
# The Carbon Cycle of North America in a Global Context

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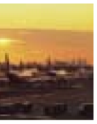
## KEY FINDINGS

- Human activity over the last two centuries, including combustion of fossil fuel and clearing of forests, has led to a dramatic increase in the concentration of atmospheric carbon dioxide. Global atmospheric carbon dioxide concentrations have risen by 31% since 1850 and are now higher than they have been for at least 420,000 years.
- North America is responsible for approximately 25% of the emissions produced globally in 2004 by fossil-fuel combustion, with the United States accounting for 86% of the North American total.
- Human-caused emissions (a carbon source) dominate the carbon budget of North America. Largely unmanaged, unintentional processes capture a fraction of this carbon in plants, soils, and other sinks. Currently, these sinks (970 ± 360 million metric tons of carbon (Mt C) per year, based on atmospheric inversion studies, or 530 ± 265 Mt C per year, based on the inventories used in this report) capture approximately 30-50% of the North American emissions, 7-13% of global fossil-fuel emissions, and 30-50% of the global terrestrial sink inferred from global budget analyses and atmospheric inversions.
- While the future trajectory of carbon sinks in North America is uncertain (substantial climate change could convert current sinks into sources), it is clear that the carbon cycle of the next few decades will be dominated by the large sources from fossil-fuel emissions.
- Because North American carbon emissions are at least a quarter of global emissions, a reduction in North American emissions would have global consequences.

## 2.1 THE GLOBAL CARBON CYCLE



The modern global carbon cycle is a collection of many different kinds of processes, with diverse drivers and dynamics, that transfer carbon among major pools in rocks, fossil fuels, the atmosphere, the oceans, and plants and soils on land (Sabine *et al.*, 2004b) (Figure 2.1). During the last two centuries, human actions, especially the combustion of fossil fuel and the clearing of forests, have altered the global carbon cycle in important ways. Specifically, these actions have led to a rapid, dramatic increase in the concentration of carbon dioxide ($CO_2$) in the atmosphere (Figure 2.2), changing the radiation balance of the Earth (Hansen *et al.*, 2005), and very likely causing much of the warming observed over the last 50 years (Hegerl et al., 2007). The cause of the recent increase in atmospheric $CO_2$ is confirmed beyond a reasonable doubt (Prentice, 2001). This does not imply, however, that the other components of the carbon cycle have remained unchanged during this period. In fact, the background, or unmanaged parts, of the carbon cycle have changed dramatically over the past two centuries. The consequence of these changes is that only about 40% ± 15%[1] of the $CO_2$ emitted to the atmosphere from fossil-fuel combustion and forest clearing has remained there (Sabine *et al.*, 2004b). In essence, human actions have received a large subsidy from the unmanaged parts of the carbon cycle. This subsidy has sequestered, or hidden from the atmosphere, approximately 279 ± 160 billion tons (gigatons [Gt]) of carbon[2].

[1] Most of the uncertainty in this number is due to the approximately 100% uncertainty in carbon lost from forest clearing. This includes uncertainties in areas deforested, in conditions at the time of deforestation, and in the fate following deforestation (Houghton, 1999). Except where otherwise noted, the uncertainty bounds on the numbers in this chapter are expert assessments by the authors of the cited literature, based on synthesizing a wide range of empirical and modeling studies. The details of the approaches to assessing uncertainty are discussed in the literature cited.

[2] Unless specified otherwise, throughout this chapter, the pools and fluxes in the carbon cycle are presented in Gt C [1 Gt = 1 billion tons or $1 \times 10^{15}$ g]. The mass of $CO_2$ is greater than the mass of carbon by the ratio of their molecular weights, 44/12 or 3.67 times; 1 km[3] of coal contains approximately 1 Gt C.

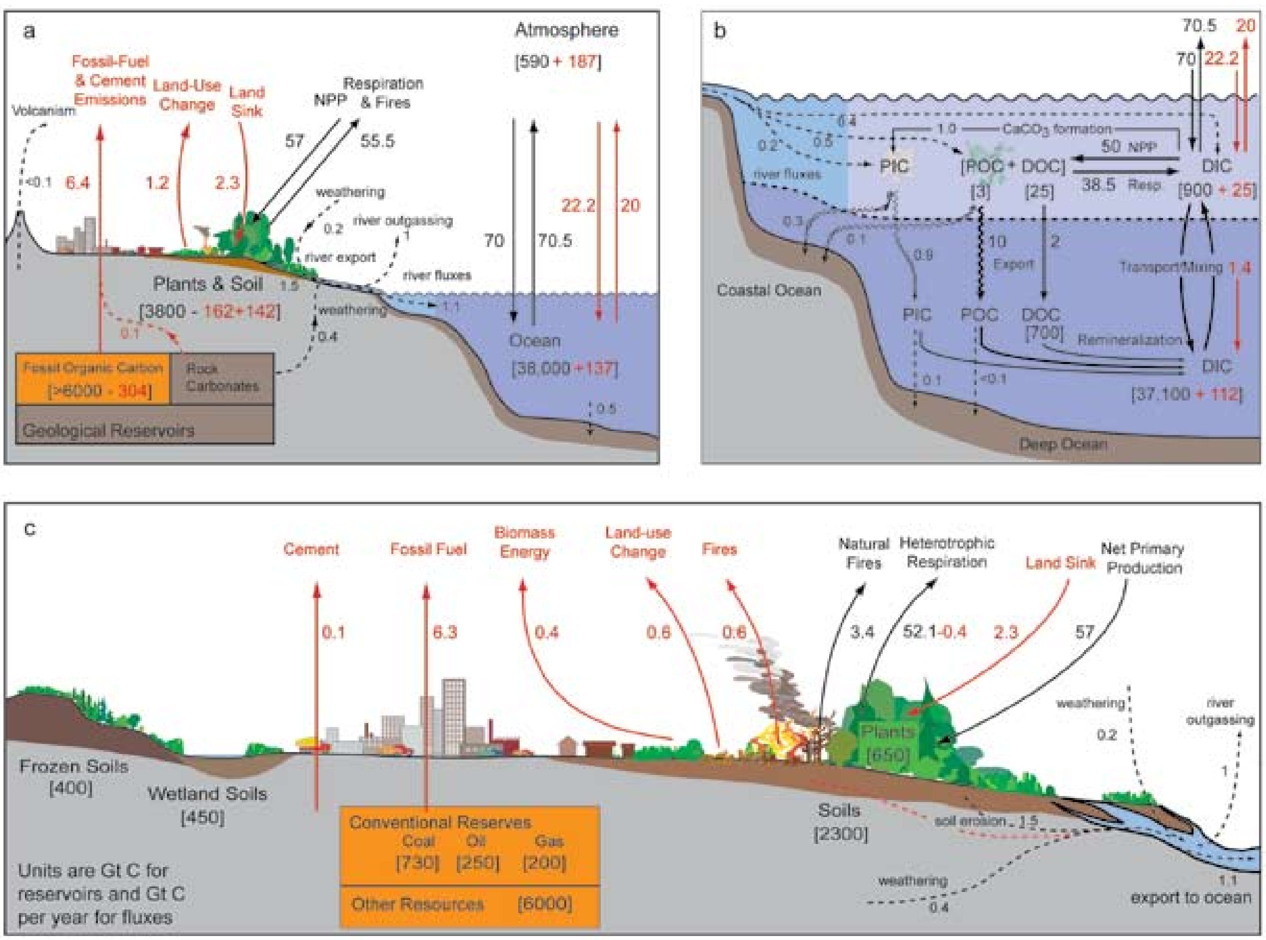



**Figure 2.1** Schematic representation of the components of the global carbon cycle. The three panels show (a) the overall cycle, (b) the details of the ocean cycle, and (c) the details of the land cycle. For all panels, carbon stocks are in brackets, and fluxes have no brackets. Stocks and fluxes prior to human-influence are in black. Human-induced perturbations are in red. For stocks, the human-induced perturbations are the cumulative total through 2003. H uman-caused fluxes are means for the 1990s (the most recent available data for some fluxes). Redrawn from Sabine *et al.* (2004b) with updates through 2003 as discussed in the text.

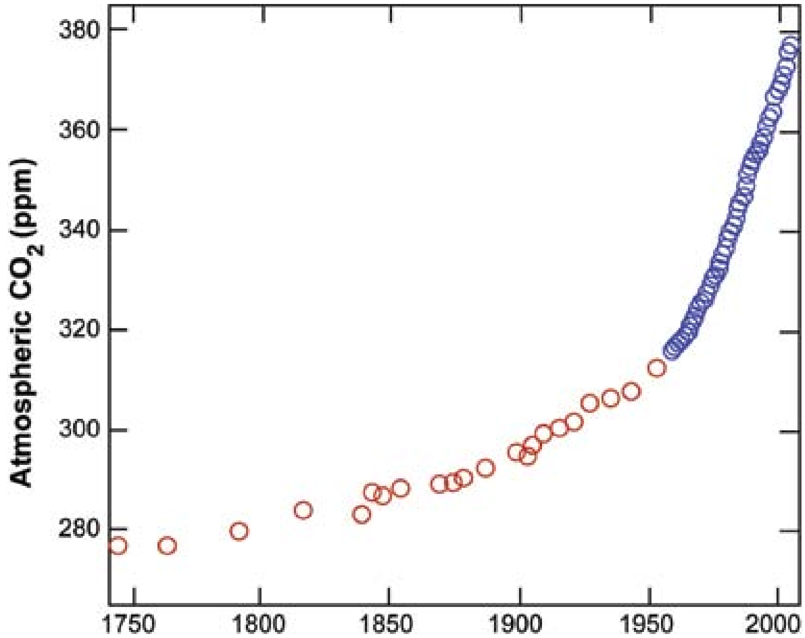



**Figure 2.2** Atmospheric $CO_2$ concentration from 1750 to 2005. The data prior to 1957 (red circles) are from the Siple ice core (Friedli et al., 1986). The data since 1957 (blue circles) are from continuous atmospheric sampling at the Mauna Loa Observatory (Hawaii) (Keeling *et al.*, 1976; Thoning *et al.*, 1989) (with updates available at http://cdiac.ornl.gov/trends/co2/sio-mlo.htm).

The recent subsidy, or sequestration, of carbon by the unmanaged parts of the carbon cycle, makes them critical for an accurate understanding of climate change. Future increases in carbon uptake in the unmanaged parts of the cycle could moderate the risks from climate change, while decreases or transitions from uptake to release could amplify the risks, perhaps dramatically.

In addition to its role in the climate, the carbon cycle intersects with a number of critical Earth system processes. Because plant growth is essentially the removal of $CO_2$ from the air through photosynthesis, agriculture and forestry contribute important fluxes. Wildfire is a major release of carbon from plants and soils to the atmosphere (Sabine *et al.*, 2004b). The increasing concentration of $CO_2$ in the atmosphere has already made the world's oceans more acid (Caldeira and Wickett, 2003). Future changes could dramatically alter the composition of ocean ecosystems (Feely *et al.*, 2004; Orr *et al.*, 2005).

### 2.1.1 The Unmanaged Global Carbon Cycle

The modern background, or unmanaged, carbon cycle includes the processes that occur in the absence of human actions. However, these processes are currently so altered by human influences on the carbon cycle that it is not appropriate to label them natural. This background part of the carbon cycle is dominated by two pairs of gigantic fluxes with annual uptake and release that are close to balanced (Sabine *et al.*, 2004b) (Figure 2.1). The first of these comprises the terrestrial carbon cycle: plant growth on land annually fixes about 57 ± 9 Gt of atmospheric carbon, approximately ten times the annual emission from fossil-fuel combustion, into carbohydrates. Respiration by land plants, animals, and microorganisms, which provides the energy for growth, activity, and reproduction, returns a slightly smaller amount to the atmosphere. Part of the difference between photosynthesis and respiration is burned in wildfires, and part is stored as plant material or soil organic carbon. The second comprises the ocean carbon cycle: about 92 Gt of atmospheric carbon dissolves annually in the oceans, and about 90 Gt per year moves from the oceans to the atmosphere (While the gross fluxes have a substantial uncertainty, the difference is known to within ± 0.2 Gt)[3]. These air-sea fluxes are driven by cycling within the oceans that governs exchanges between pools of dissolved $CO_2$, bicarbonate ($HCO_3$), carbonate ($CO_3$), organic matter, and calcium carbonate ($CaCO_3$).

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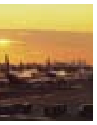
Before the beginning of the industrial revolution, carbon uptake and release through these two pairs of large fluxes were almost balanced, with carbon uptake on land of approximately 0.45 ± 0.18 Gt C per year transferred to the oceans by rivers and released from the oceans to the atmosphere (Jacobson *et al.*, 2007). As a consequence, the level of $CO_2$ in the atmosphere varied by less than 25 parts per million (ppm) in the 10,000 years prior to 1850 (Joos and Prentice, 2004). However, atmospheric $CO_2$ was not always so stable. During the preceding 420,000 years, atmospheric $CO_2$ was 180-200 ppm during the ice ages and approximately 275 ppm during interglacial periods (Petit *et al.*, 1999). The lower ice-age concentrations in the atmosphere most likely reflect a transfer of carbon from the atmosphere to the oceans, possibly driven by changes in ocean circulation and sea-ice cover (Sigman and Boyle, 2000; Keeling and Stephens, 2001). Enhanced biological activity in the oceans, stimulated by increased delivery of iron-rich terrestrial dust, may have also contributed to this increased uptake (Martin, 1990).

[3] This uncertainty is one-half the range among the subset of the 19 Ocean Carbon-Cycle Model Intercomparison Project (OCMIP) models that are consistent with the available $^{14}C$ and CFC-11 data (Matsumoto *et al.*, 2004).

*Per capita* emissions in the United States were nearly 5 times the world average, 2.5 times the *per capita* emissions for Western Europe, and more than 8 times the average for Asia and Oceania.



In the distant past, the global carbon cycle was out of balance in a different way. Fossil fuels are the product of prehistorically stored plant growth, especially 354 to 290 million years ago in the Carboniferous period. During this time, luxuriant plant growth and geological activity combined to bury a small fraction of each year's growth. Over millions of years, this gradual burial led to the accumulation of vast stocks of fossil fuel. The total accumulation of fossil fuels is uncertain, but probably in the range of 6000 ± 3000 Gt (Sabine *et al.*, 2004b). This burial of carbon also led to a near doubling of atmospheric oxygen (Falkowski *et al.*, 2005).

### 2.1.2 Human-induced Perturbations to the Carbon Cycle

Since the beginning of the industrial revolution, there has been a massive release of carbon from fossil-fuel combustion and deforestation. Cumulative carbon emissions from fossil-fuel combustion, natural gas flaring, and cement manufacturing from 1751 through 2003 are 304 ± 30 Gt (Marland and Rotty, 1984; Andres *et al.*, 1999)[4]. Land-use change from 1850 to 2003, mostly from forest clearing, added another 162±160 Gt (DeFries *et al.*, 1999; Houghton, 1999)[5]. The rate of fossil-fuel consumption in any recent year would have required, for its production, more than 400 times the current global primary production (total plant growth) of the land and oceans combined (Dukes, 2003). This has led to a rapid increase in the concentration of $CO_2$ in the atmosphere since the mid-1800s, with atmospheric $CO_2$ rising by 31% (*i.e.*, from 287 ppm to 375 ppm in 2003; the increase from the mid-1700s was 35%).

In 2004, the three major countries of North America (Canada, Mexico, and the United States) together accounted for carbon emissions from fossil-fuel combustion of approximately 1.88 ± 0.2 Gt C, (about 25%) of the global total[6]. The United States, the world's largest emitter of $CO_2$, was responsible for 86% of the North American total. *Per capita* emissions in 2004 were 5.5 ± 0.5 metric tons in the United States, 4.9 ± 0.5 metric tons in Canada, and 1.0 ± 0.1 metric tons in Mexico. *Per capita* emissions in the United States were nearly 5 times the world average, 2.5 times the *per capita* emissions for Western Europe, and more than 8 times the average for Asia and Oceania (DOE EIA, 2006). The world's largest countries, China and India, have total carbon emissions from fossil-fuel combustion and the flaring of natural gas that are growing rapidly. The 2004 total for China was 80% of that in the United States, and the total for India was 18% of that in the United States. *Per capita* emissions for China and India in 2004 were 18% and 5%, respectively, of the United States rate (DOE EIA, 2006).

## 2.2 ASSESSING GLOBAL AND REGIONAL CARBON BUDGETS

Changes in the carbon content of the oceans and plants and soils on land can be evaluated with at least five different approaches—flux measurements, inventories, inverse estimates based on atmospheric $CO_2$, process models, and calculation as a residual. The first method, direct measurement of carbon flux, is well developed over land for measurements over the spatial scale of up to 1 $km^2$, using the eddy flux technique (Wofsy *et al.*, 1993; Baldocchi and Valentini, 2004). Although eddy flux measurements are now collected at more than 100 networked sites, spatial scaling presents formidable challenges due to spatial heterogeneity. To date, estimates of continental-scale fluxes based on eddy flux must be regarded as preliminary. Over the oceans, eddy flux is possible (McGillis, 2001), but estimates based on air-sea $CO_2$ concentration difference are more widely used (Takahashi *et al.*, 1997).

Inventories, based on measuring trees on land (Birdsey and Heath, 1995) or carbon in ocean-water samples (Takahashi *et al.*, 2002; Sabine *et al.*, 2004a) can provide useful constraints on changes in the size of carbon pools, though their utility for quantifying short-term changes is limited. Inventories were the foundation of the recent conclusion that 118 ± 19 Gt of human-caused carbon entered the oceans through 1994 (Sabine *et al.*, 2004a) and that forests in the mid latitudes of the Northern Hemisphere absorbed and stored 0.6 to 0.7 Gt C per year in the 1990s (Goodale *et al.*, 2002). Changes in the atmospheric inventory of oxygen ($O_2$) (Keeling *et al.*, 1996) and carbon-13 ($^{13}C$) in $CO_2$ (Siegenthaler and Oeschger, 1987) provide a basis for partitioning $CO_2$ flux into land and ocean components.

Process models and inverse estimates based on atmospheric $CO_2$ (or $CO_2$ in combination with $^{13}C$ or $O_2$) also provide use-

[4] Updates through 2003 available at http://cdiac.ornl.gov/trends/mis/tre_glob.html.

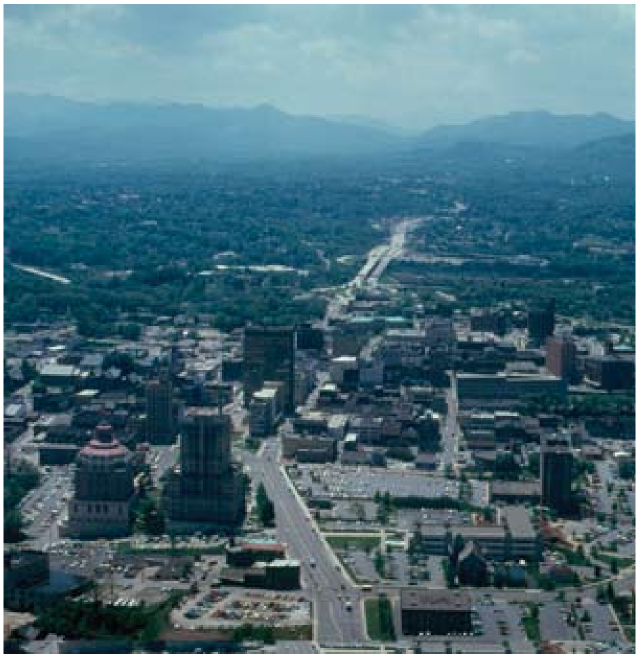
[5] Updates through 2000 online at http://cdiac.ornl.gov/trends/landuse/houghton/houghton.html. The total through 2003 was extrapolated based on the assumption that the annual fluxes in 2001-2003 were the same as in 2000.

[6] Uncertainties in national and *per capita* emissions are based on data reported by individual countries.

ful constraints on carbon stocks and fluxes. Process models build from understanding the underlying principles of atmosphere/ocean or atmosphere/ecosystem carbon exchange to make estimates over scales of space and time that are relevant to the global carbon cycle. For the oceans, calibration against observations with tracers (*e.g.*, carbon-14 [$^{14}C$] and chlorofluorocarbons) (Broecker *et al.*, 1980) tends to nudge a wide range of models toward similar results. Sophisticated models with detailed treatment of the ocean circulation, chemistry, and biology all reach about the same estimate for the current ocean carbon sink, 1.5 to 1.8 Gt C per year (Greenblatt and Sarmiento, 2004) and are in quantitative agreement with data-inventory approaches. Models of the land carbon cycle take a variety of approaches. They differ substantially in the data used as constraints, in the processes simulated, and in the level of detail (Cramer *et al.*, 1999; Cramer *et al.*, 2001). Models that take advantage of satellite data have the potential for comprehensive coverage at high spatial resolution (Running *et al.*, 2004), but only over the time domain with available satellite data. Flux components related to human activities, deforestation, for example, have been modeled based on historical land use (Houghton *et al.*, 1999). At present, model estimates are uncertain enough that they are often used most effectively in concert with other kinds of estimates (*e.g.*, Peylin *et al.*, 2005).

Inverse estimates based on atmospheric gases ($CO_2$, $^{13}C$ in $CO_2$, or $O_2$) infer surface fluxes based on the spatial and temporal pattern of atmospheric gas concentration, coupled with information on atmospheric transport (Newsam and Enting, 1988). The atmospheric concentration of $CO_2$ is now measured with high precision at approximately 100 sites worldwide, with many of the stations added in the last decade (Masarie and Tans, 1995). The $^{13}C$ in $CO_2$ and high-precision $O_2$ are measured at far fewer sites. The basic approach is a linear Bayesian inversion (Tarantola, 1987; Enting, 2002), with many variations in the time scale of the analysis, the number of regions used, and the transport model. Inversions have more power to resolve year-to-year differences than mean fluxes (Rodenbeck *et al.*, 2003; Baker *et al.*, 2006). Limitations in the accuracy of atmospheric inversions come from the limited density of concentration measurements (especially in the tropics), uncertainty in the transport, and errors in the inversion process (Baker *et al.*, 2006). Recent studies that use a number of sets of $CO_2$ monitoring stations (Rodenbeck *et al.*, 2003), models (Gurney *et al.*, 2003; Law *et al.*, 2003; Gurney *et al.*, 2004; Baker *et al.*, 2006), temporal scales, and spatial regions (Pacala *et al.*, 2001), highlight the sources of the uncertainties and appropriate steps for managing them.

A final approach to assessing large-scale $CO_2$ fluxes is solving as a residual. At the global scale, the net flux to or from the land is often calculated as the residual left after accounting for fossil-fuel emissions, atmospheric increase, and ocean uptake (Post *et al.*, 1990). Increasingly, the need to treat the land as a residual is receding, as the other methods improve. Still, the existence of constraints at the level of the overall budget provides an important connection with reality.



## 2.3 RECENT DYNAMICS OF THE UNMANAGED CARBON CYCLE

Of the approximately 466 ± 160 Gt C added to the atmosphere by human actions through 2003, only about 187 ± 5 Gt remain. The "missing carbon" must be stored, at least temporarily, in the oceans and in ecosystems on land. Based on a recent ocean inventory, 118 ± 19 Gt of the missing carbon was in the oceans, as of 1994 (Sabine *et al.*, 2004a). Extending this calculation, based on recent sinks (Takahashi *et al.*, 2002; Gloor *et al.*, 2003; Gurney *et al.*, 2003; Matear and McNeil, 2003; Matsumoto *et al.*, 2004), leads to an estimate of 137 ± 24 Gt C through 2003. This leaves about 142 ± 160 Gt that must be stored on land (with most of the uncertainty due to the uncertainty in emissions from land use). Identifying the processes responsible for the uptake on land, their spatial distribution, and their likely future trajectory has been one of the major goals of carbon cycle science over the last decade.

Much of the recent research on the global carbon cycle has focused on annual fluxes and their spatial and temporal variation. The temporal and spatial patterns of carbon flux provide a pathway to understanding the underlying mechanisms. Based on several different approaches, carbon

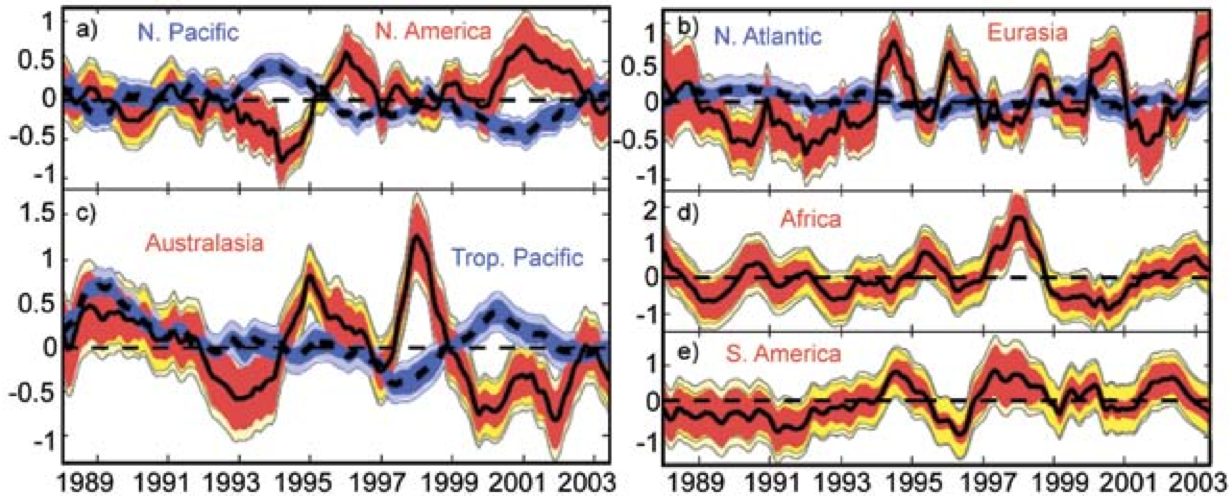



**Figure 2.3** The 13-model mean $CO_2$ flux interannual variability (Gt C per year) for several continents (solid lines) and ocean basins (dashed lines). In each panel, the dark inner band is the 1σ intermodel spread, the lighter adjacent band is the 1σ estimation uncertainty on interannual variability, and the outer band (visible only for the land) is the root sum of squares of the two uncertainty components. (a) North Pacific and North America, (b) Atlantic north of 15°N and Eurasia, (c) Australasia and Tropical Pacific, (d) Africa, and (e) South America (note the different scales for Africa and South America) (Baker *et al.*, 2006).

uptake by the oceans averaged 1.7 ± 0.2 Gt C per year[7] for the period from 1992-1996 (Takahashi *et al.*, 2002; Gloor *et al.*, 2003; Gurney *et al.*, 2003; Matear and McNeil, 2003; Matsumoto *et al.*, 2004). The total human-caused flux is this amount, plus 0.45 Gt per year of preindustrial outgasing, for a total of 2.2 ± 0.4 Gt per year. This rate represents an integral over high-latitude areas, which are gaining carbon, and the tropics, which are losing carbon (Takahashi *et al.*, 2002; Gurney *et al.*, 2003; Gurney *et al.*, 2004; Jacobson *et al.*, 2007). Interannual variability in the ocean sink for $CO_2$, though substantial (Greenblatt and Sarmiento, 2004), is much smaller than interannual variability on the land (Baker *et al.*, 2006).

In the 1990s, carbon releases from land-use change were more than balanced by ecosystem uptake, leading to a net sink on land (without accounting for fossil-fuel emissions) of 1.1 ± 1.5 Gt C per year (Schimel *et al.*, 2001; Sabine *et al.*, 2004b). The dominant sources of recent interannual variation in the net land flux were El Niño and the eruption of Mount Pinatubo in 1991 (Bousquet *et al.*, 2000; Rodenbeck *et al.*, 2003; Baker *et al.*, 2006), with most of the year-to-year variation in the tropics (Figure 2.3). Fire likely plays a large role in this variability (van der Werf *et al.*, 2004).

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On a time scale of thousands of years, the ocean will be the sink for more than 90% of the carbon released to the atmosphere by human activities (Archer *et al.*, 1998). The rate of $CO_2$ uptake by the oceans is, however, limited. Carbon dioxide enters the oceans by dissolving in seawater. The rate of this process is determined by the concentration difference between the atmosphere and the surface waters and by an air-sea exchange coefficient related to wave action, wind, and turbulence (Le Quéré and Metzl, 2004). Because the surface waters represent a small volume with limited capacity to store $CO_2$, the major control on ocean uptake is at the level of moving carbon from the surface to intermediate and deep waters. Important contributions to this transport come from the large-scale circulation of the oceans, especially the sinking of cold water in the Southern Ocean and, to a lesser extent, the North Atlantic.

On land, numerous processes contribute to carbon storage and carbon loss. Some of these are directly influenced through human actions (*e.g.*, the planting of forests, conversion to no-till agriculture, or the burying of organic wastes in landfills). The human imprint on others is indirect. This category includes ecosystem responses to climate change (*e.g.*, warming and changes in precipitation), changes in the composition of the atmosphere (*e.g.*, increased $CO_2$ and increased tropospheric ozone), and delayed consequences of past actions (*e.g.*, regrowth of forests after earlier harvesting). Early analyses of the global carbon budget (*e.g.*, Bacastow and Keeling, 1973) typically assigned all of the net flux on land to a single mechanism, fertilization of plant growth by increased atmospheric $CO_2$. Recent evidence emphasizes the diversity of mechanisms.

### 2.3.1 The Carbon Cycle of North America

The land area of North America is a large source of carbon, but the residual (without emissions from fossil-fuel combustion) is, by most estimates, currently a sink for carbon. This conclusion for the continental scale is based mainly on the results of atmospheric inversions. Several studies address the carbon balance of particular ecosystem types (*e.g.*, forests [Kurz and Apps, 1999; Goodale *et al.*, 2002; Chen *et al.*, 2003]). Pacala and colleagues (2001) used a combination of atmospheric and land-based techniques to estimate that the 48 contiguous United States are currently a carbon sink of 0.3 to 0.6 Gt C per year. This estimate and a discussion of the processes responsible for recent sinks in North America are updated in Chapter 3 of this report. Based on inversions using 13 atmospheric transport models, North America was a carbon sink of 0.97 ± 0.36 Gt C per year from 1991-2000 (Baker *et al.*, 2006)[8]. Over the area of North America, this amounts to an annual carbon sink of 39.6 g C per square meter per year, similar to the sink inferred for all northern lands (North America, Europe, Boreal Asia, and Temperate Asia) of 32.5 g C per square meter per year (Baker *et al.*, 2006).

Very little of the current carbon sink in North America is a consequence of deliberate action to absorb and store (sequester) carbon. Some is a collateral benefit of steps to improve land management, for increasing soil fertility, improving wildlife habitat, *etc*. Much of the current sink is unintentional, a consequence of historical changes in technologies and preferences in agriculture, transportation, and urban design.

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## 2.4 CARBON CYCLE OF THE FUTURE

The future trajectory of carbon sinks in North America is very uncertain. Several trends will play a role in determining the sign and magnitude of future changes. One important controller is the magnitude of future climate changes. If the climate warms significantly, much of the United States could experience drought-related decreases in plant growth and an increase in the risk of wildfire (Bachelet *et al.*, 2003), especially if the warming is not associated with substantial increases in precipitation. Exactly this pattern—substantial warming with little or no change in precipitation—characterizes North America in many of the newer climate simulations (Rousteenoja *et al.*, 2003). If North American ecosystems are sensitive to elevated $CO_2$, nitrogen deposition, or warming, plant growth could increase (Schimel *et al.*, 2000). The empirical literature on $CO_2$ and nitrogen deposition is mixed, with some reports of substantial growth enhancement (Norby *et al.*, 2005) and others reporting small or modest effects (Oren *et al.*, 2001; Shaw *et al.*, 2002; Heath *et al.*, 2005).

Overall, the carbon budget of North America is dominated by carbon releases from the combustion of fossil fuels. Recent sinks, largely from carbon uptake in plants and soils, may approach 50% of the recent fossil-fuel source (Baker *et al.*, 2006). Most of this uptake appears to be a rebound, as natural and managed ecosystems recover from past disturbances. Little evidence supports the idea that these ecosystem sinks will increase in the future. Substantial climate change could convert current sinks into sources (Gruber *et al.*, 2004).

In the future, trends in the North American energy economy may intersect with trends in the natural carbon cycle. A large-scale investment in afforestation could offset substantial future emissions (Graham, 2003). However, costs of this kind of effort would include loss of the new-forested area from its previous uses (including grazing or agriculture), the energy costs of managing the new

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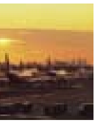
[8] This uncertainty is a sample standard deviation across monthly output from 13 models.

forests, and any increases in emissions of non-$CO_2$ greenhouse gases from the new forests. Large-scale investments in biomass energy (energy produced from vegetative matter) would have similar costs but would result in offsetting emissions from fossil-fuel combustion, rather than sequestration (Giampietro *et al.*, 1997). The relative costs and benefits of investments in afforestation and biomass energy will require careful analysis (Kirschbaum, 2003). Investments in other energy technologies, including wind and solar, will require some land area, but the impacts on the natural carbon cycle are unlikely to be significant or widespread (Hoffert *et al.*, 2002; Pacala and Socolow, 2004).



Like the present, the carbon cycle of North America during the next several decades will be dominated by fossil-fuel emissions. Deliberate geological sequestration may become an increasingly important component of the budget sheet. Still, progress in controlling the net release to the atmosphere must be centered on the production and consumption of energy rather than the processes of the unmanaged carbon cycle. North America has many opportunities to decrease emissions (Chapter 4 this report). Nothing about the status of the unmanaged carbon cycle provides a justification for assuming that it can compensate for emissions from fossil-fuel combustion.

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