4th Dynamic Green Ocean Project Workshop

December 10, 2004

Report, draft 1.
Villefranche-sur-mer, 21-22 October, 2004.
http://www.bgc-jena.mpg.de/bgc-synthesis/projects/green_ocean

In attendance:

1. Louis Legendre
2. I. Colin Prentice
3. Sandy Harrison
4. Richard Rivkin
5. Corinne Le Quéré
6. Andrew Watson
7. Christine Klaas
8. Dieter Wolf-Gladrow
9. Erik Buitenhuis
10. Laurent Bopp
11. Leticia Cotrim da Cunha
12. Meike Vogt
13. Manfredi Manizza
14. Shubha Sathyendranath
15. Trevor Platt
16. Marie-Alexandrine Sicre
17. Icarus Allan
18. Lars Stemmann
19. Cyril Moulin
20. Marion Gehlen
21. Fabrizio D'Ortenzio
22. Julia Uitz
23. Débora Iglesias-Rodriguez
24. Olivier Aumont
25. Emmanuel Devred
26. Frede Thingstad
27. Chris Reid

About a third of the participants attended a green ocean workshop for the first time.

1 Introduction

The Dynamic Green Ocean Project was launched in 2001 by a group of scientists with a common interest to develop a new, more comprehensive model of the oceanic compartment of the Earth system, with a view to improving our understanding of the functioning of the global ocean in the past, present and future.

During the first three workshops, we defined objectives and laid out a plan to develop such models, focusing on the distinction of Plankton Functional Types (PFTs) and on the use of the widest possible range of reliable observations to build and evaluate the models. See the Green Ocean web page for the full description of the objectives, and for the reports of the previous workshops. The fourth workshop has focused on a few topics where progress has been done in the past year, both on the modeling and on the observation side. This report summarizes the arguments put forward during the discussions (Sections 2-7), briefly describes the ongoing and planned activities (Section 8), and lists the needed developments for which there are yet no plans (Section 9).

2 Stability of marine ecosystems in models

When more than one phytoplankton type is included in a global ecosystem model, the natural response of the model is to create *kingdoms* where the PFTs dominate in specific regions, but rarely co-exist. In nature, both kingdoms and co-existence is observed. This problem could have several sources and thus different solutions:

- the problem of kingdoms in models can be caused if loss rates particularly through grazing are not in phase with the growth rate of phytoplankton. In models, the grazing rates and preference for food are fixed as a function of the size of zooplankton. The preference for food is particularly poorly constrained because of the total lack of data. When the abundance and groups of phytoplankton change, the grazing has to be changed in parallel to account for the new distribution of the food. Tests with PISCES-T provide support to this hypothesis. The grazing rate of meso-zooplankton was varied within the range of observed values. The modeled meso-zooplankton biomass was closest to observations when the total chlorophyll was at its maximum. It is possible to calculate the grazing rate that would allow co-existence of the PFTs in models.

- theory on predator-prey relationships suggest that the addition of small non-linear terms in the PFT equations leads to steady states with more species than resources. The non-linear terms could represent for example physical aggregation of grazing. More basic connections to maximum entropy production and the second law of thermodynamics could help to improve the foundations of ecosystem models and would need to be explored further.

- the presence of kingdoms could be naturally avoided if local conditions provide different niches in space. This is the case in terrestrial modeling, where the forests offer different conditions as the vegetation moves from the soils to the top of the canopy. A parallel in the ocean would be the mixed layer and the location below the mixed-layer and above the euphotic depth (where there is still enough light for photosynthesis).

- disturbances can create variable conditions that could allow co-existence of different PFT at one location, although the PFTs would be present in different times. The seasonality is one obvious disturbance, but also storms and eddies can lead to a total de-stratification of the water column and a restoring of temperature and nutrient conditions over periods of a few days. The models we use are forced with daily fields from NCEP, and thus should include at least part of the observed storm activity, although no-one could comment on the performance of that aspect of the models. Our global models do not resolve eddies, thus this has to be indirectly parameterized.

3 Understanding ecosystem behavior using enrichment experiments and natural laboratories

The multiplication of Fe enrichment, P enrichment, and mesocosm experiments provide test beds which allow us to challenge our understanding of ecosystem behavior, and which provide unique evaluation data for the short-term response of DGOMs. The study of natural environments have also been underexploited. One "natural experiment" to test modelling of changing atmospheric Fe source to HNLC regions would be the Ocean Station P record – with forcing provided by modelling of dust transport from Asia. Other regions include the Fe plume coming out of the Kerguelen plateau and Marquise Islands. Further, large-scale climatic oscillations such as El Niño events or the North Atlantic Oscillation create climate variations that are similar to the expected climate change of this century.

- ten iron enrichment experiments were made during 1993-2004, four in the Southern ocean, two in the North Pacific, and four in the eqpac. All experiments show an increase in chla ($\sim$0.3-19 mg/m^3) and decrease of fCO2 (14-95 uatm). The amplitude of the observed responses was inversely proportional to the mixed-layer depth (MLD). Eisenex shows large change in the community structure (shift towards large diatoms) but no change in the physiological characteristics.

- Fe experiments show small or no increase in export of organic matter after two weeks (end of experiments). The reason for this is debated, but could be due to the fact that large copepods which graze on large diatoms need about 2 weeks for the hatching and development of their eggs. Some experiments have started to count the presence or absence of eggs as an indirect way to assess the response of zooplankton.

- P enrichment experiment in the Mediterranean sea has driven no increase in primary production but an increase in bacteria biomass. Bacteria can use N from DON, but phytoplankton were limited by N. The increased bacteria activity lead to a decrease in phytoplankton biomass, although an increase in P:C was observed (luxury consumption of P). P is also needed for eggs production by copepods. The modeling of such a behavior requires the inclusion of a complex ecosystem model and of N and P as separate nutrients.

- Fe enrichment experiments were done in the ORCA-PISCES model. Chl increased by 3-40 times its initial concentration. pCO_2 decreased by 30-90 ppm. The modeled response was also inversely proportional to the MLD. The export showed a mixed response to the enrichment.

- Fe enrichment was imposed everywhere on the global model. Because of the seasonality of light (and plankton growth), Fe is used only a few months per year and the global enrichment did not result in a full use of the surface nutrients. The results from this model show an increase in export by 1 PgC/y only. The response decreases with time due to the increasing limitation by other nutrients. As soon as Fe enrichment is stopped, the export ceases and the primary production falls to levels below the starting of the experiment because other nutrients have been depleted.

- the ORCA model has a too stratified MLD in the southern ocean during summer (10 m compared to the observed 60 m). This problem seem to be caused by a wrong transfer of the wind energy under stratified conditions in TKE models. Fe enrichment experiments were repeated restoring the MLD to observed values. This introduces a lag and reduces the amplitude of the chla increase.
- after 50 years of Fe enrichment, the model shows an increase of 1 mgChl/m3, more diatoms, more N2-fixation in the tropics, increased anoxic conditions due to more export, potentially more N2O production (but only a few ppb), 10-15% decrease in DMS.
- an analysis of zooplankton abundance in the North West Atlantic showed a significant correlation with the position of the detachment of the Gulf Stream. Experiments and analysis of the ERSEM ecosystem model can reproduce such a behavior, although it is not present statistically in the forcing variables. This experiment suggests that the cascade of processes amplifies a climatological signal initially hidden in the forcing variables.

4 Processes that influence the export and remineralization of particles

There was a lot of progress in recent years to build and analyze large data sets of bacterial consumption and export fluxes. The recent use of cameras to record the changes in properties of sinking particles add further information to understand the fate of organic matter.

- the analysis of a time-series of particles vs depth results at the Dyfamed station (Mediterraneen sea) shows that the dry weight of the particles do not change below 400 m. Only the size distribution changes with large particles being less abundant (i.e. larger number of particles). The implication of this observation is that sinking speed of particulate matter must decrease with depth between 100 and 1000 m. This contradicts previous knowledge which suggest an increase in the sinking rate below 100 m, although the number of data used to constrain this information is scattered or inexistent. Christine Klaas's recent analysis of sediment trap data in shallow waters support a decrease of sinking speed with depth.

- the representation of southern ocean export in the models is still far away from that estimated by R. Schlitzer based on an inversion of biogeochemical tracers. PISCES-T could not reproduce Schlitzer's high export, even when extreme values were assumed for meso-zooplankton rates and for the remineralization of organic matter. It is possible the Schlitzer may over-estimate export as observations are mostly available during winter. Long simulations with PISCES reproduce biogeochemical tracers (except Si) without the need for high export flux in the Southern Ocean. However, if Schlitzer is correct, it suggests that important processes are missing in the model. These could be the transport of carbon by the vertical migration of zooplankton, the export by salps and other mucous web feeders and macro-zooplankton, or different rates of growth for meso-zooplankton at high latitudes. Export should be studied with models that do not include nutrient restoring, because restoring enhances primary production due to the artificial supply of nutrients (from 58 to 95 PgC/y).

- the growth of the PFT is parameterized as a function of temperature. Although this may be observed in reality, it may also hide the response of different species that are present under different conditions. Within a PFT, there may be a need to include further a growth size spectrum. This would allow us to really isolate the temperature dependence of the processes, and not to use temperature for a proxy for size. An intermediate solution could be to isolate the species that are present at high latitudes which are the ones that appear different from the rest.

- 60-80% of the total CaCO3 production dissolves in the upper 500-1000 m, although the saturation horizon is well below that (3000 and 4500 m for aragonite and calcite dissolution, respectively). The pH of sea water is very important for dissolution. The fact that dissolution does not necessarily occur in open water but rather in aggregates or in the zooplankton guts, where the pH may be different, may explain the gap between observed and theoretical dissolution. The representation (or parameterization) of these processes is essential to obtain reasonable distribution in carbon species.

- the ratio of nutrients coming from rivers also has an influence on the export of organic material in some regions of the world. The location of the river mouth is much more important than the river load itself to determine its influence on biogeochemistry: rivers that are located in regions of upwelling and that feed oligotrophic waters have a large influence on the biogeochemistry of the open ocean. This is illustrated by the larger impact of South West Africa rivers compared to the Amazon and other South American rivers. Among nutrients brought about by rivers, Fe has the largest influence on the biogeochemistry of the open ocean. However the amount of Fe that precipitates in estuaries is difficult to estimate.

5 Importance of light quality

On way by which marine ecosystems and climate interact is through the impact of phytoplankton biomass on the penetration of light in the surface ocean.

- the penetration of solar radiation in the ocean transforms the spectra of radiation because infrared is absorbed at the top, whereas blue light can penetrate for 10s of m if the water is clear. In oligotrophic waters, the maximum light intensity is in the blue, and it is in the green in eutrophic waters. PFTs have specific abilities to absorb different wave length: diatoms absorb green light more efficiently than blue light, whereas the prochlorophytes do the opposite. These different affinities for light create a positive feedback between light color and PFTs, whereby the presence of a PFT modify the spectrum of light to its own advantage. To resolve this feedback, a minimum of six wave bands must be resolved in models.
- in the models, light absorption is spectral with 2 (in PISCES-T) or 3 (in PISCES) bands, but the absorption of light by PFTs is not spectral.

With the 2-band model, the presence of total biomass amplifies by 10% the seasonality of SST, MLD, ice cover, albedo, and the fluxes of CO2, O2 and DMS. Similar simulations are being analyzed whereby the effect of individual PFTs on light absorption is considered. The impact on ocean physics is mostly similar to the total biomass model, but the feedback on the ecosystem composition and on biogeochemical fluxes is very different, suggesting that individual PFTs should be considered for climate change experiments and lending support to the inclusion of a full spectral model.

6 Assessment of PFTs distribution for the global ocean

The development of DGOMs has to be paralleled by an effort to quantify the biomass of the different PFTs in order to assess the model performance. Whereas it appeared at the beginning of this project that databases of PFTs would pose huge challenges, several independent methods are emerging to provide global maps of PFT concentrations. In addition to the pigment database and coccolithophorid blooms presented in previous workshops, new and promising methods include

- an estimate of the presence of the most frequent PFT among Haptophytes, SLC (cyanobacteria), Prochlorococcus and diatoms. This method uses the information that PFTs have a different absorption spectra for different wave lengths. Thus an analysis of the absorption of light gives information on the most abundant PFT.

- an analysis of the continuous plankton recorder (CPR) data. This simple instrument has been pulled behind ships since 1931 in the North Atlantic, and transects are starting in the North Pacific and Southern ocean. The CPR provides mainly information on the ocean color, which is linearly correlated with chla. Furthermore, analysis of large zooplankton has been extensively done, and the presence or absence of smaller PFTs has been documented but much of the data has not yet been analyzed and a comparison with ocean models still needs to be done. Results of the CPR show a shift in chla starting in 1987, about one year **before** the observed shift in temperature.

- analysis of satellite observations to detect favorable conditions for diatom blooms.

7 Challenge raised by paleo reconstructions

Reconstruction of ocean temperatures in the past is based on the application of statistics techniques (transfer function, modern analogues) to species assemblages (e.g. foraminferal, dinoflagellate and diatom assemblages), changes in shell chemistry (and specifically the ratio of Ca/Mg), isotopic composition (e.g. for foraminfera) and alkenone palaeothermometry. Reconstructions of ocean temperatures at the last glacial maximum (ca 21,000 years ago) using each of these different methods have been made by the MARGO project. Over most regions of the world, the different methods lead to similar conclusions. However, in the North Atlantic, statistical approaches using foraminfera assemblages indicate conditions colder than today whereas dinoflagellates and alkenone measurements indicate conditions warmer than present. The difference is between 4-6C.

It is possible that factors other than the SST have influenced the ecology of forams and Dinocysts, but it is not possible to tell how at this point, and why this would be specific to the North Atlantic. For example, the extension of the seasonal sea-ice, the mixing depth or the nutrient limitation may all have influences on shell sizes and isotope composition. The PMIP community (Paleo Modeling Intercomparison Project) is about to produce an archive of model simulations for the LGM, which could be exploited to resolve this question using DGOM models.

8 Ongoing and planned work

Here is information on some of the ongoing or planned work for this year.

- both the Jena and the Paris groups are working on climate change simulations over at least the 2000-2050 period. Some input will be requested for sensitivity studies of different rates to SST, pH, salinity and stratification.

- Erik is working on the analysis of the model simulations with 5 PFT (PISCES-T plus calcifiers). Erik is also working on the implementation of the light acclimation model of Geider 1997, which introduces modifications to the chla:C ratio of the PFTs.

- Richard R. and Christine are working on a database of micro-zooplankton rates and biomass which would allow Erik's work on meso-zooplankton to be extended, and would improve the export fluxes of organic matter (hopefully).
- Christine and Lars are working (independently) on the sinking and transformation of particles in the meso-pelagic region (100-1000 m).
- Laurent is working on the inclusion of bacteria in PISCES. Erik and Meike will incorporate some of Laurent's work in the Jena-DGOM, and Erik will push it further to include all our remaining PFTs except macro-zooplankton. At a further point, Erik will relax the Redfield ratio for P and C.
- Meike (with help from Laurent) is working on the inclusion of DMS as a prognostic tracer in the Jena-DGOM. Meike will include DMS-producers if still needed.
- Manfredi, Shubha and Trevor are working on the spectral model and on feedbacks between climate and ecosystem via light.
- Erik, Corinne, Meike and Julia are working on model evaluation with the pigment database of Julia and with the CPR and satellite data.
- Olivier and Laurent are working on the N cycle. An anonymous post-doc (funding by Greencycles) will include N2-fixers starting in Sept. 2005.

9 Needed work, no plans yet

Some items were brought up at this and previous meetings which require more theoretical work, data synthesis and/or model developments. We do not yet have a strategy for these items below. See previous reports for further details.

- the iron cycle

- data compilations on the rates of growth of all PFTs
- include internal quota of nutrients in PFTs
- consider within-PFT characteristics (such as size)
- better quantification of CaCO3 dissolution rates
- improve the quantification of coastal processes
- improve the quantification of external sources of nutrients
- introduction of a sediment model
- include a more explicit treatment of DOC and POC with components of terrestrial origin
- include macro-zooplankton and the life-cycle of zooplankton
- full coupled simulations of climate change
- new genetic methods improve our knowledge of the characteristics of PFTs. Although this is yet too early, some of this information can be used to ameliorate the representation of PFTs in DGOMs.
- simulations of the LGM