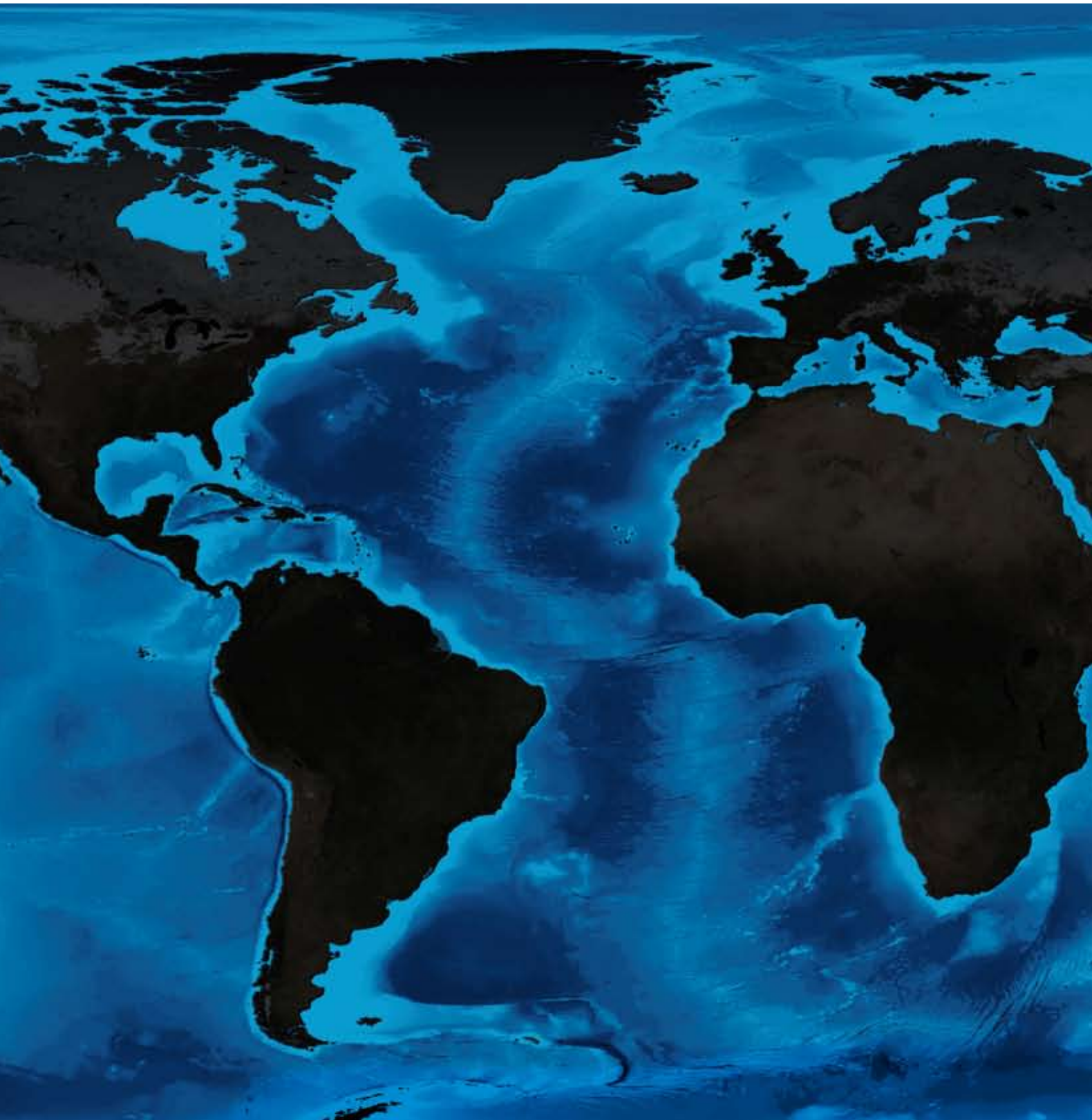
future ocean
KIEL MARINE SCIENCES

09 | Annual Report



Understanding the ocean sustaining our future

Dear Reader,

In 2009 the Cluster of Excellence Future Ocean completed its third full working year. It has been another one of both the generation of new knowledge and budgetary growth, and an important step in the structural developments of our exciting endeavor. Quite a few of the activities are documented in this report. The achievements in 2009 can be characterized by a few keywords:

Lived interdisciplinarity: the thirteen junior research groups are flourishing. All groups started with tremendous enthusiasm in 2007 and 2008, invested money into labs, instruments, and hired personnel. Now the interdisciplinary research is becoming a natural focus of their projects and work in conjunction with the already established scientist. This interaction is developing into an inspiring Future Ocean spirit felt by everyone involved. The broad disciplinary base is what makes the Future Ocean such an exciting project, and Kiel such a unique place to work as a marine scientist. Within this report, we present the latest findings and current research of the Junior Research groups in the science chapters on pages 24 and the findings of 5 research projects by the diverse group of Kiel marine scientist, some spawning off other projects leading to significant extramural funding. See pages 50 ff. for some selected project reports.

Collaboration: Another important step taken in 2009 relates to the project's data management. In order to improve on this, the two collaborative research projects SFB 574 and 754, IFM-GEOMAR and the Future Ocean joined forces and decided to pool personnel founding the "Kiel Data Management" group. This collaboration is an important showcase, how infrastructures can be merged among different large projects, to create a synergy all partners can profit from. We hope that this model can work likewise for other topics too in the future.

Performance: 2009 marks the year, where the planning for the second phase of Future Ocean – the time past 2012 - commenced. During 2010 we will perform a careful evaluation of all aspects of the Cluster of Excellence Future Ocean, to begin to steer into a successful future. To aid this process we are permanently collecting statistical data on the project, publications, personnel, financial data, but also external visitors, visits abroad and others. Collecting these data is a vital part of our concept, to produce robust performance metrics in order to be successful in the competition for continued funding.

Internationalization: the Future Ocean has set course to explore new paths in attracting the best young scientists to work in Kiel. To support this, a collaboration agreement was signed with the Alexander von Humbold Foundation, in order to recruit the brightest minds from abroad to come to Kiel and collaborate with the local marine sciences. This is anticipated as a long-term collaboration, and we will be able to report further on this project within the coming years.

The excellence initiative invited new concepts to be developed and implemented for modern and attractive research environments how an ideal research environment can be created. We are happy to present our progress along those lines within this report. I wish you all a pleasant read and want to thank all the contributors, supporters and especially our international advisory board who all allowed us to generate an exciting research environment in Kiel for integrated Marine Science.

Speaker of the Cluster of Excellence „The Future Ocean"

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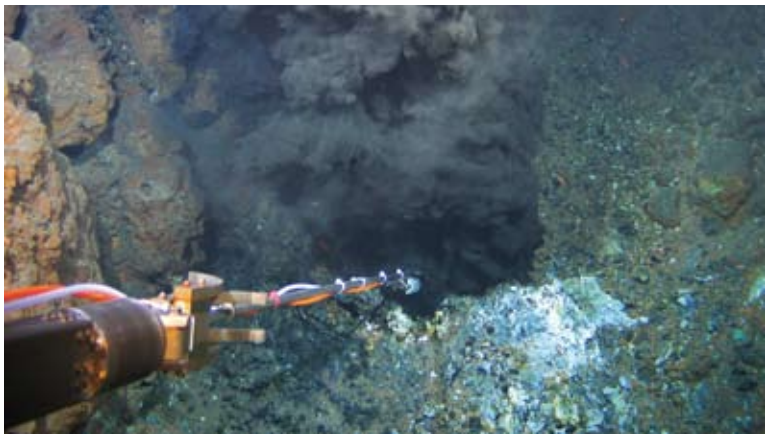

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The Project

The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom.

Isaac Asimov

About the Future Ocean

Motivation

The ocean hosts our planet's largest ecosystem, helps regulate the composition of the atmosphere and global climate, and provides mankind with essential living and non-living resources. Coastal regions are home to the majority of the world's population and the open seas are key to global trade and security and a source of major natural hazards. In short, the global ocean is vital for human welfare now and in the future. But mankind is altering the oceans in both direct and indirect ways and on a global scale. The alteration started with fishing which has already drastically changed the global marine ecosystem. Human impact now extends from regional changes, such as alteration of coastal and deep sea habitats, to global scale impact on marine life, ocean circulation and carbon cycling through emission of CO_2 and other pollutants.

The Future Ocean therefore is the recognition of mankind's increasing dependency on the ocean in the context of our increasing power to alter it. These two factors imply a need to understand our environment in order to be able to predict and manage. They also imply a need to educate, in order to make the next generation aware of the need for responsible and sustainable use of the ocean. We need tools to be able to decide, whether to adapt to, or to mitigate the changes that we have already set in motion.

Implementation

The Future Ocean was funded in fall 2006, in response to a general call for proposals by the German Research Foundation (DFG) within the framework of the Excellence Initiative by the german federal and state governments. The visions formulated in the proposal were deeply affecting research, university structures, administration and science management in Kiel and demonstrated the firm commitment of the university and its partners, to advance to a new, modern level of science organization in Kiel. This commitment prevails, manifested in the many activities that have been directed to implement the envisioned research framework.

To enhance the already existing research environment the Future Ocean comprises several components interlocked within each other to form a structure allowing scientists to perform at their best. It is designed around funding instruments promoting research in marine and related science in Kiel. Core of this structure are thirteen new junior research groups, all working at the interface between traditional scientific disciplines. These groups are bridging traditional marine sciences with its aspects in biology, chemistry, physics, geology, and previously loosely related subjects like economy, medicine, law, molecular biology and computer science. Secondly a platform concept was established, setting up four research platforms, supporting all researchers with the technical infrastructure needed to deliver world class results. Thirdly the Future Ocean issues its own scientific proposal calls in order to be able to quickly respond to the latest scientific developments in the most flexible way. All these proposals are fully reviewed externally to ensure the highest quality in science. Finally the project fosters a fast-track funding concept, where money for start-up proposals,

Figure 1 | Members and employees of the Cluster of Excellence Future Ocean.

Structural Elements of the Future Ocean

- The thirteen Junior Research Groups form the scientific core of „The Future Ocean". These newly established groups are funded to investigate bridging topics between classical disciplines. They are equipped with sufficient funds to support whole working groups for up to 6 years. The JRG leaders hold professorships which have a tenure option.

- The platform concept consolidates certain types of technical infrastructure under a single roof, enabling researchers to access available and needed instruments easily.

- Research projects, travel, visitors and conferences can be funded through a fast track internal proposal process. Project proposals undergo an external review process before funding.

- The Integrated School of Ocean Science supports graduate students with soft skill courses targeted to prepare for a future life in marine science, industry or at a non-governmental organization (NGO).

- The public outreach project promotes marine sciences to the general public, but also fosters exchange of internal information within the Future Ocean.

travel, conferences, and funds to invite renowned colleagues to Kiel can be applied for and granted quickly with little additional administrative work.

The junior research groups started operating as group leaders became hired between summer 2007 and spring 2008. During 2008 the groups successfully hired most of the required personnel and begun work on their related scientific questions. 2009 saw further but slower growth of the groups, however, many initial results can now be presented within this report. Furthermore 14 of the projects from the first three proposal calls issued between late 2006 and 2007, ended in 2009. These projects are typically running for two years, some leading to new follow-up projects and extramural funding, many of them to very interesting scientific findings. Projects funded during proposal rounds 2008 and the latest proposal round in 2009 are continuing throughout the year. The number of active projects was 59 at the end of 2009 (see the list of active projects in the appendix).

The Future Ocean has so far initiated a tremendous array of large and small initiatives of inter- and transdisciplinary nature, creating a positive forward orientated spirit of curiosity in Kiel's research landscape. This is not only visible within the Christian-Albrechts University, but also at the the partner institutions IFM-GEOMAR, the Institute for the World Economy (IfW) and the Muthesius School of Fine Arts and Design. The Future Ocean is guided by the underlying principle to provide the most effective service and infrastructure, to support marine science to develop a thorough understanding of the future of our oceans.

Supporting Kiel Marine Sciences

Attracting students to study marine sciences is one of the central goals of the Future Ocean. To promote this, a multi-level strategy is applied, addressing all levels of society from the general public, to the education in schools and offering events for children, to the active support of masters- and graduate students. In 2009 the general public was addressed through various events and public displays of marine research. This was done in conjunction with state government organized events like the annual German reunion day on October 3, 2009, in Saarbrücken, and the subsequent exhibition on a barge (see page 65), but also through special exhibitions like the continuing display in the International Maritime Museum in Hamburg and preparations for the upcoming exhibition in the Deutsche Museum in Munich in 2010.

The Future Ocean successfully continued to address schools and teachers directly by providing marine science practice boxes to schools in Schleswig-Holstein, to enable teachers to integrate this topic into their classes in a practical and demonstrative manner. This activity is complemented by the organization of the 2009 Children University on marine sciences in Kiel (page 66), offering public lectures targeted at for children aged 8-14 and 12-16. Overall these activities have been proven very successful so far. The public is indeed identifying itself with the themes of the Future Ocean, and local citizens are proud to hear that researchers in Kiel and Schleswig-Holstein are actively providing research to tackle many of the global critical environmental questions ahead. Monitoring the press and public expressions it was is realized that Kiel is more and more recognized as the leading location for marine science in Germany, a circumstance that is of course intended and which the Future Ocean strives to expand on. Last but not least an important goal of the Future Ocean is, to establish Kiel Marine Sciences as a trademark for highest class marine research not only in Germany, but on a global level, a goal that we pursue within the upcoming years.

Future Ocean Technical Infrastructure Platforms

To provide technical infrastructure and resources for all scientists within the Future Ocean, a platform concept has been established.

P1 Numerical Simulation: Numerical Simulations play a key role in the Cluster of Excellence. They require an infrastructure for high-performance computing, development of interfaces for algorithms and software from different areas, in particular marine science and numerical mathematics, the ability to store and manage data in an efficient way, and to provide expertise from mathematics and computer science for large-scale numerical problems. Platform P1 is predominantly used by the groups investigating Oceanic CO_2 uptake and Ocean Circulation.

P2 Tracer Analysis: Tracer analysis provides analytical infrastructure for the use of isotopes, trace elements, and trace compounds, which are the basis for marine research. It plays a key role in the research of ocean conditions of the past and has an important role in guiding our understanding of the future ocean. This research requires highly specialized and accurate isotope and trace metal analysis. Research platform P2 is used by groups researching the sea surface chemistry, ocean acidification, mineral seafloor resources, seafloor warming and gas hydrate formation.

P3 Molecular Technology: This platform provides high-throughput molecular technologies to marine biology projects. It was founded in an interdisciplinary approach by three faculties (Medicine, Mathematics & Natural Sciences and Agriculture/Nutrition) to concentrate automated technologies in life sciences. Platform P3 is mainly used by the Ocean Acidification, Seafloor Warming and Marine Medicine groups.

P4 Ocean Observatories: This platform has the mandate to provide multi-facetted observational capabilities that meet the wide range of requirements for research to be carried out within in the Kiel Future Ocean Network. The platform holds instruments deployed at the sea floor, traveling the water column, swimming on the surface or observing from various distances. Platform P4 is mainly used by the research groups working on Sealevel-rise and coasts at risk, submarine hazards, and seafloor resources.

The platforms set up in the Future Ocean allow for an efficient use of resources and will be extended according to the needs of the working groups.

Research Themes

The mission of the cluster of excellence is, to address the future ocean in its entirety with respect to climate, ecosystems, resources and hazards. To achieve this, the scientific structure has been designed as two major research themes, subdivided into research topics (Fig. 1). The research themes are titled „The Ocean in the Greenhouse World" and „Marine Resources and Risks". Both themes document the future oriented approach of the research, aiming to predict and advise rather than to document and explain what has happened. This notion is also intended to be the glue between the projects as predictions rather require a completely different view of the earth, than documenting the current or historic state. The research themes are supported by several platforms, installations of infrastructure which in principle are open for use by any scientific member of the Future Ocean.

The Ocean in the Greenhouse World

The oceanic response to anthropogenic greenhouse gas emissions is investigated under the theme „The Ocean in the Greenhouse World". The combined oceanic response to this forcing is complex and includes large-scale changes in ecosystem structure and ocean circulation. The internal cycling of carbon, nutrients and oxygen within the ocean and physical exchange of greenhouse gas, heat, water and momentum across the air-sea and ocean-seafloor interfaces are also affected by anthropogenic greenhouse gas emissions and global climate change. Internal oceanic feedbacks may amplify the external anthropogenic forcing with largely unknown consequences for oceans, global climate, and human society. „The Ocean in the Greenhouse World" encompasses basic and applied research into these roles and responses of the oceans in the Greenhouse World. The overarching questions of this research theme are:

- What are the biological and chemical responses of the ocean to changing atmospheric composition?
- How do ocean circulation and the ocean ecosystem interact with altered radiative forcing?
- What is the ocean's capacity for current and future mitigation of atmospheric CO_2 increase?
- What are the implications of these changes to the marine system for human welfare and greenhouse gas management?

Seven research topics have been defined as projects. „Ocean Acidification" is establishing new linkages between expertise in marine biology and geochemistry and related physiological and biochemical expertise at Kiel. It is intended to improve the mechanistic understanding of the response of marine organisms to elevated CO_2 and decreased pH. Warming of intermediate-depth waters has the potential to drive major changes in seafloor processes, including accelerated decomposition of methane hydrates and as yet unknown effects on benthic ecosystems. The „Seafloor Warming" project addresses this issue by combining expertise in benthic ecology and geochemistry with new observational technologies. „Oceanic CO_2 Uptake" builds on expertise in ocean modeling, marine carbon observations and synthesis in a new partnership with research on advanced numerical techniques. The goal is to improve our ability to quantify the current and future anthropogenic CO_2 uptake of the ocean. The „Ocean Circulation" project takes advantage of the existing expertise in past ocean climate proxy research and uses ocean and climate models in order to reconcile observational records from past climates with dynamically consistent climate scenarios. In „Sea Surface Chemistry" physical chemical structures and interactions at and near the air-sea interface are studied, including reactions important for understanding the ocean's response to the changing composition of the surface ocean and troposphere. Here, new linkages between physical and theoretical chemistry and marine science are being established. The changes predicted for the future ocean by the described projects have considerable implications for human welfare. Ocean carbon sequestration (on-going or deliberate) is important for an evaluation of carbon abatement strategies and global carbon management accounting. The economic and human welfare implications of future ocean change are the focus of a project titled „Valuing the Ocean", which takes advantage of the existing economic expertise at IfW and the scientific insight provided by other parts of the Future Ocean. This project is strategically placed at the interface between basic scientific insight, quantitative assessment, and socio-economic understanding to produce evaluations of the human-dimension implications of future ocean change.

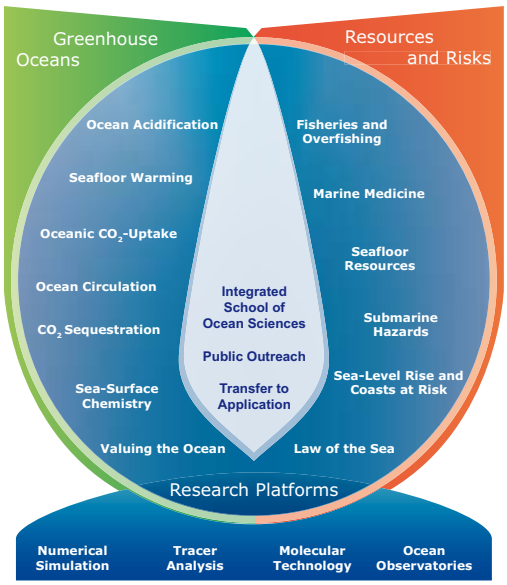


Figure 1 | Structure of the Cluster of Excellence „The Future Ocean" consisting of the research themes Greenhouse Ocean (green) and Resources and Risks (red), central services (light blue) and the infrastructure platforms (dark blue).

Marine Resources and Risks

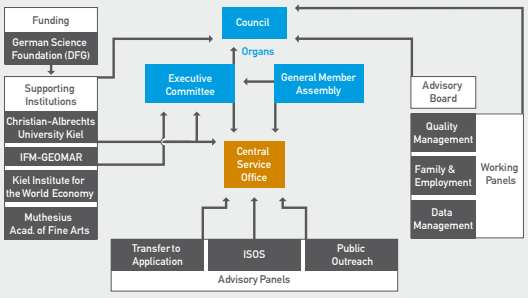
The second research theme of the Future Ocean deals with „Marine Resources and Risks". It focuses on the understanding and management of marine resources and the assessment of hazards. Oceans provide resources and services to mankind, such as fish and seafood, genetic resources for medical purposes, fossil fuels and minerals. However, the sea is also a source of hazards through tsunamis, storm surges and sea-level rise. These opportunities and risks pose several general questions:

- Which physical, chemical, biological, and geological mechanisms lead to the evolution of certain resources?
- What are the mechanisms that lead to marine hazards threatening coastal population?
- Are ocean organisms a model system for human diseases providing a new tool in medical research?
- How should ocean resources be managed in a sustainable manner and which institutional and legal frameworks are necessary for such endeavors?
- How can risks be assessed, how can damages from hazardous events be evaluated, and which countermeasures can be taken to mitigate these?

The „Fishery and Overfishing" project evaluates marine management with a special focus on multispecies interaction and the link between commercial species, non-commercial species, and the ecosystem. Marine life and fisheries are presently studied, but have not previously been linked to economic expertise. Building on this expertise, a research group was established to improve the management strategies of fish stocks and fisheries, incorporating economic, legal, and scientific aspects. Scientists from medical and natural sciences join in the „Marine Medicine" project to study marine organisms as model systems to gain a better understanding of the mechanisms triggering human diseases. The new JRG applies a genomics approach to investigate the evolution and function of orthologs to human susceptibility genes for barrier dysfunction in marine organisms from diverse phyla. This approach is possible because the genes causing barrier diseases have been conserved through evolution. As an ultimate goal, the knowledge required in the marine model organisms will be applied to develop novel therapeutic or preventive strategies for human barrier disorders. The study of the occurrence and formation of marine resources, such as gas hydrates and hydrothermal deposits, is an important focus of research in Kiel. Further expertise is needed in the area of fluid flow and coupled reactions, which are responsible for the formation of these deposits. This aspect is addressed by a modeling-oriented working group titled „Seafloor Resources" which serves as a link to existing research groups in this field. Despite growing concerns regarding submarine earthquakes, slumps and slides and their consequences, such as the triggering of tsunamis, marine seismology is not an established discipline in Germany. To close this gap, the „Submarine Hazards" research group was established, which addresses submarine hazards at continental margins. To strengthen the existing groups investigating sea-level change, coastal evolution and coastal zone management tasks, new expertise is needed to analyze physical-morphological changes in coastal seas and to develop new tools to assess the vulnerability and resilience of coastal zone communities. The socio-economic relevance of coastal change and risk assessment led to the establishment of two new research groups on „Sea-level Rise and Coastal Erosion" and „Risk Assessment in the Coastal Zone" covering these important fields. While the former concentrates on rapid physical and morphological changes at those coasts of the world being severely under stress by natural or anthropogenic impacts, the latter focuses on techniques to assess and evaluate risks and hazards in coastal areas under various stresses. Finally the „Law of the Sea" project strengthens the expertise in maritime law contributing to the development of new laws for the sustainable use of marine resources based on a sound understanding of the oceanic ecosystem. The link between the topics of „Marine Resources and Risks" is the focus on marine resources and risks for human society. Therefore, the economic and legal aspects bridge the six topics and create a unique scientific network being capable of developing innovative and comprehensive approaches in the investigation and management of marine resources and risks.

Organization of „The Future Ocean"

The cluster's Executive Committee is responsible for the overall management of the cluster of excellence and is accountable to the Cluster Council and the General Assembly. It consists of the Chair, the Vice Chair, the two speakers of the research platforms and representatives from the research themes. The Council of the cluster of excellence gives advice to the Executive Committee on all strategic decisions, such as scientific priorities, yearly budget planning and monitoring criteria. The Council comprises the two leading proponents of each research topic and research platform, the leader of each JRG, the Presidents of Kiel University and Muthesius Academy of Fine Arts, the Directors of IFM-GEOMAR and IfW, as well as the Chair and Vice-Chair of the Executive Committee. An external Advisory Board acts as an independent quality-control and advice body to evaluate the progress of the project. It consists of ten leading scientists, both national and international, reflecting expertise of all cluster-relevant research fields. Additional members are appointed to evaluate the cluster's outreach to the general public, stake-holders and industries. The central service office provides necessary support for project management and monitoring activities. It also supports the public outreach and technology transfer activities and the Integrated School of Ocean Sciences (ISOS).



2009 – Some Events in Brief

It will not surprise anyone that we can state - 2009 was a very busy year. Many large and small activities and initiatives were started within the Future Ocean, many projects and undertakings continued. In this section we will summarize some of them, but several are discussed in more detail later in this report.

Annual Retreat 2009

All members and employees of the Future Ocean are working in their host institutions, which are scattered all over Kiel. Due to this circumstance, the annual retreat forms an important opportunity, to meet each other, present current research activities and discuss future projects. In 2009 the annual retreat of the Future Ocean took place in the State Cultural Center Salzau. More than 150 members and employees participated to hear interesting talks, see, present, and discuss latest scientific findings on posters and develop visions for the future. After a general introduction by the speaker the audience heard two talks by Future Ocean visitor Ralph Keeling (SCRIPPS, La Jolla, Calif., U.S.A.) on the scientific and social challenges of global warming and Helga (Kikki) Kleiven from the University Bergen, Norway on "10,000 years of climate behavior as a guide to future climate misbehavior". The afternoon session was dedicated to brief presentations by the Schleswig-Holstein synergy network on applied sciences from the Kiel Active Agent Center (KiWiZ), the Society for Marine Aqua Culture (GMA), the Research and Technology Center Westcoast (FTZ) in Büsum, Germany, and the Research and Development department of the technical college Kiel (FH Kiel). During the following poster session everyone had the opportunity to recap everything heard and discuss ongoing science. The second day was dedicated to the planning of the future of the Future Ocean. The presidents and directors of the founding institutions shared their expectations and ideas for the coming years, including visions for a potential second phase of the Future Ocean. Subsequently these visions were discussed within the audience. This discussion marked the start of the planning for a possible Phase 2 of the Future Ocean.

Cluster Projects spark new initiatives and collaborations, like the measurement of nanolayers on the ocean surface with pulsed laser beams.

Proposal Round 2009

The Future Ocean distributes most of its funds through two main funding lines: junior research groups and open proposals. Proposal calls are issued, about once per year. In Summer 2009 a proposal call was published. 47 project proposals were submitted with a total funding volume of 4.4M €. Following an external review process and a careful budget projection for 2010/2011 the executive board decided to distributed 1.5M € over the next 2 years for these projects. This resulted in 17 proposals getting funded, or roughly 33% of the total proposed funds. Among them are such diverse topics as "Experimenting with marine protected areas in an ecological-economic fishery model" by T. Requate and R. Voss or "A glider fleet to observe sub-mesoscale physical-biogeochemical coupling in the tropical ocean" by T. Kanzow, J. LaRoche and A. Körtzinger. See a full list of funded Future Ocean Projects in the appendix of this report.

Members and employees of the future ocean gathered in the State Cultural Center Salzau, Germany for the annual retreat in March 2009.

Marine Scientists from the Clusters of Excellence in Bremen, Hamburg and Kiel meet to exchange information about their projects.

Nordcluster Meetings

Within the excellence initiative, there exist three northern German clusters with maritime themes, the CLISAP in Hamburg, marum in Bremen and Future Ocean in Kiel. Since cooperation and exchange among these german maritime science centers is traditionally close, the speakers Martin Claussen (CLISAP, Hamburg), Michael Schulz (marum, Bremen) and Martin Visbeck (Future Ocean, Kiel) meet regularly, to inform each other about ongoing activities. During a meeting in fall 2008 they decided to enhance communication and information among the cluster scientists, in order to make everyone aware of the other ongoing projects and foster potential collaborations and exchange. Within 2009 two meetings took place. The first meeting was held on March 26-27 at the marum in Bremen. The meeting began with an introduction to the three projects, highlighting research topics, goals and setup of the clusters. The following two days focussed on marine Earth science topics, like novel sea floor sampling tools, coupled sedimentary-climate models and sea floor resources. The meeting also featured an afternoon session on graduate education concepts, which proved to bring together the different concepts and subsequently strengthened the collaboration in this area.

The second meeting titled „Ocean & Earth System – past, present and future" was held on October 8-9 in the Wissenschaftszentrum in Kiel. The 21 talks in the program were split into five sessions, with topics spanning from oceanography and modeling to economy and law. One session was dedicated to public outreach measures, in order to explore, how special marine science topics can be brought to the general public's attention. About 50 posters were shown next to the venue allowing discussions on other topics in the afternoon of the first day and during lunch and coffee breaks.

These meetings have proven to be a very successful way to cooperate and bridge between the three projects. This is in particular important for postdoctoral researchers and PhD students. As the other institution may well be a potential employer during the next career step. The meetings also demonstrate impressively, that unlike in other disciplines, the marine science institutions in Germany, refrain from competing overly aggressively among each other for the same funding, but rather try to organize themselves around themes, that complement to each other. Consequently the next meeting is planned for 2010 in Hamburg, with a special focus on young researchers and their perspectives in the German marine science research environment.

Future Ocean Partner Projects in Kiel

- SFB 574 - The Collaborative Research Center (Sonderforschungsbereich) SFB 574, funded by the German Research Foundation, investigates the pathways and fluxes of fluids and volatile components (carbon, sulfur, halogens, and water) through subduction zones. Major aims include the evaluation of processes controlling subduction recycling, the effects of these volatiles on the climate and the geochemical evolution of the hydrosphere and atmosphere, as well as origin and causes of natural hazards.

- SFB 754 - The Collaborative Research Center SFB 754 addresses „Climate-Biogeochemistry Interactions in the Tropical Ocean". Since spring 2008 it is in its first phase which lasts until 2011. The key research of the SFB 754 includes subsurface dissolved oxygen in the tropical ocean and its response to variability in ocean circulation and ventilation, the sensitivity and feedback mechanisms linking low or variable oxygen levels and key nutrient source and sink mechanisms in the benthos and the water column, and studies on the magnitudes and time scales of past, present and likely future variations in oceanic oxygen and nutrient levels on various spatial scales.

- SUGAR - In summer 2008, the SUGAR project (Submarine Gas Hydrate Reservoirs) was launched in Germany. The project aims to produce natural gas from marine methane hydrates and to sequester carbon dioxide (CO_2) from power plants and other industrial sources as CO_2-hydrate in marine sediments. The project has 30 institutional partners from academia and industries and is coordinated at the Kiel-based Leibniz Institute of Marine Sciences (IFM-GEOMAR).

- KEI – Kiel Earth Institute: Kiel Earth Institute (KEI) is a virtual institution designed to research key issues of global change and its socio-economical consequences. Globalization of economic activities, the scarcity of natural resources, and a changing environment are challenges all modern societies have to face. The idea for KEI emerged from an intensive cooperation between the Leibniz Institute of Marine Sciences (IFM-GEOMAR) and the Kiel Institute for the World Economy (IfW) within the scope of the Cluster of Excellence „The Future Ocean". Bringing together research and decision-making for societal needs in the area of global change is the main task for KEI.

PhD Student Exchange with Kyoto University

In March Thomas Bosch from the Future Ocean was visited by Professor Kiyokazu Agata from the Center of Excellence „Formation of a strategic base for biodiversity and and evolutionary research: From genome to ecosystem" in Kyoto, Japan. Professor Agata gave a talk about the current research in the Center of Excellence and informed himself

about organization and structure of the Future Ocean. He suggested to explore the possibility of an exchange program among PhD students between Kyoto University and the Cluster of Excellence Future Ocean. The Future Ocean executive board welcomed the brilliant idea. The first round of exchange is scheduled for fall 2010, when a group of students from Kiel will visit Japan for two weeks. The return visit by Japanese students is planned for spring 2011.

Iron Fertilization Project Statement

Iron fertilization is considered a possible geo-engineering measure to bind carbon dioxide in the ocean in order to reduce the effects of global warming. Large scale iron fertilization projects are extremely disputed though, since their efficiency and possible effects are not yet well understood and impacts on the ecosystem in the ocean may be severe. Due to the unknown consequences for ecosystems even small scale research experiments may generate retention in the public. This was impressively demonstrated in summer 2009, when an expedition with the German research icebreaker *Polarstern* was tentatively deferred, due to the unclear legal situation under which the experiments were about to be conducted. A group of scientists from the Future Ocean around A. Oschliess, oceanographer, A. Proelss, legal science and W. Rickels, economy, gathered the scientific, economic and legal arguments for this case. The interdisciplinary study published in December suggested, that continuing research in this field is necessary to be able to estimate the full potential of iron fertilization for geo-engineering purposes. According to this study the iron fertilization experiments needed are in line with international law and scientific criteria. It came to the conclusion that so far neither scientific nor economic criteria suggest to exclude iron fertilization as supporting measure for climatic protection. The authors also point out, that from a legal point of view a stop of the scientific iron fertilization experiments can not be justified, as the appropriate research activities are legal in the context of the relevant international-law agreements. Model results and experiments have shown, that iron fertilization in the southern ocean can lead to a significant increase of carbon transport from the sea surface into the deep sea. From the economic perspective the iron fertilization may thus be more efficient in capturing CO_2 from the atmosphere than e.g. measures in afforestation.

This example shows an integral strength of the Future Ocean community: to quickly be able to come up with inter-disciplinary responses to complex questions. The community reacts upon arising demands, and brings together researchers from very different scientific areas to solve a suddenly arising complex problem in a way, that would have been impossible for each of them individually. Strong teamwork!

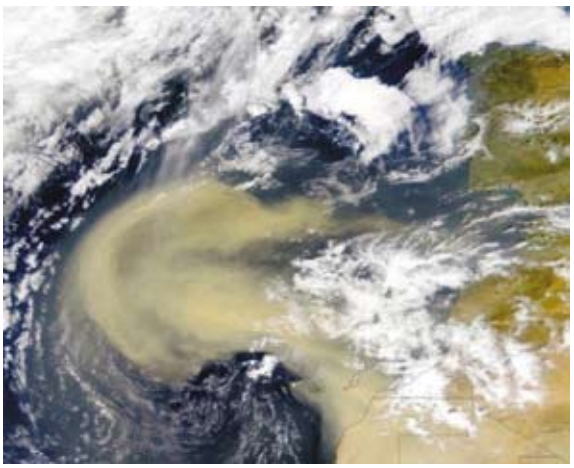
Data Management Team

Marine research data is expensive to produce. It requires ships, robots, significant technical infrastructure that needs to be acquired, maintained, operated. Consequently the data created with such infrastructure is valuable and expensive to reproduce. Therefore the sustainable management and dissemination of marine research data is an important task in conjunction wirth marine research projects.

In order to improve the current structures in Kiel, the Future Ocean decided in 2008 to pool data management resources with the IFM-GEOMAR and two DFG collaborative research projects SFB 574 and SFB 754 in order to install a common Kiel data management team and to create a single point of contact for data management issues in marine science. The team has begun to work in 2009 and a brief report on it's first steps can be found on page 68.

Future Ocean Alexander von Humboldt Fellowships

The Cluster of Excellence Future Ocean will cooperate with the Alexander von Humboldt Foundation, in order to attract international researchers, working on ocean and global change and their consequences for mankind as Humboldt Fellows. This was agreed between Dr. Thomas Hesse, chair of the selection committee at the Alexander von Humboldt Foundation and Professor Dr. Gerhard Fouquet, president of the Christian-Albrechts University on October 30, 2009 in a joint statement. It is planned to have the first fellows in the selection process of the Humboldt Foundation in summer 2010. This will enable selected fellows to begin their research in Kiel by end of 2010. The possible fellowships span the whole spectrum of disciplines covered by the Future Ocean, like oceanographers, earth scientists, economists, lawyers, medics, mathematicians or computer scientists. Prospective applicants can apply with the Alexander von Humboldt Foundation, who conducts the selection process. Successful



Sandstorm over the eastern Atlantic Ocean. The dust contains iron, a natural fertilizer for the ocean, which can lead to plankton blooming and an increased fixation of CO_2 on the sea floor in algal remains.

CAU Vice President Frank Kempken, AvH representative Dr. Thomas Hesse and the speaker of the Future Ocean Martin Visbeck sign the agreement between the university and the Alexander von Humboldt Foundation.

fellows will subsequently conduct research in Kiel. The Alexander von Humboldt Foundation views this cooperation as a possible model for similar cooperation with other institutions in Germany.

Public Outreach / ISOS / Transfer to Application

Last but not least many activities in the sectors public outreach, graduate education and transfer to application took place as well. These are featured in detailed reports in the service section of this report on pages 60-77.

The Founding Institutions

Christian-Albrechts-Universität zu Kiel

The Christian-Albrechts-Universität zu Kiel is the only full university in Schleswig-Holstein. It is home to more than 22,000 students as well as 2,000 university teachers and researchers. From A for Agricultural Sciences to Z for Zoology, the university currently offers around 80 different subjects of study.

Creating links among the different scientific cultures is the top priority at Kiel University. After all, reality that is reflected in scientific research is multi-layered and complex and so are the research focuses of the university: marine and geological sciences, life sciences, cultural spaces as well as nanosciences and surfaces. During its nearly 350-year history, the Christian-Albrechts-Universität zu Kiel is closely linked with the city of Kiel. Together with the university hospital it is now the largest employer in the region.

Leibniz Institute of Marine Sciences

The Leibniz Institute of Marine Sciences (IFM-GEOMAR) is one of the world's leading institutes in the field of marine sciences. The institute investigates the chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere. This broad spectrum makes IFM-GEOMAR unique in Germany. Additionally, the institute has successfully bridged the gap between basic and applied science in a number of research areas. IFM-GEOMAR has four major research foci: Ocean Circulation and Climate Dynamics, Marine Biogeochemistry, Marine Ecology and Dynamics of the Ocean Floor. Four research vessels, large-scale seagoing equipment such as the manned submersible JAGO, the unmanned deep-sea robots ROV Kiel 6000 and AUV Abyss as well as state-of-the-art laboratories, analytical facilities, and a hierarchy of numerical models provide a unique basis for excellent marine research. With a number of internationally-based curricula the Institute actively contributes to educating young scientists in the field of marine sciences.

IFM-GEOMAR is a member of the Leibniz Association, the German Marine Research Consortium (KDM) and the Marine Board of the European Science Foundation.

Kiel Institute for the World Economy

The Kiel Institute is one of the major centers for Research in global economic affairs, economic policy advice and economic education.

The Institute regards research into potentially innovative solutions to urgent problems of the world economy as its main task. On the basis of this research work, it advises decision makers in politics, the economy and society, and keeps the interested public informed on important matters of economic policy. As a portal to world economic research, it manages a broadly cast network of national and international experts, whose research work flows directly or indirectly into the Kiel Institute's research and advisory activities.

The Kiel Institute attaches particular value to economic education and further training and co-operates with the world's largest library in the economic and social sciences.

Muthesius Academy of Fine Arts and Design

Founded on 1st January 2005, the Muthesius Academy of Fine Arts and Design in Kiel is Germany's northernmost and youngest school of higher education devoted to the systematic study of art and design. Thanks to an innovative course structure, the Academy's concept features a diverse programme of curriculum options in the fields of art, spatial strategies and design. The history of the Academy began in 1907 with the founding of separate classes in artistic design at the School of Applied Arts, the Muthesius Academy. It is a story of constant, gradual change in both curriculum and academic structure. The newly founded Academy of Fine Arts and Design will offer approximately 400 places for students.

The Art Academy's size enables it to offer project-oriented and practical instruction in small groups - a tradition harking back to the days of the Muthesius Academy - as well as close contact between instructors and students. Modern media play no less important a role than that of the traditional canons of art and design.

Project Statistics

During 2009, three years after its establishment, the Cluster of Excellence Future Ocean passed its temporal median. The first two years were committed to foundation and growth of the project. 2009 can be attributed as a year of intensive work under full setup conditions. All groups have been operating completely staffed and the amount of investments is decreasing. Since the beginning in 2006, statistical data on various aspects of the project has been collected. In particular data on funding, personnel, publication and international exchange has been compiled. The annual report 2009 therefore offers the opportunity, to compare some of these numbers between the years to show, how the project is developing.

Monitoring

Each year the Future Ocean conducts an online survey among its members and employees, to compile data on publications, participation in workshops and meetings, visits to external institutions, and incoming visitors from external institutions. The survey also collects data on use of the platforms, the ISOS course offerings, family and employment measures, networking within the cluster and with other institutions, within Germany and abroad. The surveys are conducted using an online survey tool, allowing to set up questionnaires as custom made forms. Subsequently the data is compiled and plotted by the central service office to be discussed and analyzed by the Future Ocean's quality management panel. The quality management panel reports findings and recommendations to the cluster's council and to the executive board in order to allow adjustments to the overall Future Ocean strategy and plan for a successful future.

The financial data of the cluster are compiled from the financial reports of the four project partners and evaluated in the controlling section of the Future Ocean's central service office. The data is organized in a way that allows to view data and draw conclusions according to the overall employee structure and gender balance, but also relative to the Future Ocean's major funding lines.

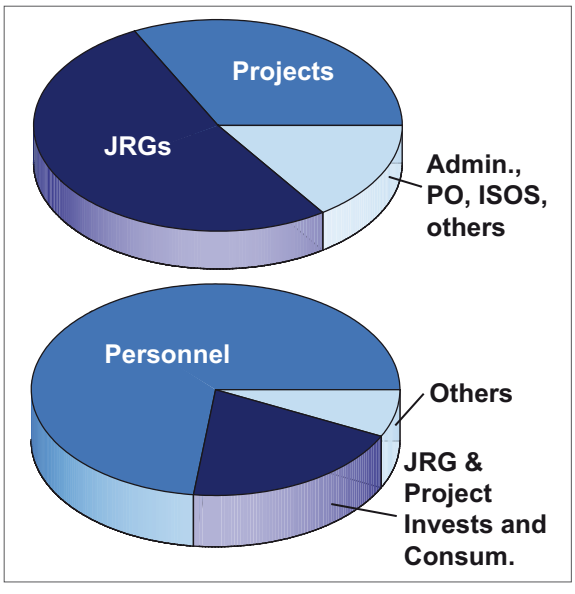


Figure 1 | Overview of fund allocation in the Future Ocean in 2009.

Budget and Funding

The total annual budget for 2009 was 5.3M €. In addition 0.5M € were carried over from 2008, resulting in a total Future Ocean budget in 2009 of 5.8M €. Overall roughly 4.28M € (73%) were spent on personnel, about 1.15M € (19,5%) on project and JRG investments and consumables and nearly 425.000 € (7%) on other budget items like internal workshops and retreats, meetings and outreach activities, travel grants for outgoing and incoming visitors, equal opportunity measures and others (Fig. 1).

The Future Ocean spends funds along three major funding lines: (1) junior research groups, (2) proposed research projects, and (3) technical infrastructure platforms. The thirteen junior research groups use their funds to build up competent research groups on their respective scientific topics. They received about 3M € in total, an increase of about 17% compared to 2008 and 52% of the total budget.

One of the most important elements of the Future Ocean is the flexible budget on open projects, which are advertised about once per year. Between 2006 and 2009 the Future Ocean issued five calls for proposals on general Future Ocean topics (Fig. 2). Two calls on platform investments were issued in 2007. Future Ocean projects typically run for a maximum of two years, and usually focus on strategic targets, like start-up proposals, to prepare for large scale projects, or special "risky" research, which looks promising, but may turn out to fail scientifically. All proposals are externally and internally reviewed before a funding decision is made.

The Future Ocean research projects spent about 1.9M €, about 20% more than 2008 and 32.5% of the total budget. The time-line of the Future Ocean proposals is shown in figure 2. It is important to note, that during 2009 three project phases were active (CP07/I, CP07/II and CP08), resulting in a maximum amount of money being spent on general research projects. The same will be true for 2010, while the number of running projects will probably temporarily be reduced in 2011.

Unlike in 2007, where platform investments supported the build-up of a sustainable technical infrastructure, nearly no money was spent on platform investments in 2008, and no platform investments took place in 2009. Consequently the funding for the other categories was expanded accordingly.

Other expenses amounted to about 0.9M €, a budget that remains about stable through the last years, 15.5% of the 2009 budget (Fig. 3). The "other" expenses can be attributed to administration, public outreach activities, expenses for the ISOS graduate school and miscellaneous small funding lines

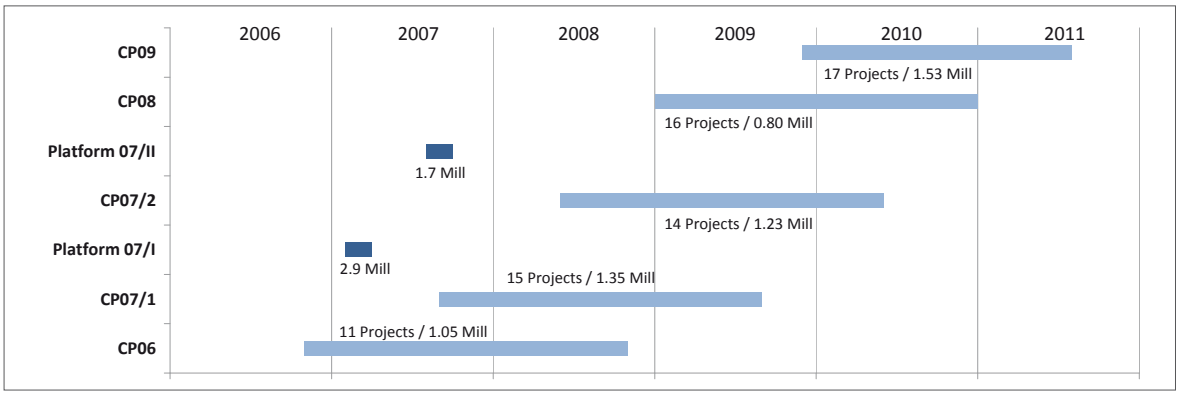


Figure 2 | Timeline of the cluster projects as funded between 2006 and 2011. Light blue bars represent research projects. darker bars represent funding for platform investments.

to support travel, visits of foreign scientists, equal opportunity measures, symposia and meetings.

A comparison of fiscal year 2009 to previous years shows, that there is a clear tendency towards an increased employment of personnel, in particular within the junior research groups, while the demand to invest into instruments and laboratory is shrinking. This is a straightforward development, as most important investments have been made within the first year of the Future Ocean, before personnel was hired. Now instruments and laboratories purchased through the platforms are open for use for all researchers, resulting in little need for additional investments in most areas.

Despite a careful long-term planning, a critical question for a large scale research project as the Future Ocean is: how flexible is the project with its funding, how quickly could the project react to immediate demands? In 2009 the Future Ocean spent approximately 73% of its funds for personnel, 20% on investments and consumables and 7% on other budget items like travel and meetings. If all personnel contracts were long-term, this distribution would allow only very limited adjustments to the overall course of the project within a fiscal year. However, about 30% of the personnel expenses, in particular within the Future Ocean research projects occur in short-termed research projects, allowing moderate adjustment to expenses throughout a year. The Future Ocean management is therefore capable to carefully adjust the direction the project is steering as it progresses. Rapid large scale changes in funding, however, are difficult to implement.

Personnel

During 2009 the number of Future Ocean employees grew from 123 to 157 people, 84 women, 73 men. For details on gender distribution see the chapter on equal opportunity measures on page 20. Employees can be grouped into four categories: junior professors on tenure track, post doctoral researchers, PhD students and technical and administrative personnel as illustrated in figure 4. Unlike the previous years, in 2009 the junior research groups hired mainly postdoctoral researchers to join their groups. The number of PhD students is stable. This indicates the fact that the groups are maturing, asking for more experienced staff organizing larger scale projects. In contrast the projects shifted toward hiring preferably PhD students. This is most likely caused by the proposal round in late 2008, which limited proposals to 50k €, making it difficult to propose full post doc positions. It should be noted, that the Future Ocean to date does not fund any full professorships, only junior professors, being on tenure track positions. Projecting into the coming years, it can be expected, that the total number of employees will stay well below 150. This expectation is mainly based on a need to maintain a healthy balance between investments and personnel and to keep the project in a flexible state, ready to be able to follow the established paths, but capable of opening new fields as demand arises. As instrumentation will need maintenance and updates in the future, the expenses may swing back a little towards investments and consumables.

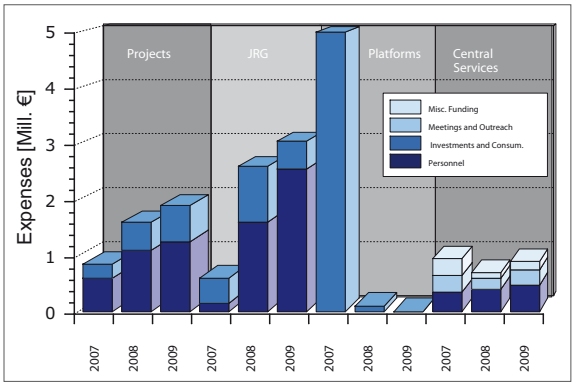


Figure 3 | Development of expenses throughout 2007-2009 in the categories (1) Research Projects, (2) JRG, (3) Platforms and (4) Central Service Projects i.e. ISOS, Technology Transfer and Public Outreach (PO).

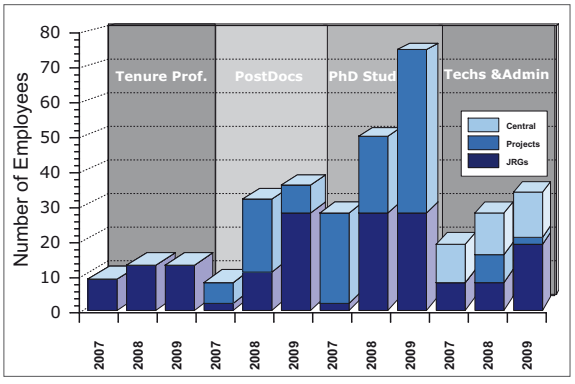


Figure 4 | Development of the distribution of positions within the different funding lines, junior research groups, cluster projects and central services.

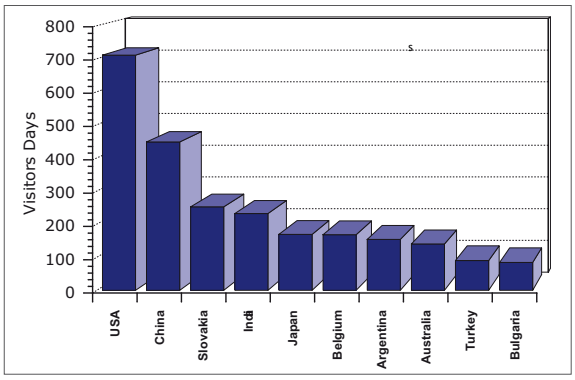


Figure 5 | Number of visitor days in 2009 per country.

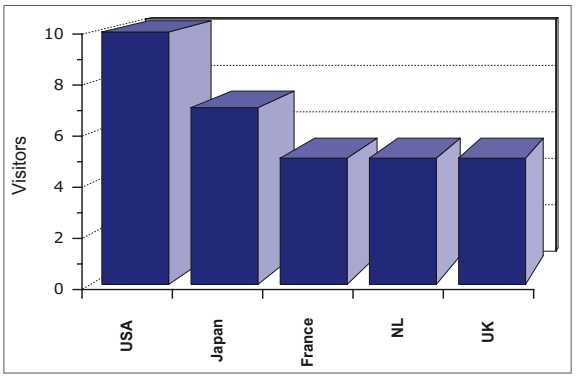


Figure 6 | Number of visitors per country for the five most visiting countries.

National and International Institutional Networking

A important measure of external exchange for any research location is the rate of interaction of scientists with external colleagues and institutions. During our survey the members of the Future Ocean were asked to list the national and international institutions they regularly cooperate with. It turned out that the most important national partners of the Future Ocean researchers are the GKSS in Geesthacht near Hamburg, the Clusters of Excellence Marum in Bremen and Clisap in Hamburg including the respective universities, the Alfred Wegener Institute in Bremerhaven, the Research Center Borstel for Medicine and Biosciences in Schleswig Holstein, and the University Luebeck. The most often mentioned international institutions were the National Oceanography Centre (NOC), Southampton, UK, the Royal Netherlands Institute for Sea Research (NIOZ), the University of Bergen, Norway, and the Woods Hole Oceanographic Institution (WHOI), Massachusetts, USA. In total, the members of the Future Ocean mentioned 172 different international institutions outside Germany they cooperate with.

International Exchange

Incoming visitors and visits to foreign institutions by Future Ocean scientists are an important benchmark for international cooperation. In 2009 the Future Ocean scientists had 79 visitors in total. 33 of them were on professor level, 27 postdoctoral researchers and 19 PhD students. The most important countries in terms of the number of visitors were the USA, Japan, France, the United Kingdom and the Netherlands (Fig. 6). Accounted by the number of visiting days the USA plays a leading role. The numbers of China, Slovakia and India are based on very few long term visitors.

Looking at the number of visits Future Ocean Members and employees spent abroad, the USA, France and Sweden are the most important partner countries. In terms of total time spent abroad, however, extended stays to Australia and Canada also took place (Fig. 8). It is surprising, that the UK does not play a great role in this statistic, even though the most often mentioned international cooperation takes place with the National Oceanography Centre (NOC), Southampton, UK. It can only be assumed, that due to the close distance visits are only very short or very frequent and were hence not mentioned within this survey.

These numbers illustrate, how well integrated the Future Ocean and its members are within the international science community. The project cultivates an extensive exchange of research, knowledge, and personnel with foreign colleagues on all levels, in order to actively contribute to the forefront of marine science.

Meetings

Like the publication venues, the most important meetings and conferences are biased by the earth and ocean science communities. The European Geoscience Union (EGU) annual assembly was the most frequented meeting in 2009, however, the Annual Conference of the European Association of Environmental and Resource Economists (EAERE) attracted five participants as well. The most important national meeting was the Annual meeting of the German Geophysical Society (DGG), most likely because it was held in Kiel.

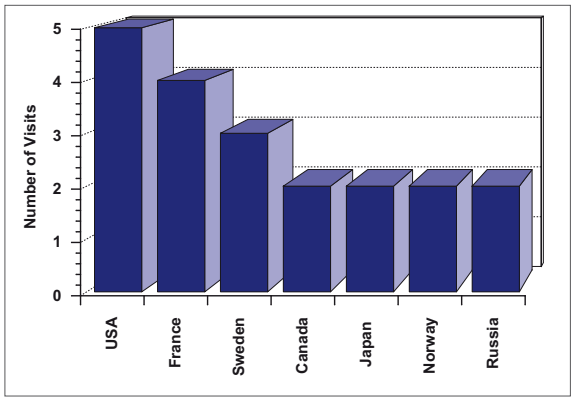


Figure 7 | Number of visits per country for the seven most visited countries.

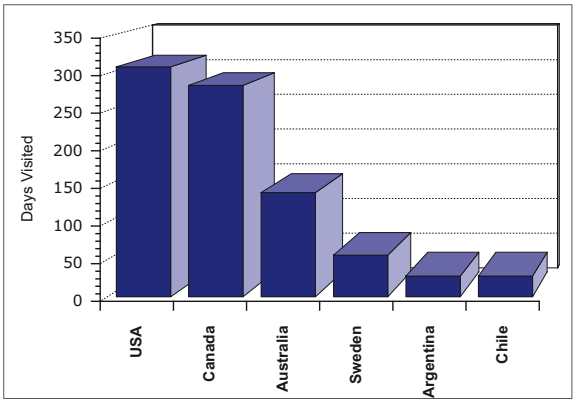


Figure 8 | Number of days Future Ocean scientists stayed abroad, for the six most visited countries

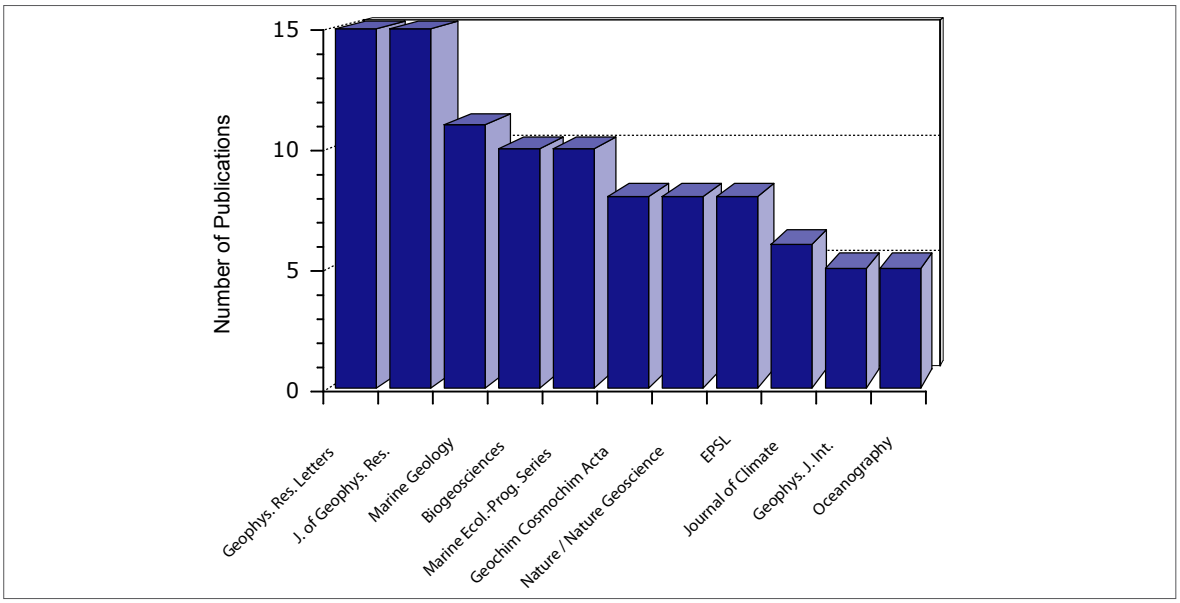


Figure 9 | The eleven most frequently used journals Future Ocean researchers published in in 2009.

Publications

The most important benchmark factor to evaluate people, projects or institutions are related to publication statistics. Experience shows though, that the peak of publications in projects typically occurs after about 5 years. For this reason, we just present very simple statistics of the Future Ocean for 2009. More detailed analysis, e.g. about citation of Future Ocean published articles, should be conducted at a later stage. In 2009 Future Ocean researchers published about 361 articles in about 169 different Journals. In 2009 the most important journals were the Geophysical Research Letters and the Journal of Geophysical Research with 15 articles each, followed by Marine Geology with 11 articles. Initially counted 43 publications in Geochimica Et Cosmochimica Acta had to be corrected to 8 due to a number of listed publications being abstracts to the 2009 Goldschmidt conference. The journals members published most frequently in are summarized in Figure 9. From the list of the eleven most important journals we note only three changes compared to 2008: *Global Biochemical Cycles*, *Limnology and Oceanography* and *Geochemistry, Geophysics, Geosystems* are missing, with *Journal of Climate*, Geophysical Journal International and Oceanography replacing them. Although the spectrum of these journals is strongly biased by the earth science community, which has the strongest representation in the Future Ocean, the publications span whole spectrum of research conducted in the project, from oceanography to law, from geoscience to economy, from medicine to mathematics.

For the broad range of publications in 2009 see the "Selected publication" section in the Appendix (Page 82).

Statistics Contact

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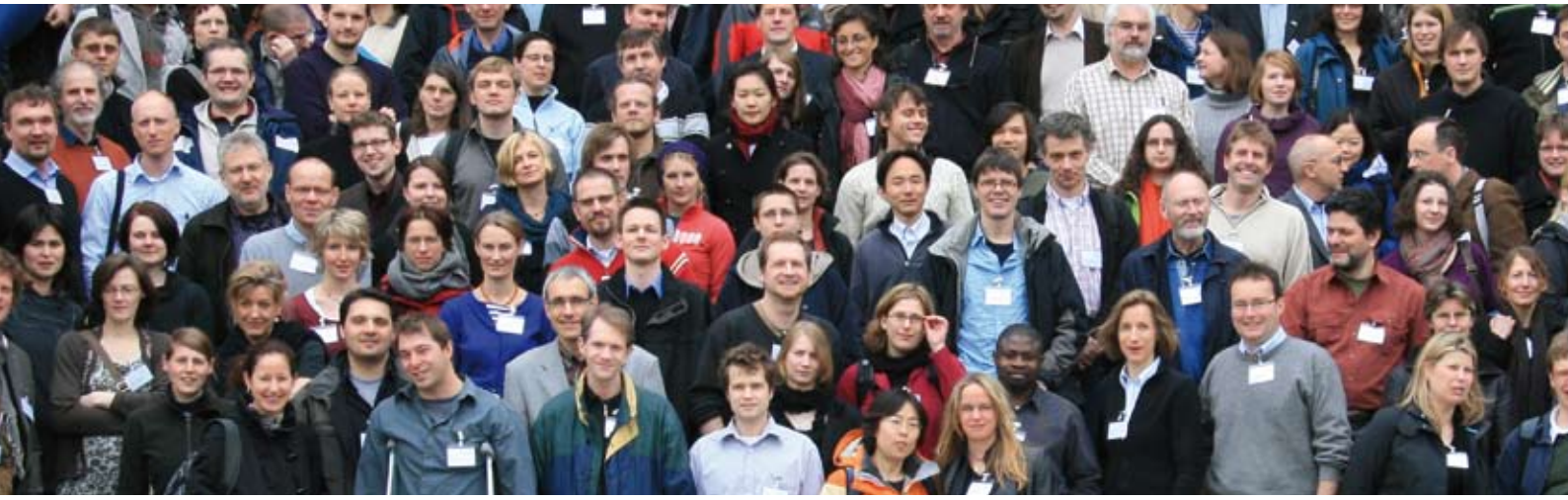

Equal Opportunity?

Providing an equal opportunity environment in research is important. The excellence initiative is tasked to explore new paths in many aspects - in research, but also in establishing structures supporting world class science. In order to improve scientific quality, the provision of equal opportunity measures in work and life is mandatory. They provide the foundation for employees to be able to follow their optimal personal career paths. Measures fall into two distinct categories: 1. Family and Employment measures, which allow employees to follow an ambitious career while raising kids and taking care of a family (work life balance) and 2. Career measures, aiming to overcome possible disadvantages in career planning of female scientists and to ensure, that the proportion of women in high level positions is increased. As these measures require different approaches, they are independently organized within the project.

Family and Employment

Family and Employment measures are established with the goal to allow researchers and other employees to raise and take care of kids, without sacrificing critical career opportunities. For this purpose the regular standards set by the DFG are followed. This means, that on all career levels, measures are established to allow equal chances for male and female parents to be successful in acquiring and performing in their job. These measures are supervised and guaranteed by the regular institutions established at the university and its partner institutes. I.e., the Future Ocean consults and shares information on recruitment with the respective equal opportunity commissioner of the institution. The Future Ocean takes special action in daily child care for kids under three years, which can not be covered by regular Kindergartens, by founding a small childcare group. These "cluster crabs" are a group of currently five kids under three years from Future Ocean employees (Fig. 1). The Future Ocean also works together with the university's Family Office, to plan for childcare facilities offered during meetings and symposia. The University Kiel is certified as a family-friendly university and therefore already offers many facilities needed to supply a family and employment friendly environment.

The Future Ocean also funds extra student workers for pregnant employees, to help in laboratories and support with tasks impossible or forbidden for pregnant colleagues to do. The project made a commitment, to try to extend temporary working contracts interrupted due to pregnancy, to the overall initial full length of this contract within the lifetime of the project.

Figure 1 | Impression from the Future Ocean day care facilitiy „cluster crabs" for small children under three years.

Promoting Women in Science

The Future Ocean employs 157 people in total, 84 women and 73 men. These are distributed within separate employment levels through the first three years of the Future Ocean as shown in figure 3. The numbers show, that the percentage of women is highest at the PhD student level, where the numbers of male and female students are roughly equal. This is in line with the numbers of dissertations at the University Kiel, showing an equal number of male and female graduates. The relation goes slightly down at the postdoc level to about 44% females. At the Junior Research Group level the rate is constant at four women out of thirteen, at 31%. It is remarkable, though not unexpected, that women are vastly overrepresented in the technician and administration category, while underrepresented in the JRG leader category. The reason probably lies in the higher number of

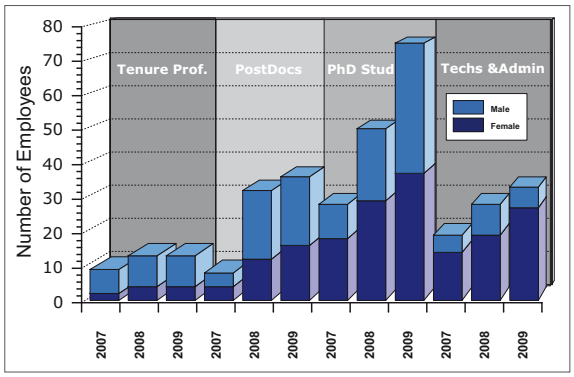

Figure 2 | Gender composition of the group of Future Ocean employees between 2007 and 2009.

part time positions in this sector, which seem to be more attractive for women than for men. Fig. 2 also shows, that the numbers are roughly stable during the recent years, despite additional hiring of personnel. One could argue, that this means, that the percentage reflects the gender composition of the group of potential candidates available for the advertised positions.

The data also shows that the number of women in the project decreases with rising scientific career level after the PhD, most likely beginning within the early post-doc phase. This is a well known trend in Germany caused by many factors. There are probably many reasons for this, which we don't know in detail, but it can be suspected, that at least some are discipline related. In the future we will try to identify these factors, in order to be able to work out special, targeted support where we find shortcomings in providing fair career chances for women. We will therefore continue to monitor and further womens career development.

Another aspect of equal opportunity is "equal participation", reflecting the fact that women may not be adequately and proportionally present within project panels and commissions. The Future Ocean's goal is, to have at least as many women in any panel and commission as the relative quota is within the respective source group. Within the Future Ocean the membership of women is about 12%, which as of 2009 is above the average quota in professorships at the University Kiel of about 10%. Each panel fulfills the stated requirement of women membership of at least 12% (Fig. 3). The goal prevents the few present women to become overcommitted just to fulfill a certain quota in a number of panels, but leaves room for engagement in certain areas of special interest.

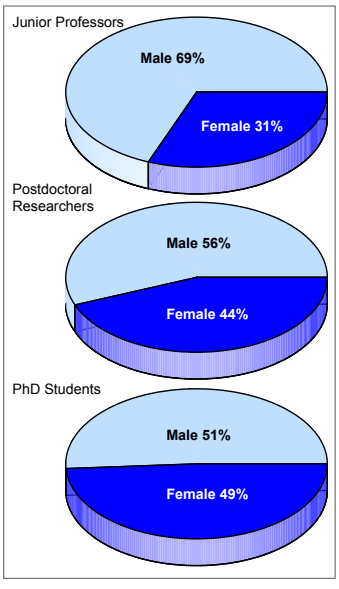

Figure 3 | Gender composition of Future Ocean employees within three career stages: PhD Students, Postdocs and Junior Professors.

Overall we believe that transparency and awareness of patterns which help to stabilize the gender inequality in higher level positions in science is a key factor to improve a situation, which might not be equally balanced, and which may lead to disadvantages for some employees. We therefore strive to publish gender related project data on a frequent basis in order to achieve transparency, encourage discussions and stimulate solutions.

Outlook

There certainly is room for improvement. In particular the drain of female researchers in the post-doc stage is alarming. It can be assumed that at least some of the reasons for this brain drain are specific to marine science disciplines, e.g. necessity to participate in research cruise lasting several weeks. Other factors (highest performance and presence expected in a short time slot) may be of more general nature and hold true for all scientific fields. The Future Ocean is taking these issues very seriously, monitoring performance and careers of its employees on a standard basis to learn about reasons and migration paths of researchers in marine science. It does, however, also work together with dedicated social science initiatives like Frauen in der Spitzenforschung (women in high-level science) from the University Hamburg, Germany. Learning from their view on our project, receiving an outsider's feedback, their experience and data may help us to better identify where women's careers may be furthered. We are thus currently learning about this situation, hoping to be able to start additional focused initiatives and actions within the near future of the Future Ocean. Some of them are easy to achieve, like a systematic invitation of female speakers to our symposium in order to provide modern role models for male and female undergraduates and scientists. Other actions, which are requested by scientists of the Future Ocean, seem to be impossible to implement, e.g., travel support for kids to accompany single raising parents to conferences. We are continuing to identify factors supporting equal opportunity on all levels, and will strive to implement whatever is necessary to offer fair career chances independent of gender.

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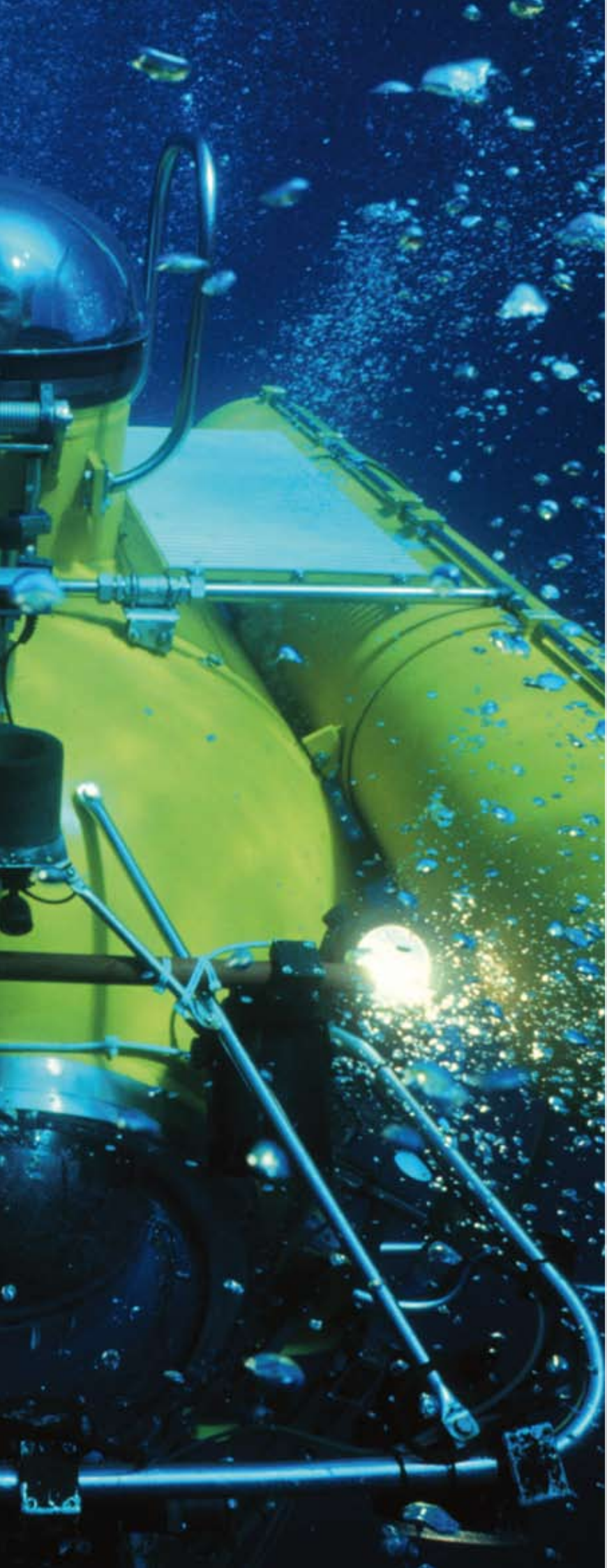

The Research

What is a scientist after all? It is a curious man looking through a keyhole, the keyhole of nature, trying to know what's going on.

Jacques Yves Cousteau

Ocean Acidification and Marine Animal Physiology

The ocean acidification group is interested in understanding basic mechanisms that contribute to marine animal sensitivity to future ocean acidification. Using ecological, physiological, biochemical and molecular biological methods, both, in laboratory and in field settings, the group tries to gain a cause and effect based understanding of crucial processes that define vulnerability to elevated seawater pCO_2. By comparing characteristics of more tolerant model groups (e.g. cephalopods) with those of more sensitive groups (e.g. bivalves) it aims at identifying traits that promote sensitivity vs. tolerance. The working group is following a dual strategy by carrying out laboratory based CO_2 perturbation studies to assess physiological responses and by simultaneously studying physiological adaptations of animals exposed to naturally elevated seawater pCO_2 levels. In the following, two current projects on bivalve and cephalopod mollusk model systems are highlighted.

Mussels in a Naturally CO_2-Enriched Habitat

Together with colleagues from the IFM-GEOMAR departments of Chemical Oceanography and Marine Ecology, the ocean acidification group is using Kiel Fjord as a model system or natural analogue of a future, more acidic ocean. Due to upwelling of CO_2 rich waters in summer and autumn, Kiel Fjord shallow water (<10 m water depth) mussel bed communities (*Mytilus edulis*) come into contact with acidified water during large parts of the year. Peak pCO_2 values of >200 Pa (2000 µatm) and average summer (July-August) values of approximately 100 Pa (ca. 1000 µatm) have been encountered in 2008/2009. Thus, this habitat is characterized by a carbonate system we might expect in a few hundred years in the average world ocean. As species most likely

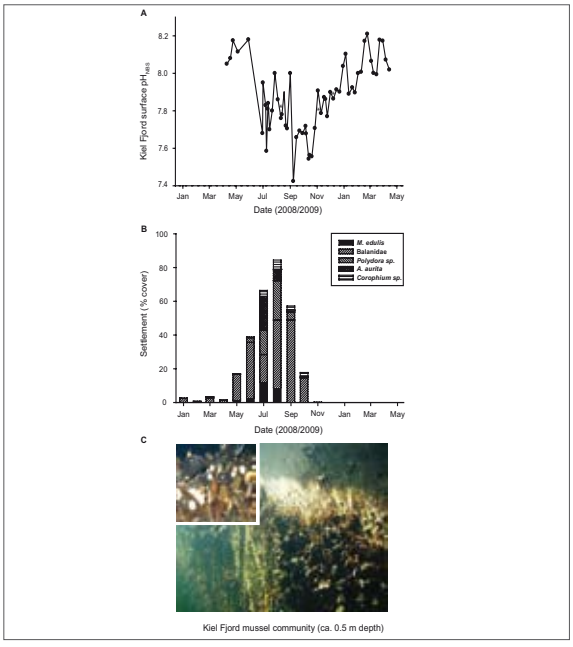

Figure 1 | (A) Surface pHNBS in Kiel Fjord during 2008/2009, (B) settlement of marine invertebrate larvae in Kiel Fjord assessed using PVC settlement plates that were sampled monthly, (C) Kiel Fjord mussel community in 0.5 m depth.

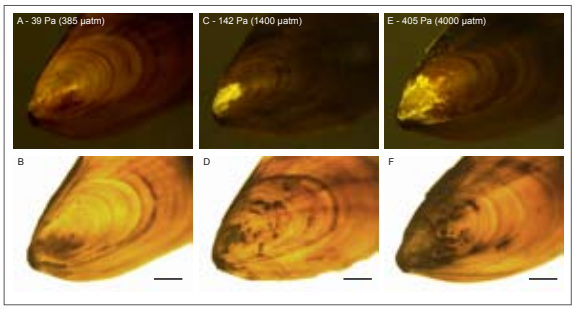

Figure 2 | External shell dissolution on the posterior part of blue mussels acclimated for 8 weeks to (A, B) 39 Pa (385 µatm), (C, D) 142 Pa (1400 µatm) and (E, F) 405 Pa (4000 µatm). External shell dissolution of carbonates is favored on older shell parts, where friction has abraded the protective organic cover (periostracum) of the shell. Upper panels: reflected light, lower panels: transmission light, scale bars: 2 mm.

are adapted to these specific abiotic conditions, populations from this habitat are ideal models to assess potential future changes in species performance and community structure.

Surprisingly, it could be demonstrated that mussel recruitment (settlement of larvae on settlement plates) is highest when pH values are lowest (Fig. 1). In addition, laboratory growth and calcification trials demonstrated that mussels can maintain rates of calcification at high pCO_2 of 140 Pa, thus waters severely undersaturated with aragonite and calcite, despite not being able to control the pH value of their extracellular fluids. Contrary to previous studies that suggested that uncompensated extracellular pH leads to metabolic depression, we could demonstrate that metabolic rates increase with CO_2 stress. While mussels seem to be able to cope with current levels of acidification in this particular habitat, future, non linear changes may lead to seawater pCO_2 values >400 Pa (4000 µatm). Such changes, which may be encountered in many coastal areas worldwide, will most likely affect calcification performance and increase external shell dissolution (Fig. 2).

Elevated Cephalopod Calcification at High pCO_2

In contrast to the situation in bivalves, cephalopods can fully maintain rates of somatic growth, metabolism and calci-

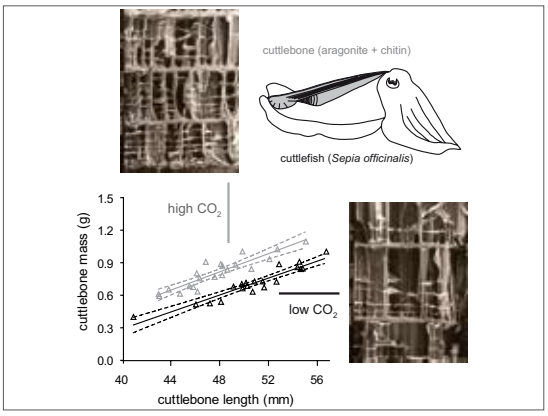

Figure 3 | Hypercalcification in a cephalopod cuttlebone following a 6 week growth trial at 60 Pa and 600 Pa. The cuttlebone is composed of $CaCO_3$ (aragonite) and an organic phase and appears much denser following exposure to high pCO_2. Hypercalcification might not be beneficial, as the cuttlebone is used as a buoyancy device.

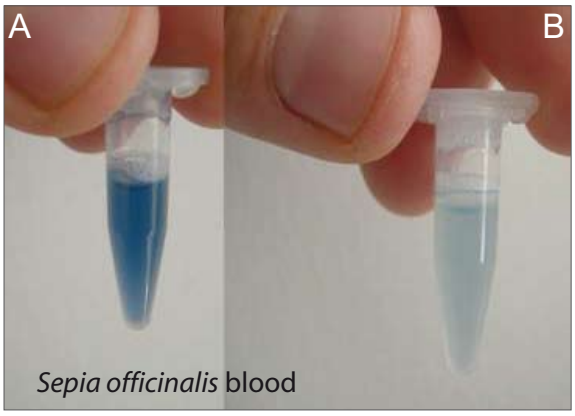

Figure 4 | (A) Oxygenated and (B) De-oxygenated cephalopod (*Sepia officinalis*) blood. The extracellular, pH sensitive oxygen carrying pigment of cephalopods (hemocyanin) appears blue when oxygenated.

fication even at very high pCO_2 values of >500 Pa (5000 µatm). In fact, high seawater pCO_2 results in a hypercalcified endoskeleton (cuttlebone): Using SEM techniques it could be demonstrated, that a denser microstructure of the cuttlebone develops with an increased $CaCO_3$ fraction (Fig. 3). This could be related to the strong extracellular pH regulatory machinery these animals possess. Using surgically implanted catheters it was possible to continuously monitor extracellular acid-base status in these animals: unlike in bivalves, exposure to elevated pCO_2 leads to an extracellular accumulation of bicarbonate (HCO_3^-), which helps compensate the blood acidosis. This is important, as hemocyanin, the extracellular pigment of cephalopods (Fig. 4), is highly pH sensitive. Uncompensated drops in pH can easily lead to asphyxiation in cephalopods. However, high extracellular HCO_3^- concentrations might also directly impact calcification as it increases the $CaCO_3$ saturation state in extracellular fluids, making precipitation of $CaCO_3$ less energy demanding, or it might alter transport kinetics across calcifying epithelia. Hypercalcification has so far only been observed in marine animals that possess a pH sensitive respiratory pigment and have the ability to accumulate extracellular HCO_3^-.

We have begun to locate and characterize the gill ion regulatory epithelia that are most likely involved in extracellular pH regulation. We have cloned and localized several gill ion transporters that are potentially related to extracellular pH regulation in cephalopods (e.g. NBCe, NDCBE, cCA2, Na^+/K^+-ATPase, V-type H^+-ATPase). Judging from the mRNA expression patterns and the localization of these transporters, it seems possible that HCO_3^- import is regulated in a similar fashion as in the proximal tubule of the human kidney: an acidification of the water close to ion regulatory cells drives CO_2 inside the cells, where cytoplasmatic carbonic anhydrase (cCA2) converts CO_2 into HCO_3^-, which is then transported into the plasma via an electrogenic Na^+ -HCO_3^-- co-transporter (NBCe). We are currently generating a transcriptome of gill- and calcifying epithelia in order to gain a more accurate picture of the potential ion transport mechanisms in cephalopods. As ion regulatory capacity might be a key element that promotes tolerance towards seawater acidification, future experiments are focused on early embryonic stages, as these life stages only possess rudimentary gills.

Working Group

Martina Langenbuch, Rainer Kiko, Marian Y. Hu, Meike Stumpp, Agnes Heinemann, Frank Melzner, Jörn Thomsen, Julia Saphörster, Katja Trübenbach

Selected Publications

1 | Melzner, F., Gutowska, M. A., Langenbuch, M., Dupont, S., Lucassen, M., Thorndyke, M.C., Bleich, M., Pörtner, H.O. (2009): Physiological basis for high CO_2 tolerance in marine ectothermic animals: pre-adaptation through lifestyle and ontogeny?, Biogeosciences 6:2313-2331, doi:10.5194/bg-6-2313-2009

2 | Melzner, F., Göbel S., Langenbuch, M., Gutowska, M.A., Pörtner, H.O., Lucassen, M. (2009) Swimming performance in Atlantic Cod (Gadus morhua) following long-term (4-12 months) acclimation to elevated sea water pCO_2, Aquatic Toxicology 92:30-37.

3 | Gutowska, M.A., Melzner, F. (2009). Abiotic conditions in cephalopod (*Sepia officinalis*) eggs: embryonic development at low pH, Marine Biology 156:515-519.

Seafloor Warming

The Seafloor Warming Group investigates the consequences of temperature increases at the seafloor caused by global warming. One of its topics is the potential destabilization of submarine gas hydrates in sensitive regions such as the Arctic Ocean. Melting of gas hydrates could release large quantities of methane, a very potent greenhouse gas, into the atmosphere. The Seafloor Warmig group aims at understanding the physical and biogeochemical processes that are connected with temperature-induced gas hydrate dissociation in marine sediments.

Gas Hydrates Under Global Warming

The Arctic has considerably warmed during the recent decade, as witnessed by the rapid sea ice melt. Climate models project an acceleration of Arctic climate change in the future, if global greenhouse gas emissions continue to increase. Stabilized by year-round cold temperatures, Arctic methane hydrates are deposited at shallow water depth close to shelf edges, which makes them very sensitive to atmospheric warming and changes in temperature regimes of the upper water masses. Within an interdisciplinary study involving several subprojects of the Cluster of Excellence Future Ocean, Arctic bottom water temperatures were analyzed, and their future evolution projected by a climate model applying a business-as-usual scenario. The impact of the temperature changes on the distribution of gas hydrate stability zones in the seafloor was then estimated. The resulting warming turned out to be spatially inhomogeneous, with strongest impact on shallow regions affected by Atlantic inflow (Fig. 1). Within the next 100 years, the warming affects 25% of the shallow and mid-depth regions (water depth <600 m) containing methane hydrates. In worst case scenarios, i.e., under a total release of methane from hypothetical gas hydrate reservoirs into the hydrosphere or atmosphere (135 Mt CH_4 yr^{-1} over the first 100 years), the melting could enhance ocean acidification and greenhouse warming, respectively. However, we suppose that major parts of the liberated methane could be consumed due to microbial processes, i.e., the anaerobic oxidation of methane (AOM), in the sediment prior to a release into the hydrosphere. For a better quantification of this benthic methane filter physical and biogeochemical gas hydrate dissociation modeling was continued from last year (see the Future Ocean annual report 2008) and several field and laboratory studies were conducted as described below.

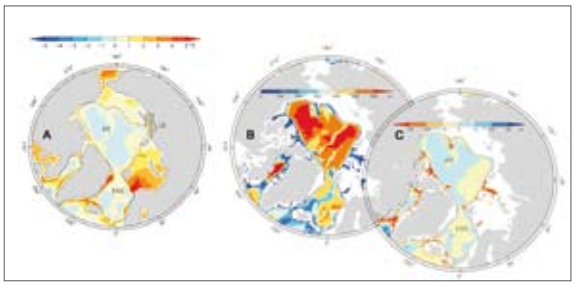

Figure 1 | A: Ensemble-mean trend in Arctic bottom water temperatures (in °C per 100 years) in the climate model simulation under CO_2 increase. B: Thickness (in m) of the submarine gas hydrate stability zone (GHSZ) according to current bottom water temperatures C: Changes (in m) to the thickness of the gas hydrate stability zone (GHSZ) under global warming. The contour line depicts the 400 m isobath. Acronyms mark the Arctic Ocean (AO), European Nordic Seas (ENS) and the Laptev Sea (LS). Contributions: A. Biastoch, T. Treude, L. H. Rüpke, U. Riebesell, C. Roth, E. B. Burwicz, W. Park, M. Latif, C. W. Böning, G. Madec, and K. Wallmann

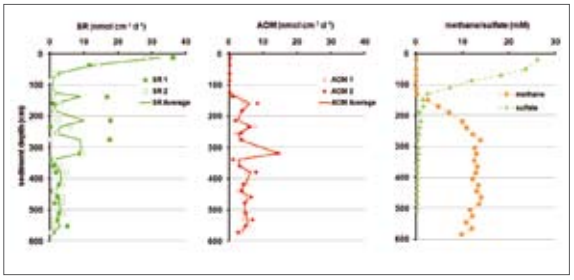

Figure 2 | Rates of sulfate reduction (SR), anaerobic oxidation of methane (AOM), as well as concentrations of methane and sulfate in a sediment piston core, taken at 342 m water depth offshore Alaska in the Beaufort Sea. The core displays a typical methane-sulfate-transition zone in which all methane is consumed. What is unusual is that methane oxidation is active even in deeper parts of the core, were only little sulfate is present. We are currently conducting experiments to better understand this phenomenon. Contributions: T. Treude, S. Krause, L. Hamdan

Methane in the Arctic Shelf and Slope

In September 2009 two members of the group joined an expedition with the U.S. coast guard cutter *Polar Sea* to the Beaufort Sea offshore Alaska, which was conducted by the U.S. Naval Research Laboratory (NRL) in collaboration with the U.S. Department of Energy's National Energy Technology Laboratory, the Royal Netherlands Institute for Sea Research (NIOZ), and a team of 32 university and government scientists from the U.S., Netherlands, Belgium and Germany. The 12-day Methane in the Arctic Shelf/Slope (MITAS) expedition represents the first step towards a more thorough evaluation of the distributions and concentrations of methane and methane hydrates in the Arctic permafrost and oceans. This expedition also contributed to the understanding of methane as a source of energy and its potential role in global climate cycles. During the expedition three transects of piston cores were taken across the shelf and upper continental margin. The Seafloor Warming research group investigated microbial

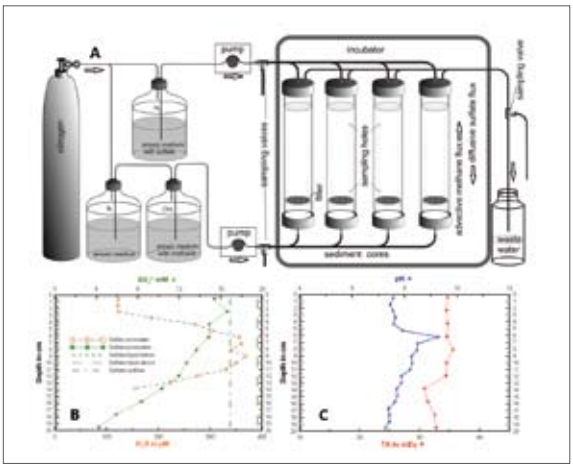

Figure 3 | A: Scheme of the sediment-flow-through-system, which was constructed to study the control mechanisms and limits of the benthic microbial methane filter. B and C: Porewater geochemical profiles of sulfate/sulfide (A) and pH/alkalinity (B) in a first test of the system with a core from the Eckernförde Bay, which harbors an active methanotrophic community. The fluid flow rate was set to 320 cm per year with an inflow methane concentration of 1.5 mM. Contributions: Phillip Steeb, Stephanie Reischke, Peter Linke, Tina Treude

methanotrophy and methanotrophy in the sediments. First results revealed a lively microbial community that prevents methane emissions from the active methanogenic zone (Fig. 2). Ongoing studies are concentrating on changes in both methanogenesis and methane oxidation under increasing temperatures.

Challenging the Benthic Methane Filter

For studying control mechanisms, dynamics, and limits of the benthic methane filter, a so-called sediment-flow-through-system was developed (Fig. 3). Sediment cores taken from active methane seeps are connected to an open system with an advective methane-rich (sulfate-free) seawater flux from the bottom and a diffusive supply of sulfate-rich (methane-free) seawater from the top, thereby simulating seepage conditions and supplying the electron donor (methane) and acceptor (sulfate) under natural conditions. Sampling openings (sealed with silicon) along the core wall enables sub-sampling of sediment and pore water in addition to the system's in- and outflow.

A first goal during the technical development in 2009 was to setup the system, to keep it anoxic, and to establish natural advection/diffusion conditions. For testing, model sand (quartz sand, SiLiBeads) and tracer (fluorescine) were used to mimic the sediment and the diffusion of solutes from the top, respectively. Resazurin was used as an indicator for oxygen contamination. After the first test phase has been successfully completed we are now testing natural sediment cores from methane-rich environments in the Eckernförde Bay (Fig. 3). First results after 15 days of constant high fluid flux (320 cm yr^{-1}) revealed a distinct zone of sulfide production between 5 and 10 cm with concurrent sulfate depletion, as well as pH and alkalinity increase. In a next step it will be tested whether the profile is in accordance with AOM and if the process retains methane in the sediment completely. Data gained by the sediment-flow-through-system will be integrated into numerical models to assess the impact of transport processes on biomass distributions, rates of AOM and methane releases from the seafloor. This study is a joint project of the the Future Ocean's Seafloor Warming group and the collaborative research center SFB 574 on volatiles and fluids in subduction zones in Kiel.

Outlook: Benthic Nitrogen Fixation in OMZ's

Within a separately granted Future Ocean research project the group is investigating benthic nitrogen fixation in oxygen minimum zones (OMZ). One major objective of the study is to increase understanding how nitrogen fluxes across the benthic boundary layer would change if OMZs are spreading due to global warming. Starting with spring 2010 the group is conducting monthly sampling trips to the Eckernförde Bay, which becomes a natural OMZ during warm summer periods. The project involves several partners from the Future Ocean, the collaborative research center SFB 754 Climate – Biogeochemistry Interactions in the Tropical Ocean and a postdoctoral researcher sponsored by the Alexander von Humboldt Foundation, who starts work in early 2010.

Working Group

Members of the JRG in 2009 (from back to front, from left to right): David Vardeh, Stefan Krause, Phillip Steeb, Lars Bremer, Lihua Liu, Dorothee Makarow, Julia Hommer, Hannah Weber, Tina Treude. Missing: Marion Liebetrau.

Selected Publications

1 | B. Orcutt, S.B. Joye, S. Kleindienst, K. Knittel, A. Ramette, A. Reitz, V. Samarkin, T. Treude, and A.Boetius (in press): "Impact of natural oil and higher hydrocarbons on microbial diversity, distribution and activity in Gulf of Mexico cold-seep sediments", *Deep-Sea Research*, doi:10.1016/j.dsr2.2010.05.014

2 | S. Sommer, P. Linke, O. Pfannkuche, H. Niemann, T. Treude (2009): „Benthic respiration in a novel seep habitat dominated by dense beds of ampharetid polychaetes at the Hikurangi Margin (New Zealand)", *Marine Geology*, Volume 272, Issues 1-4, p. 223-232, doi:10.1016/j.margeo.2009.06.003

3 | T. Treude, C.R. Smith, F. Wenzhöfer, E. Carney, A.F. Bernardino, A.K. Hannides, M. Krüger, A. Boetius (2009): „Biogeochemistry of a deep-sea whale fall: sulfate reduction, sulfide efflux and methanogenesis", *MEPS* 382, 1–21 (Feature Article)

CO_2 Uptake of the Ocean – Optimizing Biogeochemical Models by Mathematics

The amount of CO_2 in the ocean is mainly determined by ocean currents and biogeochemical processes. The simulation of these processes is important, e.g. to investigate the future behavior of the ocean as CO_2 buffer for the increasing emissions in the atmosphere. Models of CO_2 uptake consist of equations for different tracers such as nutrients, phyto- and zooplankton. These models use many parameters that are fitted to measurement data. For this purpose, methods of mathematical optimization, high performance computing, and uncertainty analysis are used. Main challenges are the huge computational effort to spin-up 3-D models to steady seasonal cycles in order to optimize them. Among others different optimization techniques, the algorithmic generation of sensitivities, and Newton-like methods for the computation of periodic states are used in the project.

The Role of CO_2 in the Ocean

CO_2 is a main topic in the discussion about climate change and climate protection strategies. It is one of the main greenhouse gases, i.e. it holds back a part of the radiation reflected from the earth's surface in the atmosphere. Thus, on the one hand, CO_2 is responsible for the comfortable warm climate on earth allowing us to survive at all. On the other hand, the increase of CO_2 emissions in the last 200 years has caused a temperature rise with all consequences such as sea ice melting, changes in vegetation etc. Climate model simulations indicate that these effects, summarized as global warming, will continue and even become stronger. Even though the atmospheric CO_2 is most discussed, its amount in the oceans is also very important. In fact, much more of this gas is dissolved in the oceans, and two thirds of the emitted CO_2 is taken up from the atmosphere via the sea surface. This effect thus mitigates the greenhouse effect, but, naturally, it also changes the chemical composition of the ocean water, leading e.g. to acidification. Moreover it is unclear how this mitigation property will change in the future due to global warming.

Modeling the CO_2 Uptake

The amount and distribution of CO_2 in the ocean is determined by the water circulation, by biochemical processes, namely the assimilation of CO_2 by phytoplankton (algae) and its mineralization by zooplankton (animals), and sedimentation. A well-accepted theory describes the relation of the amounts of CO_2 and nutrients that are converted to biomass by photosynthesis. Thus the CO_2 uptake is usually modeled in a system of transport (or advection-diffusion) equations for so-called tracers. The coupling relations between the tracers in these models are more or less empirical, i.e. it is not very clear how the coupling terms look like mathematically, and, moreover, how many tracers have to be taken into account. Many model parameters are used: They are chosen such that the model results remain feasible (i.e. tracer concentrations remain non-negative) and that given measurement data are matched by the model output.

Parameter Optimization

The aim is to minimize the model misfit with respect to the data. The optimization variables are the unknown parameters in the nonlinear coupling terms in the system of tracer transport equations. It is well known that this kind of problems are hard to tackle, even more since the models are high-dimensional, and the available data are not very dense with respect to space and time, and are subject to uncertainty. For a typical marine biogeochemical model a profound optimization and uncertainty analysis was performed. It showed that the model is well suited for optimization, even though the real data could not be fitted satisfactorily. This implies that the model actual has some deficiencies. Moreover, a strategy of random restart of a gradient-based optimization could be successfully used to avoid local minima, a well-known problem in parameter optimization.

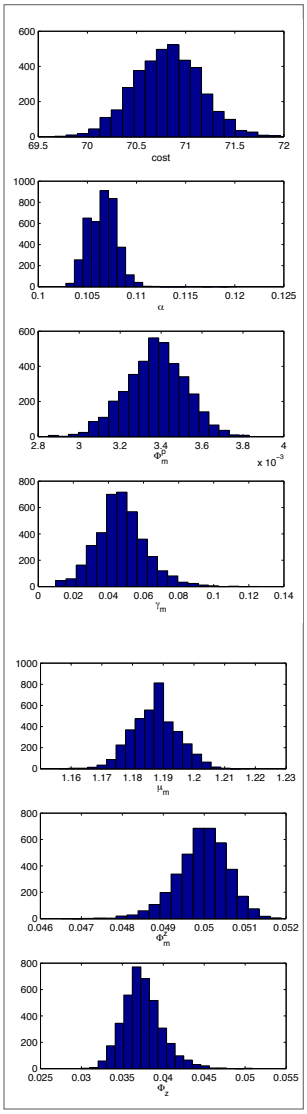

Figure 1 | Results of uncertainty analysis: Distribution of cost (top) and optimized model parameters among totally 3840 runs with Gaussian disturbed data.

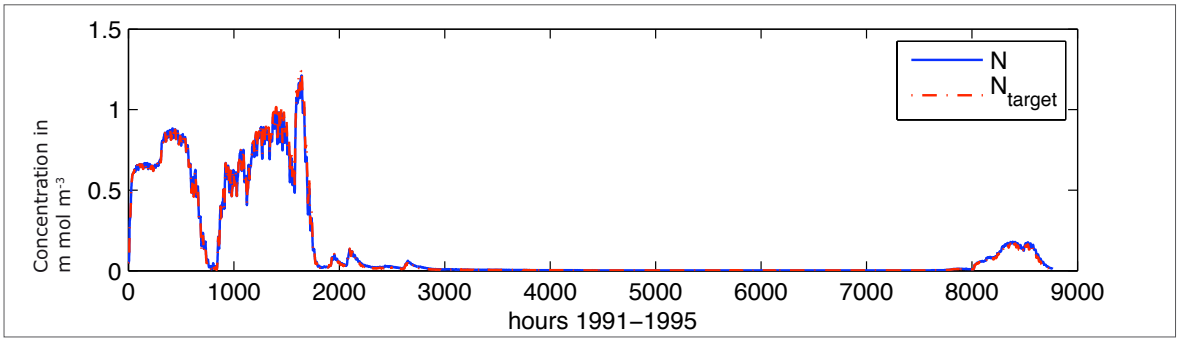

Figure 2 | Successful reconstructed model trajectory for nitrogen (N) in an NPZD model for attainable target data.

Fast Solution Algorithms

The mathematical algorithms used for parameter optimization require several model runs with different parameter values. Because it is necessary to run the models into a periodic state (corresponding to the annual cycle), the efficient computation of this spin-up is crucial for optimization. The often used technique to integrate the model in time until the periodic state is reached, was replaced by a direct computation a variant of the classical Newton method adapted to the huge amount of unknowns in global 3-D models. Additionally, computations on GPU (graphics processing unit) hardware are currently tested, which have promising computational velocity.

One-shot Optimization: Simultaneous Analysis and Design

Another approach to deal with the huge computational effort when iterating the process cycle „model spin-up -> parameter update" was successfully applied to a box model of the thermohaline circulation: The two iterations (simulation and optimization) are combined in the sense that a parameter (or model design) update is performed in every model iteration, and not only when the spin-up is complete. This method is now extended to a 3-D marine biogeochemical model.

Further Methods and Outlook

Using the method of Linear-Quadratic Control Theory, the problem is relaxed in the sense that parameters are allowed to change in time, resulting a better fit. The aim now is to develop a reasonable temporal variation (e.g. corresponding to the seasonal cycle) of the parameters in a new model. In this research field many models are in use, and some of them can be ordered hierarchically. Here the technique of Space Mapping or Surrogate Optimization is investigated. It aims at obtaining an optimal solution in an efficient way by optimizing with a cheap and simple model, while performing only some model runs with a more sophisticated and expensive one. The main goal for the next time in the project is to extend the methods above to fully realistic 3-D biogeochemical models and to improve the used optimization methods.

Working Group

The Research Group on Oceanic CO_2 Uptake, left to right: Johannes Rückelt, Henrike Mütze, Malte Prieß, Mustapha El Jarbi, Anna Heinle, Jaroslaw Piwonski, Thomas Slawig (not shown: Claudia Kratzenstein)

Selected Publications

1 | Neitzel, I., Prüfert, U. and Slawig, T. (2009): Strategies for time-dependent PDE control with inequality constraints using an integrated modeling and simulation environment. In: Numerical Algorithms 50 (2009), Nr. 3, S. 241-269, doi: 10.1007/s11075-008-9225-4.

2 | Rückelt, J., Sauerland, V., Slawig, T., Srivastav, A., Ward, B., Patvardhan, C. (in press): Parameter optimization and uncertainty analysis in a model of oceanic CO_2 uptake using a hybrid algorithm and algorithmic differentiation, Nonlinear Analysis: Real World Applications, doi:10.1016/j.nonrwa.2010.03.006.

3 | Heinle A., Macke A., Srivastav A. (in press): Automatic cloud classification of whole sky images. Atmospheric Measurement Techniques Discussions 3, 269–299.

Biogeochemical Oceanography and Climate

The Ocean Circulation Group joins expertise from ocean biogeochemical and paleo climate modeling in order to enhance our understanding of past, present and future climate mechanisms. A state-of-the art coupled atmosphere ocean climate model, the Kiel Climate Model (KCM), is applied to different warm climates from the present and the geological past. Focusing on ocean circulation, marine biogeochemical cycles and the atmospheric hydrological cycle, the aim is on the one hand to test the model performance in representing climate conditions fundamentally different from today. On the other hand, model results can be used as a physically consistent background against which climate trends from paleo proxy reconstructions can be validated. An ocean biogeochemical model is used to link model results with proxy data and to test the sensitivity of marine biota to ocean acidification and climate change, including potential consequences for the global carbon cycle thus feedbacks on climate.

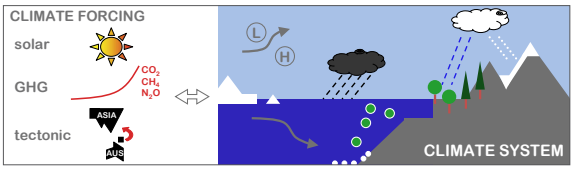

Figure 1 | Components of the climate system and forcing mechanisms considered by the Ocean Circulation group.

Simulating the Past to Understand the Future

In order to simulate past climates, the coupled atmosphere-ocean general circulation model KCM is run with boundary conditions typical for past warm periods such as the Holocene (10kyr BP - preindustrial), the Eemian (126 - 115kyr BP) and the Pliocene (5.3-2.6 Myr). The forcing of the different periods is introduced by respective changes in incoming solar radiation, tectonic setting as well as greenhouse gas concentrations in the atmosphere (Fig. 1).

Paleo Proxy Validation

In a combination of climate model results and reconstructions of Holocene Sea Surface Temperature (SST) trends, linked by modern satellite data of marine net primary production (NPP) and SST, it could be shown that systematically diverging trends achieved by the two most commonly used paleo proxies for SST (UK'37 alkenone method and Mg/Ca isotope ratios) can be reconciled by a difference in the seasonal signals that are preferentially recorded by the respective proxy organisms (Schneider et al., in press). Accordingly, alkenones measured from marine phytoplankton organisms are representing the warm (cold) season in high (low) latitudes (Fig. 2). The zooplankton-based Mg/Ca data may also carry a seasonal signal, but the spatial pattern is less clear. Based on these findings the reconstruction of past climate trends can actually go beyond the explanation of annual mean climate conditions and resolve the evolution of internal climate variability, such as the seasonal cycle.

El Niño Southern Oscillation

Paleo climate simulations of the Holocene and the Eemian have shown that the variability of El Niño Southern Oscillation (ENSO) is stronlgy controlled by the mean climate state of the Eastern Equatorial Pacific (EEP). A larger ENSO amplitude is found with (1) overall increasing SSTs, (2) a higher east-west SST gradient, and (3) a larger seasonal SST amplitude in the EEP. These findings have implications for the prediction of the future development of ENSO, which accordingly is expected to increase in amplitude rather than frequency (Salau et al., in prep.).

Asian Monsoon

An insolation-induced intensification of the Asian Monsoon during the early and middle phases of both the Holocene

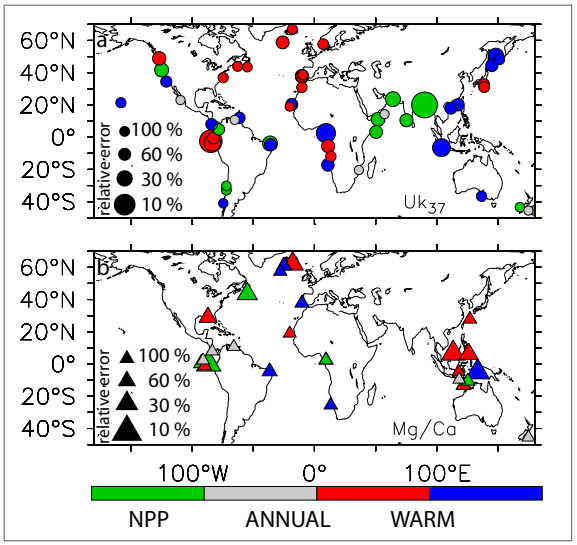

Figure 2 | Maps showing the climate signal that is preferentially recorded by the two most commonly used paleo proxies for SST: alkenones (a) and Mg/Ca (b). The color bar indicates the best match between modeled and reconstructed SST for the warmest/coldest month of the year (red/ blue), SST trends weighted by the seasonal cycle of NPP (green), or annual mean (grey) (Schneider et al., in press). The larger the symbols the better the match between proxy data and filtered model results.

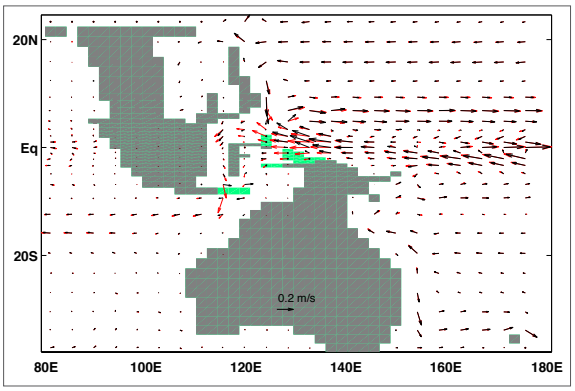

Figure 3 | Indonesian Passage modified to Pliocene conditions and resulting change in circulation at 130m depth (arrows: present = black, past = red). Grey areas depict modern land points, green areas indicate the topographic changes (removed land points) in comparison to present.

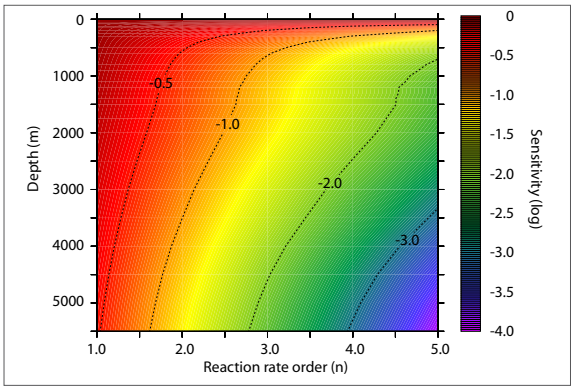

Figure 4 | Sensitivity of the calcite dissolution rate to ocean acidification as a function of the reaction rate order (n) and depth (Schneider, unpubl.).

and the Eemian can be fully attributed to water vapor import from the Southern Hemisphere. In contrast, in a global warming scenario based on rising atmospheric CO_2 concentrations the resulting enhanced monsoon is caused equally by moisture advection and evaporation. In a future warming climate on millennial time scales both effects are expected to act together (Khon et al., in press).

Tectonic Climate Impact

A narrowing of the Indonesian Gateway around 5Myr ago during the Pliocene has probably resulted in a reduction of throughflow and/or shift of the source region of water masses transported from the Pacific into the Indian Ocean (Fig. 3). The resulting subsurface cooling in the Indian Ocean, as diagnosed by paleo reconstructions, can be reproduced by our climate model results. A further climate response was a strong aridification of the climate of Australia (Krebs-Kanzow et al., in prep.).

Modelling the Marine Calcium Carbonate Cycle

On multi-millennial time scales the uptake and storage of anthropogenic CO_2 in the ocean will be greatly enhanced by buffering of $CaCO_3$ dissolution from the water column and marine sediments. First, to assess the vulnerability of the pelagic $CaCO_3$ cycle to ocean acidification an offline biogeochemical model PISCES is used with different formulations for $CaCO_3$ dissolution kinetics. Theoretically, depending on the description of the saturation state of sea water with respect to $CaCO_3$ the sensitivity of $CaCO_3$ dissolution to ocean acidification may vary by a factor up to 1000 (Fig. 4).

Next Steps

Climate model results from quasi-steady state (time slice) simulations will be compared with results from transient (Holocene, Eemian) simulations with different factors of orbital acceleration. Furthermore, marine biogeochemical cycling will be coupled to the atmosphere-ocean model (KCM). The impact of hydrological changes on vegetation patterns resulting from the Indonesian Gateway closure during the Pliocene will be tested with an offline vegetation model. In the BMBF-funded project BIOACID the impact of ocean acidification on the organic carbon turnover and vertical particle flux will be investigated.

The Research Group

The Ocean Circulation group has reached its full personnel strength in September 2009. Two PhD-students (one from BMBF funding) and five Postdocs (three in part-time positions) from five different countries constitute the highly interdisciplinary and international research group (Fig. 5).

Working Group

Members of the Research Group "Ocean Circulation" (from left to right): Laura Bordelon, Dr. Anke Dürkop, Dr. Uta Krebs-Kanzow, Dr. Vyacheslav Khon, Dr. Liya Jin, Stefanie Maack, Prof. Dr. Birgit Schneider, Opeyemi Salau.

Selected Publications

1 | Khon, V., I. I. Mokhov, M. Latif, V. A. Semenov and W. Park (2009): Perspectives of Northern Sea Route and Northwest Passage in the twenty-first century. *Climatic Change*, doi: 10.1007/s10584-009-9683-2.

2 | Sarnthein, M., G. Bartoli, M. Prange, A. Schmittner, B. Schneider, M. Weinelt, N. Andersen, and D. Garbe-Schönberg (2009): Mid-Pliocene shifts in ocean overturning circulation and the onset of Quaternary-style climates. *Climate of the Past*: 5: 269-283.

3 | Steinacher, M., F. Joos, T. L. Frölicher, L. Bopp, P. Cadule, S. C. Doney M. Gehlen, B. Schneider, and J. Segschneider (2009): Projected 21st century decrease in marine productivity: a multi-model analysis. *Biogesciences Discussions*, 6: 7933-7981.

Physicochemical Methods for Ocean Surface Research

The ocean surface resembles a vast chemical reactor where many heterogeneous and photochemically initiated processes occur. Moreover, the sea surface micro layer is covered by a thin film of surface active substances that is known to hinder air-water gas exchange at low wind speeds. Including fresh marine aerosols, which are also enriched with organic compounds due to their formation from surface water by bubble bursting, air-water interface processes play a decisive role for modeling the coupling between the ocean and the atmosphere. Modern optical, mostly laser based detection tools help to unravel the structure, composition, and chemical reactivity of such interfaces. Molecular level resolution combined with high detection sensitivity allows one to study ocean surface chemistry on spatial scales and in concentration ranges where interface mediated processes ultimately happen.

Optical Detection Methods for Marine Research

Recent years have seen an upturn in optical detection methods with many potential applications in environmental sciences. In this regard, the Ocean Surface Chemistry group aims to (1) identify and study heterogeneous chemical processes occurring at environmental interfaces – in particular the water-air interface – by using sensitive laser spectroscopic methods and (2) to provide modern optical detection technologies for use in marine research applications such as trace gas detection or biofilm monitoring. For example, isotope analyzers relying on ultra-sensitive cavity-ringdown absorption spectroscopy (CRDS) are used to monitor the isotopic composition of the trace gases N_2O and CO_2. Isotope signatures of these important greenhouse gases can be used to differentiate between denitrification and nitrification pathways of marine N_2O sources and, in case of CO_2, to separate the relative contributions of different processes acting on the surface ocean layer carbon budget. For the first time, a CRDS analyzer has been successfully operated aboard research vessel *Polarstern* during a cruise across the Atlantic Ocean. Unprecedented five weeks of on-line data of the isotope ratio $^{13}CO_2/^{12}CO_2$ have been obtained and are currently analyzed. Yet another project is concerned with the development of a submersible, compact, and low power consumption biofilm sensor based on fluorescence spectroscopy. In this short report, a focus is set on recent results obtained with the surface sensitive non-linear sum frequency generation spectroscopy that is used to investigate the structure, composition, and reactivity of the sea surface nanolayer.

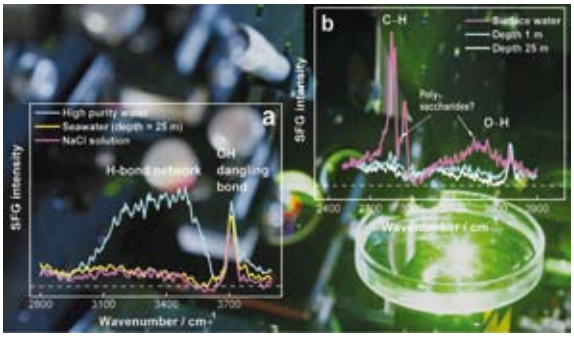

Figure 1 | Sum frequency generation spectroscopy (SFG) sheds light on organic nanolayers. Example spectra: (a) high purity water and seawater without nanolayer present, and (b) water from the Western Baltic Sea with organic nanolayer present.

Looking into the Ocean Nanolayer

The uppermost molecular layer directly at the water-air interface is called the ocean nanolayer. It is part of the sea surface microlayer representing the top 1 to 1000 µm of the ocean water column. The microlayer is enriched by organic material of biological and anthropogenic origin and is known to modulate physical, chemical, and biological processes. Actually, almost all ocean surfaces have been found to be covered by such organic layers to a variable extent. Nevertheless, detailed knowledge of nanolayer composition, dynamics, reactivity and molecular structure is scarce. The combination of sum frequency generation spectroscopy (SFG) as a surface-sensitive tool and experiments on simple model systems as well as field samples provide novel insights into the properties of these films.

SFG spectroscopy is a second-order non-linear optical technique. The superposition of two short intense laser pulses at a surface generates a third background-free SFG beam. SFG is surface specific, meaning that only molecules located directly at the interface are measured. It is species selective, because vibrational spectra are measured and also orientation selective due to the polarization dependence of the SFG signal. In a high purity water spectrum (Fig. 1a) the broad peak centered at 3300 cm^{-1} corresponds to OH vibrations of the H-bonded molecular network of interfacial water. Solvation of ions disturbs this network and results in lower SFG intensities. The narrow peak at 3700 cm^{-1} can be assigned to the stretch vibration of the free OH dangling bond at the water surface. As it is illustrated in Fig. 1b, with surfactant layers present at the air-water interface, these OH bonds are buried and disappear for higher film coverages. Next to the striking changes of the OH band shape, the organic nanolayer gives rise to strong signals in the CH stretch vibration spectral range as well. These signals can be attributed to vibrations related to CH_3 and CH_2 groups of the alkyl chains of lipids.

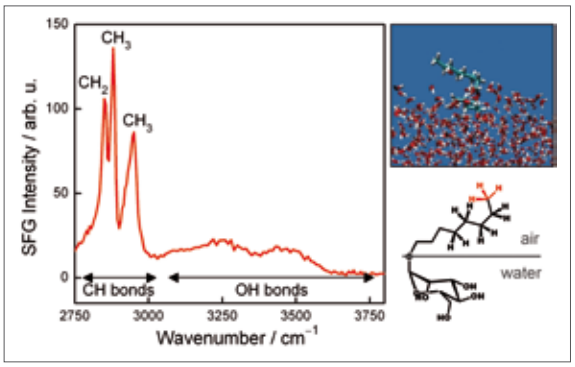

Figure 2 | Combinded SFG and molecular dynamics study of the glycolipid octylmannoside at the air-water interface. The wet surfactant yields an SFG spectrum similar to the spectra measured for natural organic nanolayers.

Carbohydrates at the Water-Air Interface

Preliminary results on surface reactivity, structure, and composition of natural marine nanolayers indicate that a large fraction of the detected surfactants resemble wet surfactants. These are partly soluble compounds that are in adsorption equilibrium with the interface. As it is known that carbohydrates constitute a large fraction of the dissolved organic matter and are prevalent in sea-borne aerosols as well, we tentatively ascribe the observed spectral patterns of the SFG spectrum shown in Fig. 1b, in particular the broad band centered around 3500 cm^{-1}, to the presence of polysaccharides, glycolipids, or confined water molecules. In order to clarify this spectral interpretation, first SFG spectra of octylmannoside, which is used as a proxy for glycolipids, have been measured. The spectrum illustrated in Fig. 2 reveals similarities with the spectrum of the marine nanolayer shown in Fig. 1b. Currently, more SFG spectra of a series of differently substituted carbohydrates are investigated in order to identify spectral trends. Moreover, molecular dynamics simulations and semi-empirical calculations assist with spectral assignments.

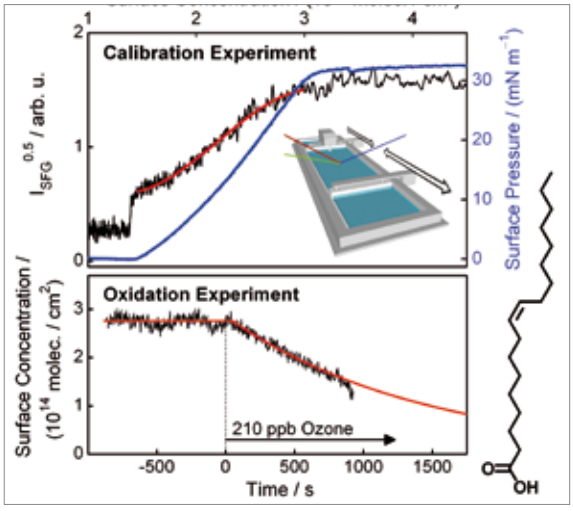

Figure 3 | Kinetic measurement of oleic acid oxidation using quantitative time-resolved SFG spectroscopy. Langmuir trough calibration signal (upper plot) and ozone oxidation experiment (lower plot).

Reactivity of Organic Monolayers

Natural organic nanolayers are subject to degradation processes driven by photolytic, chemical, and biological transformations. For example, as it was shown for aerosol aging processes, oxidation reactions convert surface-active substances into more soluble compounds. In this project, time-resolved SFG spectroscopy was established as a new method to directly measure surface oxidation of organic monolayers. The ozone oxidation of oleic acid served as a well-known benchmark system for aerosol reactivity. Presumably due to the fact that SFG signal intensity, next to surface coverage, also depends on surface order, SFG spectroscopy had not been used extensively for kinetic measurement so far. We actually solved the problem of quantitative surface coverage determination by combining a Langmuir trough setup with our SFG spectrometer. This allows us to calibrate the SFG signal intensity by slowly compressing monolayers with known surface concentrations to smaller surface areas. The SFG measurements outlined in Fig. 3 represent the first successful kinetic investigation of monolayer reactivity at the air-water interface.

Working Group

Members of the Ocean Surface Chemistry group: Kristian Laß, Gernot Friedrichs, Meike Becker, Joscha Kleber, Nancy Faßheber, Carsten Fehling, Johannes Dammeier.

Selected Publications

1 | Laß, K., Kleber, J., and Friedrichs, G. (in print): Vibrational sum-frequency generation as a probe for composition, chemical reactivity, and film formation dynamics of the sea surface nanolayer, *Limnol. Oceanogr.: Methods*, doi: 10.4319/lom.2010.8.216.

2 | Friedrichs, G., Bock, J., Temps, F., Fietzek, P., Körtzinger, A., and Wallace, D. (under revision): Towards Continuous Monitoring of Seawater $^{13}CO_2/^{12}CO_2$ Isotope Ratio and pCO_2: Performance of a Cavity Ringdown Spectrometer and Gas Matrix Effects, *Limnol. Oceanogr.: Methods*.

3 | Fehling, C. and Friedrichs, G. (in print): A Precise High-Resolution Near Infrared Continuous Wave Cavity Ringdown Spectrometer using a Fourier Transform based Wavelength Calibration; *Rev. Sci. Instrum.*, doi: 10.1063/1.3422254.

Valuing the Ocean: Economic Aspects of Ocean Fertilization

The ocean provides a number of services which are used by mankind in multiple ways, but, have not been considered systematically in economics so far. The ocean provides nutrition and health services through the biomass they produce. The ocean supplies energy in the form of renewable or non-renewable resources. Finally, the ocean constitutes an essential component of the earth system, both as an integral part of the global carbon cycle and as part of important ecosystems. The Valuing the Ocean research group evaluates the different ecosystem services provided by the ocean by integrating them into economic models. We are currently considering research questions related to the following topics: carbon management including ocean acidification, energetic and mineral resources and shipping. In the following detailed information is provided on a study related to the first topic (carbon management) investigating economic aspects related to the use of ocean fertilization to mitigate climate change.

Carbon Management

Today, most countries have accepted a 2°C temperature increase above preindustrial levels as maximum tolerable limit for global warming. An exceedance probability of below 20 percent for this limit implies an emission budget of less than 250 Gt of carbon from 2000 until 2049, of which more than one third has already been emitted by now. Extrapolating the current global CO_2 emissions this budget will only last until 2024. These numbers emphasize that all options including geo-engineering options need to be considered to mitigate climate change.

Geo-engineering options include the enhancement of natural carbon sinks to reduce atmospheric carbon concentration by removing past emissions and, thereby, extending the remaining carbon emission budget. The terrestrial carbon sink can be enhanced by means of forestation. The oceanic sink can be enhanced by means of iron fertilization. Doubts have been expressed about the potential of mitigating climate change by sink enhancement due to its partially temporary characteristics. Nevertheless, terrestrial vegetation sinks have entered the Kyoto Protocol as offsets for anthropogenic greenhouse gas emissions. So far, ocean sinks have not.

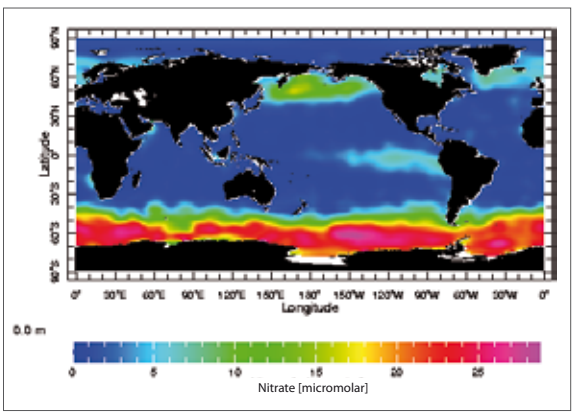

Figure 1 | Annual average nitrate concentrations in the surface waters of the oceans. Data from the Levitus World Ocean Atlas 1994. (http://www.atmosphere.mpg.de/enid/1vv.html)

The potential of ocean iron fertilization (OIF) to enhance the oceanic carbon sink is questioned in particular due to uncertain efficacy and side effects. This has led some authors to conclude that research and in particular large-scale experiments on OIF should not be further pursued. However, even courageous climate polices may run the risk that catastrophic climate change takes place, although it is expected to happen with a low probability. If this risk increases, OIF may become one of the options of last resort and needs to be explored in a timely manner. In our recent publications we have investigated how carbon credits generated by OIF could be accounted for in an international agreement on climate change (Rickels, Rehdanz and Oschlies, 2009a) and if there is an economic potential for OIF compared to terrestrial carbon sinks (Rickels, Rehdanz and Oschlies, 2009b).

Ocean Iron Fertilization

In major regions of the ocean, the Eastern Equatorial Pacific, the North Pacific, and in particular vast areas of the Southern Ocean, macro-nutrients, such as phosphate and nitrate, are present at high concentrations under conditions that would seem ideal for total depletion of these macro-nutrients by phytoplankton growth. Instead, these regions show rather low phytoplankton growth, named thereby as high nutrient low chlorophyll (HNLC) regions. Fig. 1 shows the high levels of nitrate in the HNLC regions.

Besides observational and theoretical evidence for a non-negligible carbon sequestration potential, there is also evidence for significant perturbations of marine biogeochemistry and ecology by large-scale OIF. In fact, some alteration of the function of pelagic ecosystems is the very objective of carbon sequestration by OIF. Any assessment of OIF therefore has to account for both, intended and unintended consequences including for example enhanced production of nitrous oxide (N_2O) and methane (CH_4). See Oschlies, Koeve, Rickels and Rehdanz (2010) for a recent assessment. Also, they provide new estimates of the reduction in atmospheric CO_2 (see Fig. 2).

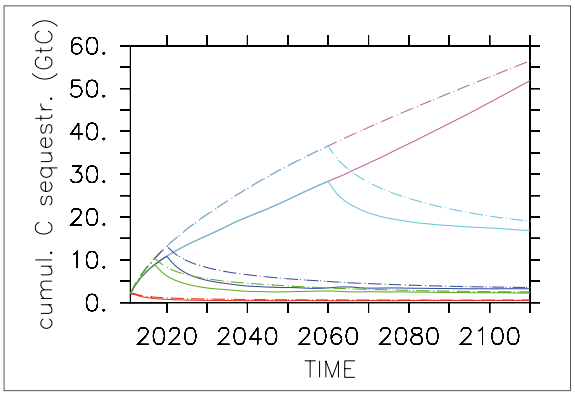

Figure 2 | Solid lines: Cumulative temporal integral of the fertilization-induced reduction in atmospheric CO_2. Dashed lines: Cumulative temporal integral of the fertilization-induced change in global air-sea flux of CO_2. Units are GtC. Colored lines refer to model fields after 1 year of OIF (red), 7 years (green), 10 years (blue), 50 years (cyan), and 100 years (magenta) of continuous OIF south of 30°S. (Oschlies, A., Koeve, W., Rehdanz, K. and W. Rickels (2010), Side Effects and Accounting Aspects of Hypothetical Large-scale Southern Ocean Iron Fertilization)

Economic Potential of Ocean Iron Fertilization

To explore the economic potential of OIF in the context of an international treaty on climate change requires first answers to the following questions: How many carbon credits are generated, how are they assigned, and can they be used for compliance? Different carbon accounting methods exist that assign carbon credits permanently or temporary. Rickels et al. (2009a) discuss all these accounting methods and apply them to OIF. The results indicate that overall, and from an economic perspective, the short-term method is most appropriate for temporary OIF. Based on this method the largest amount of carbon credits is provided at an early state. From an environmental perspective, the short-term method seems most appropriate as well as the effect of OIF is at least neutral. No additional carbon emissions will be released, because all credits have to be replaced at some point in time. As a substantial fraction of carbon is stored permanently, the method leads to net carbon reductions.

Considering the still existing uncertainty regarding costs of OIF, Rickels et al. (2009b) turn the question around and seek to determine the critical cost levels and the critical amounts for carbon credits from OIF that indicate if OIF would be competitive to forestry or clean development mechanism (CDM) activities under the Kyoto Protocol. Applying short-term OIF model experiments for the duration of 1, 5, and 7 years and two different fertilization efficiency rates we obtain critical unit costs for the upper level of between 95 to 119 USD per t CO_2 and between 22 to 23 USD per t CO_2 for the lower level. The upper level of the estimates indicates if OIF could be considered an abatement option at all compared to the current status of climate policy including existing abatement option. For the lower level it is assumed that the current limitations regarding the use of carbon credits generated in low cost countries is completely relaxed. The lower level of the estimates, therefore indicates, if OIF would be comparable to options which achieve a given emission reduction target at lowest costs. Overall, and from an economic perspective, our results indicate that OIF can be considered as an additional abatement option, but, further research, especially on adverse side effects, is needed.

Outlook

Members of the research group are involved in a number of research projects. These include for example an analysis of economic aspects related to the use of ocean pipes for mitigating climate change. Is there an economic rationale for this geoengineering option? Another area of research is directed to the ocean's potential to provide mineral resources. How can these resources be exploited optimally? How do environmental impacts influence optimal extraction policies? A third line of research addresses the issue of regulation CO_2 emissions from international shipping. How can greenhouse gas emissions of the world merchant fleet be regulated? What would the economic consequences be if these emissions were integrated into an international emission trading system? Is such an integration legally possible and politically feasible?

Working Group

From left to right: Daiju Narita, Christine Bertram, Sebastian Petrick, Katrin Rehdanz, Wilfried Rickels, Nadine Heitmann

Selected Publications

1 | Narita, D. Tol, R.S.J and D. Anthoff (2009), Damage Costs of Climate Change through Intensification of Tropical Cyclone Activities: An Application of FUND, Climate Research 39, 87-97

2 | Rickels, W., K. Rehdanz and A. Oschlies (2009a), Accounting Aspects of Ocean Iron Fertilization, Kiel Working Paper, 1572, Kiel Institute for the World Economy, Kiel.

3 | Rickels, W., K. Rehdanz and A. Oschlies (2009b), Economics Prospects of Ocean Iron Fertilization in an International Carbon Market, Kiel Working Paper, 1573, Kiel Institute for the World Economy, Kiel.

Sustainable Fisheries

Three quarters of all marine fish stocks worldwide are deemed fully exploited or overfished. The Research Group on Fisheries and Overfishing aims at developing improved management strategies that promote a sustainable fishery. For this sake true interdisciplinary research is needed, taking into account both ecological and economic processes which are integrated into ecological-economic models. In 2009, a research focus has been on how to manage age-structured fish stocks to overcome the problems of growth and recruitment overfishing.

From Overfishing to Sustainable Fisheries

The overall objective of the research group is to provide the scientific basis for a more sustainable use of ecosystem services, in particular for more sustainable fisheries. The focus is ecosystem based management of fisheries, because no efficient and sustainable use of natural resources is possible without taking the relevant processes and interactions in the marine ecosystems into account. In the group's research, the effects of the age structure of fish populations, uncertainty in fish recruitment, multi-species interactions, and spatial heterogeneity and migration of fish are studied. Conceiving strategies for more sustainable fisheries also requires an economic approach for two complementary reasons: First, economic incentives determine how resources are used in a market economy. Second, unlike ecology, economics provides sound methods to operationalize normative societal objectives such as welfare and sustainability. Both, incentives and operational normative objectives, play an important role in our research on how to design instruments and institutions for the sustainable management of fisheries (Fig. 1).

Integrating Economic and Ecological Expertise

Integrated mathematical models of the ecosystems and the economy are among the most powerful scientific methods to analyze the current management of the environment and natural resources and to develop novel management concepts that promote a sustainable fishery. Our approach is to develop such models in an interdisciplinary collaboration between economists and ecologists (Fig. 1). The focus is on generic models that retain enough structure to be applicable to realistic systems (for example, the Baltic cod fishery), but are general enough to enable insights of broad relevance. We continuously discuss research questions and results with

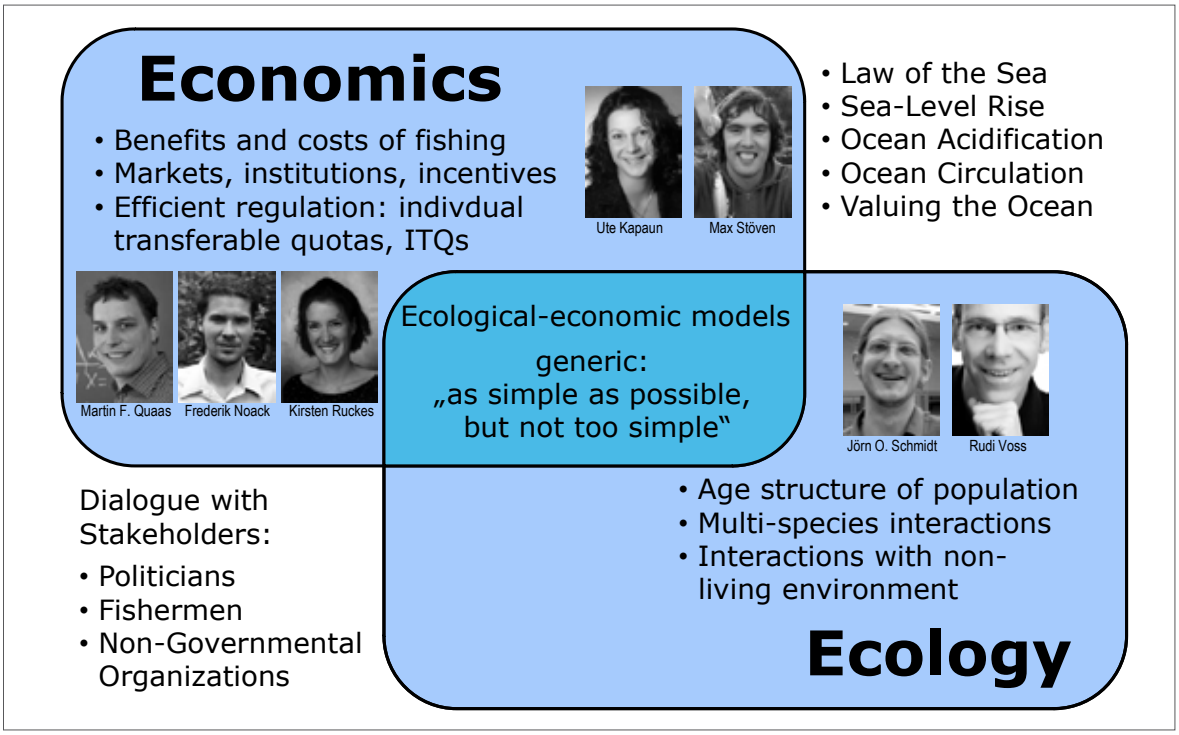

Figure 1 | Conceptual diagram on interdisciplinary ecological-economic research (M. Quaas, J. Schmidt, R. Voss).

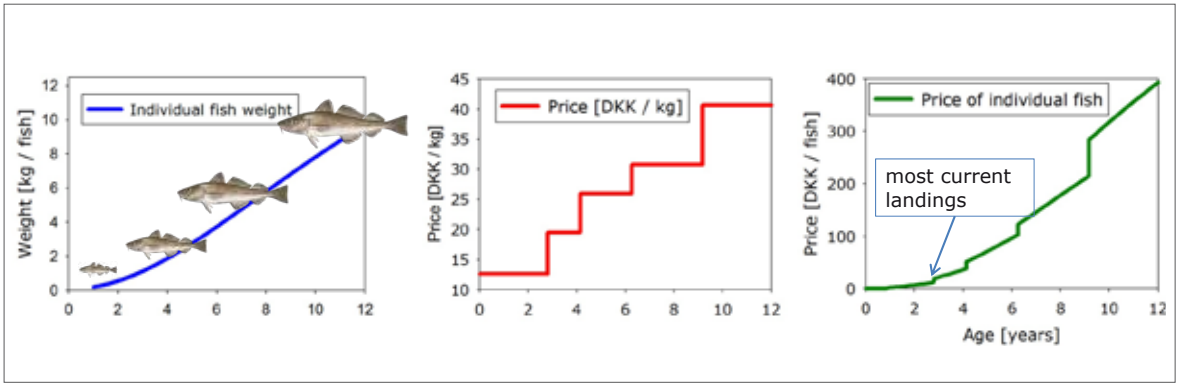

Figure 2 | Weight-at-age, value per kilogram of fish and value per individual fish as functions of age for the Baltic cod. Data are taken from ICES (2008) and from Danish fishery statistics. Ten Danish Crowns (DKK) are approximately equivalent to 1.30 Euros.

fishermen (e.g., Deutscher Fischereiverband), politicians and representatives from non-governmental organizations. This transdisciplinary dialogue with stakeholders is crucial in order to develop management strategies suitable for practical implementation.

Incentives for Optimal Management

According to a common rule, a fishery is sustainable if harvest does not exceed natural growth of the fish population. This rule is too rough. For an age-structured fish population two different processes of natural growth are relevant: recruitment, i.e. the number of offspring, and the growth of individual fish. Accordingly, recruitment overfishing means too little reproduction and growth overfishing means that fish is harvested too young and small. The example of Baltic cod (Fig. 2) shows that currently most fish is landed at an age where the value of an individual fish is low.

We have set up an ecological-economic model of an age-structured fishery and determined general conditions for the dynamically optimal fishery management using optimal control theory. Our results show that current fishery management, which limits the biomass harvested by setting a total allowable catch in tons, fails to solve the problem of growth overfishing in an efficient way. As a solution we propose a fishery management by individual tradable quotas in terms of the number of fish. With this innovative instrument fishermen would have an incentive to target fish of optimal size, thus preventing growth overfishing. We applied the generic model also to the real case study of the Baltic cod fishery (Fig. 3). Optimization of the age-structured model, using most up-to-date biological data (as provided by the international biological assessment working groups), and economic data from Danish fishery statistics yielded two major and interesting insights: (a) despite a recently increasing stock, the Baltic cod is significantly overfished (this holds true despite the considerable uncertainties indicated by the errorbars) and (b) after a transition period of few years stock as well as yield could be maintained at a much higher level than today. Thereby, a viable fishery could be generated.

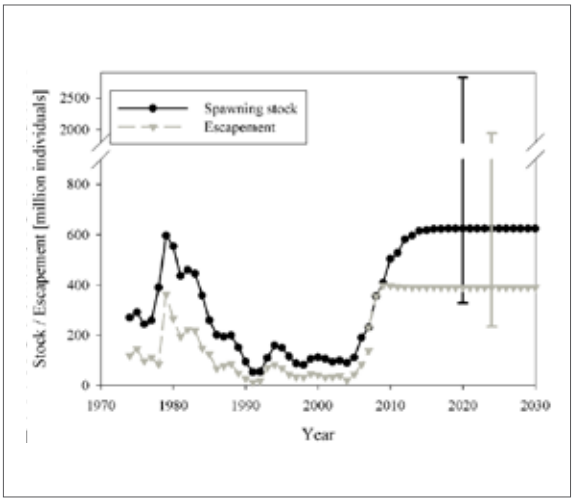

Figure 3 | Spawning stock and escapement of Eastern Baltic cod. ICES data from 1974-2007, results of numerical optimization from 2007 to 2030.

2010 and Beyond: Integrating Ecology and Economics

In 2010 we will further develop the approach of interdisciplinary collaboration between ecologists and economists to develop sensible management strategies for sustainable fisheries. In particular, we will refine the modeling of age-structured fish populations to take multi-species interactions in marine ecosystems more properly into account. Another research focus will be on the development of decentralized policy instruments, in particular the development of market mechanisms that promote sustainable resource use.

Selected Publications

1 | Schmidt, JO, van Damme, CJG, Röckmann, C, Dickey-Collas, M (2009). Recolonisation of spawning grounds in a recovering fish stock: recent changes in North Sea herring. *Scientia Marina*.

2 | Voss, R, Dickmann, M, Schmidt, JO (2009). Feeding ecology of sprat (*Sprattus sprattus L.*) and sardine (*Sardina pilchardus* W.) larvae in the German Bight, North Sea. *Oceanologia* 51(1):119-140.

3 | Baumgärtner, S and Quaas, MF (2009). Ecological-economic viability as a criterion of strong sustainability under uncertainty. *Ecological Economics* 68: 2008-2020.

Working Group

Martin Quaas, Rudi Voss, Jörn Schmidt, Ute Kapaun, Kirsten Ruckes, Frederik Noack, Max Stöven

Marine Medicine

Regulating host-microbial homeostasis at epithelial barriers is recognized as a major function of the immune system. Over the past years it has become increasingly clear that most of the genes constituting the molecular risk maps of human inflammatory diseases are of phylogenetically ancient origin. Many of the identified genes are involved in basic biological processes that evolved either at the unicellular or early multicellular level, e.g. cytoskeletal dynamics, autophagy, altered structural integrity of epithelial cells, the related secretion and composition of extracellular matrix components and primordial (innate) immune responses. These cellular programs govern the interaction between the host and the environment and are pivotal for survival. The host is in continuous contact to a microbiota-laden environment and clear evidence for a host-genetic control of the resident microflora has been presented already in basal metazoans. The main objective of the Marine Medicine group is to describe how this constant molecular cross-talk within the holobiont, i.e. the animal with all its associated microorganisms, contributes to epithelial homeostasis, immunological integrity and maintenance of the resident microbial diversity.

Background

Life in diverse environments and complex communities is coupled with the interaction of the individuals and species living within. Recognition of self and non-self and the maintenance of self-integrity are pivotal for survival and proper physiological function. The primordial challenge of the immune system at epithelial barriers is the quandary to simultaneously maintain tolerance and responsiveness to microbiota. Most, if not all epithelial surfaces of multicellular organisms contain a complex resident microflora that has not yet been fully characterized. Evidence for a host-genetic control of the epithelial colonization has been presented; however, the microflora is also shaped by environmental factors, especially during early ontogeny. The complex interaction of the intestinal tract and its associated microbiota is an archetype for physiological crosstalk between hosts and microbes in general. This homeostasis is disturbed in chronic inflammatory diseases of the gut, but a defective meta-organism (i.e. a dysbalanced host-microbiota "symbiosis") may also contribute to malignant transformation of epithelia e.g. in colorectal carcinoma or stomach cancer.

In the absence of a complex adaptive immune system, marine invertebrates rely on the innate immune system, which mediates invariant recognition of danger signals, clearance of intracellular pathogens by autophagy, the recruitment of mesoderm-derived professional immune cells and the secretion of local or circulating effector molecules such as antimicrobial peptides and simple opsonic forms of complement. As it has been shown that many of these principles are major constituents of the human genetic risk maps for inflammatory disorders at epithelial barriers (Crohn disease, ulcerative colitis, Asthma bronchiale), we focus on the following main topics:

1) To systematically understand the phylogeny, diversification and function of disease-associated genes during animal evolution and recent human history;

2) To investigate functional effects of disease-associated sequence variants in a context of epithelial barrier function and innate immunity;

3) To use non-vertebrate and vertebrate model organisms to understand interkingdom signalling networks at host/environment interfaces;

4) To develop novel tools and techniques to understand regulatory events and transcriptomal response profiles in non-model organisms using ultra-fast sequencing (gs-flx massively parallel pyrosequencing and SoliD sequencing by ligation);

5) To assess therapeutic augmentation of barrier function and epithelial drug delivery, both in marine model organisms and mammalian cells.

Genetic and functional risk maps

Over the past year, the group has contributed to genomic (gene models, regulation of expression, alternative splicing) and functional annotations for several disease genes in human chronic inflammatory barrier diseases in humans. It has also worked on basic functional concepts of host-microbiota interactions in the intestinal tract and has shown several new principles that play a role in mucosal homeostasis. These include e.g. the role of Reactive Oxygene Species (ROS) as defense molecules via NOD-like receptors (NLR) and the regulated proteolysis of epithelial growth factors by ADAM17 (Orinska et al., Blood in press and Chalaris et al., J Exp Med in press). Importantly, the group has shown for the first time that the innate immune receptor NOD2 plays an essential role for the temporal development of a stable gut flora in mice and humans. Dysbiosis is present in NOD2-deficient individuals already at a very early age and affects the temporal development of a physiological gut flora. The findings suggest that NOD2 is an integral part of a co-evolved interaction between host and intestinal and that, indeed, deficiency of a simple receptor system already present in basal metazoans may

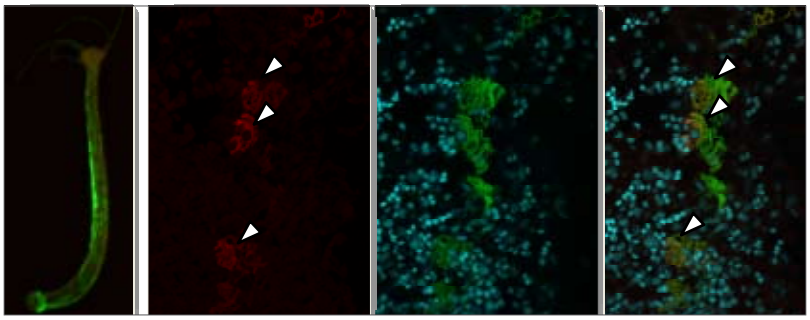

Figure 1 | Transgenic Hydra expressing a modified form of a hyNLR gene. (green depicts cells where the transgene has been stably included, red is a staining against the hyNLR, blue are nuclei)

lead to inappropriate bacterial colonization starting early in infancy (Rehmann et al., in revision).

Immune Responses in Marine Invertebrates

We have continued to describe transcriptomal defense-related cellular programs that govern host-microbe and host-environment interactions. Together with the microbiological lab led by Prof. Bosch at the Biology department in Kiel, Germany, the Marine Medicine group started to characterize the innate immune armamentarium of basal metazoans and has completed the view on the complexity of NOD-like receptors using data mining of transcriptome sequencing data sets in basal marine metazoans. It has generated transgenic Cnidaria (*Hydra* spp.) that express artificially activatable NLRs (Fig. 1) and is currently looking into cellular responses and influence of NLR activation on the residing microbiota composition. Moreover, the group has established larval cultures of sea urchin larvae (*S. droebachiensis* and *purpuratus*) and has begun to characterize transcriptomal responses to simple immune challenges (i.e. *Vibrio parahaemolyticus* infection) using deep RNA sequencing. Over the past 18 months the Marine Medicine group was involved in the implementation of several next generation sequencing projects and successfully established novel protocols for deep sequencing of RNA samples and created own tools for data analysis and visualization (Mol Ecol 2010; Schulte et al., NAR 2010; Melum et al., Hum Mut 2010).

A focus of 2009 has been the identification of immune system parameters and their response patterns in the blue mussel (*Mytilus edulis*). Having developed an inducible model of intestinal inflammation in *M. edulis*, the group has generated and analyzed 1,400,711 EST sequences with

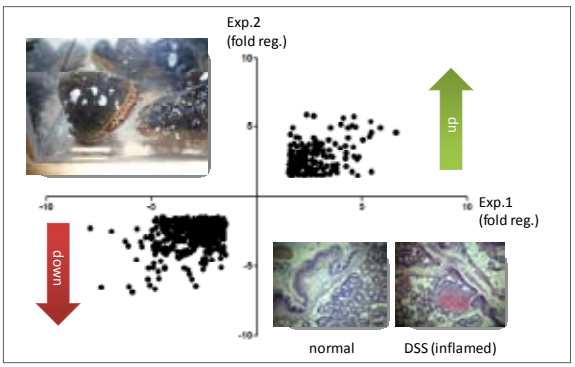

Figure 2 | xpression analysis of two independent Mytilus DSS experiments. Intestinal inflammation was induced using 4% DSS in seawater, intestinal RNA was harvested, sequenced, assembled and differential read distribution per contig was plotted as fold change on the x- and y axes representing the two experiments.

an average length of 230bp from 3.5 454-runs representing different stress and inflammatory conditions. The sequences were assembled into 61.239 transcript contigs (average length 461bp). A data mining tool was developed and it was possible to systematically describe the network of innate immune genes in this species. Currently, the Marine Medicine group is using these data sets to understand gene regulatory networks in *Mytilus hemocytes* upon stimulation with different bacterial molecular structures *in vitro* and in animals under inflammatory stress conditions (infection and DSS colitis) *in vivo* (Fig. 2).

2010 and Beyond

With current advances in genomic technologies it becomes feasible to expand the investigations on two levels: 1) Although several hurdles of de novo genome assembly and annotation exist, it will become possible to sequence complete individual genomes and to use this information for a deeper understanding of the molecular basis of genome dynamics in response to selective pressures. This will be especially interesting in cosmopolitan marine species (e.g. *Aurelia aurita, Mytilus spp., Mnemiopsis, Thalassiosira*). The projects are performed in close cooperation with partners from the Future Ocean (Bosch, LaRoche, Reusch, Schmitz-Streit and Melzner). 2) RNA sequencing allows us to move transcriptomal profiling to the single cell level. Thus, we cannot only determine net effects of complex tissues, but also pinpoint identities and unique functions of sorted individual cells. Using these methods together with transgenic green fluorescent protein (GFP) labelling, we are currently addressing the question of individual epithelial stem cell signatures and how host-microbe interactions influence epithelial regenerative capacity.

Selected Publications

1 | Lipinski, S, Till, A, Sina, C, Arlt, A, Grasberger, H, Schreiber, S, Rosenstiel, P. (2009) DUOX2-derived reactive oxygen species are effectors of NOD2-mediated antibacterial responses. *J Cell Sci*. 122, 3522-3530.

2 | Franke, A, et al. (2010) Genome-wide association study for ulcerative colitis identifies risk loci at 7q22 and 22q13 (IL17REL). *Nat Genet*. 42, 292-294.

3 | Chalaris, A, et al. (2010) Critical role of the disintegrin metalloprotease ADAM17 for intestinal inflammation and regeneration. *J Exp Med*. in press.

Working Group

Philip Rosenstiel, Gunnar Jacobs, Eva Philipp, Simone Lipinski, Susanne Billmann, Ulrich Klostermeier, Christina Lange, Julia Saphörster, Niels Grabe, Gunnar Husmann, Matthias Barann, Lars Krämer, Tanja Kaacksteen, Melanie Schlapkohl

Seafloor Resources

The global ocean hosts large natural resources of commercial interest. Gold, cupper, and zinc can, for example, be found in massive sulphide deposits surrounding submarine hydrothermal vent sites. Methane hydrates, a potential future energy source, are abundant in the thick sedimentary covers of continental margins. The Seafloor Resources Research group uses numerical modelling techniques to explore the geological processes controlling the formation of these natural resources and to ultimately make predictions on their global distribution and abundance.

Deep Sea Hydrothermal Systems

Deep sea hydrothermal systems, with their characteristic black-smoker vent sites, have been discovered at mid-ocean ridge segments all over the world (Fig. 1). Seawater enters the young ocean floor along fractures and fault zones, reaches and reacts with hot partially molten rocks at depth, and vents back into the ocean as a mineral rich hydrothermal fluid. The growing interest in these systems results from their relevance for many different field of geosciences: economic geologists are interested in the associated ore deposits, biologists study life in extreme environmental conditions, and marine geoscientists explore the feedback mechanisms between crustal accretion and hydrothermal flow as well as the long term chemical fluxes between the solid Earth and the global ocean. The Seafloor Resources Research Group develops new numerical models for reactive hydrothermal flow which can serve as a platform for interdisciplinary research and data integration. In 2009, we have set the focus on two aspects of hydrothermal activity: feedback mechanisms between alteration reactions and fluid flow and controls of hydrothermal convection on oceanic crust accretion.

Fluid-Rock Interaction

Chemical reactions often result in a net volume change of the reacting rock and may thereby affect bulk properties like permeability and porosity. A quantitative understanding of fluid rock interaction is therefore essential for resolving hydrothermal flow patterns in porous crustal rocks. Particularly strong feedback mechanisms between reactions and flow may exist during mantle serpentinization as this reactions leads to a significant increase in rock water content and associated reduction in porosity and permeability. To study

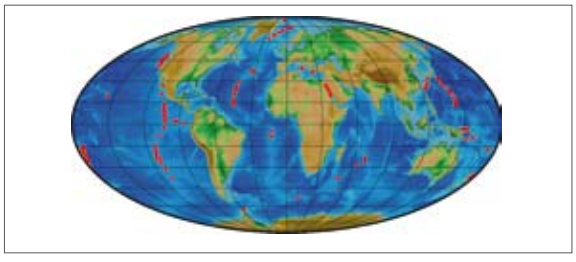

Figure 1 | Locations of known hydrothermal vent sites on the seafloor.

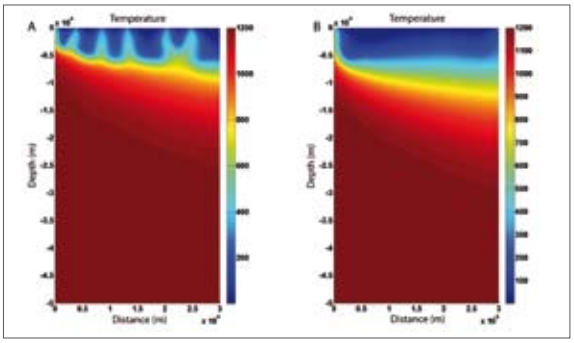

Figure 2 | Coupled simulations of hydrothermal convection and alteration reactions at mid-ocean ridges. The left panel plot shows the results for a fast-spreading and the right panel plot for a slow spreading ridge.

these relations, we have coupled a hydrothermal convection model to a reaction module for fluid rock interaction (Fig. 2). The key findings of this study are that (1) serpentininzation is a self-limiting process due to a reaction induced closure of porosity, (2) slow spreading ridges experience higher degrees of alteration and hydration than fast spreading ridges, and (3) near ridge hydrothermal convection results in an important chemical exchange between the global ocean and the seafloor. Future work in this direction will include multiphase fluid flow modelling as well as the development of new and more flexible reaction modules. These future steps will allow us to better resolve feedbacks between reactions and flow and learn more about preferential flow paths and favorable conditions for deep sea ore deposit formation.

Seafloor Spreading and Hydrothermal Cooling

The formation of new oceanic crust and hydrothermal cooling are intimately linked to each other. Mantle melting creates the primary basaltic melts that upon crystallization form the new oceanic crust. The cooling and crystallization process is largely controlled by the circulation of cold seawater through the young ocean floor. While it is clear that these feedback mechanisms exist, their resolution in numerical models remained challenging due to the different spatial and temporal scales on which the involved processes operate on. We have now, for the first time, been able to formulate an integrated model that resolves all scales by using a very efficient 2-D solver. Using this new tool, predicted melt lens locations (the depth to the 1200°C isotherm, where melts

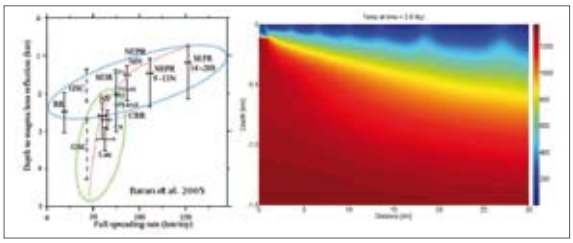

Figure 3 | Feedbacks between hydrothermal convection and crustal accretion. Observed depths of the melt lens are used to benchmark the simulations.

start to crystallize) have systematically been studied and those values have been compared to direct seismic observations (Fig. 3). It turns out that the model is very sensitive to variations in permeability, which may render it useful as a proxy for likely permeability values at ocean-spreading centres. A pilot study has, for example, shown that fast and slow spreading ridges have different permeability structures. Future work will include a better coupling between solid deformation and fluid flow, in order to explore how fluid controlled cooling affects the dynamics of ocean floor accretion.

Marine Gas Hydrates

Gas hydrates are ice-like structures, which can be found on the seafloor, in ocean sediments, and in permafrost regions. They contain gases, such as methane, that reside inside symmetrical cages of water molecules. The potentially significant amount of natural methane hydrate occurrences makes them of major interest as a potential energy resource. But methane is also a greenhouse gas with a global warming potential about 25 times higher than CO_2. It has been hypothesized that melting hydrates may have a positive feedback on global warming. In order to assess the importance of marine gas hydrates in the Earth system it is necessary to constrain their global abundance and possible reactions to global change. The Seafloor Resources group explores both aspects using newly developed reaction transport models.

In 2009 we have re-inventoried the global abundance of marine gas hydrates. For this purpose, we have compiled global data sets on sedimentation rates, total organic carbon (TOC) content of deposited sediments, bottom water salinities, bottom water temperatures, heat flow, and water depth. A multi-1-D model solving for hydrate formation as a consequence of POC degradation was then used to compute the likely global distribution of gas hydrates (Fig. 4). Two scenarios have been explored, a high and a low sedimentation rate scenario. For these two scenarios we find 4.2 Gt and 1876 Gt of methane carbon locked up in marine gas hydrates. According to the low sedimentation scenario there is no significant formation of gas hydrate deposits from organic matter decomposition at present. The high sedimentation scenario is representative for hydrates formed mainly in the past when higher rates of sedimentation provided significant hydrate formation.

The Arctic has considerably warmed over the past decades. This warming may result in rising bottom water temperatures causing widespread hydrate melting. In a joint study between the Seafloor Warming Research Group and IFM-GEOMAR's Theory & Modelling experts, we are currently exploring how marine gas hydrates are reacting to global warming. Two key aspects of hydrate melting in the Arctic are currently explored: regional ocean acidification and global atmospheric warming. This interdisciplinary work on the interface between the global ocean and the solid earth will become one of the future focus points in the Seafloor Resources group.

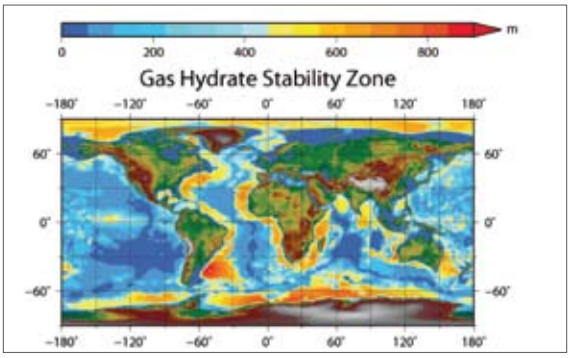

Figure 4 | Predicted present day gas hydrate stability zone thicknesses.

Working Group

Sonja Theißen, Karthik Iyer, Volker Schenck, Dominique Lattard, Kaj Hoernle, Francoise Boudier, Lars Rüpke, Larry Cathles, Adolphe Nicolas (photographer)
missing: Ewa Burwicz, Nasser Bani Hassan, Christine Andersen and Jörg Hasenclever

Selected Publications

1 | Theissen, S. and Rüpke, L. H. (2009): Feedbacks of sedimentation on crustal heat flow new insights from the Vøring Basin, Norwegian Sea. *Basin Research*, doi:10.1111/j.1365-2117.2009.00437.x.

2 | John T., Medvedev S., Rüpke LH, Andersen TB., Podladchikov YY., Austrheim H. (2009): Generation of intermediate-depth earthquakes by self-localizing thermal runaway. *Nature Geoscience*, doi:10.1038/ngeo419

3 | Iyer K. and Podladchikov Y.Y. (2009): Transformation-induced jointing as a gauge for interfacial slip and rock strength. *Earth and Planetary Science Letters*, 280, 159-166. Sci 65(9): 1361-1377.

Submarine Hazards at Continental Margins

Earthquakes, submarine slope failures, and resulting tsunamis pose a major threat to coastal communities, which are home to over sixty percent of mankind and location of a large proportion of major industrial installations, including increasingly offshore installations. Scientists involved in this project focused their activities in the following two themes: (1) Assessment of the link between the structure and dynamics of subduction zones and the megaearthquake cycle, (2) Slope stability issues at continental margins.

The main emphasis of the Submarine Hazards research group at continental margins is the analysis of submarine slope failures and associated hazards. Submarine slides are able to destroy offshore infrastructure (e.g., cables, pipelines, and platforms) and generate tsunamis. It is also discussed whether submarine slides can release large amounts of greenhouse gases bound in hydrates by the removal and liquefaction of the involved sediment. Today, the importance of submarine slope failure processes rises with increasing infrastructure on the sea-floor and near the coasts.

The global distribution of major slides and the main working areas of the research group are shown on Fig. 1. So far numerous slides in different tectonic settings including active and passive margins have been investigated, as well as lakes by means of hydroacoustic, seismic, sedimentological and geotechnical methods. This report will focus on first results of the multidisciplinary expedition M78/3 with RV *Meteor* off Uruguay/Northern Argentina and on slope stability in the Arctic Ocean.

Sediment Dynamics off Uruguay and Argentina

The continental margin off Uruguay and Northern Argentina is characterized by a high amount of fluvial input by the Rio de la Plata river in a highly dynamic oceanographic regime. Cold Antarctic water masses of the northward flowing Malvinas current meet warm water masses of the southward flowing Brazil current. Sediments deposited on the slope are relatively unstable due to high water contents and high sediment accumulation rates.

The seagoing expedition *RV Meteor* Cruise M78/3 in May-July

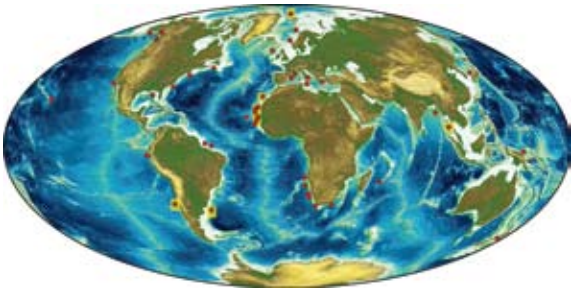

Figure 1 | Map showing the distribution of major slides along the continental margins. Note that the distribution of slides is biased by the availability of data. The yellow boxes show the main working areas of JRG B4.

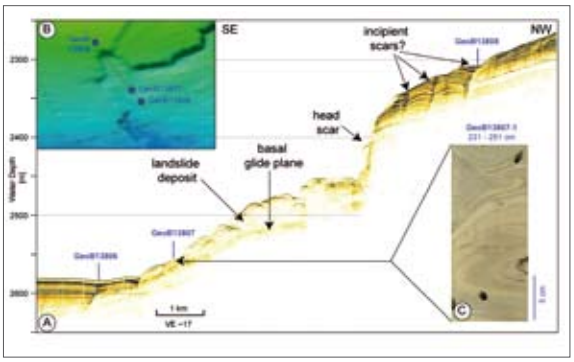

Figure 2 | Sediment echo sounder data crossing a small amphitheater like incision at the continental margin off Uruguay. The incision is interpreted as landslide scarp. Landslide deposits are imaged as chaotic to transparent facies beneath the headwall. Small faults above the headwall are interpreted as possible incipient scarps. B: Location of profile crossing the amphitheater like incision. Locations of cores are shown as blue dots. C: Core photograph of core GeoB13807 from 231-251 cm depth below the sea floor showing debrite deposits with internal deformation and rotational fold structures.

2009 aimed at investigating the interaction processes of sediment redistribution, partitioning, deposition and diagenesis from the coast to the deep-sea along the western South-Atlantic passive continental margin. The shelf, slope and rise offshore Argentina and Uruguay have been investigated by means of hydroacoustic and seismic mapping as well as geological sampling.

Various types of sediment instabilities have been imaged in geophysical and core data, documenting particularly the continental slope offshore Uruguay to be locus of frequent submarine landslides (Fig. 2). Apart from individual landslides, however, gravitational downslope sediment transport along the continental slope is restricted to the prominent Mar del Plata Canyon and possibly to smaller canyons indentified in bathymetric data. The location of the canyons seemed to be controlled by tectonics. In contrast, many morphological features, like progradational terraces and slope parallel scarps with scour-geometries, reveal that sediment transport is predominantly controlled by strong contour bottom currents. This suggests a significant impact of the western boundary currents on the overall architectural evolution of the margin.

Future studies using the acquired geophysical, sedimentological, physical property and geochemical data will (1) quantify the relative contribution of gravitational down-slope

vs. along-slope processes through time in shaping this ocean margin and how it relates to the global ocean circulation pattern and sea-level change through time, (2) investigate depositional and post-depositional processes and how they control submarine slope stability and submarine landslide initiation and (3) explore the interaction and relative contribution of the various processes in controlling margin evolution, sediment dynamics and geohazard off Uruguay and Northern Argentina.

Slope Stability in the Arctic Ocean

The Hinlopen/Yermak Megaslide (HYM) is one of the largest known submarine landslides. It occurred on the passive continental margin facing the Arctic Ocean north of Svalbard 30 kyr ago. One of its main characteristics is the exceptional headwall height of up to 1600 m. The slide removed large parts of the Hinlopen Trough Moth Fan (TMF) in a single catastrophic event. The HYM developed as a translational submarine slide and transformed into a debris avalanche with large blocks reaching dimensions of 2.5 x 5 x 0.45 km^3. The avalanche moved into the semi-enclosed Sophia Basin. From there, the avalanche had to funnel out into the Nansen Basin which led to further disintegration and transport as debris flow. Minor failures followed the megaslide as a consequence of the retrogressive developments of the upper headwalls.

The partial removal of the Hinlopen TMF challenges the stability of the adjacent sediments of the eastern continental slope that have been undercut by the megaslide (see map in Fig. 3 for location of the slope). Our investigations of seismic reflection, hydro-acoustic and sediment core data show that large parts of the slope deform along detachments; extensional listric faulting causes block rotation and further ductile deformation of the involved sediments. The overall inclination of the upper slope increases due to this deformation and stimulates creeping of shallow sediments. Staircase structures and morphological bulges in the bathymetric data (slope map of Fig. 3) are shallow expressions of this deep deformation.

The timing of this deformation is difficult to assess. Distinct reflectors within the undisturbed sediments of the Sophia Basin image terrigenous input events (TIEs). They can be used for acoustic stratigraphy in the area and allow a correlation to undisturbed reflectors below the shallowest deformed (creeping) sediments. This correlation to the well-dated TIEs indicates to a post-megaslide timing of the deformation.

The detachments (lower part in Fig. 3) are interpreted to be formed as a consequence of the megaslide. Thus, the identified staircase structures in association with listric faulting and detachments are interpreted as precursor for future slope failure at this part of the continental margin. Seismic acceleration may turn the slow slope failure (creeping along detachments) into a fast one (e.g. sliding along glide planes).

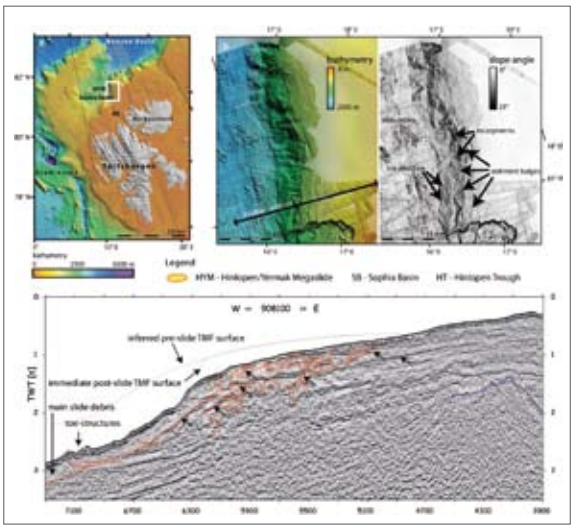

Figure 3 | Upper left: Location of the Hinlopen/Yermak Megaslide north of Svalbard. Upper right: Slope angle map (upper right) displaying creeping sediments with numerous escarpments, small-scale failures and canyons on the slope adjacent to the removed Hinlopen Trough Mouth Fan (combined data set of AWI and University of Tromsö). Bottom: Seismic reflection profile (data of the Norwegian Petroleum Directorate) across the adjacent eastern continental slope, imaging down-slope sediment transport along detachments (arrows), as well as inferred pre-slide and immediate post-slide morphology.

Working Group

Andrea Anasetti, Maxlimer Vallee, Mathias Meyer, Stephanie Koch, Prof. Dr. Sebastian Krastel, Katja Lindhorst, Dr. Daniel Winkelmann, Julia Schwab, Mathias Grün. Missing: Dr. Deniz Çukur.

Selected Publications

1 | Strozyk, F., Huhn. K., Strasser. M., Krastel. S., Kock. I., Kopf. A., 2009. New evidence for mass wasting at the NE Cretan slope: a multi-stage slide complex from the eastern Mediterranean. *Marine Geology*, 263, 97-107.

2 | Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S.O., Ülgen, U.B., Niessen, F. (2009) Lake Van Drilling Project 'PALEOVAN', International Continental Scientific Drilling Program (ICDP): Results of a recent pre-site survey and perspectives. *Quaternary Science Reviews*, 28, 1555-1567.

3 | Winkelmann, D., Geissler, W., Stein, R., Niessen, F. (in print). Post-Megaslide Slope Stability north of Svalbard, Arctic Ocean. In: Mosher, D.C., Shipp, C., Moscardelli, L., Chaytor, C., Lee, H., and Urgeles, R. (eds.): Submarine Mass Movements and Their Consequences IV, Advances in Natural and Technological Hazard Research, Springer-Verlag Berlin-Heidelberg-New York, 279-287.

Sea Bottom Interaction in Coastal Areas and River Mouth Systems

The Sea-level Rise and Coastal Erosion group focuses on rapid physical and morphological changes at those coasts of the world, which are severely under stress due to natural and anthropogenic impacts, in particular river mouth systems. Reliable prognoses of future coastal development must be based on a fundamental knowledge of the complex interrelated and interacting coastal processes. The understanding of these processes is lacking for many coastal hotspots. Modern measuring techniques with high temporal and spatial resolution are used to fill the gaps in current data sets and to improve our understanding of coastal processes.

Background Information

Coasts are not only highly diverse and dynamic geological elements on earth, most of them are densely populated, especially river mouth systems. Sea-level variations, changes of storm intensity and duration and above all, manmade interferences force many coasts to adapt in an unintentional way. Often consequences such as flooding, erosion, decrease in water quality, or habitat change arise. Thus, comprehensive knowledge on coastal development and dynamics is needed to react on coastal changes and to provide reliable prognoses to fulfill high-quality coastal zone protection and management. Prerequisite is a detailed understanding of natural and anthropogenic influenced coastal processes, which act on various time scales, spanning seconds to thousands of years, and spatial scales ranging from centimeters to hundreds of kilometers. It is most challenging to resolve these processes, especially the highly diverse, physical and sediment related interactions at the interfaces land - sea, water column - seafloor, and freshwater - seawater. A multi-methodical approach with modern, high sophisticated measuring techniques is used in this group to specify these interactions in a qualitative and quantitative way.

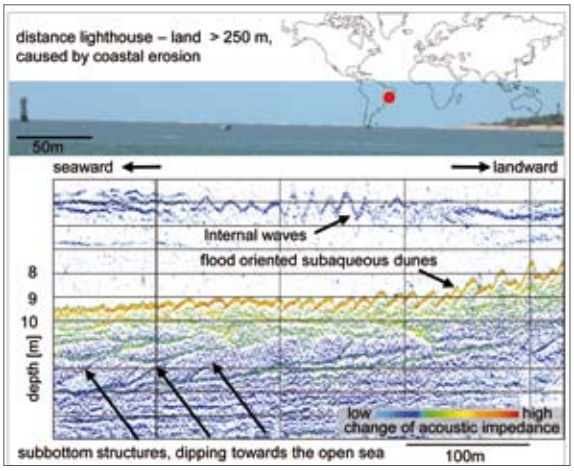

Figure 1 | a) Coastal retreat at the São Francisco River mouth (Northern Brazil) indicated by a lighthouse, which was originally located on land. b) Longitudinally aligned acoustic profile of the riverbed near the mouth, showing flood-oriented subaqueous dunes on top of seaward dipping subbottom sediment structures. Internal waves in the water column reflecting interaction of different water layers.

Loss of Deltas Due to Water Damming

Many rivers are dammed to serve the growing demand on freshwater for domestic and industrial use. This reduces discharge and related sediment transport to adjacent coastal regions. Severe coastal retreat and a systems adaptation from deltaic to estuarine conditions often occur. These effects are prominent at the São Francisco River (Northern Brazil), facing retreat rates of ~25 m per year (Fig. 1a). Field data from 2009, which were collected in the frame of an international research program, support the hypothesis of an estuarine development (Fig. 1b). This can be exemplarily shown by acoustic data, representing the sedimentary construction of the riverbed as well as internal structuring of the water column (Fig. 1b). Sediment layers of the lower sub-bottom tend to dip towards the open sea. They reflect former deltaic conditions with seaward directed sediment transport. Flood-oriented bedforms, forming the actual riverbed, indicate a pronounced tidal induced water inflow (Fig. 1b). Internal waves, generated at the boundary of different water masses also document a pronounced saltwater intrusion into the estuary up to 7 km. Significant ecological and economical consequences can now be predicted.

Anthropogenic Impact in Tidal Estuaries

Ship-based cargo transport increases worldwide, harbor sites, in particular at river mouth systems expand. Thus, most navigation channels need further deepening and intensive maintenance, e.g. by dredging, to guarantee vessel access. This has economical and ecological side-effects due to the disturbance of the natural sediment dynamics. The German estuary Ems is a perfect example for a tremendous increase of fine-grained deposits due to channel adaptation for shipping purpose, studied in a current research project. Dredging impact is also analyzed in another joint measuring program in the Weser estuary (Germany) with participation of seven partner institutions. New results underline the advantages of the water-injection dredging technique. Estuarine research of this group is also extended by a large joint-research program 'AUFMOD', which was launched in November 2009. Funding is given by the Federal Ministry of Education and Research for eight partner institutions with co-coordination of the program in Kiel. Aim is to set-up integrated model systems for the analysis of long-term morphodynamics in

the German Bight (Germany). Focus of this group is laid on the estuaries Weser, Elbe and Ems.

Forcing Factors for the Wadden Sea

The Wadden Sea from the Netherlands to Denmark forms the largest joined tidal flat environment worldwide. The Dutch and German parts have been awarded a UNESCO world heritage area in 2009, respecting this unique ecosystem. Responding to sea-level rise and diking, the Wadden Sea seems diminishing by 'Coastal Squeeze'. Natural and anthropogenic induced hydrological, sedimentological and morphological interrelations between the sub-tidal part of the Norderhever-Heverstrom tidal basin and adjacent intertidal areas, salt marshes and holms of the North-Frisian Wadden Sea are far from being fully understood. Detailed insight is given in a newly funded research project, launched in autumn 2009, where old data sets will be compared with new records. A new laser-based particle size system is frequently used for grain-size analyses here, as exemplarily shown in figure 2 for a transect in the southern part of the area, reflecting a seaward-directed change in particle-size distribution.

Coarse-Grained Sediment Transport

Severe coastal retreat of many soft-rock cliff-coasts along the Southwestern Baltic Sea is ongoing. Under erosion, fine grains are easily removed, whereas pebbles, cobbles and boulders (residual sediments) seem to be left at place for longer time. Beach ridges of adjacent coastal lowlands, which play an important role as shore-protection elements, are mainly composed of coarse-grained sediments. It is assumed that they are delivered from the cliffs and the seafloor. Sediment transport pathways and -speed are now studied for better prediction of coastal development. For the first time, detailed mappings of the complete foreshore were done in 2009, using new, small-scaled side-scan sonar. Spatial sediment distribution is exemplarily shown in figure 2a. Interpretation of large-scaled sediment transport is combined with tracer experiments. Metal coated, color-coded and labeled tracers also equipped with acoustic micro-transmitters indicate storm-induced transport (Fig. 3c-e). This program is supported by scientific scuba divers of the Research Diving Centre of Kiel University, managed by the head of this group since 2009.

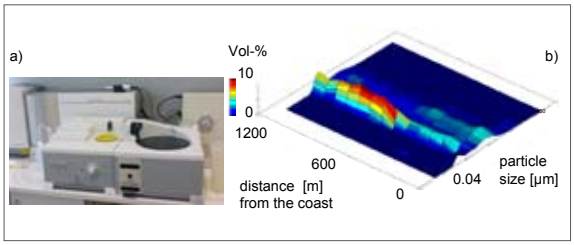

Figure 2: a) LS13320 - Beckman Coulter Laser for highly resolved grain-size analyses. b) Seaward directed change of particle-size distribution of surface sediments over one transect at the North-Frisian coast.

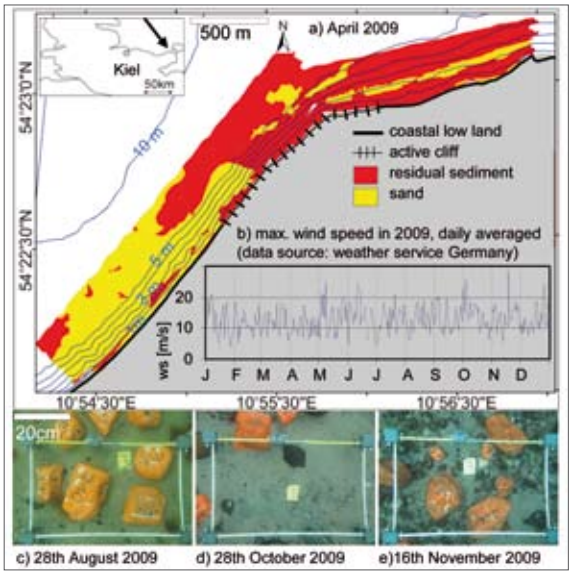

Figure 3 | a) Map of the spatial distribution of surface sediments in the fore-shore of Heiligenhafen (Baltic Sea) in April 2009, based on acoustic data. b) Daily averaged, maximum wind speed in 2009, recorded at the island Fehmarn. c) Seabed in front of the active cliff, in ~2 m water depth. Tracers were laid out in August 2009. d) Original position had changed in October and e) in November 2009, indicating coarse-grained sediment transport.

Working Group

Rik Tjallingii, Andreas Jacobsen, Henning May, Kerstin Schrottke, Svenja Papenmeier, Christian Schiffer, Sarah Ohlemacher

Selected Publications

1 | May, H., Schrottke, K., Schwarzer, K.: Coarse-grained sediment distribution in shallow water of the south-western Baltic Sea (Germany). *Coastline Report*, in press.

2 | Papenmeier, S., Schrottke, K., Bartholomä, A., Steege, V.: Controlling impact of water injection dredging of subaqueous dunes fields in the lower Weser, based on hydro-acoustics, optics and laser-optical measurements. German Soc. of Limn. (DGL), ext. proceedings, annual conference, 28 September - 11; 2 October 2009 (Oldenburg).

3 | Papenmeier, S., Schrottke, K., Bartholomä, A.: Total volume concentration and size distribution of suspended matter at sites affected by water injection dredging of subaqueous dunes in the German Weser Estuary. - *Coastline Report*, in press.

Risk Assessment in the Coastal Zone

Climate induced sea-level rise (SLR) is expected to exacerbate the impacts of existing natural and anthropogenic pressures in the coastal zones. The Coastal Risks and Sea-Level Rise research group examines the risks arising from the coupling of SLR and existing coastal stresses and assesses their potential impacts. The group considers human response, in the context of adaptation, as a defining factor for evaluating future impacts and incorporates it in its analyses. Ongoing work investigates different coastal processes at a range of spatial and temporal scales, aiming to provide input for policy and management support concerning issues that coastal regions will be facing in the forthcoming years due to accelerated SLR and increasing human pressure.

Global to Regional Scale – The DIVA Model

The Dynamic and Interactive Vulnerability Assessment (DIVA) model is an integrated model of coastal systems that assesses biophysical and socio-economic impacts of sea-level rise and socio-economic development. An innovative aspect of DIVA is that adaptation options are explicitly incorporated in the model. Therefore, estimated impacts do not only depend on the selected climatic and socio-economic scenarios but also on selected adaptation strategies. Work in 2009 focused on the further development of the model and of the global spatial database that underpins DIVA, as well on a range of applications for different regions of the world. Examples include the application of DIVA for the Coral Triangle region and for the European Union (EU27). Results for the Coral Triangle indicate that SLR will significantly impact coastal populations and habitats; however these impacts will vary considerably across the region. Indonesia will be most affected in terms of coastal flooding (Fig. 1) and wetland loss. Meanwhile, damage costs are dramatically reduced when adaptation is considered. Results for the EU27 show that, in the first half of the century, impacts are driven by socio-economic development whereas the consequences of SLR become significant only after 2050. The largest part of total monetary damage will be due to floods. However, adaptation reduces the number of people flooded annually by a factor of 200 and costs by a factor of 9. These results suggest that adaptation measures to SLR are beneficial and affordable and will be widely applied throughout the EU.

Local Scale – Shipping Effects in Venice Lagoon

Maritime transportation of goods and raw products has increased rapidly over the last two decades and continues to expand each year posing great environmental challenges to the coastal zone. One impact of navigation is the interaction between ship wakes and sediment resuspension. Vessel wakes create high near bottom current velocities leading to high sediment shear stress and eventually sediment resuspension and erosion of beaches and salt marshes. Frequent passage of vessel-induced wakes will erode sediments, increase turbidity, and may disturb fisheries, especially if the larvae of juvenile fish communities are found in the shoals. The group has completed a project studying the effect of ship wakes on sediment resuspension in Venice Lagoon, Italy. During two sampling campaigns the group utilized a suite of instruments to simultaneously measure water depth, water velocity and turbidity, while receiving vessel navigation data. Resuspension events were directly linked to the ship waves recorded by the sensors (Fig. 2). Sediment resuspension was found to be related to the ship's Bernoulli wake. The size of the Bernoulli wake is dependent upon the size and speed of the vessel as well as the tidal water level. An algorithm relating these parameters to resuspension was developed and a threshold was found, below which important resuspension events do not occur. If vessels navigate below this threshold, it will greatly reduce turbidity and the ongoing erosion of shoals and associated contaminant remobilization in Venice Lagoon. Adhering to this condition will

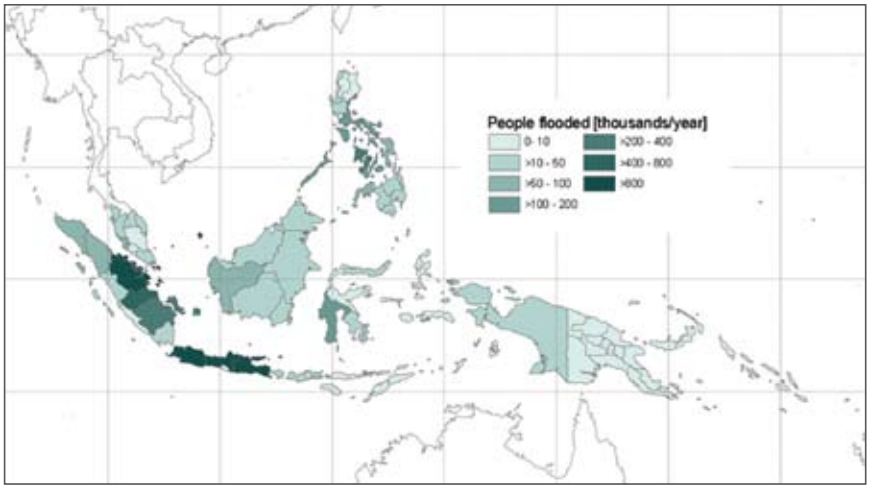

Figure 1 | Number of people flooded annually in 2100 under the A2 scenario without adaptation

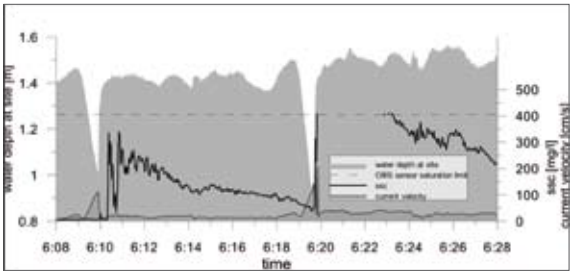

Figure 2 | Depth, SSC, and water velocity as recorded by the S4 instrument after the passages of two vessels within 10 minutes of each other on 8 July, 2009.

increase the average navigation time of vessels by 15%; a small price to pay to protect the lagoon ecosystem. This is by no means unique to Venice Lagoon; similar issues are likely affecting ports around the world. Increased understanding of shipping-induced sediment resuspension will serve to greatly reduce harmful environmental effects of the shipping industry.

Local Scale - Salt Marshes in the Wadden Sea

There are about 12,200 ha of salt marsh within the Schleswig-Holstein Wadden Sea. Due to their natural location at the interface between sea and land, salt marshes are among the most vulnerable coastal ecological systems. Our aim is to investigate the effects of climate change, especially sea-level rise and changes in storminess, on the ability of salt marshes to survive. Salt marshes naturally keep pace with sea-level rise due to high sedimentation rates, yet their survival is dependent on how sedimentation rates will evolve in the future. Work in 2009 concentrated on measuring the historical sedimentation rates of two marshes on the islands of Sylt and Föhr. ^{210}Pb and ^{137}Cs isotope activities were analyzed in order to reconstruct the historical evolution of these marshes and correlate the accretion rate with existing sea-level rise and meteorological data (Fig. 3). A process-based model is being developed, coincident with this work, in order to analyse how sedimentation will change under certain scenarios of sea level rise and changes in storm patterns. Model development is currently underway and preliminary results are expected in late 2010.

Local Scale – Adaptation of Coastal Residents

Due to the time required for climate stabilisation and the "commitment to sea-level rise", mitigation alone will not suffice in order to cope with the adverse effects of climate change in coastal regions. There is an explicit need for adaptation at the national level as well as at the individual level. The aim of this research is to identify which factors influence actual adaptation and the adaptation intention of residents living in high-risk areas. For this purpose, a questionnaire survey was conducted in six areas in Germany and Denmark which are below 5 m above mean sea level, and protected by dikes. Analysis is currently underway and results are expected to provide insights regarding the representation of adaptation in impact models.

Outlook

Current work on assessing the impacts of accelerated SLR and human-induced pressures in the coastal zone will continue in 2011. Multi-scale, multi-risk assessments will enable us to gain further insights in the vulnerability of coastal zones, with the aim to develop operational tools that will provide answers for management and policy questions to be addressed in the forthcoming years. Such questions will include the extent of SLR-related impacts, the feasibility and effectiveness of different adaptation options (e.g. protection, retreat, accommodation) and the optimal utilization of the coastal zone by humans.

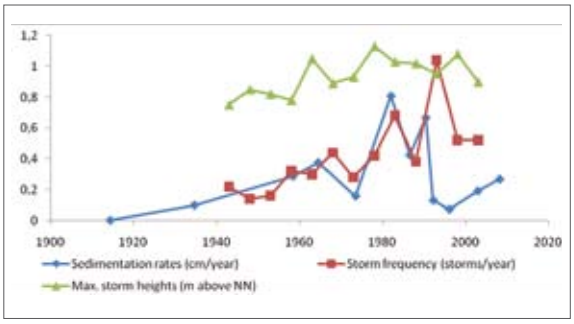

Figure 3 | Time series of measured sedimentation rates (on Sylt) and historical storm data for the islands of Wittdün on Amrum located close to the Sylt marsh site

Working Group

Daniela Arp, Morgan Gelinas, Nassos Vafeidis, Michal Lichter, Mark Schürch, Tina Geisler, John Rapaglia
Missing: Jana Koerth, Eva Papaioannou, Juliane Zimmermann

Selected Publications

1 | Rapaglia, J.P. and Bokuniewicz, H.J. (2009). The effect of groundwater advection on salinity in pore waters of permeable sediments. *Limnology and Oceanography*, Vol. 54 (2), pp. 630-643.

2 | McLeod, E., Hinkel, J., Vafeidis, A.T., Nicholls, R.J., Harvey, N. and R. Salm (in Print). Sea-level rise vulnerability in the countries of the Coral Triangle. Sustainability Science.

3 | Klein, M. and Lichter, M. (2009). Statistical analysis of recent Mediterranean sea-level data. *Geomorphology*, Vol. 107 (1-2), pp. 3-9.

International Law of the Sea

Any determination whether and under what circumstances ocean activities can be undertaken, be it the carrying out of marine scientific research, fishing, shipping, the exploitation of resources, laying pipelines or cables on the seafloor or even the environmental protection of the ocean itself, requires a detailed examination of the legal issues linked to these activities. The legal framework within which such a determination can be made is provided by the international law of the sea, which constitutes one of the oldest and most practically relevant areas of public international law. The research group on The International Law of the Sea comprehensively analyzes the existing legal framework in light of current challenges deriving from climate change, increasing energy resource scarcity and the increased exploitation of the seas.

A Realistic and Comprehensive Approach

Since its inception, the research group on The International Law of the Sea has followed a „realistic" approach to investigating and answering legal questions concerning the law of the sea. This approach is based on the premise that attention should first of all be directed at the existing law before asking what international law should say, i.e. that an identification of the pertinent legal rules and their interpretation based on a stringent application of the accepted methods of interpretation should first be carried out before speculating as to further possibilities for development or change. By so doing, the research group aims to further the international understanding of existing norms, thereby highlighting those areas where there is a genuine need for reform. This approach takes as its starting point the provisions of the United Nations Convention on the Law of the Sea of 1982 (UNCLOS). Based on the regulatory requirements contained therein, the group comprehensively examines the legality of individual ocean activities against the prerequisites of the concept of sustainability. In order to further this aim, the research group continues to collaborate closely with other groups within the Future Ocean. For instance, aspects of marine biology (current status of European fish stocks; determination of maximum sustainable yield) played a central role in a recent evaluation of the effectiveness of the international and European law of fisheries (Froese and Proelss, 2010). The members of the research group on The International Law of the Sea also participated in a working group on the future common fisheries policy of the European Union (EU), which included stakeholders from all relevant branches, and which submitted a comment to the European Commission´s green paper „Reform of the Common Fisheries Policy". The same is true with regard to almost all other ocean activities: Whether or not a certain activity (such as, e.g., storage of CO_2 below the seabed) may lawfully be undertaken in light of a risk assessment based on the precautionary principle depends on an in-depth analysis of the probability and gravity of the dangers which might result from the activity concerned. The need for such multidisciplinary approaches is reflected in the involvement of the group in the project Sub-seabed CO_2 Storage: Impact on Marine Ecosystems (ECO_2), which was submitted under the European Union's Framework Program 7 (EU FP7) cross thematic call on The Ocean of Tomorrow, and which sets out to assess the risks associated with storage of CO_2 below the seabed.

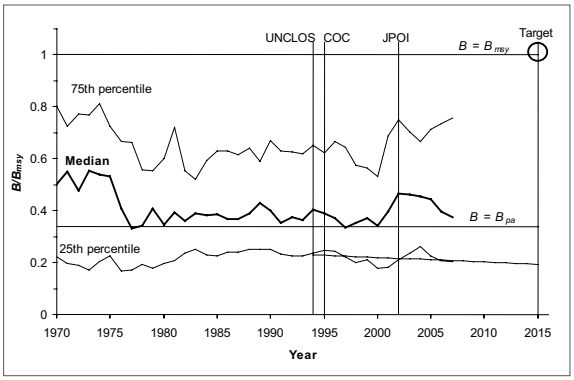

Figure 1 | Time series of stock biomass B relative to biomass associated with maximum sustainable yield Bmsy (Froese and Proelss, 2010). The target biomass ratio B = Bmsy which is to be reached not later than 2015 and the biomass limit B = Bpa are indicated by horizontal lines. The vertical broken lines indicate the dates of relevant international agreements, such as United Nations Convention on the Law of the Sea (UNCLOS), the Code of Conduct for Responsible Fisheries (COC), and the Johannesburg Plan of Implementation (JPOI). A dotted line extends the trend in the 25th percentile from 1994 to 2007; this line would have to meet the Target circle for compliance with JPOI.

Contacts with state authorities, non-governmental organizations and other stakeholders were further developed. In early 2009, Alexander Proelss delivered a legal opinion on the legality of iron fertilization experiments, on which the German Federal Ministry of Education and Research based its decision to approve the undertaking of the Indo-German iron fertilization experiment LOHAFEX in the Southern Atlantic Ocean. Following on from this project, the research group is engaged in a sounding-opinion from this Ministry on the legal regulation of climate engineering more generally. The researchers are continuing their cooperation with the Federal Maritime Agency on issues such as the legal regime relevant to ship emissions (legal opinion on the specifications for exhaust emissions from sea vessels under international, European and national law). They are involved in the North Sea Ballast Water Opportunity Project (sponsored by the

Interreg IVB North Sea Region Programme) as a subpartner of that Agency. Furthermore, Alexander Proelss has been requested to act as an external evaluator for the Federal Agency for Nature Conservation Working Group for the research and development of a Handbook on the National Law of Marine Conversation in the North and Baltic Seas. The research group has also delivered legal opinions concerning socio-juridical questions of the law of the sea such as an expert opinion on the legality of the extension of national labour standards to foreign supply vessels in the Exclusive Economic Zone (EEZ) under international law provided for the Norwegian Shipowners' Association.

International Cooperation

International cooperation constitutes the third pillar of the work conducted by the research group on The International Law of the Sea as evidenced by the recent appointment of Alexander Proelss as one of the two German members to the newly established Committee on Baselines under the International Law of the Sea of the International Law Association. He continues to co-organize the international law lecture series of the Walther-Schücking-Institute for International Law and has successfully nominated Prof. Bing Bing Jia of the Tsinghua University, Beijing, one of the leading scholars on the law of the sea, for a Friedrich Wilhelm Bessel Research Award of the Alexander von Humboldt-Foundation. Relevant activities also include the organization of an international symposium with well renowned speakers on The Nord Stream Pipeline: Legal, Economic and Environmental Issues which was held in February 2009 with the support of the State Parliament of Schleswig-Holstein, the Institute for East European Law of the University at Kiel, and the financial assistance of the Dräger Foundation as well as the ZEIT (Bucerius) Foundation.

Protection and Sustainable use of the Oceans

Research activities undertaken in 2009 comprised several talks and publications on, *inter alia*, the international and European law of fisheries, the fight against piracy, and the legality of ocean iron fertilization activities. In an article published in the Carbon and Climate Law Review (Marine Biodiversity and Climate Change), Alexander Proelss and Monika Krivickaite addressed the issue of the conflicts which can arise in the regulation of a specific problem by more than one international convention, in this particular instance the provisions of the Convention on Biological Diversity on the one hand and the UN Framework Convention on Climate Change on the other. The article comprehensively examined the legal parameters concerning the threat posed to marine biodiversity by global warming. It was concluded that despite the presence of overlaps in the existing legal regime, which may, in turn, lead to a conflict of treaty objectives and rules, the principles of international environmental law, such as the precautionary principle, can be used as a common denominator to find a solution to the conflict. A reading of the precautionary principle as a balancing tool would guarantee that the objectives of all the relevant legal instruments can be pursued to the greatest possible extent.

In a paper submitted in 2009, Rainer Froese and Alexander Proelss analyzed stock assessment data of all major fish stocks of the Northeast Atlantic to determine whether the EU will be able to deliver on its commitment to maintain or restore fish stocks at levels that are capable of producing maximum sustainable yield (MSY). The analysis showed that, if current fishing pressure continues, 91% of the European stocks will remain below target. If current trends continue, Europe will miss the 2015 deadline contained in the Johannesburg Plan of Implementation of 2002 by more than 30 years. It was argued that from a legal perspective, such repeated enactment of fisheries management measures, which are incapable of maintaining or restoring MSY, does not comply with the requirements contained in the UNCLOS and constitutes a breach of the precautionary principle of European Union law.

2010 and Beyond: Governing the Future Ocean

The members of the research group on The International Law of the Sea will continue to undertake research on all pertinent aspects of the law of the sea. Primary attention will be paid to a 3,000 page commentary on the UNCLOS, which will be edited by Alexander Proelss and published by C.H. Beck in collaboration with Hart Publishing in 2012. The treatise will be the first systematic, element by element analysis of the provisions of the Convention and will involve the cooperation of the majority of law of the sea experts worldwide.

Working Group

Monika Krivickaite, Petra Gnadt, Alexander Proelß, Kerstin Güssow, Ursula Blanke-Kießling, Killian O'Brien

Selected Publications

1 | Proelss, A. and M. Krivickaite (2009): Marine Biodiversity and Climate Change, *Carbon and Climate Law Review*, 4/2009, pp. 437-445.

2 | Froese, R. and A. Proelss, Rebuilding Fish Stocks No Later than 2015 – Will Europe Meet the Deadline?, *Fish and Fisheries*, 11 (2010), pp. 194-202.

3 | Proelss, A. (2009): Governing the Arctic Ocean, *Nature Geoscience* 2 (2009), pp. 310-313.

Economic Valuation of the Ocean's Role in the Carbon Cycle and Consequences for Abatement and Mitigation Strategies

We investigate the optimal anthropogenic intervention into the carbon cycle in the light of global warming as a social planner's problem in a micro-economic partial analysis framework. The planer needs to determine the global optimal amounts of extraction and ocean sequestration through time. The dynamic constraints are the carbon accumulation in the atmospheric-oceanic carbon cycle and the depletion of the fossil reserve.

It has been tested, that for analytical results the atmosphere-ocean carbon cycle can be sufficiently represented by a two-box model. The upper box aggregates the carbon stocks in the atmosphere and in the upper mixed layer of the ocean. We assume that the atmosphere and the upper mixed layer are always in equilibrium and that the stock of carbon in the atmosphere is a constant fraction of the carbon stock in the upper box. Therefore, the uptake bottleneck is the transport of anthropogenic carbon to the deeper parts of the ocean. The lower box entails the carbon stock in the deep ocean. The downward flux of carbon from the upper box to the lower box is represented by the fraction $\gamma S(t)$ and the upwards flux of carbon from the lower box to the upper box by the fraction $\gamma\omega W(t)$. These two fluxes are represented in figure 1 by the two white vertical arrows between the boxes. Both arrows have the same size, indicating that the upward flux is balanced by the downward flux. Putting these two fluxes together, we obtain the net transfer between the boxes, $\gamma(S(t) - \omega W(t))$. There will be a net flux between these two boxes if there is a difference between the relative stock sizes. An increase in the stock size in the upper box causes a downward transfer of excess carbon into the deep ocean, whereas up-welling water is still free of excess carbon, so that we observe a net transfer from the upper box into the lower box. The upper box is relatively small in comparison to the lower box. Consequently, ω is the proportionality factor to scale the stock of carbon in the lower box with respect to the upper box and γ is the turnover factor to describe the speed of the adjustment process. For the parameterization of the model we use instead a three-box model, where a feedback mechanism is included within the carbon fluxes between atmosphere and upper ocean. Additionally, nutrient stocks in the upper and lower ocean are included to allow the investigation of iron fertilization.

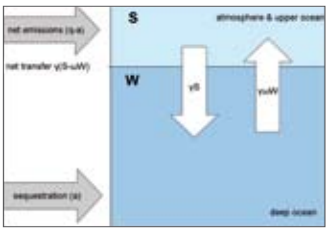

Figure 1 | Two-box representation of atmosphere-ocean carbon cycle

Ocean sequestration is either a temporary option or the long run option for the usage of fossil fuels. We derived the critical cost level which distinguishes these two regimes. Given ocean sequestration is the long-run option, the usage of fossil fuel is extended. The additional inclusion of stock dependent extraction costs allows for an interior solution and allows two additional optimal emission tax paths, an inversely U-shaped one and a monotonically decreasing one. The description of the global carbon cycle with three boxes does not alter the characteristics of the model. Consequently, the two-box model framework is sufficient for analytical investigation. Numerical runs confirmed the result that ocean sequestration allows for lower atmospheric peak concentration while extending the usage of fossil fuels at reasonable rates. Additionally, we investigate the situation where the atmospheric carbon stock is limited by a ceiling instead of including a damage function. Given such a climate policy, which formulates an atmospheric carbon stabilization goal, ocean sequestration cannot increase the total amount of fossil fuel consumption. However, the option of ocean sequestration does extend the period that fossil fuels can be extracted in reasonable amounts, whereas without ocean sequestration the amounts of extraction would have to decline much earlier due to the inertia of the carbon cycle. Consequently, ocean sequestration constitutes a serious option to buy time to deal with the atmospheric carbon accumulation problem. The effectiveness of this option depends on the injection depth of the sequestered carbon and the time preference of society.

Within the analysis of the model it became necessary to solve multistage optimal control problems, because several model variants exist, which do not allow an interior solution. To solve such problems a solution algorithm was developed, which was summarized in a technical paper. Additionally, a calibration of the three-box model is planned. The objective of this model extension is to investigate the effect of feedback mechanism within the oceanic carbon uptake. Furthermore, a comparison between direct carbon injection into the deep sea and enhancement of the biological pump by iron fertilization with a dynamic context is planned. For doing so, the three-box model is extended by two state variables, which represent the nutrient stocks in the upper and lower ocean.

Project Team

G. Klepper, A. Oschlies, T. Requate, U. Riebesell, K. Wallmann

Selected Publications

1 | Wilfried Rickels and Thomas Lontzek (2008). Optimal global carbon management with ocean sequestration. Kiel Working Paper 1432, Kiel Institute for the World Economy.

2 | Thomas Lontzek and Wilfried Rickels (2008). Carbon Capture and Storage & the Optimal Path of the Carbon Tax. Kiel Working Paper, 1475, Kiel Institut for the World Economy. Under Review Journal of Dynamics and Control.

Selected Projects

Metabolic Response of the Cold-Water Coral *Lophelia Pertusa* to Variations in Ambient Temperature and pH

The global climate is currently changing at an unprecedentedly rapid pace due to the steep increase of atmospheric CO_2 affecting the oceans through both warming and acidification. Since cold-water species from deep-sea as well as polar regions are well adapted to low ambient temperatures but exhibit a rather narrow physiological temperature tolerance, even small changes are likely to have a severe effect on their metabolism and, thus, will profoundly alter the partitioning of the overall benthic carbon and energy flow pattern at a community level. Community changes will also be induced through climate change through a significant decrease in pH (ocean acidification) in the future. As such community scale shifts are difficult to study and predict, the metabolic response of a selected benthic organism, *Lophelia pertusa* (Scleractinia, Fig. 1), to changes in both temperature and pH was studied in an experimental approach.

Global climate change causes ocean warming and acidification, both of which will have profound ecological effects at all trophic levels, since temperature and pH are prime environmental factors driving marine biology from cellular biochemistry and physiology to ecosystem-wide food-web and habitat structure. To quantify these effects at an ecophysiological level, we measured oxygen consumption rates of selected branches (4-7 replicates) of the widely distributed cold-water coral *Lophelia pertusa* at different temperature (7.5 and 11.0 °C) and elevated pCO_2 regimes (585, 770, 960, and 1200 ppmv, resulting in ambient seawater pH values ranging from 7.99 to 7.69) by means of advanced optode technology allowing for continuous high-precision recordings of O_2 and pH under variable experimental settings. The experiments showed that *L. pertusa* responded to a shortterm (2 days) temperature increase of 2.5 °C with significantly elevated (by 50% on average) oxygen consumption. The high Q10 values recorded (3.5 on average) suggest that this species may not be able to compensate for such changes in temperature and is thus quite sensitive to ocean warming. The results of the long-term acidification trials (several months) demonstrated that branch respiration, measured at the end of the experiments, decreased significantly with pCO_2 (by an average of ~33% with the first two 200 ppmv pCO_2 steps and ~20% with the following 200 ppmv pCO_2 steps, Fig. 2), suggesting that mean metabolic rates may decline with ocean acidification. Moreover, across a pCO_2 gradient from 770 to 1200 ppmv, final oxygen consumption was positively correlated to calcification rates assessed over a previous two-month period. The latter did not exhibit a significant relationship to pCO_2, suggesting that average metabolic performance is more clearly affected than calcification rates by a decrease in ambient pH, at least within the range covered by our experiments. In conclusion, our results imply that concurrent ocean warming and acidification will have diverging effects on the routine metabolism of *L. pertusa*, the physiological causes of which have yet to be studied in greater detail. Furthermore, the relationship between metabolic activity and calcification performance appears to be complex and needs to be further investigated.

Figure 1 | Branch of *Lophelia pertusa* stock.

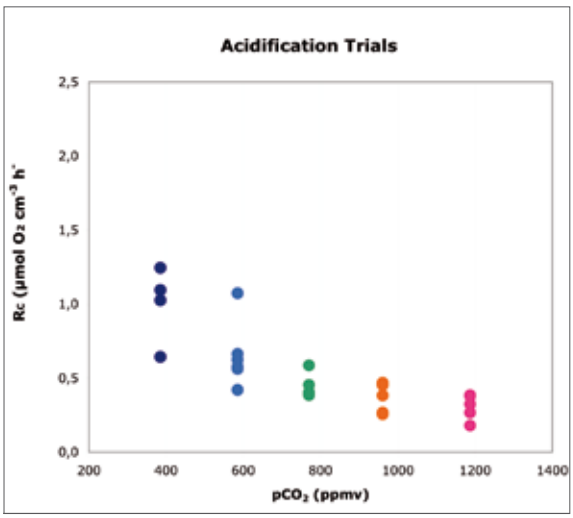

Figure 2 | Respiration of *Lophelia pertusa* in relation to pCO_2 levels.

Project Team

D. Piepenburg, A. Form, M. Bartz

Iceflow Activity Revealed from Submarine Morphology – Mapping Glacial – Morphological Manifestations of a Retreating Ice-Front

Aim of the project „Iceflow Activity" was to map the bathymetry of Ilulissat Icefjord in West-Greenland using a portable multibeam system onboard a small local vessel. Thus it was possible to survey areas inside the Icefjord which are inaccessible to large research vessels. A considerable area could be mapped in summer 2008 and complemented the data set acquired during the cruise MSM05/03 of RV *Maria S. Merian* in 2007. From both datasets a comprehensive image of the morphology of the area of the mouth of Ilulissat Icefjord was achieved which will help to understand glacial geological processes that shaped the area and will give indications on temporal changes of the iceflow activity.

Description of the Project

The Ilulissat Icefjord is one of the few places in West-Greenland where the ice cap reaches the sea. Furthermore, it is the fastest and most productive iceberg calving area outside Antarctica. The line at which the icebergs are broken off the ice cap has encountered a steady recession since about 150 years and seems to have reached now the same position as during the climatic optimum 4000 – 5000 years ago. Consequently, the changes in climate exert a first order control on the recession of the ice-front and the calving of icebergs, which are transported through the Icefjord into Disko Bay with a speed of about 1 m per hour. Large icebergs accumulate over a sill off the fjord mouth where they reside several months until they are finally released through the combined effect of tides and streams, melting, and melt-water lubrication. All these processes shape the morphology of the seafloor in front of the mouth and create characteristic submarine landforms. Revealing the morphology helps to understand these processes.

Current Status of Research

The main activities during the time covered by this report concentrated on further processing of the data and the interpretation of the morphology. Two theses have been finished in this time period using the data of this project. Alexander Schmidt, a student of hydrography at Hafen City University of Hamburg finished his diploma thesis on a comparison of different processing methods and tools successfully in November 2009. Kai Schumann, student of geology at Martin-Luther-University of Halle-Wittenberg, processed, analyzed and interpreted multibeam and parasound echosounder data of the Icefjord area in his diploma thesis, which he will finish in March, 2010. The results he achieved are highly interesting: the data show strong indications for the presence of gas hydrates in the area off the mouth of Ilulissat Icefjord.

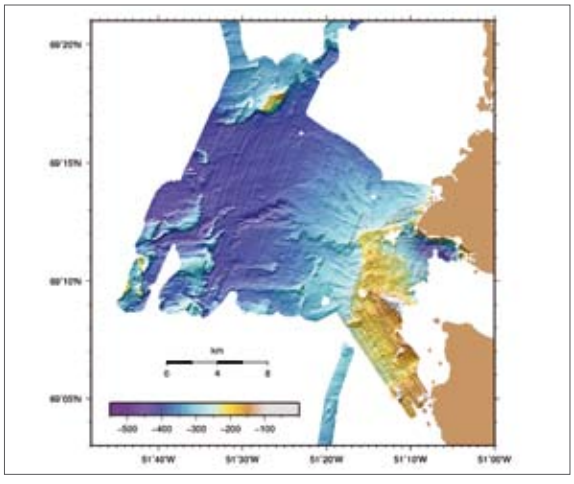

Figure 1 | Bathymetric map of the area off the mouth of Ilulissat Icefjord.

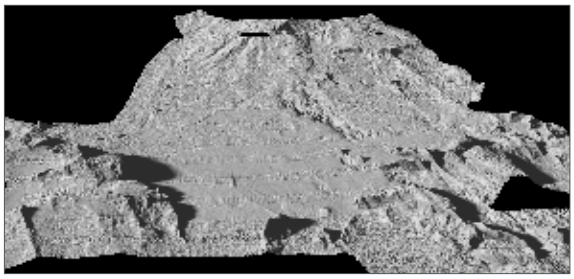

Figure 2 | Perspective view of the morphology of the survey area, view from west.

Preliminary Results

A high-resolution bathymetric map was produced based on the multibeam data (Fig. 1). The map displays a morphology shaped by glacial geological processes. The southern part of the mouth of Ilulissat Icefjord is formed by a large sill with water depths as shallow as up to 50 m, whereas close to the northern bank depths up to 420 m are found. This explains the prevailing drift direction of calved icebergs to the north.

Different morphological features such as ridges, shaped like drumlins and valleys which could be connected to channel systems, directing debris flows to a deposition centre characterize the central part of the survey area (Figs. 2, 3). Here, a series of prominent circular features 80 m to 150 m in diameter and up to 30 m deep have been found and are interpreted as pockmarks.

A parasound echosounder profile across one of the pockmarks documents the absence of the upper sedimentary unit inside the pockmark (Fig. 4). This interpretation is supported by a blank zone in the central part of the pockmark, indicating uprising fluids or gas. The northeast – southwest

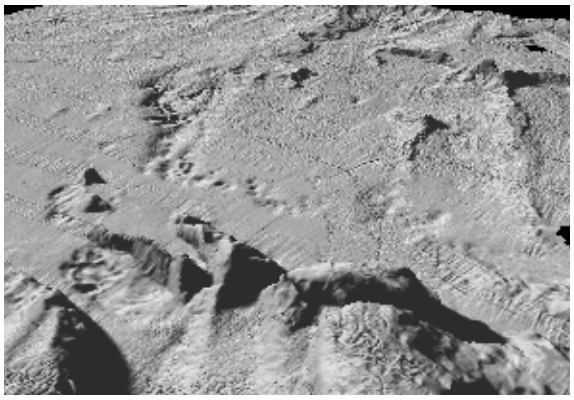

Figure 3 | Perspective view of the morphology, view from south showing the central depression with pockmarks.

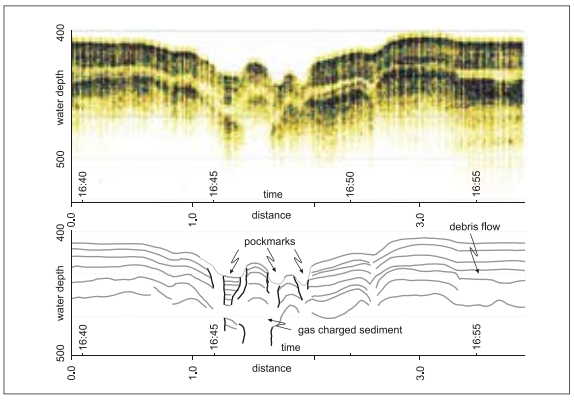

Figure 4 | Parasound profile of a composite pockmark in the central part of the mapping area. The upper sedimentary unit is clearly missing in the pockmark. An acoustical blanked area is visible in the central part beneath the composite pockmark. This might be the pathway for fluids.

alignment of the pockmarks points to a formation related to slides, faults, and iceberg furrows. The depth of their occurrence of around 400 m indicates a formation by dissociating gas hydrates. The most recent active pockmarks are located in the centre and the northeastern end of the depression in a depth of 395 m. The gas hydrate stability zone in arctic regions tapers out at around 400 m at 3° bottom water temperature which coincides with the values measured with a CTD during the *Merian* MSM05/03 cruise quite close to this position. The decreasing age from southwest to northeast could be explained by changing water temperature coupled to sea level rises. The gas hydrate stability zone would migrate upward with rising sea level. Coupled to climate warning, the upward migration of the gas hydrate stability zone would be retarded (Fig. 5).

Outlook

During the presentation of the poster at the AGU fall meeting in December 2009 contacts have been established to colleagues at Lehman College, CUNY, New York and the Antarctic Research Centre, Victoria University of Wellington, New Zealand. Both groups work on the deglaciation of the coastal margin of Greenland. Sharing the data and future joint proposals are planned.

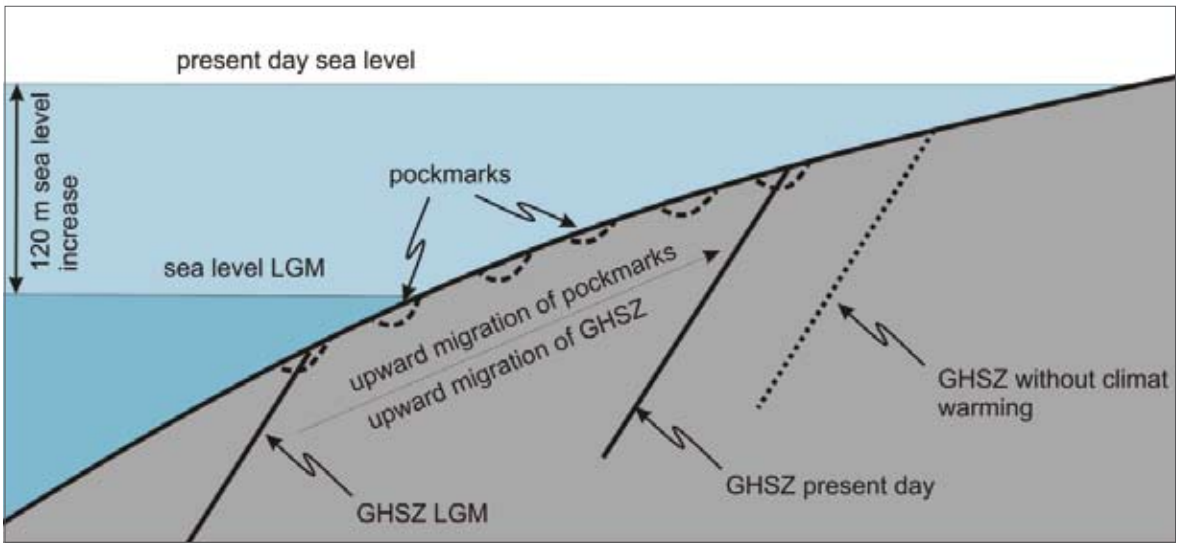

Figure 5 | Perspective view of the morphology, view from south showing the central depression with pockmarks

Project Team

Wilhelm Weinrebe

In close cooperation with:
A. Kuijpers, J. B. Jensen and N. Mikkelsen from GEUS – the Geological Survey of Denmark and Greenland, Marine Geology Dpt. S. Troelstra from Amsterdam Vrije Universiteit, Faculteit der Aard- en Levenswetenschappen J. Lloyd from Department of Geography, Durham University, UKR. Endler from Institut für Ostseeforschung, Warnemünde, Germany D. Zillmann from Greenland Tours Elke Meissner, Ilulissat, Greenland

Complex Barriers: The Biotic Control of Marine Biofilms on Algal Surfaces

The formation of microbial biofilms on surfaces is ubiquitous (e.g. teeth, skin, intestinal mucosa, ship hulls, boulders, outer surfaces of dead or living marine organisms) and may be beneficial or detrimental (Wahl 1997). In the marine environment, surfaces are exposed to a particularly powerful and diverse colonization pressures. Possible effects of these epibiotic microorganisms include pathogenesis, chemical camouflage, production or masking of cues for third species, promotion of further fouling, insulation. The quantity and composition of biofilms on live surfaces should strongly impact the host's interactions with the environment – as has been demonstrated for other forms of epibiosis (e.g. Wahl and Hay 1995). For several reasons we expect, that marine organisms invest substantial evolutionary and ecological effort into the control of biofilms at their surfaces: high fouling pressure, important consequences of fouling, thin and physiologically active surfaces.

This project had three interdependent foci:

1. Characterization of the epibacterial community on macroalgae.
2. Investigation of the chemical interaction between the alga and epibacteria.
3. Monitoring of microfouling on artificial and live surfaces.

Epibacterial Communities on Macroalgae

To characterize the epibacterial community composition of different macroalgae, we seasonally analyzed the associated biofilm of *Ulva intestinalis*, *Fucus vesiculosus* and *Gracilaria vermiculophylla* in the Baltic Sea. Using molecular fingerprinting techniques we found a host-specific but temporally variable association between algae and their biofilm (Fig. 1). The fact that the similarity between epibacterial communities on conspecific hosts sampled at a given season was always substantially greater than on different host species or in different seasons, or with the pool of colonizers in the surrounding seawater (Fig. 2) is a very strong indication that the composition of the biofilm is controlled by (chemical) properties of the host alga's thallus surface. The results of this study are submitted to ISME Journal (Lachnit et al., subm.) Based on these results, we proceeded to study the effect of algal surface metabolites on the recruitment of bacteria and the resulting composition of the biofilm.

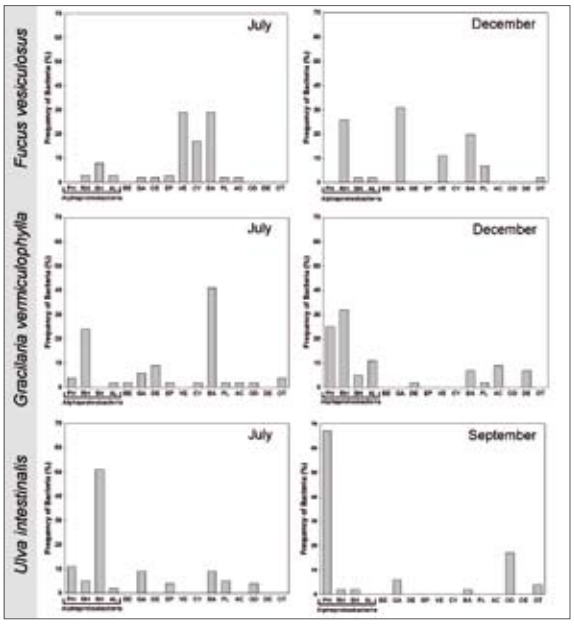

Figure 1 | Comparison of bacterial communities associated with *Fucus vesiculosus*, *Gracilaria vermiculophylla* and *Ulva intestinalis*, sampled in July, September and December 2007 based on 16S rDNA phylogenetic analyses.

Alga / Epibacteria Chemical Interactions

To investigate the effect of algal metabolites on the development and composition of biofilms, we optimized an extraction method which exclusively sampled the metabolites associated with the algal host's surface without damaging any epidermal cells. These algal metabolites were tested under natural conditions in the Baltic Sea for their ability to control settlement of bacteria and invertebrate larvae. A newly developed test apparatus permitted to continuously provide polar algal surface metabolites to an artificial substrate containing the non-polar components extracted from the algal surface. Thus, the chemical conditions on the artificial surface should closely mimic the microhabitat on an alga's thallus. Indeed, we were able to imitate the chemical modulation of epibacterial community composition and the

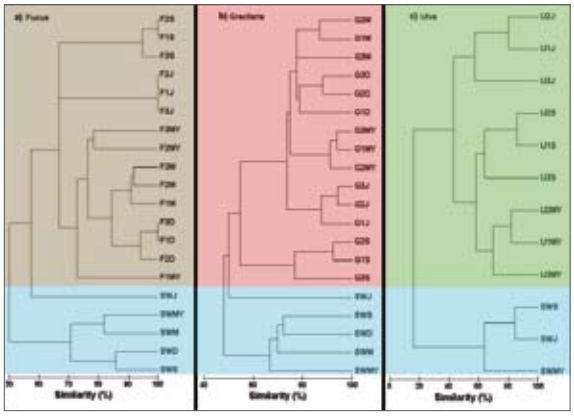

Figure 2 | Cluster analysis of DGGE banding patterns based on 16S rDNA amplified from epibacterial communities. (a) *F. vesiculosus*, (b) *G. vermiculophylla*, (c) *U. intestinalis*, and the respective bacterial community of the surrounding seawater (SW) sampled in 2007 and 2008 at bimonthly intervals (D, December; M, March; MY, May; J, July, S, September). Generally three different individuals were analysed (1-3). Cluster analysis of DGGE banding patterns was performed using the Bray-Curtis index (Jackson 1993); similarity values are given in %.

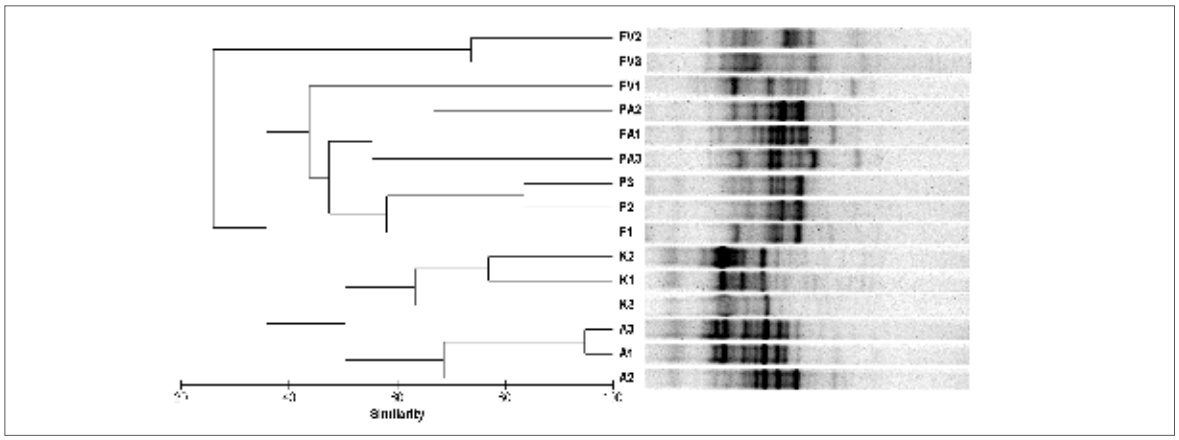

Figure 3 | Cluster analysis of DGGE banding patterns based on 16S rDNA amplified from epibacterial community composition of *Fucus vesiculosus* and chemically manipulat ed hydrogel substrates (n=3). K=Control, A=Aploar; P=Polar; PA=Polar and apolar surface extract.

control of barnacle settlement on artificial surfaces fairly well (Figs. 3 & 4). The results of this study are accepted for publication in Biofouling (Lachnit et al. 2010).

Microfouling on Artificial and Live Surfaces

In order to monitor the dynamics of microbiofouling with high temporal resolution, we developed — in cooperation with Ocean Surface Chemistry group of Gernot Friedrichs — a real-time, on-line and non-destructive optical fiber biofilm sensor. As a proxy for bacteria mass, the sensor measures the intrinsic fluorescence of the aromatic amino acid tryptophane. The sensor system consists of a 280 nm LED/bandpass filter excitation light source, 19 quartz optical fibers for collecting the fluorescent light of the biofilm, and a 350 nm bandpass filter/PMT light detection unit working as a single photon counter. The calibrations of the sensor were accomplished with the marine gram-negative bacteria *Pseudoalteromonas carrageenovora* (DSM 6820) and gram-positive *Bacillus subtilis* (DSM 1092). Fluorescence intensity of bacterial settlement in a UV-transparent Petri dish was measured by the biofilm sensor and was found to correlate with to the bacterial numbers counted after DAPI (a fluorescent stain that binds to DNA) staining by fluorescence microscopy. Automated image analysis using the Software ImageJ (National Institutes of Health) combined with a specifically programmed macro facilitated the counting of bacteria. The measurements demonstrated a reliable signal acquisition of the sensor with a detection limit of 7x103 cells cm^{-2} (Fig. 5). The biofilm sensor is now ready for use in the laboratory and, following some modification of the control electronics, will be tested soon in field experiments.

A follow-up DFG proposal based on some of these results was recently granted and started in 2009, two further proposals are in preparation.

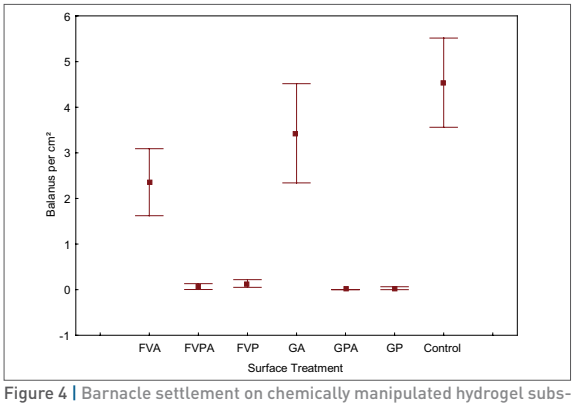

Figure 4 | Barnacle settlement on chemically manipulated hydrogel substrates (n=3).. K=Control, A=Aploar; P=Polar; PA=Polar and apolar surface extracts of FV=*Fucus vesiculosus* extract and G=*Gracilaria vermiculophylla* extract.

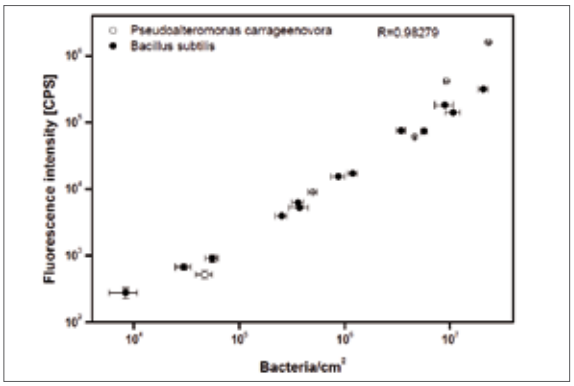

Figure 5 | Linear regression plot of fluorescence intensity against bacteria density (DAPI count).

Project Team

M. Wahl R. Schmitz-Streit, T. Lachnit, F. Symanowski, D. Meske, M. Fischer, in collaboration with G. Friedrichs

Selected Publications

1 | Lachnit, T, Meske, D, Wahl, M, Harder, T & Schmitz, RA (sub.) Species-Specific Patterns and Temporal Variability of Epibacterial Communities on Marine Macroalgae. *ISME Journal*.

2 | Lachnit, T, Wahl, M & Harder, T (2010) Isolated thallus-associated compounds from the macroalga Fucus vesiculosus mediate bacterial surface colonization in the field similar to that on the natural alga. *Biofouling* 26: 247-255.

3 | Fischer, M, Wahl, M, Friedrichs, G. (in prep.): Intrinsic fluorescence sensor for on-line and in situ detection of biofilms.

The Potential for Field Measurement of Surface Water pCO_2 and $\partial^{13}C(CO_2)$ on Volunteer Observing Ships using Cavity-Ringdown Spectroscopy

A CRDS isotopic analyzer for monitoring the isotope ratio $^{13}CO_2/^{12}CO_2$, which was operated in combination with a water/air equilibration setup, has been thoroughly tested by quantitative measurements of the response time, precision and accuracy of the instrument. An outstanding relative accuracy of $(\partial^{13}C(CO_2)) = \pm 0.05‰$ with 480 min averaging time was demonstrated. By contrast, when performing measurements of CO_2 in gas matrices with a composition different from that of ambient air, significant errors in both $\partial^{13}C(CO_2)$ and pCO_2 values were observed. However, this gas matrix effect could be traced back to pressure broadening linewidth effects and thus can be quantitatively taken into account by using a fully spectroscopically based correction procedure. Moreover, the analyzer was successfully operated aboard research vessel *Polarstern* during an Atlantic Ocean transect. For the first time, five weeks of on-line data of oceanic $\partial^{13}C(CO_2)$ and pCO_2 have been collected. First results reveal reliable, virtually drift-free data acquisition performance. Considerable, spatially dependent correlations between pCO_2 and $\partial^{13}C$ were found.

Objective

Due to the presence of anthropogenic CO_2 in the atmosphere, the world ocean acts as a net CO_2 sink, which is driven by the CO_2 partial pressure (pCO_2) difference across the air-sea interface. However, the global sink is masked by large regional and seasonal variations of surface water pCO_2associated with natural physical and biological processes. Seasonal time-series data of surface water dissolved inorganic carbon (DIC) and its isotopic ratio $\delta^{13}C(CO_2)$ are needed to separate the relative effects of processes such as photosynthesis, mixing, and air-sea gas exchange for a surface layer carbon budget.

So far, autonomous equilibrator/NDIR detection systems installed on voluntary observing ships perform regular measurements of pCO_2. Discrete samples of water are used for high precision laboratory analysis of $DI^{13}C$ by Isotopic Ratio Mass Spectrometry. The goal of this work was the development and testing of cavity-ringdown spectroscopy (CRDS) as a new approach for simultaneous measurements of pCO_2 and $\delta^{13}C(CO_2)$. This modern optical analyzer holds the potential for *in situ* accumulation of $DI^{13}C$ data at high spatial resolution over regions where carbon dynamics of the ocean mixed layer are poorly understood.

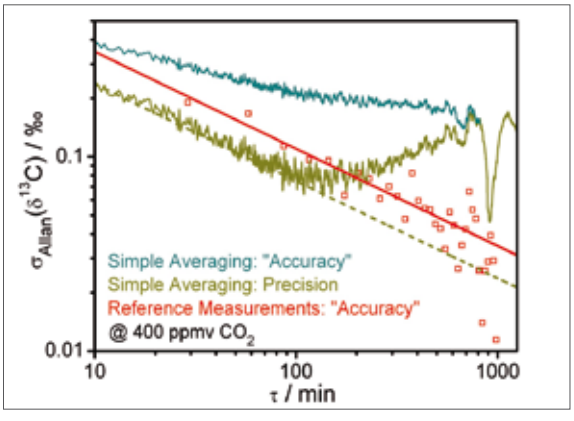

Figure 1 | Precision analysis in terms of a modified Allan plot.

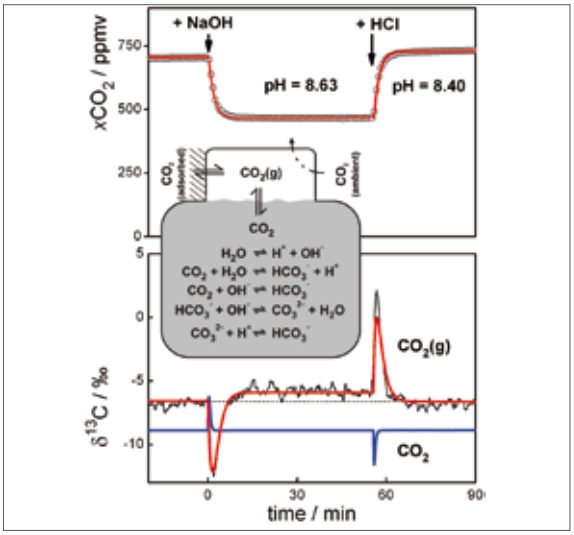

Figure 2 | Combination of CRD analyzer with a water/air equilibrator set-up: pH-step experiment and kinetic simulation.

Course of the Project

In June 2008, a commercial $\delta^{13}C(CO_2)$ CRD Isotopic Analyzer (EnviroSense 2050, Picarro Inc.) was installed at the Institute of Physical Chemistry. The performance of the analyzer was thoroughly tested with regard to response time, susceptibility to external interferences, long-term stability and precision. At the end of the year, the setup was transferred to CONTROS GmbH (Kiel). The instrument was operated in combination with an air-water equilibration system under laboratory conditions for side-by-side comparison with existing NDIR-based equilibrator systems for pCO_2 measurements. The absolute accuracy of the instrument was further tested by analyzing gas samples at the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research and at the Institute of Environmental Physics in Heidelberg. Motivated by the trouble-free operation of the analyzer in all test experiments, it was decided to skip any further testing phase and instead, take

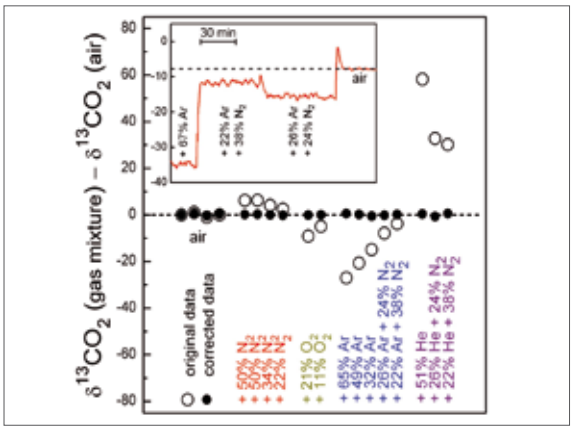

Figure 3 | Gas matrix effect: influence of carrier gas composition on determined $\delta^{13}CO_2$ values.

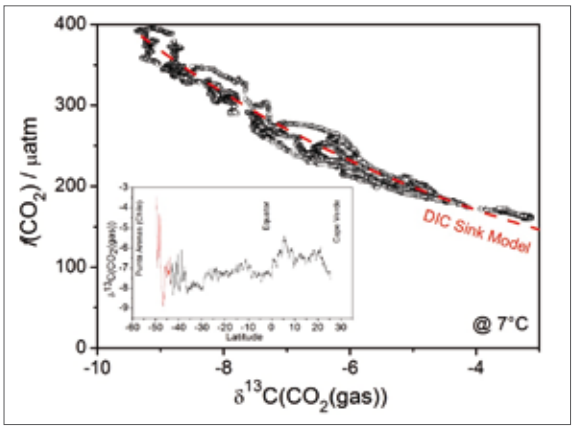

Figure 4 | Field measurements aboard RV Polarstern.

a chance to participate in a RV *Polarstern* research cruise starting in October 2009. Successful underway operation of the analyzer yielded five weeks of on-line data of oceanic $\delta^{13}C(CO_2)$ and pCO_2, which are currently analyzed. In order to verify the data, a follow-up cruise is already scheduled for April 2010. Afterwards, in collaboration with E. Bahlmann (University of Hamburg) a Lagrangian type experiment of the isotopic composition of near water/air interface atmospheric CO_2 is planned for a RV *Poseidon* cruise in upwelling areas near Mauretania in June 2010.

Results

The precision of the CRD spectrometer with respect to $\delta^{13}C(CO_2)$ was analyzed based on switching experiments using two different compressed air samples. Figure 1 displays a typical Allan plot analysis showing that even for averaging times $\tau > 300$ min a simple data averaging procedure is limited to an overall accuracy of -0.2‰ (green curve). Although the instrument exhibits excellent long-term stability (0.15‰), it was possible to further improve its precision by performing measurements relative to a reference gas sample. $\Delta(\delta^{13}C) = 0.1$‰ for $\tau = 2$ h and 0.05‰ for $\tau = 8$ h (red line) was achieved, which is sufficient for the planned field applications.

The CRD analyzer was successfully operated in combination with a commercial water/air equilibrator test setup and was run side-by-side with a conventional NDIR pCO_2 system (LiCOR). Figure 2 illustrates the outcome of an experiment where pH-steps were generated by adding acid or base to a 130 L water tank connected to the water/air equilibration system. Fast response times of several minutes have been observed, which are mainly originating from the intrinsic time response of the CRD analyzer and the relaxation times of the adsorption equilibria at the wetted reactor walls. A full kinetic model of the carbonate system including the gas-equilibration processes can reproduce the measured pCO_2 and $\delta^{13}C(CO_2)$ signals (red curves in Fig. 1).

A significant influence of the gas matrix on measured isotope ratios was found. As illustrated in Fig. 3, measured $\delta^{13}C(CO_2)$ values strongly depend on carrier gas composition. $^{12,13}CO_2$ concentration determination is based on fitting (high-resolution) absorption profiles and thus relies on an accurate absorption lineshape model. As the instrumental data reduction procedure implicitly assumes a Galatry lineshape model for standard air, carrier gases different from air induce small lineshape inaccuracies resulting in significant errors in the determined $\delta^{13}C$ values. Experiments with different carrier gases have shown that a linear correction procedure can account for this effect, however, care has to be taken to properly include the correction, e.g., for precise measurements of $DI^{13}C$ in oxygen depleted water.

Interestingly, assuming a constant Ar/N_2 ratio, we could show that it is even possible to extract the actual O_2 mole fraction with an accuracy of $\Delta(xO_2) = \pm 0.005$ from the measured Galatry collisional broadening parameters. By this means, the instrument offers simultaneous measurement capabilities for $^{12}CO_2$, $^{13}CO_2$, pCO_2, H_2O and O_2!

First field measurements during the Atlantic Ocean crossing of RV *Polarstern* mark a milestone for the Institute of Physical Chemistry, which up to now had never been directly involved in experiments during ocean cruises. First of all, successful operation of the CRDS analyzer demonstrated that it is in fact possible to use sophisticated laser instrumentation aboard research vessels. Moreover, measured on-line data reveal considerable, spatially dependent variations of pCO_2 (150 – 420 ppmv) and $\delta^{13}C(CO_2)$ (-2.5‰ to -9.0‰). Figure 4 illustrates experimental data clearly showing the expected strong negative correlations between pCO_2 and $\delta^{13}C(CO_2)$ for biologically active surface waters in the shelf area close to Argentina. In other geographical areas, significantly different dependencies were observed (not shown) indicating that $\delta^{13}C$ data can serve as valuable additional information in order to trace carbon fluxes based on CO_2 measurements in surface ocean water.

Project Team

Gernot Friedrichs, Nils Andersen, Peter Croot, Arne Körtzinger, Andreas Oschlies, Friedrich Temps, Douglas Wallace, Meike Becker, Julia Bock, Peer Fietzek, Contros Systems & Solutions

Selected Publications

1 | G. Friedrichs, J. Bock. F. Temps, P. Fietzek, A. Körtzinger, D. Wallace, Towards Continuous Monitoring of Seawater $^{13}CO_2/^{12}CO_2$ Isotope Ratio and pCO_2: Performance of a Cavity Ringdown Spectrometer and Gas Matrix Effects, *Limnol. Oceanogr. Methods*, under revision.

The Services

Those people who think they know everything are a great annoyance to those of us who do.

Isaac Asimov

Public Outreach – An Overview

Public interest in the interdisciplinary research topics addressed by the Cluster of Excellence „The Future Ocean" is growing continuously. The activities organized by the Excellence Cluster „Future Ocean", be they lectures of interest to the general public, presentations on the marine sciences intended for students, exhibitions, or contributions published in various print or online media, have all proved to be real visitor magnets. This can be attributed to the fact that the general public, politicians, and the business community are showing a steadily rising interest in environmental issues in the broadest sense.

The Cluster's Public Outreach Group is taking advantage of this mood in society to keep the research topics firmly in the public eye in a lasting, long-term manner. Moreover, the outreach group intends to continue the ongoing conversation between science and society by offering a diverse program. In so doing, the attention of opinion leaders and of the general public is to be drawn to the overarching subject area of global ocean and climate change, on the one hand, while focusing on issues of immediate public concern, such as overfishing, on the other.

Internal Communication – Fostering Identification

The virtual research cluster „Future Ocean", consisting of 13 working groups, keeps growing so that many new members and employees were involved in the research; altogether there were some 240 scientists at the end of the year. The decentralized structure of the Excellence Cluster still is one of the obstacles impeding a natural and lively exchange of ideas between the researchers. As regards internal communications, the Public Outreach Group is therefore concentrating on tools that are already well established to disseminate and exchange information and knowledge on a broad basis.

The internal German-language newsletter (INTERN) published once a month is supplemented by an English edition that is issued from time to time. The main purpose of the newsletter is to disseminate scientific publications related to the Cluster of Excellence across faculties. In addition, it features new members or employees and their research projects, announces the arrival of visiting scientists, and provides information on important dates or other news that might contribute to building up the network. Beyond that, the newsletter reflects the broad scope of topics and activities.

A series of internal events launched by the Public Outreach Group under the heading „Blue Hour" was also continued this year. This is a program in which the Junior Research Groups are given the opportunity to present their main areas of research. As a rule, all members of the working group contribute to these presentations. On July 23, JRG A3 headed by Birgit Schneider hosted the event to discuss changes in ocean circulation.

Figure 1 | Teaching marine science to young pupils – excursion with the *vessel Littorina.*

Figure 2 | Presentation of the Future Ocean Explorer to the public in Kiel City Hall.

Unmistakable Public Presence

A visual presence that is quite unusual for a research network gave a substantial boost to the public profile of the Cluster of Excellence in the German-speaking area. The continuously growing traffic on the website www.ozean-der-zukunft.de and the rising number of people attending the events are two especially clear indicators of the success of these activities. An exceptional corporate design plays a key role in this context: it is used in all communications measures and enjoys a high level of recognition in the public. Besides the website, many flyers intended for conferences, fairs, projects and other activities, such as the promotion of junior researchers, also were produced in 2009; as were posters and presentations. On its online portal the German Research Foundation, DFG, presents a short film about every institution that receives funding within the framework of the Initiative for Excellence. The Cluster of Excellence "Future Ocean" is featured here in a German and an English film. Since its inauguration in January 2009, some 230,000 visitors have clicked onto the video portal. The film on "The Future Ocean", which has been online since March 2009, ranked among the top 10 most viewed films every month until the end of the year 2009.

Public Programs

The Public Outreach Team organizes public-interest lectures and panel discussions about the subject matter dealt with by the Cluster of Excellence. For example, the Excellence Cluster launched the so-called Kiel Week Lectures in cooperation with the Leibniz Institute for Marine Sciences (IFM-GEOMAR). These lectures are part of the biggest sailing event and summer festival in Northern Germany. This year, the topics taken from current research ranged from climate change seen from an economic perspective to chemical reactions in the ocean and causes of ocean floor warming. With an average of 60 visitors these talks were well-received indeed.

But even more events were conducted in 2009. The public outreach team organized a six-week display of the meanwhile famous Future Ocean Exhibition in Saarland, Germany, just following exhibition at the german reunion day (see page 65). The multi-touch table Future Ocean Explorer was finally finished and displayed on several events throughout Germany it (see page 64). This 6 m interactive screen is a huge beast requiring significant infrastructure to move, maintain and operate it. Last but not least the performative lecture "ocean, mobilis in mobile", a new concept to communicate marine science was created by our colleagues from the Muthesius Academy of fine Arts (see page 62), supported by public outreach group.

Outlook

All in all the outreach work continues to be one of the success stories of the Future Ocean. The topic is still very well received, and we get a growing feedback on all levels, may it be journalist requesting background information on current topics, or he general public and researchers, who are supposed to recognize Kiel as one of the leading locations in marine science.

Following our approach to "think big", for 2010 we have accepted the challenge to organize a 350 m^2 exhibition on Marine Science and Technology in one of the leading technical museums in the world, the Deutsches Museum in Munich. Planning and organization has commenced since summer 2009, with many brilliant new ideas emerging and spawning dozens of side projects. We will report in detail on this event in our annual report 2010.

Figure 3 | Exhibition „The Future Ocean" at Deutsches Museum Munich in 2010

„Ocean, Mobilis in Mobile“ – An Ocean-Related Performance

The title „ocean, mobilis in mobile” – based on Jules Verne’s story „20,000 Leagues under the Sea“ – held the promise of movement and the audience attending the performative lecture certainly encountered plenty of it during the three evenings it was shown at the packed lecture hall of the Museum of Fine Arts in Kiel.

In the program, hosted jointly by the Muthesius Academy of Fine Arts and the Cluster of Excellence “Future Ocean”, professors, scientists and artists explored an unusual avenue in the arts for the first time in order to impart knowledge on oceans. Rainer W. Ernst, President of the Muthesius School of Fine Arts, and the filmmaker Stephan Sachs, Professor for Film/ Time-Based Media, were the ones to conceive and implement the idea, namely an experimental piece composed of film, literature, theater, music and real scientific lectures. Film clips shot on an expedition of the research vessel *Atalante* (2008) to the South Atlantic were projected onto a big screen and accompanied by music from the opera La Traviata and by a dialogue between two speakers from the off. In other sequences, the scientists Arne Körtzinger, Thomas Bosch and Alexander Proelß, all members of the Future Ocean, gave an entertaining and lively account of their research, spanning from ocean currents, some small organisms like the polyp hydra to the legal claims that the countries bordering the North Pole are making on valuable natural resources in the Arctic Ocean.

From the background, the melodious voice of the singer Birthe Bendixen could be heard time and again; her songs about the ocean let many people in the audience get goose bumps. The dramatic advisor, Ingrid L. Ernst, shed light on the ocean from yet another angle by reading uncommon, exceptional texts about the ocean. And in between, voices could be heard from the off again and again: the voices of Rainer Ernst, questioning mind and lateral thinker, and Stephan Sachs, observer and film narrator, arguing about various aspects of European cultural history with regard to the perception of the ocean. At the end of this unique experiment, the audience applauded for a long time. Many people said that the performance which intended to serve as a trial how to merge science and arts, two disciplines which usually hardly go together, should indeed be repeated and extended. We will continue to further explore this – promised.

Figure 3 | Thomas Bosch giving a lively account of his research.

Figure 1 | Rainer W. Ernst performing with his Saxophone.

Figure 2 | Film-sequences of the ocean.

Bridging Gaps Between Young Scientists and Industry

Knowledge exchange between science and industry takes many routes. Early exposure of early stage researchers at the interface between science and industry has been supported within the Cluster of Excellence "The Future Ocean" by joined action of the Tranfer to Application initiative and the Integrated School of Ocean Sciences (ISOS).

Figure 1 | PhDs of the Integrated School of Ocean Sciences Monika Krivickaite and Peer Fietzek with their Mentor Dr. Warner Brückmann at the Offshore Technology Conference (OTC) in Houston, Texas

"Messe Mentoring"

For early career scientists, visiting a commercial, career or scientific fair is often overwhelming. To enable PhD students to make optimal use of such events, a Mentoring Programme for PhD students at scientific and commercial fairs - so-called "Messe Mentoring" - has been initiated. Mentors – senior scientists of the Future Ocean – share their experience, provide insights and introduce the PhD mentees to the right people. Messe Mentoring proved to be particularly enriching when mentor and mentee have different scientific backgrounds, as each can gain from the discipline-coloured perspective of the partner's view.

In May 2009, ISOS PhDs Monika Krivickaite and Peer Fietzek visited the Offshore Technology Conference (OTC) in Houston, supported by their „Messe-Mentor" Dr. Warner Brückmann, a geoscientist at the IFM-GEOMAR. OTC is the world's largest show of the offshore industry with more than 2500 exhibitors and 65,000 visitors.

„I got background information about the pipeline industry's practical experience with the regulatory procedures on the laying, maintenance, protection and repair of submarine pipelines necessary for a discussion of the law and policy issues in my PhD thesis." (Monika Krivickaite, PhD student in international law, deals with the legislative background of the Nord Stream pipeline in the Baltic Sea)

"Visiting industrial fairs and conferences within the graduate studies is exactly the right action at the right time to start networking and getting acquainted with possible business fields. It was one of my intentions at the OTC to talk to as many companies as possible and to find out whether there was a market for industrial underwater CO_2 sensors." (Peer Fietzek, PhD student in Chemical Oceanography at IFM-GEOMAR, develops and optimizes underwater CO_2 sensors. He works in a collaborative project between IFM-GEOMAR and the private enterprise CONTROS).

Science and Industry Networking

Workshops on key themes are jointly conducted by the Transfer to Application and the Integrated School of Ocean Sciences. They provide a platform for networking of partners from university and external partners and introduce early-career scientists to applied fields.

In the workshop „Energy from the Sea: Science meets industry" in September 2009 early-career scientists had the opportunity to talk to key players from academia and commerce involved in the SUGAR project – a collaboration of 30 partners from academia and industry – that deals with submarine gas hydrate reservoirs.

Project coordinator Klaus Wallmann, gas hydrate scientists and the companies RWE and CONTROS contributed to the workshop. Talks from industry representatives and on-site visits to the oil production facility of the RWE Dea AG in Friedrichskoog left the participants with a broader understanding of how such a partnership works.

Figure 2 | Prof. Dr. Judith Schicks presents research topics of the SUGAR (Submarine Gas Hydrate Reservoirs) project in the first workshop „Science meets industry - Energy from the Sea".

The Future Ocean Explorer – An Interactive Expedition Through the World's Oceans

After its successful premiere in the year 2008, the Future Ocean Explorer was refined in form and content and since then has been the centerpiece of the exhibits used to present the Cluster of Excellence. The unveiling of the multi-touch table platform measuring 5.20 by 1.30 meters took place at the main lecture hall of Christian-Albrechts-University in April 2008.

The Future Ocean Explorer, one of the largest of its kind, was developed at the Muthesius School of Fine Arts. Its interactive design takes up the metaphors associated with the ocean: current and depth influence how the content is presented.

The visualization illustrates the depth of the ocean while, at the same time, the table appears like a basin with a volume. Topics pertaining to marine research swim as typographical swarms along the multi-touch table measuring 5 meters in length and can be activated by touch. Visitors can catch bits of information like fish in the virtual basin, thus enabling them to go on an expedition of their own. Users face each other across the table and can start up a conversation. This interactive option is quite unusual because in most exhibitions visitors generally look at the visual display unit all by themselves.

In contrast to an ordinary touch screen capability, the multi-touch surface can record and process multiple touches at once, so that users have access to the programs and menus at their fingertips. The table enclosures consisting of several modules, the beamer technology inside the table, and the entire software package were designed and developed at the Muthesius School of Fine Arts. Depending on the requirements of the respective exhibition, different content can be included in the platform. Thanks to the Future Ocean Explorer's innovative technology, information about the 13 different subject areas covered by the Cluster of Excellence „The Future Ocean" can be presented in a sophisticated, aesthetic way, which points to the close links between the individual topics. The multi-touch technology opens up new perspectives for human interaction with computers.

On the occasion of Kiel Week in June, the Future Ocean Explorer drew and convinced many visitors at its presentation in Kiel City Hall. It proved to be a visitor magnet in the tent that the State Chancellery of Schleswig-Holstein had pitched in Saarbrücken from October 3 to 5 as part of the celebrations marking the German National Holiday (see next page).

Up to twelve visitors to the exhibition can simultaneously access texts, films or animations providing information about different areas of research on the ocean and our climate. By using earphones, visitors can also listen to the conversation carried on by the scientists.

Figure 1 | The Future Ocean Explorer is visitor magnet during the celebrations of the german National Holiday in Saarbrücken

The Exhibition „The Future Ocean" in Saarbrücken, Germany

The exhibition "The Future Ocean" went on loan to the Saarland for six weeks in the fall of 2009. From the beginning of October until the middle of November, the Cluster of Excellence displayed many exhibits illustrating ocean and climate change in Saarbrücken and Merzig (Saarland, Germany).

The exhibition was shown on the historic barge *Anna Leonie*, which is listed as a historical monument and functions as an exhibition ship jointly operated by the State Ministry of the Environment and the Fisheries Association of the Saar region.

The concept behind the show presented by the Cluster of Excellence let the visitors become immersed in the deep sea. More than 100 school classes and some 12,000 patrons, including delegations from the state ministries of the Saarland, political opinion leaders and other interested key players, were fascinated by the opportunity to look at unusual details, such as the sandy ground and other exhibits pertaining to ocean and climate change that are rarely on display. Everyone also appreciated the chance to see original equipment used in marine research.

Accompanied by experienced guides and students, visitors learned more about subjects like new natural resources from the ocean floor, modern research methods applied in ocean observation, tsunamis and land slides, fishery and the changes in living resources in the marine habitat as well as the use of state-of-the-art research equipment. This equipment seemed to be floating through the space. The exhibition was supplemented by a comprehensive cultural framework program consisting of lectures on the ocean, current research or literature as well as continuing education programs for teachers, concerts and theater performances.

Figure 2 | The exhibition on the historic barge *Anna Leonie*.

Figure 1 | The opening ceremony. Martin Visbeck (right) gives insight in the research of the Kiel Cluster of excellence.

Public Outreach Working Group

Public Outreach activities are jointly organized by:
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Public Outreach – School Programs

To transfer new scientific knowledge directly to schools and to address the next generation of science students, „The Future Ocean" together with its partners offers various opportunities for joint experiments for pupils/students in the laboratory, at sea and through public lectures. In 2009 the emphasis on reaching a wider audience, particularly of younger pupils, was continued. Major acitvities in 2009 are summarized here.

Kids' and Students' University 2009

In the second year again six lectures were given and more than 2000 students took part in the Kids' and Students' University „The Future Ocean". Professors from marine science faculties from different departments of the Kiel University Cluster of Excellence „The Future Ocean" introduced children into their research. They vividly reported on various subjects concerning the ocean and climate: marine resources at the seafloor, starfishes, coasts at risk and sediments, global change in the Arctic, earthquakes, submarine slides and tsunamis and the ocean as a system. Pupils experienced the excitement and fascination of marine sciences. Each lecture is complemented with handouts in order to allow the audience to review the content at home. Handouts and videos are made available online free of charge (on the website www.ozean-der-zukunft.de), in order to enable students, parents and teachers to learn more about marine systems and the latest scientific findings.

To call attention to the lectures and to spread their topics in the surroundings of Kiel the media partnership with the local daily newspaper (Kieler Nachrichten, circulation 100.000) and the nationwide journal Geolino continued. The Kids' and Students' University Kiel is also listed on the german web portal www.die-kinder-uni.de and is an active member of the European Children's Universities Network (http://eucu.net/).

Figure 1 | More than 2000 school kids were listening to the lectures at the Children's University „The Future Ocean".

The Future Ocean currently strives to establish the Kids' and Students' University as a permanently recurring event at the University of Kiel with annually changing topics, not only from marine science, but also communicating other topics researched in Kiel. The School Programs therefore collaborate closely with other large scale projects, like the Cluster of Excellence Inflammation at Interfaces, or active collaborative research programs (SFBs) to promote this initiative and further sharpen Kiel's profile as an outstanding research location to potential students and the general public.

Littorina-Expeditions – for Students and Teachers

From 12th to 15th October 2009 four day-trips were organized for teachers and students from Kiel on the research *vessel Littorina*. Physical, chemical and biological parameters were measured and evaluated in the bay of Kiel with regard to oxygen content in the western part of the Baltic Sea.

On the 13th October a special training for teachers took place. Devices applied were the gravitiy corer, a box grab, multimeter, a plankton net, a water sampler, filtration frames, centrifuge, a photometer, and a seafloor dredge. Most of the equipment is part of the five expedition boxes which can be borrowed by teachers for project work.

This project was organized by marine biologist Katrin Knickmeier from The Future Ocean together with colleagues from the Leibniz Institute for Marine Sciences IFM-GEOMAR, oceanographer Andreas Lehmann, and marine biologist Sally Dengg.

The Federal Environmental Competition (BUW)

The Federal Environmental Competition (BUW) is conducted annually by the Leibniz Institute for Science and Mathematics Education (IPN) on behalf of the Federal Ministry for Education and Research (BMBF). It addresses young people between 13 and 21. The competitors' task is to identify and analyse an environmental problem in their own sphere, then to develop practical solutions. The nationwide environmental competition has provided an opportunity for committed and talented students throughout Germany to test their abilities

in the field of environmental studies. To highlight the topics of the Future Ocean within schools throughout Germany a special award advertised in 2008/2009, called „Future Ocean – too high, too warm, too acidic".

On 18th September the award ceremony took place in Kiel. Prof. Martin Visbeck introduced the winners and gave a laudation speech. The first price was awarded to Philipp Griehl (17) from Halle, Germany for his work on „Microalgae: CO_2-Killer and Future Energy Source", two additional awards went to Julia Lenz from Berlin, Germany, who worked on the „Influence of Global Warming on the Gulf Stream" and Kai Dehlwes, Martin Hinze und Christoph Seifert from Erlangen, Germany, for their work on the „Development of a Novel Wave Power Plant with a Design Model". The public outreach team of the Future Ocean was actively involved in the preparation and conduct of the official event in Kiel. Martin Visbecks laudation was subsequently published in the annual report of the BUW.

X-perimenta – a Science Festival

A festival for natural sciences was organized by the IQSH (Institute for Quality Development of Schools in Schleswig-Holstein) in September. It was the first big science festival for pupils in Schleswig-Holstein and among the largest in Germany. Nearly 11.000 pupils came to the festival location, the biggest roofed sports arena in the state. The Future Ocean school programs exhibited an installation featuring aquaria, expedition boxes, experiments and a demonstration of the Kids' and Students' University Kiel. Numerous interested pupils and teachers gathered information about opportunities in marine sciences.

Kiel - Federal City of Young Scientists

A nationwide proposal competition to support the education and cooperation between schools and extracurricular facilities (Stadt der jungen Forscher) is sponsored, coordinated and advertised by the foundations Körber Stiftung, Robert Bosch Stiftung and Deutsche Telekom Stiftung. After an unsuccessful application in 2008/2009 the city of Kiel, supported by the school programs from the Future Ocean, decided that it had learned its lesson and participated again in the competition. To organize and brainstorm for the proposal the city of Kiel established a local network comprising the university, several research institutes, schools, enterprises and other facilities. Therefore, even if unsuccessful, the initiative provides a unique chance to strengthen the ties between schools and research institutions. The submitted proposal promoted the concept „Sailing the schools of Kiel on a Research Vessel", centering on the major topics of the Future Ocean and marine sciences. We will report further on this topic in the future as Kiel successfully won the competition in summer 2010.

Medien Dom Kiel Collaboration

Together with Mediendom Kiel, a 360 degree multimedia cinema operated e.g. as planetarium by the University of Applied Sciences, a concept to present background information and challenges of climate change to kids was drafted. The presentation should feature modern presentation techniques and aim for preschool and elementary school children. The story will make use of a popular German cartoon figure,

Figure 2 | Kerstin Schrottke (CAU) explains the significance of sand.

Lars the little polar bear. It adapts and modifies parts to the already existing book by Hans de Beer „Little Polar Bear and the Whales". In the latest book of this series Lars faces the first signs of global change in the Arctic region. It is planned to use the little polar bear as an ambassador to kids for the threats on the Arctic. This 360 degree cinema multimedia production is split into three distinct parts: information about the starry sky in the Arctic, the book and information about the life of the polar bears at times of global change, the change of habitat and the environment.

Outlook 2010

In 2010 the Kids´ and Students´ University at the University of Kiel for kids aged 8 to 16 will of course be continued. The focus will gradually shift away from Future Ocean topics, demonstrating the growing responsibility for the whole university.

The Future Ocean will coordinate the publication of a small school book (64 pages) on marine sciences, with a special focus on Future Ocean topics. This project takes place in cooperation with the Cornelsen-Verlag, Berlin, well known for its popular school book publications. Various projects for students and scientists on current research issues will be continued in 2010 as well as the cooperation with Federal Environmental Competition (BundesUmweltWettbewerb, coordinated by IPN). The network set up to organize the proposal for „Stadt der jungen Forscher" is lively and active and will be preparing the science festival planned for 2011. Finally the multimedia production „Little Polar Bear and the climate change" will have to move forward from the concept stage to production.

Organisation and Support

The school programs are organized by the Cluster of Excellence „The Future Ocean" and the project „NaT-Working Marine Research" at the Leibniz Institute for Marine Sciences. The Kids´ and Students´ University is a collaboration of the former and the Institute for Science and Mathematics Education, Kiel (IPN), with technical support from the computer center of the Kiel University. It is actively sponsored by the Foundation „Stiftung 200 Jahre Sparkasse Kiel" and promoted through a media partnership with the major local newspaper Kieler Nachrichten and Geolino, a nationwide popular science journal for kids.

Kiel Data Management: A Joint Team for Future Ocean, SFB 574, SFB 754 and IFM-GEOMAR

The Kiel Data Management concept focuses on the identity of an individual scientist and his or her work(flow). Instead of following the classical project based practice the newly developed personalized data management approach avoids redundancy in data management efforts and facilitates interdisciplinary collaboration. A web-based portal was established, which forms the starting point for a virtual research platform providing efficient access for all users of the centralized data management. The portal integrates customized personal and project community pages and provides full Web 2.0 enabled technologies. These are e.g. project communities with document libraries, wikis, and forums supporting daily project activities. The generated data, whether it originates from field observations or experiments, is treated as a process irrespectively of the discipline it comes from. This approach allows to store the data in a single consistent data model.

Organization of the Data Management

The Kiel Data Management group was founded in late 2008 as a collaborative effort between the Leibniz Institute of Marine Sciences (IFM-GEOMAR), the two collaborative research projects SFB 574 and SFB 754, and the Cluster of Excellence Future Ocean. It recognizes, that the projects and the Institutes have urgent demands to organize, handle and disseminate scientific data in an effective and standardized manner. The resources of each individual project were not sufficient to provide full coverage for each project, however, the demands centring on marine science data were very similar. It was therefore agreed among the projects, to pool the available positions (one per project and institute), found a data management group, rather than four individual data managers, and task this group to come up with a common data management concept suitable to deal with the most important marine science data. It was also agreed to form a data management advisory board, providing guidance and advice to the group, and to install a formalized path allowing the projects to express their upcoming specific needs. The group of four data managers was subsequently installed in early 2009.

Current State

In the beginning numerous personal interviews with researchers and group leaders of the projects were carried out in order to evaluate specific data management needs on various levels of the different disciplines. Besides getting to know each other, information of already existing legacy data management strategies were collected. The group also got an overview of the variety of parameters to be expected.

The currently installed data management system follows a personalized data concept and consists of a web portal https://portal.ifm-geomar.de, providing personal access by scientists to project communities and their contents. Access rights can be based on the user identity. The portal offers several services, among them the possibility of document exchange, set up of common or individual wikis, blogs, and forums as well as the incorporation of external web pages and -services. Moreover, scientists can access an expedition metadata application, organizing meta information and exchange of research data for cruises and expeditions for all projects. Geo-referenced information can be exported into XML formatted datasets compliant with the Open Geospatial Consortium (OGC) standards. Exports to KML formats e.g. for use with Google-Earth, allow a visualization of any stations

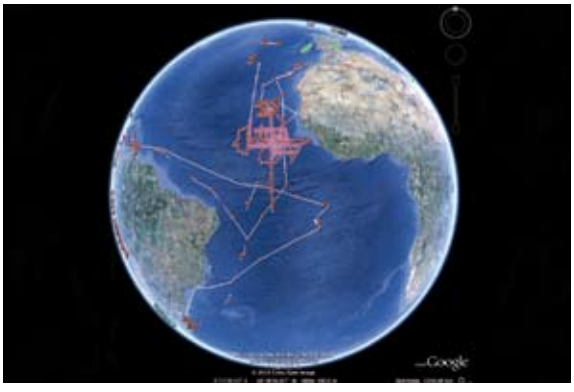

Figure 1 | Atlantic

Figure 2 | Europe

Figure 3 | East Pacific

Figure 4 | West Pacific

from research expeditions and may provide additional links to access in-depth datasets.

The currently envisioned data management infrastructure is intended to store data to cover the time period from data acquisition to publication, or 10 years following a DFG data policy. The ultimate long-term archiving of data will not be done by a local infrastructure. It will be achieved using existing national and international facilities, e.g. world data centres like Pangaea in Bremen, Germany, the Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge, Tennessee, USA

The next steps planned will cover two prominent data management challenges: metadata from numerical modelling and the linkage between publication records and the respective metadata and data records. Set up of a common publication repository of the Leibniz Institute of Marine Sciences (IFM GEOMAR) together with the Cluster of Excellence Future Ocean is planned for 2010 using the EPrints system developed at the National Oceanography Centre, Southampton, UK.

Services

Besides pure data handling, the data management group offers several general services to researchers. These are e.g. guidance in proposal writing, aiding to explain data management concepts and implementation like required staff and hardware for research projects. The group also provides support and training on how to use the portal, e.g. how to log in, where to upload data, and how to retrieve data. Data managers also give recommendations for collaboration within teams, research units, or projects and collect demands and ideas for a possible future data policy.

The group proactively advertises the data portal and the metadata applications to potential users, like the Junior Research Group leaders of the Future Ocean. A discussion workshop on a possible future data policy, data templates and data archives is planned for Fall 2010. Interested scientists are welcome to contact the data management team for information and participation.

Co-operations

Co-operations exist to numerous working groups, but are in particular close to the institute for computer science at the University Kiel. Data management collaborates with N. Luttenberger from the communication systems department e.g. on the implementation of a GUI to achieve a XML workflow from a graphical user interface. Workflow systems will be developed together with W. Hasselbring from the Software Engineering group. This collaboration led to a joint Research Proposal to DFG in April 2010. The data management group also established contact to the centre for geo-information (ZfG) at the University Kiel specialised in GIS applications in order to get support with GIS applications for cruises. Ties also exist to the

Graduate School Human Development in Landscapes funded through the German excellence initiative at the University Kiel. The graduate school intends to develop robust database structure in order to store archeological and historical data and is interested in contact and cooperation. Other networks include the GKSS-Research Centre, Geesthacht, Germany, which operates the COSYNA data portal, and the Federal Administration for Maritime Traffic and Hydrography BSH/DOD. A close cooperation exchanging data and station books from the Davis System used onboard the German research vessels, has been established.

Future Plans

At the time being the data in the data management portal is currently stored and organized in files. Accordingly, it is at the moment not possible to make automatic synthesis queries of e.g. several cruises or a certain individual set of parameters. The data management group is therefore developing a generic data model based on a data provenance system. This description will provide full documentation of data integrity, quality assessment and control for all users. The one-time necessity to develop and define an initial workflow is balanced by the advantage of individually customized data input forms based on the mentioned data provenance description. Following a requirement analysis undertaken in Summer 2009 the IBM data base management system DB2 had been purchased in late 2009. It will allow to merge data originating from a great variety of marine disciplines, and will support the „discovery" of cross-discipline data by geo coordinates.

The Data Management Team

Hela Mehrtens, Pina Springer, Dirk Fleischer, Carsten Schirnick

Web Link https://portal.ifm-geomar.de

Integrated School of Ocean Sciences

The Integrated School of Ocean Sciences has given a face to interdisciplinary marine science education at the Christian-Albrechts University that is driven by and incorporates all research disciplines in the Future Ocean. Our PhD programme is research-driven and career oriented, providing in equal measure research skills and interdisciplinary exposure as well as components that aim to "empower" and "inspire" and extend to life beyond a PhD.

As a central element of the Future Ocean, the Integrated School of Ocean Sciences (ISOS) is the common ground on which education in cluster-driven research topics from economics, law, computing and medicine converge with the classical oceanographic disciplines. The challenge at the ISOS has thus been to provide added value beyond the curricular framework – to develop ways by which students and PhD candidates from differing disciplines can find common ground and access the diversity that characterises the new Kiel focus in marine research. Simultaneously, a key focus has been on creating excellence in graduate education in a strongly academic environment that will empower and enable young scientists to apply their skills in a competitive and rapidly evolving job market.

Courses for Marine Sciences

We have chosen a four-pronged approach, in which basic course-work is largely conducted outside of and complementary to curricular courses and defined by the generic needs of students from several disciplines. Interdisciplinary cross-over, strongly supported by Future Ocean Professors, plays a central role at the ISOS and builds bridges between scientists at an early career stage. A large demand is in provision of compact courses for applicable skills for research e.g. Geographic Information Systems, Digital Image Optimization, advanced methods of scientific computing, use of data bases and many others.

Transferable-Skills: Overrated or Undervalued?

Transferable-skills at the ISOS feed directly into the output of PhD candidates and give them tools to orient themselves on a wider level. PhDs learn and practice moderation of podium discussions, discuss the ethics of good scientific practice, or are taught by a freelance journalist to write for the popular press (see the portrait of ISOS PhD Maike Kramer, page 72). Visit our website for a comprehensive list.

Support Structures

Active support structures such as thesis committees, peer mentoring, PhD-tutoring and mentoring at scientific fairs (see page 62), to name but some, play a major role in furthering diversity and gender equality. They support senior scientists by providing input in areas often beyond the reach and mandate of academic supervision, and form a strong network of next-generation scientists.

During its development, ISOS has anchored itself broadly at the University, contributed lasting graduate foci to University Institutions, and has involved external partners from academia, policy, NGOs, Industry, alumni etc., giving a new visibility to marine science education in Kiel.

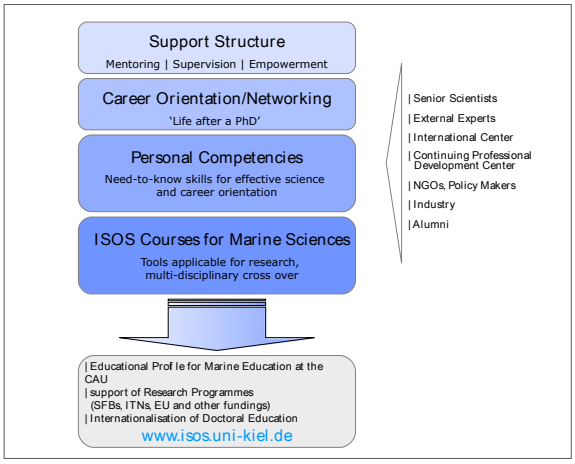

Figure 1 | By providing extracurricular components that boost scientific, professional and personal skills, ISOS allows PhD candidates to stand out during and after their doctoral research.

Project Team

Avan Antia, Angelika Hoffmann, Kerstin Hoffmann, Dorothea Janofske

Life after a PhD?

Orientation towards research, interdisciplinary exposure and academic performance are at the core of education within the Future Ocean. But how can PhDs transfer skills and innovative potential gained during their time in research in a fruitful and personally satisfying manner to a wider context – academic or otherwise?

At the Integrated School of Ocean Sciences PhD candidates are encouraged to think beyond the PhD, to be enthused and inspired by role models who have forged individual career paths and to network personally outside their own academic field. Several events at the ISOS address "Life after a PhD", including the PhD Retreats, Career Evenings, "Meet the Prof." events and workshops with Science and Industry (see page 63). Regardless what path the individual may choose, we are convinced that the skills developed and networks forged are as applicable within the research environment as outside, and are an essential component of all-round academic education.

PhD Retreat "Life after a PhD"

In 2009 the annual 2-day Retreat focussed on the PhD students' expectations and concerns with life after a PhD. ISOS PhD candidates from law, natural sciences and economics were asked to review a successful career path, a wide variety of attributes were seen worth aspiring to. Excellence, dedication and the ability to be excited and to excite others were mentioned, but equally a role model was doing something meaningful – for society, for climate, in a non-governmental organization (NGO). The "non-straight" career path, changing by aptitude and passion, held particular attraction as were less measurable but equally important aspects such as creativity, a moral basis and happiness.

The highlights were round table discussions with invited guests from science, industry, a private company, governmental authority, science administration and medical/pharmaceutical collaborations. Asked to reflect on how they chose their careers, each expert came ready to contribute thoughts, experience and expertise and answer questions as they came.

A recurrent theme was the long working hours spent on a scientific career and how or even whether this can be reconciled with leading a satisfying personal and family life. But as one participant wrote: "It remained a positive take home message — as the speakers' life suggested — that it is possible to take your life in your own hands and form it so that you can enjoy your time."

Career Evenings

Following up on the Retreat, in a series of Career Evenings we heard personal testimonials of several role models: Thomas Heningsen, Campaign Director of Greenpeace International, Markus Salomon, Scientist at the German Advisory Council on the Environment (SRU) and Rasmus Prieß who co-founded "Thema 1", a think-tank in Berlin that engages with industry on carbon footprinting.

"Meet The Prof."

Meet the Prof. events with personal access to visiting scientists underscore the importance of building contacts, standing out from the crowd, and using a network to open the Post-Doc position of choice. Leading international scientists give insights into education and research at the international level and discuss what they seek in the best young scientists.

Figure 1 | Invitation to an ISOS Career Evening

Research in the Refrigerator: Life in Sea Ice

Does your grandmother understand what you are doing in your research? What sounds like an absurd question has a serious background. Scientists should be able to explain their research in a way intelligible to all. ISOS PhDs rose to this challenge as part of an ISOS course on Scientific Writing conducted by a freelance journalist. As one of the results, Maike Kramer's portrait delivers insight into the work of an early-stage researcher in the Cluster of Excellence "The Future Ocean".

Maike Kramer takes a sip of tea from her thermos, and then she returns her concentration to the binocular microscope. For two hours now the doctoral candidate has been sitting in the laboratory at refrigerator temperatures and sorting animals hardly recognizable to the naked eye. She has carefully extracted the animals from within sea ice, and is now offering them different single-celled plants and animals to determine their feeding preferences. „Most people think I have misspoken when I talk about animals *in* the ice," the biologist grins. „But it is true: there are animals in the ice and they really are alive. That is exactly what makes it so fascinating."

Alive in the ice – how is that possible? The answer lies in the way sea ice is formed when salt water freezes. While the water freezes into ice crystals, the salt is concentrated into a saline solution, the brine. As the sea ice gets thicker, narrow brine channels are formed within the ice, connected to each other like the branches of a tree. Much as the salt on our roads keeps water from freezing even at minus temperatures, brine in sea ice remains fluid. The organisms living in the brine channels include Maike's 'house pets', the so-called sympagic meiofauna. Maike pauses to explain; the word sympagic means "with ice", meiofauna are what scientists call minute animals between 0.1 and 1 mm in size.

Figure 1 | After the ice sample is melted, Maike Kramer examines the sea-ice meiofauna in a cooled laboratory under a binocular microscope.

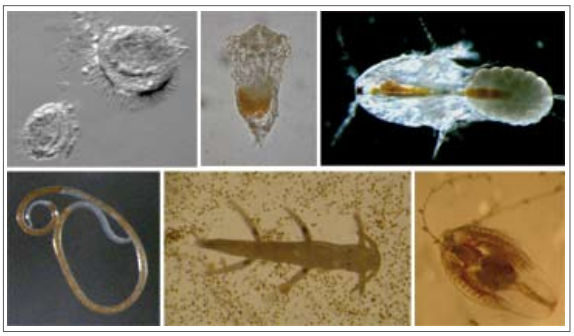

Figure 2 | Sympagic meiofauna: CILIATES (upper left), rotifer (upper centre), copepod (upper right), nematode (lower left), slug (lower middle), comb jelly (lower right).

"People often ask me how I manage to work for hours at a time on the ice at freezing temperatures," says the 27-year old. Of course the work is taxing. "I have at times worked on a windy ice floe at minus 30°C for eight hours without a break. By lunch-time the tea in my thermos was cold and the cheese in my sandwich frozen," Maike laughs. Thanks to special clothing and constant movement she hardly feels the cold on the ice—it's another story when she works for long hours in the refrigerated laboratory. "As long as I am looking into the microscope I do not feel cold, but when I take a break after a few hours I notice that I am really chilled to the bone". Maike shivers involuntarily as she speaks.

For four years now Maike has been studying her favorite ice organisms—first within the scope of her Diploma thesis, later as a doctoral candidate. The organisms of the meiofauna are as diverse as they are bizarre: single-celled ciliates with beating cilia like eyelashes, worms, tiny shrimp-like copepods and gyrating rotifers. The animals swim or crawl through the brine channels, eat and reproduce there. "I am interested in what these organisms eat and how much," explains the researcher and adds: "Especially in times of climate change it is important to examine the biology of ice-associated organisms so that we can estimate what impact receding sea ice may have on the ecosystem of the polar seas."

Maike recalls her first contact with sea ice during a concert tour to Finland with the salon orchestra of her high school. "I was unbelievably fascinated by the fact that we could take a walk on the frozen Baltic Sea," Maike remembers. In school

she was already interested in marine biology and worked during her holidays as an intern in this field. Feeling a tug toward the north, she studied Finnish and worked for a year in Finland as a volunteer. It was during courses at Helsinki University that she met her current thesis advisor and found her way to Kiel for PhD research.

Since then the young polar researcher has been on expeditions to the Arctic and Antarctic, and reminisces on how unique marine polar research is. Sea ice researchers work from ice-breakers that ram their way through the pack ice. Once the ship docks at a suitable ice floe the scientists gather their gear and descend the gangway onto pristine sea ice. Drills are used to take ice cores that are cut lengthwise into sections, which are then carefully melted and examined. From such melted cores Maike has carefully, gently, pipetted out animals for her feeding experiments. "Working on the ice is the nicest part of my job," the researcher raves. "The varied forms of the ice, the light, the colors are beautiful." An added excitement is in having special encounters with animals others see only in zoos. Penguins in the Antarctic are curious and sometimes come to take a closer look at the work of the human intruders. In the Arctic work on the ice is more tense, since polar bears can turn up at any time and they are not always so peaceful. "On cruise in the central Arctic we saw polar bears every few days", reports Maike Kramer, "sometimes only 50 meters away – but luckily, we were always on board!"

Whether these encounters will be possible in the future is questionable, since the melting of sea ice threatens the Arctic ecosystem – most people have heard of threats to polar bears, but what about the sympagic meiofauna that Maike studies, and that is at the base of the entire food web? This troubles Maike Kramer: "It was frightening to see that Arctic sea ice looks completely different than in the textbooks: much thinner and more brittle, full of deep melt ponds. If you have seen this with your own eyes you can hardly have any doubts about climate change and its dramatic impact."

Figure 3 | PhD student Maike Kramer taking ice samples. Ice samples are taken with a special ice drill and then the ice core is cut lengthwise into pieces.

Then she adds determinately: "I see it as my responsibility as a polar researcher to spread the word – and as everyone's responsibility to do something about it."

This text was written as part of a media and press training conducted by the Future Ocean's Integrated School of Ocean Sciences.

Figure 4 | Penguins sometimes come to take a closer look at Maike Kramer's work on the Antarctic pack-ice.

Education for the "Future Ocean"

In the past three years the spectrum of educational offers within the Cluster has included a wide range of activities outside of curricular programmes that are used by PhD candidates and students from all the disciplines in the "Future Ocean" Cluster. Web-based learning (E-Learning) plays an important role in ensuring continuity of courses, using new tools for education and providing a resource that can be used "anytime, anywhere" for both teachers and learners.

Concept

The Integrated School of Ocean Sciences (ISOS), through its PhD Programme (see page 70) and the implementation of an E-Learning framework, provides new and innovative educational structures anchoring marine sciences at Kiel University. The concept we follow a) gives young scientists access to the research spectrum of the cluster b) provides targeted courses for research skills where the demand is high, c) enthuses and enables PhD candidates to develop personal competencies and d) anchors marine science education on a web-based platform. The strategy places minimal extra teaching load on cluster scientists by spreading the course structure over several institutions and involving external experts where needed.

Courses for Science

In course development, emphasis is placed on new cluster research foci, on basic skills for research and on exposure to multidisciplinary themes. Several of our courses are requested from groups of PhD candidates, others are offered by cluster members or involve visiting scientists. Three major categories of scientific courses have been developed:

1) Specific, in-depth courses on cluster research themes: A prime example of this is the one-week course on Numerical Optimization held in 2009, in which professors and their students from computational sciences, biogeochemical modelling and economics were involved.

2) Generic Skills for Science: targeted courses in basic skills for research are in great demand, ranging from the generic (e.g. uni- and multivariate statistical analyses, Matlab, GIS, Digital Image Optimization etc.) to the more specific (Lab Rotation in Molecular Techniques, Facilities for Isotopic Research, Mass Spectrometry and Optical Spectroscopy etc.). Young scientists not only expand their scientific tool-box, they also acquire basic, certified, skills with which to enter the job market.

3) Multidisciplinary courses outside of curricular programmes conducted by cluster scientists, guest professors and invited lecturers: Typical course durations are 1-3 days, and the emphasis is placed on providing participants with applicable knowledge of adjoining disciplines. Courses on Law of

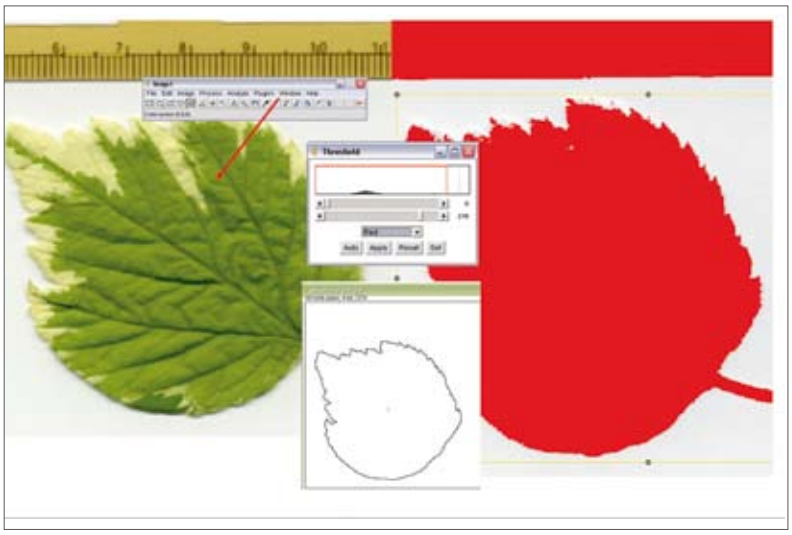

Figure 1 | Skills for scientific Research: Image Analysis with "Image J".

the Sea and Natural Resource Economics, Carbon Footprinting and Marine Environmental Protection to name but some, also bring young scientists from diverse disciplines in dialogue with their peers.

Personal Competencies

In 2009 we developed several exciting (and sometimes exploratory) courses aimed at giving PhD students short, intensive interactions outside of the traditional University environment. Talents that surface here are equally important in an academic and non-academic framework. The overarching theme of these courses is in learning and applying communication techniques at several levels, and the underlying assumption is that clarity of communication improves clarity of thought. PhD candidates not only learn techniques to moderate a discussion, but do this themselves on a podium with experts from science and politics. Students work with a freelance journalist on public communication of science, with a theatrical expert on optimising a scientific (lecture) "performance" and with a multimedia expert on designing a poster. More traditional "transferable-skills" courses are conducted in collaboration with University bodies such as the Center for Academic Further Education, the International Center and the Graduate Center of the University.

Figure 3 | An Online WiKi on "Organisms of the Baltic Sea" is in development.

E-Learning as an Educational Tool

At the ISOS the use of E-Learning to anchor course content on a web-based platform offers several advantages: courses can be repeated and incremented with minimal effort, teachers are able to use the resources for their own teaching, and most importantly, contact time within courses can be optimised by providing background material on a web-based platform. New teaching forms that enhance the learning experience are being developed within ISOS. Such new forms include engaging course participants as authors of E-Content, applying dynamic media such as audio and video tutorials and the online availability of podcasts of teaching units.

Figure 2 | E-Learning is accessible anytime, anywhere.

A central University facility for E-Learning – based on the original ISOS Model – will be available in 2010. This will reduce the administrative burden on the ISOS, allowing us to concentrate on developing innovative E-Content outside of the traditional teaching framework. Photo, video and audio equipment as well as professional E-Learning software is being developed for the production of E-Lectures, tutorials, podcasts and WiKis. A first such project in development is an ISOS WiKi on "Organisms of the Baltic Sea", in which course participants studying the distribution, taxonomy and physiology of Baltic Organisms publish their work online. In 2009 the E-Lecture "Introduction to Marine Geology" was recorded and published as a combination of slides, video and audio material. These recordings were highly valued by the students as a welcome addition to classroom activities.

Although E-Learning is currently used as supplementary to personal contact, it is also a powerful tool for anchoring teaching across distances, as part of international programmes and educational outreach. ISOS is now initiating the use of online learning more extensively in close collaboration with partners at the University and other faculties by pooling resources for content development.

Outlook

The cluster Model of research-oriented education is now well consolidated within the ISOS and offers a unique profile at the University of Kiel. Its main pillars of 1) academic, multi-disciplinary "added-value" outside of curricular programmes, 2) empowerment of young scientists for academic and non-academic careers and 3) the use of E-Learning to build a resource of targeted marine science offers, provides a successful model for wider application.

Further Information

www.isos.uni-kiel.de
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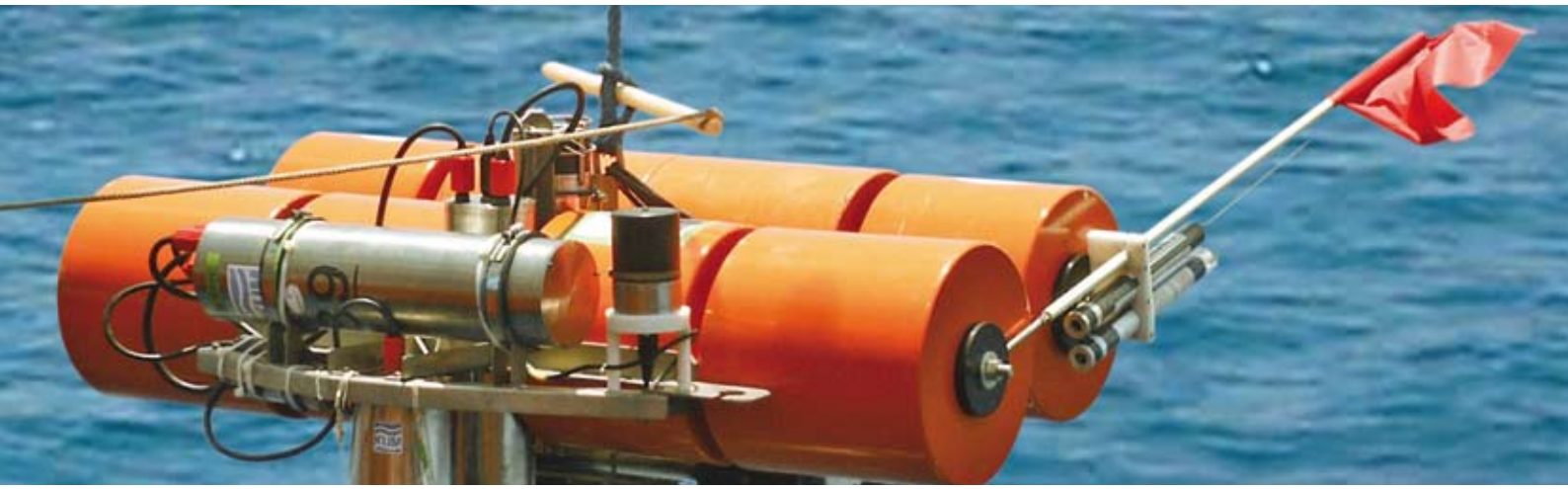

Transfer to Application

The Transfer to Application project aims to communicate innovative knowledge and new technologies developed by the Future Ocean into industry and to non-governmental organizations. Many university and industry related organizations are already active in this field. Some establish connections between scientists and industry partners, some help local companies to become internationally visible, some strive to disseminate the latest research to spark new ideas and investment opportunities with potential investors. The Future Ocean cooperates with all of them through its Transfer to Application project. Together with various partners we start knowledge and exploitation projects, in order to communicate our science to the public and to the benefit of our local industry and stakeholders. Some initiatives have been started in 2008 as test balloons. More of them have been started in 2009, in order to evaluate where the potentials of success lie. This process is still ongoing. The Transfer to Application project is a test bed of measures, where the outcome is not always known in advance. In the end, however, these measures are evaluated to determine, which parts of this project offer potential for successful knowledge transfer and which ones do not apply to either industry or the marine science community. In 2009 the initiatives focused in particular on PhD students and postdocs of the Future Ocean.

Science Marketing

In May 2009 the Offshore Technology Conference (OTC) has taken place in Houston. The OTC is the biggest global offshore technology meeting in the world. More than 65,000 visitors from all over the world attend the show, as it is both, an industrial show with more than 2500 exhibitors of the branch and at the same time a conference with technical and science sessions. Together with the IFM-GEOMAR the Cluster of Excellence "Future Ocean" set up an exhibition booth in the pavilion organized by the German Federal Ministery for Economics and Technology.

Figure 1 | Our Offshore-Technology-Conference-Team, in the background our new booth.

Two PhD candidates were sent to OTC as part of a cooperation with the Integrated School of Ocean Sciences (ISOS, see page 70). One of them, Peer Fietzek presented an in-house developed ocean bottom seismometer (OBS) to the public. The seismometer is a low-budget high frequency sea floor solution which can be used for shallow water seismic measurements like e.g. foundation soil analysis for offshore construction for water depths up to about 60 meters. The seismometer generated some interest of companies. Overall this was a very good experience in order to learn how this kind of industry events work and to introduce the Future Ocean to industry. Based on this good experience we are preparing attendance of the Future Ocean at the Oceanology International 2010 in London.

Science and Industry Networking

The workshop "Science meets Industry" was developed and conducted by the Transfer to Application and the ISOS. The workshop focused on PhD students and postdocs of the Future Ocean, pursuing the goal to support the link between science and economy on a young researcher's level. For this purpose a highly relevant topic was chosen: "Science meets industry - Energy from the Sea". Key players from academia and industry gave talks about their practical experiences. The participants gained further insight through site visits to midsize and large companies.

This first workshop also involved the large scale project on submarine gas hydrate reservoirs (SUGAR). Conducted by the Kiel Leibniz Institute of Marine Sciences (IFM-GEOMAR)

Figure 2 | PhD students and postdocs are informed about company related questions.

Figure 3 | Networking: Flagship projects meet at the FTZ (Forschungs- und Technologiezentrum Westküste).

30 partners from science and economy will develop new technologies to extract natural gas (methane) from methane hydrates in the seabed and conversely store carbon dioxide from power plants and at the sea floor. This project is funded by the German Federal Government. Project coordinator Klaus Wallmann, gas hydrate scientists, and representatives from the companies RWE and Contros contributed to the workshop. Subsequently participants could take a tour through the company Contros in Kiel, Germany, and an RWE Dea production facility in Friedrichskoog, Germany, were visited. This left the 30 participants with a better understanding of how these kinds of partnerships work.

Based on the the experience a second workshop "Science meets Industry – Algae of the Future" will be organized.

Other Topical Events

Scientists of the Future Ocean have started a lecture series with Det Norske Veritas (DNV) in Hamburg, Germany, one of the world´s leading ship classification societies. The lectures circled around various maritime topics like underwater technologies, climate change, deep sea drilling and tsunamis.

In 2009 the Transfer to Application project also began to support networking between the six Northern German maritime flagship projects, supported by the federal state of Schleswig-Holstein. These projects comprise Research and Technology Centre (FTZ) in Büsum, Germany, the Society for Marine Aquaculture (GMA), Kiel Agent Center (KiWiZ), Fraunhofer-Institute for Marine Biotechnology (EMB), the FuE-Zentrum FH Kiel, and the Center of Excellence Future Ocean. By initiative of the Future Ocean these institutions met several times in 2009, and will strive to meet frequently in the future to exchange information on projects and to exploit possible synergies among each other. The Transfer to Application of the Future Ocean is committed to foster marine science and research not only within the project, but throughout the whole state of Schleswig-Holstein and beyond.

Outlook

In 2010 the Transfer to Application plans to continue many of the already begun projects. The Oceanology International Fair in London will be attended in February, with a joint Future Ocean / IFM-GEOMAR booth. Future Ocean will present a model of a low cost 3-D seismic system, which can be operated from small to mid-sized vessels. In addition more Science Industry workshops are on the schedule, as well as another summer school organized together with ISOS in September.

Transfer to Application Contact

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The Appendix

The most exciting phrase to hear in science, the one that heralds new discoveries, is not ‚Eureka!' but ‚That's funny...'

Isaac Asimov

Members of the Future Ocean

Name	Institution
Andersen, Nils	CAU
Behrmann, Jan	IFM-GEOMAR
Bensch, Wolfgang	CAU
Beyer, Martin	CAU
Bialas, Jörg	IFM-GEOMAR
Biastoch, Arne	IFM-GEOMAR
Bilger, Wolfgang	CAU
Bleich, Markus	CAU
Böning, Claus	IFM-GEOMAR
Börm, Steffen	CAU
Bosch , Thomas	CAU
Braack, Malte	CAU
Brandt, Peter	IFM-GEOMAR
Bröck, Ralf	CAU
Brückmann, Warner	IFM-GEOMAR
Clemmesen-Bockelmann, Catriona	IFM-GEOMAR
Colijn, Franciscus	FTZ
Croot, Peter	IFM-GEOMAR
Dahmke, Andreas	CAU
Dengg, Joachim	IFM-GEOMAR
Depmeier, Wulf	CAU
Devey, Colin	IFM-GEOMAR
Dullo, Christian	IFM-GEOMAR
Duscher, Tom	MKHS
Eden, Carsten	IFM-GEOMAR
Ehlers, Claudia	CAU
Eisenhauer, Anton	IFM-GEOMAR
Ernst, Rainer W.	MKHS
Feeser, Volker	CAU
Fietzke, Jan	IFM-GEOMAR
Flögel, Sascha	IFM-GEOMAR
Flüh, Ernst R.	IFM-GEOMAR
Fouquet, Gerhard	CAU
Frank, Martin	IFM-GEOMAR
Friedrichs, Gernot	CAU
Froese, Rainer	IFM-GEOMAR
Garbe-Schönberg, Dieter	CAU
Garthe, Stefan	FTZ
Giegerich, Thomas	CAU
Götze, Hans-Jürgen	CAU
Greatbatch, Richard	IFM-GEOMAR
Grevemeyer, Ingo	IFM-GEOMAR
Grotemeyer, Jürgen	CAU
Hackbusch, Wolfgang	CAU

Name	Institution
Harms, Ute	IPN
Hartke, Bernd	CAU
Hasselbring, Wilhelm	CAU
Hauff, Folkmar	IFM-GEOMAR
Hensen, Christian	IFM-GEOMAR
Herzig, Peter	IFM-GEOMAR
Hoeher, Peter	CAU
Hoernle, Kaj	IFM-GEOMAR
Holzheid, Astrid	CAU
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Imhoff, Johannes F.	IFM-GEOMAR
Jansen, Klaus	CAU
Jegen-Kulczar, Marion	IFM-GEOMAR
Jenisch, Uwe	CAU
Jung, Christian	CAU
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Kläschen, Dirk	IFM-GEOMAR
Klepper, Gernot	IfW
Koch, Reinhard	CAU
Kopp, Heidrun	IFM-GEOMAR
Körtzinger, Arne	IFM-GEOMAR
Krastel, Sebastian	IFM-GEOMAR
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Krüger, Kirstin	IFM-GEOMAR
Kuhnt, Wolfgang	CAU
Kunzendorf , Ulrich	CAU
Lackschewitz, Klas	IFM-GEOMAR
LaRoche, Julie	IFM-GEOMAR
Latif, Mojib	IFM-GEOMAR
Lehmann, Andreas	IFM-GEOMAR
Linke, Peter	IFM-GEOMAR
Luttenberger, Norbert	CAU
Maser, Edmund	CAU
Mayerle, Roberto	FTZ
Meier, Sebastian	CAU
Melzner, Frank	IFM-GEOMAR
Molinero, Juan Carlos	IFM-GEOMAR
Müller, Johannes	CAU
Müller, Wolf Ulrich	CAU
Nadeau, Marie-Josée	CAU

Name	Institution
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Peterson, Sonja	IfW
Pfannkuche, Olaf	IFM-GEOMAR
Piatkowski, Uwe	IFM-GEOMAR
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Proelß, Alexander	CAU
Quaas, Martin	CAU
Rabbel, Wolfgang	CAU
Rehdanz, Katrin	IfW
Requate , Till	CAU
Reusch, Thorsten	IFM-GEOMAR
Ricklefs, Klaus	FTZ
Riebesell, Ulf	IFM-GEOMAR
Rimbach , Gerald	CAU
Rosenstiel, Philip	CAU
Rüpke, Lars	IFM-GEOMAR
Sachs, Stephan	MKHS
Schäfer, Priska	CAU
Schenk, Volker	CAU
Schmidt, Mark	CAU
Schmidt, Ulrich	CAU
Schmidt, Ingmar	CAU
Schmitz-Streit, Ruth	CAU
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Schneider, Birgit	CAU
Schönfeld, Joachim	IFM-GEOMAR
Schreiber, Stefan	CAU
Schröder, Jens-Michael	CAU
Schrottke, Kerstin	CAU
Schulenburg, Hinrich	CAU
Schulz, Manfred	MKHS
Schulz, Rüdiger	CAU
Schwarzer, Klaus	CAU
Siebert, Ursula	FTZ
Slawig, Thomas	CAU
Snower, Dennis	IfW
Sommer, Ulrich	IFM-GEOMAR
Srivastav, Anand	CAU
Stattegger, Karl	CAU
Sterr, Horst	CAU
Temps, Friedrich	CAU
Thalheim, Bernhard	CAU

Name	Institution
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Vafeidis, Athanasios	CAU
Visbeck, Martin	IFM-GEOMAR
Wahl, Martin	IFM-GEOMAR
Wallace, Doug	IFM-GEOMAR
Wallmann, Klaus	IFM-GEOMAR
Weinberger, Florian	IFM-GEOMAR
Weinrebe, Wilhelm	IFM-GEOMAR
Wirtz, Kai	GKSS
Zimmer, Martin	IFM-GEOMAR

Institutions	
CAU	Christian-Albrechts-Universität zu Kiel
GKSS	GKSS-Forschungszentrum Geesthacht GmbH
IFM-GEOMAR	Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR)
IfW	Institut für Weltwirtschaft
IPN	Leibniz-Institut für die Pädagogik der Naturwissenschaften (IPN)
Leibniz Labor	Leibniz-Labor für Altersbestimmung und Isotopenforschung
MKHS	Muthesius Kunsthochschule
FTZ	Forschungs- und Technologiezentrum Westküste (FTZ)

Selected Publications

a

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Wallace, Doug	IFM-GEOMAR
Wallmann, Klaus	IFM-GEOMAR

* Full name of the Institutions see page 81.

Funded Cluster Projects

ID	Author	Titel	Duration
CP0602	Bleich	CO_2-induced Ocean Acidification: Biological Responses and Adaptions	24 months
CP0603	Eisenhauer et al.	Boron Isotopes as a Proxy for pH decresse an pCo2 increase	0 (Investment)
CP0605	Froese et al.	Managing Cod and Sprat in the Central Baltic Sea - A bio-economic multi-species approach with Stochastic regeneration functions	24 months
CP0608	Luttenberger et al.	dearX - XML Technology for marine Data Exchange, Archiving and Retrieval	12 months
CP0609	Macke et al.	The role of light fluctuations on ocean heting and photosynthesis	24 months
CP0610	Piepenburg et al.	Synergetic effects of temperature, pH and salinity on the metabolism of benthic organism	12 months
CP0611	Schmitz-Streit et al.	Complex Barriers and Microbiota in the Ocean: implications for human barrier disorders	24 months
CP0612	R Schneider et al.	Radiocarbon dating of fossil biogenic as an indicator of age differences in surface and subsurface water masses in the past ocean	12 months
CP0614	Srivastav et al.	Mathematical and Algorithmic in Modelling Marine Biogeochemical Cycles	24 months
CP0618	Zimmermann et al.	Beyond Mineral Resources - The International Legal Regime and Regulation of New Uses of the Deep Sea Bed	24 months
CP0619	Latif et al.	Development of a Coupled Climate/Ocean Biogeochemistry Model	24 months
CP0063	Körtzinger	Data Mining	6 months
CP0702	Bosch et al.	Transgenic Aurelia allow functional analysis of genes involved in control of tissue homeostasis and biological barriers	24 months
CP0704	Schulz-Friedrich et al.	Carbon acquisition in coccolithophores: molecular basis and adaptive potential	12 months
CP0706	Wahl & Schmitz-Streit	Complex barriers: The biotic control of marine biofilms on algal surfaces	24 months
CP0709	Maser et al.	Marine Steroid Pharmaceuticals to Control Human Diseases	24 months
CP0710	Eisenhauer et al.	VARAN -Variations of Trace Element Fluxes induced by Ocean Acidification at Ca2+-Channels/ Ca2+-ATPases	24 months
CP0713	Oschlies et al.	A new computational framework to efficiently integrate biogeochemical models from seasonal to multi-millennial time scales	24 months
CP0717	Thomsen et al.	Complex barriers and microbiota in the Ocean	24 months
CP0718	Klepper et al.	Economic valuation of the ocean's role in the carbon cycle and consequences for abatement and mitigation strategies	24 months
CP0721	Braack et al.	Parameterization of near surface vertical mixing processes by multiscale methods	24 months
CP0722	Sommer et al.	Building up the capacity for δ34S measurements from organic samples by continuous flow isotope mass spectrometry	24 months
CP0724	Braack & Schneider	3-D Simulation of Thermohaline Convection in the Ocean's Crust with Adaptive Finite Elements	24 months
CP0725	Schönfeld et al.	Changing habitats of calcareous plankton in the Greenhouse World	24 months
CP0726	Wallace et al.	Improved Methods for Nitrogen Isotope Studies with Specific Application at the Tropical Eastern North Atlantic Time-Series Observatory, Cape Verde	24 months
CP0727	Rosenstiel et al.	Deciphering transcriptomal responses to environmental stimuli in simple aquatic model organisms by massive parallel sequencing technology	24 months
CP0730	Oschlies et al.	Modelling chemosensor-aided foraging in zooplankton	24 months

ID	Author	Titel	Duration
CP0732	Koch et al.	3-D Modeling of Seafloor Struktures	8 months
CP0734	Oschlies et al.	Carbon and Nitrogen Cycle Dynamics	18 months
CP0737	Luttenberger et al.	An XML-based workbench for marine and biological data (XDataCollection)	6 months
CP0739	Oschlies et al.	Neuronal-network based coupling of benthic and pelagic..	12 months
CP0743	LaRoche et al.	Bioprospecting of Deep-Sea genetic resources	24 months
CP0745	Dullo et al.	Biogeochemical Studies on the effects of ocean accidification	6 months
CP0746	Weinberger et al.	A transcript profiling tool to investigate synergistic effects of non-biotoc and biotic changes	15 months
CP0747	Karstensen et al.	Glider swarm Project	18 months
CP0751	Requate et al.	Alternative Scenarios for European Fisheries Management	12 months
CP0752	Wahl et al.	The neglected bottleneck: Early life stage ecology in times of global change	24 months
CP0753	Weinrebe	Iceflow activity revealed from submarine morphology - mapping ...	12 months
CP0754	Piepenburg et al.	Ecophysiological consequences of ocean warming and acidification	12 months
CP0758	Friedrichs et al.	The Potential of Field Measurement of Surface Water pCo_2	24 months
CP0765	Melzner et al.	Gene expression patterns in sea urchin embryos: Establishing a model system for	12 months
CP0801	Schönfeld & Spindler	Foraminiferal shell loss in the Flensburg Fjord (SW Baltic Sea). Living benthic communities under the risk due to acidification?	10 months
CP0802	Zimmer	Bacterial symbionts of an invasive species in a warming sea: Mnemiopsis leidyi	12 months
CP0805	Bosch et al.	Developing a novel framework for understanding evolutionary adaption to changing environments: comparative transcriptomics of disparate members of marine Cnidaria	6 months
CP0809	Reusch & Waller	Pipefish-parasite interactions under global warming	12 months
CP0810	Bialas et al.	OBS-Thermo: co-registration of geophysical data at hydrothermal vents - a first step to a new ocean bottom observatory	14 months
CP0811	Meier & Kinkel	Planktonic calcifiers in the Baltic Sea: adaption to carbonate undersaturation in calcifying dinoflagellates?	15 months
CP0812	Quaas et al.	Tradable Fishing Grounds	8 months
CP0813	Oschlies et al.	Can different feeding strategies help to resolve the paradox of the plankton?	6 months
CP0815	Mayerle	The effects of sea-level rise and climate change on long-term morphodynamics in the german wadden sea	24 months
CP0816	Melzner & Körtzinger	Seasonal carbonate system variability in Kiel Bay and correlated physiological performance of local blue mussels	12 months
CP0818	Weinberger & Treude	Consequences of seafloor warming and salinity decrease for macroalga-microbe interactions	12 months
CP0819	Lehmann & Bumke	Detailed assessement of climate variability of the Baltic Sea area for the period 1970-2008	24 months
CP0820	Vafeidis et al.	Shipping induced sediment resuspension in the port of Venice: a case study of the effects of forced Shallow water waves	12 months
CP0822	Wallmann et al.	Assessing the risk of leakage from submarine CCS	15 months
CP0823	Rosenstiel & Schreiber	Establishment of marine invertebrate cell cultures as a tool for immune system and invironmental stress research	25 months
CP0824	Wallace et al.	Air-sea flux measurements of trace gases with atmospheric pressure chemical ionization time of flight mass spectometry (APCI-TOF-MS)	12 months

ID	Author	Titel	Duration
CP0901	Martin Wahl et al.	Missing Baselines and Ecological Noise	18 months
CP0906	Anna Bockelmann et al.	Effects of global change on Labyrinthula-infection in eelgrass Zostera marina	18 months
CP0910	Hermann Bange et al.	A novel system for continuous high-resolution measurements of atmospheric and dissolved N2O	20 months
CP0911	Tina Treude et al.	The occurrence and relevance of nitrogen fixation in sediments of oxygen minimum zones	18 months
CP0912	Sebastian Krastel et al.	Submarine landslides and associated tsunami risk: Combining observations and an integrated modeling approach	18 months
CP0915	Peter Linke et al.	Novel, non-invasive investigation of seafloor warming on oxygen and heat fluxes from the benthic boundary layer into the water column	18 months
CP0918	Friedrich Temps et al.	Photolysis of Carbonyl Compounds in Seawater: Primary Products, Quantum Yields, and Loss Rates in Natural Sunlight	15 months
CP0923	Rainer Kiko et al.	The role of zooplankton in tropical oxygen minimum layers: physiological adaptation and contribution to fluxes of carbon and oxygen	12 months
CP0924	Priska Schäfer	The bryozoan Flustra foliacaea - impact of ocean acidification on benthic organisms	18 months
CP0927	Andreas Oschlies et al.	Does the rise of slime foster an oceanic jelly carbon pump?	18 months
CP0931	Rainer Froese et al.	Winners and Losers in the Future Ocean	12 months
CP0932	Anton Eisenhauer et al.	Magnesium Isotope Fractionation in Planktic Foraminifera as a Proxy for Sea Surface pH Variations	12 months
CP0933	Till Requate et al.	Experimenting with marine protected areas in an ecological-economic fishery model	12 months
CP0937	Nils Andersen et al.	Stable isotope fingerprinting of marine organisms	18 months
CP0938	Torsten Kanzow et al.	A glider fleet to observe sub-mesoscale physical-biogeochemical coupling in the tropical ocean	20 months
CP0943	Kerstin Schrottke et al.	Response of tidal basins to sea-level rise and climate change	18 months
CP0946	Magdalena Gutowska et al.	Mechanisms of intracellular $CaCO_3$ crystalization in hemocytes of Mytilus edulis: sensitivity of bivalve calcification to ocean acidification.	18 months

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