of both humanity and the environment when dealing with climate, energy, and sustainability.

What Is Climate Change?

Climate change is a term used to refer to the increase of the earth's average surface temperature, due largely to a buildup of greenhouse gases in the earth's atmosphere, primarily from the burning of fossil fuels and the destruction of the world's rain forests. The term was coined by Svante Arrhenius, a Swedish scientist and Nobel Laureate, in 1913. The term is often used to convey the concept that there is actually more going on than just rising temperatures. It is a misnomer that the issue involves just the atmosphere and temperature rising a few degrees; hence, the major reason for the name change from global warming to climate change in order to more accurately convey the multifaceted nature of the phenomenon. Climate change encompasses long-term changes in climate, which include temperature, precipitation amounts, and types of precipitation, humidity, and other factors.

Today, climate change has become one of the most controversial issues in the public eye, appearing frequently in print and televised news reports, documentaries, scientific and political debates, and other venues and economic issues, and the messages can be contradictory and confusing. One goal of this book is to set that record straight by presenting various points of view and clarifying them with the facts. Climate change also receives a lot of attention because it is more than just a scientific issue—it also affects economics, sociology, and people's personal lifestyles and standards of living. It is one of the hottest current political issues, not only in the United States but worldwide. Political positions on climate change have become major platforms and debating issues as public demands toward a solution have intensified in recent years.

More than 2500 of the world's most renowned climatologists, represented by the Intergovernmental Panel on Climate Change (IPCC), support the concept of climate change and agree that there is absolutely no scientific doubt that the atmosphere is warming. They also believe that human activities—especially burning fossil fuels (oil, gas, and coal), deforestation, and environmentally unfriendly farming practices—are playing a significant role in the problem. The IPCC is an organized group of more than 2500 climate experts from around the world that consolidates their most recent scientific findings every 5–7 years into a single report, which is then presented to the world's political leaders. The World Meteorological Organization (WMO) and the United Nations Environment Programme established the IPCC in 1988 to specifically address the issue of climate change. As a result of their comprehensive analysis, the IPCC determined that this steady warming has had a significant impact on at least 420 animal and plant species in addition to natural processes. Furthermore, this has not just occurred in one geographical location, but worldwide.

Unfortunately, the science of climate change does not come with a crystal ball. Scientists do not know exactly what will happen, such as what the specific impacts to specific areas will be, nor can they say with certainty when or where the impacts will hit the hardest, making it all the more difficult for land resource managers, planners, politicians, and economists to do the best job possible in long-range planning. But they are certain that the effects will be serious and globally far-reaching. According to the National Oceanic and Atmospheric Administration (NOAA)/NASA/EPA Climate Change Partnership, potential impacts include increased human mortality, extinction of plants and animal species, increased severe weather, drought, and dangerous rises in sea levels.

Although climatologists still argue about how quickly the earth is warming and how much it will ultimately warm, they do agree that climate change is currently happening, and that the earth will continue to keep warming if something is not done soon to stop it.

DID YOU KNOW?

There are several interesting facts concerning climate change. For instance, did you know that as of January 2016 (Ppcorn, 2016):

- The year 2015 was the world's hottest year on record. Every year of the past decade has been in the running for the world's hottest year on record. Before 2014 was declared the hottest, it was 2010.
- Every year the CO_2 concentration level in the atmosphere steadily climbs higher and that the earth will reach a "tipping point" of no return if humans do not reverse the trend. In order to avoid a rise of 6°C by the end of this century—which is the critical level identified by climate change research scientists—total global emissions need to have peaked by 2015 and reduced by at least 80 percent by 2050 to prevent nonreversible damage. The peak limit will not be met.
- Although every person plays a role in the problem and has a responsibility for its solution, the lion's share of the problem can be attributed to 23 of the world's most wealthy nations—which constitute only 14 percent of the world's population. These "developed" countries are guilty of producing 60 percent of the world's carbon emissions since 1850 when industrialization became an integral part of their lifestyles. Even though many of these nations pledged to reduce CO_2 below 1990 levels by 2012 through the ratification of the Kyoto Protocol, their emissions have risen instead.
- Climate change costs the United States more than $100 billion each year. This is due to costs spent combating the effects of crop loss, rising sea levels, foot and water shortages, and higher temperatures—all because of climate change.
- Thirty-seven percent of Americans still believe climate change is a hoax. Ignoring numerous studies that show climate change is real, nearly 4 of 10 Americans do not believe it. And these are some of the biggest offenders.
- The United States is responsible for 80 percent of the world's fossil fuel use annually. Behind other progressive countries on the problem, the United States still obtains 84 percent of its total energy from coal, oil, and gas (fossil fuels).
- The earth's human inhabitants release a collective 37 billion metric tons of CO_2 annually. These emissions need to decrease more than 5 percent each year just to give us a 50/50 chance of keeping under the 2°C threshold leading to disastrous effects.
- By 2050, we could see nearly 40 percent of the plant and animal species on earth become extinct. That is only 33 years from now.
- Up until 2007, the United States emitted the highest levels of greenhouse gases. China is now the largest emitter of CO_2, surpassing the United States. As of 2015, China emitted nearly 30 percent of the global total.
- Climate change is a problem that affects every nation sociologically, politically, and economically. In fact, the World Health Organization estimates that climate change was

causing 150,000 deaths worldwide from malaria, malnutrition, diarrhea, and flooding.
- The low-lying island of Tuvalu in the Pacific has already evacuated 3000 of its inhabitants to New Zealand.
- By 2020, up to 250 million people in Africa and 77 million in South America will be under increased water stress because supplies will no longer meet demand.
- By 2025, tens of millions more will go hungry due to low crop yields and rising global food prices.
- A rise in sea level of just 1 meter would displace 10 million people in Vietnam and 8–10 million in Egypt.
- The number of people in Africa at risk of coastal flooding will rise from 1 million in 1990 to 70 million by 2080 according to the Stern Enquiry into Climate Change and Developing Countries.
- Nearly two-thirds of Americans do NOT believe that climate will affect their lives.

Let us take a brief look at the status of climate change at the end of 2015 before we continue. These are some highlights from the year and where we stand on getting climate change voluntarily under control (Hood, 2016):

- While registering as the hottest year on record for the planet as a whole, 195 states pledged to curb the carbon pollution that drove climate change at the December 12 Paris Agreement talks (United Nations Framework Convention on Climate Change) (Figure 2.1).
- Experts believe it is now up to each country to take appropriate action in order to make a difference. The Paris Agreement is the key to our salvation or too-little-too-late will depend on what happens now: who takes what action, when, and how much.
- Experts have identified the year 2015 as the tipping point for climate change. It is sink or swim now.

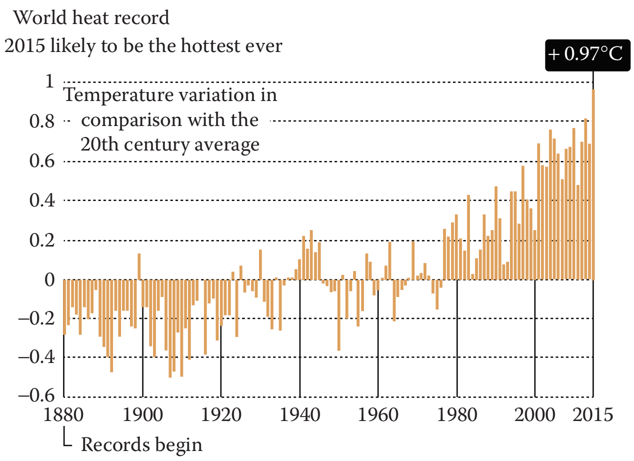

FIGURE 2.1 Trend in the average temperature of the earth's surface 1880–2015. (Courtesy of NOAA, Silver Spring, MD.)

- The Paris talks was seen as the most serious gathering where officials seem to be coming to grips with the real issues. The seriousness was prompted by the deadly extreme weather seen in 2015, as well as recent technological and scientific advancements in climate science.
- Specific climate events served as powerful illustrations from 2015: the most powerful hurricane ever registered; freakish, above-freezing temperatures at the North Pole in December; and life-threatening droughts in eastern and southern Africa.
- The elevated CO_2 levels have likely pushed back the next Ice Age by 50,000 years—a shocking result as to the extent to which human activity has destroyed the earth's natural cycles. In tandem with that idea, the earth's biochemical systems have also been permanently impacted an altered.
- Just added to the list of global risks and concerns is "climate change mitigation and adaptation."
- On the brighter side, the balance of investment is shifting away from fossil fuels and toward renewables, as reported by Bloomberg New Energy Finance.

The Global System Concept

Although different types of climate exist in different parts of the world, the climate does work as a complete unified global system—conditions and actions in one area can impact conditions and actions in others. For example, because the earth shares one atmosphere, what goes on in China will affect the United States. Similarly, what goes on in South America eventually affects Africa, and so on. NASA has reported that soot (black carbon) originating from industrial practices is being deposited on Arctic snow and ice, causing incoming *electromagnetic radiation* to heat up the now-darker surfaces that the soot is covering, causing more snow and ice to melt, creating a cycle of increased melting.

Because of these interactions, climate change is also a global issue—it is affecting the earth in different ways, such as destabilizing major ice sheets, melting the world's glaciers, raising sea levels, contributing to extreme weather, and shifting biological species northward and higher in elevation, ensuring that no area of the earth is immune from its effects. In fact, NASA scientists have determined that the atmospheric concentration of carbon dioxide, the principal greenhouse gas, is now higher than it has been for the past 650,000 years.

A remark often heard is that the earth's temperature and CO_2 levels have risen in the past so these cyclic variations are normal. This is true, as can be seen in the illustration (Figure 2.2). As paleoclimatologists have studied ice age cycles they have determined that the atmospheric CO_2 closely follows the earth's surface temperature. It is a known fact that as biological activity rises (with increases in temperature), CO_2 levels also rise because more CO_2 is

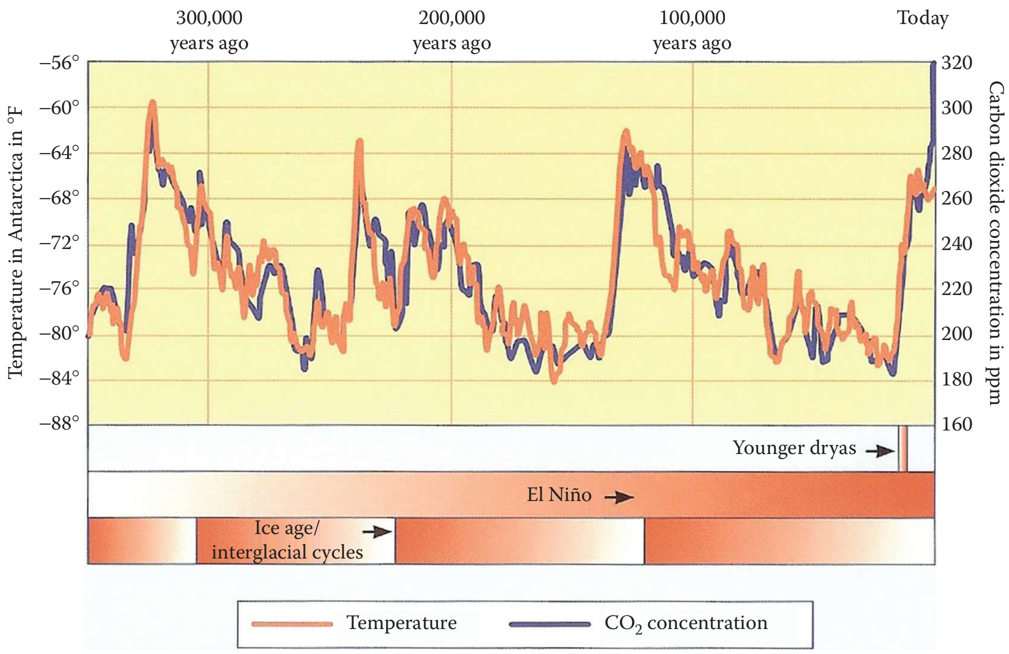

FIGURE 2.2 Fluctuations in temperature (orange line) and in the amount of carbon dioxide concentrations in the atmosphere (blue line) over the past 350,000 years. The temperature and carbon dioxide concentrations at the South Pole run roughly parallel to each other, showing the strong correlation between the two. (From Casper, J. K., *Global Warming Trends: Ecological Footprints*, Facts on File, New York, 2009.)

produced and is entered into the atmosphere. This increases warming and encourages more CO_2 production. It is critical to note, however, that under natural processes (non-anthropogenic), CO_2 concentrations never exceeded 300 ppm (parts per million) until the Industrial Revolution occurred in the late eighteenth century. It was at that point that CO_2 levels began to continually rise. In 1958, when CO_2 concentrations began to be recorded, the atmosphere was at 315 ppm. In March 2016, CO_2 concentrations were at 404.16 ppm and are still steadily rising (co2.earth, 2016). In addition, NASA's scientists from the Goddard Institute for Space Studies in New York released a report in 2014 outlining that their scientific studies provided clear evidence that an enhanced greenhouse effect is ongoing. Their study involved satellites, data from buoys, and computer models to study the earth's oceans. Scientists were able to conclude that more energy from the sun is being absorbed by the atmosphere than is emitted back to space, which is causing the earth's energy to become unbalanced and is now significantly warming the earth. NASA scientists claim that the world is entering "largely uncharted territory as atmospheric levels of greenhouse gases continue to rise." Today, scientists have no doubt that the recent spike in the graph showing the rise of CO_2 concentration is due to anthropogenic activity. In summary, because the earth is a global system, climate change must be approached as a global issue with far-reaching cause-and-effect issues, and it will take all nations working toward a common solution to effectively mitigate the problem (ScienceDaily, 2010).

The Atmosphere's Structure

The atmosphere can be thought of as a thin layer of gases that surround the earth. The two major elements, nitrogen and oxygen, make up 99 percent of the volume of the atmosphere. The remaining 1 percent is composed of what is referred to as "trace" gases. The trace gases include water vapor (H_2O), methane (CH_4), argon (Ar), carbon dioxide (CO_2), and ozone (O_3). Although they only make up a small portion of the atmosphere, the trace gases are very important. Water vapor in the atmosphere is variable: Arid regions may have less than 1 percent, the tropics may have 3 percent, and over the ocean, there may be 4 percent.

The atmosphere is not uniform from the earth's surface to the top; it is divided vertically into four distinct layers: (1) the troposphere; (2) the stratosphere; (3) the mesosphere; and (4) the thermosphere, designated by height and temperature. The lowest level, closest to the surface of the earth, is the troposphere. It extends upward to an average height of 12 kilometers. This level is critical to humans because all of the earth's weather occurs in this layer. In this level, the temperature gets cooler with increasing height. In fact, the temperature at the surface of the earth averages 15°C, and at the tropopause (the top of the troposphere) the temperature is just −57°C. In addition, the moisture content decreases with the altitude in this layer; above the troposphere, there is not enough oxygen in the atmosphere to sustain life; and winds increase with height. To illustrate this, one of the most pronounced wind systems, the jet stream, is located at the top of the troposphere.

The climate of an area is the result of both natural and *anthropogenic* factors. Natural elements come from the following four principal inputs:

- Atmosphere
- Lithosphere
- Biosphere
- Hydrosphere

The human factor influences climate when it alters land and resource uses—a principal concern for land, wildlife, and natural resource managers worldwide. For example, when a natural forested area is converted into a city, it has a direct effect on climate—one of the most notable, the *urban heat island effect*.

Even though climate does change naturally, those types of changes occur so slowly (such as over millennia) that they are not readily detectable by humans. Climate changes caused by humans, however, are occurring much faster (such as in centuries or even decades) and are becoming noticeable within a few generations. Often, a change in one part of the climate will produce changes in other areas of climate as well. Since the Industrial Revolution began in the late eighteenth century—and especially since the introduction and use of fossil fuels involved in the rapid modernization of the twentieth and twenty-first centuries in developed countries—the global average temperature and atmospheric CO_2 concentrations have increased notably. Because CO_2 levels are higher now than they have been in the past 650,000 years and surface temperatures on earth have risen significantly during the same time, this has led scientists to the conclusion that humans are responsible for some of the unusual warmth that exists today. In support of this notion, climatologists at both NOAA and NASA have run two types of computer models: one of climate systems with natural climate processes alone and another with natural climatic processes combined with human activities. The models that include the human activities more accurately resemble the actual climate measurements of the twentieth century, giving scientists further conviction that human activity does play a significant role in the climate change issue that is apparent today.

Since the 1970s, instruments on satellites have also monitored the earth's climate. In addition, measurements of the atmospheric CO_2 have been obtained since 1958, when the world's first monitoring station was built on top of Mauna Loa, the highest mountain on Hawaii, to enable scientists to monitor the atmospheric CO_2 levels in order to document any increases. They were able to determine a documentable increase—one that is still occurring today—known worldwide as the famous "Keeling Curve." Currently, the CO_2 monitoring network has expanded to more than 100 stations globally in order to track the concentrations of carbon dioxide, methane, and other greenhouse gases.

Even though scientists know natural climate variability and cycles will continue to occur, they also expect CO_2 levels to rise and climate change to increase because of human interactions with climate. How much variability actually occurs will ultimately depend on the choices humans make in future population growth, energy choices, technological developments, and global policy decisions.

Dr. Rajendra Pachauri, the chairman of the IPCC, said at an international conference attended by 114 governments in Mauritius in January 2005 that the world has "already reached the level of dangerous concentrations of carbon dioxide in the atmosphere." He recommended immediate and "very deep" cuts in the pollution levels if humanity is to survive. He also said, "Climate change is for real. We have just a small window of opportunity and it is closing rather rapidly. There is not a moment to lose" (Lean, 2005).

In the most recent IPCC Synthesis Report (2014), the following observations were made: According to Ban Ki-Moon, UN Secretary-General, "With this latest report, science has spoken yet again and with much more clarity. There is no ambiguity in their message. Leaders must act. Time is not on our side." In fact, the unrestricted use of fossil fuels must be phased out by 2100 if the world is to avoid the dangerous effects of climate change. The IPCC reported that most of the world's electricity *must* be produced from low-carbon sources by 2050. If it was not, the world would be facing "severe, pervasive, and irreversible" damage.

According to Thomas Stocker, a Swiss Climatologist and cochair of the IPCC Working Group I, "Our assessment finds that the atmosphere and oceans have warmed, the amount of snow and ice has diminished, sea level has risen and the concentration of carbon dioxide has increased to a level unprecedented in at least the last 800,000 years" (IPCC Synthesis Report, 2014). U.S. Secretary of State, John Kerry, reported from the 2014 conference that climate change was "another canary in the coal mine. Those who choose to ignore or dispute the science so clearly laid out in this report do so at great risk for all of us and for our kids and grandkids."

Chris Rapley, head of the British Antarctic Survey, commented that the huge west Antarctic ice sheet may be starting to disintegrate, an event that would raise sea levels around the world by 5 m. He said, "The IPCC report characterized Antarctica as a slumbering giant in terms of climate change. I would say it is now an awakened giant. There is real concern." (CICERO, 2006). According to the American Geophysical Union, "Natural influences cannot explain the rapid increase in the global near-surface temperatures observed during the second half of the 20th century" (American Institute of Physics, 2010).

The Carbon Cycle: Natural versus Human Amplification

The carbon cycle is an extremely important earth cycle and plays a critical role in climate change. Carbon dioxide enters the atmosphere during the carbon cycle. Because it is so plentiful, it originates from several sources. Vast amounts of carbon are stored in the earth's soils, oceans, and sediments at the bottoms of oceans. Carbon is stored in the earth's rocks, which is released when the rocks are eroded. It exists in all living matter. Every time animals and plants breathe, they exhale CO_2.

When examining the earth's natural carbon cycle, it is important to understand that the earth maintains a natural carbon balance. Throughout geologic time, when concentrations of CO_2 have been disturbed, the system has always gradually returned to its natural (balanced) state. This natural readjustment operates very slowly.

Through a process called diffusion, various gases that contain carbon move between the ocean's surface and the atmosphere. For this reason, plants in the ocean use CO_2 from the water for photosynthesis, which means that ocean plants store carbon, just as land plants do. When ocean animals consume these plants, they then store the carbon. Then when they die, they sink to the bottom and decompose, and their remains become incorporated in the sediments on the bottom of the ocean.

Once in the ocean, the carbon can go through various processes: It can form rocks, then weather; and it can also be used in the formation of shells. Carbon can move to and from different depths of the ocean, and also exchange with the atmosphere. As carbon moves through the system, different components can move at different speeds. Their reaction times can be broken down into two categories: short-term cycles and long-term cycles.

In short-term cycles, carbon is exchanged rapidly. One example of this is the gas exchange between the oceans and the atmosphere (evaporation). Long-term cycles can take years to millions of years to complete. Examples of this would be carbon stored for years in trees; or carbon weathered from a rock being carried to an ocean, being buried, being incorporated into plate tectonic systems, and then later being released into the atmosphere through a volcanic eruption.

Throughout geologic time, the earth has been able to maintain a balanced carbon cycle. Unfortunately, this natural balance has been upset by recent human activity. Over the past 200 years, fossil fuel emissions, land-use change, and other human activities have increased atmospheric carbon dioxide by 30 percent (and methane, another greenhouse gas, by 150 percent) to concentrations not seen in the past 420,000 years (which is the time span of the longest fully documented ice core record).

Humans are adding CO_2 to the atmosphere much faster than the earth's natural system can remove it. Figure 2.3 illustrates the greenhouse effect. Prior to the Industrial Revolution, atmospheric carbon levels remained constant at approximately 280 ppm. This meant that the natural carbon sinks

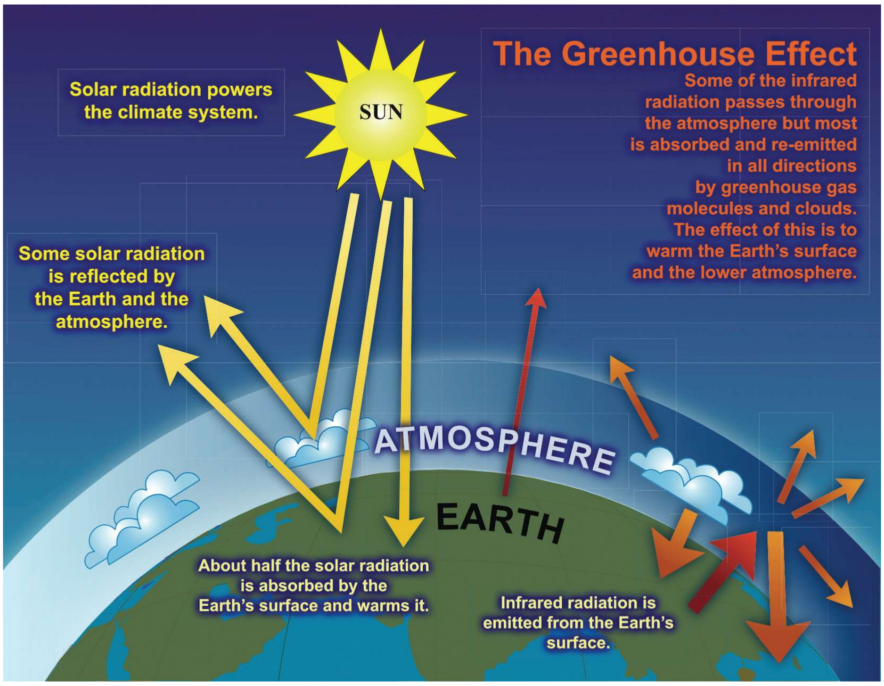

FIGURE 2.3 Diagram illustrating the earth's natural greenhouse effect. The natural greenhouse effect is what makes earth a habitable planet—if the greenhouse effect did not exist, the earth would be too cold, and life could not exist. As more greenhouse gases are added to the atmosphere through the burning of fossil fuels, deforestation, and other measures, however, less heat is able to escape to space, warming the atmosphere unnaturally—causing a situation called the enhanced greenhouse effect. This is what is contributing to climate change today. (From Gines, J. K., *Climate Management Issues: Economics, Sociology, and Politics*, CRC Press, New York, 2012.)

were balanced between what was being emitted and what was being stored. After the Industrial Revolution began and carbon dioxide levels began to increase—from 315 ppm in 1958 to 391 ppm in 2010 to 404 ppm in 2016—the "balancing act" became unbalanced, and the natural sinks could no longer store as much carbon as was being introduced into the atmosphere by human activities, such as transportation and industrial processes. In addition, according to Dr. Pep Canadell of the National Academy of Sciences, 50 years ago for every ton of CO_2 emitted, natural sinks removed 600 kilograms (Global Carbon Project, 2007). In 2006, only 550 kilograms was removed per ton, and the amount continues to fall today, which indicates the natural sinks are losing their carbon storage efficiency. In a 2013 BBC News Report, they reported the evidence of European forests that were nearing their "carbon saturation point," which means that the forests' ability to sequester carbon was dramatically slowing. This means that, although the world's oceans and land plants are absorbing great amounts of carbon, they simply cannot keep up with what humans are adding. The natural processes work much slower than the human ones do. The earth's natural cycling usually takes millions of years to move large amounts from one system to another. The problem with human interference is that the impacts are happening in only centuries or decades—and the earth cannot keep up with the fast pace. The result is that each year the measured CO_2 concentration of the atmosphere gets higher, making the earth's atmosphere warmer.

Another way that humans are contributing to climate change is through deforestation. By burning, or cutting down, the rain forests, two things happen: (1) the forest can no longer store carbon and (2) burning the trees releases the carbon that had been stored long term in the wood back to the atmosphere, further exacerbating the problem.

The Hydrologic Cycle and the Relationships between the Land, the Ocean, and the Atmosphere

The hydrologic cycle is also important because it plays a direct role in the function of healthy ecosystems. It describes the movement of all the water on earth. It has no starting point, and involves the existence and movement of water on, in, and above the earth. The earth's water is always moving and changing states—from liquid to vapor to ice and back again. This cycle, illustrated in Figure 2.4, has been in operation for billions of years, and all life on earth depends on its continued existence. What have scientists concerned is that climate change is affecting the major components of the water cycle and it is having a negative impact.

When the cycle is in equilibrium, water is stored as a liquid in oceans, lakes, rivers, the soil, and underground aquifers in the rocks. Frozen water is stored in glaciers, ice caps, and snow. It is also stored in the atmosphere as water vapor, droplets, and ice crystals in clouds. Water can change states and

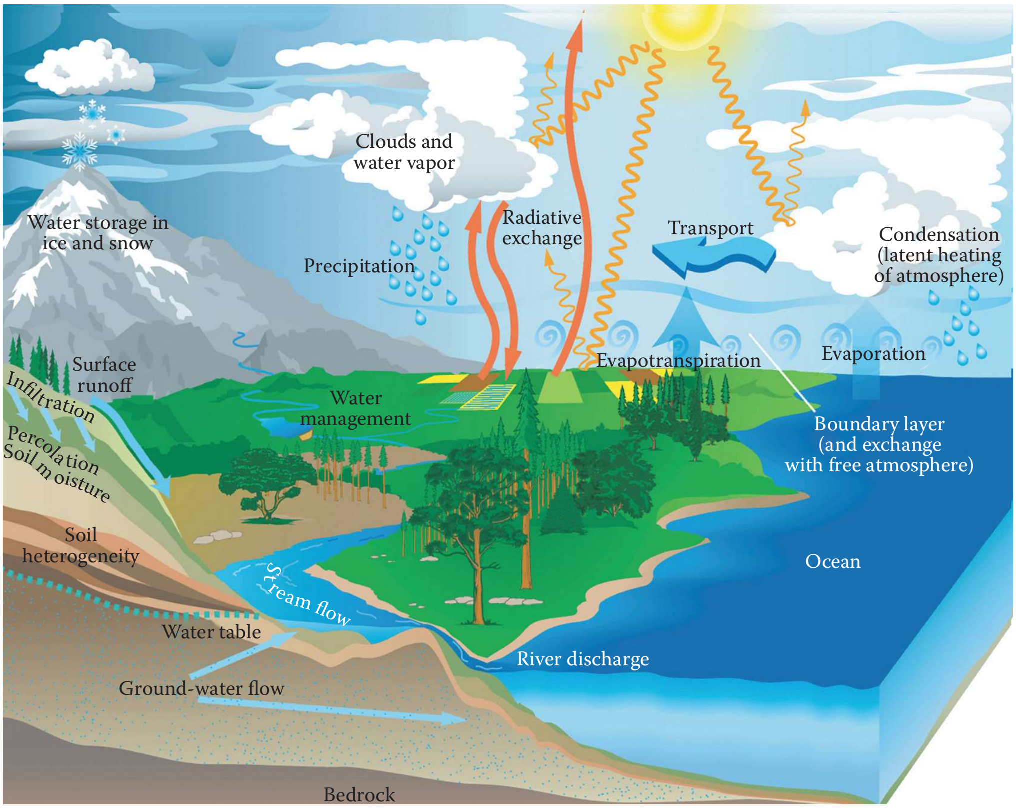

FIGURE 2.4 The earth's hydrologic cycle. (Courtesy of NASA, Washington, DC.)

move to different locations. For instance, water can move from the ocean to the atmosphere when it evaporates and turns from a liquid to a gas (vapor). Plants release water as a gas through transpiration. Water in the atmosphere condenses to form clouds, which can then form rain, snow, or hail, and return to the earth's surface. Water that comes back to earth can be stored where it lands (in an ocean) or can flow above the ground (river), or can infiltrate and move under the ground (as groundwater).

This is a recount of how the earth's natural water cycle works. When climate change becomes an issue, however, it enhances the water cycle, making it more "extreme." Because climate change causes the earth's atmosphere to be warmer, it develops a higher saturation point, enabling the atmosphere to evaporate and hold more water from the earth's surface. This may have a twofold effect. First, in areas where more water vapor exists, more clouds will form, causing more rain and snow. In other areas, especially those further away from water sources, more evaporation and transpiration (together referred to as evapotranspiration) could dry out the soil and vegetation. The result would be fewer clouds and less precipitation, which could cause drought problems for farmers, ranchers, cities, and wildlife habitat. All ecosystems in these areas on an international scale could be negatively impacted.

In areas that are receiving increasing amounts of precipitation, such as portions of Japan, Russia, China, and Indonesia, they will also experience more water infiltrating into the ground and over the surface. It could increase the levels of lakes and rivers, causing serious flooding, and may even form new lakes. Wetter conditions will also affect the plants and animals in the area.

The drier areas, such as Africa and the southwestern United States, will also experience serious impacts. As the ground dries out from evapotranspiration, the atmosphere loses an important source of moisture. This, in turn, creates fewer clouds, which means there is less rain, making the area more arid. As less water is available to infiltrate the ground, less will be able to live off, on, or in the soil. Rivers and lakes would dry up, vegetation would die off, and the land would no longer be able to support humans, animals, and other life.

There are many cycles operating on earth, with elements continually passing in and out of them. All natural cycles on earth must work together in a state of dynamic equilibrium. This means that as substances move and change at different times and places, they do it in a way that does not negatively impact the entire working system—all the components in the system work together and complement each other. This dynamic equilibrium changes as the seasons change, because different needs must be met at different times. In the spring and summer when plants grow, they need carbon so they take it from the atmosphere and the soil. Then, when the growing season is over in the fall and winter, plants release carbon back to the soil and atmosphere. This plays a significant role especially in the earth's Northern Hemisphere because most of the landmasses are located there, creating a global seasonal change of carbon dioxide in the atmosphere. The oceans and atmosphere also interact extensively. Oceans are more than a moisture source for the atmosphere. They also act as a heat source and a heat sink (storage), as well as a carbon sink.

Global Energy Balance

Interactions between energy from the sun, the earth, and the atmosphere all have an effect on the earth. This is called the global energy balance, an energy balance that also plays a role in climate. If the energy balance changed and the atmosphere began retaining more heat, this could trigger climate change. It is this scenario that climatologists are concerned about now and in the future.

The global energy balance regulates the state of the earth's climate. Modifications to it—a concept called "forcings"—can be either natural sources or human-made sources and could cause global climate to change. Natural forcings might include variations in the sun's intensity, a shift in the earth's orbit around the sun, a shift in the earth's tilt, or an increase in volcanic activity. Human-caused forcings could include burning fossil fuels, changing land-use patterns, or deforestation.

Greenhouse gases in the atmosphere do have an effect on the global energy balance. Without the natural amount of greenhouse gases in the atmosphere, the earth would not be an inhabitable planet because it would be too cold. The natural amounts of carbon dioxide, water vapor, and other greenhouse gases make life possible on earth because they keep the atmosphere warm.

Several things can have an effect on the energy balance, such as clouds and atmospheric aerosols. Clouds can interact in several ways with energy. They can block much of the incoming sunlight and reflect it back to space. In this way, they have a cooling effect. Clouds also act like greenhouse gases, and they block the emission of heat to space and keep the earth from releasing its absorbed solar energy. The altitude of the cloud in the atmosphere can affect the energy budget. High clouds are colder and can absorb more surface-emitted heat in the atmosphere; yet they do not emit much heat to space because they are so cold. Clouds can cool or warm the earth, depending on how many clouds there are, how thick they are, and how high they are. For this reason, it is not yet fully understood what effect clouds will have on surface temperatures if climate change continues into the next century and beyond.

Climatologists have proposed different opinions. Some think that clouds may help to decrease the effects of climate change by increasing cloud cover, increasing thickness, or decreasing in altitude. Others think that clouds could act to increase the warming on earth if the opposite conditions occurred. According to Anthony Del Genio of NASA's Goddard Institute for Space Studies, when air temperatures are higher, clouds are thinner and less capable of reflecting sunlight, which increases temperatures on earth, exacerbating climate change. Del Genio, in an interview with *CNN*, said that "in the larger context of the climate change debate I'd say we should not look for clouds to get us out of this mess. This is just one aspect of clouds, but this is the part people assumed would make climate change less severe" (Environmental News Network, 2000). After 15 years of climate modeling, the overall consensus in 2015 based partly on a study conducted just prior to that was that clouds could not be counted on to counteract climate change, but could possibly contribute to additional warming (Clement et al., 2009).

One way that scientists try to predict the future climate change and the effects of climate change is through the analysis and interpretation of mathematical climate models. In these computer models, climatologists attempt to account for all items that affect climate. Cloud cover is one of those variables. Today, this is still one of the most difficult variables to control and interpret. The climate is so sensitive as to how clouds might change, that even the most complicated, precise models developed today often vary in their climate change prediction under all the different methods available for cloud modeling.

The main reason clouds are so difficult to model is that they are so unpredictable. They can form rapidly and complete their life cycle in a matter of hours. Other climate variables work on a much slower timescale. Clouds also occur in a relatively small geographic area. Other climate variables operate on a much larger—regional or global—scale. According to climate research scientists at NASA, the world's fastest supercomputers can only track a single column of the surface and the atmosphere every 80–322 kilometers. By comparison, a massive thunderstorm system might cover only 32 kilometers. Features that are small, fast, and short-lived are hard to predict. This is one of the reasons why predicting specific individual weather events is more difficult than predicting long-term climate changes over broad areas.

Clouds are just one thing that can change the global energy balance; snow and ice can also do it. If the earth becomes cold enough, allowing large amounts of snow and ice to form, then more of the sun's energy will be directly reflected back to space because snow and ice have a high albedo. Over a period of time, this will change the global energy balance and the global temperature. Conversely, if the earth warms, the snow and ice will melt. This lowers the surface albedo, allowing more sunlight to be absorbed, which will warm the earth more.

Deforestation can also upset the global energy balance if forested area is removed and land is left bare; the ground can then reflect more sunlight back to space, causing a net cooling effect. However, if the forest material is burned, then the CO_2 stored in the trees is released into the atmosphere, contributing to climate change. Also, forests are good reservoirs of existing CO_2. The plants store and hold the CO_2, keeping it out of the air. If the forest is burned, not only does the already stored CO_2 now enter the atmosphere, but any future storage potential of CO_2 in that forest is now destroyed, creating two negative conditions of CO_2 toward climate change.

Atmospheric aerosols (tiny smoke particles) can be added to the atmosphere by sources such as fossil fuels, biomass burning, and industrial pollution. Aerosols can either cool or warm the atmospheric temperature depending on how much solar radiation they absorb versus how much they scatter back to space. Fossil fuel aerosols can also pollute clouds. Scientists need to do a lot more research on aerosols before they fully understand the full impacts of aerosols on climate change. The composition of the aerosol, its absorptive properties, the size of the aerosol particles, the number of particles, and how high in the atmosphere all have an effect on whether they cool or warm the atmospheric temperature and by how much.

Another effect aerosols have on clouds is that as aerosols increase, the water in the clouds gets spread over more particles; and smaller particles fall more slowly, resulting in a decrease in the amount of rainfall. Scientists believe aerosols have the potential to change the frequency of cloud occurrences, cloud thickness, and amount of rainfall in a region. Like clouds, aerosols are also a challenge to accommodate in climate models.

Rates of Change

Climate change "drivers" (causes) often trigger additional changes (feedbacks) within the climate system that can amplify or subdue the climate's initial response to them. For instance, if changes in the earth's orbit trigger an interglacial (warm) period, increasing CO_2 may amplify the warming by enhancing the greenhouse effect. When temperatures get cooler, CO_2 enters the oceans, and the atmosphere becomes cooler. Sometimes, the earth's climate seems to be quite stable; other times, it seems to have periods of rapid change. According to the U.S. Environmental Protection Agency (EPA), interglacial climates (such as like the climate today) tend to be more stable than cooler, glacial climates. Abrupt or rapid climate changes often occur between glacial and interglacial periods.

There are many components in a climate system, such as the atmosphere, the earth's surface, the ocean surface, vegetation, sea ice, mountain glaciers, deep ocean, and ice sheets. All of these components affect, and are affected by, the climate. They all have different response times, however, as shown in Table 2.1.

TABLE 2.1
Climate System Components and Response Times

Climate System Component	Response Time	Example
	Fast Responses	
Land surface	Hours to months	Heating of the earth's surface
Ocean surface	Days to months	Afternoon heating of the water's surface
Atmosphere	Hours to weeks	Daily heating; winter inversions
Sea ice	Weeks to years	Early summer breakup
Vegetation	Hours to centuries	Growth of trees in a rain forest
	Slow Responses	
Ice sheets	100–10,000 years	Advances of ice sheets over Greenland
Mountain glaciers	10–100 years	Loss of glaciers in Glacier National Park
Deep ocean	100–1500 years	Deepwater replacement

The amount of change applied, as well as the component's ability to naturally respond determines largely what the climate actually ends up doing. For instance, if there is a slow climate change, but the system component reacts quickly (in a short period of time), then the response will be visible. If the climate change is rapid, but then reverts back to its previous condition and the component's response time is naturally slow, then there will be no response. If the climate change alternates from one extreme to another at a rate that the components can keep up with, these changes will be seen as visible adaptations. It is these types of rates of change that are most enlightening for climatologists because it allows them to more efficiently model all the subtle components of the climate system.

Atmospheric Circulation and Climate Change

When pressure differences alone are responsible for moving air, the air—or wind—will be pushed in a straight path. Winds do follow curved paths across the earth, however, as illustrated in Figure 2.5. Named after the scientist who discovered this effect, Gustave-Gaspard Coriolis, this phenomenon is called the Coriolis force, which is an apparent drifting sideways (a property called deflection) of a freely moving object as seen by an observer on earth.

Given in nonvector terms, the property can be described as follows: at a given rate of rotation of the observer, the magnitude of the Coriolis acceleration of the object is proportional to the velocity of the object and also to the sine of the angle between the direction of movement of the object and the axis of rotation.

In mathematical terms, the vector formula for the magnitude and direction of the Coriolis acceleration is

$$a_c = -2\Omega \times v$$

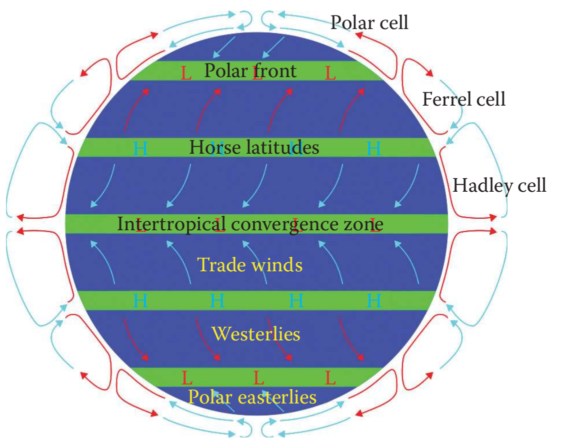

FIGURE 2.5 Diagram representing the earth's major atmospheric circulation patterns. Major wind systems, such as the trade winds and Westerlies, lie between permanent bands of high or low pressure located at specific latitudes. (Courtesy of NASA, Washington, DC.)

where:

a_c is the acceleration of the particle in the rotating system
v is the velocity of the particle in the rotating system
Ω is the angular velocity vector which has a magnitude equal to the rotation rate w and is directed along the axis of rotation of the rotating reference frame

The equation may be multiplied by the mass of the object in question to produce the Coriolis force as follows:

$$F_c = -2m\Omega \times v$$

The *Coriolis effect* is the behavior added by the *Coriolis acceleration*. The formula implies that the Coriolis acceleration is perpendicular to both the direction of the velocity of the moving mass and the frame's rotation axis. Therefore, the following conditions apply:

- If the velocity is parallel to the rotation axis, the Coriolis acceleration is *zero.*
- If the velocity is straight inward to the axis, the acceleration is *in the direction* of local rotation.
- If the velocity is straight outward from the axis, the acceleration is *against the direction* of local rotation.
- If the velocity is in the direction of local rotation, the acceleration is *outward from the axis.*
- If the velocity is against the direction of local rotation, the acceleration is *inward to the axis*.

Therefore, the Coriolis force is the tendency for any moving body on or above the earth's surface, such as an ocean current, an air mass, or a ballistic missile—to drift sideways from its course because of the earth's rotation underneath. In other words, a moving object appears to veer from its original path. In the Northern Hemisphere, the deflection is to the right of the motion, whereas in the Southern Hemisphere, it is to the left.

The Coriolis deflection of a body moving toward the north or south results from the fact that the earth's surface is rotating eastward at greater speed near the equator than near the poles, because a point on the equator traces out a larger circle per day than a point on another latitude nearer either the North or the South Pole (the equator is a great circle and other latitudes are smaller). A body traveling toward the equator with the slower rotational speed of higher latitudes tends to fall behind or veer to the west relative to the more rapidly rotating earth below it at lower latitudes. Similarly, a body traveling toward either the North or the South Pole veers eastward because it retains the greater eastward rotational speed of the lower latitudes as it passes over the more slowly rotating earth closer to the pole.

The practical applications of the Coriolis force are important when calculating terrestrial wind systems and ocean currents. Scientists studying the weather, ocean dynamics, and other related earth phenomena must take the Coriolis force into account. The Coriolis also affects regional and global weather patterns because it interacts with the jet streams.

According to a study conducted in 2006 by Gabriel Vecchi of the University Corporation for Atmospheric Research, the trade winds in the Pacific Ocean are weakening as a result of climate change (Vecchi, 2006). This conclusion is based on the findings of a study that showed the biology in the area may be changing, which could be harmful to marine life and have a long-term effect of disrupting the marine food chain. Researchers predict that it could also reduce the biological productivity of the Pacific Ocean, which would impact not only the natural ecosystem and balance, but would affect the food supply for millions of people.

The study used climate data consisting of sea-level atmospheric pressure over the past 150 years and combined that with computer modeling to conclude that the wind has weakened by about 3.5 percent since the mid-1800s. The researchers predict another 10 percent decrease is possible by the end of the twenty-first century.

Some of the computer modeling simulations included variables such as the effects of human greenhouse gas emissions, whereas other simulations included only natural factors that affect climate such as volcanic eruptions and solar variations. Vecchi concluded that the only way they could account for the observed weakening of the trade winds was through the model that included human activity—specifically from greenhouse gases and the burning of fossil fuels.

Vecchi believes climate change is to blame because in order for the ocean and atmosphere to maintain an energy balance, the rate that the atmosphere absorbs water from the ocean must equal the amount that it loses to rainfall. As climate change increases the air temperature, more water evaporates from the ocean into the air. The atmosphere cannot convert it into rainfall and return it back fast enough. Because the air is gaining water faster than it can release it, it gets overloaded and the natural system compensates by slowing the trade wind down, decreasing the amount of water being drawn up into the atmosphere in order to maintain the energy balance. The drop in winds reduces the strength for both the surface and subsurface ocean currents and interferes with the cold water upwelling at the equator that is responsible for supplying ocean ecosystems with valuable nutrients, which are the lifeblood of the fishing industry.

This was later substantiated by Dr. Larry Mayer Unh of the University of New Hampshire in 2015, who also believes that this is one of the major contributing factors that contributes to El Niño climate patterns, and a continued weakening could lead to an increase in both the severity and the frequency of them. Other detrimental effects can be expected to occur as well, such as disrupted food chains, reduced fish harvests, and variations in episodes of droughts and floods. He emphasized that a continued weakening puts the entire ocean ecosystem at risk (Unh, 2015).

This is one example of how climate change can affect atmospheric circulation. It is also affecting oceanic circulation. In a recent study conducted in 2015 by the Potsdam Institute for Climate Impact Research, a slowdown of the Great Ocean Conveyor Belt has been observed. This is the major current that helps drive the Gulf Stream, which greatly modifies the climate in Western Europe, bringing warmer temperatures to their higher latitudes. Although a slowdown will not trigger another Ice Age, it could cause other negative effects, such as an increase in sea level, which could result in disastrous flooding of cities such as London, Boston, and New York. The researchers discovered that the overturning circulation began weakening in the North Atlantic around 1970, which they believe was caused by an unusual amount of sea ice traveling out of the Arctic Ocean, melting, and lowering the local salinity. The circulation began to recover in the 1990s, but was only temporary. According to Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research, the circulation has further weakened due to the massive Greenland ice sheet losing enough freshwater due to melting, which is weakening the circulation by lowering the water's salinity. This is substantiated by the fact that the ocean region south of Greenland and between Canada and Britain is becoming colder, which indicates that there is now less northward heat transport. Rahmstorf also points out that, although the winter of December 2014 through February 2015 was the warmest on record for the globe as a whole, there was a major anomaly—there were also record cold temperatures in the middle of the North Atlantic (where the Great Ocean Conveyor Belt flows). This equates to a circulation that is about 15–20 percent weaker—something that has not happened since the year 900. Adding to the scientific unease, this was not predicted in climate models. Although the IPCC, in 2013, projected a slowdown of the current from 1 to 54 percent (most likely 11–34 percent) over the course of this century, actual data collected by Rahmstorf and his team showed that we were already within that window of change as of 2015 (Rahmstorf, 2015).

Extreme Weather

A serious concern about climate change is the potential damage that can be done to humans, property, and the environment as a result of extreme weather events, such as severe drought and storms. The EPA studies the aspects of change in extreme weather and climate events. Although extreme weather events are typically rare, they have noted that climate change is increasing the odds of more extreme weather events taking place. Although establishing the most likely causes behind an extreme weather event can be challenging, because each event is due to a combination of multiple factors (including natural variability), scientists have been able to make a connection between extreme climate patterns (and individual events) and climate change by focusing on whether an extreme weather event was made *more likely* by climate change. What they have determined is that there have been changes in some types of extreme weather events in the United States over the past several decades—including more intense and frequent heat waves, less frequent and intense cold waves, and regional changes in floods, droughts, and wildfires. This rise in extreme weather events fits a pattern that is expected with a warming climate. Scientists project that climate change will make some of these extreme weather events more likely to occur

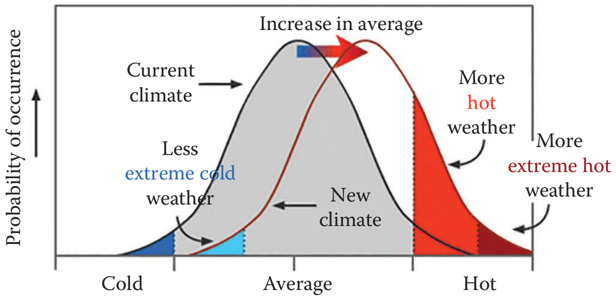

FIGURE 2.6 As the planet warms, more extreme weather events are expected to take place. (Courtesy EPA, Washington, DC.)

and/or more likely to be severe (Environmental Protection Agency, 2016) (Figure 2.6).

Another recent example of climate change increasing the intensity of hurricanes is evident from climate-fueled Hurricane Sandy that surged up and over retaining walls and destroyed countless homes of New York residents in 2012. Because of the extreme destruction wrought from this storm, the NOAA announced it would now employ a new practice of keeping hurricane and tropical storm watches and warnings in effect even after storms lose their tropical characteristics if they pose significant danger to life and property. The intensity of Sandy's post-tropical phase caught residents unprepared and its disastrous storm surge caused damage of approximately $50 billion, making it the second costliest cyclone to hit the United States since 1900. At least 147 people died in the Atlantic basin. According to Michael Oppenheimer, professor of geosciences and international affairs at Princeton University, and a member of the IPCC, "Hurricanes could become more intense as the earth warms. They are frightening, destructive, and extremely costly, and we expect future hurricanes to leave an even greater trail of damage in their wake" (Livescience, 2013) (Figure 2.7).

FIGURE 2.7 Coastal damage caused by Hurricane Sandy in Mantoloking, New Jersey. (Courtesy of U.S. Air Force by Master Sgt. Mark C. Olsen—http://www.defense.gov/photoessays/PhotoEssaySS.aspx?ID=3316, http://www.defense.gov/dodcmsshare/photoessay/2012-10/hires_121030-F-AL508-081c.jpg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=22549477.)

The WMO has warned that extreme weather events, such as drought, hurricanes, and heavy rainfall, may very likely increase because of climate change. It is an organization of meteorologists from 189 countries. It is a specialized agency of the United Nations and serves as its voice on the state and behavior of the earth's atmosphere, its interaction with the oceans, the resulting climate as a product from the interaction, and the resulting distribution of water resources. There are not many forces in nature that can compare to the destructive capability of a hurricane. These storms can have winds blow for long periods of time at 249 kilometers per hour or higher. Not only the wind destructive but also the rainfall and storm surges can cause significant damage and loss of life (Climateaction, 2010).

Hurricane Katrina, which formed on August 23, 2005 and dissipated on August 30, 2005, affecting the Bahamas, South Florida, Cuba, Louisiana, Mississippi, Alabama, and the Florida Panhandle, was one of the deadliest hurricanes in the history of the United States, killing more than 1800 people and destroying more than 200,000 homes. There were more than 900,000 evacuees, many relocated to states in the western United States. It was also the costliest hurricane in U.S. history at more than $75 billion in estimated damages. By 2010, only about 40 percent of the New Orleans pre-Katrina residents had returned to the city. The demographics, however, are partly determined by race, age, and income level. As of 2013, only 30 percent of residents of predominantly lower income, black areas in one precinct had returned. Younger residents were also less likely to return.

A hurricane—or tropical cyclone—forms over tropical waters—between latitudes 8° and 20° in areas of high humidity, light winds, and areas where the sea surface is warm. Typically, temperatures must be 26.5°C or warmer to start a hurricane, which is why climate change and the heating of the ocean is such a concern.

Protecting life and the environment from severe weather triggered by climate change currently has many research scientists at the National Hurricane Center at NOAA and elsewhere engaged in theoretical studies. For example, computer modeling and the collection and analysis of field data are providing an avenue to gain a better understanding of the mechanics of climate change. It also sheds light on climate change's interaction with the environment, which helps improve forecasting methods, rapid response procedures, and safety protocols.

In an article published in Switzerland by the Environment News Service (2010), extreme weather events, such as wildfire outbreaks across Russia, record monsoonal flooding in Pakistan, rain-induced landslides in China, and the calving of a huge chunk of ice off the Petermann Glacier in Greenland, fall in line with what the WMO are warning of when they project "more frequent and intense extreme weather events due to global warming" (WMO/UNFCCC, 2011).

These identified unprecedented events that are occurring concurrently around the world are causing loss of human life and property. The WMO has brought to public attention the fact that the similar timing of all these incidences closely coincides with the IPCC's Fourth Assessment Report published back in 2007, suggesting a scientific connection in support of climate change (IPCC, 2007). In the IPCC's Summary for Policy Makers, it states "that the frequency and intensity of extreme events are expected to change as earth's climate changes, and these changes could occur even with relatively small mean climate changes." The summary points out that some of these changes have already occurred, specifically the examples previously mentioned. In Moscow, they experienced 30 daily record temperature rises in June 2010, leading to massive forest and peat fires. In Pakistan, the monsoonal flooding was so intense that they received 300 millimeters over a 36-hour period, and the Indus River in the northern portion of the country reached its highest water levels in 110 years. Southern and central areas in the country were also flooded, killing more than 1600 people. As a result, more than six million people have been driven from their homes. The Pakistan government reports more than 40 million of their citizens have been adversely affected by flooding thus far. China is also being negatively impacted by the worst flooding in decades. A resulting mudslide in the Gansu province on August 7, 2010, killed more than 700 and left more than 1000 others unaccounted for. In China, their government has reported that 12 million people have lost their homes to unexpected flooding.

NASA's Aqua satellite, via the moderate resolution imaging spectroradiometer (MODIS) sensor, discovered the calving of a major iceberg—the size of those typically found in Antarctica—on August 5, 2010. It is the largest chunk of ice to calve from the Greenland ice sheet in the past 50 years, dwarfing the tens of thousands of much smaller icebergs that normally calve from the glaciers of Greenland.

What is significant about these extreme weather events, according to the WMO, is that "all these events compare with, or exceed in intensity, duration or geographical extent, the previous largest historical events," leaving human interference as the critical link (WMO, 2011). Figure 2.8 shows the calving of the Petermann Glacier in Greenland on August 5, 2010. It is a chunk of ice, roughly 251 square kilometers in size (Environment News Service, 2010).

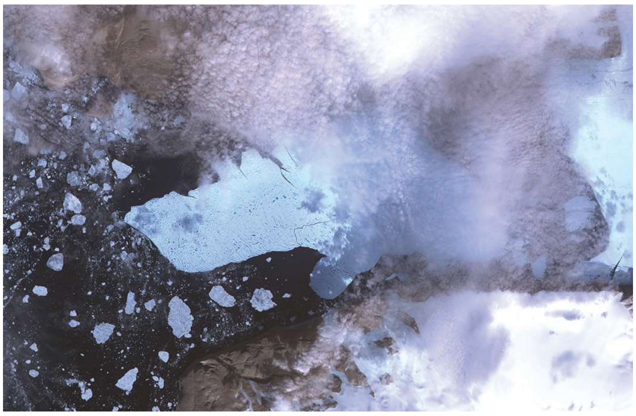

FIGURE 2.8 On August 5, 2010, an enormous chunk of ice, ~251 km^2 in size, broke off the Petermann Glacier along the northwestern coast of Greenland. According to climate experts at the University of Delaware, the Petermann Glacier lost about one-fourth of its 70-km-long floating ice shelf. The recently calved iceberg is the largest to form in the Arctic in 50 years. (Courtesy of NASA, JPL, La Cañada Flintridge, CA.)

In a report issued by NOAA on November 5, 2015, human activities, such as greenhouse gas emissions and land use, influenced specific extreme weather and climate events in 2014, including tropical cyclones in the central Pacific, heavy rainfall in Europe, drought in East Africa, and stifling heat waves in Australia, Asia, and South America. Figure 2.9 illustrates the location and type of events analyzed in the study. Key findings of the report are shown in Table 2.2.

According to Stephanie C. Herring, PhD, lead editor for the report, "Understanding our influence on specific extreme weather events is ground-breaking science that will help us adapt to climate change. As the field of climate attribution science grows, resource managers, the insurance industry, and many others can use the information more effectively for improved decision making and to help communities better prepare for future extreme events" (NOAA, 2015).

The Role of Ocean Circulation in Climate Change

There are two factors that make water more dense (which causes it to sink) or less dense (which keeps it on the surface): (1) salt content and (2) temperature. Atmospheric flow and ocean currents are the mechanisms that carry heat from the equator to the poles. There are many processes that can alter the circulation patterns, and when this happens, it can change the weather of an area. If the ocean did not distribute heat throughout the world, the equator would be much warmer and the poles would be much colder.

The role of the oceans is equally as important in transporting heat from the equator to the polar regions as the atmosphere, as shown in Figure 2.10. In terms of how much heat and water it can hold, its capacity is much greater than that of the atmosphere. In fact, the world's oceans can store approximately 1100 times more heat than the atmosphere. The oceans also contain 90,000 times more water than the atmosphere does.

As more knowledge is gained about climate change, also gained is a better appreciation of the role the oceans play in shaping the earth's climate. For this reason, much more research has been done on the oceans in the past 15 years, leading to the discovery that the ocean's depths have warmed considerably since 1950. According to scientists at the Woods Hole Oceanic Institution, up until recently, scientific models predicting climate change could not account for where the projected warmth had gone; it was unaccounted for in the atmosphere. This discrepancy in the model had caused much confusion until researchers finally figured out that the world's oceans were storing the "missing" greenhouse warming. Water has a tremendous capacity to hold heat. The warming had occurred, but up until then, no one had thought to look toward the oceans for the answer (Schmitt, 2010).

Now that scientists understand this relationship, those that study climate change agree that including the ocean system in climate change studies is critical. Not only do the oceans have an enormous thermal capacity, the constant movement of slow and fast water can affect the weather for months at a time.

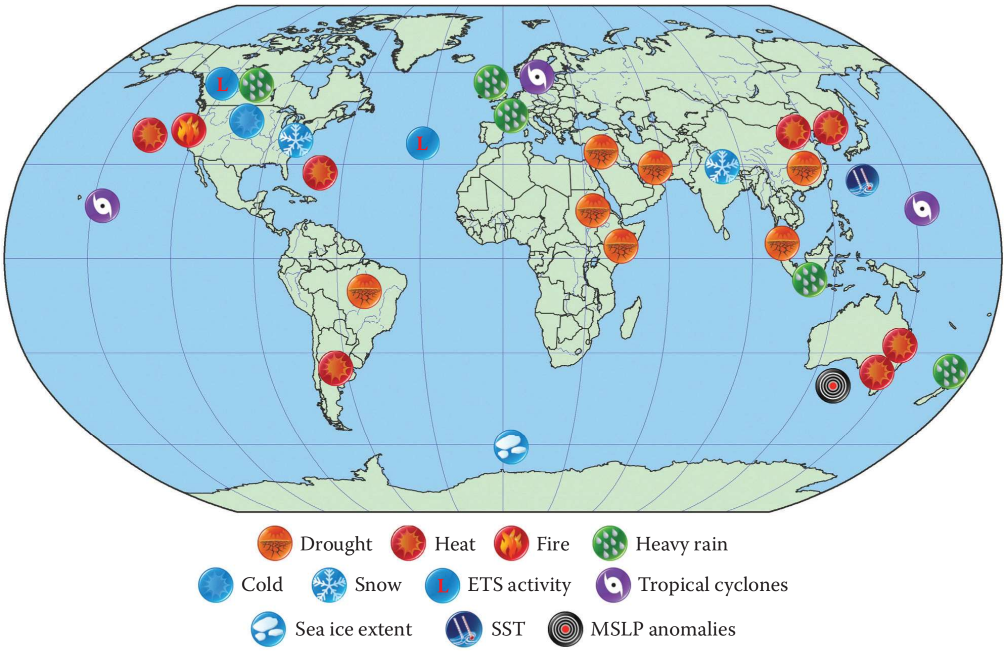

FIGURE 2.9 Location and type of events analyzed in "Explaining Extreme Events of 2014 from a Climate Perspective." (Courtesy of NOAA.)

TABLE 2.2
Key Findings of NOAA Extreme Events of 2014 Report

North America:

- The overall probability of California wildfires has increased due to human-induced climate change.
- Though cold winters still occur in the upper Midwest, they are less likely due to climate change.
- Cold temperatures along the eastern United States were not influenced by climate change, and eastern U.S. winter temperatures are becoming less variable.
- Tropical cyclones that hit Hawaii were substantially more likely because of human-induced climate change.
- Human-induced climate change and land use both played a role in the flooding that occurred in the southeastern Canadian Prairies.

South America:

- The Argentinean heat wave of December 2013 was made 5 times more likely because of human-induced climate change.
- Water shortages in southeast Brazil were not found to be largely influenced by climate change, but increasing population and water consumption raised vulnerability.

Europe:

- All-time record number of storms over the British Isles in winter 2013–2014 cannot be linked directly to human-induced warming of the tropical west Pacific.
- Extreme rainfall in the United Kingdom during the winter of 2013–2014 as not linked to human-caused climate change.
- Extreme rainfall in the Cévennes Mountains in southern France was 3 times more likely than in 1950 due to climate change.
- Human influence increased the probability of record annual mean warmth over Europe, Northeast Pacific, and Northwest Atlantic.

Middle East and Africa:

- Two studies showed that the drought in East Africa was made more severe because of climate change.

Asia:

- Extreme heat events in Korea and China were linked to human-caused climate change.
- Devastating 2014 floods in Jakarta are becoming more likely due to climate change and other human influences.
- Meteorological drivers that led to the extreme Himalayan snowstorm of 2014 have increased in likelihood due to climate change.
- Human influence increased the probability of regional high sea surface temperature extremes over the western tropical and northeast Pacific Ocean during 2014.

Australia:

- Four independent studies all pointed toward human influence causing a substantial increase in the likelihood and severity of heat waves across Australia in 2014.
- It is likely that human influences on climate increased the odds of the extreme high-pressure anomalies south of Australia in August 2014 that were associated with frosts, lowland snowfalls, and reduced rainfall.
- The risk of an extreme 5-day July rainfall event over Northland, New Zealand, such as was observed in early July 2014, has likely increased due to human influences on climate.

Antarctica:

- All-time maximum of Antarctic sea ice in 2014 resulted chiefly from anomalous winds that transported cold air masses away from the Antarctic continent, enhancing thermodynamic sea ice production far offshore. This type of event is becoming less likely because of climate change.

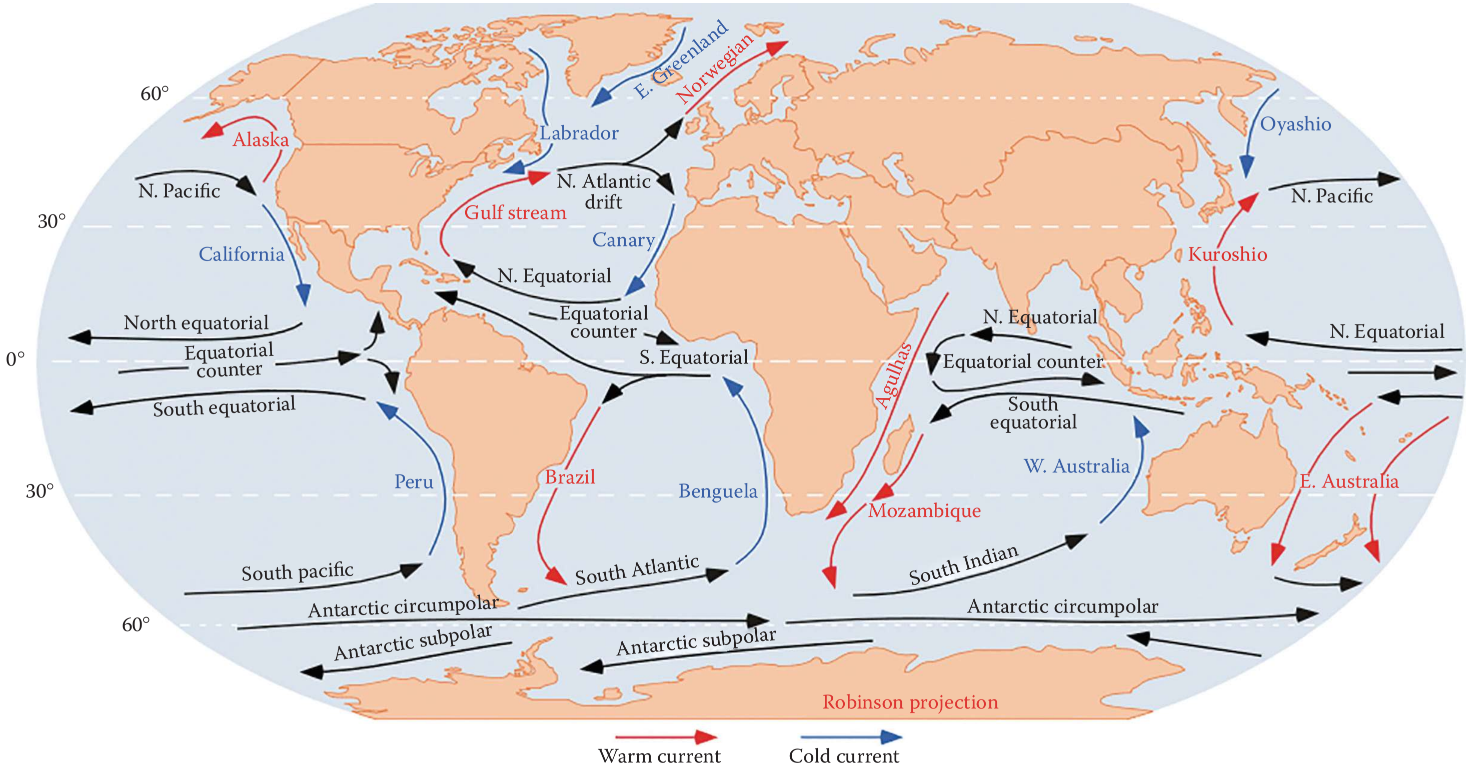

FIGURE 2.10 The earth's major ocean currents are responsible for the global transport of heat. Without them, many areas would be much cooler than they currently are. (From Gines, J. K., *Climate Management Issues: Economics, Sociology, and Politics*, CRC Press, New York, 2012.)

It is important for climatologists to understand these interactions in the ocean in order to be able to predict regional trends in climate. It is also important to understand the deepwater processes as well as processes that occur near the surface in order to understand what mechanisms drive climate. The oceans also play a critical role in balancing the CO_2 levels. The amount of CO_2 stored in the atmosphere and that dissolved in the ocean maintain an equilibrium. If something happens to upset this balance—such as changes in chemistry—then sudden shifts in the CO_2 levels can affect the climate. This is one of the concerns about the steadily increasing levels of greenhouse gases. If the oceans reach the point where they cannot continue to absorb any more CO_2, it could upset the balance of ocean currents and climate patterns on a global scale.

In the world's oceans, the properties of density, temperature, and salinity all work together and result in distinct characteristics that ultimately relate to climate change. Solar energy is absorbed by seawater and stored as heat in the oceans. Some of the energy that is absorbed may evaporate seawater, which increases its temperature and salinity. When a substance is heated, it expands and its density is lowered. Conversely, when a substance is cooled, its density increases. The addition or subtraction of salts also causes seawater density to change. Water that has higher salinity will be denser than lower salinity water.

Pressure is another factor that affects density. It increases with depth, as does the density of water mass. Because high-density water sinks below the average density seawater, and low-density seawater rises above the average density seawater, this distinct change in density generates water motion. This concept is extremely important in the world's oceans because it is a chief mechanism controlling the movement of major currents and ocean circulation patterns.

Oceanographers and climatologists are interested in the distributions of both the temperature and the salinity in the world's oceans because they are two factors that determine the vertical thermohaline circulation in the oceans. The term *thermohaline* comes from two words: *thermo* for heat and *haline* for salt. Of the three factors—temperature, salinity, and pressure—that have an effect on water density, temperature changes have the greatest effect. In the ocean, the thermocline (a water layer within which the temperature decreases rapidly with depth) acts as a density barrier to vertical circulation. This layer lies at the bottom of the low-density, warm surface layer and the top of the cold, dense bottom waters. The thermocline keeps most of the ocean water from being able to vertically mix because these two layers are so drastically different. In the polar regions, the surface waters are much colder than they are anywhere else on earth. This means they are denser, so that little temperature variation exists between the surface waters and the deeper waters—basically eliminating the thermocline. Because there is no thermocline barrier, vertical circulation can take place as the surface waters sink (a process called downwelling), where they replenish deepwaters in the major oceans.

Water surface temperatures have significant effects on coastal climates. Because seawater can absorb large amounts of heat, it enables coastal locations to have cooler temperatures in the summer than inland areas. Coastal currents also affect local climate. For example, Los Angeles, California, and Phoenix, Arizona, are at similar latitudes, yet Los Angeles has a much more moderate summer climate because of the effect of the ocean.

The Great Ocean Conveyor Belt and Consequences of Destabilization—Abrupt Climate Change

One of the most significant features in the ocean is the thermohaline circulation—more commonly referred to as the Great Ocean Conveyor Belt. This massive, continuous loop of flow, shown in the illustration, plays a critical role in determining the world's climate. The two mechanisms that make this conveyor belt work are heat and salt content (Figure 2.11).

The Great Ocean Conveyor Belt plays a major part in distributing the sun's thermal energy around the globe after the ocean has absorbed it. In fact, if it was not for this flow, the equator would be much hotter, the poles would be much colder, and Western Europe would not enjoy as warm a climate as they currently do.

The Great Ocean Conveyor Belt does not move fast, but it is enormous. It carries as much water within it as 100 Amazon Rivers could hold. The mechanism that drives it is the differences in density that range throughout it. It is the ratio of salt and temperature that determines the density. The colder and saltier the water is, the denser it is and tends to sink. When it is warm and fresh, it is less dense and rises to the surface.

The Conveyor Belt literally travels the world. In general, in a continuous loop, it transfers warm water from the Pacific Ocean to the Atlantic as a shallow current, then returns cold water from the Atlantic to the Pacific as a deep current that flows further south. Specifically, as it travels past the north of Australia, it is a warm current. It travels around the southern tip of Africa, then moves up into the Atlantic Ocean. At this point, it turns into the Gulf Stream, which is a very warm, north-flowing current critical for providing warmth to Western Europe and the northeast coast of the United States. After it passes Western Europe and heads to the Arctic, the surface water evaporates and the water cools down, releasing its heat into the atmosphere. It is this released heat that Western Europe enjoys as part of their moderate climate.

At this point, the water becomes very cold and increases in salinity, becoming very dense. As its density increases, it begins to sink. The cold, dense water descends hundreds of meters below the surface of the ocean. It now travels slowly southward through the deep ocean abyss in the Atlantic and flows to the Southern Hemisphere south of Australia and heads north again, until it eventually mixes upward to the surface of the ocean and starts the process again. This entire conveyor belt cycle takes about 1000 years to complete.

Scientists at Argonne National Laboratory (ANL) have been actively researching how long it takes water to move through this conveyor system by tracking the levels of the radioactive argon-39 isotope in the earth's ocean circulation.

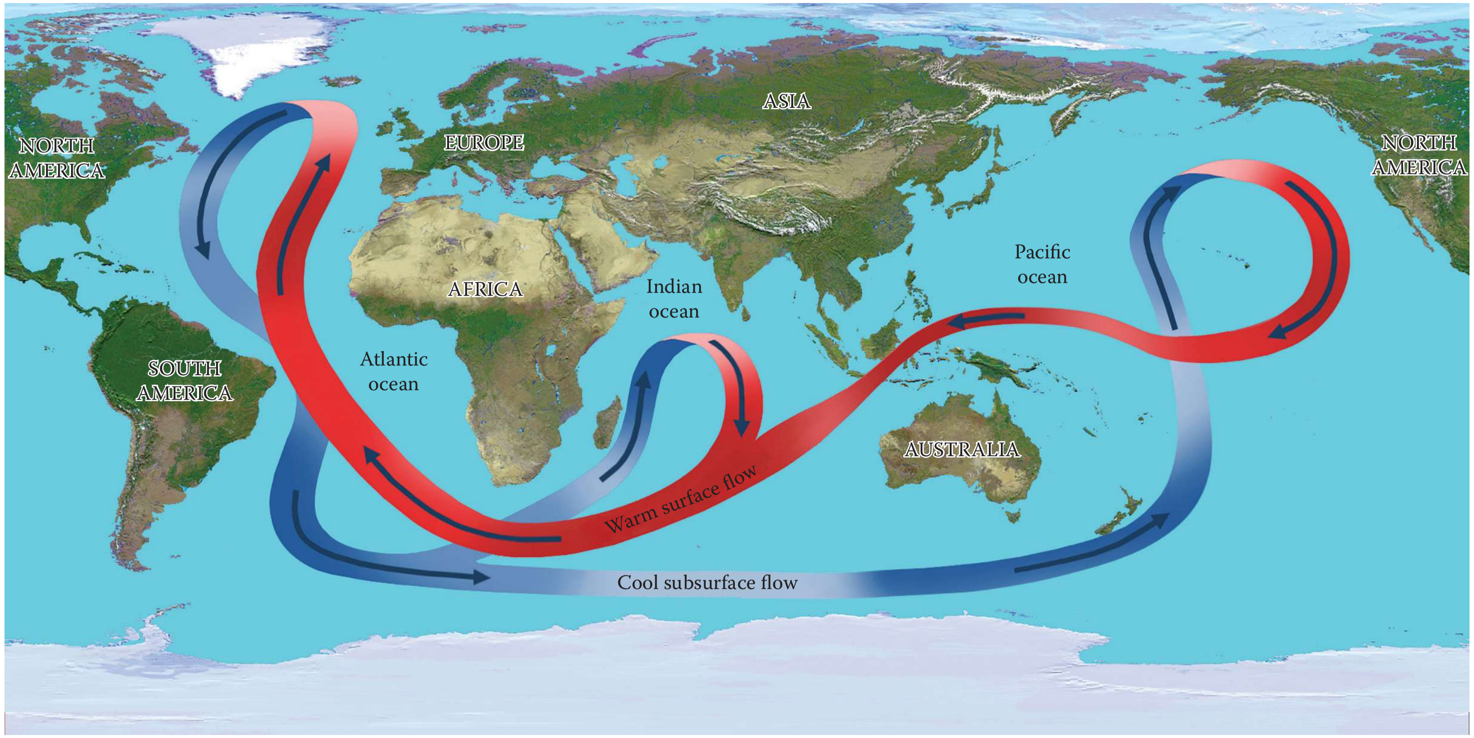

FIGURE 2.11 The Great Ocean Conveyor Belt is the major transport mechanism of heat in the ocean. If its flow were disrupted, it could trigger an abrupt climate change, such as an ice age in Western Europe. (Courtesy of NOAA, Silver Spring, MD.)

They are interested in tracking changes in ocean circulation because scientists have long believed that this system plays an important role in climate moderation. According to Ernst Rehm, a physicist at ANL, "We have some idea that if the 'conveyor belt' stops, then the warm water that is brought to Europe will stop. We have some idea that this may cause an Ice Age in Europe" (Climate Policy Watcher, 2012). In addition, scientists believe that climate change could modify the ocean's circulation if water temperatures were to rise (the heat component of thermohaline) and glaciers melt and release more of their locked up freshwater into the oceans, lowering the salinity levels (the salt component, or haline). If climate change caused this to happen—and some scientists claim it already is—it could slow, or stop, the thermohaline circulation (Argonne National Laboratory, 2003).

In a recent update, research shows that Arctic sea ice is melting faster than expected. As the earth continues to warm and Arctic sea ice melts, the influx of freshwater from the melting ice is making seawater at high latitudes less dense. Data show that the North Atlantic has become fresher over the past several decades. The less dense water will not be able to sink and circulate through the deep ocean as it does currently. This could disrupt or stop the Global Ocean Conveyor. Scientists estimate that, given the current rate of change, the Global Ocean Conveyor may slow, or even come to a halt, within the next few decades. The ramifications of this could cause cooling in Western Europe and North America. If it were to stop completely, the average temperature of Europe would cool 5°C–10°C (Windows to the Universe, 2011).

The Great Ocean Conveyor Belt plays an extremely important role in shaping the earth's climate; a slight disruption in it could destabilize the current and trigger an abrupt climate change. Climatologists at NOAA and NASA believe that as the earth's atmosphere continues to heat from the effects of climate change, there could be an increase in precipitation as well as an influx of freshwater added to the polar oceans as a result of the rapid melting of glaciers and ice sheets in the Arctic Ocean. They believe that large amounts of freshwater could dilute the Atlantic Gulf Stream to the point where it would no longer be saline—and, hence, dense enough—to sink to the ocean depths to begin its return from the polar latitudes back to the equator.

Measurements taken over the past 40 years have shown that salinity levels within the North Atlantic region are slowly decreasing. What makes this situation so serious is that if cold water stopped sinking—which means the Gulf Stream would slow and stop—there would be nothing left to push the deep, cold current at the bottom of the Atlantic along, which is what ultimately drives the worldwide ocean current system today. If this were to happen, the results would be dramatic. Western Europe and the eastern part of North America would cool off. Temperatures could plummet up to 5°C. This is about the same temperature difference as the average global temperature during the last Ice Age and today.

Effects of Sea-Level Rise

There are several impacts associated with rising sea levels making the world's coastlines vulnerable. As climate change continues and sea levels rise, storm surges will increase in intensity, destroying land further inland from the coastal regions. Flooding will become one of the major problems, and associated with flooding are several other negative impacts. As ocean waters move inland, freshwater areas will become contaminated with saltwater. As saline water intrudes rivers, bays, estuaries, and coastal aquifers, they will become contaminated and unusable. Wildlife that depends on freshwater will have their habitat negatively impacted and drinking water will become unusable. Erosion will increase along coastlines, causing disaster for many of the world's population that currently reside along the coasts. It will leave many people homeless and be economically devastating, especially in undeveloped countries.

As wetlands, mangroves, and estuaries are impacted, fragile habitats will be lost worldwide. Species will become threatened, endangered, and extinct. Other marine ecosystems will also be harmed, such as coral reefs. Reef habitats are extremely fragile and significant physical changes in their environment can quickly destroy them. The most vulnerable areas are the low-lying countries of the world with extremely large coastal populations, such as Bangladesh, the Maldives, Vietnam, China, Indonesia, Senegal, Tuvalu, Mozambique, Egypt, the Marshall Islands, Pakistan, and Thailand. Affected developing countries do not have the economic resources to implement adaptation measures, such as building sea walls to hold back rising waters. If sea levels rise, the inhabitants of the coastal areas will have no other choice but to move inland to higher ground, if possible, losing what they have at lower levels. If mass migrations result, this could lead to a host of other negative issues, such as hunger, disease, and civil unrest.

Island states are particularly vulnerable. One of the nations that are most at risk is the Maldives. This nation lies in the Indian Ocean and is composed of nearly 1200 individual islands. Their elevation above the sea level is only 2 meters. With a population of more than 200,000 people, if sea levels were to rise significantly, the entire country could become uninhabitable, leaving the entire countries' population homeless. The Marshall Islands and Tuvalu, in the Pacific, face a similar situation. Rising sea levels would first contaminate drinking water supplies, then drown the landmasses, leaving the population homeless. Other vulnerable locations include London, Amsterdam, Shanghai, New York City, many of the Caribbean islands, and Jakarta.

In a study conducted by Sugata Hazra, an oceanographer at Jadavpur University in Kolkata, India, over the past 30 years, 80 square kilometers of the Sundarbans has disappeared because of rising sea level, displacing more than 600 families. Another area, Ghoramara, has had all but 5 square kilometers of its land submerged, which is now half the size it was in 1969. The Sundarbans represents some of the world's biggest collection of river delta islands that lie between India and Bangladesh. Sea-level rise has contaminated their drinking water and destroyed the forested areas in the ecosystem. It has also threatened the existence of the wildlife, including the Bengal tiger. More than four million people live on the tiny island state, and hundreds of families have already been pushed out of their homes and been forced to move to refugee camps on neighboring islands. This is just one example of how rising sea levels are presently impacting developing countries (George, 2010). In the past few years, satellite images show that 9990 hectares of the Sundarbans forests has disappeared and several islands have completely vanished. The coastlines are retreating by as much as 200 meters a year, equating to ecosystem degradation and biodiversity loss amounting to about $107 million annually (Krishnan, 2015).

The impacts will also be felt in the United States. Both the Atlantic and Gulf Coasts face serious impacts in the face of encroaching ocean levels and saline waters. Washington DC is one of the more vulnerable areas. Higher sea levels would flood the Potomac and encroach on many famous, historical landmarks. Baltimore and Annapolis are in a similar situation.

In the Mississippi delta, the loss of wetlands is a serious issue. Changes in sea level can cause wetlands to migrate landward. The Atlantic coast is one of the more sensitive areas to wetland vulnerability. Not only is this a problem for natural habitats, but historically, these areas have been one of the most rich commercial fisheries in the world. If wetlands are endangered or destroyed, it would also have significant economic ramifications. These issues make the monitoring and control of rising sea levels a critical concern. Areas particularly in danger include Florida, Mississippi, Louisiana, North Carolina, South Carolina, Alabama, Georgia, and Texas.

Future Projections

One of the key issues is that of future sea-level rise. Because the ocean's thermal inertia is so great, it will take decades for the oceans to adjust their levels to the heat absorbed. In fact, for the heating caused by greenhouse gas emissions already released into the atmosphere, sea levels are still trying to find a point of equilibrium. Therefore, even if all greenhouse emissions stopped today, there would still be a lag time for the oceans to stop rising. During this lag time, the oceans will likely rise another 13–30 centimeters by 2100. In the 2007 Fourth Assessment Report of the IPCC, a sea-level rise of 18–58 centimeters by 2100 was projected. In the 2013 Fifth Assessment Report of the IPCC, the map of regional sea-level rise is shown in Figure 2.12. A summary of their key findings is shown in Table 2.3.

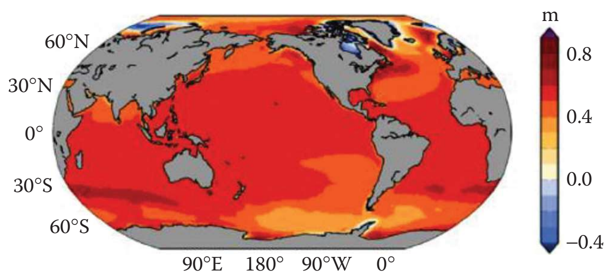

FIGURE 2.12 Regional sea-level rise by the end of the twenty-first century. (Courtesy of IPCC, Geneva, Switzerland.)

TABLE 2.3
Key Findings of the IPCC Fifth Assessment Report on Sea Level Rise

- It is *virtually certain* (99%–100% probability) that global mean sea-level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions.
- Medium confidence that global mean sea-level (GMSL) rise by 2300 will be <1 m for a radiative forcing corresponding to CO_2 concentrations <500 ppm but ≥1 m for 700–1500 ppm.
- Larger sea-level rise could result from sustained mass loss by ice sheets, and some part of the mass loss might be irreversible.
- Sustained warming greater than a certain threshold above preindustrial would lead to the near-complete loss of the Greenland ice sheet (high confidence).
- The threshold is estimated to be >1°C (*low confidence*) but <4°C (medium confidence) global mean warming with respect to preindustrial.
- It is *very likely* (90%–100% probability) that sea level will rise in about >95% of the ocean area.
- About 70% of the coastlines worldwide are projected to experience sea-level change within 20% of the global mean sea-level change.
- It is *very likely* that the twenty-first-century mean rate of GMSL under all RCPs will exceed that of 1971–2010, due to the same processes.
- It is *very likely* that sea level will rise in about >95% of the ocean area.
- It is *very likely* that there will be a significant increase in the occurrence of future sea-level extremes.
- It is *virtually certain* that global mean sea-level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions.

Based on the extensive work that has been done to date, scientists have a clear idea of where conditions are going in the future. According to the United States Geological Survey (USGS), based on the information obtained from both tidal gauges and satellite measurements worldwide, scientists can say with confidence that sea-level rise has increased during the twentieth century. Based on the data acquired from Australia's Commonwealth Scientific and Industrial Research Organization, data gathered from January 1993 to December 2015 shows that sea level has risen on average 3.3 mm/year (Figure 2.13). Increased scientific knowledge has also clarified some issues that were not well understood previously, such as that the large polar ice sheets are far more sensitive to surface warming that initially thought, with significant changes currently being observed on the Greenland and West Antarctic ice sheets. Scientists now realize that these melting ice sheets can add water mass much more quickly to the oceans than previously assumed and play a significant part in overall global sea-level rise. A notable consensus among specialists in climate change at USGS is also marked today. It is largely recognized and accepted that there could be a rapid collapse of the polar ice sheets, and scientists have keyed in on the fact that anthropogenic actions, such as burning fossil fuels, could result in triggering an abrupt sea-level rise before the end of this century. They stress public education and political policy be brought to the forefront in order to deal

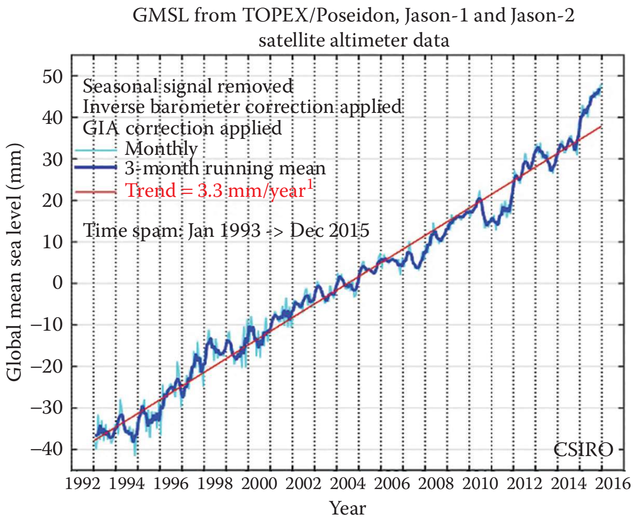

FIGURE 2.13 High-quality measurements of (near)-global sea level have been made since late 1992 by satellite altimeters, in particular, TOPEX/Poseidon (launched August 1992), Jason-1 (launched December 2001), and Jason-2 (launched June 2008). These data have shown a more-or-less steady increase in GMSL rate of ∽3.2 ± 0.4 mm/year over that period. This is more than 50% larger than the average value over the twentieth century. Whether or not this represents a further increase in the rate of sea-level rise is not yet certain. (Courtesy of CSIRO, Canberra, Australia.)

most effectively with a situation that affects every person living on earth now and in the future. Figure 2.14a shows the drastic decrease in ice coverage in the Arctic over the past 30 years—approximately half now of what it was in 1979. Today the ice extent is below 4 million square kilometers. Ice volume shows a comparable rapid decrease. Figure 2.14b shows the annual average temperature in the Arctic region from 1979 to 2012. Figure 2.14c illustrates the average sea ice extent from 1979 to 2012. Satellites have measured a warming trend of 0.53°C per decade; which is considerably higher than the 0.16°C per decade global temperature increase. Since 1979, the Arctic has warmed about 3.3 times faster than the earth in general. Referred to as the "Arctic amplification," it is partially caused by the disappearance of sea ice and the effect this has on regional albedo (referred to as the *ice-albedo feedback*). Scientists recognize that greenhouse gases play a major role in the sea ice decline of recent decades (Hagelaars, 2013). Because of these relationships and effects, it is important that the scientific basis of climate change be well understood when dealing with the sustainable ramifications caused by climate change.

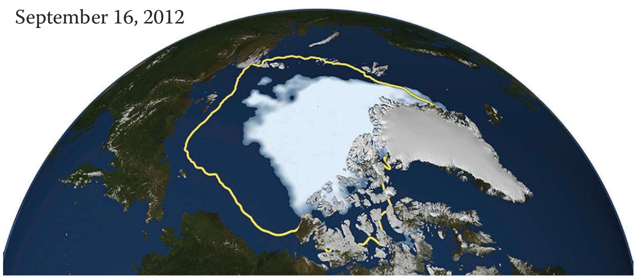

FIGURE 2.14 (a) Line indicates the average minimum ice extent of the past 30 years compared to the minimum ice extent on September 16, 2012. (b) Average annual temperature in the Arctic region from 1979 to 2012. (c) Average sea ice extent from 1979 to 2012. (Courtesy of NSIDC, Boulder, CO.)

CONCLUSIONS

The information presented in this chapter was geared to provide insight into the physical processes of climate change as well as the anthropogenic component and its overall significance to the problem. Based on the nature of the earth's natural processes, there is already substantial evidence that climate change is well underway, and the society as a whole can no longer ignore the issue and sit on the sidelines. In addition, the days of passing the buck are over—it is no longer "somebody else's problem." We all have a vested interest in its outcome. In order to become empowered and contribute meaningfully to the solution, however, it is necessary to understand the pertinent multifaceted issues—the scientific, political, economic, social, and technological components. Although each different in nature, they are all important pieces to the complete issue—a phenomenon so immense it touches nearly every fabric of society from broad, international scales to personal ones. Similar to just reading a language out loud without truly understanding the words and meanings, without a working knowledge of the scientific foundation it rests upon, it is not possible to comprehend its vastness and relevance to other critical components of our lives—namely, those that encompass the economic, political, and social aspects, in addition to future energy choices and sustainable lifestyle decisions. For example, without a working understanding of the Great Ocean Conveyor Belt and the possibility of abrupt climate change, it is not possible to understand the significance and urgency of economic issues and the loss of homes, food, natural resources, incomes, and basic security; the social aspects of personal loss, fear, riot, unrest, and migration; or the political aspects of security, defense, order, peace, and leadership. Understanding first the scientific basis is critical to finding workable, meaningful long-term solutions that will find an effective fit in all cultures and societies.

Not often have problems had such far-reaching consequences. Being the first world society to be faced with this dilemma, there is, unfortunately, no prior historical experience to fall back on. This is a modern problem that not only will our decisions and actions affect lifestyles and opportunities today, but will also affect those of generations long into the future. For that, we owe it to ourselves and future generations to obtain a good grasp of the basic scientific theory behind climate change. Without this crucial background, it is not possible to take a convincing stand backed by facts, examples, and viable suggestions for solutions. Knowledge is power and personal, and community education is critical to successful solutions. The correct scientific concepts need to be taught and understood so that the misinformation also being distributed by procrastinators and those in denial is put to rest in order to stop muddling the issue and delaying action. Perhaps one of the best ways to look at, and approach the issue, is from the standpoint of a global community where it is necessary to reach across borders, boundaries, personal differences, and comfort levels to solve this immense problem together—for this is a war unlike any fought before and we are all on the frontlines.

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