GLOBAL EDITION

Introduction to Geography

People, Places & Environment

SIXTH EDITION

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ALWAYS LEARNING

PEARSON

Introduction to Geography

People, Places & Environment

▲ **Figure 4-8 Deforestation in Brazil.** Land is being cleared for both crops and grazing; on the right is a large soybean field.

Amazon Deforestation

excess precipitation that is not evapotranspired runs off to the Atlantic Ocean via the Amazon River, which has the world's greatest discharge. The Atlantic is the original source of water that falls as precipitation on the Amazon Basin. This recycling presents a fine example of the hydrologic cycle at work.

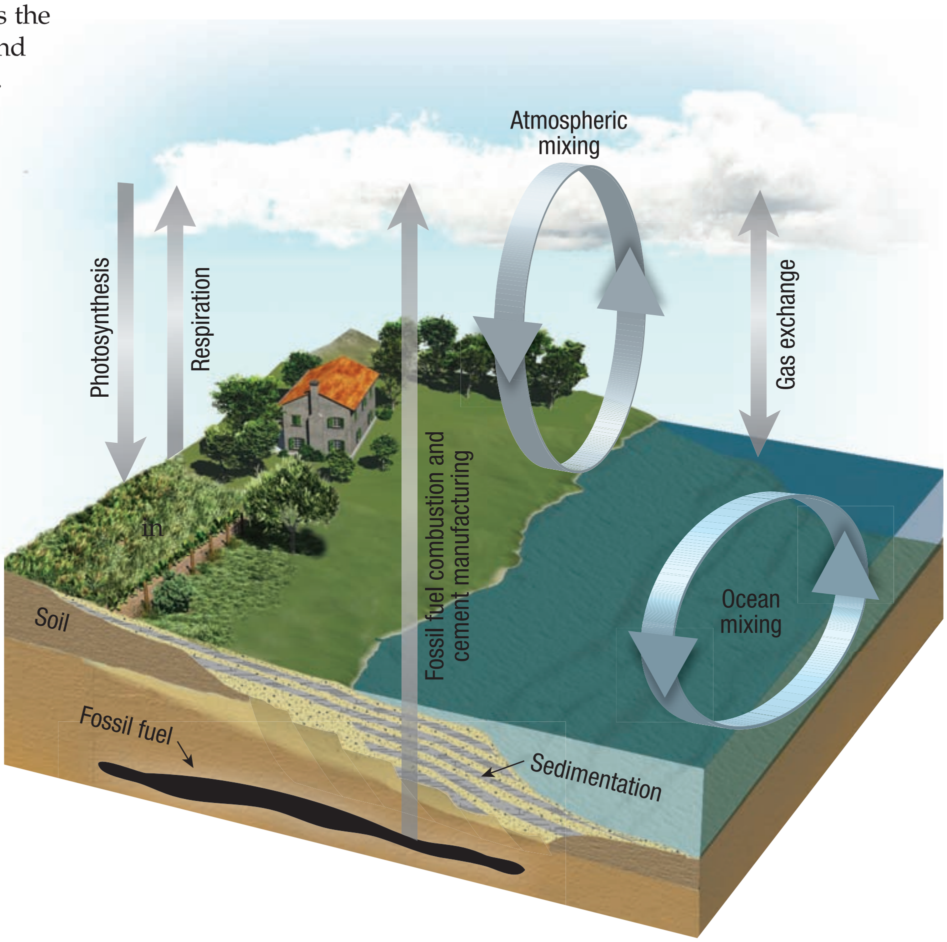
The Amazon Basin's interior, however, is more than 2,000 kilometers (1,200 miles) from the Atlantic, and most of the atmospheric water falls closer to the coast. This precipitated water infiltrates the soil, trees transpire it back into the air, and easterly winds carry it further inland. This cycle repeats, moving water step by step westward. Thus, rainfall in the Amazon Basin's interior already may have been precipitated and transpired several times in its westward journey.

Forests clearly are integral to the hydrologic cycle. If we continue to cut very large areas of forests and if the grasses that replace the trees transpire much less than the trees would, precipitation in the interior could be reduced. Such precipitation changes so far are only predictions computer models, but they help to show the important role that vegetation plays in the hydrologic cycle.

Carbon, Oxygen, and Nutrient Flows in the Biosphere

Carbon is not the most abundant element on Earth, but in combination with hydrogen, it is the most important for sustaining life. Compounds of carbon and hydrogen are the major component of the foods that plants produce and animals consume, and of the fossil fuels (coal, oil, natural gas) that are our most important sources of power. Living things constantly exchange carbon with the environment by photosynthesis, respiration, eating, and disposal of waste.

Exchanges of carbon among the biosphere, atmosphere, oceans, and rocks are collectively called the *carbon cycle* (Figure 4-9). An oxygen cycle is inextricably linked with the carbon cycle, and we will consider them together.



► **Figure 4-9 The carbon cycle.** Carbon is taken from the atmosphere and stored in biomass through photosynthesis. It is returned to the atmosphere through respiration. Combustion of fossil fuels and manufacture of cement release vast quantities of carbon to the atmosphere from long-term storage in rocks. Large quantities are also exchanged between the biosphere and atmosphere via photosynthesis and respiration, and between the atmosphere and oceans via gas exchange.

Global Carbon Uptake by Plants

The Carbon and Oxygen Cycles

In the **carbon cycle**, carbon in the form of atmospheric carbon dioxide (CO_2) is incorporated into carbohydrates in plant tissues through photosynthesis. Animals consume plants and use the plant carbohydrates for their own life processes. Through respiration, which occurs in almost all living organisms, carbon is returned to the atmosphere (as CO_2). Carbon dioxide is also added to the atmosphere by the combustion of fossil fuels. Thus, these three processes—photosynthesis, respiration, and combustion—cycle carbon and oxygen back and forth between living things and the environment.

Photosynthesis can be shown by the following equation:

carbon dioxide + water + energy → carbohydrates + oxygen

For this reaction, land plants obtain carbon dioxide from the air, water from the soil, and energy from solar radiation. They store carbohydrates in tissue for later use and release oxygen to the atmosphere. Plants are the source of atmospheric oxygen, without which animals could not exist.

Respiration involves the opposite reaction to photosynthesis:

carbohydrates + oxygen → carbon dioxide + water + energy (heat)

In respiration, carbohydrates are broken down when they combine with atmospheric oxygen to carbon dioxide and water. Energy is released in the process. Some of this energy is lost as heat and some is stored in chemical compounds for later use in other life processes.

The lithosphere is a major storehouse of carbon. Through geologic time, carbon enters the lithosphere slowly through rock formation, principally from oceanic sediments such as limestone but also through creation of fossil fuels such as coal.

The spatial and temporal distribution of photosynthesis is determined mostly by climate (Figure 4-10). Seasonal cycles of solar radiation are reflected directly in the carbon dioxide content of the atmosphere. The air we breathe has been monitored for carbon dioxide concentration since the late 1950s at the Mauna Loa observatory in Hawaii (Figure 4-11).

- Carbon dioxide varies annually with the seasons by a few parts per million. The greatest carbon dioxide concentrations in the Northern Hemisphere are during spring, because during winter, photosynthesis is reduced while respiration continues, returning carbon dioxide to the atmosphere.
- The lowest carbon dioxide concentrations are during autumn. Carbon dioxide concentration drops during the summer because plants are actively photosynthesizing, removing carbon dioxide from the atmosphere and storing it in the biosphere.
- The Mauna Loa data also clearly reveal the steady increase in atmospheric carbon dioxide levels that results from fossil fuel consumption, and also from the manufacture of cement from limestone.

The extraction and combustion of coal, oil, and natural gas since the Industrial Revolution began in the late 1700s is a relatively new process affecting the carbon cycle. Rates of carbon released into the atmosphere through this process have increased steadily over the past 200 years, and they are expected to continue to increase at least well into the 21st century. The long-term carbon dioxide increase that is so evident in Figure 2-60 illustrates this increase. Uncertainty about future fossil fuel use makes it difficult to predict future atmospheric carbon dioxide concentrations.

Checkpoint: Carbon Dioxide Concentration

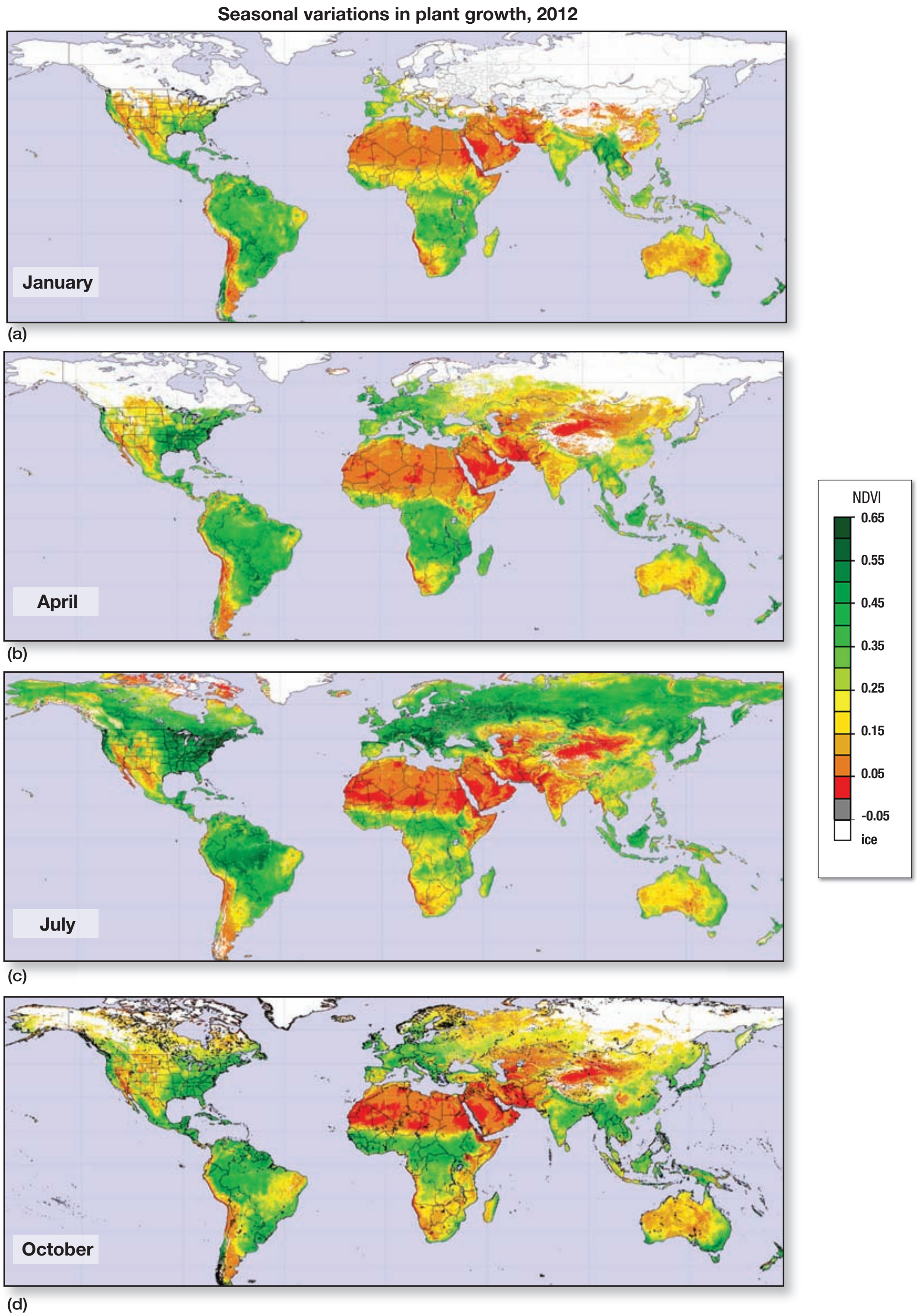
Explain why the carbon dioxide concentration at Mauna Loa is highest in April and lowest in November.

The Global Carbon Budget

Exchanges of carbon between the atmosphere and the biosphere and lithosphere are evident in the trend shown in Figure 4-11. Large amounts of carbon are also exchanged between the oceans and the atmosphere, as well as within various parts of the biosphere. Table 4-1 provides a summary of the major flows, along with an indication of the uncertainties surrounding our knowledge. The values shown in the table are average annual values, so they do not include seasonal exchanges.

Over time, the total amount of carbon in the atmosphere increases. In the 1980s, the amount of the increase was about 3.3 gigatons (Gt) of carbon per year (a gigaton is a billion metric tons, or 1,015 grams), and by the period 2000–2010 it was about 4.1 Gt per year. This increase is caused primarily by fossil fuel combustion and cement manufacture, which totaled about 7.9 Gt per year in 2000–2010—much more than the rate of accumulation in the atmosphere.

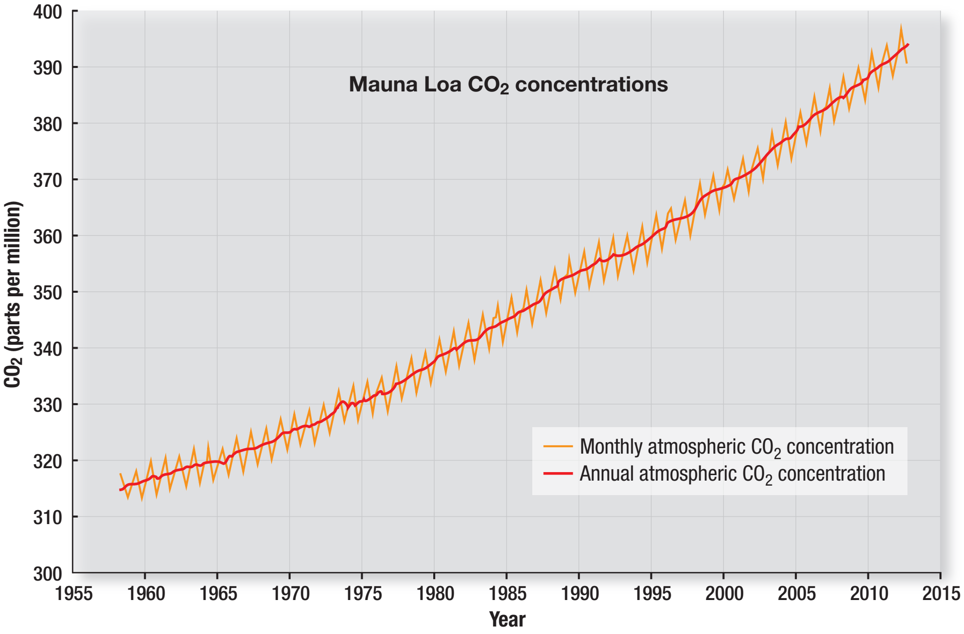
The amount of carbon accumulating in the atmosphere is less than our emissions because carbon is taken up by the land and oceans. The largest share of this uptake, about 2.3 Gt per year, occurs in the oceans. Ocean uptake is driven by the relative amounts of carbon dioxide in the atmosphere and oceans. Carbonated beverages illustrate this process. When they are made, carbon dioxide is added to the beverage either through the biological processes of fermentation under pressure or through direct injection of gaseous carbon dioxide into the beverage. When a pressurized carbonated beverage is opened, the gas is released back to the atmosphere in bubbles that rise to the surface. Humans have added large



▲ **Figure 4-10 Seasonal variations in plant growth.** Seasonal maps of the world, showing vegetation growth, in these images of a measurement derived from satellite data known as the Normalized Difference Vegetation Index (NDVI), green tones are growing vegetation, red indicates absence of vegetation growth, and white indicates snow cover.

amounts of carbon dioxide to the atmosphere in recent decades, raising the carbon dioxide pressure in the atmosphere. This causes the net flow to be from the atmosphere to the oceans. The carbon dioxide will not bubble out of the oceans, however, unless we somehow lower the carbon dioxide concentration of the atmosphere sometime in the future.

A second reason that accumulation of carbon in the atmosphere is less than our fossil emissions is that there is a substantial net flow from the atmosphere to the biosphere. Carbon constitutes a large part of **biomass**—living plant and animal matter in the biosphere. When forests are cut down, most of the carbon in the trees is released to the atmosphere, through



◀ **Figure 4-11 Atmospheric carbon dioxide concentrations measured at Mauna Loa, Hawaii.** Mauna Loa, located at 19.5° north latitude in the mid-Pacific Ocean, provides data that reflect general Northern Hemisphere conditions. The annual increase and decrease of carbon dioxide concentrations corresponds to seasonal patterns of plant growth and decay, with atmospheric concentrations decreasing in the Northern Hemisphere summer and increasing during the winter. The growth of atmospheric carbon dioxide slowed briefly in the early 1990s as a result of the collapse of the Soviet Union.

Carbon Dioxide Information Analysis Center

TABLE 4-1 The Global Carbon Budget

	1980s	1990s	2000–2010
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.2
Fossil carbon dioxide emissions	5.4 ± 0.3	6.4 ± 0.4	7.9 ± 0.5
Net ocean-to-atmosphere flux	–1.8 ± 0.8	–2.2 ± 0.4	–2.3 ± 0.5
Net land-to-atmosphere flux	–0.3 ± 0.9	–1.0 ± 0.6	–1.5 ± 1.7

Values are in gigatons (Gt; billions of metric tons) per year.
Sources: Data from IPCC and Global Carbon Project.

decomposition or perhaps fire. But when forests grow back, there is a net flow of carbon from the atmosphere to the biosphere, reducing atmospheric carbon dioxide and thus limiting global warming. In many parts of the world, especially the humid tropics, deforestation and urban development are reducing carbon storage in the biosphere and sending the carbon to the atmosphere (Figure 4-12). But in other areas, such as the eastern United States, forest area is actually increasing, and young forests are growing, storing carbon in the process. Similarly, when undeveloped lands are first converted to agriculture there is usually a loss of organic matter and thus carbon from the soil, but later that carbon can be replaced if the soils are allowed to recover. At present, the available evidence indicates that the net balance of all these land use–related exchanges is a transfer of carbon from the atmosphere to the biosphere, but as you can see by the ranges of estimates shown in Table 4-1, there is considerable uncertainty.

The carbon cycle is affected by many different aspects of human activity, including agricultural management practices, production and recycling of paper and other materials made from biomass, our choices with regard to energy production and conservation, and the way we manage water resources. (see *Rapid Change:* "Geography, Geographic Information Systems, and the Global Carbon Budget," p. 179).

Checkpoint: Vegetation and the Carbon Cycle

Describe the effect of a widespread reduction in vegetation on the carbon cycle.

Soil

The interface between the lithosphere and the biosphere/atmosphere is the soil. **Soil** is a dynamic, porous layer of mineral and organic matter in which plants grow. Soil is the uppermost part of the lithosphere, and at the same time is a key portion of the biosphere. Soil is a storage site for water, carbon, and plant nutrients.

Soil properties are attributable to five major factors:

1. *Climate* regulates both water movements and biological activity.
2. **Parent material** is the mineral matter from which soil is formed.
3. *Biological activity*—plants and animals—moves minerals and adds organic matter to the soil.
4. *Topography* affects water movement and erosion rates.
5. All these factors work over *time*, typically requiring many thousands of years to create a mature soil.

Soil Formation

The first step in soil formation is weathering, or the breakdown of rock into smaller particles and new chemical forms. Chapter 3 explained the two ways that rocks weather: mechanical weathering (such as ice expansion or tree roots growing in the cracks between rocks) and chemical weathering (such as


(a)


(b)

▲ **Figure 4-12 Land use change and carbon storage.** (a) Carbon is released to the atmosphere when forest is cleared for agriculture, as in this farm field in Brazil. (b) Abandonment of former agricultural land, as in this Massachusetts site with an aging stone wall field boundary, removes carbon from the atmosphere and returns it to the biosphere.

dissolving limestone in water in the soil). The parent material from which soil is formed is important because it influences soil's chemical and physical characteristics, especially in young soils.

Water plays an important role in rock weathering and soil formation. A water budget indicates how much water moves through the soil in a place and measures the significance of water in local weathering. For example, if mean annual precipitation is 100 centimeters (39 inches) and evapotranspiration is 70 centimeters (27 inches), then 30 centimeters (12 inches) of water would seep down through the soil in an average year. This water would be a powerful weathering agent. However, if an area has 70 centimeters of precipitation and the atmosphere is capable of evaporating 150 centimeters (59 inches) of water, virtually all water is evapotranspired by plants, so little would be left to percolate down through the soil to help weather the rocks.

In a very humid climate, much water passes through the soil and leaches out soluble minerals on its way. Because of this, soils in humid climates generally have lower amounts of soluble minerals such as sodium and calcium compared to soils in dry climates. However, in semiarid areas, water enters the soil and picks up soluble minerals, which are drawn toward the surface as water is evapotranspired. Soils of semiarid and arid climates often have a layer rich in calcium and other relatively soluble minerals near the surface.

Plant and animal activities are also critical to soil formation. Plants produce organic matter that accumulates on the soil surface, and animals redistribute this organic matter through the soil. Plants and animals also play a role in weathering processes. Topography also affects the amount of water present in the soil, largely through controlling drainage and erosion. Steeply sloping areas generally have better drainage than flat or low-lying areas, and they are often more eroded. Finally, soil formation is a slow process that takes place very gradually over thousands of years. Soils that have only been forming for a few hundred or even a few thousand years have very different characteristics from those that have been modified by chemical and biological processes for tens of thousands of years.

Checkpoint: Desertification

How can the process of desertification occur? Can it be reversed?

Soil Horizons

Soil is a complex medium, containing six principal components:

1. *Rocks* and *rock particles*, which constitute the greatest portion of the soil and may weather, releasing nutrients needed for plant growth.
2. *Organic matter*, which is composed of dead and decaying plant and animal remains that holds water, supports soil organisms, and supplies nutrients.
3. *Dissolved substances*, including phosphorus, potassium, calcium, and other nutrients needed for plant growth.
4. *Organisms*, including animals such as insects and worms and many microorganisms, including bacteria, and fungi.
5. *Water from rainfall*, which is necessary for plant growth and helps to distribute other substances through the soil.
6. *Air*, which shares soil pore spaces with water and is necessary for respiration by plant roots and soil organisms.

These substances are not uniformly distributed in soils but found in layers called **soil horizons** (Figure 4-13). Soil horizons are formed through the vertical movement of water, minerals, and organic matter in the soil and also by variations in biological

RAPID CHANGE

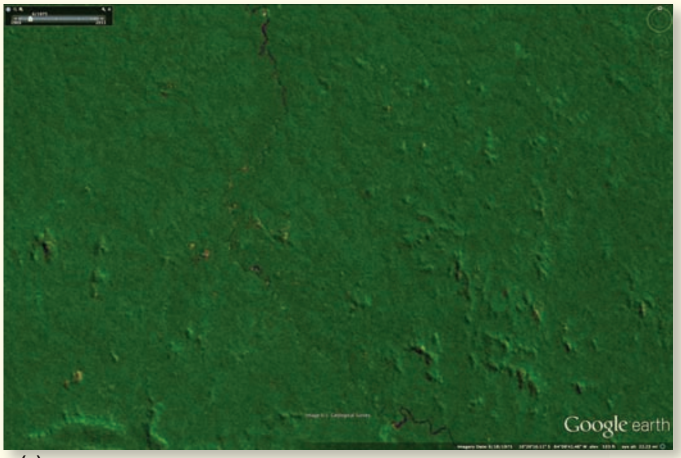
Geography, Geographic Information Systems, and the Global Carbon Budget

There is much that we do not understand about the global carbon budget. The parts of the budget that we do understand relatively well—the ones in Table 4-1 that have relatively small uncertainty terms—are the flows to the atmosphere from fossil fuels, the increase in atmospheric carbon dioxide concentration, and the movement of carbon dioxide from the atmosphere to the ocean. These flows are relatively easy to calculate based on readily available information on fossil fuel combustion, and measurements of carbon dioxide in the atmosphere and oceans.

THE ROLE OF VEGETATION AND SOILS The biggest uncertainties in the budget relate to exchanges between the atmosphere and ecosystems—vegetation and soils. These exchanges are affected by factors like rates of vegetation growth, or changing soil characteristics, which are extremely variable from place to place. Unlike atmospheric carbon dioxide concentration, we cannot just monitor a relatively small number of places and extrapolate to the rest of the Earth. Rather, we need much more sophisticated ways of monitoring conditions at thousands of individual locations, and combining those observations into a quantitative global summary.

THE ROLE OF GEOGRAPHERS Geographic approaches and geographic information systems (GISs) are essential to complicated environmental assessments such as this. Using satellite imagery and GIS, we can make detailed maps of land cover showing the spatial extent of each different kind of surface (such as Figure 1-35). Remotely sensed information on plant growth, estimated from information on the color of plants as seen from space, can tell us about uptake of atmospheric carbon dioxide in the biosphere (such as Figure 4-10). Ecological models, which are in many ways more complex than the highly sophisticated computer models used to predict the weather, can be used to estimate respiration that returns carbon to the atmosphere. Satellite imagery and GIS can measure changes in land cover associated with urban development, changing agricultural practices, or deforestation (Figure 4-1-1). These various information sources are then brought together in GISs to make estimates of global carbon fluxes between the atmosphere and biosphere, such as are included in Table 4-1.

Geography and geographers will continue to play a central role in this work. Geographers bring to the task a unique combination of understanding a broad range of factors that influence the carbon budget, and the technical skills to convert that broad understanding into useful quantitative information. The global carbon budget exemplifies a problem of central concern, to which geographers can play a key role in finding solutions.



(a)

(b)

◄ **Figure 4-1-1. Deforestation in Rondônia, Brazil.** Satellite images reveal land cover change between (a) June 1975; and (b) September 2011.