Climate Change Research: Evaluation and Policy Implications
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Global Emiliania Modeling Initiative (GEM)

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Abstract
Biological climate forcing is important, but difficult to assess in quantitative terms, as it depends on the ecological and evolutionary success of many different interacting organisms. The Global Emiliania Modeling Initiative (GEM) addresses this problem by focusing on a single key organism, the unicellular calcifying alga *Emiliania huxleyi* and by subsequent generalisation to include the climatic effects of larger biological entities, such as the total calcifying plankton. In this paper, the general strategy of GEM is worked out. We believe that our approach may be more widely applicable.

1. THE PROBLEM

Three major forcing functions are distinguished by which the marine pelatic biota may influence the global climate system [1]: (1) the drawdown of CO2 from the upper mixed water layer and the atmosphere to intermediate and deep waters by the formation, export and remineralisation of particulate organic carbon (POC) (the organic carbon pump); (2) the removal of dissolved inorganic carbon and alkalinity from the upper mixed layer and its partial regeneration in the deep ocean by the formation, sinking and partial dissolution of calcium carbonate (the carbonate pump); and (3) large-scale albedo effects mainly owing to the formation of highly reflecting clouds following gaseous emissions of dimethyl sulphide (DMS) from algal blooms.

The climatic effects of these mechanisms vary geographically and through time, as they depend on the abundance and the behaviour of the participating organisms. Many species of algae, protozoa, bacteria, viruses and animals interact with the physico-chemical environment and with each other, and it is from all these interactions that the climatic effects emerge. In view of these complexities, the crucial question is: Can we formulate general rules that adequately describe these interactions and that at the same time are simple enough to be useful for climate modelling?

The *Global Emiliania Modelling Initiative (GEM)* provides a 'model system' approach [2] whereby this fundamental problem is addressed.It assumes that, at all levels of organization, biological systems obey a limited set of fundamental rules. GEM is an attempt to track down some of these rules and to implement them in models of biosphere-climate interactions.

Although this 'model system' approach is primarily applied to the calcifying pelagic biota, it is in principle applicable to many other systems [3]. The approach tends to reveal the conserved and widely distributed attributes of living systems involved in biogeochemical cycling and climate forcing, at levels of biological organisation ranging from (macro)molecules to global-scale phenomena. Diversity is considered as variation on this common theme. We therefore expect this methodology to lead to the formulation of stylized and simplified biogeochemical models, well adapted to the resolution of physical and chemical models of ocean dynamics.

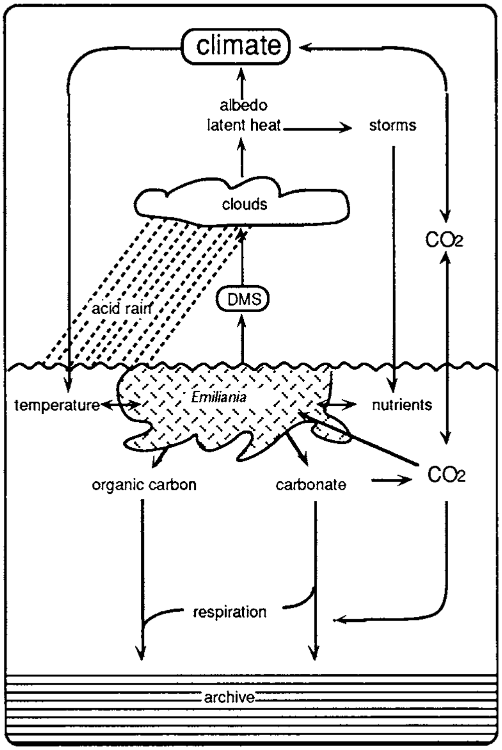

Figure 1. Overview of the *Emiliania huxleyi* system

2. GEM - A SYSTEM'S APPROACH

The concept underlying the Global Emiliania Modelling Initiative (GEM) is clear and attractive [2]: a single dominant organism, the coccolithophore alga *Emiliania huxleyi,* is selected as an exemplary model system, much as the bacterium *Escherichia coli* became a key to the biochemistry of all organisms.

Climate forcing by *E. huxleyi* is studied in depth in an interactive modelling and experimental investigation and the acquired understanding of this system then serves as a key to investigate the wider implications of biological climate forcing.

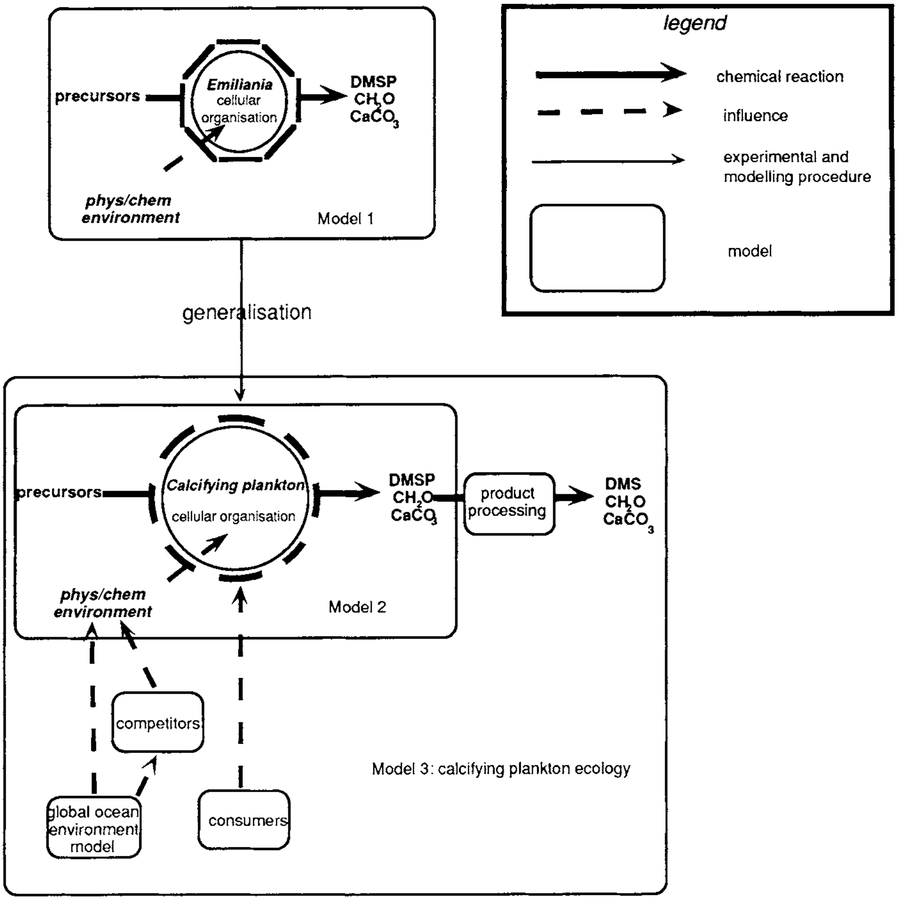

Figure 2. GEM modeling of net calcium carbonate, organic carbon and DMS production

Fig. 1 is an overview of the major oceanic and atmospheric processes associated with the *E. huxleyi* phenomenon. *E. huxleyi* is a major component of virtually all open marine plankton world-wide, and forms very large blooms, particularly at mid latitudes. The figure shows that in *E. huxleyi* all three climate forcing functions are coupled, and that the history of this system can be reconstructed from the rich archive at the floor of the deep sea. Major assets of the GEM strategy are the following: (1) it offers a key to the problem of biological diversity, as in-depth information on *E. huxleyi* may be extended to

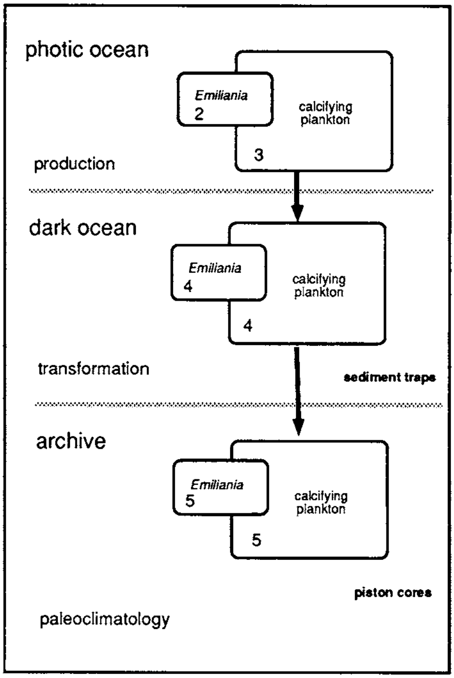

Figure 3. GEM modeling of (1) net calcium carbonate, organic carbon and DMS production in the photic ocean (see fig. 2), (2) export production into and transformation in the dark ocean of calcium carbonate and organic carbon, and (3) preservation of these materials in the geological archive.

include a wide range of other organisms; (2) it highlights the highly non-linear character of the biological intervention in the climate system; (3) it allows the intimate coupling of the three forcing functions to be modelled; (4) it optimally exploits the unique accessibility of *E. huxleyi* for laboratory and field research; and (5) the integration of biological and stratigraphic studies permits quantification of carbonate fluxes to the ocean floor as well as extensive model validation by comparing biological responses to diverse climate regimes.

3. GEM STRATEGY IN OUTLINE

A simplified overview of the GEM research strategy is worked out in Fig. 2 and 3 (not all relationships are shown). Fig. 2 shows how a combination of dedicated physiological and molecular genetical research on *Emiliania huxleyi* leads to a model simulating the $CaCO_3$, CH_2O and DMSP output of a single cell, as it depends on physico-chemical environmental conditions (model 1) (NB. DMSP is the precursor of DMS). Laboratory studies additional to the work on *E. huxleyi* on the major represented organisms lead to a generalised model of $CaCO_3$, CH_2O and DMSP productivity (model 2) by the calcifying biota in the pelagic ocean.

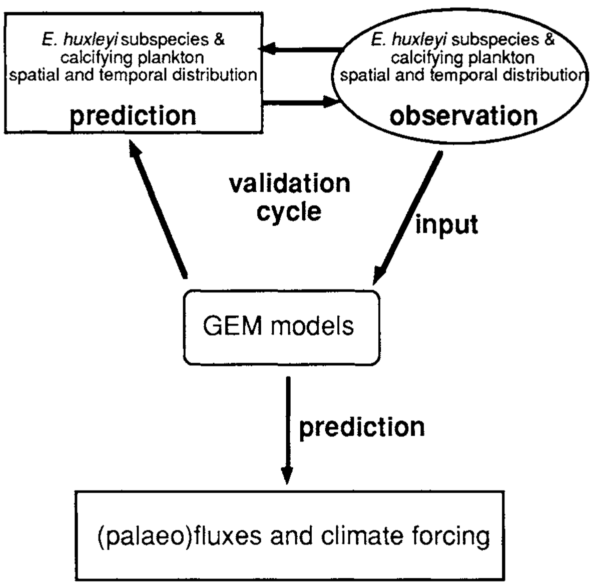

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Fig. 4. Validation cycle of GEM models required prior to incorporation into GCM's and estimation of climate forcing by pelagic calcifying biota.

By combining model 2 with a global ocean environment model, the potential gross production of $CaCO_3$, CH_2O and DMSP by the calcifying plankton in general is predicted. Competing organisms (preferably classified in functional groupings such as phytoplankton taxa thriving under phosphate, nitrate or silica limitation) are known to modify the physico-chemical conditions and thus the output of the calcifying plankton. To account for these effects, an extra competition model is included. Furthermore, special models are introduced to implement the effects of consumers on the proliferation of the calcifiers and on the fate of their products ('consumers' and 'product processing' models). These interacting factors are combined in model 3, which predicts the actual global net production of $CaCO_3$, CH_2O and DMS by the calcifying biota. Model 3 is validated by laboratory cultures in chemostats, mesocosms in the Norwegian fjords, *in situ* studies of blooms in the ocean and by remote sensing.

Models 1 - 3, which apply to production in the photic ocean, provide an input for export production and transformation models (mainly simulating CaCO3 and biomarker sedimentation and dissolution fluxes in the dark ocean and the top sedimentary layer) and subsequent carbonate palaeoflux (Fig. 3). The latter models allow, vice versa, an interpretation of the geological archive in terms of global productivity of carbonate, organic carbon and DMS by the calcifying biota in the geological past. This geological part of GEM research concentrates on laboratory work of coccolith dissolution and biomarker degradation, as well as sediment trap and core profiling at chosen localities in the N. Atlantic and the Pacific.

Comparison of the geological and biological data with model predictions will allow extensive validation of the GEM models (fig. 4). Optimisation of the models will finally lead to increasingly realistic predictions of (paleo)fluxes and climate forcing by the marine calcifying plankton.

4. REFERENCES

1 P.M. Holligan. In: P.G. Falkowski and A.D. Woodhead (eds.), Primary productivity and biogeochemical cycles in the sea, Plenum, New York (1992) 487-501.

2 P. Westbroek et al. Global and Planetary Change 8 (1993): 1-20

3 P. Westbroek et al. In: Doumenge, F. (ed.), Past and present biomineralization processes. Considerations about the carbonate cycle. Monaco Musée Océanographique (1994) num. sp., 13: 37-60.