MODELING BIOGEOCHEMICAL PROCESSES IN MARINE ECOSYSTEMS

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Summary

Ecosystems are dynamic systems and the study of their functioning and evolution requires the development of dynamic biogeochemical models. A wide application and a pronounced development of this type of model has taken place during the last two decades due essentially, to the development of computer technology, which has permitted the handling of very complex mathematical systems, and also to the increasing need of understanding marine ecosystems and their dynamic response to environmental stresses from localized pollution to global climate changes.

A review of the progresses realized in ecosystem modeling, starting from simple NPZ-type models to more complex models, describing in parallel the biogeochemical cycles of different biogenic nutrients, is made in this paper. The evolution of the complexity introduced to the model's structure and in the parameterization of biochemical laws, is analyzed. The increasing coupling of ecosystem models with hydrodynamical models in order to assess the role of physical processes on the ecodynamics is discussed. The efforts made to develop ecosystem models more and more consistent with the available observations by, for instance, improving the calibration of the most sensitive model

parameters and/or by determining the "optimal" model structure using data assimilation techniques are outlined.

Finally, some regional applications of the coupled physical-biogeochemical models for various oceanic basins and coastal and shelf seas, as well as the recent attempts at incorporating them into the global carbon cycle models are described.

1. Introduction

The oceans exhibit highly diverse and variable ecosystems governed by complicated sets of physical-biogeochemical interactions between the atmosphere, the surface ocean, and its interior, on a variety of spatial and temporal scales. The marine biogeochemical cycling involves organic matter generation by photosynthesis by primary producers constituting the first trophic level of the food web, its transfer to higher trophic levels by the feeding activities of animals, and its decomposition back to inorganic forms (Figure 1).

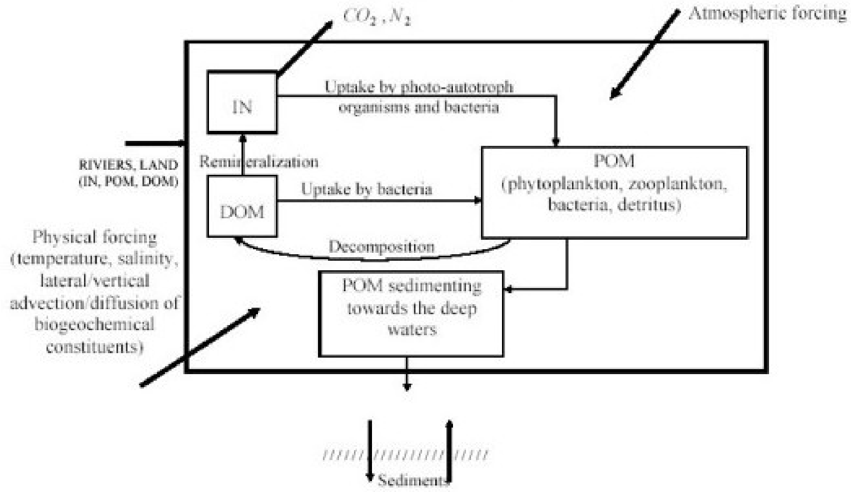

Figure 1. Schematic simplified representation of the organic and inorganic matter cycling in the ocean.

Particulate non-living organic material (the so-called detritus) is formed through the natural mortality of phytoplankton and zooplankton, or through the production of fecal pellets. Dissolved organic matter is formed by soluble organic materials released during excretion and exudation. These organic materials are then decomposed by microbial processes. The growth of primary producers is usually limited by the availability of one or several biogenic elements such as nitrogen (NO_3+NH4+NO2), bioavailable iron (Fe), phosphate (PO_4), and dissolved silicon ($Si(OH)_4$). The silicon cycle is relatively simple, affects primarily diatoms and involves only inorganic forms. The phosphorus cycle is also relatively simple; organic phosphate is converted back to an inorganic form which then becomes available again for uptake by phytoplankton. It is a rapid process, and therefore phosphorus is generally not limiting in the marine environment. Recycling of nitrogen is a more complex process. Organic nitrogen is regenerated in the water column by bacterial activities and zooplankton excretion in the form of ammonium, which is then oxidized to nitrite and then to nitrate in the nitrification process occurring in the oxygenated part of the water column. In the anaerobic systems, mostly in sediments, nitrate is consumed as an oxidizer instead of oxygen. This process is referred to as the denitrification, and results in conversion of nitrate by bacteria, into first nitrite and then to nitrogen gas, thus leading to the loss of nitrogen from the system. The atmospheric nitrogen gas may also be converted to organic nitrogen compounds by some phytoplankton species (e.g., the blue-green algae).

The ocean is the largest reservoir of carbon with rapid exchanges with the atmosphere, and it is the largest net sink for anthropogenic atmospheric CO_2. A fundamental process regulating the air-sea balance of CO_2 and the amount of CO_2 fixed in the ocean is the biological pump; namely the efficiency of photosynthesis, the foodweb structure and the amount of new nitrate entered into the euphotic zone, coupled with remineralisation at depth. In general, CO_2 is converted from inorganic to organic carbon by the photosynthesis of the phytoplankton. This is then consumed by the higher trophic levels, and some CO_2 is recycled as inorganic bicarbonate formed by interaction of free dissolved CO_2 with water. Some losses may occur from the ocean surface in gaseous form. Respiration and remineralisation processes also contribute to CO_2 production in the water column. (see *Marine biogeochemical cycles: effects on climate and response to climate change*).

All the biogeochemical processes and interactions between living and non-living components of the ecosystems cannot possibly be explored through observations alone. The satellite-based observations, which are the only means of synoptic information on regional and global scales, are restricted to the upper few meters of the water column, and their correct interpretation requires additional knowledge on the physical-biogeochemical processes taking place in the ocean interior. Comprehensive observational programs for basin-scale measurements are economically not yet feasible, and have to make compromises between temporal and spatial coverages as well as on the number of variables to be measured. The observations alone are therefore unable to provide a complete description of ecosystems. Observations generally provide distributions of concentrations and/or biomass, but hardly yield details on the spatial and temporal properties of the rates and processes controlling these distributions. Some mathematical tools are necessary to interpolate and extrapolate the available data to other parts of the region, and to complement missing data in a dynamically consistent way. The relative importance of different factors and their response to different conditions can be most efficiently analyzed using models, by varying individual factors independently.

The ecosystem models may therefore be defined as mathematical tools that help to further understand, conceptualize, and predict marine environmental processes using a simplified representation of the real world in the form of a series of differential equations. Biogeochemical modeling has made considerable progress during the last two decades thanks essentially to the development of computer technology, and increasing public concern about environmental stresses spanning from localized pollution to global climate changes. In the following sections, highlights from some important modeling initiatives are presented in order to describe the progress made in marine biogeochemical modeling within the last ten years. The biogeochemical models are first classified according to their objectives. The structural complexity introduced into the food webs and nutrient cycles are then described. It is followed by a description of efforts on the coupling of upper ocean physics and biogeochemistry, and of the role of physical controls on the biological production. The next section deals with inverse approaches used in the biogeochemical modeling for a more realistic estimation of the model parameters by means of assimilating the available data. The rest of the paper describes the regional applications of the coupled physical-biogeochemical models for oceanic basins and coastal and shelf seas, as well as the recent attempts of incorporating them into global carbon cycle models.

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Biographical Sketches

Temel Oguz was born on 13 November 1952 in Aydın, Turkey. He has B.Sc and M.Sc degrees in Physics from the Middle East Technical University (METU), and Ph.D degree in Dynamical Meteorology and Oceanography form the University of Reading (United Kingdom). Dr. Oguz joined Institute of Marine Sciences of the METU as an Assistant Professor in 1981. He was promoted to Associate Professor in 1986 and full Professor in 1992 at the same institution. Dr. Oguz is recognized for his work on Black Sea circulation and ecosystem dynamics. His major interests within the last 10 years were mainly concentrated on studying the transports and ecological processes that control biogeochemical cycles in the Black Sea using coupled physical-biogeochemical models with data assimilation capabilities. More specifically he has been working on circulation dynamics, their effects on the biogeochemical transports, and understanding biogeochemical processes in the Black Sea.

Recent publications:

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