Report

First Meeting of the
JGOFS Global Synthesis Working Group

Royal Netherlands Academy of Arts and Sciences
Amsterdam, the Netherlands

6 July 2001

Introduction

The first meeting of the GSWG took place on 6 July 2001 at the Royal Netherlands Academy of Arts and Sciences in Amsterdam, Netherlands. All group members except M. Behrenfeld and Y. Yamanaka participated. As guests, J. Campbell, N. Hoepffner and P. Schlittenhardt were invited to give an overview talk on the application of remote sensing methods for the determination of marine productivity and to provide background knowledge on satellite sensor technology and details of primary productivity algorithms. For a complete list of participants, see **Annex 1**.

The purpose of the meeting was threefold:

1. To discuss and define the terms of reference for the group.
2. To initiate the planning for an open workshop on global ocean productivity and the fluxes of carbon and nutrients.
3. To obtain an overview over the present scientific status of different methods for the determination of marine productivity and the transports of carbon and nutrients.

A detailed meeting agenda is given in **Annex 2**.

1. Terms of Reference

The GSWG terms of reference, which were drafted following the group discussions, have been later approved by JGOFS SSC Executives with only minor modifications (see **Annex 3**).

2. Workshop

JGOFS has employed a large variety of different approaches for the determination of marine productivity and the fluxes of carbon and nutrients. The methods range from satellite observations, shipboard measurements, sediment traps, benthic flux determinations to numerical modelling on regional or global scales. With JGOFS now in the synthesis phase and the end of the project in sight, there is a pressing need to compile and compare the results from the different methods and to investigate whether a consistent picture emerges. The overview talks given at the GSWG Amsterdam meeting (see below for summaries) indicated that significant discrepancies between different techniques exist and that more multi-disciplinary projects aimed at comparing and/or combining different techniques should be carried out.

To foster the interaction and cooperation between scientists from different research fields (observationalists and modellers), the GSWG together with the OCMIP JGOFS-GAIM Task Team is planning for a workshop on *Global Ocean Productivity and the Fluxes of Carbon and Nutrients: Combining Observations and Models* in May/June, 2002 in Ispra, northern Italy. This workshop will be open to all scientists that contribute to the overall goal of determining marine productivity rates and the fluxes of carbon and nutrients. A call for abstracts will be issued in early December.

3. Overview Talks

Satellite-based estimation of marine primary production: current status and future directions (J. Campbell)

Janet Campbell from the University of New Hampshire reviewed the current status and future directions of remote sensing technologies that yield data for the estimation of primary production in the ocean. Two instruments, SeaWiFS and MODIS, are currently providing global coverage for ocean colour data. Plans are underway in the US, Europe and Japan to deploy improved instruments with more spectral bands, better spectral resolution and better spatial or temporal sampling resolution. To obtain productivity values from the primary sensor data (radiance at the top of the atmosphere) requires application of atmospheric corrections and the estimation of surface water chlorophyll or pigment concentrations as intermediate steps. Primary productivity is then obtained from the estimated surface chlorophyll values. Because this step involves the transformation of concentration data (chlorophyll) into rate constants (productivity), the procedures can be expected to be non-trivial. Presently, more than a dozen different algorithms of varying complexity are in use worldwide, which all express productivity as a function of surface chlorophyll and a number of additional parameters, such as light availability, depth of euphotic zone, and optimal water-column productivity. These free parameters have to be determined independently, which, for some parameters, requires *in situ* productivity calibration measurements on a global scale.

Campbell reported about a round-robin comparison of satellite primary productivity algorithms (Campbell *et al.*, 2001) that was conducted to determine the accuracy of twelve different approaches in predicting depth-integrated primary production from surface chlorophyll values. For this comparison, observations at 89 stations in geographically diverse oceanic provinces were used. Comparisons of algorithm-derived productivity values with ^{14}C uptake measurements showed relatively large deviations on the order of a factor of two. In addition, many satellite algorithms exhibited significant systematic deviations at low, medium or high productivity levels. Part of the discrepancies might be due to problems with the ^{14}C productivity measurements themselves, however, the large differences among the satellite algorithms suggest that more algorithm development and a much broader calibration database for the parameters of the algorithms is needed. While remote sensing undoubtedly is an ideal tool for detecting spatial and temporal variability at the ocean surface (due to good spatial and temporal data coverage), satellite-derived numerical values for ocean productivity on regional or global scales still have significant errors and care should be taken when using them for large-scale or global budgets.

Currently, another satellite PP model comparison exercise, called the Primary Production Algorithm Round Robin 3 (PPARR3), which builds from previous efforts led by Janet Campbell

(PPARR1 and PPARR2) is underway. For more information on this new study, contact Mary-Elena Carr (E-mail: mec@pacific.jpl.nasa.gov).

Behrenfeld M.J., *et al.* 2001. Biospheric primary production during an ENSO transition, *Science*, 291, 2594-2597.

Behrenfeld M.J., Falkowski P.G., 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnol. Oceanogr.*, 42, 1-20.

Campbell J., Antoine D., Armstrong R., Arrigo K., Balch W., Barber R, Behrenfeld M., Bidigare R., Bishop J., Carr M.E., Esaias W., Falkowski P., Hoepffner N., Iverson R., Kiefer D., Lohrenz S., Marra J., Morel A., Ryan J., Vedemikov V., Waters K., Yentsch C., Yoder J., 2001. Comparison of algorithms for estimating ocean primary production from surface chlorophyll, temperature and irradiance, *Glob. Biogeochem. Cycl.*, in revision.

Model estimates of new and primary production: influence of model physics and numerics (A. Oschlies)

Andreas Oschlies from the University of Kiel presented a compilation of model-derived estimates of marine new production obtained by simple, coarse box-models or from more complex inverse or high-resolution, dynamical models. For the global ocean carbon export production he finds systematic and significant differences between the models that seem to be related to the underlying model architecture but not to the details of the implementation of the biogeochemical processes. For the early box models that represent the global ocean with less than 10 or 20 boxes, and in most cases, only resolve a surface and a deep volume, the export fluxes are relatively small, ranging between about 2 and 5 GtC yr^{-1}. This is in contrast with results from a large number of more complex coupled physical/biogeochemical models with horizontal grid sizes between 2 and 5 degrees and vertical resolution between 100 and 500 m. These models have carbon export fluxes that are more than twice as high as those of the simple box models.

Oschlies attributes this discrepancy to differences in the model physics and numerics and specifically to the unrealistically large explicit and implicit diapycnal mixing present in the coarse resolution dynamical models. The obviously too large vertical mixing causes too large upward nutrient fluxes and subsequent downward particle fluxes. When increasing the spatial and temporal resolution of his North Atlantic model and incorporating explicit treatment of eddy and mixed layer processes, Oschlies finds smaller export fluxes again (extrapolating to global ocean). Comparison of his model export production with independent estimates gave mixed results: whereas there seems to be good agreement in productive waters of the north and west Atlantic, the model could not accommodate the relatively large export estimate of Jenkins (1982) in the beta triangle region which is based on oxygen and transient tracer measurements.

It was noted that in addition to the differences in the model physics, differences in the assumed depth of the euphotic zone between the different models could be responsible for the different carbon export production estimates because of the sharp decrease of particle fluxes with depth in the upper water column. Some group members expressed their belief that a “too loose” definition of what is meant by euphotic zone was responsible for part of the discrepancies of export fluxes found in the literature.

Oschlies A., 2001. Model-derived estimates of new production: New results point towards lower values. *Deep-Sea Res. II*, 48, 2173-2197.

Oschlies A., 2000. Equatorial nutrient trapping in biogeochemical ocean models: the role of advection numerics. *Global Biogeochem. Cycles*, 14, 655-667.

Export production in the Southern Ocean derived from dissolved nutrient distributions: comparison with satellite based estimates (R. Schlitzer)

Reiner Schlitzer from the Alfred Wegener Institute showed results of a comparison of carbon export fluxes from a global ocean inverse model with estimates based on satellite data. In his model, the downward particle fluxes are constrained by water-column dissolved nutrient, carbon and oxygen fields, which contain structures produced by particle formation in the euphotic zone and remineralisation below. Information from within as well as from below the productive surface layer is utilized in the model, while the satellite values derive from observations of the surface processes only. Over most of the global ocean, the model results and satellite values compare reasonably well (factor of about two; sign of the difference in many areas changes, depending on satellite sensor, specific dataset or algorithm used). However, two large areas are identified which exhibit significant discrepancies independent of specific model solution or satellite field: (1) in the Southern Ocean south of 50°S, the model export fluxes are more than two times higher than satellite fluxes, whereas (2) over most parts of the eastern North Atlantic, the model predicts much smaller carbon exports compared with satellite estimates. The higher downward carbon fluxes in the Southern Ocean (compared with satellite-based estimates) remain if the model is fitted to chlorofluorocarbon (CFC) and natural radiocarbon data in addition to hydrography and nutrients as for the base experiments. Including the tracer data in the model further constrains vertical transports and exchange rates as well as the strength of the global overturning circulation. A numerical experiment, which aimed at finding a model solution that could explain the observed nutrient distributions with a low productive Southern Ocean (as suggested by satellites), failed because of large remaining tracer misfits.

It is argued by Schlitzer that the discrepancy could be due to an underestimation of productivity by the satellites in the sub polar and polar Southern Ocean. Possible causes could be inappropriate corrections for the frequently occurring subsurface chlorophyll maxima not visible to the satellite and due to an unsatisfactory overall calibration in this region. Among more than 3000 calibration points used for the Behrenfeld and Falkowski (1997) study only 32 are from the Southern Ocean.

Caldeira K., Duffy P.B., 2000. The role of the southern ocean in uptake and storage of anthropogenic carbon dioxide. *Science* 287, 620-622.

Schlitzer R., 2001. Carbon export fluxes in the Southern Ocean: results from inverse modeling and comparison with satellite based estimates, *Deep Sea Res. II*, in print.

Schlitzer R., 2000. Applying the adjoint method for global biogeochemical modeling, In: *Inverse Methods in Global Biogeochemical Cycles*, Kasibhatla, P., M. Heimann, D. Hartley, N. Mahowald, R. Prinn and P. Rayner (Eds.), *AGU Geophys. Monograph Series*, Vol. 114, 107-124.

The relationship between primary and export production in the open ocean - Theory and observations (E. Laws)

Ed Laws from the University of Hawaii reported on new theoretical studies on the relationship between primary and export production in the ocean. This is an important aspect of marine biogeochemical cycles because reliable estimation of export fluxes from available primary productivity data is a fundamental requirement for the determination of the biological pump intensity and for the oceanic uptake capacity for anthropogenic CO_2. Laws and co-workers used a complex pelagic foodweb model including small and large phytoplankton and searched for "maximum stability" solutions under various environmental conditions (*e.g.*, temperatures).

In contrast to Eppley and Peterson (1979), who assumed *ef* ratios (export production/primary production) to be independent of temperature, Laws *et al.* find that *ef* ratios and their dependence on productivity vary with temperature. In warm water (T>25°C), the export efficiency is relatively small (*ef*~0.1-0.2) and only weakly dependent on primary productivity (*ef* rises slightly with PP). At low temperatures, however, the *ef* ratio is highly dependent on productivity (increases non-linearly with production; saturates at high PP) and can be as large as 0.67 in high productivity waters. When comparing these results with independent EP/PP measurements, Laws finds much better agreement compared to temperature-independent *ef* values of Eppley and Peterson. The Laws *et al.* results suggest that the carbon exports in productive tropical and subtropical waters might have been overestimated considerably in the past.

Eppley R.W., Peterson B.J., 1979. Particulate organic matter flux and planktonic new production in the deep ocean. *Nature* 282, 677-680.

Laws E.A., Falkowski P.G., Smith W.O., Ducklow H., McCarthy J.J., 2000. Temperature effects on export production in the open ocean. *Glob. Biogeochem. Cycl.*, 14(4), 1231-1246.

Particle fluxes to the deep ocean: recent findings, problems and strategies (G. Fischer)

Gerd Fischer from the University of Bremen summarized measurements of particle fluxes in the water column as obtained by moored or drifting sediment traps. When normalizing the trap measurements to a common depth (1000 m) using the Martin curve and comparing with primary productivity values taken from satellite maps at the trap location, he finds a general positive correlation with the particle flux at 1000 m amounting to between about 0.2 and 3% of the primary production (percentage increasing with productivity). However, the scatter is large and some regions such as the Southern Ocean with relatively large water column particle fluxes but low productivity estimates from satellites stand out with flux percentages of more than 3 (possibly because of too low PP estimates from satellites).

The opal-to-carbon ratio of the sinking material varies between about 3.3 in the North Pacific and 0.1 in the Greenland Sea and seems to be closely related to surface water dissolved silica concentrations which are determined by the global overturning circulation. There seems to be an abrupt shift from carbonate-dominated production and flux for surface water silicate/nitrate ratios below 2 (*e.g.*, Atlantic) to an opal-dominated flux for Si/N values above 2 (Southern Ocean, North Pacific). Trap data from time-series stations show changes in the opal/carbonate ratio of the sinking material on decadal time scales. The direction of the changes appears to be opposite in the Atlantic when compared to the east Pacific, and the causes for these changes are yet unclear.

There is mounting evidence from radionuclide measurements and inverse modelling that traps in the upper 500 to 1000 m of the water column might significantly underestimate the actual particle fluxes, and several laboratories now routinely complement trap deployments with radionuclide measurements. Estimation of export production or the exponent in the Martin curve from uncorrected trap data appears to be unreliable.

Deuser W.G., 1996. Temporal variability of particle flux in the Sargasso Sea. In: V. Ittekkot, P. Schäfer, S. Honjo and P.J. Depetris (Editors), *Particle Flux in the Ocean*. Scope UNEP, Wiley, Chichester, pp. 185-198.

Dugdale R.C., Wilkerson F.P. and Minas H.J., 1995. The role of a silicate pump in driving new production. *Deep-Sea Research*, 42(5), 697-719.

Lampitt R.S. and Antia A.N., 1997. Particle flux in deep seas: regional characteristics and temporal variability. *Deep-Sea Research*, 44(8), 1377-1403.

Ragueneau O. *et al.*, 2000. A review of the Si cycle in the modern ocean: recent progress and missing gaps in the application of biogenic opal as a paleoproductivity proxy. *Global and Planetary Change*, in press.

Yu E.F., Francois R., Honjo S., Fleer A.P., Manganini S.J., Rutgers van der Loeff M.M., Ittekkot V., 2001. Trapping efficiency of bottom-tethered sediment traps estimated from the intercepted fluxes of ^{230}Th and ^{231} Pa. *Deep-Sea Research*, 48, 865-889.

The Distribution of Deep Biogenic Fluxes and Their Relation to Surface Processes as Estimated from Benthic Studies (R. Jahnke)

Richard Jahnke from Skidaway Institute of Oceanography presented maps of benthic oxygen consumption rates, which have been shown to closely follow the flux of organic carbon to the sea floor. He finds an overall agreement between benthic fluxes and large-scale surface productivity patterns (low in gyres, high in ocean margins). However, when plotted *versus* latitude, there is a dominance of the benthic fluxes at low latitudes (30°S-30°N), whereas most of the primary productivity according to satellite-based maps is at higher latitudes (North Atlantic, North Pacific). Like for the inverse model results, the productivity signal in the eastern North Atlantic seen in the satellite maps of Behrenfeld and Falkowski (1997) are not found in the benthic flux fields.

Jahnke R.A., 1996. The global ocean flux of particulate organic carbon: areal distribution and magnitude, *Glob. Biogeochem. Cycl.*, 10, 71-88.

The dynamics of the marine nitrogen cycle*, *Redfield ratios: The holy grail of ocean biogeochemistry* and *The role of the ocean as a sink for anthropogenic CO_2 (N. Gruber)

Nicolas Gruber from the University of California at Los Angeles summarized the status of current knowledge concerning the marine nitrogen cycle, the elemental ratios of marine particulate matter and the estimation of anthropogenic CO_2 in the ocean. Whereas about 10 years ago, nitrogen fixation and denitrification were believed to occur at rates that are small compared to N-supply by, for instance, upwelling, these processes now attract much more attention, and global estimates of the nitrogen gain by fixation and loss due to denitrification have been revised upward. Because N-fixation and denitrification are controlled by different mechanisms, the two processes need not to be in balance. Old estimates actually suggested a large net nitrogen loss of the ocean (about 68 Tg N yr^{-1}) that would remove all nitrogen in about 300-year time. Historical nitrate data in the ocean and rivers do not support this view, and it appears that if fixation and denitrification are indeed out of balance, the net removal or source rate is much smaller than the above value.

Much of our knowledge about N-fixation and denitrification is derived from dissolved nutrient fields and derived quantities such as N*, which is obtained from nitrate concentration by correcting for particle formation and remineralisation (assumed to occur in constant N:P relation of 16:1). N* values are found to be negative in the North Pacific and Indian Ocean indicating large nitrogen losses due to denitrification. To balance these losses, large inputs of N from nitrogen fixation in low latitudes are required. N-fixation might be much more important for the marine nitrogen cycle than previously thought. Elemental N:P ratios of particulate material often differ markedly from the classical Redfield value of 16:1, which might reflect the regional and temporal variability of the relative rates of N-fixation and denitrification.

The uptake of anthropogenic CO_2 by the ocean has been estimated by global ocean physical/biogeochemical models, and results agree remarkably well, even for models with very different implementations of physical and biogeochemical processes (1.9±0.6 PgC yr^{-1} during the early 1990s). Other approaches for quantifying air-sea CO_2 fluxes are based on atmospheric oxygen and CO_2 budgets, stable carbon isotope measurements, observations of air-sea pCO_2 differences and the separation of the anthropogenic component from the total carbon content of seawater.

Anderson L.A. and J. Sarmiento, 1994. Redfield ratios of remineralization determined by nutrient data analysis, *Glob. Biogeochem. Cycl.*, 8, 65-80.

Codispoti L.A., Christensen J.P., 1985. Nitrification, denitrification and nitrous oxide cycling in the eastern tropical south {Pacific Ocean}. *Marine Chemistry*, 16, 277-300.

Falkowski P.G., 1997. Evolution of the nitrogen cycle and its influence on the biological sequestration of CO_2 in the ocean, *Nature*, 387, 272-275.

Gruber N., Sarmiento J.L., 1997. Global patterns of marine nitrogen fixation and denitrification. *Glob. Biogeochem. Cycl.*, 11, 235-266.

Gruber N., 1998. Anthropogenic CO_2 in the Atlantic Ocean, *Glob. Biogeochem. Cycl.*, 12, 165-191.

Minster J.F. and M. Boulahdid, 1987. Redfield ratios along isopycnal surfaces--a complementary study, *Deep Sea Res.*, 34, 1981-2003.

Sabine C.L. *et al.*, 1999. Anthropogenic CO_2 inventory of the Indian Ocean, *Glob. Biogeochem. Cycl.*, 13, 179-198.

Ecological Control of Marine Biogeochemical Cycles: Carbon vs. Silicate (A. Yool)

Andrew Yool from the Southampton Oceanography Centre reported on a recently initiated ecological modelling study aimed to study the factors that limit and control the global ocean's silicate cycle. The majority of modelling efforts focuses on nutrients such as nitrate and phosphate, and how their coupling to the carbon cycle drives the biological pump. An understanding of the processes that drive export production, is crucial to the determination of the biological processes affecting the carbon distribution and inventory in the deep ocean. In many marine systems, diatoms drive the majority of export production because their large blooms and subsequent die-back transport significant quantities of biogenic material quickly into the ocean interior. As silicate is the major constituent of diatom cell walls, and is known to control their abundance and dominance of ecological systems, the silicate cycle is increasingly thought to be an important factor in the ocean's carbon cycle.

Extrapolating from a related nitrate/phosphate model, Yool has constructed a simple, two box model of the silicate and phosphate cycles. As well as including both nutrients, the model represents the ocean ecosystem with two competing groups of algae: siliceous algae (diatoms) and non-siliceous algae (all other groups). A primary aim of the study is to examine whether long-term coexistence between (competitively superior) diatoms and other algae could both control the cycles of these nutrients and reproduce their distribution and fluxes through the ocean. Analysis and simulations of the model find that silicate, relative to phosphate, is more limiting to the model diatoms, preventing them from reaching their full competitive potential but tightly controlling the cycling of silicate through the ocean. Despite their competitive inferiority, the modelled other algae are thus able to persist and "take up the slack" on the phosphate cycle left by the diatoms. While shifts in the availability of both nutrients affect the balance between the phytoplankton groups, the availability of phosphate controls total primary production. Although a full carbon cycle submodel is yet to be added to the base model, these modelled shifts in the role of diatoms may have profound consequences for the export flux and the ocean carbon cycle. The relatively recent dominance of the silicate cycle by the diatoms (from 65 million years to the present) may thus have had important consequences to the carbon cycle across geological time.

Brzezinski M. A., Villareal T. A. and Lipschultz F., 1998. Silica production and the contribution of diatoms to new and primary production in the central North Pacific. *Mar. Ecol. Prog. Ser.*, 167: 89-104.

Dugdale R. C. and F. P. Wilkerson, 1998. Silicate regulation of new production in the equatorial Pacific upwelling. *Nature*, 391: 270-273.

Egge J. K. and D. L. Aksnes, 1992. Silicate as regulating nutrient in phytoplankton competition. *Mar. Ecol. Prog. Ser.,* 83: 281-289.

Pondaven P., Fravalo C., Ruiz-Pino D., Tréguer P., Quéguiner B. and C. Jeandel, 1998. Modelling the silica pump in the Permanently Open Ocean Zone of the Southern Ocean. *J. Mar. Sys.* 17: 587-619.

Siever R., 1991. Silica in the oceans: biological-geological interplay. In: Scientists On Gaia, edited by S. H. Schneider and P. J. Boston. pp. 287-295, MIT Press, Cambridge MA, U.S.A.

Smetacek V. S., 1985. Role of sinking in diatom life-history cycles: ecological, evolutionary and geological significance. *Mar. Biol.,* 84: 239-251.

Tréguer P., Nelson D.M., Van Bennekom A.J., DeMaster D.J., Leynaert A. and B. Quéguiner, 1995. The silica balance in the world ocean: a re-estimate. *Science*, 268: 375-379.

Tyrrell T., 1999. The relative influences of nitrogen and phosphorus on oceanic primary production. *Nature*, 400: 525-531.

Modelling Marine Biogeochemical Cycles: Present Status and Future Plans (P. Monfray)

Patrick Monfray from the Institute Pierre-Simon Laplace reviewed the present status of global-ocean coupled physical/biogeochemical models that are currently used to quantify nutrient and carbon transports within the ocean and the CO_2 exchange with the atmosphere. Thirteen of those models have recently participated in the Ocean Carbon-Cycle Model Intercomparison Project (OCMIP). With respect to the current total uptake of anthropogenic CO_2 by the ocean, the models agreed remarkably well. However, considerable differences have been found in forecasts of future uptake rates. Large differences among the models in CO_2 uptake, transport and storage have been found in the Southern Ocean, which could partly be attributed to failures in the models to correctly represent vertical exchange processes and water mass formation and spreading as traced by CFC fields. There is a general agreement among modellers that more tracer data should be incorporated and better tracer simulations should be achieved before more reliable flux estimates can be obtained on regional scales. There was concern that the neglect in most models of explicit river input of nutrients and carbon (occurring predominantly in the Northern Hemisphere) could cause erroneous net meridional transports in the models. Meridional transports are key diagnostic properties and are relevant for such aspects as the location of the so-called missing CO_2 sink.

There is an ongoing trend towards increasing complexity in the biogeochemical models. While 20 years ago, biological productivity was represented by means of nutrient restoring terms, more mechanistic approaches such as Michaelis-Menten kinetics or N-P-Z ecological feedback modules are now in common use. Current developments include the incorporation of iron and other micronutrients as limiting factors, the influence of terrestrial inputs (dust and rivers) on ocean productivity, the separate modelling of more functional organism groups and the study of silicate-driven productivity *versus* carbon.

During the discussion, concerns were expressed that moves towards very complex biogeochemical models were premature and unjustified for models that still exhibited serious deficiencies in physical transports. There was also concern that many of the newly introduced tracers and biogeochemical processes could not be verified because of lack of direct measurements.

Dutay J.C. *et al.*, 2001. Evaluation of ocean model ventilation with CFC-11: comparison of 13 global ocean models, *Ocean Modelling*, in print.

Orr J.C. *et al.*, 2001. Estimates of anthropogenic carbon uptake from four three-dimensional global ocean models. *Global Biogeochemical Cycles*, 15(1), 43-60.

Orr J. C. *et al.*, 2001. Ocean CO_2 sequestration efficiency from 3-D ocean model comparison, in Greenhouse Gas Control Technologies, (Proceedings of the 5th Inter. Conf. on Greenhouse Gas Control Technologies), edited by D. Williams, B. Durie, P. McMullan, C. Paulson and A. Smith, CSIRO, Collingwood, Australia, pp. 469-474.

Future Changes in Marine Biogeochemical Cycles: Modelling and Observational Evidence (R. Matear)

Richard Matear from CSIRO, Hobart reported on recent modelling work aiming at the study of potential future changes in marine biogeochemical cycles under gradually warming conditions. Several coupled atmosphere/ocean or ocean-only models have been used to determine the response of the thermohaline overturning cell to decreasing surface water densities in the water mass formation areas because of rising temperatures and the influence of fresh water from melting ice. Almost all of these models react with an overall weakening of the overturning circulation and with changes in the location of the main water masses. Some models show a complete slow-down of the meridional circulation in the North Atlantic under ice-melting rates, which (according to geological evidence) occurred repeatedly during the last 100,000 years.

A warming of ocean surface waters will lead to a net outgasing of oxygen into the atmosphere, and because of weaker vertical exchange with nutrient-rich deeper waters, the ocean productivity could be reduced by about 50%. The reduced ventilation of the deep ocean will lead to an increase of dissolved nutrients and a decline of oxygen concentrations in the interior because of particle remineralisation. Indications for such model-predicted oxygen changes are already seen in observations from the Southern Ocean. According to model simulations, it would take on the order of several thousand years to drive bottom water oxygen concentrations to zero. Uncertainties of model forecasts of biogeochemical fields in the ocean are due to model-specific deficiencies but also to possible but yet poorly understood or documented changes in the underlying processes. One example is the effect of a reduction in pH on the calcification rates of coccolithophores and coral reef communities, which has recently been found in laboratory experiments.

Bopp L., Monfray P., Aumont O., Dufresne J.L., Le Treut H., Madec G., Terray L., Orr J.C., 2001. Potential impact of climate change on marine export production. *Global Biogeochemical Cycles*. 15(1), 81-99.

Matear R.J., Hirst A.C., 1999. Climate change feedback on the future oceanic CO_2 uptake. *Tellus*, 51B(3), 722-733

ANNEX 1

Participants

GSWG Members

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Invited scientists

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JGOFS Global Synthesis Working Group Meeting - Agenda
July/6/2001

09.00 Welcome, Introduction

09:15 Rationale for GSWG, Terms of Reference

09:45 Overview Presentations: Marine Production and Downward Material Fluxes

Satellite-based estimation of marine primary production: current status and future directions (J. Campbell)

Model estimates of new and primary production: influence of model physics and numerics (A. Oschlies)

Export production in the Southern Ocean derived from dissolved nutrient distributions: comparison with satellite based estimates (R. Schlitzer)

The relationship between primary and export production in the open ocean -
Theory and observations (E. Laws)

Particle fluxes to the deep ocean: recent findings, problems and Strategies (G. Fischer)

The Distribution of Deep Biogenic Fluxes and Their Relation to Surface Processes as Estimated from Benthic Studies (R. Jahnke)

Summary

13:30 Overview Presentations: Process Studies and C, N, Si Cycles

"The dynamics of the marine nitrogen cycle" and "Redfield ratios: The holy grail of ocean biogeochemistry" (N. Gruber)

Modelling focused on Chemical Components: A Biogeochemical Cycle Model Coupled with Ecosystem (Y. Yamanaka) - cancelled

Ecological Control of Marine Biogeochemical Cycles: Carbon *vs*. Silicate (A. Yool)

Summary

15:00 Overview Presentations: Anthropogenic Influence and Future Change

The role of the ocean as a sink for anthropogenic CO_2 (N. Gruber)

Modelling Marine Biogeochemical Cycles: Present Status and Future Plans (P. Monfray)

Future Changes in Marine Biogeochemical Cycles: Modelling and Observational Evidence (R. Matear)

Summary

16:30 Status and Future Plans (*Meetings, Workshops, Publications; Links with other TT*)

18:00 End of meeting

ANNEX 3

JGOFS Global Synthesis Working Group

Terms of Reference

as of October 2001

The objective of the GSWG is to review our current knowledge on the fluxes of dissolved and particulate material in the global ocean and the biogeochemical processes that affect these fluxes. Of particular importance are the comparisons of the different observational and modelling approaches and the identification of controversies, methodological weaknesses and knowledge-gaps. This should influence the planning of future marine research programmes and should lead to the development of new, improved biogeochemical models that make use of the emerging biogeochemical data.

Specific goals of the GSWG are:

- To compare and evaluate estimates for marine productivity, downward particle fluxes and respiration rates in the water column and the sediment from different observational techniques as well as from modelling.
- To foster interactions between observationalists and modellers and to stimulate joint research projects.
- To liaise and link GSWS activities with the JGOFS-GAIM and Data Management Task Teams and the regional synthesis groups under JGOFS.
- To promote the development of new, improved biogeochemical models that utilize the emerging and diversity of marine biogeochemical data.
- To identify potential biogeochemical and physical changes under global warming conditions.
- To organize a workshop on the measurement and modelling of global ocean productivity and biogeochemical fluxes.
- To promote a joint publication of synthesis papers on marine biogeochemical fluxes.