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PROJECT TITLE: ORFOIS

"ORigin and Fate of biogenic particle fluxes in the Ocean and their Interactions with the atmospheric CO_2 concentration as well as the marine Sediment"

PROJECT CO-ORDINATOR: Christoph Heinze, NERI

PARTNERS:
1. **NERI, Denmark**
2. **LSCE/CNRS, France**
3. **UBO/CNRS, France**
4. **MPG.IMET, Germany**
5. **Uni-HH, Germany**
6. **NCMR, Greece**
7. **NIOO, Netherlands**
8. **UEA, United Kingdom**

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Project home page:
http://www.pangaea.de/Projects/ORFOIS/

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2. EXECUTIVE SUMMARY

ORFOIS is one of the EU FP5 projects on the marine carbon cycle.

Problems to be solved by ORFOIS:
The simulation of thoroughly backed up surface ocean pCO_2 distributions will narrow the uncertainties of carbon redistribution estimates within the earth system. This knowledge has direct economic consequences because it enables early political measures to react on and prevent undesired climate change evolutions. This knowledge enables a well planned procedure for fullfilling the Kyoto Protocol obligations of member states. Early planning on the basis of solid research results within this context has been shown to be of extreme economic value.
The calculation of the fate of particles will be the foundation for valid estimates of removal and storage of hazardeous substances within the ocean (coming from land based sources through river runoff and atmospheric transport as well as from direct marine disposal). The particle flux and sediment ``community models" will provide a basis for future operational biogeochemical forecasting of environmental key variables. Thus these models will help to prevent marine areas around EU member states from environmental damage and foster sustainable use of these oceanic areas.

The main scientific objectives of ORFOIS are to:
1. Identify and quantify globally the mechanisms underlying the transformation of biogenic particles to dissolved substances within the ocean water column in order to predict correctly surface ocean carbon dioxide sources and sinks.
2. Develop a refined particle flux model for operational use in ocean general circulation models which realistically describes particle dynamics in the water column, deposition of material to the sediment, and the interaction with the carbon dioxide partial pressure (pCO_2).
3. Provide a global closed carbon and nutrient budget for modern (preindustrial) conditions including the water column sediment interaction.

4. Estimate the changes in CO_2 sea surface source sink patterns and vertical redistributions of carbon as well as nutrients for future global change, climate change as well as carbon sequestration scenarios including the associated potential economic impacts.

The project's main technological objectives are to:
1. Establish publically available community models for particle flux dynamics in the water column and early sediment diagenesis which are suited for use in general circulation ocean climate models.
2. Establish data bases for marine carbon and nutrient cycling which will be easily publically available.

Work achieved during the first project year (summary):
A particle dynamics module was implemented in a 1-D modelling environment as well as in two different 3-D global biogeochemical ocean models. Both, the 1-D and the 3-D models include a sediment reservoir mimicking realistically the exchange between the water column and the sediment. Comprehensive observational data sets in marine carbon and nutrient data as well as sea surface pCO_2 were compiled and are being extended. First longer model runs with the 3-D models reveal their ability to realistacally advect the biogeochemical tracers. First sensitivity studies with the 1-D and 3-D models were carried out to study the impact of advanced particle dynamics modelling on the carbon cycle. Laboratory experiments on dissolution of $CaCO_3$ (calcium carbonate) and BSi (biogenic silica, opal) as well as on reverse weathering on shallow sediments provided significant observational input to present and coming model formulations. The modeling and observational data system can now be combined and step by step optimised to provide the foundation for a succesful application to global warming and other scenarios.

3. OBJECTIVES AND STRATEGIC ASPECTS

The project will result in best estimates of sea surface CO_2 source sink patterns. Comprehensive observational data bases on surface ocean pCO_2 and marine carbon cycle data will be collated and made publically available through web access. Community models on marine particle flux dynamics and early diagenesis (top sediment zone) will be made publically available for use in any other ocean model. Estimates of socio-economic impacts of a better knowledge of sea surface CO_2 source sink patterns and particle flux dynamics will be provided for future climate change as well as carbon sequestration scenarios.

4. SCIENTIFIC AND TECHNICAL PERFORMANCE

4.1 Summary of the specific project objectives for the relevant period

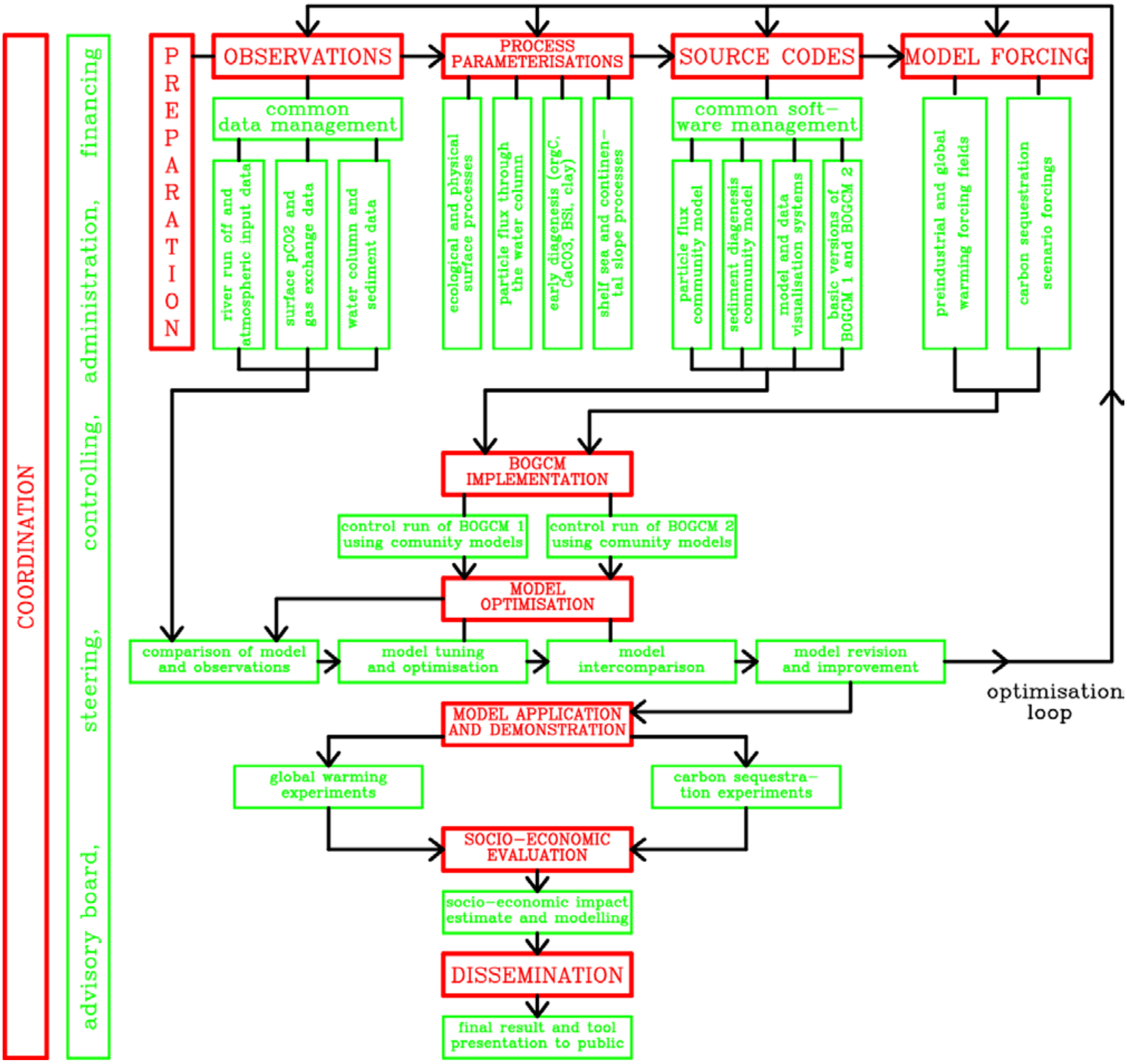

Figure 1: Conceptual diagram on project flow.

Workpackages to be addressed during year 2 of the project are WPs 1-3, 5-8, and 10. Also some work was already carried out on dissemination of project results (WP9) though this was not anticipated in the original decription of work. The goals of the relevant workpackages and their tasks to be carried out during the second year are:

WP1. Data base compilation of observations:
To provide a synoptic multi tracer data base of existing observations (stocks and fluxes) in surface

water, water column, sediment traps, sediments, early diagenesis, and sediment pore waters including level of data access, meta-documentation and referencing information (month 1-18).

Tasks:

1.1 Online data extraction of publically available data from data centers; data compilation from the literature (partners 3, 6, 8).
1.2 Data acquisition from Principal Investigators around the globe including extensive travelling (partners 3, 6, 8).
1.3 Processing of analytical data and complementary meta-information by application of an advanced online data model which is already available (partner 3).
1.4 Data archiving in the World Data Center Europe (partners 3, 6, 8)
1.5 Data quality evaluation including consultation with their PI (partners 3, 6, 8).
1.6 Development of presentation software (GIS, 2-D plot, cross-section) (partner 3).

WP2. Process parameterisations:
Development and calibration of 1-D biogeochemical model components of (1) a particle flux module which simulates particle interaction, modification and sinking speed (including a surface particle production formulation) and (2) an early diagenesis sediment model (including organic carbon chemistry). The model components simulate parts of the marine carbon, nitrogen and silicon cycles (month 1-15).

Tasks:

2.1 Coupling of an already existing ecological model (particle production, organic matter,$CaCO_3$, opal) to a particle dynamics module describing coagulation, disaggregation, and settling of biogenic particles (partners 2, 4).
2.2 Development of time dependent 1-D early diagenetic model describing the C, N, and Si cycles in the sediment (including bi-directional vertical sediment advection and anaerobic pore water chemistry) (partners 2, 3, 6, 7).
2.3 Coupling of 1-D ecological/particle flux and sediment diagenesis models as consistency check. Calibration with observations (partners 2, 3, 4, 6, 7).
2.4 Realisation of a well defined restricted number of laboratory experiments in order derive correct parameterisations (opal dissolution in the water column and the water/sediment interface, conversion of opal within the sediment mixed layer into other mineral phases) (partners 3, 6).
2.5 Laboratory experiments on calcium carbonate reactivity (solubility and dissolution kinetics) (partner 2).

WP3. Community model development:
To provide source codes for the model components on particle flux dynamics and early diagenesis which can easily be coupled to various existing 1-D models as well as 3-D Biogeochemical Ocean Circulation Models (BOGCMs) (month 1-15).

Tasks:

3.1 1-D Codes are modified to allow full vectorisation for use in 3-D models, which are run on high end supercomputers (partners 1, 2, 4).
3.2 Homogenisation of nomenclature; common mnemotechnical variable names are defiend from the very beginning of the project (partners 1, 2, 4, 7).
3.3 Development of coupling interfaces to BOGCM I and BOGCM II (partners 1, 2).
3.4 The community model source code development will be carried out through use of the ClearCase source code control software, which allows easy book keeping of changes made in the FORTRAN programmes as well as simultaneous work of different partners on one model component in parallel (partners 1, 2, 4, 7).

WP5. BOGCM implementation:
To implement community models for particle flux and sedimentary reactions in BOGCMs (month 7-18).

Tasks:

5.1 Integration of the physical (dynamical) part of the BOGCMs into statistical equilibrium using *the preindustrial forcing fields as compiled in WP4 (partners 1, 2).*

5.2 Coupling of the community model versions for particle flux dynamics and sediment early diagenesis into BOGCM I and BOGCM II, including adjustment of the ecological modules already existing within BOGCMs I and II (partners 1, 2).

5.3 First test integrations of BOGCMs I and II using the same basic FORTRAN codes for the community models but with possibly different model parameter settings through application of the ClearCase source code control system (partners 1, 2).

5.4 Longer model integrations to provide basic preindustrial tracer and pCO_2 distributions (water column, sediment) as basis for the subsequent model optimisation (through application of burst coupling in order to accelerate the sediment equilibration) (partners 1, 2).

5.5 Rough comparison with observations as collated in WP1 in order to adjust model tracer distributions to correct order of magnitude (partners 1, 2).

5.6 Implementation and test of crude parameterisations of shelf sea processes (retention of nutrients and carbon loads entering the ocean from land, shelf/open ocean exchange, high shelf sediment accumulation regimes with anoxic pore water reactions) (partner 1).

WP6. Optimisation of the prognostic system.

To (a) provide optimnised runs of BOGCMs I and II, (b) update the high quality data base of C, N, and Si cycling in the world ocean, (c) revise process parameteristions of the water column and sediment community modules, (d) set up corrected atmospheric forcing fields.

Tasks:

6.1Comparison between BOGCM outputs and observations, identification of the crucial disagreements to be removed (partners 1, 2, 3, 4, 6, 7, 8).

6.2 Tune BOGCMs optimally using an SVD technique (partners 1, 2, 4).

6.3 Fill in gaps in data coverage for model verification (partners 3, 6, 8).

6.4 Revise atmospheric forcing (e.g., for ACC strength adjustment) (partners 1, 2).

6.5 Quality check of the observations (partners 3, 6, 8).

6.6 Revise process parameterizations through 1-D modeling and feed these improvements into the community model components as used by BOGCMs Ia nd II (through use of the ClearCase source code control system including the test of the 1-D codes in selected case studies) (partners 2, 3, 4, 6, 7, 8).

WP7. Model application and demonstration.

To (a) provide an improved simulation of surface ocean CO2 sources and sinks and a closed biogeochemical budget for the preindustrial ocean, (b) assess modifications in surface ocean production patterns and associated changes in particle fluxes for climatic warming scenarios, (d) assess first order effects for anthropogenic carbon sequestration scenarios.

Tasks:

7.1 Final integration of the preindustrial reference runs with BOGCMs I and II using the optimized prognostic system (partners 1, 2).

7.2 Integration of greenhouse gas induced warming scenarios restarting from preindustrial conditions (partners 1, 2).

7.3 Integration of Fe-fertilisation scenario introducing additional iron input to areas with high preformed nutrient surface concentrations (restart from modern conditions, few hundred years) (partners 1, 2).

7.4 Integration of deep ocean CO_2 disposal scenario through CO_2 injection into selected $CaCO_3$ rich deep sea areas (partners 1, 2).

7.5 Integration of glacial ocean scenario (partner 4).

7.6 Compilation of results for economic evaluation (partners 1, 2).

WP8. Economic evaluation.

To (a) estimate regional emission reduction cost differentials for the optimized marine carbon cycle representations of WPs 6 and 7, (c) estimate the costs of sequestering carbon in the ocean, [(d) deleted, see kick-off meeting].

Tasks:

8.1 Adoption of already existing models for the specific purpose of the project (partner 5).

8.2 Estimate differences in carbon ffluxes due to the alternative representation of the marine carbon cycle and estimate impact on the costs of meeting certain emission reduction targets (partner 5).

8.3 Estimate (based on previous step) (1) effects on atmospheric CO_2 concentrations, climate change and sea level rise, and (2) differences in the impacts of climate change and sea level rise (partner 5).
8.4 Complementation of the impact estimates of marine carbon sequestration on carbon cycle and ecology of WP7 with estimates of the costs of marine carbon sequestration (partner 5).
[8.5 Omitted, see kick-off meeting.]

WP9. Dissemination:
To (a) provide all necessary tools for optimal use of and advertise the models (particle flux and early diagenesis community models, BOGCMs) and the data base of observations to the public. To (b) forward results of project to end users and the non-specialists.
Tasks:
9.1 Data base of observations including user manual: (1) CD-ROM, (2) on the Internet (partners 3, 6, 8).
9.2 Community models (ecological/particle flux dynamics and early diagenesis modules): (1) On the Internet, (2) publication on paper as technical report (partners 1,2,3,4,6,7).
9.3 BOGCMS I and II plus output from preindustrial, climate change, and carbon sequestration runs: (1) Electronic online publication on the Internet, (2) publication on paper as technical report within an established report series, (3) storage of model results in online data base and forwarding of meta information to European and overseas data centers (partners 1,2).
9.4 Publication of results including economic evaluation as handout for the public (schools, universities, policy makers, fisheries agencies, energy and life science enterprises, and other end users) (all partners).
9.5 Update of project's web page (partner 3 with contributions from all partners).
9.6 Final project workshop, which will be advertised to the scientific and end user community (partner 1, with contributions from all partners).

WP10. Coordination:
To ensure timely submission of deliverables, coordinate the project flow, compile the management and scientific reports for the EC, enhance communication between partners, organise work shops, keep in touch with the consultants, promote dissemination of results (month 1-36).
Tasks:
10.1 Contact partners early to receive results in time.
10.2 Gather contributions of participants for management and scientific reports and compile these reports for submission to the EC.
10.3 Contact participants regularly to discuss problems and solve them jointly.
10.4 Invite participants and consultants to workshops and meetings.

4.2 Overview about the technical and scientific progress made (task by task)

WP1. Data base compilation of observations:

The data collection concentrates on multi-tracer and multi-compartment biogeochemical tracer data sets as well as pCO_2 data. This choice aims at finding consistent data sets which can be compared with the models in an integrated synoptic approach and to keep the data collection task within a feasible limit. The World Data Center for Marine Environmental Sciences (WDC-MARE, www.wdcmare.org) and its operating system PANGAEA (Network for Geological and Environmental Data, www.pangaea.de) which both are already involved as data and information management system in several EC projects (cf. http://www.wdc-mare.org/Projects) continue to give the infrastructural framework for all acquired data. Thus, ORFOIS benefits from a central information centre where all project-relevant data needed are collected as complete and consistent data sets.

1.1 Online data extraction of publicly available data from data centres; data compilation from the literature (partners 3, 6, 8).

The progress from the former 800 data sets to now more than 5,000 ORFOIS data sets archived at PANGAEA / WDC-MARE is mostly due to the enormous effort that is still being conducted by the working group at Foundation Alfred Wegener Institute for Polar and Marine Research (AWI, Bremerhaven, Germany). AWI actually compiles the complete JGOFS data collection that was elaborated during the last decade. The effort to archive all JGOFS data appropriately in PANGAEA / WDC-MARE will take more than two years full-time man-power. Once the JGOFS work is done (supposedly in spring 2004) the WOCE data collection will be included in PANGAEA and be available for ORFOIS (supposedly summer 2004), too. However, a smaller part of data – nevertheless of crucial importance – is retrieved by browsing the literature.

Partner 6 carried out a literature review on deposition of calcium carbonate in the coastal oceans, P and C accumulation and cycling in coastal sediments, nutrient benthic fluxes, sediment accumulation rates.

1.2 Data acquisition from Principal Investigators around the globe including extensive travelling (partners 3, 6, 8).

So far 5,149 ORFOIS relevant data sets were compiled in the data base and are available online. See:
http://www.pangaea.de/Projects/ORFOIS/Results/
or
http://www.pangaea.de/PangaVista?query=ORFOIS
As during the report periods before, several institutes and laboratories were visited successfully. International meetings led to personal contacts that helped to advance distinctly. Among them were the IGBP OCEANS Open Science Conference, Paris, January 7-10, 2003, (now IMBER), the potential FP6 Network of Excellence Eur-OCEANS (ex-ECCO) initiative meeting, Paris, April 24-25, 2003, and the Chapman Conference on the role of diatom production and Si flux and burial in the regulation of global cycles, Paroikia, Paros, Greece, September 22-26, 2003. Always very fruitful and helpful are and were the meetings at AWI and MARUM to solve problems and to discuss specific efforts to be undertaken with respect to the relational data base management and information system PANGAEA / WDC-MARE.

Partner 6 completed the collection of archived and new sediment samples from major deltaic depositional systems. Archived sediment samples from the Ganges-Brachmaputra deltaic systems were kindly provided from Dr. Kudrass (Geozentrum Hannover). Dr . Michalopoulos visited Geozentrum Hannover in April 2003 and sampled the available archived material. New samples were obtained from the Mississippi River deltaic system during two research cruises (May and July 2003) organized by Prof. Allisson of Tulane University. Dr. Michalopoulos participated in the two cruises and obtained new samples from the river and the nearshore deltaic deposits (May cruise) as well as sediment samples from the subaqueous delta proper and prodelta deposits (July cruise).
The CO_2 data collection as performed by partner 8 in ORFOIS was presented in a poster at the 2nd general CARINA (CARbon dioxide IN the Atlantic Ocean) meeting. Copies of the A0 poster and an A4 summary poster are at http://lgmacweb.env.uea.ac.uk/ORFOIS.htm. The aims of the conference were highly relevant to ORFOIS. Database managers of CDIAC, CARINA, CAVASSOO, PICES and ORFOIS attended the meeting, which offered an ideal platform for discussions on database issues, such as a uniform format for surface water CO_2 data and access to databases. Dorothee Bakker discussed data storage at CDIAC (Carbon Dioxide Information Analysis Center) and WDC-MARE (World Data Centre for Marine Environmental Sciences) with individual scientists at the CARINA meeting.

Dozens of marine CO_2 scientists were contacted on behalf of ORFOIS with a request for submission of surface water CO_2 data to the CDIAC and/ or WDC-MARE data bases.
A uniform data format for surface water fCO_2 data is essential for data access by ORFOIS modelers and by CO_2 scientists in general. Work is in progress at UEA to put surface water fCO_2 data from the CDIAC database into a temporary format, on behalf of the ORFOIS modelers.

1.3 Processing of analytical data and complementary meta-information by application of an advanced online data model which is already available (partner 3).

Formatting of data was carried out to achieve the homogenisation of the acquired data sets with the already existing data sets. Several system relevant variables such as the native data format (i.e., the presentation of the "numbers" transferred from the data centres) as well as environmental parameters such as units and variable names were checked and corrected. This work included programming of macros and application software. Again, valuable support was given by the PANGAEA group at AWI Bremerhaven (Germany).

1.4 Data archiving in the World Data Center Europe (partners 3, 6, 8)

Data were archived as analytical data and their corresponding meta-information using a highly sophisticated front-end software based on *4th Dimension®*, that permits direct access to the central data base server via Internet. All files were loaded online into a temporary table at the server side where a second quality check was initiated and analytical data and meta-information were examined for coherence with entries already archived. Then, all data were transferred to the import server and stored temporarily in order to update the data warehouse at regular intervals. Finally after arrival at the export server, a uniform resource locator (URL) is generated and data are offered online to the scientific community.

Data on calcium carbonate accumulation in the oceans, P and Organic C accumulation in coastal sediments, dissolved P fluxes and sediment accumulation rates have been added to the data base by partner 6.

1.5 Data quality evaluation including consultation with their PI (partners 3, 6, 8).

Personal contact between data management staff and PIs proved to be beneficial to both parties. Together with the PI, all important meta-information was collated: Project facts, cruise mnemonics, official station lists as well as notes on institutions and co-workers involved. The most critical performance was summing up and discussing the analytical data, which would serve as a first quality check: Are all values valid? Are all units consistent? Are all parameters adjusted? Are ridiculous and suspect numbers to be corrected or to be flagged or to be wiped out, respectively? Are methods checked for completeness? Are publications referenced? Finally, meta-information and analytical data both were converted into tab-delimited ASCII spread sheets following standardized input forms available online. Each data set was subjected to a brief scrutiny to ensure that no gross corruption of the data had occurred, namely the data check (1) before archiving together with the PI as part of the data preparation; (2) during and after transfer to the database as part of PANGAEA data import/export routines; and (3) after archiving by the PI's feedback who consults his data sets online.

1.6 Development of presentation software (GIS, 2-D plot, cross-section) (partner 3).

While PANGAEA offers the operating system for data management, information management is assisted by the WDC-MARE. The ongoing project is documented online and created with respect to WDC-MARE standards. The ORFOIS web page is accessible publicly at:
http://www.wdc-mare.org/Projects/

This site comprises home page, projects working plan, information on scientific partners, project results, and a - publicly not accessible - discussion forum where authorisation is required. Main and subordinate sites have been regularly updated.

Moreover, visualisation software solutions have been updated at AWI to better present scientific information: PanMap (version 1.4) for mapping scientific data along with several geographical resources converted to PanMap layer-format; PanPlot (version 10.16) for plotting scientific data. Ocean Data View (ODV, version 1.4) is the software solution for general visualisation of huge (i.e. unlimited) amounts of scientific data. None of these software solutions have been funded through ORFOIS. However, as free-ware products they serve and are adapted for the proper use of data retrieved via PANGAEA / WDC-MARE. We acknowledge the enormous effort by R. Sieger (AWI, PanMap, PanPlot) and R. Schlitzer (ODV).

WP2. Process parameterisations:

2.1 Coupling of an already existing ecological model (particle production, organic matter, $CaCO_3$, opal) to a particle dynamics module describing coagulation, disaggregation, and settling of biogenic particles (partners 2, 4).

Done during year 1.

2.2 Development of time dependent 1-D early diagenetic model describing the C, N, and Si cycles in the sediment (including bi-directional vertical sediment advection and anaerobic pore water chemistry) (partners 2, 3, 6, 7).

Partner 2 started its contribution to action 2.2 with a one week visit at NIOO (partner 7) in March 2003. During this visit, the scientist in charge got introduced to the FEMME modelling environment (Soetaert et al., 2002). The 1-D early diagenetic model of C, N, and Si cycles in surface sediment is since used at LSCE. Partner 2 built on the first version of the Si early diagenesis model developed by partner 7. This model is designed to be run both at steady state and dependent on time. Its gives the operator direct control on bioturbation and irrigation. Laboratory studies (partner 3) suggested that biogenic silica (BSi) is made of several phases, each having its distinct solubility and dissolution properties. Following these experimental results, the Si early diagenesis model was modified to include two-phases of BSi. Distinct solubility and dissolution parameters are assigned to each phase. Dissolution of either fraction follows first order kinetics. The respective dissolution rate parameters are constant with depth (no aging). The model is run at steady state. A parameter that divides the deposition flux into the two fractions is added. Its value is between [0,1]. Pore water and solid Si distributions predicted by the model were compared to experimental data reported from the Southern Ocean, the Equatorial Pacific and the North Atlantic (Porcupine Abyssal Plain). A general good agreement was found between predicted and measured dissolved and solid Si distributions. (Refer to ANNEX for figures).

Experimental work on reverse weathering processes (partner 6) indicated the existence of reactions involving Al and BSi. These reactions might explain the observed decrease in BSi solubility with depth in sediments. In order to represent the coupling between BSi and Al, Partner 2 added an explicit term of reprecipitation to the Si early diagenesis model. Different model versions

were tested. The model of the first version contains one type of BSi. The second includes two types of BSi, which differ by their reactivity (fast dissolving and slow dissolving). The distributions of pore water and solid Si predicted by the models were compared to data from the Southern Ocean, the Equatorial Pacific and the North Atlantic. Only the model with two types of BSi gave a good agreement between predicted and measured dissolved Si distributions. This was particularly true for BSi. For the model with one type of BSi, it was difficult to fit the dissolved and solid Si at the same time. The apparent Si dissolution rate constant, the saturation concentration of BSi dissolution, the BSi flux deposited at the sediment-water interface, the dissolved Si reprecipitation rate constant, and the saturation concentration for Si reprecipitation, were the critical parameters.
K. Khalil and C. Rabouille, from Partner 2, met with partner 3 in Brest in May 2003, to discuss in detail the refinements to be brought to the preliminary silica diagenetic model, already capable of running both dynamically and to steady-state, developed by partner 7. It has been decided that this model should include several (starting by two) phases of biogenic silica phases, with distinct dissolution properties, following our recent observations (Gallinari et al., 2002), and that a precipitation term should also be introduced, to account for the recent results obtained by the group of Prof. van Cappellen (Dixit et al., 2001 ; van Cappellen et al., 2002). The dissolution and degradation experiments described above aim at parameterizing the deposition flux of biogenic silica, which typically reaches the seabed in the forms of faecal pellets of large grazers, or aggregates.

Partners 2 and 3 met again in Gif-sur-Yvette, France, in October 2003, to examine the first results obtained by K. Khalil. She clearly demonstrated that to fit properly the downcore profiles of both DSi AND BSi, two phases of BSi had to be distinguished, with different dissolution properties. The steady-state version of the early diagenetic model has been tested (i) at the PAP site, making use of the data set collected within the EU BENGAL project, (ii) at the EqPac site, using data collected by the US JGOFS project and (iii) the KTB06 site, using data from the French ANTARES Programme. The dynamic version of the model will be tested using the seasonal data sets collected during the EU-BENGAL (Ragueneau et al., 2001; Gallinari et al., 2002) and NSF-FOODBANC (Gallinari et al., submitted) projects. It is this version that will be dynamically coupled to the 1D transformation model developed in the water column by partner 7.

2.3 Coupling of 1-D ecological/particle flux and sediment diagenesis models as consistency check. Calibration with observations (partners 2, 3, 4, 6, 7).

Several modifications and additions have been made to the already existing compilation of 1-D codes for modelling biological and biogeochemical processes in the water column. These include implementation of modules explicitly describing nitrogen fixation, calcification and silica detritus dynamics. The module dealing with inorganic carbon dynamics has been modified, following early simulations, to include the effect of nitrification on alkalinity.

Standard 1-D formulations for biological and biogeochemical water column processes have been made available in accord with workpackage description (d_3_2.5.4 “Milestones”)

Full coupling and testing of the pelagic and benthic 1-D components has been delayed due to the late completion (resulting from initial hiring problems) of the sediment module.

To allow implementation of the sediment $CaCO_3$ module by partner 2 (LSCE) in the simulation environment, a new integration routine, DASSL was implemented by partner 7. This routine, available from the Internet is specifically designed for solving differential algebraic equations (DAE). The other integrators already included in the simulation environment do not deal with DAEs, but can only solve ordinary differential equations. Following a visit to NIOO by partner 2 implementation of their sediment carbonate module in the 1-D modelling framework is underway.

The effect of sediment-water interactions on the functioning of the pelagic system was investigated for shelf conditions (0-150 m). Based on literature information, the enhanced exchanges between water and sediment induced by filter-feeding animals or by physical advection through sands were quantified in terms of the number of litres of water, with its dissolved and particulate contents, that is exchanged per unit area and time. These parameterisations were then added to the coupled physical-biological modelling framework and run for a series of water columns with water depth increasing from 2m to 150 m.

2.4 Realisation of a well defined restricted number of laboratory experiments in order derive correct parameterisations (opal dissolution in the water column and the water/sediment interface, conversion of opal within the sediment mixed layer into other mineral phases) (partners 3, 6).

Given the importance of aggregation and zooplankton faecal pellets in modifying the particle fluxes through surface and deep waters, dissolution experiments have been conducted on the biogenic silica of diatoms by partner 3, either as free cells or in aggregates and faecal pellets. Beyond these new experiments, the work on degradation is continuing, to help better characterize the various phases of biogenic silica as evidenced by Gallinari et al. (2002).

Dissolution experiments on aggregates (partner 3) :
The experience of partner 3 on BSi dissolution (Ragueneau et al., 2001; Gallinari et al., 2002) has been combined with the experience of Dr. Passow (AWI, Bremerhaven, Germany) on aggregation processes. Brivaela Moriceau (Ph.D. student, funded elsewhere) has successfully conducted some 10 dissolution experiments, working on three different diatom species (*Chaetoceros sp., Thalassiosira weissflogii and Skeletonema costatum)*. For each, batch experiments were performed on free cells and on aggregates and several parameters were followed, such as the increase in silicic acid concentration, BSi, POC, bacteria, TEP, etc. For two species, dissolution rates were found to be clearly lower, by a factor of ~3, in aggregates, as compared to free cells (Figure in annex on page 59). Three hypotheses have been proposed to explain this difference in dissolution rates:

1. Normalized to the number of diatom cells, the number of bacteria is clearly lower in aggregates than on free cells. As bacterial activity is essential at removing the organic matter coating opal surfaces before dissolution can start (Bidle and Azam, 1999), dissolution can be at least retarded inside aggregates.
2. The silicic acid (DSi) concentration inside the aggregates has been found to be 5-20 times higher than in surrounding waters. Because of the non linearity of dissolution rates far from equilibrium (van Cappellen and Qiu, 1997), such a difference could lead to strongly reduced dissolution rates inside aggregates.
3. Cells remained alive much longer when aggregated (Figure in annex on page 59). Because dissolution affects mostly dead cells (Nelson et al., 1976), such a longer viability inside aggregates could also account for lower dissolution rates.

Thanks to the help of Prof. van Cappellen (Utrecht University, The Netherlands), a simple model describing a spherical aggregate has been built, to account for the process of diffusion of silicic acid from inside the aggregate to the surrounding waters, with a much lower concentration. With this model, it can easily be shown that with a slow dissolution inside the aggregate, diffusion would be too fast for DSi to accumulate inside the aggregate. Thus, a process must retard the diffusion of DSi outside the aggregate, following BSi dissolution. TEP are a good candidate and experiments have been designed in this sense at the AWI to test this hypothesis. It is possible that diatoms form aggregates with the strategic objective, not only of increasing their sinking rate to escape the surface waters depleted in nutrients (Smetacek, 1985), but also for preserving elevated DSi concentration in such a microenvironment, thereby helping them to survive longer. The observed lower dissolution would then be just a consequence of this strategy. These results have all been incorporated in a manuscript to be submitted shortly.

Dissolution rates are now being used in the aggregation model of Dr. Kriest (Partner 4; Kriest and Evans, 2000), that has been implemented within the NIOO 1-D modelling environment by partner 7. B. Moriceau has spent two weeks at the NIOO (Partner 7) with this objective. At AWI, experiments have been conducted on free cells and 1 cm aggregates. These two sizes represent the two extremes of the size range used in the aggregation model. One additional experiment is presently being conducted at UBO (Partner 3) to study the dissolution rate of 1 mm-size aggregates, which will allow the characterization of the shape of the relationship between dissolution rate and aggregate size.

Dissolution experiments on faecal pellets (partner 3):
In order to study the (potential) preservation of biogenic silica in faecal pellets of copepods, dissolution experiments will be performed on faecal pellets produced by the copepod *Calanus helgolandiscus* maintained in the laboratory climatic room and fed with the diatom *Thalassiossira weissflogii*.

Copepods were maintained in PP tubing ("cages") that were sealed at one end with 500-µm mesh sieve. Each tubing was suspended in an aquarium filled with filtered seawater (in climatic room, 13°C). Each day, copepods were feeding on the diatom *Thalassiossira weissflogii* grown in Guillard's f/2 medium. Faecal pellets were collected with a 200 µm-mesh sieve. They were rinsed with ammonium formiate in order to eliminate salts. Then, they were centrifuged and stored in the freezer, until a sufficient quantity of material (necessary for the dissolution experiments performed by means of flow-through reactors - need of 0.5-1g of faecal pellets by reactor, 5 reactors) was obtained.

This fastidious work started in March 2003 and will be finished in December 2003; the dissolution experiment will be conducted in February 2004. During 2003, in parallel to the collection of this faecal material, another approach has been undertaken, extending the one developed to study the decoupling between C and N during grazing (Vincent et al., 2003), to include the Si and Fe cycles.

Experiments were carried out to study the role of copepods in the C, N, Si and Fe cycling, with a particular interest on the transfer of these elements between the phytoplankton and the zooplankton compartment and between the zooplankton compartment and the surrounding environment.
For this, 4 experiments, on a day-time scale, were performed on two different copepods (*Calanus helgolandiscus* and *Temora longicornis*) grazing on the diatom *Thalassiossira weissflogii*, beforehand labelled. Two distinct series of experiments were done: one using radio-labelled tracers ^{32}Si and ^{55}Fe and the other, using stable isotope tracers ^{13}C and ^{15}N.

The first stage of these experiments consisted in labelling the phytoplankton. Then this labelled phytoplankton was grazed by copepods and at intervals of 6 hours (on a 24 h experiment), each component of the system phytoplankton-zooplankton-surrounding water (particular and dissolved material, faecal pellets, eggs and copepods) has been sampled in order to establish a budget for each element. To clearly establish these budgets, complementary experiments were necessary to measure separately processes such as those acting in the copepod metabolism (like excretion) or the contribution of dissolution of faecal pellet in the surrounding waters.

These original experiments implied collaborations with other French laboratories in Vimereux (D. Vincent), Brest (S. L'Helguen) and Marseilles (G. Slawik). Si and Fe being measured by means of Cerenkov counting, results start to come out. C and N measurements make use of stable isotopes which will be measured by mass spectrometry. Results are expected during the first trimester of 2004.

Degradation experiments:
Two types of degradation experiments have been performed, are ongoing and/or planned: *in-situ* simulated, and laboratory experiments.
(i) In-situ simulated experiments – These have been conducted by B. Moriceau onboard the "Seaward Johnson" to conduct dissolution experiments at the DYFAMED site. This cruise (May 5 – May 13, 2003) was part of the NSF MedFlux project, with a group from Stony Brook as PIs (Cindy Lee, Robert Armstrong). Our group has been invited to provide the complementary expertise on Si, to the experimental work they had planned in their proposal on organic matter degradation. Onboard, degradation experiments have been carried out on various kinds of particles, including free cells separated by density or sinking velocity, aggregates or zooplankton faecal pellets. B. Moriceau has collaborated with the group of M. Goutx, from the University of Marseille, for the microbiological part of these degradation experiments.
Results are already available for Si, but will be fully exploited when the C results will be available. These experiments are very interesting for ORFOIS purposes. Not only will they allow us to study the influence of the removal of the organic matter coating the opal surfaces, which has a strong influence on biogenic silica dissolution (Biddle et al., 2002); they will also allow to test the so-called "ballast hypothesis" developed by Armstrong et al. (2002), by studying the effect of biogenic silica dissolution onto the rate of degradation of the internal organic matter of the diatoms.
(ii) *Laboratory experiments* – Degradation experiments are being conducted by B. Moriceau at the NIOO, in close collaboration with J. Greenwood (Partner 7). The principle of these experiments is similar to the one described in the first annual report. They will be extended to different diatom species, and in addition to studying changes in BSi dissolution properties, changes in diatom structure/morphology will be followed by means of SEM, BET measurements will be performed to study changes in specific surface area during degradation, and titrations to follow changes in surface chemistry (collaboration with Prof. Van Cappellen, Utrecht University).

Work is also being conducted in Brest, on a single diatom presenting different silicification degrees. It has been shown that Fe-limited diatoms grow thicker frustules (Takeda, 1998 ; Hutchins and Bruland, 1998). The impact of such an observation onto the preservation of the frustules is as yet unknown, which causes problems in interpreting the opal sedimentary record in the Southern Ocean where Fe limitation has been proven (De Baar et al., 1995). A diatom (*Thalassiosira weissflogii*) has been grown by E. Bucciarelli in September/October 2003, under Fe-repleted and Fe-depleted conditions. The comparative dissolution experiments will be studied within ORFOIS by Dr. M. Gallinari in February 2004, by means of flow-through reactors.

Partner 6 carried out dissolution experiments of different sediment materials. Previous studies in tropical deltaic systems such as the Amazon delta have shown that biogenic silica particles such as diatoms upon deposition to the sediments undergo rapid conversion to cation-rich alumoninosilicate phases (Michalopoulos et al. 2000). Such conversion has important implications for the estimated mass of biogenic silica stored in these deposits. It has been recently estimated that inclusion of newly formed authigenic minerals and converted biogenic silica increases the amount of reactive silica (i.e. biogenic silica + converted biogenic silica+silica in newly formed aluminosilicates) stored in Amazon deltaic sediments by a factor of six (Michalopoulos and Aller, in press). The estimate of the amount of reactive silica stored in deltaic sediments is based on operational leaches that account for the formation of new cation rich aluminosilicate phases derived both from the conversion of biogenic particles and precipitation from solution . Hence in order to arrive to estimates for the degree of biogenic silica conversion to other mineral phases, both the standard operational alkaline leach method for the determination of biogenic silica in marine sediments (DeMaster 1991) and a modified operational leach method which includes a mild acid pretreatment step (Michalopoulos and Aller, in press) are used. The results from both methods in each sample are used for construction of an alteration index that quantifies the degree of biogenic silica alteration. These methods have been used for the determination of biogenic silica alteration in Ganges-Brachmaputra deltaic sediments and Mississippi deltaic sediments obtained during the sample acquisition phase of ORFOIS. Results from this study are shown in ANNEX, partner 6.

In addition to the operational analytical approach described above, evidence for conversion of biogenic silica particles and formation of new mineral phases as products of reverse weathering can also be obtained through direct observations of natural particles buried in deltaic deposits.(Michalopoulos et al, 2000). Such observations have been carried out on selected sediment samples from the Ganges-Brachmaputra with encouraging result. Diatom frustules and diatom fragments have been observed in the >63-μm fraction. Frustule remnants may be reduced just to the external rim or may yield a darker rim. SEM images show rare precipitates on frustule aureolae and EDS spectra on a few specimens indicate iron-rich coatings. Altered diatom frustules and diatom fragments have been observed as well within the 63-40-μm fraction. Round plates and membranes have also been observed within the >63-μm faction. EDS mapping proved they are siliceous and contain Fe, K and Mg. Pyrite has been observed inside some round plates, which we speculate is an early diagenetic product of the degradation of organic matter within the diatom cytoplasm .

We have observed common light-brown to grayish-green phyllosilicate mineral flakes (resembling “book” layers) up to 100-μm thick in the >63-μm fraction (see ANNEX, partner 6). Separating thickest flakes from the rest of the material may result in breaking them apart along the horizontal plane. Some of them yield circular holes, up to 10-15 μm large, right at the centre. They may show some concentric zoning. SEM-EDS spectra proved they are K,Mg,Fe-rich aluminosilicates. The morphological and physical characteristics of these particles strongly indicate formation in situ and not an allochthonous origin. Thus, there is strong likelihood that these particles are authigenic mineral phases, products of “reverse weathering” processes. They are potential sinks for major elements such as Mg, K, Si in this environment. These types of particles have not been described before in other rapidly deposited deltaic sediments and their discovery may lead to a reassessment of the role of Ganges-Brachmaputra system in the long-term global carbon cycling. Formation of such minerals in the marine environment will tend to counterbalance the consumption of CO_2 during silicate weathering processes on land (Lafford and Derry, 1997).

Preliminary experiments to investigate the effects of seawater ‘aging’ of diatom skeletons on specific surface area and dissolution kinetics have been conducted by partner 7. This has been necessary for the optimization of dissolution techniques, and frustule cleaning methods consistent with both dissolution measurements, and BET surface measurement. Further degradation studies are currently underway at NIOO in collaboration with partner 3 (UBO).

2.5 Laboratory experiments on calcium carbonate reactivity (solubility and dissolution kinetics) (partner 2).

The quantification of *in situ* carbonate dissolution rates relies on an accurate parameterisation of carbonate dissolution kinetics, which implies an improved knowledge of the rate constant and the solubility product. Dissolution, both it in the water column and surface sediments, is driven by the departure from solubility with respect to the particular carbonate phase. The solubility product evolves with depth under the combined influence of pressure and temperature. Because biogenic marine carbonates are complex solid-solution mixtures, their solubility product and dissolution kinetics are poorly known.

- R*eassessment of existing data* : Broecker and Takahashi (1978) proposed an empirical relationship to describe the evolution with depth of the critical carbonate ion concentration, $CO_3^{2-}{}_{CRIT}$. Their approach combined ocean measurements (GEOSECS), sediment data (depth of lysocline) and results from *in situ* saturometry The resulting empirical relationship for calcite writes : $CO_3^{2-}{}_{CRIT}$ (µM/kg) = 90 exp(0.16(d-4)), where: d, depth in km. The original GEOSECS data have been revised several times during the past years and the use of the empirical relationship combined to the corrected GEOSECS data rises the question of internal consistency. Following the approach by Broecker and Takahashi (1978), we derived a revised empirical relationship based on the corrected GEOSECS data base. In contrast to the earlier work, we tied $CO_3^{2-}{}_{CRIT}$ at d=0 to the value derived from Mucci (1983) for synthetic calcite. Our approach results in the following relationship : $CO_3^{2-}{}_{CRIT}$ (µM/kg) = 41.82 exp(0.172d).
- *Experimental work* : the pH-stat approach presented in the preceding report could not been applied on a routine basis. The reaction rates of marine carbonates proved to be too slow close to equilibrium to be resolved be the system. In order to achieve our objectives, we came back to the free-drift approach. It was doubled by an independent approach targeting the solubility. During these long term equilibration experiments, the solid fraction was allowed to equilibrate with artificial seawater starting from supersaturated, respectively undersaturated conditions. We selected surface sediments from three bathymetric transects located in the tropical Atlantic (Sierra Leone Rise and Cape Verde Plateau) and Pacific (Ontong Java Plateau).

Dissolution experiments yielded asymptotic alkalinity levels (apparent solubility) supersaturated with respect to calcite. The observed asymptotic solubility estimates along the Sierra Leone transect could be due to either the precipitation of authigenic carbonate phases, probably Mg-calcites, in surface sediments in contact with supersaturated bottom waters or to the progressive dissolution of primary biogenic carbonate that included components with a range of solubilities. The comparison between experimental estimates of the calcite saturation state and the in situ saturation state of bottom waters show a striking agreement. Our results indicate that bottom water saturation state provides a first-order control on the solubility of surface sediments. This part of our study gave rise to a first paper by Gehlen et al. (2003) submitted to *Geochimica Cosmochimica Acta* (refer to ANNEX for abstract).

Kinetic experiments allowed us to derive reaction rate constants normalized with respect to specific surface and solid solution ratio. The average reaction rate constant was 0.13 ± 0.05 meq/m^2/d. The order of reaction was greater than 1 (1.6 ± 0.2).

<u>*WP3. Community model development:*</u>

3.1 1-D Codes are modified to allow full vectorisation for use in 3-D models, which are run on high end supercomputers (partners 1, 2, 4).

Due to the necessarily different structure of the 1-D and 3-D codes – the 3-D codes in general have to be more simplistic than the elaborate and much more detailed 1-D codes – all codes have been optimnised with respect to the specific computeres on which they are used (scalar, vector, multi-processor parallelization).

3.2 Homogenisation of nomenclature; common mnemotechnical variable names are defined from the very beginning of the project (partners 1, 2, 4, 7).

As discussed at the ORFOIS modelling workshop in Yerseke (at NIOO, 2002) a completely homogenised nomenclature turned out not to be feasible due to the different historical developments and concepts of the various 1-D and 3-D codes. In order to circumvent associated difficulties in understanding the various source codes, mnemotechnically easily to understand variable names were chosen, comments were introduced in the program codes and model descriptions were provided. These were extremely detailed (as for partner 4 and BOGCM I, see WP9 on dissemination) easiliy understand and modify the source code for different applications.

3.3 Development of coupling interfaces to BOGCM I and BOGCM II (partners 1, 2).

Both BOGCMs were written in a strictly modular structure. Respective modules such as the sediment codes (pore water chemistry, exchange between sediment and water column etc.) can thus be exchanged between the different model frameworks and adjusted to the respective internal model architecture.

3.4 The community model source code development will be carried out through use of the ClearCase source code control software, which allows easy book keeping of changes made in the FORTRAN programmes as well as simultaneous work of different partners on one model component in parallel (partners 1, 2, 4, 7).

As discussed at the ORFOIS modelling workshop in Yerseke (at NIOO, 2002), the parallel code development using the ClearCase software proved not to be feasible due to the complex modeling development inbfrastructure which simply would be too complicated in our case. Thed common update of codes in one tree-hierarchy would have caused rather more confusion and work overhead than improvement of results. Therefore, it was decided to feed the ready model products later into an existing source code development structure as ready "model cycles" in order to freeze and archive the tested and verified model codes.

<u>*WP5. BOGCM implementation:*</u>

5.1 Integration of the physical (dynamical) part of the BOGCMs into statistical equilibrium using the preindustrial forcing fields as compiled in WP4 (partners 1, 2).

The BOGCM1 model HAMOCC5 is now running on our local system at NERI and on the Horseshoe supercluster located at the University of Southern Denmark. The parallelisation of the code for MPI-CH has now been initiated. A parallel version of the model can potentially speed up the calculations substantially, and also the integration of the model would benefit from the large numbers of cpu's which are available for us at the Horseshoe cluster. Currently the model integrates with a speed of 2.6 model years pr. real day, and therefore the spinup on our local cluster is relatively slow. A long integration of the model has been carried out for more than 800 model years.

5.2 Coupling of the community model versions for particle flux dynamics and sediment early diagenesis into BOGCM I and BOGCM II, including adjustment of the ecological modules already existing within BOGCMs I and II (partners 1, 2, 4).

An update of the model version of BOGCM1 at NERI (partner 1) has been carried out in the fall 2003, based on the revised code provided by partner 4.

The original workplan separates the development of community models for particle dynamics and sediments from their implementation into BOGCM II. This sequence could not be completely followed. We started the implementation of both components from published non-community versions. These were Kriest and Evans (1999, 2000) for the particle dynamics and Heinze and Maier-Reimer (1999) for the sediment module.

- *particle flux*: The particle flux module developped by I. Kriest is currently coupled to BOGCM II (ORCA/PISCES). This has implied a number of modifications, both on the already existing ecologial module (PISCES) and on the particle flux dynamics module. We have for example included the effects of biological processes (mortality, grazing, particle-flux zooplankton feeding, …) on the particle size.

First comparisons between simulated and observed (SeaWifs) surface chlorophyll have revealed some defaults in the simulated field (too much chlorophyll in the oligotrophic gyres and in the Southern Ocean, see Figure 1 in annex on page 56). A second version of BOGCM II with modified constant values for the particle flux module (see Kriest 2002 for a discussion of the different parameters/values) has been developped and tested (see Figure 1 in Annex on page 56).

- *sediment module*: The sediment module is currently coupled to BOGCM II. This implies the harmonization between the in- and outputs of the sediment model and OPA/PISCES (adaptation to the OPA C-grid configuration, format of in/output files, units, time step of integration etc.). Closely following Heinze et al. (1999), the sediment module describes early diagenetic processes including pore water /solid matter interactions, pore water diffusion, vertical advection of sediment (upward/downward) and bioturbation. The model is tested for the combination of Si as a reactive tracer and clay as an inert phase. It is running off-line within the configuration of BOGCM II and forced with output from PISCES. In a close future, organic matter remineralisation will be added. The dominant electron acceptors in open ocean sediments, O_2 and NO_3, will be considered.

The aggregation module described in Kriest (2002) has been implemented into the BOGCMI by partner 4. To account for possible iron limitation of oceanic production, monthly mean fields of dust deposition (Timmreck et al., unpubl.) have been added to the model, which provide an iron source mainly to the Atlantic Ocean, but may cause iron deficient conditions e.g., in the Southern Ocean. $CaCO_3$ dissolution in copepod guts has been parameterized, depending on the saturation level of the animals

5.3 First test integrations of BOGCMs I and II using the same basic FORTRAN codes for the community models but with possibly different model parameter settings through application of the ClearCase source code control system (partners 1, 2, 4).

Test runs were already made during year 1. For usage of ClearCase, please seeWP3.

5.4 Longer model integrations to provide basic preindustrial tracer and pCO_2 distributions (water column, sediment) as basis for the subsequent model optimisation (through application of burst coupling in order to accelerate the sediment equilibration) (partners 1, 2, 4).

Several longer model integrations of about 100 year duration hava been carried out by partner 1 with the BOGCM1 for testing the model settings and paramterisations. Longer intergrations are initiated for providing a preindustrial pCO_2 distribution.

Partner 2 has to complete the coupling of the sediment module before starting the longer model integrations. This delay does not impede on the study of the feedback of particle export schemes on surface ocean pCO2. Today, several simulations without the sediment module but including the particle flux dynamics module were carried out. Due to their high CPU cost, each of these simulations were only run a few hundred years (250 yrs each).

The model BOGCM1 has been spun up for 769 years by partner 4, starting from constant mean tracer distributions, and using constant preindustrial forcing and atmospheric boundary conditions. A parameterization that allows accelerated degradation, dissolution and diffusion in the sediment is used in order to keep the integration time for the equilibration between sediment and ocean water column low. The model has been calculated another 150 years, applying the sediment acceleration every 50 years, yielding an overall integration time for the sediment of 30916 years. Alltogether, the biogeochemical model has run for 919 years, allowing the tracers to adapt more or less to the forcing and constants.

5.5 Rough comparison with observations as collated in WP1 in order to adjust model tracer distributions to correct order of magnitude (partners 1, 2).

The comparisons with sediment trap observations as collated in WP1 has started. Figure 2 (annex on page 56)shows the flux of particulate organic matter at 800 m in the Arabian Sea (Station S05). The use of the community particule flux dynamics module to compute the sinking speed enables to adequately reproduce the timing of the flux at depth, which is not reproduced when a constant sinking speed of 7 m/day is used.

BOGCMI has been compared to global climatologies of phosphate, silicate, oxygen, total inorganic carbon, and chlorophyll. It is further compared to large data sets (covering different biogeochemical regimes) of sedimentation (POC, opal, calcium carbonate), dissolved iron, as well as to sediment constituents (calcium carbonate, opal). Data sets at discrete time series stations are also used to check more detailed characteristics of the model.

After 919 years of integration the model already reflects many features of the observed nutrient and TCO_2 distributions (Fig. 1, 2 in annex on page 61).

Simulated chlorophyll (Fig. 3, annex on page 62) is within the range of that of pigments observed by satellites (Fig. 4, annex on page 62), although the model overestimates the blooms in equatorial regions, and underestimates the winter concentrations in northern temperate regions. The increase in chlorophyll leads to increased sinking rates (Fig. 5, annex on page 63), and thus to enhanced sedimentation in these regions.

To compare model sedimentation with observations, the model has been sampled at the same location as those of the global data set compiled by Ragueneau et al. (2000), and both data are plotted together in Figure 6 (annex on page 64). The model is already within the range of particulate organic carbon (POC) sedimentation, though in mid-latitude regions the POC export is slightly too low, while especially the shallower traps in the high latitudes exhibit less flux than the model. Opal and CaCO3 sedimentation are too high especially in the equatorial regions. This may, however, be attributed to the too high production in these regions.

The model sediment (after being simulated in accelerated mode, i.e., after 30916 years of integration) already shows many of the observed features (Fig. 7, annex on page 65): There is a belt of opal rich sediments around the Antarctic continent, and a slightly enhanced opal fraction in the northern North Atlantic. Carbonate rich sediments are found mainly in the Atlantic Ocean, although the carbonate rich sediments along the Mid Atlantic Ridge do not show up as clearly in the model as in the observations, and are underestimated beneath the Pacific equatorial upwelling. Experiments concerning the rain ratios of opal and calcium carbonate are underway.

Finally, simulated pCO_2 with its low concentrations between 220-380 ppm to a large extend reflects the pre-industrial forcing of 280 ppm constant atmospheric pCO_2,. Delta pCO_2 nevertheless exhibits the patterns observed, as. e.g. increased values along equatorial upwelling regions, and drop in pCO_2 in the northern North Atlantic especially during spring and summer, or in the Southern Ocean during austral summer Fig. 8, annex on page 66).

Summarizing, this first long-term coupled aggregation-BOGCM model already exhibits many of the observed or expected features, other processes still require a more detailed investigation and will be further refined during the optimization loop.

5.6 Implementation and test of crude parameterisations of shelf sea processes (retention of nutrients and carbon loads entering the ocean from land, shelf/open ocean exchange, high shelf sediment accumulation regimes with anoxic pore water reactions) (partner 1).

BOGCM I has been prepared to include a more detailed parameterization of riverine inputs of nutrients and carbon from the continents. At the locations were freshwater is fed into the physical model, also nutrients and carbon are added in dissolved form to the oceqan. This was done by introducing additional variable arrays for riverine substances as corresponding to the respective oceanic substances. In order to avoid a direct utilization of nutrients at the river mouths which led to unrealistic "hot spots" of biological production at estuarine sites in the model, these riverine concentrations were released with a tunable time constant from the riverine reservoir to the oceanic (and biologically active) model concentrations (example given in Figure of annex, page 48) relaxation time scales can be further refined taking into account various shelf processes as discussed during a meeting between partners 1 and 6 in Roskilde (NERI, partner 1) in December 2002. More detailed river load data will be made available from the SISYPHE group in Paris. Respective data inputs were prepared during the OCEANS conference in Paris (January 2003) and a meeting at the Centre for Marine Tropical Ecology (Bremen, December 2003) together with Michel Meybeck and Josette Garnier from SISYPHE.

<u>WP6. Optimisation of the prognostic system:</u>

6.1 Comparison between BOGCM outputs and observations, identification of the crucial disagreements to be removed (partners 1, 2, 3, 4, 6, 7, 8).

To investigate the sensitivity of the ocean-atmosphere CO_2 partitioning to the description of water column vertical fluxes of organic matter, partner 2 has run 4 different versions of the PISCES model, forced with the same dynamical preindustrial forcing fields (obtained with the Océan Parallélisé (OPA) model).

<u>CASE 1.</u> In the first version, only one size fraction of particles is considered. It sinks with a constant sinking speed (set to 7 m/day) over the water column This simulation represents the control-simulation.

<u>CASE 2</u>. In the second version of the PISCES model, we have introduced a more advanced particles dynamic module, based on the work of Kriest and Evans (1999,2000). We explicitely represent the sinking of particles below the photic zone, incorporate a mechanistic representation of aggregation/disaggregation of particles and include the effects of biological break-up of aggregates during zooplankton feeding.

<u>CASE 3.</u> This is the standard version of PISCES. Two O.M. particle size fractions are considered. Sinking speeds are constant over time but differ for the 2 fractions. For the small

particles, the sinking speed is set to 3 m/day in the euphotic layer and increase to 10 m/day at depth. For the large particles, the sinking speed is set to 10 m/day in the photic layer and increases to 200 m/day at depth.

CASE 4. In this fourth version of PISCES, we have included a simple representation of the ballast effect. Sinking speed of particles in the water column is computed as a function of organic matter, calcite and biogenic silica concentrations and of their respective densities.

Comparison of the simulated surface chlorophyll with remote sensing observations have shown skills and deficiencies of the different particle flux modules (not shown here). Figure 3 (annex on page 57) shows the incoming O.M. flux to the sediment for three of the above-mentionned versions of BOGCM II. A comparison with data compilation of O2 fluxes from the sediment (R. Jahnke) is underway.

To investigate how the different particle flux dynamics module impact the air-sea CO2 fluxes, we have compared simulated pre-industrial ΔpCO2. Figure 4 (annex on page 57) reveals large differences between the different versions of the BOGCM II : up to 20 ppm in the Equatorial Pacific for the zonal mean for example.

6.2 Tune BOGCMs optimally using an SVD technique (partners 1, 2, 4).

Originally, it was planned to carry out the model tuning of the BOGCMs systematically through a-SVD technique as applied in Heinze et al. (2003). This method allows quasi –objective tuning of complex BOGCMs with respect to observed data. The method requires, that the respective BOGCMs are computed into quasi-equilibrium several times with small perturbations in the parameters to be optimized. Given the long integration times of BOGCMs I and II, this method proved to be not aplicable in our case. Alternative tuning methods were therefore applied. The first method is based on global bulk numbers. The models are first tuned so that global bulk numbers for biological production and sedimentation are satisfied giving then at least correct large scale rates of throughput of matter from continent-derived input at the sea surface to output by sediment accumulation (“loss to the lithosphere”). The second tuning method uses gridded start fields for moedlled variables on the basis of measurements. It is then followed how quickly the modelled results diverge from the observed arrays. Model parameters can then either successively adjusted or in severe cases then models have to be initialized newly with corrected parameter choices.

6.3 Fill in gaps in data coverage for model verification (partners 3, 6, 8).

Additional observational data sets were included in the data base as described under WP1.

6.4 Revise atmospheric forcing (e.g., for ACC strength adjustment) (partners 1, 2).

Building on WP4, the atmospheric forcing fields for the global warming scenarios to be carried out were refined. The forcingfields for HAMOCC5 (BOGCM1) for the preindustrial conditions are based on the OMIP data set (Frank Röske, An atlas of surface fluxes based on the ECMWF re-analysis- A climatological dataset to force global ocean general circulation models, Report no. 323, Max-Planck Institute für Meteorologie, Hamburg, Germany). This dataset is based on a re-analysis of 15 years of numerical weather predictions in the period from 1979 to 1993, from which a yearly cycle of all the forcing variables is determined. Due to lack of reliable data for the preindustrial period, the present day forcingfields will be the basis for the transient experiments and thereby act as preindustrial forcingfields.

In the first phase of ORFOIS, time dependent ocean forcingfields from the transient climate change scenarios with the coupled ocean-atmospher-sea ice model ECHAM4/OPYC3 was downloaded from the CERA-database. These experiments are documented in (Roeckner, E. et al., Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle, J. Climate, 3004-3032, 1999). Two climate change scenarios are downloaded, corresponding to the GHG and the GSDIO-experiment, described in Roeckner et al. (1999).

The final interpolation from the ECHAM4/OPYC3 dataset onto the modelgrid of BOGCM1 (HAMOCC5) includes sevaral steps, and the software for each step has now been developed. First the orignal dataset from the CERA-database has been converted from the GRIB to a LOLA-format by the PINGO-package (Wasckewitz J. et al., The PINGO package, Internal report, DKRZ, Hamburg, Germany). Differences between the landmasks of the ECHAM4/OPYC3 model and the HAMOCC5 model can lead to large spatial gradients of the forcingfields in the HAMOCC5 model, and therefore oceanpoints in the ECHAM4/OPYC3 are "diffused" onto land areas with a bilinear interpolation matrix who only considers oceanpoints in the ECHAM4/OPYC3 dataset. This dataset is then subsequently interpolated onto the HAMOCC5 grid by the use of the SCRIP-interpolation package (Jones, P. W., A users guide for SCRIP: A spherical coordiante remapping and interpolation package", version 1.4, http://climate.acl.lanl.gov/software/SCRIP, Los Alamos National Laboratory, USA). A general bilinear interpolation method is used between the gaussian T42 grid of the ECHAM4/OPYC3 model and the curvilinear orthogonal spherical grid of HAMOCC5. Finally the forcingfields are stored with the original ECHAM4/OPYC3 12 hour interval in netCDF-files for each forcingvariable for each year. The format of the netCDF-files can therefore now be read directly into the HAMOCC5 model, and used for the transient experiments. The dataset prepared for the transient experiments cover the period 1860 - 2050, corresponding to 191 years. A year of forcingfields for a single variable amounts to about 36 MB of data, and the complete dataset with all the forcingfields corresponds to about 50 GB of data for each experiment.

The software developed for the above sequence of steps, are sufficiently general to be applied for other datasets as well.

Direct comparisons between the OMIP-air temperature and the ECHAM4/OPYC3 - air temperature after interpolation onto the HAMOCC5-grid show minor differences in the yearly averaged values, except for polar areas where differences in sea ice cover results in relatively large temperature differences (see enclosed figure). The transient change in the global forcingfields has been analysed, and they show a gradual increase in the global averaged surface air temperature from 1860 to 2050, with a pronounced change in the northern polar and subpolar areas (see enclosed animation of the GHG-experiment).

6.5 Quality check of the observations (partners 3, 6, 8).

Consistency checks and quality tests were made with all data which were fed into the data base (see also WP1).

6.6 Revise process parameterizations through 1-D modeling and feed these improvements into the community model components as used by BOGCMs Ia nd II (through use of the ClearCase source code control system including the test of the 1-D codes in selected case studies) (partners 2, 3, 4, 6, 7, 8).

Several simulations have been conducted by partner 7 in order to tune and optimise parameterizations for biological and biogeochemical processes in the water column, and to check the general consistency of the 1-D code. A 1-D physical representation of the upper 1000m, with a resolution of 10m, has been tuned for station ALOHA in the sub-tropical North Pacific based on a well tested turbulent mixing scheme. A 1-D steady-state re-mineralisation model has been used to make a preliminary examination of the major processes affecting the vertical distribution of hydrogen ion concentration, dissolved inorganic carbon and oxygen below the euphotic zone between 150m and 1000m at ALOHA. A coupled physical-biogeochemical 1-D dynamic model has also been applied and tested for the upper 1000m at station ALOHA.

A method that allows the identification of parameter combinations that can be estimated from given observations, so-called “identifiability analysis”, was implemented by partner 7. This technique calculates both the sensitivity of the model to single parameters and the near-linear dependence of parameter subsets. Both measures then give guidance in the selection of identifiable parameter subsets used for parameter identification.

Partner 8 has conducted two studies on surface pCO_2 uptake parameterisations:

Pelagic carbon budget for SOIREE - A full pelagic carbon budget has been made for the Southern Ocean Iron Release experiment. In particular, it was possible to assess to what extent closure of this budget was achieved, a primary objective of biogeochemical ocean programmes, such as Joint Global Ocean Flux Study (JGOFS). A manuscript describing the budget is in revision after an initial submission to Deep-Sea Research (Bakker et al., 2003).

Storms influence oceanic CO_2 uptake. A comparison of the results from the SOIREE and EisenEx experiments highlight how differences in meteorological and hydrological forcing influence CO_2 uptake upon iron fertilization (Bakker et al., in preparation).

<u>WP7. Model application and demonstration:</u>

7.1 Final integration of the preindustrial reference runs with BOGCMs I and II using the optimized prognostic system (partners 1, 2).

Preindustrial reference runs were carried out with BOGCMs I and II. These runs were repeated iteratively until the best possible version within the given time frame was available (see WP 6).

7.2 Integration of greenhouse gas induced warming scenarios restarting from preindustrial conditions (partners 1, 2).

The integrations of the greenhouse gas induced warming scenarios has been prepared, and the setup of the experiments has been initiated.

7.3 Integration of Fe-fertilisation scenario introducing additional iron input to areas with high preformed nutrient surface concentrations (restart from modern conditions, few hundred years) (partners 1, 2).

New parameterizations of iron fertilisation have been tested with BOGCM I. Both BOGCMS (I and II) are ready for these scenarios.

7.4 Integration of deep ocean CO_2 disposal scenario through CO_2 injection into selected $CaCO_3$ rich deep sea areas (partners 1, 2).

These scenarios were prepared for BOGCMs I and II. Exact configurations of respective experiments will be discussed on the 2nd annual ORFOIS meeting in Gif-sur-Yvette (location of partner 2).

7.5 Integration of glacial ocean scenario (partner 4).

The glacial ocean scenario is being prepared through selection of the most suited model/forcing data combination. It may be advisable to carry out the glacial scenario with the already tested fast HAMOCC version based on the LSG model dynamics rather than to use BOGCM I, which is computationally quite expensive. Details on this alternative will be discussed on the 2nd annual ORFOIS meeting in Gif-sur-Yvette (location of partner 2).

7.6 Compilation of results for economic evaluation (partners 1, 2).

Values for the preindustrial ocean are available.

WP8. Economic evaluation:

8.1 Adoption of already existing models for the specific purpose of the project (partner 5).

The first task, adoption of the *FUND* model, has been completed by partner 5, allowing us to turn to the scientific objectives of the project.

The *FUND* model has been extended to include a richer representation of climate change (e.g., sulfur dioxide), and the spatial resolution (16 instead 9 regions) has been increased, allowing for a more careful regional assessment of climate change impacts and greenhouse gas emission reduction costs. Additional climate change impacts (e.g., diarrhea) have been included, and other greenhouse gases (methane, laughing gas) have been added. This will allow for more accurate estimates of the impact of marine carbon fluxes.

8.2 Estimate differences in carbon fluxes due to the alternative representation of the marine carbon cycle and estimate impact on the costs of meeting certain emission reduction targets (partner 5).
This activity was planned for after month 24.

8.3 Estimate (based on previous step) (1) effects on atmospheric CO_2 concentrations, climate change and sea level rise, and (2) differences in the impacts of climate change and sea level rise (partner 5).
This activity was planned for after month 24.

8.4 Complementation of the impact estimates of marine carbon sequestration on carbon cycle and ecology of WP7 with estimates of the costs of marine carbon sequestration (partner 5).
This activity was planned for after month 24.

[8.5 Omitted, see kick-off meeting.]

WP9. Dissemination:

9.1 Data base of observations including user manual: (1) CD-ROM, (2) on the Internet (partners 3, 6, 8).

Preliminary versions of CD and Internet versions are available. Data bases are improved throughout the process of the project.

9.2 Community models (ecological/particle flux dynamics and early diagenesis modules): (1) On the Internet, (2) publication on paper as technical report (partners 1,2,3,4,6,7).

Writing of detailed model documentation for BOGCMI (for later use with community model) has proceeded alongside with the community model development (partner 4).

9.3 BOGCMS I and II plus output from preindustrial, climate change, and carbon sequestration runs: (1) Electronic online publication on the Internet, (2) publication on paper as technical report within an established report series, (3) storage of model results in online data base and forwarding of meta information to European and overseas data centers (partners 1,2).

9.4 Publication of results including economic evaluation as handout for the public (schools, universities, policy makers, fisheries agencies, energy and life science enterprises, and other end users) (all partners).

9.5 Update of project's web page (partner 3 with contributions from all partners).

The website is available at:
http://www.pangaea.de/projects/ORFOIS/
The website is updated regularly in order to document the progress of the project.

9.6 Final project workshop, which will be advertised to the scientific and end user community (partner 1, with contributions from all partners).

<u>WP10. Coordination:</u>

10.1 Contact partners early to receive results in time.
Partners were contacted before relevant deadlines (such as for reports and the cost statements). The notification concerning timely providing of deliverables will go on as during the coming year a series of deliverables is due.

10.2 Gather contributions of participants for management and scientific reports and compile these reports for submission to the EC.
The third and fourth 6 months management reports as well as this 2^{nd} annual progress report were written on the basis of the information provided by each group through the principal investigator responsible for ORFOIS.

10.3 Contact participants regularly to discuss problems and solve them jointly.
Several minor problems concerning the project flow and the carrying out of the tasks could be solved. Partner 6 visited NERI in order to discuss open questions concerning the shallow water and reverse weathering activities. On a data base meeting in Hamburg (May 8-9, 2003) the data flows from the different sources were updated and coordinated.

10.4 Invite participants and consultants to workshops and meetings.
The coordinator invited all partners and advisors to the second annual ORFOIS workshop which will kindly be hosted by CEA/LSCE at Gif-sur-Yvette (February 26-27, 2004). This workshop will take care of the application phase of the project and prepare the final deliverables of the project.

4.3 Comparison of planned and actual work accomplished by the partners

The project progresses as anticipated. A few minor delays are listed below. None of these delays affects the project flow in a significant way. Overall the working discipline in the project was very god and all partners communicated in a very constructive and friendly manner.

The implementation of a sediment module in BOGCM II by partner 2 was delayed due to the maternal leave of N. Emprin. M. Gehlen visited partner 4 (MPI in Hamburg) on November 28, 2003, in order vto discuss several technical details for the finalising of the implementation. Partners 4 and 2 are in contact for accomplishing the sediment coupling.

Due to the late acquisition of samples for the study of biogenic silica conversion to new mineral phases and reverse weathering processes the progress of deliverable #7 has been delayed. The data from the Ganges-Brachmaputra system indicate the existense of conversion processes for biogenic silica. In addition, the first results from the Mississippi delta system also point to the existense of biogenic silica conversion. The laboratory work on the existing samples will be completed in January 2004 and a synthesis of the results will be available in February 2004.

The community model development could for technical reasons not be exactly carried out as planned (see description on WP3 above). As a counter balance, descriptions/user manuals of all models used will be provided. This issue will be discussed on the forthcoming second annual ORFOIS workshop.

4.4 State of the art review: comparison of current work with competing activities

Concerning particle dynamics modules, which are implemented in global coarse resolution BOGCMs, ORFOIS is at present world leading project. To the best of the ORFOIS partners' knowledge, no other consortium has performed similar simulations or is planning those concretely. The combination of comparatively simply 3-D large-scale models and highly sophisticated 1-D gives appropriate ground truth for the reduced process parameterizations in the large-scale models.
The data bases as compiled for comparison berween models and observations are of high quality and can be shared by all scientists world wide, already at this stage of the project. Excluded from general public access are those data sets, of course, for which the originatos allowed exclusive use within ORFOIS. The pCO2 data base includes a mirror site of the CDIAC data set and therefore embeds ORFOIS properly in the worldwide assessment of carbon cycle evoluition under changing climate. The data management and cutting edge modeling put ORFOIS partners into a pivotal position for upcoming rsearch activities within the new instruments of EU FP6.

4.5 Planned activities for the next period

WP6. Optimisation of the prognostic system.

6.1Comparison between BOGCM outputs and observations, identification of the crucial

disagreements to be removed (partners 1, 2, 3, 4, 6, 7, 8).
6.2 Tune BOGCMs optimally using an SVD technique (partners 1, 2, 4).

6.1-6.2: Comparison of model results and observations will be continued. Model parameters will be adjusted using different tuning techniques. The SVD technique had to be abandoned in our case due to excessive integration times of the sophisticated BOGCMs. For the next 6 months some further experiments with BOGCM I are planned regarding the effects of different parameterizations of organic matter production, degradation and sedimentation.

6.3 Fill in gaps in data coverage for model verification (partners 3, 6, 8).
6.4 Revise atmospheric forcing (e.g., for ACC strength adjustment) (partners 1, 2).
6.5 Quality check of the observations (partners 3, 6, 8).

6.3-6.5: Data bases for forcing data and in situ measurements will be continuously updated and improved. The acquisition, processing, and quality check of observational data sets (former WP1) will continue in the WDC-MARE / CDIAC framework. The pCO_2 data formatting work due the expected new data format definition for the CDIAC data base will continue. The acquisition of archived samples for the study of reverse weathering processes in continental margin environments will continue. The literature review for the compilation of data sets regarding the role of continental margins in nutrient cycling will continue.

Special emphasis will be placed on a *uniform data format*: A uniform data format for surface water fCO_2 data is essential for data access by ORFOIS modellers. Unfortunately planned work on a uniform data format for the CDIAC surface water fCO_2 database by Dr. Andrew Dickson (Scripps Institute for Oceanography) has been delayed. As ORFOIS modellers need access to surface fCO_2 data, Dorothee Bakker has defined a 'temporary' uniform format for fCO_2 data. Work is in progress to put surface water fCO_2 data from the CDIAC database into this temporary format. The 'temporary' uniform format incorporates recommendations by Andrew Dickson, the PICES community and CARINA scientists. Putting the surface water fCO_2 data at CDIAC into a uniform format requires a considerable amount of work and will be completed in early 2004.A workshop on ocean surface pCO_2, data integration and database development will take place on 14-17 January 2004 in Tsukuba, Japan. Dorothee Bakker will participate in the meeting, where she will give a short presentation on the ORFOIS project and uniform data formatting issues, which will open a larger discussion on data formats for underway pCO_2 measurements. The objectives of the meeting include:

- To reach agreements on best practices for metadata information and data formats for underway pCO_2 measurements and to publish a technical paper / best practices guide describing the proposed data format and metadata structure;

- To discuss collaborations for regional and global data integration and database development for surface pCO_2 measurements.

The realization of the first objective will be an important driver towards an international uniform data format for surface water CO_2 data in major databases. Hopefully the meeting will also convince more marine CO_2 scientists that they should make their data publicly accessible. Participants include US, European, Japanese, Australian and New Zealand scientists. The sponsors of the meeting are the National Institute for Environmental Studies (NIES), the International Ocean Carbon Coordination Project (IOCCP), and the North Pacific

Marine Science Organization (PICES) Working Group 17.
Access of surface water fCO_2 data at CDIAC from WDC-MARE - The WDC-MARE will implement ANSI/NISO Z39.50 protocol (http://www.cni.org/pub/NISO/docs/Z39.50-brochure/) for the PANGEAE database by the end of 2003. If CDIAC were to implement the same protocol, this would ensure direct data exchange between the WDC-MARE and CDIAC databases for CO_2 data. In this case mirroring of CDIAC's surface water fCO_2 data at WDC-MARE would become superfluous. Mr Alex Kozyr, data manager of marine CO_2 data at CDIAC, is presently looking into the matter.

6.6 Revise process parameterizations through 1-D modeling and feed these improvements into the community model components as used by BOGCMs I and II (through use of the ClearCase source code control system including the test of the 1-D codes in selected case studies) (partners 2, 3, 4, 6, 7, 8).

During the coming months, partner 2 will test the current model version of the 1-D Si early diagenesis model under non steady state conditions. In the course of a sensitivity study, different scenarios describing the Si cycle in surface sediments will be investigated. In a first scenario, the precipitation of Si with Al will be included, the saturation concentration of BSi dissolution will be constant and different from the Si asymptotic concentration. This model will contain one type of BSi. The dissolution rate will vary with depth. In a second scenario, the model will include precipitation, the Si dissolution rate will be constant. This model will contain one type of BSi. The saturation concentration of BSi dissolution will vary with depth or with the ratio SiDetrital/SiBiogenic. The model output of these case studies will be compared to data. Finally, the apparent Si dissolution rate constant, the saturation concentration of BSi dissolution, the dissolved Si reprecipitation rate constant and the saturation concentration for Si reprecipitation will be related to the ratio SiDetrital/SiBiogenic.

Partner 2 will couple a model of carbonate diagenesis to the 1-D diagenetic model of sedimentary C and N cycles developed by partner 7. The module is developed by partner 2 in collaboration with partner 7.

The laboratory experiments on calcium carbonate dissolution kinetics were successful and resulted in a large data set. The coming months will be devoted to the in-depth treatment of experimental results.

The implementation and optimisation of the sediment module in BOGCM II will be continued.

During the coming months partners 1, 2 , and 4 will compare model output for different types of the parameterisation of particle fluxes in the water column. The model output data comparison will benefit with the comprehensive data base collated within ORFOIS. Special emphasis will be put on the feedback of water column remineralization of organic carbon on surface ocean pCO_2.

1-D model output will continue to be compared with the data base of observations. Explicit bacterial dynamics and calcification will be added to the existing 1-D simulation at ALOHA to examine the influence of DOM and $CaCO_3$ precipitation/dissolution on biological and biogeochemical output. Parameterisation of 1-D pelagic silica dynamics has also been planned in collaboration with partner 3 (UBO) using BATS data. Ongoing degradation experiments in collaboration with partner 3 (UBO) will be completed. Coupling of the pelagic and benthic 1-D components will proceed in close collaboration with partner 2 (LSCE) and partner 3 (UBO).

In the next six months the following activities will be carried out by partner 6: (i) Continuation of laboratory analysis of existing and acquired samples with regard to biogenic silica conversion to other mineral phases and cation uptake by continental margin sediments. (ii) Synthesis of results

and quantification of biogenic silica conversion in deltaic environments. (iii) Microscopic investigation of "reverse weathering" products from Mississippi river sediments with the SEM.
Partner 7 will place more work on the following issues: (i) Parameterisation of particle flux dynamics (sinking velocity, coagulation, disaggregation) for the Iberian shelf system (deliverable 5). (ii) Parameterisation of the dissolution rate of POC, $CaCO_3$, and biogenic silicate in the water column was provided (deliverable 6). (iii) Full compilation of 1-D ecological/particle flux model code was provided (deliverable 8)

WP7. Model application and demonstration.
7.1 Final integration of the preindustrial reference runs with BOGCMs I and II using the optimized prognostic system (partners 1, 2).

Selected preindustrial runs will be repeated after optimnisation of the prognostic system.

7.2 Integration of greenhouse gas induced warming scenarios restarting from preindustrial conditions (partners 1, 2).

The transient climate change scenarios will be carried out based on the prepared forcing fields for the period 1860 - 2050. The development of the BOGCM1 for integration on parallel machines will be continued.

7.3 Integration of Fe-fertilisation scenario introducing additional iron input to areas with high preformed nutrient (restart from modern conditions, few hundred years) (partners 1, 2).

Model set ups and scenarios for these experiments will be discussed and established during the forthcoming second annual ORFOIS woerkshop. Model integrations will be carried out in the middle of 2004.

7.4 Integration of deep ocean CO_2 disposal scenario through CO_2 injection into selected $CaCO_3$ rich deep sea areas (partners 1, 2).

Model set ups and scenarios for these experiments will be discussed and established during the forthcoming second annual ORFOIS woerkshop. Model integrations will be carried out in the middle of 2004.

7.5 Integration of glacial ocean scenario (partner 4).

The setup of the glacial scenario and suitable model configurations will be discussed during the second annual ORFOIS workshop. The glacial run will be carried out by J. nSegschneider at MPI Hamburg during 2004.

7.6 Compilation of results for economic evaluation (partners 1, 2).

Preliminary fields for setting up the economical evaluation are available. Final assessments will be made after all optimizations (WP6) have been finished. Procedures will be discussed and agreed on during the second annual ORFOIS workshop.

WP8. Economic evaluation:

8.1 Adoption of already existing models for the specific purpose of the project (partner 5).

Done.

8.2 Estimate differences in carbon fluxes due to the alternative representation of the marine carbon cycle and estimate impact on the costs of meeting certain emission reduction targets (partner 5).
8.3 Estimate (based on previous step) (1) effects on atmospheric CO_2 concentrations, climate change and sea level rise, and (2) differences in the impacts of climate change and sea level rise (partner 5).
8.4 Complementation of the impact estimates of marine carbon sequestration on carbon cycle and ecology of WP7 with estimates of the costs of marine carbon sequestration (partner 5).

For 8.2-8.4: In the next period, we will apply the adopted FUND model to estimate the effects of marine carbon flows on climate change, climate change impacts, greenhouse gas emission reduction targets, and costs of emission abatement.

[8.5 Omitted, see kick-off meeting.]

WP9. Dissemination:

9.1 Data base of observations including user manual: (1) CD-ROM, (2) on the Internet (partners 3, 6, 8).

Preliminary data products are available upon request. Final data products will be provided by end of project.

9.2 Community models (ecological/particle flux dynamics and early diagenesis modules): (1) On the Internet, (2) publication on paper as technical report (partners 1,2,3,4,6,7).

Documentations and models will be made available.

9.3 BOGCMS I and II plus output from preindustrial, climate change, and carbon sequestration runs: (1) Electronic online publication on the Internet, (2) publication on paper as technical report within an established report series, (3) storage of model results in online data base and forwarding of meta information to European and overseas data centers (partners 1,2).

Will be available at end of project. Issue will be discussed during second annual ORFOIS workshop.

9.4 Publication of results including economic evaluation as handout for the public (schools, universities, policy makers, fisheries agencies, energy and life science enterprises, and other end users) (all partners).

Will bedone at end of project. Issue will be discussed during second annual ORFOIS workshop.

9.5 Update of project's web page (partner 3 with contributions from all partners).

The website is being continuously updated until end of project.

9.6 Final project workshop, which will be advertised to the scientific and end user community (partner 1, with contributions from all partners).

The date and logistical details about the workshop wil be ssiued in due time. At this stage it is planned to hold the workshop in Bergen, Norway, in early 2005. Details will be discussed at second annual ORFOIS workshop.

WP10. Coordination:

10.1 Contact partners early to receive results in time.

10.2 Gather contributions of participants for management and scientific reports and compile these reports for submission to the EC.

The 5th management report will be written. The project flow including the deliverables due will be checked continuously.

10.3 Contact participants regularly to discuss problems and solve them jointly.

10.4 Invite participants and consultants to workshops and meetings.

The second annual ORFOIS workshop will be held in Gif-sur-Yvette during February 26-27, 2004.

Meeting attendance:

Workshop on ocean surface pCO_2, data integration and database development, January 14-17, 2004, in Tsukuba, Japan (D. Bakker, partner 8; N. Dittert, partner 3).

CarboOcean IP stage2 proposal writing meeting, Paris, January 19-21, 2004.

AGU Ocean Sciences Meeting in Portland, OR, USA, January 25-30, 2004 (M. Gehlen, partner 2; C. Heinze, coord.).

5. LIST OF DELIVERABLES

Deli-vera-ble No.	Deliverable description	Month where due
46	Workshop 1 (kick-off)	1
37	Management report to the EC after 6 months	6
13	Preindustrial atmospheric forcing fields for BOGCM I and II	6
14	Atmospheric forcing fields for anthropogenic climate change scenarios (for BOGCM I and II)	6
43	Scientific report to the EC after 12 months	12
38	Management report to the EC after 12 months	12
47	Workshop 2 (implementation and optimisation)	12
4	Data extraction techniques	15
5	Parameterisation of particle flux dynamics (sinking velocity, coagulation, disaggregation)	15
6	Parameterisation of the dissolution rate of POC, $CaCO_3$, and biogenic silicate in the water column and in the sediment	15
7	Parameterisation of the conversion of biogenic silicate to other mineral phases in the sediments	15
7a	Parameterisation of $CaCO_3$ dissolution	15
8	1-D ecological/particle flux model	15
9	1-D sediment early diagenesis model	15
10	Coupled version of 1-D biogeochemical/particle flux and sediment model	15
11	Particle flux dynamics module ready for coupling to BOGCM (community model)	15
12	Sediment module ready for coupling to BOGCM (community model)	15
1	Storage of data sets in online data base	18
2	CD-ROM with copy of online data base (basic version)	18
3	Project home page with references to the data sets (basic version)	18
15	Basic BOGCM I version with community model components running for preindustrial conditions	18
16	Basic BOGCM II version with community model components running for preindustrial conditions	18
17	Basic shelf regime parameterisation (BOGCM I)	18
39	Management report to the EC after 18 months	18
24	Distribution of surface ocean CO_2 sources and sinks and oceanic biomass for the preindustrial ocean	24
40	Management report to the EC after 24 months	24
44	Scientific report to the EC after 24 months	24
48	Workshop 3 (application)	24
41	Management report to the EC after 30 months	30
36	Invitation to final project workshop	33
18	Optimised data sets of observations including data coverage in key regions for BOGCM tuning, final CD-ROM with data bases	36
19	Optimised process parameterisations implemented within the community model components	36
20	Optimised community model source codes which can be coupled in a user friendly	36

	way to other models (1-D, 3-D)	
21	Optimised preindustrial physical ocean forcing fields which are consistent with the ocean model physical fields	36
22	Comparison between BOGCM I, BOGCM II, and observations	36
23	List of publications on the prognostic system	36
25	Closed carbon and nutrient balance for the preindustrial ocean including marine sediments	36
26	Distribution of surface ocean CO_2 sources and sinks and oceanic biomass for greenhouse gas induced warming conditions	36
27	Distribution of surface ocean CO_2 sources and sinks and marine biomass under Fe-fertilisation HNLC regions	36
28	Distribution of surface ocean CO_2 sources and sinks and sediment coverage under deep-ocean disposal of CO_2	36
28a	Distribution of surface ocean CO_2 sources and sinks and sediment coverage for a glacial ocean scenario	36
29	List of publications on application of the prognostic system	36
30	Estimates of economic impact of changes in sea surface CO$_{2}$ source/sink patterns	36
31	List of publications on economic evaluation	36
32	Public data sets including user manual	36
33	Public model source codes and model data	36
34	Presentation of the main steps and results for non-specialists	36
35	Electronic (online) presentation of the main steps and results	36
42	Management report to the EC after 36 months	36
45	Scientific report to the EC after 36 months	36
49	Workshop 4 (finish, open to the public)	36

6. EXPLOITATION AND DISSEMINATION OF RESULTS

A number of presentations (oral and poster) as well as several publications resulted from ORFOIS so far. All are listed below in section 7. The project homepage is accessible at (at URL http://www.pangaea.de/Projects/ORFOIS). The project label (created by N. Dittert, UBO, and D. Bakker, UEA) is integral part of the web page. It is available at URL **http://www.pangaea.de/Projects/ORFOIS/logo.jpg**.
A new detailed documentation for BOGCM I is making progress (draft available). Already, ORFOIS results are used within the Carbon Cycle community, especially the data sets and parts ofd the models. The project work enabled a large number of ORFOIS scientists to contribute to a new Integrated Project proposal CARBOOCEAN (pending, stage 1 successful). ORFOIS results will be especially used in core themes 4 (feedbacks) and 5 (future scenarios) of this IP in case its stage 2 proposal would be successful.

7. MANAGEMENT AND CO-ORDINATION ASPECTS

The ORFOIS coordinator, Christop Heinze, started a professorship for global carbon cycle modeling at the University of Bergen (Geophysical Institute, Bjerknes Centre for Climate Research) by January 1, 2004 (see new address in PI table below). Christoph Heinze will continue to act as coordinator in charge of the project. The logistical support (travel money, money for inviting advisers to meetings, etc.) will be funded through part of the grant shifted from NERI to MPI of Meteorology through an amendment in the contract. The glacial run within ORFOIS will be performed at MPI and not at NERI according to this amendment.

Overall the project went smoothly and all partners should high commitment to the project.

ORFOIS workshops/meetings:

First annual ORFOIS workshop, MPI f. Meteorology, Hamburg, January 20-21, 2003.

P. Michalopoulos (partner 6) visits NERI (partner 1) for discussions of coastal ocean and reverse weathering issues, 9 December 2002.

Meeting of partners 2 and 7 at NIOO. Coordination of 1D-modellingt. Introduction of K. Khalil to the FEMME modelling environment, March 2003.

Meeting of partners 2 and 3 at UBO. Parameterisation and optimisation of Si early diagenesis model, May 2003

ORFOIS data base meeting, MPI f. Meteorology, Hamburg, May 8-9, 2003.

Meeting of partners 2 and 3 at LSCE. Parameterisation and optimisation of Si early diagenesis model. October 2003.

The **second annual ORFOIS workshop** will be held in Gif-sur-Yvette, February 26-27, 2004. A corresponding invitation has been submitted to all people involved in ORFOIS and to the European Commission.

Further project related meetings:

N. Dittert, C. Heinze, O. Ragueneau, B. Moriceau, M. Gallinari: Chapman Conference on the role of diatom production and Si flux and burial in the regulation of global cycles, Paroikia, Paros, Greece, 22-26 September 2003.

M. Diepenbroeck, N. Dittert: Annual data base meeting, AWI Bremerhaven, Germany, 29 October – 05 November 2003.

C.Heinze, M. Gehlen, N. Dittert, Workshop on Ocean Carbon Coordination Project, IOC Paris, January 2003.

Conference attendance, presentations (posters/talks):

Talks:

Bakker, D.C.E., N. Dittert, C. Heinze, I. Kriest, P. Michalopoulos. ORFOIS meeting on observational data. Max Planck Institute of Meteorology. Hamburg, Germany. 8 May 2003.

Bakker, D.C.E., N. Lefèvre, U. Schuster, A.J. Watson, H. Lüger, D. Wallace, A. Körtzinger, J. Orr. Carbon sinks in the North Atlantic and European marginal seas (invited). CarboEurope Conference 'The continental carbon cycle'. 21 March 2003. Lisbon, Portugal.

Bakker, D.C.E, M. Hoppema, A.J. Watson, Y. Bozec and H.J.W de Baar. The Southern Ocean a key player in the global carbon cycle (invited speaker). International Union of Geodesy and Geophysics 2003. 4 July 2003. Sapporo, Japan.

Bakker, D.C.E, M. Hoppema, A.J. Watson, Y. Bozec and H.J.W de Baar. The Southern Ocean akeyplayer in the global carbon cycle. Progress in Chemical Oceanography (PICO) meeting. 18 July 2003. University of East Anglia, Norwich.

Bakker, D.C.E, Watson, A.J., Nightingale, P.D.,Law, C.S., Bozec, Y., Goldson, L., Messias, M-J., de Baar, H.J.W., Liddicoat, M. and Skjelvan, I.. Inorganic carbon changes in two Southern Ocean iron release experiments: effects of iron,hydrography and meteorology; followed by a discussion on 'Carbon storage by greening the oceans'. 5 January 2003. Evening seminar on R.V. *Polarstern*.

Bendtsen, J., 19-21 January 2003: Oral presentation at the ORFOIS-workshop held at the Max-Planck Institute in Hamburg, Germany: "Forcing fields as boundary conditions in the OGCMs.

Bendtsen, J., 12. september 2003: Oral presentation at a ecological modelling seminar at the Danish Hydraulic Institut, "Modelling marine ecosystems".

Bendtsen, J., 12. november 2003: Presentation at internal seminar at NERI," Transient climate change experiments".

Bopp L. , Particle flux dynamics in BOGCM, Dynamical Green Ocean Model Project, Third Workshop, Villefranche-sur-Mer, 20-22 October, 2003.

Gehlen, M. Reassessing solubility and dissolution kinetics of marine carbonates. Alfred Wegener Institut für Polarforschung, Bremerhaven, Germany, Kolloquium December 2002.

Gehlen, M. Le cycle du carbone océanique à l'ère de l'anthropocène. Centre Universitaire de Luxembourg, Luxembourg, January 2003.

Greenwood J. and Soetaert K. 1D Pelagic Modeling of Carbon Dioxide Geochemistry in the Open Ocean. Gordon Conference for Chemical Oceanography, USA, August 2003.

Heinze, C., The effect of Diatoms and Si on the carbon cycle, oral presentation, AGU Chapman Conference, on the role of diatom production and Si flux and burial in the regulation of global cycles, Paroikia, Paros, Greece, 22-26 September 2003, invited contribution.

Heinze, C., Simulating the response of the CaCO3 counter pump to climate change, oral presentation, Seminar on Biogeochemistry and high latitudes, Bjerknes Centre for Climate Research, Bergen, November 6-7, 2003, invited contribution.

Heinze, C., Partikel-reaktive Metalle als ozeanische Tracer, Colloquim of the ICBM, University of Oldenburg, November 26, 2003, invited contribution.

Khalil, K., C. Rabouille, K. Soetaert, J. Greenwood and O. Ragueneau, 1-D sediment early diagenetic model in global perspective. Summer school Si-Webs, Athens, Greece, June 2003.

Ragueneau, O. Calibration of Biogenic Silica (BSi) as a paleo productivity proxy: towards a mechanistic understanding of BSi dissolution/preservation and Si/C decoupling in the world ocean. AGU, Chapman Conference on "The Role of Diatom Production and Si Flux and Burial in the Regulation of Global Cycles", Paros (Greece), September 22-26, *invited communication*.

Ragueneau, O., Claquin, P., DeMaster, D.J., Dittert, N., Gallinari, M., Heinze, C., Leynaert, A., Martin-Jézéquel, V., Pondaven, P., van Cappellen, P. Calibration of biogenic silica (BSi) as a paleoproductivity proxy: towards a mechanistic understanding of BSi dissolution/preservation and Si/C decoupling in the world ocean. EGS-AGU-EUG Joint Assermbly, Nice, 6-11 avril 2003. *Oral communication.*

Ragueneau, O., Gallinari, M. et Moriceau, B. Etude de l'influence des conditions environnementales et du couplage pelagos-benthos sur la dissolution de l'opale biogène dans les sédiments profonds. Actions Thématiques Innovantes (ATI), Colloque de Restitution des Résultats. Paris, 27 janvier 2003.

Posters:

Bakker, D.C.E, Watson, A.J., Nightingale, P.D., Law, C.S., Bozec, Y., Goldson, L., Messias, M-J., De Baar, H.J.W., Liddicoat, M. and Skjelvan, I.. Inorganic carbon changes in two Southern Ocean iron release experiments: effects of iron, hydrography and meteorology. Poster at: The Role of the Southern Ocean in global processes: an Earth science system approach, 15 July 2003, Royal Society, London.

Bakker, D.C.E., P.W. Boyd, M.A. Charette, M.P. Gall, J.A. Hall, S.D. Nodder, K. Safi, R.J. Singleton, T.W. Trull, A.M. Waite, A.J. Watson, J. Zeldis, E.R. Abraham, C.S. Law and K.Tanneberger. A pelagic carbon budget for the Southern Ocean Iron enrichment Experiment (SOIREE), February 1999. Poster at: The Role of the Southern Ocean in global processes: an Earth science system approach, 15 July 2003, Royal Society, London.

Bakker, D.C.E, Watson, A.J., Nightingale, P.D., Law, C.S., Bozec, Y., Goldson, L., Messias, M-J., De Baar, H.J.W., Liddicoat, M. and Skjelvan, I.. Inorganic carbon changes in two Southern Ocean iron release experiments: effects of iron, hydrography and meteorology. Poster at: Frontiers in Geochemical and Isotopic Cycles in the Ocean, 29-30 September 2003. Geological Society, Burlington House, London.

Bakker, D.C.E., N. Dittert, A. Kozyr, U. Schuster and A.J. Watson. Towards better access to and safe keeping of oceanic CO_2 and carbon data: Data collection for the CDIAC and WDC-MARE databases in ORFOIS. Poster at: 2nd general CARINA (Carbon dioxide in the Atlantic Ocean) meeting and open science conference. 26 February- 1 March 2003, Maspolomas, Gran Canaria, Spain.

Bendtsen, J., 6-11 april 2003: Poster presentation at the EGS-EUG Joint Assembly, Nice, France, April 2003, "On the regulation of deep-sea refractory dissolved organic carbon".

Bendtsen, J., C. Lundsgaard, M. Middelboe, and D. Archer, 6-11 april 2003: Poster presentation at the EGS-EUG Joint Assembly, Nice, France, April 2003, "Influence of bacterial uptake on deep-ocean dissolved organic carbon

Bendtsen, J., and C. Heinze, 3. june 2003: Poster presentation the Danish Center for Scientific Computing seminar day, H. C. Oersted Laboratory, University of Copenhagen, "Modeling the global marine carbon cycle".

Gehlen, M., F. Bassinot and D. McCorkle (2003) The dissolution of marine carbonates: Shedding a new light on reaction kinetics and solubility. Ocean biogeochemistry and Ecosystem Analysis, IGBP/SCOR, abstract PS1-4.8, January 2003.

Gallinari, M., Ragueneau, O., DeMaster, D.J., Rickert, D., Hartnett, H., L. Corrin, and Thomas, C. Influence of seasonal deposition of phytodetritus on BSi dissolution properties in marine sediments. Potential effect on BSi preservation? AGU, Chapman Conference on "The Role of Diatom Production and Si Flux and Burial in the Regulation of Global Cycles", Paros (Greece), September 22-26, *Poster.*

Greenwood J. and Soetaert K. 1D Pelagic Modeling of Carbon Dioxide Geochemistry in the Open Ocean. Gordon Conference for Chemical Oceanography, USA, August 2003.

Moriceau, B., Garvey, M., Passow, U. and Ragueneau, O. Evidence of a low biogenic silica dissolution rate in diatom aggregates. AGU, Chapman Conference on "The Role of Diatom Production and Si Flux and Burial in the Regulation of Global Cycles", Paros (Greece), September 22-26, *Poster.*

Ragueneau, O., Claquin, P., Corrin, L., Dittert, N., Heinze, C., Maier-Reimer, E., Martin-Jézéquel, V. Pondaven, P. Quantification of Si and C decoupling in the world ocean. OCEANS meeting, International Open Science Conference, Paris, 7-10 janvier 2003. *Poster.*

Workshops:

Bakker, D.C.E. Participation (upon invitation) in SCOPE (Scientific Committee on Problems of the Environment)-GCP (Global Carbon Project) Rapid Assessment Project: Toward CO_2 stabilization: Issues, strategies and consequences. Ubatuba, Brazil, 1-7 February 2003.

Watson, A.J, and R. Valentini. Chairs of Session BG7: 'Understanding and quantifying the greenhouse gas budgets of ocean and continental regions', EGS/AGU/EUG Joint Assembly. Nice, France, 6-11 April 2003.

Activities for the public understanding of science

Bakker, D.C.E. Summer in the Southern Ocean. Presentation to the Norfolk Hill Walking Club, Norwich. 9 October 2003.

Visiting scientist:

Bendtsen, J., Visit to Max-Planck Institute for Meteorologie, Hamburg, 18 - 20 August 2003, on optimization of BOGCM1.

Cooperation with other projects/networks (also planned activities in FP6):

Proposal for NoE EUR-OCEANS EU FP6: Several ORFOIS PIs take part in this pending proposal, which will exploit ORFOIS results (data, models).

Proposal for CARBOOCEAN IP EU FP6: Several ORFOIS PIs contribute to this initiative for an integrated project which builds on current EU FP5 projects. Christoph Heinze and the Bjerknes Centre for Climate Resaerch are coordinating the proposal.

Ocean Carbon Coordination Project (Maria Hood, IOC; Chris Sabine, USA): Contributions from ORFOIS scientists to data management, data collection, process studies and modeling.

Nicolas Dittert: IMBER (ex OCEANS), IGBP, coordinated by Julie Hall, cooperation in data management.

Olivier Ragueneau / Brivaëla Moriceau: Dissolution of aggregates, AWI/Bremerhaven, Dept. of Pelagic Ecosystems and Marine Carbon Fluxes, Uta Passow

Olivier Ragueneau / Brivaëla Moriceau: Dissolution of aggregates, University of Utrecht, Dept. of Earth Sciences / Geochemistry, Philippe van Cappellen

Olivier Ragueneau / Brivaëla Moriceau: joint degradation experiments on BSi and POC

- MEDFLUX @ State University of New York, Marine Sciences Research Center, Cindy Lee and Robert Armstrong
- University of Marseille, Laboratoire de Microbiologie Marine, Madeleine Goutx

Olivier Ragueneau / Morgane Gallinari: Si, C, N and Fe decoupling during grazing

- University of Marseille, G. Slawick
- Station Biologique de Vimereux, Dorothee Vincent
- Station Biologique de Roscoff, Stefane L'Helguen

P. Michalopoulos (partner 6):
Cooperation with the EU DANUBS project has been already established. In addition cooperation with the new EU project Si-Webs in the fields of TEM observations of biogenic silica and laboratory kinetic experiments of biogenic silica conversion processes will be initialized in the next 6 months. During the last six months, a Si-Webs post doc (Dr. Massimo Presti) has been trained on reverse weathering processes and biogenic silica conversion processes on the samples collected and analyzed for ORFOIS.

Forthcoming: Bakker, D.C.E. (by invitation) Workshop on Ocean Surface pCO_2, data integration and database development. Sponsors: National Institute for Environmental Studies (NIES), International Ocean Carbon Coordination Project (IOCCP), and North Pacific Marine Science Organization (PICES) Working Group 17. 14-17 January 2004, Tsukuba, Japan.

Publications:

Bakker, D.C.E. (2002) The marine carbon cycle and climate. 23-28. In: Bhattacharya, S.K., T.K. Mal and S. Chakrabarti (eds.) Recent research developments in biotechnology and bioengineering. Special Issue: Biotechnology and bioengineering of CO_2 fixation. Research Signpost, Fort P.O. Trivandrum, India, 183 pp.

Bakker, D.C.E. (2003) Storage of carbon dioxide by greening the oceans? In: C. Field et al. SCOPE/GCP Rapid Assessment Project of the Carbon Cycle. Towards CO_2 stabilization: Issues, strategies and consequences. Special Issue, in press. Island Press.

Bakker, D.C.E., P.W. Boyd, M.A. Charette, J.A. Hall, S.D. Nodder, K. Safi, R.J. Singleton, T.W. Trull, A.M. Waite, A.J. Watson, J. Zeldis, E.R. Abraham, C.S. Law, and K. Tanneberger (2004) A Pelagic Carbon Budget for the Southern Ocean Iron RElease Experiment (SOIREE), February 1999. In revision after initial submission to Deep-Sea Research.

Bakker, D.C.E., Y. Bozec, P.D. Nightingale, L.E. Goldson, M.J. Messias, H.J.W. de Baar, R. Bellerby, C.S. Law, V. Strass, and A.J. Watson (2004) Storms influence inorganic carbon changes upon iron fertilisation in the Southern Ocean - Results from SOIREE and EisenEx. In preparation.

Rangama, Y., J. Boutin, J. Etcheto, L. Merlivat, T. Takahashi, B. Delille, M. Frankignoulle, and D.C.E Bakker (2004) Variability of net air-sea CO_2 flux inferred from in situ and satellite measurements in the Southern Ocean south of Tasmania and New Zealand. In preparation.

Bozec, Y., D.C.E. Bakker, C. Hartmann, R.G.J. Bellerby, P.D. Nightingale, U. Riebesell, A.J. Watson, and H.J.W. de Baar (2004). The CO_2 system in a Redfield context during an iron enrichment experiment in the Southern Ocean. In revision after initial submission to Marine Chemistry, Special Issue.

Dittert N, Diepenbroek M, Huber R (2003) World Data Center for Marine Environmental Sciences provides lessons in marine Geosciences data management. EOS, Transactions, AGU, **84**(16): 149.

Dixit, S., Gallinari, M., Van Cappellen, P. and Ragueneau O. What controls opal preservation in marine sediments? *Global Biogeochemical Cycles*, in prep.

Gallinari, M., Ragueneau, O., Corrin, L., DeMaster, D.J. et Tréguer, P. (2002). The importance of water column processes on the dissolution kinetics of biogenic silica in deep-sea sediments. I. Solubility. *Geochimica et Cosmochimica Acta*, 66 (15): 2701-2717.

Gallinari, M., Ragueneau, O., DeMaster, D.J., Rickert, D., Hartnett, H. and Thomas C. Influence of seasonal phytodetritus deposition on biogenic silica dissolution properties in marine sediments – Potential effect on preservation. *Deep-Sea Research*, submitted.

Gehlen, M., F. C. Bassinot, L. Chou and D. McCorkle (submitted). Reassessing the dissolution of marine carbonates : I. Solubility. Geochimica Cosmochimica Acta.

Heinze C, in prep., The marine silicon cycle on long time scales, manuscript for SCOPE book on global marine Si cycle (edited by V. Ittekkot, ZMT Bremen)

Leynaert A., Bucciarelli E., Claquin P., Dugdale R.C., Martin-Jézéquel, V., Pondaven P., Ragueneau O. Effect of iron deficiency on diatom cell size and silicic acid uptake kinetics. *Limnology and Oceanography*, in press.

Middelburg, JJ and K.Soetaert, 2004. The role of sediments in shelf ecosystem dynamics. In: The Sea, Vol.13 chapter 12

Moriceau, B., Garvey, M., Passow, U., Van Cappellen, P. and Ragueneau, O. Reduced biogenic silica dissolution rates in diatom aggregates. *Marine Ecology Progress Series,* In prep.

Ragueneau, O., Dittert, N., Corrin, L., Tréguer, P. et Pondaven, P. (2002). Si:C decoupling in the world ocean: is the Southern Ocean different ? Deep-Sea Research II, 49 (16): 3127-3154.

Raupach, M., J. Canadell, D.C.E. Bakker, P. Ciais, M.-J. Sanz, J.Y. Fang, J. Melillo, P. Romero Lankao, J. Sathaye, D. Schulze, P. Smith, and J. Tschirley (2003) Interactions between CO_2 stabilisation pathways and requirements for a sustainable earth system. In: C. Field et al. SCOPE-GCP Rapid Assessment of the Carbon Cycle. Towards CO_2 stabilization: Issues, strategies and consequences. Special Issue, in press. Island Press.

Sabine, C.L., M. Heimann, P. Artaxo, D.C.E. Bakker, C.-T.A. Chen, C.B. Field, N. Gruber, C. LeQuéré, R.G. Prinn, J.E. Richey, P. Romero Lankao, J. Sathaye, and R. Valentini (2003) Current Status and Past Trends of the Carbon Cycle. In: C. Field et al. SCOPE-GCP Rapid Assessment of the Carbon Cycle. Towards CO_2 stabilization: Issues, strategies and consequences. Special Issue, in press. Island Press.

Tréguer P, Legendre L, Rivkin RT, Ragueneau O, Dittert N (2003) Water column biogeochemistry below the euphotic zone. In: Fasham MJR (Ed.) Ocean biogeochemistry: a synthesis of the Joint Global Ocean Flux Study (JGOFS): 145-156.

Fulfilment of the workplan:

Table: Diagram showing the carried out (O) and planned (X) activities.

WP no.	*Workpackage name*	*Year 1*	*Year 2*	*Year 3*
1	Data base compilation of observations	**O O O O**	**O O**	
2	Process parameterisations	**O O O O**	**O**	
3	Community model development	**O O O O**	**O**	
4	Compilation of model forcing fields	**O O**		
5	BOGCM implementation	**O O**	**O O**	
6	Optimisation of the prognostic system		**O O O O**	**X X X X**
7	Model application and demonstration		**O O**	**X X X X**
8	Economic evaluation		**O O**	**X X X X**
9	Dissemination			**O X X**
10	Coordination	**O O O O**	**O O O O**	**X X X X**

Table: Workpackage list. (In the description of work, an error in table WPL for WP 8 must be corrected to be compatible with table WPM, which is correct: person months 9 instead of 8, start month 19 instead of 29. See below under 1.4.)

WP no.	*Workpackage name*	*Lead participant*	*Person months, total as planned*	*Person months used up to now*	*Duration, month from/til*
1	Data base compilation of observations	3	63	20	1--18
2	Process parameterisations	4	73	28	1--15
3	Community model development	1	17	6	1--15
4	Compilation of model forcing fields	1	4	3	1--6
5	BOGCM implementation	2	19	0	7--18
6	Optimisation of the prognostic system	2	158	0	13--36
7	Model application and demonstration	1	21	0	19--36
8	Economic evaluation	5	9	0	19--36
9	Dissemination	3	38	1	28--36
10	Coordination	1	3	0.7	1--36

General remark: The project could be started successfully and the tasks/deliverables are under way as planned. A slight general delay of the project of about one month was caused by the extremely short notice concerning the start of the project. The coordinator of the project was informed on Friday, November 30, 2001, that the project would start on Saturday, December 1, 2001. Due to all the legal issues involved such as periods of notice associated with the hiring of personnel, the actual scientific work of the project started on January 1, 2002 (see letter on commencement of work from C. Heinze from December 14, 2001).

Updated version of "Participants Information" - Table:

No.	Institution	Address	PI name	Phone/fax	email
	Workplace of coordinator, University of Bergen, Geophysical Institute, Bjerknes Centre for Climate Research	Allégaten 70, N-5007 Bergen, Norway	Dr. Christoph Heinze Prof. for Global Carbon Cycle Modelling	P +47 5558 9844 F +47 5558 9883	heinze@gfi.uib.no
1	National Environmental Research Institute **NERI**	Frederiksborgvej 399, P.O.Box 358, DK-4000 Roskilde, DENMARK	Dr. Jørgen Bendtsen	P +45 46301863 F +45 4630 1114	job@dmu.dk
2	Laboratoire des Sciences du Climat et de l'Environnement, CEA DSM **CEA-DSM**	C.E.N. Saclay - Orme des Merisiers Bât. 709, F- 91191 Gif-sur-Yvette CEDEX, FRANCE	Dr. Marion Gehlen	P +33 1 69088672 F +33 1 69087716	gehlen@ lsce.saclay.cea.fr
3	Laboratoire des Sciences de l'Environnement Marin (LEMAR), UMR CNRS 6539 **UBO**	Institut Universitaire Européen de la Mer (IUEM), Place Nicolas Copernic, Technopôle Brest-Iroise, F-29280 Plouzané, FRANCE	Dr. Nicolas Dittert	P +33 298 498673 F +33 298 498645	nicolas.dittert@univ-brest.fr
4	Max Planck Institute of Meteorology **MPIG.IMET**	Bundesstrasse 55, D-20146 Hamburg, GERMANY	Dr. Ernst Maier-Reimer Dr. Christoph Heinze	P +49 40 41173233 F +49 40 41173298	maier-reimer@ dkrz.de
5	Hamburg University, Research Unit Sustainability and Global Change, Centre for Marine and Climate Research **Uni-HH**	Troplowitzstrasse 7, D-22529 Hamburg, GERMANY	Dr. Richard S.J. Tol Michael Otto Professor of Sustainability and Global Change	P +49 40 428387007 P +49 40 428387008 F +49 40 428387009	tol@dkrz.de
6	National Center for Marine Research Institute of Oceanography **NCMR**	P.O. Box 712, Anavyssos 19013, GREECE	Dr. Panagiotis Michalopoulos	P +3 0291076337 F +3 0291076323	pmichalo@ ncmr.gr
7	Netherlands Institute of Ecology, Centre for Estuarine and Marine Ecology **NIOO**	Korringaweg 7, P.O. Box 140, NL-4400 AC Yerseke, NETHERLANDS	Dr. Karline Soetaert	P +31 113 577300 F +31 113 573616	soetaert@ cemo.nioo. knaw.nl
8	University of East Anglia, School of Environmental Sciences **UEA**	University Plain, NR4 7TJ Norwich, UNITED KINGDOM	Dr. Dorothee Bakker	P +44 1603 592648 F +44 1603 591327	D.Bakker@ uea.ac.uk

Table: Personnel working in ORFOIS.

Participant No.	*Name*	*position*	*% of full time employment paid by project*	*Begin of employment*	*End of employment*
1	Christoph Heinze	Senior scientist	41.6	Dec 1, 2001	Mar 31, 2003
1	Jørgen Bendtsen	Researcher	100	Feb 1, 2002	-
2	Marion Gehlen	Senior scientist	20	Dec 1, 2001	-
2	Christophe Rabouille	Senior scientist	17	Dec 1, 2001	-
2	Benoît Thiebault	Chem. engineer	100	June 17, 2002	June 16, 2003
2	Nadia Emprin	Post doc	100	Nov 12, 2002	Jan 11, 2004
2	Karima Khalil	Post doc	100	Feb 18, 2003	Nov 30, 2004
2	Anne Cozic	Comp. Engineer	100	Jan 6, 2003	Oct 5, 2004
2	Morgane Gallinari	Post doc	100	Jul 1, 2003	Dec 31, 2003
2	Gwenaëlle Phillipon	Student Trainee	100	Sep 29, 2003	Nov 2, 2003
3	Nicolas Dittert	Researcher	100	Dec 1, 2001	-
3	Morgane Gallinari	Post doc	100	Dec 1, 2001	May 31, 2002
3	Sabrina Rousseau	PhD student	100	Mar 1 2002	Apr 30, 2002
3	Aude Leynaert	Senior scientist	-	-	-
3	Philippe Pondaven	Senior scientist	-	-	-
3	Olivier Ragueneau	Senior Scientist	-	-	-
3	Laurent Bopp	Post doc	100	Apr 1, 2003	May 31, 2003
4	Iris Kriest	Researcher	100	Feb 1, 2002	-
4	Ernst Maier-Reimer	Senior scientist	-	-	-
4	Christoph Heinze	Senior Scientist	-	Apr 1, 2003	-
4	Joachim Segschneider	Senior Scientist	50	(Jan 1, 2004)	-
5	Richard S. J. Tol	Professor	-	-	-
6	Panagiotis Michalopoulos	Scientist	85	Jan 1, 2002	-
6	Christos Anagnostu	Senior scientist	15	Jan 1, 2002	-
6	Karageorgis Aristomenis	Scientist	15 6	Jan 1, 2002 Dec 1, 2003	Nov 30, 2003 -
6	Maria Taxiarxi	Technician	18	Jan 1, 2002	-
6	Panagiotis Traxalakis	Technician	20	Jan 1, 2002	May 31, 2002
6	Papageorgiou Alkis	Technician	7	Jun 1, 2002	-
6	Kampourie Georgia	Technician	40	Jun 1, 2002	-
6	Kanellopoulos Theodoros	Res. Associate	68	Mar 1, 2003	Aug 31, 2003
6	Batris Evangelos	Res. Associate	52	Dec 1, 2002	Dec 31, 2002
7	Henrik Andersson	PhD student	100	Feb 1, 2002	Apr 1, 2002
7	Jasper van Delft	Comput. Progr.	100	Jan 1, 2002	May 1, 2002
7	Jim Greenwood	Post doc	100	May 1, 2002	-
7	Adri Knuyt	Progr. Assist.	100	Sep 1, 2002	Nov 30, 2002
7	Karline Soetaert	Senior Scientist	-	-	-
8	Dorothee Bakker	Sen. Res. Assoc.	100	Jan 1, 2002	-
8	Andy Watson	Professor	-	-	-

8. REFERENCES

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Hamburg, January 8, 2004

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(Christoph Heinze)