Global Climate—Past, Present, and Future

We all experience and deal with weather on a daily basis—sun and clouds, wind, rain, snow—and that weather can vary considerably from day to day or even hour to hour. *Climate* is, in a sense, weather averaged over long periods of time; it is less variable on a human timescale. Both weather fluctuations and regional climate can affect the operation or intensity of the surface processes examined in the previously, and thus the impact they have on human activities. While we can’t do much about a day’s weather, it has become increasingly evident that humans can influence climate on a regional or global scale.

Major Controls on Global Climate;
The Greenhouse Effect

Climate is the result of the interplay of a number of factors. The main source of energy input to the earth is sunlight, which warms the land surface, which, in turn, radiates heat into the atmosphere. Globally, how much surface heating occurs is related to the sun’s energy output and how much of the sunlight falling on earth actually reaches the surface. Incoming sunlight may be blocked by cloud cover or, by dust and sulfuric acid droplets from volcanic eruptions. In turn, heat (infrared rays) radiating outward from earth’s surface may or may not be trapped by certain atmospheric gases, a phenomenon known as the **greenhouse effect.** In the atmosphere, molecules of various gases, especially water vapor and carbon dioxide, act similarly to the greenhouse’s glass. Light reaches the earth’s surface, warming it, and the earth radiates infrared rays back. But the longer-wavelength infrared rays are trapped by these gas molecules, and a portion of the radiated heat is thus trapped in the atmosphere. Hence the term “greenhouse effect.” (figure 10.1 .) As a result of the greenhouse effect, the atmosphere stays warmer than it would if that heat radiated freely back out into space. In moderation, the greenhouse effect makes life as we know it possible: without it, average global temperature would be closer to -17°C (about 1°F) than the roughly 15°C (59°F) it now is. However, one can have too much of a good thing.

The evolution of a technological society has meant rapidly increasing energy consumption. Historically, we have relied most heavily on carbon-rich fuels—wood, coal, oil, and natural gas—to supply that energy. These probably will continue to be important energy sources for several decades at least. One combustion by-product that all of these fuels have in common is carbon dioxide gas (CO_2).

A “greenhouse gas” in general is any gas that traps infrared rays and thus promotes atmospheric warming. Water vapor is, in fact, the most abundant greenhouse gas in the earth's atmosphere, but human activities do not substantially affect its abundance, and it is in equilibrium with surface water and oceans. Excess water in the atmosphere readily falls out as rain or snow. Some of the excess carbon dioxide is removed by geologic processes, but since the start of the so called Industrial Age in the mid-nineteenth century, the amount of carbon dioxide in the air has increased by an estimated 40% and its concentration continues to climb (fi gure 10.2). If the heat trapped by carbon dioxide were proportional to the concentration of carbon dioxide in the air, the increased carbon dioxide would by now have caused sharply increased greenhouse- effect heating of the earth's atmosphere.

Climate and Ice Reserves

Early discussions of climate change related to increasing greenhouse-gas concentrations in the atmosphere tended to focus heavily on the prospect of global warming and the resultant melting of earth's reserves of ice, especially the remaining ice sheets. If *all* the ice melted, sea level could rise by over 75 meters from the added water alone. About 20% of the world's land area would be submerged. Many millions, perhaps billions, of people now living in coastal or low-lying areas would be displaced, since a large fraction of major population centers grew up along coastlines and rivers. (The Statue of Liberty would be up to her neck in water). Also, raising of the base levels of streams draining into the ocean would alter the stream channels and could cause significant flooding along major rivers, and this would not require nearly such drastic sea-level rise.

Such large-scale melting of ice sheets would take time, perhaps several thousand years. On a shorter timescale, the problem could still be significant. Continued intensive fossil-fuel use could double the level of carbon dioxide in the atmosphere before the middle of this century. This would produce a projected temperature rise of 4° to 8°C (7°–14°F), which would be sufficient to melt at least the West Antarctic ice sheet completely in a few hundred years. The resulting 5- 6 meter rise in sea level, would nevertheless be enough to flood many coastal cities and ports, along with most of the world's beaches. This would be both inconvenient and extremely expensive. Meanwhile, the smaller alpine glaciers are clearly dwindling.

Arctic polar ice is also shrinking, in both area and thickness. It is particularly vulnerable because, instead of sitting on long-chilled rock, it floats on the circulating, warming ocean.

Oceans and Climate

One reason that there is no simple correlation between atmospheric greenhouse-gas concentrations and land surface temperatures is the oceans. That huge volume of water represents a much larger thermal reservoir than the tenuous atmosphere.

Coastal regions may have relatively mild climates for this reason:

As air temperatures drop in winter, the ocean is there to release some heat to the atmosphere; as air warms in summer, the ocean water absorbs some of the heat. The oceans store and transport a tremendous amount of heat around the globe.

Recent studies of the balance between the energy received from the sun and the energy radiated back into space have confirmed a net excess of energy absorbed, an average of 0.85 watts per square meter per year. Such a rate of energy absorption, maintained for a thousand years, could melt enough ice to raise sea level by a hundred meters, or raise the temperature of the ocean's surface-water layer by 10°C (nearly 20°F). Moreover, much of this absorbed energy is, for now, being stored in the oceans. So it has not yet been reflected by measured global temperature increases?

El Nin˜o

Most of the vigorous circulation of the oceans is confined to the near-surface waters. Only the shallowest waters, within 100 to 200 meters of the surface, are well mixed by waves, currents, and winds, and warmed and lighted by the sun. The average temperature of this layer is about 15°C (60°F).

Below the surface layer, temperatures decrease rapidly to about 5°C (40°F) at 500 to 1000 meters below the surface. Below this is the so-called *deep layer* of cold, slow-moving, rather isolated water. The temperature of this bottom most water is close to freezing and may even be slightly below freezing (the water is prevented from freezing solid by its dissolved salt content and high pressure). This cold, deep layer originates largely in the polar regions and flows very slowly toward the equator.

When winds blow offshore, they push the warm surface waters away from the coastline also. This, in turn, creates a region of low pressure and may result in *upwelling* of deep waters to replace the displaced surface waters (figure 10.13). The deeper waters are relatively enriched in dissolved nutrients, in part because few organisms live in the cold, dark depths to consume those nutrients. When the nutrient-laden waters rise into the warm, sunlit zone near the surface, they can support abundant plant life and, in turn, animal life that feeds on the plants. Many rich fishing grounds are located in zones of coastal upwelling.

Other Aspects of Global Change

It is very important to bear in mind, that “global” climate changes do not affect all parts of the world equally or in the same ways.

There are consequences for ice amount and distribution, oceanic circulation, patterns of storms, and more, as will be explored below.

*Changes in wind-flow patterns and amounts and distribution of precipitation will cause differential impacts in different areas, not all of which will be equally resilient. A region of temperate climate and ample rainfall may not be seriously harmed by a temperature change of a few degrees, or several inches more or less rainfall. A modest temperature rise in colder areas may actually increase plant vigor and the length of the growing season, and some dry areas may enjoy increased productivity with increased rainfall.

*Warming and moisture redistribution also have potential downsides. we noted the impact of the loss of alpine glaciers on water supplies. In many parts of the world, agriculture is already only marginally possible because of hot climate and little rain. A temperature rise of only a few degrees, or loss of a few inches of rain a year, could easily make living and farming in these areas impossible. Recent projections suggest that summer soil-moisture levels in the Northern Hemisphere could drop by up to 40% with a doubling in atmospheric CO_2.

*It has been argued that rising CO_2 levels should be beneficial in promoting plant growth. After all, photosynthesis involves using CO_2 and water and solar energy to manufacture more complex compounds and build the plant’s structure. However, controlled experiments have shown that not all types of plants grow significantly more vigorously given higher CO_2 concentrations in their air, and even those that do may show enhanced growth only for a limited period of time, not indefinitely. Moreover, the productivity of phytoplankton (microscopic plants) in the warming oceans has shown sharp declines. The reason may be that as the surface water warms and becomes less dense, the warm-water layer becomes more firmly stabilized at the surface, suppressing upwelling of the nutrient-rich cold water below over much of the ocean and mixing of the cold and warm waters. The effect is like that of El Nino, but much more widely distributed. Because some whales and fish depend on the phytoplankton for food, a decline in phytoplankton will have repercussions for those populations also, as well as for humans who may consume larger fish in that food web.

*Agriculture aside, places where temperature or moisture conditions already make living marginal are especially vulnerable to small increases in temperature or decreases in rainfall and soil moisture. There is reason to believe that global warming may produce more extremes—catastrophic flooding from torrential storms, devastating droughts, “killer heat waves” like that costing hundreds of lives in Chicago in 1995, and the combination of heat and drought that led to deadly wildfires in southern Australia in early 2009.
*Because of the many variables involved and the complexity of the calculations, global-climate computer models must also limit the resolution at which effects are calculated. Typical models operate on areal units, or cells, that are hundreds of kilometers on a side, meaning that small local climatic anomalies may be missed. It can therefore be difficult to anticipate the effects of global climate change at the local level.
*Public-health professionals have identified yet another threat related to global change. Climate influences the occurrence and distribution of a number of diseases. Mosquito borne diseases, such as malaria and dengue, will be influenced by conditions that broaden or reduce the range of their particular carrier species; the incidence of both has increased in recent years and is currently expected to expand further. Waterborne parasites and bacteria can grow in areas of increased rainfall. Efforts to anticipate, and plan responses to, the climate-enhanced spread of disease are growing.
*United Nations studies further suggest that less-developed nations, with fewer resources, may be much less able to cope with the stresses of climate change. Yet many of these nations are suffering the most immediate impacts: The very existence of some low-lying Pacific island nations is threatened by sea-level rise; reduced soil moisture and higher temperature quickly affect the world’s “drylands,” where many poorer countries are located; the tropical diseases are spreading most obviously in the Third World where medical care is limited. This differential impact may have implications for global political stability as well.

Evidence of Climates Past

An understanding of past climatic fluctuations is helpful in developing models of possible future climate change. A special challenge in reconstructing past climate is that we do not have direct measurements of ancient temperatures. These must be determined indirectly using various methods, sometimes described as “proxies” for direct temperature records.

Aspects of local climate may often be deduced from the geologic record, especially the sedimentary-rock record. For example, the now-vegetated dunes of the Nebraska Sand Hills are remnants of an arid “sand sea” in the region 18,000 years ago, when conditions must have been much drier than they are now. Much of North Africa was fertile, wheat growing land in the time of the Roman Empire; small reductions in rainfall, and the resultant crop failures, may have contributed to the Empire’s fall.
We have noted that glacial deposits may be recognized in now-tropical regions, and this was part of the evidence for continental drift/plate tectonics. In addition, when such deposits are widespread globally, they indicate an ice age. Conversely, widespread coal deposits indicate warm, wet conditions, conducive to plant growth, perhaps in a swampy setting. Distinctively warm- or cold-climate animals and plants identified in the fossil record likewise provide evidence of the local environmental conditions at the time they lived. Other proxies involve the chemistry of sediments, seawater, or snow and ice. For example, from marine sediments comes evidence of ocean-temperature variations. The proportion of calcium carbonate (CaCO3) in Pacific Ocean sediments in a general way reflects water temperature, because the solubility of calcium carbonate is strongly temperature-related: it is more soluble in cold water than in warm.
A particularly powerful tool involves variations in the proportions of oxygen isotopes in geological materials. By far the most abundant oxygen isotope in nature is oxygen-16 (16O); the heaviest is oxygen-18 (18O). Because they differ in mass, so do molecules containing them, and the effect is especially pronounced when oxygen makes up most of the mass, as in H2O.
Certain natural processes, including evaporation and precipitation, produce fractionation between 16O and 18O, meaning that the relative abundances of the two isotopes will differ between two substances, such as ice and water, or water and water vapor.
As water evaporates, the lighter H2 16O evaporates preferentially, and the water vapor will then be isotopically “lighter” (richer in 16O, poorer in 18O) than the residual water. Conversely, as rain or snow condenses and falls, the precipitation will be relatively enriched in the heavier H218O. As water vapor evaporated from equatorial oceans drifts toward the poles, depositing H218O-enriched precipitation, the remaining water vapor becomes progressively lighter isotopically, and so does subsequent precipitation; snow falling near the poles has a much lower 18O/16O ratio than tropical rain, or seawater .
The fractionation between 18O and 16O in coexisting water vapor and rain or snow is temperature-dependent, more pronounced at lower temperatures. Therefore, at a given latitude, variations in the 18O/16O

ratio of precipitation reflect variations in temperature. (Similarly, oxygen isotopes fractionate between water and minerals precipitated from it. This fractionation, is temperature-dependent). Thus, variations in the 18O/16O ratio in the oxygen-rich carbonate [CaCO3] or silica [SiO2] skeletons of marine microorganisms give evidence of variations in the temperature of the near-surface seawater from which these skeletons precipitated, and they have been used to track past El Nino cycles.)

The longevity of the massive continental glaciers sometimes hundreds of thousands of years makes them useful in preserving evidence of both air temperature and atmospheric composition in the past. Tiny bubbles of contemporary air may be trapped as the snow is converted to dense glacial ice. The oxygen-isotope composition of the ice reflects seawater O-isotope composition and the air temperature at the time the parent snow fell. If those temperatures can be correlated with other evidence, such as the carbon-dioxide content of the air bubbles or the presence of volcanic ash layers in the ice from prehistoric explosive eruptions, much information can be gained about possible causes of past climatic variability and the climate-prediction models may be refined accordingly.

Questions for Review

1. Explain the greenhouse effect and its relationship to modern industrialized society.
2. What is an El Nino event? What is its apparent significance to climate and to the productivity of coastal fishing grounds? Explain.
3. How is global warming related to the spread of certain diseases?
4. Water vapor and methane are both greenhouse gases. Why is the focus so often on carbon dioxide instead?

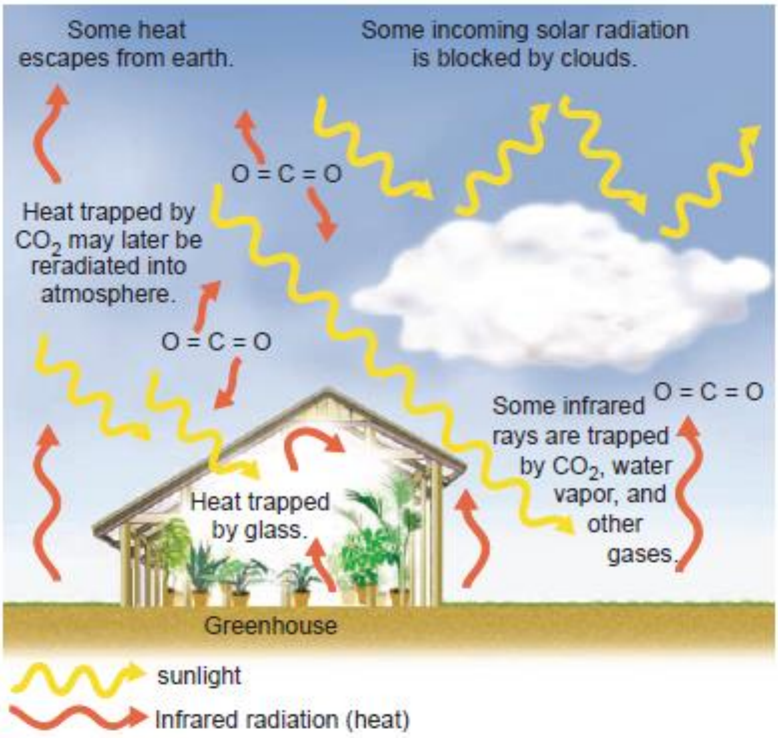

Figure 10.1

The "greenhouse effect" (schematic). Both glass and air are transparent to visible light. Like greenhouse glass, CO_2 and other "greenhouse gases" in the atmosphere trap infrared rays radiating back from the sun-warmed surface of the earth.

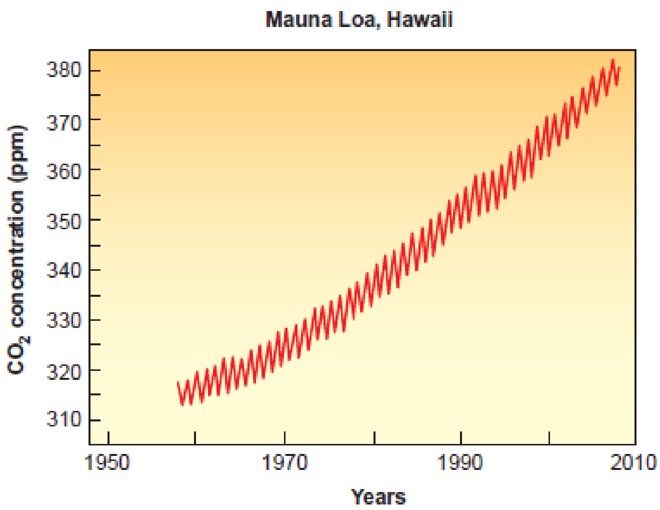

Figure 10.2

Rise in atmospheric CO_2 over past several decades is clear. (Zigzag pattern reflects seasonal variations in local uptake by plants.) Preindustrial levels in ice cores were about 280 ppm (parts per million). One ppm is 0.0001%.

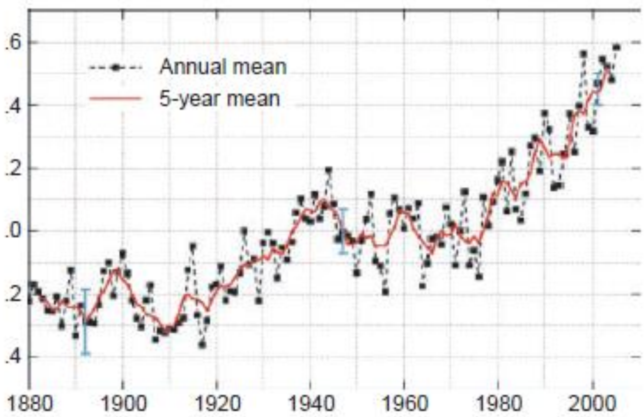

Figure 10.3

Global temperature rise emerges from background noise; blue bars indicate uncertainties. (Vertical axis measures temperature deviation, in °C, from 1951–1980 average.)

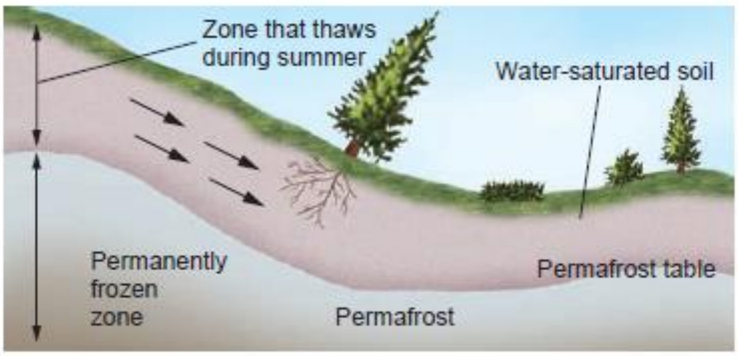

Figure 10.9

In cold climates, a permanently frozen soil zone, permafrost, may be found beneath the land surface.

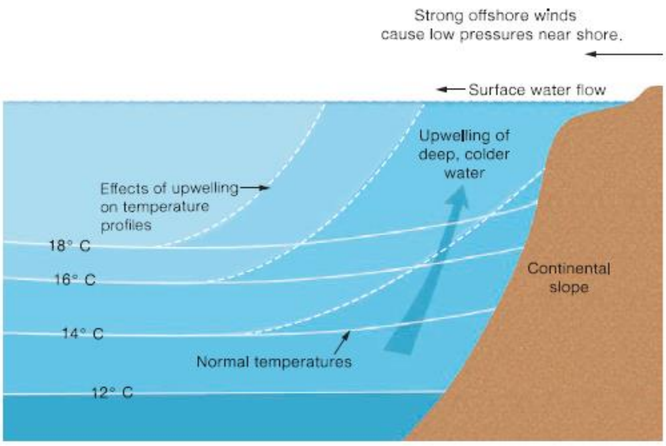

Figure 10.13

Warm surface water normally overlies colder seawater at depth. When offshore winds blow warm waters away from the South American shore and create local low pressure, upwelling of colder deep waters may occur (dashed lines). During an El Niño episode, the winds die down, and upwelling is suppressed (solid lines), so warm surface waters extend to the coast.

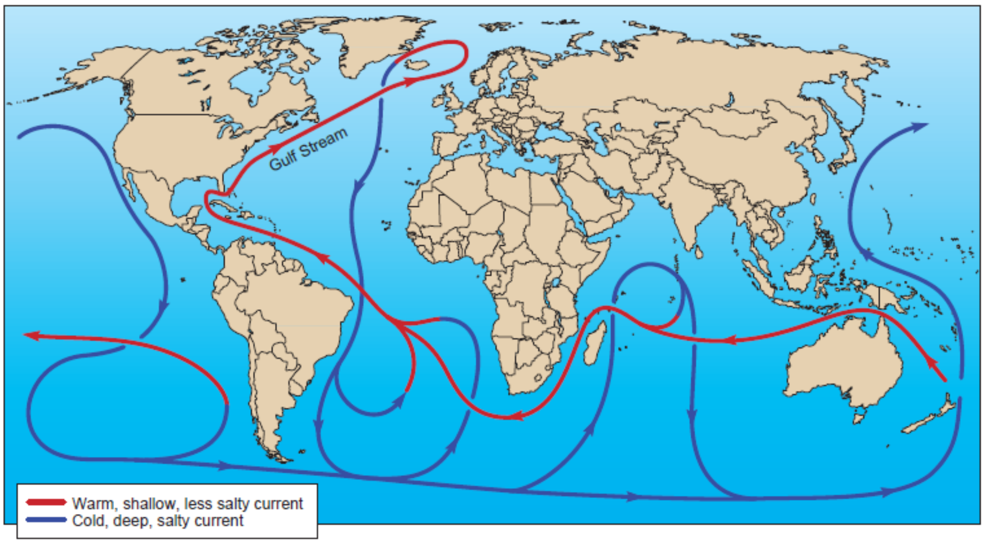

Figure 10.12

The thermohaline circulation, moving water—and thus heat—around the globe.

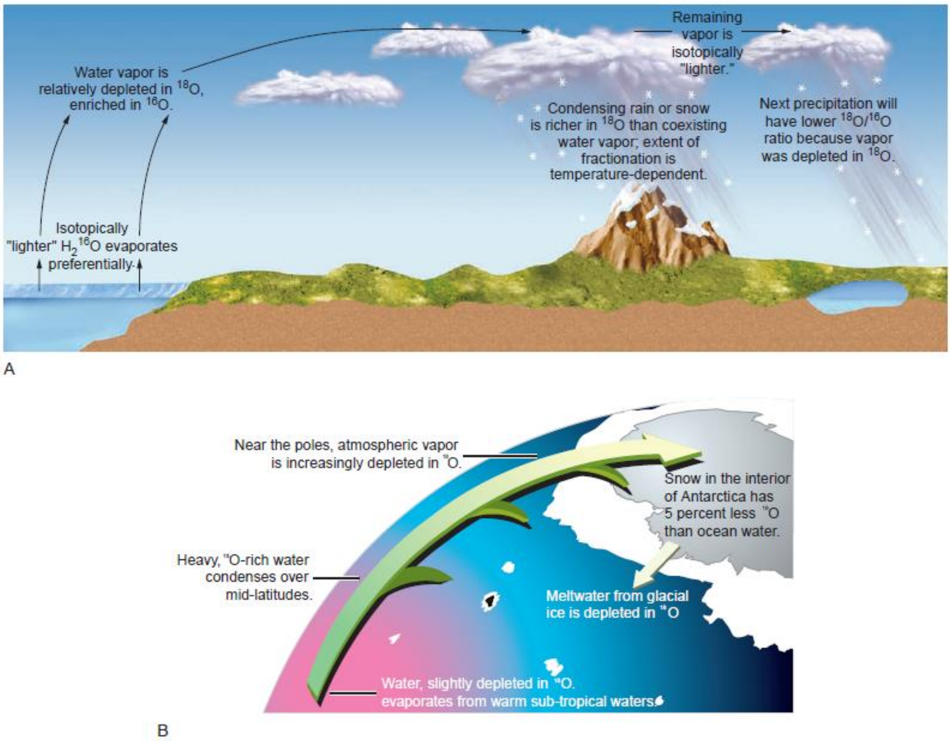

Figure 10.22

(A) Mass differences between ^{18}O and ^{16}O lead to different ^{18}O/^{16}O ratios in coexisting water and water vapor; the size of the difference is a function of temperature. (B) As the water vapor evaporated near the equator moves poleward and rain and snow precipitate, the remaining water vapor becomes isotopically lighter.