CHANGES IN BIOGEOCHEMICAL CYCLES

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Summary

The increasing concentration of carbon dioxide, largely as a result of fossil fuel burning, deforestation and expanding agriculture, appears to play a major role in determining the Earth's climate through regulation of the solar radiation balance.

Anthropogenic disturbances are imposed on the natural continuous exchange between the atmosphere and other carbon reservoirs. It is known that the relative importance of various carbon cycle processes and reservoirs depends on the rate of exchange and the size of the reservoir: when studying rapid changes, especially in small systems of the global carbon cycle, many slower and larger changes are neglected.

But over longer time periods fluctuations governed outside the small system may become important. The differences in scales of space and time in which various processes of the lithosphere, atmosphere, oceans and biosphere operate are becoming a major focus in research on the global carbon cycle.

1. Introduction

It has been clearly determined from regular measurements that the chemical composition of the atmosphere is changing. These changes are largely caused by human activities such as fossil fuel burning, deforestation, changes in land use, and use of greater amounts of fertilizers in agriculture. Some atmospheric constituents are very important for existence of life on the Earth; others may indirectly influence the biosphere. Increasing concentrations of some of the gases may enhance the greenhouse effect thereby increasing global temperature (see *Response of Climate System to Changes in Greenhouse Gases and Aerosols).*

Changes in atmospheric composition point to the variations in the cycles of chemical compounds and the elements comprising these compounds.

Numerous natural substances are circulated through the Earth's atmosphere, to the land, and through soils into streams, and to the oceans via streams. In the oceans some amount of the material forms sediments on the ocean floor and some of it comes back to the atmosphere. Various processes (physical, chemical, biological, etc) govern transfer of the element or its compounds into or out of the reservoir.

It should be emphasized that the relative importance of different processes governing the exchange of various elements between the reservoirs are strongly dependent on different time scales. For example, fluctuations of carbon dioxide caused by seasonal changes have little bearing on CO_2 concentrations on the time scale of about a hundred years. Likewise, the consumption of CO_2 during chemical weathering can have but little effect on the atmosphere during short periods of time. Weathering is one of the most important processes controlling atmospheric CO_2 over millions of years (see *History of Atmospheric Composition*).

Although the overall pattern of cycling of all the major elements is now known, there are still uncertainties in values of different reservoirs of certain elements and exchange fluxes. Moreover, the ways in which the different cycles interact with one another are poorly understood. Nitrogen, phosphorous and sulfur, for example, are thought to influence the rate of carbon accumulation by plants. As a result, changes in any one of these nutrient cycles influence the other cycles.

The role played by carbon in the biosphere is the most significant. Changes in the global carbon cycle over time scales of thousands of years and longer and anthropogenic changes are discussed in this article (See *Biogeochemistry of Greenhouse Gases and Reflective Aerosols).*

The links between the carbon cycle and the cycles of silicon and sulfur are also briefly considered in this article.

Finally, the nitrogen cycle is described, as nitrogen is one of the nutrients whose cycling is closely connected with the biological cycling of carbon. Both these cycles are changing because of man-made activities.

2. The Global Carbon Cycle

2.1 Natural Carbon Cycle

Carbon cycling is schematically shown in Figure 1. The major carbon reservoirs and fluxes of carbon are depicted in Table 1.

The present atmospheric CO_2 amount (1997) makes up about 770 GtC (363 ppmv). The total inorganic carbon produced by the reaction of CO_2 and water with minerals is the most abundant form of carbon in the oceanic reservoir and is estimated to be approximately 38 000 GtC. All but a small fraction of this carbon is dissolved in the form of bicarbonate ion (HCO_3^-), and most of the remainder is in the form of carbonate ion (CO_3^{2-}). Dissolved CO_2 makes up about 1% of the total inorganic carbon.

A. Reservoir		**Mass, Gt C**[a]
Sedimentary rocks on the continents	Calcium carbonate ($CaCO_3$)	56,300,000[b]
	Organic carbon	8,330,000[b]
Marine sediments (including sediments on shelves)	$CaCO_3$	30,000,000[b]
	Organic carbon	3,500,000[b]
Oceans	Dissolved inorganic carbon dioxide (DIC)	630[c]
	Bicarbonate and carbonate in the mixed layer (0-75 m)	38,000[c]
	Intermediate and deep ocean organic carbon in living biomass	1-3[f]
	Particulate organic carbon	30[f]
	Dissolved organic carbon	1800[f]
Land[f]	Phytomass of terrestrial plants	560
	Litter	72
	Humus - labile	700
	Humus - stable	1400
Atmosphere CO_2	Mass in year 1800	594 (280 ppmv[e])
	Mass in year 1997	771 (363.5 ppmv)
B. Flux		**Gt C yr^{-1}**
	Marine carbonate burial	0.12-0.26[d]
	Marine organic carbon burial	0.03[b]-0.13[g]
	Marine primary production	30[f]
	Particulate organic carbon	2-5[f]
	Deep ocean dissolution of $CaCO_3$	0.55-0.63[d]
	Carbon from rivers to oceans	over 0.65[h]
	Ocean exchange with atmosphere	about 100[i]
	Net primary productivity of terrestrial plants	560[f]
	Net uptake of anthropogenic CO_2 by oceans	≈2[i]

[a]Gt=10^9 metric tons=10^{12}kg=10^{15}g
[b]Budyko M.I., Ronov A.B., Yanshin A.L. (1987). *History of the Earth's atmosphere*, 139 pp., Springler-Verlag, Berlin etc.
[c]Olson J.S., Garrels R.M., Berner R.A., Armentano Th.V., Dyer M.I., Yaalen D.H. (1985). The Natural Carbon Cycle, Chapter 8. *Atmospheric Carbon Dioxide and the Global Carbon Cycle* (ed. J.R. Trabalka), 175-219. DOE/ER-0239.
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[e]ppmv – parts per million by volume
[f]Kobak K.I. (1988*) Biotical Compounds of Carbon Cycle* (ed. M.I. Budyko), 248 pp. Hydrometeoizdat, Leningrad.
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Table1: Global carbon reservoirs (A) and fluxes (B). The numbers apply for the present day situation. Units are gigatons of carbon for reservoir sizes (1Gt = 10^9 metric tons = 10^{12} kg) and GtC yr^{-1} for fluxes.

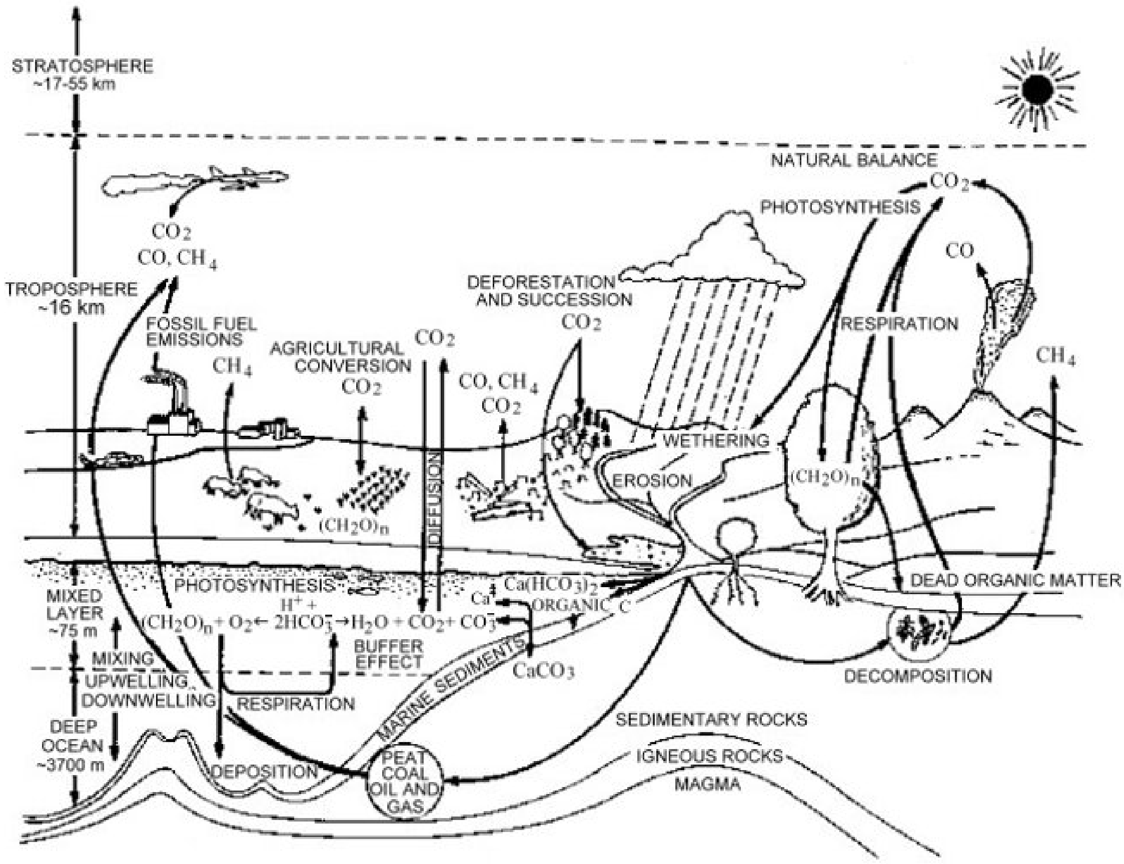

Figure 1: Schematic diagram of the global carbon cycle

Organic carbon is much less abundant (and dominated by dead organic matter). Living carbon is 1 to 3 GtC. The ocean reservoir also contains carbonate solids (formed by marine organisms) found both suspended in the water column and incorporated in surface sediments at depths less than 4 km, largely in the form of calcium carbonate. The top (~ 10 cm) of these deposits is mixed by the activities of benthic animals ("reactive sediments"). The amount of carbon in these deposits is about 400 GtC. The deeper sediments contain 700 x 10^5 GtC.

Carbon is also accumulated in terrestrial and marine biota and soils. Estimates of the amount of carbon in these organic carbon pools are less certain than those of the inorganic carbon pool. The discrepancies in the organic pool estimates are associated with high regional variability of terrestrial ecosystems and deficient data. Within the oceans, organic biomass and especially productivity vary significantly.

The vegetation contains more than 99.9% of the carbon in terrestrial biota. The turnover time in different biomes can span a few years to several decades ("turnover time" is defined as a ratio between organic carbon in the biomass and net primary productivity, NPP).

The major part of carbon in soils is stored in humus and peat. Only about 3.5% of the total soil carbon is found in litter. The turnover time of carbon in soil organic matter varies in different fraction of soils: from less than 1 year too greater than 1000 years.

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Biographical Sketch

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