

JGOFS

Joint Global Ocean Flux Study

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Introduction

Scientific interest in the global carbon cycle has grown during the last decade, in response to two main developments. Firstly, analysis of polar ice cores has shown that atmospheric carbon dioxide has previously varied in parallel with the Earth's glacial-interglacial cycles. Secondly, atmospheric CO₂ is now rapidly increasing due to human activities, and this threatens to cause major changes in the global climate. Both ocean circulation and marine biogeochemical processes play a large role in regulating the atmospheric concentration of CO₂, mediated through air-sea exchange. Ocean uptake has undoubtedly slowed the build-up of anthropogenic CO₂ in the atmosphere; however, the strength of that effect, and its future behaviour, are uncertain.

The Joint Global Ocean Flux Study is based on the premise that, by making the right measurements for a decade and synthesizing the results, it can deliver a greatly improved understanding of the processes that govern carbon flow in the ocean and its coupling with other components of the global carbon cycle. As a result, we will have much more realistic predictions of how the ocean system will react to climate change.

The oceans contain some 50 times as much carbon dioxide as the atmosphere, and small changes in the ocean carbon cycle can therefore have large atmospheric consequences. Such changes are believed to have had important feedback effects on climate during the transitions to and from ice ages; they may also have important consequences during the climate changes that are predicted to occur in the next 50 - 100 years, as a result of rapidly rising levels of atmospheric CO₂ and other greenhouse gases.

Models indicate that the oceans are currently taking up at least a third of the anthropogenic CO₂, by dissolving it in water that then loses contact with the atmosphere because of sinking or vertical mixing. Biological processes complicate the oceanic carbon cycle; although they probably do not affect the present uptake of anthropogenic CO₂, they are important (1) as a determinant of the natural background distribution of carbon; (2) because seasonal variation in biological processes complicates the effort to measure the background distribution; and (3) because biological feedbacks have the potential to amplify chemical and physical effects.

Overview of Carbon Fluxes

The Earth's major carbon pools and our current estimates of the fluxes between them are shown in Figure 1. Carbon mostly enters and leaves the ocean as CO₂, via gas exchange at the sea surface. The local flux is proportional to $DpCO_2$, the difference between the partial pressures of CO₂ in air and seawater. Physical and biological processes produce large spatial and temporal variations in pCO_2 in the surface ocean, and therefore direct determination of net global air-sea exchange is difficult. CO₂ and other forms of carbon are transported to deep water by both physical and biological processes: convection, advection, convection and small-scale turbulence are responsible for the transport of dissolved inorganic and organic carbon, whilst biological processes are responsible for the formation of particulate carbon, with its more rapid transport, by sinking, from the upper ocean.

Under natural steady-state conditions (during periods of climatic stability), the gross downward flux of carbon out of the upper ocean is compensated by an upward transport of dissolved carbon of closely similar magnitude. As a result, the net flux of CO₂ between atmosphere and ocean was near-zero, and atmospheric CO₂ levels were stable, for at least a thousand years before the onset of industrial activities.

Dissolved inorganic carbon (DIC) concentrations are lower in surface water than in deep water. One reason for this is that surface water is generally warmer than deep water, and CO₂ is less soluble in warm than in cold water. Another reason is biological uptake of carbon, due to photosynthesis. Of the total primary production in the ocean, between 10 - 40 % sinks out of the surface as particles, and an unknown further fraction (possibly as much again) is transported downwards as dissolved organic carbon. The total amount of production exported to deep water is estimated to be between 4 - 20 GtC/yr (1 GT, gigatonne, is 10¹⁵ grams), with the rest recycled in the photic zone.

Since the Industrial Revolution, human activities have introduced significant additional amounts of CO₂ into the atmosphere, creating an imbalance between the different global subsystems. The ocean contains much more carbon than the atmosphere, and over a time scale of centuries it will contain most of the anthropogenic CO₂. On this time scale, the uptake is mainly controlled by the rate at which carbon is transported to the deep ocean. Current carbon cycle models estimate the global net air-sea flux of anthropogenic CO₂ to be about 2 GtC/yr.

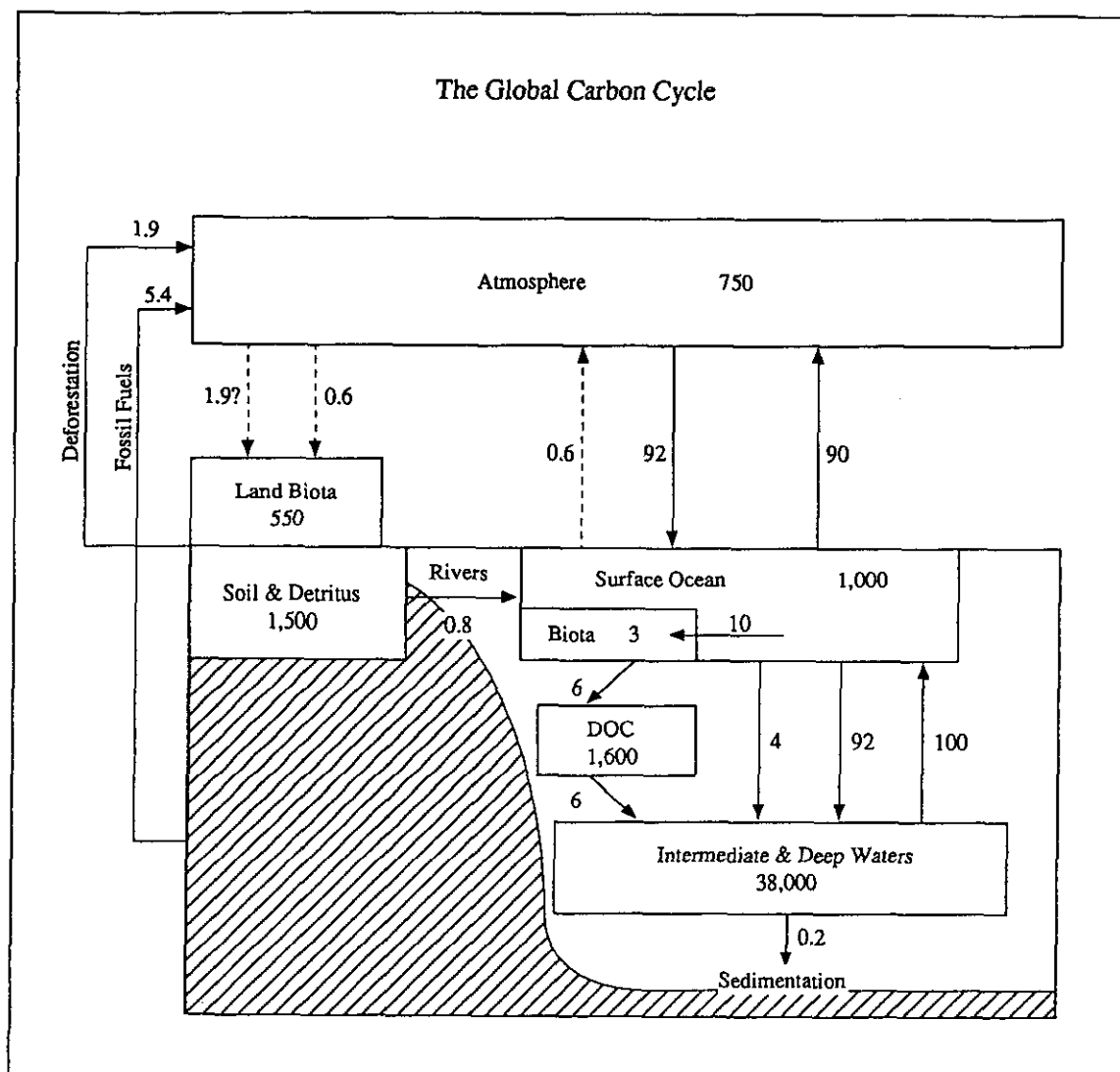


Figure 1 Major Global Carbon Pools and Fluxes

The details of these processes are not yet well understood, but it is clear that in order to reconcile the atmospheric and oceanic CO₂ observations, natural processes as well as the anthropogenic perturbation must be carefully studied.

Changes in biologically-mediated vertical transport within the ocean have the potential to cause atmospheric CO₂ variations. Thus several hypotheses on the cause of the glacial/interglacial CO₂ variations have invoked changes in the biological pump. However, many components of these models are at present over-simplified. For example, the rate of remineralization of sinking organic particles: this is usually described as an empirical function of depth, but is now known to be affected by particle size and composition, as well as by temperature and oxygen concentration. Quantitative knowledge of such relationships is required for tackling the question of how future climate change would affect the ocean carbon cycle.

Marine biological processes are usually not considered to be limited by the availability of CO₂. It is therefore unlikely that marine ecosystems have yet been directly affected by, or represent a net sink for, the anthropogenic CO₂ increase. However, the feedback role of marine biology in a changed climate is unknown. Significant environmental changes (in particular, different ocean circulation patterns) can be expected to lead to changes in ecosystem structure and composition, which in turn could have a global-scale impact on ocean carbon transport.

The carbon cycle is closely linked to cycles of other elements, in particular nutrients and oxygen. On a large scale, the relative amounts of the main elements involved in biological transformations (Redfield ratios) are roughly constant, but detailed studies show systematic regional and depth variations in these ratios. This finding has important implications for modelling the ocean carbon cycle. In equatorial and polar regions, particularly the Southern Ocean, phytoplankton biomass and primary production are often low-even when the main nutrients (nitrogen and phosphorus) are abundantly available. It is not clear what factors limit biological productivity in these nutrient-rich areas: possible candidates include grazing, temperature, light and vertical mixing, and/or the lack of a trace nutrient such as iron.

Science Plan

Many scientists worldwide are addressing aspects of the ocean carbon cycle, but to determine overall net fluxes and the processes controlling them is beyond the capability of any one nation. Therefore the Joint Global Ocean Flux Study (JGOFS) has been established, under the auspices of the Scientific Committee on Oceanic Research and as a Core Project of the International Geosphere-Biosphere Programme. Its purpose is to plan and execute the research that requires international cooperation. Close to 20 countries are already contributing to JGOFS planning or field work. The scientific goals of JGOFS were published in its Science Plan (SCOR 1990):

- To determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associated biogenic elements in the ocean, and to evaluate the related exchanges with the atmosphere, sea floor and continental boundaries.
- To develop a capacity to predict on a global scale the response of oceanic biogeochemical processes to anthropogenic perturbations, in particular those related to climate change.

The JGOFS Science Plan describes how the goals can be attained through a combination of large-scale surveys from satellites and ships; studies of key processes to help interpret and interpolate between surveyed quantities; series of monthly measurements for many years to determine how fluxes and processes vary; and studies of the record of oceanic and climatic conditions preserved in Quaternary sediments. An overarching programme of synthesis and modelling will ensure that observations are planned and interpreted with JGOFS goals in mind. JGOFS will create a high-quality data set by specifying measurement protocols and providing training in their use; it will also institute a data management system to make the data easily available to the scientific community.

Field work began in 1989, and will continue until about 1997, with a peak in 1994-95 as results from the next generation of satellite ocean colour sensors become available. Analysis and data synthesis will continue for the rest of the decade.

Implementation Plan

JGOFS Implementation Plan (IGBP/SCOR, 1992) describes how the internationally coordinated part of JGOFS will be accomplished, and what resources are needed. Planning is a continuous process, and revisions to this plan will be published to provide updated information as JGOFS develops.

JGOFS will restrict itself to the most important tasks consistent with its lifetime and resources. Carbon exchange between the atmosphere and ocean is its main focus; however, for periods longer than a year, the main factors limiting this flux may be associated with the exchange of carbon between the upper ocean and the ocean interior. JGOFS has therefore adopted the following "operational goal" for evaluating components of the programme:

To assess more accurately, and understand better the processes controlling, regional to global and seasonal to interannual fluxes of carbon between the atmosphere, surface ocean and ocean interior, and their sensitivity to climate changes.

This goal is expressed in more detail in the following objectives:

- an assessment of large-scale carbon fluxes, obtained from a greatly increased network of observations.
- a set of models that express our understanding of the processes controlling large-scale carbon fluxes.
- a procedure for observing the ocean in a routine, synoptic manner to detect possible changes in the ocean carbon cycle in response to climate change.
- a well-cared-for data set, comprising observations made according to standard protocols and a system for making subsets of these data easily available to researchers.

- knowledge and understanding of fluxes across the continental margins, to provide reliable boundary conditions for global models.
- an increased number of countries with an interest and skill in planning JGOFS-type activities and making the appropriate measurements and global-scale inferences.

The global synthesis will be carried out with the aid of a variety of models. These include concept-driven models of the underlying processes, tuned to the data collected during JGOFS, and data-driven models designed to interpolate and extrapolate as best we can between and beyond JGOFS observations.

Large-scale surveys will lead to maps of fluxes which can be integrated to produce global flux estimates. Surveys so far planned include ocean colour from satellites and carbon system measurements made on cruises of the World Ocean Circulation Experiment (WOCE).

Some ocean regions need to be studied in greater detail, either (1) because the resolution of large-scale surveys may be too coarse to adequately describe the processes occurring there; or (2) because that part of the ocean is known to be particularly sensitive to climate change; or (3) because the magnitude of the regional carbon flux is a high proportion of the global total, and therefore needs to be well determined. Four regions have been chosen for detailed study, on the basis of their likely contribution to reducing uncertainties in understanding the ocean carbon cycle.

The North Atlantic is a major area of deep water formation where dissolved CO₂ is carried away from the surface ocean, where a large seasonal biogenic signal complicates the interpretation of surveys, and where the sedimentary record indicates a large sensitivity to past changes in climate. The Equatorial Pacific has a large area and a large pool of unused nutrients (representing a potential uptake of carbon that is not occurring); interannual variability connected with El Niño effects complicates the interpretation of surveys. The Southern Ocean is a complicated region of large fluxes, which appear to be in approximate balance now but may get out of balance in a changed climate. It also has a large pool of unused nutrients, and the influence of changes in sea ice cover needs special attention. The Arabian Sea is an area of very high average chlorophyll, and of extreme seasonal variation driven by monsoonal reversals; it also offers a wide range of physical forcing in an area where light does not vary much, i.e. a region of instructive contrasts.

Process studies are ongoing or planned for all of these regions. They are designed to provide the sort of understanding that can be extended over a large area and used to make syntheses, especially understanding expressed in improved models and parameters for the key processes. They will provide an inventory of key fluxes, a definition of control mechanisms, and an understanding of forcing at time scales ranging from a week to several years.

Time series stations will be maintained for several years to observe and interpret seasonal and interannual variability of fluxes and processes over the whole water column, using a combination of shipboard observations at specific sites, made monthly or more often, and sediment trap moorings. Stations currently operate near Bermuda and Hawaii; others are planned for Kerguelen Island and the Canary Islands.

Sedimentary record studies are underway in many ocean basins to determine the relationships between ocean circulation, biological production, atmospheric CO₂, and climate over a wide range of past conditions.

A special effort will be made to determine horizontal boundary fluxes across continental margins. This work, which offers the opportunity for participation of many coastal states in JGOFS research, will be coordinated jointly with the IGBP established Core Project on Land-Ocean Interactions in the Coastal Zone.

Updated protocols will be published for measuring the most important variables. To encourage the use of these protocols by all investigators in all regions of the ocean, training workshops will be held in conjunction with JGOFS process studies. An international data management system, linking small topical (e.g. national) JGOFS data centres, will make it possible for researchers to find out about and access the data collected during JGOFS.

References:

This introductory report is taken almost entirely from the following publications:

SCOR. 1990 JGOFS Science Plan, JGOFS Report No.5.

IGBP/SCOR. 1992 JGOFS Implementation Plan, IGBP Report No.23/JGOFS Report No. 9.

Values are estimates for the decade 1980-1989 in GtC/yr for fluxes and GtC for reservoirs (IPCC 1992). The difference in the main exchange fluxes between atmosphere and ocean (solid arrows) corresponds to the oceanic uptake of anthropogenic CO₂, i.e. 2.0 ± 0.5 GtC/yr. The export production of carbon from the upper ocean is not well known; published estimates range between 4 and 20 GtC/yr. The amount of dissolved organic carbon (DOC) in the ocean is currently under debate. The values of the gross fluxes between surface and deep waters (92 and 100 GtC/yr) depend on the two levels between which the exchange is assumed to take place; very different values can therefore be chosen. The difference between these two fluxes is the net upward transport that balanced, in preindustrial time, the downward flux by particles and DOC; today, this difference is smaller, corresponding to the net downward transport of anthropogenic CO₂. For the land biosphere, only net exchange fluxes are shown. The dashed arrows of 0.6 GtC/yr from the ocean to the atmosphere, and from the atmosphere to the land biota, denote the fluxes required to balance the difference between carbon input into the ocean by rivers and continental rocks. The dashed arrow of 1.9 GtC/yr from the atmosphere to the land biota represents the flux required to balance the budget of atmospheric CO₂ perturbations.