Chapter Seven

CLIMATE CHANGE

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THE DILEMMA OF FOSSIL FUELS IN AN INDUSTRIALIZED ECONOMY

One environmental issue that nearly everyone has heard of is **global warming**. In this chapter we first describe the basic science of climate change. Then we discuss the industrialized economies that generate greenhouse gases, primarily through the burning of **fossil fuels**. Few people are aware of how their everyday choices—to eat beef, fly in an airplane, or buy a new car—affect energy consumption and therefore the global climate. The response of Earth's climate system to the addition of greenhouse gases is delayed and complicated. In the language of Chapter 2, climate change is hidden in the invisible present. Moreover, the atmosphere is the largest commons: greenhouse gases emitted anywhere on the planet affect the global climate. As Chapter 3 explains, it has been very difficult to reach international agreements to govern the atmospheric commons. The deep, pervasive link between people's everyday choices and climate change makes this environmental problem a grand challenge of sustainability.

The basic science of global climate change has been known for more than a century. Since 1988, the Intergovernmental Panel on Climate Change, an international body linking the worldwide community of climate scientists to national governments and the international community, has assembled a firm scientific consensus to warn the world that humans are changing the global climate—a warning recognized by the Nobel Peace Prize in 2007. As we'll see, some action has been taken, and there is much talk about doing still more. But little is being done yet that would bring the driving forces of human-caused climate change to a standstill.

In that sense, the classical model of environmental reform has not yet worked. That is, the threat identified by science is not being met with technological and institutional changes that could credibly manage global warming. The environmental problem is still worsening, and its driving forces are not yet being controlled.

WHY CLIMATE MATTERS

As we saw in Chapter 5, climate forms the basic architecture of the natural world (see Fig. 5.6). What makes one place different from another is shaped by the general pattern of weather it experiences—that is, its climate: the annual cycle of the seasons, the amounts of precipitation a place receives, and the frequency of extreme events such as droughts and storms. As we saw in Chapter 5, the climate also shapes the local ecosystem and determines which plants and animals can survive in that place. Even landscapes created by humans, such as parks and backyards, look different in Maryland than they do in Utah. The crops and forests of tropical Indonesia (see Fig. 5.12) do not resemble those of New England (see Fig. 2.2).

Climate is the long-term average of weather. Over the history of the planet, climate has changed. In Canada and much of the United States, a trained eye can see the signs of glaciers that covered the land about ten thousand years ago, so Earth's climate has varied dramatically while humans have inhabited the planet. What is happening now, as humans cause the global climate to change, is that long-term

Learning Objectives

When you have finished studying this chapter, you should be able to

- explain the greenhouse effect to an elementary school student or grandparent;
- discuss at least two different changes in the global climate system, such as warming, retreat of polar ice caps and mountain glaciers, rise in sea level, and changes in the frequency and intensity of storms and droughts;
- identify several activities in your daily life that are directly linked to the burning of fossil fuels and suggest some that are dependent on fossil energy indirectly;
- look into energy conservation opportunities in your life and at your college, such as using public transit or installing insulated windows, to find out firsthand why these measures are not being adopted;
- explain the implications of filling your car's gas tank on national security, the U.S. economy, and global climate;
- articulate your own and others' opinions about an international climate agreement by using ideas from this chapter and Chapter 3.

averages are changing. Indeed, the weather we are seeing today is increasingly departing from expectations based on historical experience.

It is important to bear in mind that the weather varies a lot. So a change in *climate* is subtle and hard to see. Warming—a rise in average global temperatures—is the change that has received the most attention. Perhaps more significant to human societies, though, are changes in the frequency of extreme events such as severe storms, droughts, and heat waves.

Are such changes occurring? It does seem that news reports of tornadoes, crop failures, wildfires, and floods have been increasing in recent years. But that is partly because humans have been settling in places where their vulnerability to extreme events is higher. In the developed world, scenery draws people to coastlines exposed to hurricanes, housing subdivisions are built next to forests, and cities like Las Vegas are built in deserts. In many poor countries, expanding populations have pushed into areas where agriculture is easily disrupted by bad weather, increasing the risks of storm damage and famine. Scientists who study the atmosphere agree that these changes in human vulnerability have increased much more rapidly than the weather itself has changed. But as we will see, the weather *is* changing.

As the climate changes, ecosystems on land and sea are being altered, and the ecologists who study them project larger disruptions in the decades to come. Watersheds, forests, croplands, and oyster beds that yield ecosystem services used by humans are also being changed. Some of the severe droughts that have brought hunger to eastern Africa and economic loss to the U.S. Southwest during the first decade of this century may be a reflection of climate change. These are, in any event, representative of the stresses that climate change will bring.

For the most part, though, residents of a rich nation like the United States may barely notice the disruptions. Coffee or orange juice may cost more. There may be news of starving people in a distant country as reductions in crop yields in places like Russia lead to higher grain prices in markets everywhere. But the world without edges gives people with means the ability to shift sources of supply, often without consumers noticing. That is, climate change may not affect daily life in a rich country very much, allowing skeptics to dispute whether climate change is even under way or whether it is caused by humans.

THE GREENHOUSE EFFECT

The principles of climate change are not seriously in question, although the field science is complicated enough that some scientific questions still need to be resolved. Energy from the Sun reaches Earth as light—technically, electromagnetic radiation in the visible part of the spectrum. This energy heats the earth, and Earth re-radiates a portion of that energy as **infrared radiation**—a form of light with wavelengths that are too long to be visible to the human eye, although you can *feel* infrared rays that come from the heat lamps used to keep food warm in some cafeterias. A portion of that heat is retained in the earth and the planet's atmosphere.

The way the light from the Sun heats the Earth involves the **greenhouse effect**, named after the structures gardeners build to protect their plants from frost and encourage growth. You experience a similar effect when you get into a car that has been parked in a sunlit space. The interior of the car is noticeably warmer than the outdoor temperature because the car windows turn the vehicle into a greenhouse. Energy comes in as sunlight and warms the seats, carpets, and dashboard. This is why the seats can be uncomfortably hot if you're wearing shorts.

The high temperature inside the car shows up as an excess of infrared radiation, but infrared radiation is blocked from escaping by the window glass. Glass is transparent in the visible wavelengths used by our eyes, but it is opaque to infrared light. As a result, one of the main mechanisms of heat transfer is blocked by the windows.

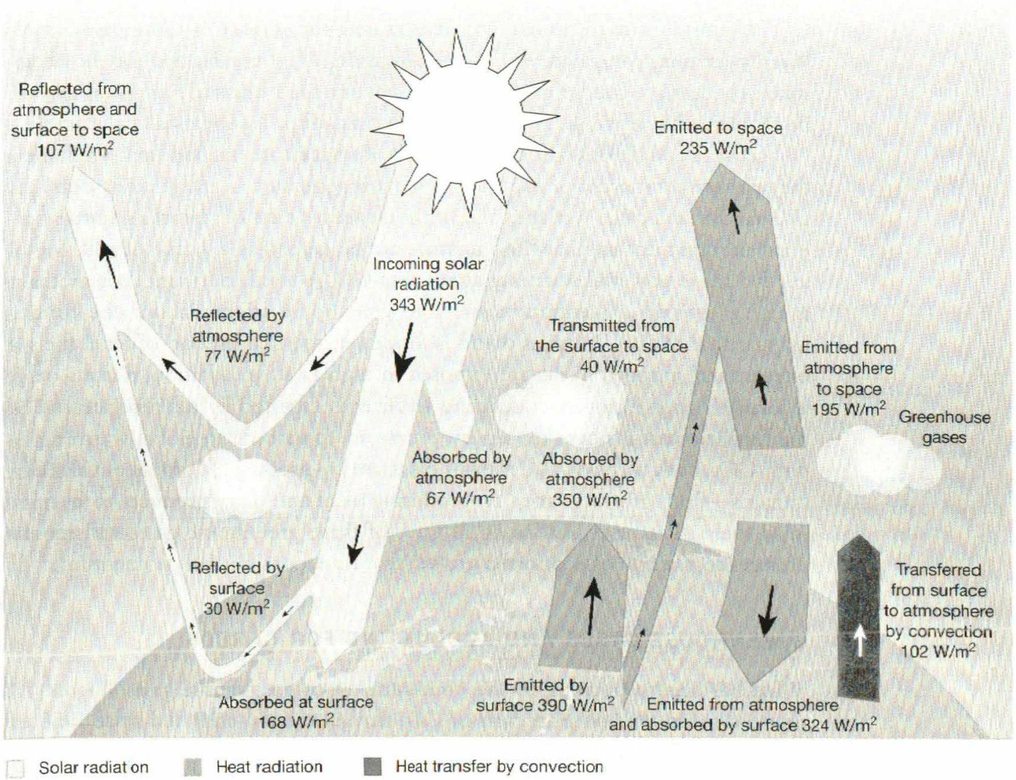
There is some leakage of heat to the outdoors, though, so in a few minutes a **steady state** is reached, in which the temperature inside the car stops rising but is higher than the air outside. The elevated temperature inside is a result of the greenhouse effect (Fig. 7.1).

Because we cannot see temperature or heat, it may be easier to understand the process with an analogy. Consider a bathtub with its drain open and the faucet running. As water flows through the faucet, filling the tub, the flow through the drain increases with the water pressure until a steady state is reached and the water level stabilizes. Now, imagine the drain clogs slightly but does not stop the outflow of water. The water flowing out slows, until the water pressure in the tub rises high enough for the outflow to equal the amount flowing in.

That higher level is the analogue of global warming: the temperature of Earth rises, like the level of water in the slightly clogged bathtub, until a steady state is reached, with energy leaving Earth at the same rate as the sunlight brings it in. The gases that block infrared wavelengths of light, which make up the bulk of heat radiation, are called **greenhouse gases**. If the concentration of those gases is increased, more infrared light is blocked and the net effect is a rise in global temperature.

By far the most significant greenhouse gas is water vapor. If Earth had no atmosphere and thus no greenhouse effect, the planet's average temperature would be about 33°C colder, below the freezing point of water. Looked at that way, the greenhouse effect produced by the atmosphere and the water in the oceans is an integral aspect of the architecture of the natural world.

The science of the greenhouse effect was worked out by French physicist and mathematician Joseph Fourier in an 1827 paper in which he remarked that humans might change the conditions on Earth sufficiently to alter the heat balance of the planet. Others confirmed Fourier's theoretical analysis, and by the end of the nineteenth century, Swedish chemist Svante Arrhenius estimated that a doubling of



SOURCE: GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY, POLICY DOCUMENT (2009).

FIGURE 7.1
Earth's energy budget, showing input of solar energy, loss of energy from Earth to space, and transfers of energy from the surface of the planet into the atmosphere. Changes in the composition of the atmosphere can alter the balance between solar inputs and losses to space, changing the average temperature of Earth.

the **carbon dioxide** (CO_2) in the atmosphere would raise Earth's average temperature by about 5°C or 6°C. It is an estimate that still stands more than a century later.

Humans have been turning Arrhenius' projection into fact, adding to the greenhouse effect by changing the composition of the atmosphere through emissions from agriculture, industry, and transportation. Climate scientists call these additions **anthropogenic radiative forcing**—changes in the heat balance shown in Figure 7.1 caused by people. As of 2005, 63 percent of these changes were being caused by CO_2, the most prominent greenhouse gas. The other major contributions came from methane (19 percent), nitrous oxide (6 percent), and other industrial gases that also affect the stratospheric ozone layer (12 percent).[1] The gases in the last category are regulated by an international treaty agreed to in 1989 called the Montreal Protocol, and these gases are slowly decreasing as emissions are phased out. Methane and nitrous oxide are removed from the atmosphere more rapidly than

CO_2. If emissions from human activities ceased, the impact of those gases would lessen over time compared with carbon dioxide. The time needed for the atmosphere to return to conditions that prevailed before the Industrial Revolution would be centuries, however. The human footprint on climate is substantial and durable.

Methane and nitrous oxide are products of agriculture and industry. Methane is the primary constituent of natural gas, and it is generated in many ways, such as in rice paddies and other wetlands and in the digestive tracts of mammals. Cattle generate enough methane that their manure can be tapped as a source of fuel. Methane is a more powerful warming agent than CO_2, pound for pound, but methane is much lower in concentration, so its net greenhouse effect is about one-third as large as that of CO_2. Nitrous oxide is formed in the combustion of fossil fuels as oxygen and nitrogen in air are exposed to high heat. In addition, nitrous oxide is formed when nitrogen-containing fertilizer is digested by microorganisms. So the fertilizer that is not taken up by plants can contribute to global warming. As with CO_2, both methane and nitrous oxide are by-products of processes valued by humans—from growing crops, to producing meat and dairy products, to burning fossil fuels. Altering emissions of all three of these greenhouse gases will require changes to patterns of economic growth that have considerable momentum.

GREENHOUSE GASES AND ACCOUNTING FOR CARBON

What has been happening to the concentration of greenhouse gases? Figure 7.2 shows data on the concentration of CO_2 that have been collected since 1958 on Mauna Loa, a volcanic mountain in Hawaii. First, notice the sawtooth pattern: the concentration of CO_2 goes up and down each year. This is Earth "breathing"—the CO_2 level drops in spring and summer as plants take up more CO_2 than they release through respiration, then the CO_2 level increases in autumn and winter as the leaves drop and decay. (The data from Hawaii reflect the behavior of the atmosphere over the Northern Hemisphere.)

Next, look at the numbers on the vertical scale: the total concentration of CO_2 is tiny, about 390 parts per million (equivalent to 1 teaspoon in about 3.6 gallons). That's the concentration of peanut butter if you were to spread one tablespoon of peanut butter on twenty loaves of bread—hard to call that a peanut butter sandwich. The change in total CO_2, as you can see, has been about 70 parts per million over the past half-century, or about 20 percent.

The other important greenhouse gases, methane and nitrous oxide, have been growing in concentration faster than CO_2 as meat production and fertilizer use have been increasing to meet demand in China, Brazil, and other rapidly growing economies. In addition, the large quantities of methane trapped in the permafrost in polar regions may be released as the climate warms and the permafrost melts. This would be an example of a positive feedback effect: the more the planet warms, the more of this potent greenhouse gas will be released, warming the planet further.

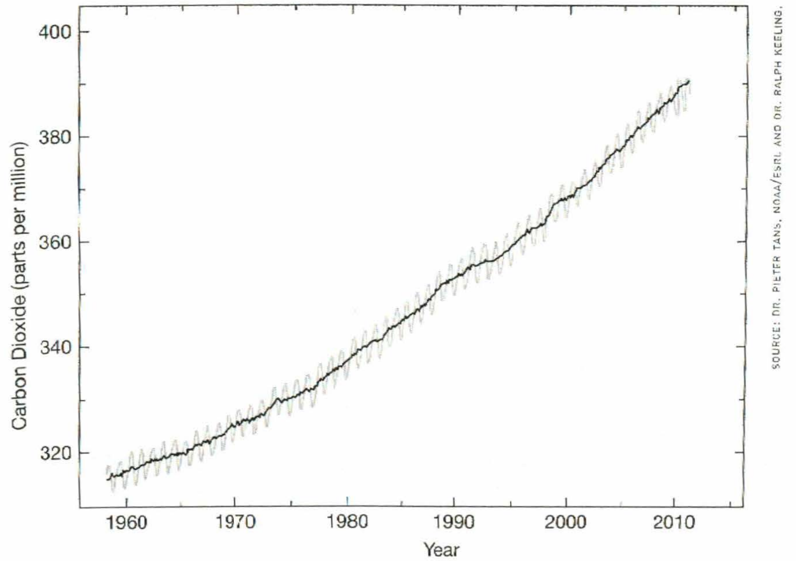


FIGURE 7.2 Atmospheric concentration of carbon dioxide recorded at Mauna Loa in Hawaii, 1958–2011.

Even though the concentration of all the greenhouse gases is very small, bear in mind that a slight change in the clogging of the drain can cause a perceptible change in the water level in the tub. Earth's average temperature is the result of an equilibrium between the heating effect of the sunlight that falls on the planet and the loss of heat through the atmosphere. The equilibrium temperature shifts in response to changes that seem very small by the standards of our everyday experience. This is one reason the invisible present is invisible: we cannot perceive the shift in greenhouse gas concentrations except through changes in climate, and these take decades to become apparent.

Carbon dioxide flows in a global carbon cycle (Fig. 7.3). The carbon cycle is an example of a **biogeochemical cycle**, an accounting mechanism used by scientists to track the flow of basic constituents of the natural world, including carbon, oxygen, nitrogen, and water, as they move through the principal components or "compartments" of the biosphere. Carbon shows up in the atmosphere as CO_2, and it moves into plants through photosynthesis, becoming part of the wood, leaves, roots, and a wide array of organic chemical compounds. The transfer of carbon into living things is called net primary production, a technical term measuring the net capture of sunlight by plants. The carbon dioxide also is taken up (absorbed) by seawater, forming carbonic acid. In all of these transformations, carbon moves from compartment to compartment, playing different roles in the chemistry of life and nature.

Earth's atmosphere holds roughly 800 gigatonnes of carbon (GtC). Rather than trying to imagine how many tons of coal contains 1 GtC, it's better simply to think

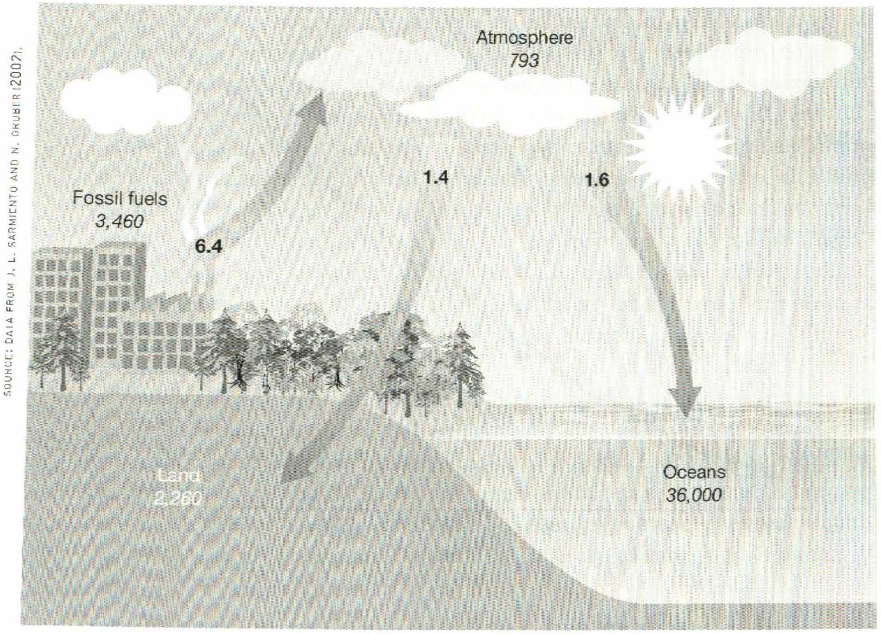


FIGURE 7.3 Earth's carbon cycle. Each of the major compartments of the planet holds carbon (italic numbers, in gigatonnes). Each year, because of both natural and human-caused changes, there are small net flows (numbers inside arrows, in gigatonnes per year) between the compartments.

of this reservoir of atmospheric carbon as a large number. Earth's rocks and ocean waters hold a great deal more. Each year, as the seasons unfold and living things process carbon, about 90 GtC flows back and forth between the atmosphere and ocean compartments. A similar flow of about 70 GtC takes place between the atmosphere and land. These are flows, not net transfers, which are much smaller (see Fig. 7.3). The flows can be seen in the sawtooth pattern of the atmospheric CO_2 data in Figure 7.2. The burning of fossil fuels contributes about 6 GtC each year. This is a net addition, which can be seen in the rising trend in Figure 7.2. Fossil fuels are burned, but because no human process soaks up this carbon, it stays in the environment.

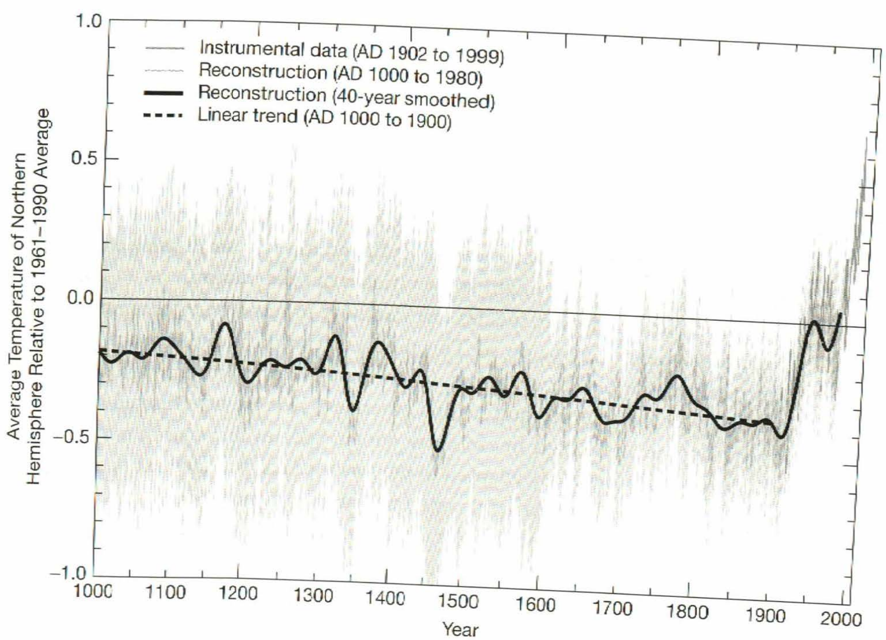
GLOBAL WARMING

As many skeptics allege, global warming *is* a "theory." Global warming is a prediction that Earth's atmosphere will continue to warm, as it began to do in the twentieth century, to levels not seen on the planet for hundreds of thousands of years. This prediction comes from the laws of physics as applied in about fifteen computer models at universities and government laboratories around the world. These models employ the same physics as Fourier's 1827 paper but break up the atmosphere into thousands of individual cells so that the physics and chemistry of the gases within each cell can be tracked as sunlight interacts with water vapor, pollutants, and the rest of the atmosphere. As noted above, the broad outlines of these model analyses affirm the numerical results arrived at by Arrhenius in the nineteenth century using far simpler scientific means. In that sense, the basic magnitude of the greenhouse effect is well settled.

Evidence continues to mount that the model predictions are correct—that global warming is not *only* a theory. This has significant implications for the world, both natural and human. One summary of a large and diverse set of data from different parts of the world is shown in Figure 7.4. The dark wavy line shows the average temperature of the Northern Hemisphere over the past thousand years. The shaded area indicates the uncertainties in the underlying data. Over the course of the twentieth century, the trend in temperature turned up sharply. This is consistent with the idea that the globe is warming.

Why would Earth's temperature change so abruptly? Because humans are burning coal, oil, and natural gas at a rapid pace, altering the heat balance of the planet and its biogeochemistry. This assertion has been the subject of a long political debate, but it is not seriously disputed within the scientific community.

FIGURE 7.4 Average temperature of the Northern Hemisphere over the past thousand years. The baseline temperature (located at 0.0 in the figure) is the average temperature over the period from 1961 to 1990. The numbers on the vertical axis are degrees Celsius.



SOURCE: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE.

A WARMING WORLD

Even a small change in CO_2 (and other greenhouse gases) implies observable and worrying changes in the natural world. The basic notion is simple and stark: if climate establishes the architecture of the living world, then a change in climate will shift the architecture of ecosystems and the species within them. Climate changes are occurring on a time scale far shorter than the evolutionary process in long-lived species such as trees or mammals. This means that the shifting of the architecture of life is less like erosion and more like an earthquake: the whole structure shakes and the parts that are unable to adapt go extinct. The collapse of some species, in turn, sets off a ripple effect of changes throughout the landscapes they inhabit.

One important example of a dramatic but invisible environmental shift is the change in the chemical composition of the oceans. Carbon dioxide in the atmosphere mixes with water, forming carbonic acid. (The CO_2 in a carbonated soft drink turns the water into a dilute solution of carbonic acid. When the soft drink can is opened, the hiss you hear is pressure being released and some of the carbonic acid turning back into water and CO_2. When the bubbles of CO_2 gas rise to the surface, the CO_2 escapes.) As the CO_2 concentration in the atmosphere rises, the oceans are absorbing more CO_2, which makes them more acidic. This process of ocean acidification has been clearly documented by oceanographers in all the world's seas.

The rising acidity of the ocean has a profound consequence: it is becoming harder for creatures with shells to form their shells. The shells of clams and many other species are primarily calcium carbonate. This compound dissolves in acid, so as the ocean water becomes more acidic, it is causing problems for species with shells, just as we would if something caused our bones to weaken. Projections indicate that some species will be driven extinct in the coming decades as the oceans' chemistry changes. This would disrupt food chains. For example, a major food of some species of Pacific salmon is the pteropod, a small shelled creature. If the pteropods die out, so might some varieties of wild salmon.

As the climate changes, species that can move in response to changing weather conditions seem likely to do so. This means that tropical diseases such as malaria may reappear in temperate zones, when these zones warm enough to become favorable for malarial mosquitoes and other pests that are now limited by climatic conditions such as a hard freeze every winter. Species that cannot move, such as plants and animals already adapted to mountain peaks, will face extinction. In the mountains of southern Arizona, one finds life forms not seen at lower altitudes, but they do not have higher, cooler environments to migrate to. These "sky island" ecosystems seem to be getting more fragile. Already, the frequency of forest fires appears to be at unusually high levels.

A warming climate has other effects in addition to a rise in temperature. In some interior areas of continents, longer droughts are likely. In the oceans, warmer water gives storms more energy, so that more severe storms can be expected. Consensus has not been reached about whether these effects might be appearing already. What's clear is that storms such as Hurricane Katrina (2005) and Hurricane Irene (2011) imposed catastrophic damage in places such as New Orleans and Vermont of a kind projected to occur more often in a future, warmer world. In some places, such as Florida and the Gulf Coast, insurance companies have declined to offer coverage to homeowners whose property is vulnerable to hurricanes and storm surges.

Existing climate models do not have enough power to predict which areas will be affected by droughts or specific storms. Scientific teams are collecting more data in the field and building more complex models in an attempt to clarify these issues. A warmer climate implies, for example, that less snow will be stored on high mountain slopes in places like the Sierra Nevada of California. This means that rivers fed by snow and ice will change their flow patterns, with large implications for agriculture and for the rivers' ecology and hydrology. So there is great interest in more precise and accurate predictions.

Sea levels will rise as the warmer ocean water expands and as the total amount of water in the oceans increases with the melting of glaciers. The magnitude of **sea-level rise** to be expected by a specific date is not known precisely, but in 2007 the Intergovernmental Panel on Climate Change estimated a rise of as much as 6 feet by the end of the twenty-first century.[2] This would have a bigger impact than one might think at first because low-lying ecosystems, including wetlands, coral reefs, and fertile soils in river deltas all over the world, will be affected. Significant economic impacts will be felt, particularly in poor countries such as Bangladesh, where millions of people live in low-lying areas. Box 7.1: That Sinking Feeling (page 166) gives an account of what this looks like to a citizen of a country that is literally disappearing. Environmental pressure is likely to be felt in extreme events such as storms, in which a higher sea level may allow surging waters to flow much farther inland. It will be possible to build sea walls and dikes, as the Dutch have done, to preserve high-value lands, and this seems likely to be done in some places. But consider the Mississippi River delta, a low-lying coastal ecosystem that stretches for hundreds of miles. As Hurricane Katrina revealed, a sizable part of New Orleans is already lower than sea level, protected only by fragile levees. Clearly, all defensive strategies have practical limits, even in a country as rich as the United States.

We have controlled our indoor climates for a long time, so we are likelier to remain clueless about climate change, which is hidden in the invisible present. The changes in temperature, storm intensity, streamflow, and ecosystems are slow, and it seems unlikely that they will stay newsworthy. So we are faced with the problem

BOX 7.1

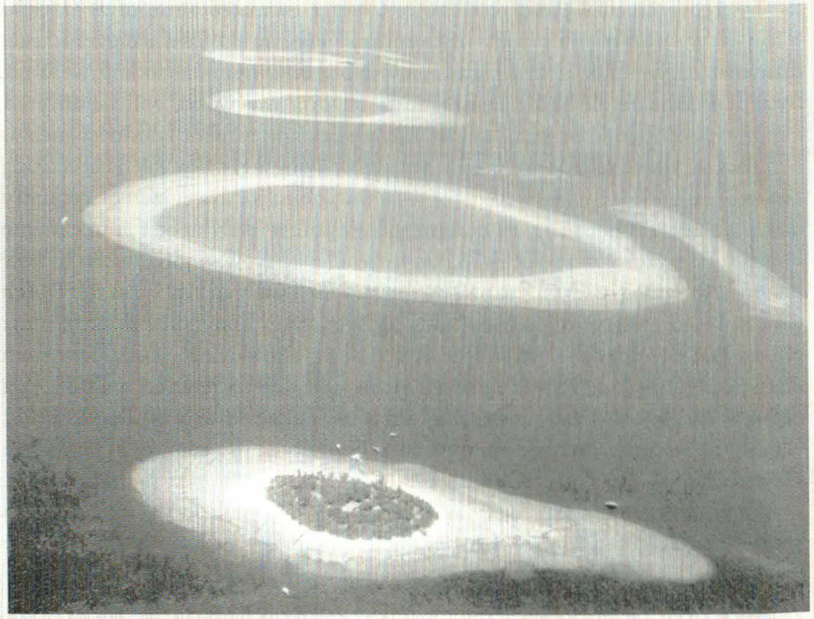
THAT SINKING FEELING

by Fathimath Musthaq

Fathimath Musthaq is from the Indian Ocean nation of the Maldives. One of her grandfathers was a Maldivian island chief. Fathimath left home when she was sixteen to study abroad, graduating from the United World College of the Atlantic in Wales in 2005. She wrote this essay in 2006 at Williams College, where she was studying political science, biology, and environmental studies—the latter because her homeland faces inundation as global climate change raises sea levels in the coming decades. This essay appeared in the online science magazine Earth & Sky *(www.earthsky.org).*

I still remember the time I looked out the window of the Monarch airplane and marveled at the majesty and beauty of what I saw spread beneath me. Even 72 hours of waiting in London's busy airport could not dampen my excitement of seeing those perfectly round living "organisms." These "organisms" protect

Alidhoo Island, Maldives.



my people and sustain their livelihood—a livelihood that is becoming harder to maintain as the temperature of the seas increase and this lethal thing that we call climate change grows stronger by the day.

The organisms that I talk of are the coral reefs, a splendid creation of nature, yet vulnerable to the slightest change in average temperature. These coral reefs protect the small low-lying islands where my great-great-grandfather lived his peaceful life of catching tuna and climbing coconut palms. Today, they protect the island where my father earns his income by luring the world to marvel at the splendor of our little islands.

Once upon a time, these creatures used to protect my childhood playground—the white sandy beach with dozens of coconut palms and the tall trees we call *Hirundhu ga*. I remember waking up every morning and running into the ocean to catch the colorful playful little fish that hid in the corals. But those days and that playground exist only in my memory and in the memories of those who were fortunate enough to be born at least 20 years ago. In 1998, massive coral bleaching (due to increased temperatures) caused severe damage to our reefs. The corals are now recovering slowly and, even today, many of the best dive spots and the whitest beaches are found in the Maldives. However, because of our vulnerability to climate change, I doubt my children will grow up, as my father would proudly say, "children of the sea."

We have lived on these little islands in the Indian Ocean for thousands of years. Our way of life is based on the unique geography of our archipelago. We have 1,192 islands of which people live on 199 islands and 86 islands are used exclusively as hotels for tourists. The population of the Maldives is about 350,000 with approximately one-third of the population living in the capital city Malé. Every year we have approximately 450,000 tourists. Although we import much of what we eat nowadays, the main source of nutrition remains different fishes, mainly tuna. The reasons for our sound economy are the tourism industry and the fisheries industry, both of which depend on our natural environment.

My friends from school in Wales and the U.S. tell me how lucky I am. It is true. Maldivians are lucky to be living in a country where the majestic beauty of the islands and the diversity surrounding the coral reefs sustain a simple and yet harmonious way of life.

The dark side that nobody wants to acknowledge is that when the temperature of the seas increase, our corals will die, our tuna will migrate, and our seas will grow and eat away the little islands. This is dreadful news for a country where the majority of people know only one way of living, a way of living rarely glimpsed in the modernized and busy world that we live in today.

It comes as no surprise that Maldivians would be reluctant to think about migrating to another land. What? Leave home?

I spoke to the director of the Environmental Assessment project in the national government, and he told me what I already knew. Maldivians are going to stay in their fragile little islands and defy nature until the big, heaving seas come and engulf the last remaining house. Even the angry 2004 "tsunami that showed the Maldivians in five minutes what would happen to their home over the next 50 or 70 years" has not prompted conversation about moving. Neither did it change people's minds drastically.

I don't blame them. To dig out the roots of ancestry and history and plant them somewhere where the soil will not nourish them is bound to erase a culture, a tradition, and a way of life.

Today, the government is busy engaging itself in "adapting" not "moving." The hesitance, no, the outright defiance of the Maldivians to moving leaves the government no choice but to invest millions in building sea walls and reclaiming land. While my people are trying their best to defy nature, sometimes tripping and falling, across the world in the land known as America, people are driving hundreds of miles in their carbon dioxide emitting automobiles. We know. We know that some things such as sinking islands are inevitable in a world that may continue to heat up. One of my classmates put it very bluntly to me once in a seminar. Life goes on.

Life will go on, for Maldivians and for the rest of the world.

While we are not ready to acknowledge the devastating impacts of climate change, Americans are not ready to change their lifestyle either. In fact, most Americans, I dare say, are unaware of the existence of the Maldives. However, it is my hope that the conflict of interest would be resolved before it is too late. It is time for Americans and the rest of the world to wake up and become educated in a global sense and realize the global tragedy we face today. There are things to be done: energy conservation, funding research for more efficient energy sources, planting trees, and so on.

While the global attention is focused on the wars in the Middle East, another war is being fought in the little islands of the Maldives. A war against nature, the most powerful enemy there is. Who will help us? Who can help us? Who is going to switch off their lights and drive a hybrid? Who is willing to do research and find new ways of adapting? Or even ways of relocating?

In a world without edges it is the responsibility of the international community to aid those forced to be in the frontline of the battle against nature, especially when we, the Maldivians, are among the least responsible for causing climate change.

We may be the first to go down in history as people who lost an identity to nature. But, we may not be the last.

Source: "That Sinking Feeling," by Fathimath Musthaq. *Earth & Sky*. Courtesy of Earthsky.org.

we encountered with the Maya in Chapter 4: when the people who are able to control things do not get feedback, the whole system can go off the rails. As we will develop further in Part III, people *can* adjust quite rapidly in some circumstances, as we did when energy prices rose dramatically in the 1970s.

THAW

As global climate responds to increased concentrations of greenhouse gases, the climate models predict that temperatures in polar regions will rise faster and by a greater amount than in tropical and temperate zones. Evidence supporting this prediction can be seen in changes to the physical geography of polar regions. These changes are leading to the retreat of the ice caps and the retreat of ice in the Arctic Ocean. This has dramatic implications for rising sea levels and for international rivalries over ocean areas that are increasingly open to travel, fishing, and oil exploitation.

An impressive example of changes in the polar environment came on an Antarctic ice shelf known as Larsen B, which was located on the eastern shore of the Antarctic Peninsula, the piece of Antarctica that extends northward toward Chile. Figure 7.5a (on page 170) is a satellite image of Larsen B at the end of January 2002. The map overlay shows that the area is a bay covered by solid ice that is about the size of the state of Connecticut. (On fast roads, one can drive across Connecticut, about 120 miles, in about two hours.)

Thirty-five days later, on March 5, 2002, a new satellite image showed that Larsen B was gone (Fig. 7.5b, page 170). It had been there for thousands of years. What remained was a collection of icebergs, some about as large as Hartford, the capital of Connecticut. The breakup of the ice shelf opened an area of more than 1,200 square miles, nearly the size of Rhode Island. It was the largest ever seen over such a short time. It is one of the most dramatic manifestations of climate change observed so far.

On the other side of the world, the North Pole has seen a rapid retreat of the ice-covered area of the sea (Fig. 7.6, on page 171)—far larger in extent than Larsen B—in the last decades of the twentieth century. This retreat is unfolding over decades instead of a month. The loss of sea ice affects polar bears, which use the ice cap as hunting habitat. In the United States, polar bears have been listed as threatened under the Endangered Species Act, although it is not yet clear what that status will mean in practical terms. A study of a range of climate models projects that polar sea ice will vanish entirely in the summer by 2100. There is now sometimes open water at the pole. The last time open water appeared there regularly was before the last Ice Age, tens of thousands of years ago.

With such dramatic effects stemming from a well-understood response of nature to human activities, one would think the case for action is clear. It is. The problem is that the kind of action needed sounds drastic, because the world economy as it is currently structured is premised on access to cheap fossil fuels.