



Chapter 3: Feedbacks in the Carbon Cycle

Sometimes when one process in a system affects another process, the effect itself leads to a change in the first process. This change is called a *feedback*. Feedbacks can be either *positive*, in which the original process or effect is eventually enhanced, or *negative*, in which the original process is eventually reduced. For example, if you work hard and get a bonus, you're motivated to work even harder—a positive feedback. If you don't study and get a bad midterm grade, fear of failing may make you study and bring up your grade; this is a negative feedback, even though it has a positive effect on you!

A number of processes in the carbon cycle can produce feedbacks. Lack of knowledge about feedbacks is a major factor limiting our ability to estimate future atmospheric CO₂ concentrations. For example, an increase in atmospheric CO₂ that leads to an increase in the earth's surface temperature may be a positive feedback in some regions because warmer temperatures increase soil respiration, thereby further increasing atmospheric CO₂. However, warmer temperatures can also extend the growing season of plants, and thus the length of time over which they draw CO₂ out of the atmosphere. This effect would reduce the amount of atmospheric CO₂, which then could reduce the amount of warming. Thus increased atmospheric CO₂ has both positive and negative feedbacks, and it is hard to discern which would prevail globally.

Terrestrial Feedbacks

Carbon Storage in Plants

Climate change affects carbon storage in terrestrial ecosystems because temperature, moisture, and radiation influence both photosynthesis, by which ecosystems gain carbon, and respiration,

by which they lose it. Warming increases respiration (which, you may remember, releases CO₂ to the atmosphere), especially of soils, because respiration is more sensitive to temperature than is photosynthesis (which takes up CO₂ from the atmosphere). Conversely, cooling decreases respiration. The reduction in the atmospheric growth rate of CO₂ during 1991–92 may have been the result of a decrease in respiration caused by cooling, because the 1991 eruption of Mt. Pinatubo in the Philippines produced a global atmospheric cooling by releasing large quantities of sulfur dioxide that blocked sunlight.

A number of processes in the terrestrial biosphere could compensate for the reduced carbon storage. For example, in nutrient-limited forests, warming may increase carbon storage by releasing organic nutrients from the soil, which the trees could use to grow and thus store more carbon in their tissues. Also, some plants whose growing seasons are now limited by cold may take up more CO₂ than at present if global warming increases their life spans.

The records of past changes of climate (such as the warming trend of 18,000 years ago) all suggest that climate change leads to major changes in terrestrial carbon storage. Scientists project that warming could lead to large losses of terrestrial carbon (~200 Gt) over the next few hundred years if temperature changes are very rapid. However, a gradual rather than a sudden change to warmer temperatures could cause the terrestrial biosphere to eventually take up 100–300 Gt C in response to warming, albeit after a significant short-term loss.

Carbon Storage in Soils

Soils generally store more carbon as latitude decreases (that is, as you move farther from the equator) because dead plants decompose more slowly in colder environments. Soil carbon



storage also increases under conditions of high precipitation. Flooded soils, which have extremely low rates of decomposition, may accumulate large amounts of organic matter as peat. If high-latitude soils get warmer and wet soils get drier as a result of climate change, some researchers have suggested that these soils would release more CO_2 to the atmosphere, creating a large positive feedback to the initial warming. This process could be under way already in the peatlands of the arctic.

Estimates of how much carbon would be lost from soils globally as temperature rises range from 11 to 34 Gt C per degree of warming. It is possible that the response will be only 5 to 17 Gt because as temperature rises decomposition will speed up, releasing nutrients that are needed for plant growth. Increased plant growth will eventually lead to increased carbon storage in the soil.

Effects of Increased CO_2 Concentration (CO_2 Fertilization Feedback)

As discussed in Chapter 2, laboratory studies have shown that photosynthesis increases in plants exposed to elevated CO_2 . If this short-term gain translates to entire ecosystems, in the future more carbon may be stored in woody tissue or in organic matter in soils. Enhanced storage would serve as a sink for excess CO_2 and thus act as a negative feedback, decreasing the rate of atmospheric CO_2 increase. Whether enhanced fertilization can be sustained, and whether enhanced photosynthesis will translate to increased carbon storage, are currently hot topics of debate. Figure 16 shows the results of a study in which plants of the Alaskan tundra in their native setting were exposed to elevated CO_2 (680 ppm, compared to the 1996 value of ~ 360 ppm) for three years. The study suggests that not all plants will continue to grow faster with continued higher levels of CO_2 .

CO_2 -fertilized foliage is typically lower in nitrogen than is foliage grown under current concentrations of CO_2 . As this lower-N foliage dies and works its way through the decomposition process, soil decomposer organisms will require additional nitrogen. As a result, vegetation may become more nitrogen limited (a change that would weaken but not eliminate the effects of CO_2 fertilization). Additional nitrogen released by

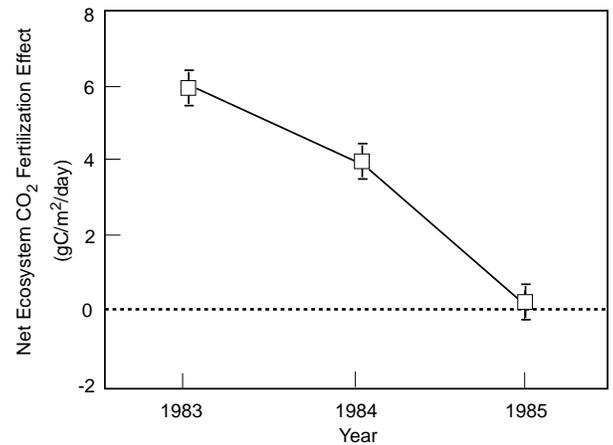


Figure 16. The CO_2 fertilization effect on plants grown for three seasons at Toolik Lake, Alaska, under doubled atmospheric CO_2 concentration (680 ppm). The effect is considered to be the difference between the flux measured at doubled and at ambient CO_2 levels. Units are grams of carbon per square meter of tundra vegetation per day. From Oechel et al. (1994), p. 500.

warming, as described above, could alleviate the nitrogen stress induced by foliage high in CO_2 .

Deposition of atmospheric nitrogen could also influence the effectiveness of CO_2 fertilization, although the effect may be modest, especially where other nutrients or conditions limit plant growth. Empirical studies are few, but a recent analysis revealed that hay yield had not changed measurably over the past 100 years despite substantial increases in the amount of nitrogen in precipitation and a 21% increase in atmospheric CO_2 concentration during the period of study.

Changes in the Geographical Distribution of Vegetation Types

Studies of the records of past climates (paleorecords) suggest that if they are able to do so, plant types (e.g., grasses, deciduous forests) will migrate to their preferred climatic conditions when changes in climate occur. For example, the ranges of several species of trees have changed in tandem with changes in climate since the last glaciation. However, if climate change is rapid, many species will not be able to migrate fast enough to keep up with the new conditions. Furthermore, some of those that can migrate



quickly still will not survive the change, because soil conditions in the new area will not be suitable for them. Thus climate change is likely to lead to loss of habitat and subsequent death for some plants, and some species may become extinct. These changes would cause not only a release of carbon to the atmosphere if the dead plants (especially trees) were burned, but also a loss of uptake via photosynthesis.

Table 5 reflects the likely direction of changes in carbon storage caused by factors described above. “Short-term” includes effects that will likely take place in the next 10 years, and “long-term” includes changes that will not be observed for 50–100 years or more. A plus sign means an increase in carbon storage; a minus sign means a decrease. A question mark indicates a high degree of uncertainty.

Table 5
Direction of feedback effects on carbon storage

| Feedback factor | Short-term | Long-term |
|--|------------|-----------|
| Increased atmospheric CO ₂ | + | + (?) |
| Increased temperature ¹ | - | + |
| Increased precipitation ² | +/- | +/- |
| Increased N deposition ³ | + | +/- |
| Vegetation redistribution ⁴ | -/+ | + |

¹ Long-term increase is possible due to release of soil nutrients.
² Increased precipitation increases both net primary productivity and decomposition; either effect could dominate.
³ Long-term effects could be negative if the amount of N deposited becomes toxic.
⁴ Short-term effects could be negative if plants cannot migrate fast enough to areas of newly suitable climate. Effects would be positive if trees replaced grasses.

Oceanic Feedbacks

Feedbacks Related to Chemical and Biological Processes

Since CO₂ is more soluble in colder water than in warmer water, warmer sea surface temperatures will affect the oceans’ ability to dissolve CO₂ and their carbon chemistry. A warmer ocean might cause dissolved organic carbon to decompose faster and convert to CO₂, reducing the amount of atmospheric CO₂ that can be absorbed by the oceans (a positive feedback). However, researchers do not think that this accelerated decomposition would significantly change the amount of atmospheric CO₂ because the quantity of dissolved organic carbon in the surface waters of the ocean is less than 700 Gt; the atmosphere currently stores more than this amount (773 Gt).

Warming is also expected to cause a decrease in the extent of sea ice, which could increase plankton and other marine growth in high-latitude regions. This would result in a greater uptake of atmospheric CO₂, thereby acting as a negative feedback.

Feedbacks Related to Ocean Circulation

Changes in oceanic circulation and their effects on the oceanic carbon cycle are difficult to

assess. Warming of the sea surface is predicted to cause a strong reduction of the deep, salty current (see Figure 13, p. 12), which is driven by the cooling and sinking of surface water at high latitudes. This suggests that the oceans’ ability to serve as a sink for excess atmospheric CO₂ would decrease with warming. Supporting this theory are studies of ocean behavior during El Niño–Southern Oscillation (ENSO) events, which are characterized by reduced upwelling of cold bottom waters in the equatorial Pacific. These studies indicate that fluxes of CO₂ to the atmosphere are enhanced during ENSO events.

A reduction of the processes by which shallow and deep water are exchanged would impact the oceanic carbon cycle in several ways.

- The downward movement of surface waters, which have been in contact with the atmosphere and thus are enriched with excess CO₂, would be reduced, thereby reducing the oceans’ capacity to take up excess CO₂.
- Any decrease in the amount of water moving upward within the ocean would affect the biological pump by reducing the flow of nutrients to the ocean surface. In regions where nutrients are the limiting factor, this would result in reduced plankton and other marine growth.



- With less marine growth at the surface, less carbon would be exported to depth as organisms sink and decompose, which could lead to an increase in CO₂ concentration at the ocean's surface.

UV-B Radiation

The depletion of stratospheric ozone is an example of a human-caused change that impacts the oceanic carbon system even though it is not directly related to global warming. Ozone depletion could cause increased ultraviolet radiation (UV-B, corresponding to light wavelengths of 280–320 nanometers, or billionths of a meter), which might affect marine life and thus influence marine carbon storage. However, even a complete cessation of marine productivity in high latitudes, where increases in UV-B are expected to occur, would result in an atmospheric CO₂ increase of less than 40 ppm.