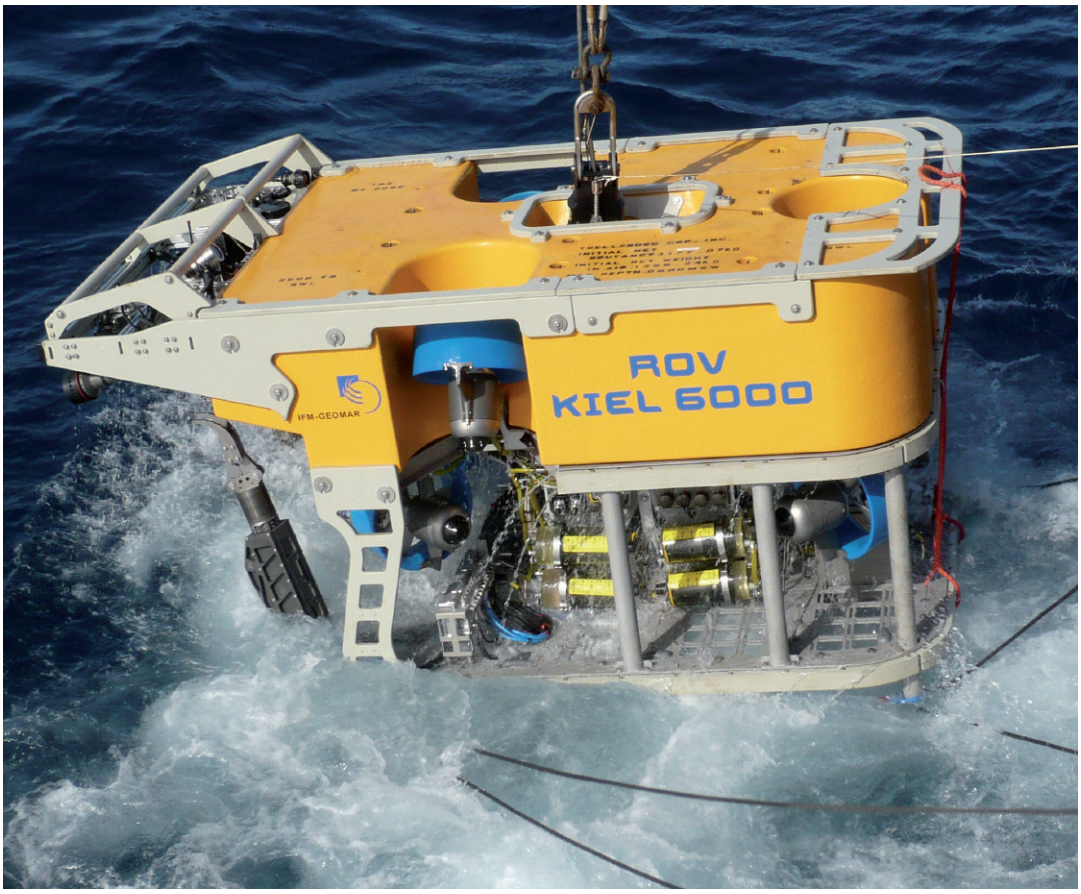
IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

IFM-GEOMAR Report 2007

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -



IFM-GEOMAR Report 2007

Editor: Andreas Villwock

Leibniz-Institut für Meereswissenschaften / Leibniz Institute of Marine Sciences
IFM-GEOMAR
Dienstgebäude Westufer / West Shore Campus
Düsternbrooker Weg 20
D-24105 Kiel
Germany

Leibniz-Institut für Meereswissenschaften / Leibniz Institute of Marine Sciences
IFM-GEOMAR
Dienstgebäude Ostufer / East Shore Campus
Wischhofstr. 1-3
D-24148 Kiel
Germany

Tel.: ++49 431 600-2800
Fax: ++49 431 600-2805
E-mail: info@ifm-geomar.de
Web: www.ifm-geomar.de

Cover photo: ROV Kiel 6000 launched for the first test dive in the Pacific Ocean (Peter Herzig, IFM-GEOMAR).
Inner cover: s.a.

IFM-GEOMAR Report 2007

Preface

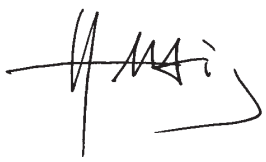
The IFM-GEOMAR success story continues after four years as a combined institute. The benefits resulting from the merger are obvious even though the institute is divided into two parts. Cooperation between scientists from different disiciplines has significantly increased since the merger. For example, 4 out of the 12 scientific highlights presented here are based on cross-disciplinary research. In addition, the increase of technical expertise resulting from workshops, technology exchange and logistical advances have led to higher productivity and extensive research results. IFM-GEOMAR has become an important and visible partner in the international scientific community, in state politics and the local economy. The institute has formed strategic alliances with the German Marine Research Consortium (KDM) and the newly founded German Climate Consortium (DKK). These alliances have not only increased support for marine sciences in Kiel but also on the national and European level. The multi-disiciplinary marine sciences research results published in internationally-renowned journals together with the above mentioned benefits of the merger led to a further increase in project funding during the past year. IFM-GEOMAR received funding for two Collaborative Research Centers (SFBs) on "Climate – Biogeochemistry Interactions in Tropical Oceans" and "The Impact of Subduction Systems on Climate and Natural Hazards." Paired with the Excellence Cluster "The Future Ocean," these large-scale projects are the backbone of basic research at IFM-GEOMAR further integrating different disiplines in the institute and between the institute and University. Furthermore, in 2007 IFM-GEOMAR expanded its research activities due to significant project funding from industry. This new field of cooperation is seen as an additional opportunity to attract funding for research areas with industry application. However, basic science remains the priority at IFM-GEOMAR.

IFM-GEOMAR is now the largest institute of the Leibniz Association and aims to further strengthen its role as a leading partner in marine research on a national and international level. In order to provide a fruitful and stimulating working atmosphere for marine research, the institute is striving to expand its facilities on the east shore by 2012 as recommended by the Leibniz Association.

This report summarises the activities of the institute during 2007 and highlights a number of actual research topics. All relevant documentation and statistics can be found in the appendices.

I hope that you will enjoy reading the "IFM-GEOMAR 2007 Highlights."

Kiel, May 2008



Prof. Peter M. Herzig
Director

Overview

Last year was very successful for IFM-GEOMAR. Project funding reached an all time high with more than 23 Mio. € generated in 2007. Not only is this a record for IFM-GEOMAR but also it is more than the two institutes brought in as separate entities prior to 2004. The excellence cluster "The Future Ocean," was initiated in November of 2006, an autonomous underwater vehicle (AUV) was funded and a number of new cooperations with industry (see pages 5-6) resulted in an increased level of funding. In addition, the German Research Foundation (DFG) supported IFM-GEOMAR in the formation of a new collaborative research centre: SFB 754 "Climate-Biogeochemistry Interactions in the Tropical Ocean" formed in January of 2008.

Major Projects

Excellence cluster "The Future Ocean"

future ocean
KIEL MARINE SCIENCES

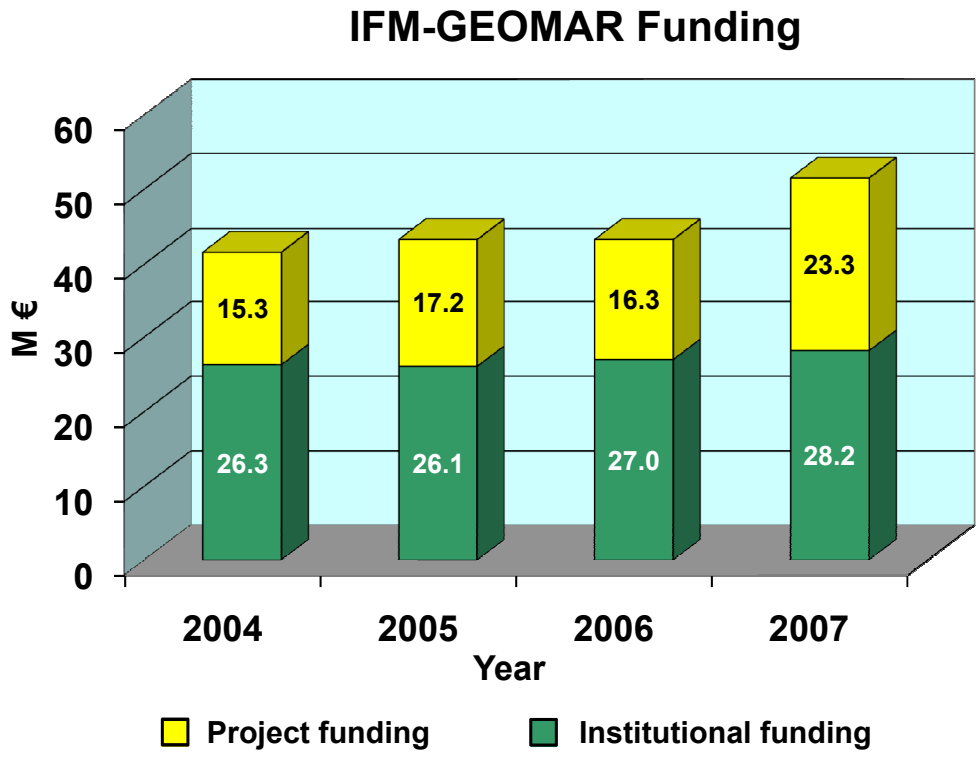
Thirteen Junior Research Groups were founded in January after the candidates gave a joint symposium on their research topics. Sixty five young scientists were invited to present their research plans with respect to Future Ocean related topics. The following candidates were selected for the four groups situated at IFM-GEOMAR:

- Prof. Dr. Frank Melzner: Ocean acidification
- Prof. Dr. Tina Treude: Seafloor warming
- Prof. Dr. Lars Rüpke: Seafloor resources
- Prof. Dr. Sebastian Krastel: Submarine hazards (starts in 2008)

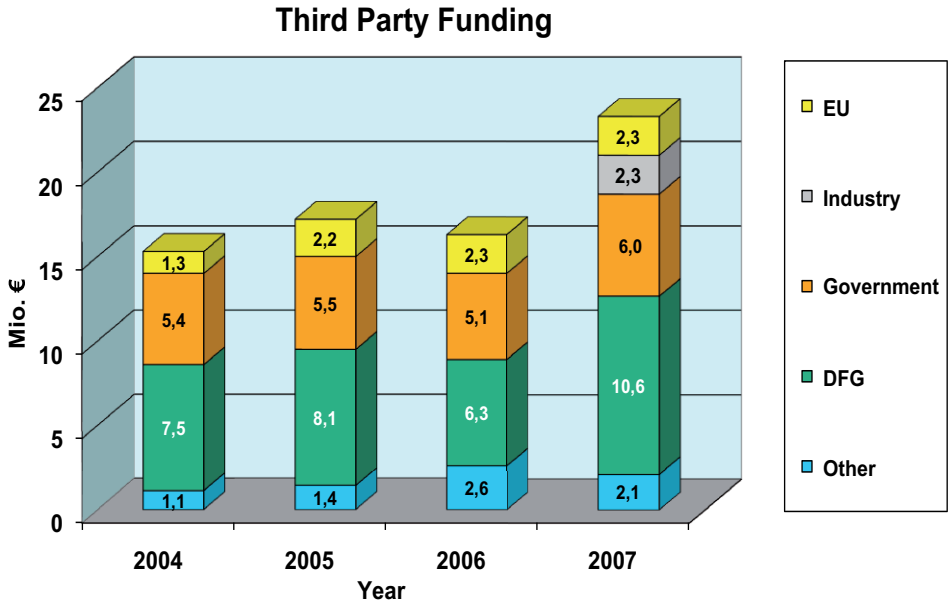
The excellence cluster's management structure was developed in autumn. In November, the initial term of the steering committee ended. The new speaker of the cluster Prof. Dr. Martin Visbeck was elected following Prof. Dr. Klaus Wallmann, both from IFM-GEOMAR. Prof. Wallmann achieved funding and led the initial stage of the junior research selection. Major investments in the cluster infrastructure were also made in 2007 (see marine infrastructure).
More information under www.future-ocean.de.

"Earth Institute"

The "Earth Institute" is a new initiative by the Kiel Institute for the World Economy and IFM-GEOMAR. The project



IFM-GEOMAR funding 2004-2007



Third party funding by sources for the years 2004-2007

is jointly funded by federal and state governments and wants to develop a strategy to manage climate change in an economically and ecologically optimised way. The project is part of the recently founded German Climate Consortium (DKK) (see page 11).

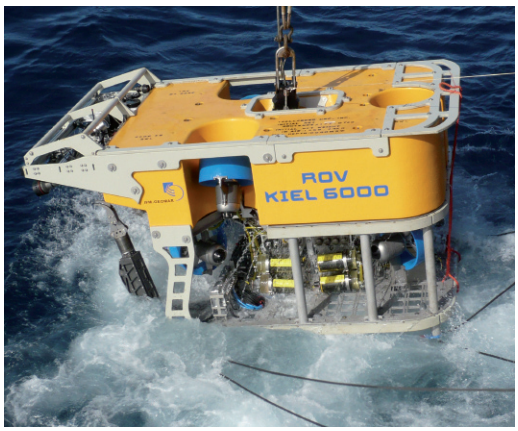
System Laptev-Sea Polynja – Changes in the Eurasian shelf sea– Oceanic fronts and Polynja systems in the Laptev-Sea

The project focuses on oceanic frontal zones and polynya systems in the Laptev Sea. Research methods include remote sensing, multi-year sea-floor observatories, ice camps and ship expeditions, coupled with sea-ice-ocean modelling. Russian-German research teams from St. Petersburg, Moscow, Tiksi, Bremerhaven, Trier and Kiel will study the flow polynja in response to oceanic, sea-ice and atmospheric forcings as well as feedbacks of the Laptev Sea flow polynja to the Arctic System.

The project with eleven German, Russian and Canadian partners is coordinated by IFM-GEOMAR. It has a budget of 2,3 Million Euros and is funded by BMBF and the Russian Ministry for Science and Education from 2007 to 2010.

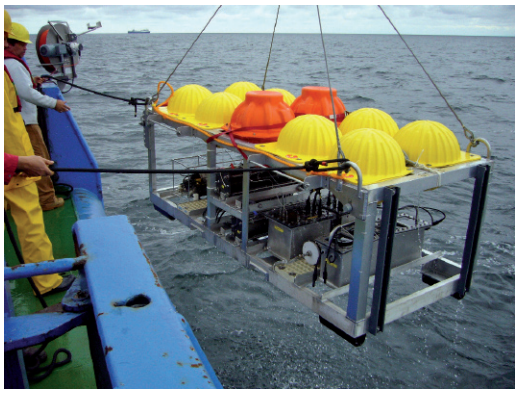
Marine Infrastructure & Technology

The construction and factory acceptance test of the remotely operated vehicle "ROV Kiel 6000" was successfully completed in June. The first deep-sea test followed on the RV "Sonne" in August off the coast of New Zealand. It's first maiden dive was scheduled on RV "Maria S. Merian" in December but it had to be shortened and relocated to the French research vessel "l'Atalante" due to technical problems with the "Maria S. Merian".



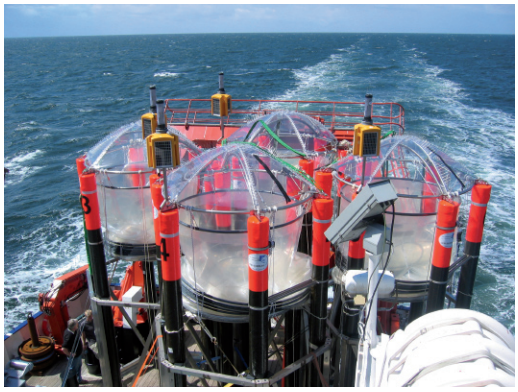
Right: ROV Kiel 6000 test in the western Pacific

The OTIS (Ocean Tracer Injection System) was successfully tested during a research cruise in the Baltic Sea. OTIS is a unique instrument used to inject chemical tracers into the ocean. The system was constructed at Woods Hole Oceanographic Institution, USA with funding from the excellence cluster "The



Left: The Ocean Tracer Injection System (OTIS) revovered after the first successful test in the Baltic.

Future Ocean", the Institute of Baltic Research (IOW) and IFM-GEOMAR. The OTIS releases a chemical inert tracer at a defined depth in order to study mixing and spreading processes in the ocean. A second experiment is planned in the tropical Atlantic near an ocean oxygen minimum zone within the Guinea upwelling regime (GUTRE).



Six off-shore mesocosms developed and built by the Technology and Logistics Centre (TLC) of IFM-GEOMAR were used for the first time to carry out a research experiment in the Baltic Sea Gotland basin. Mesocosms are used as scientific tools to investigate sea organisms and large bodies of seawater. So far, mesocosms have only been deployed relatively close to the coast and without exposure to high waves. The mesocosms of IFM-GEOMAR are much larger and designed for use in the open ocean. Each of them has a length of about 20 m with a diameter of 2 m which corresponds to a volume of 65 m^3 of seawater. The severe conditions of the open ocean require special material reliability and the crane capacity of small research vessels like the "Alkor" limits the total weight of the materials. The TLC staff was able to deliver the optimal compromise of durability and lightweight material. The new laboratory will be used to investigate the impact of changes in environmental conditions such as ocean acidification on ecological processes in greater detail than in previous studies.

A new hydraulic, video controlled, grab was officially handed over to IFM-GEOMAR in October. The instrument is able to lift about two tons of material from a depth of 6,000 meters. The Schleswig-Holstein State Ministry of Science, Economy and Transport contributed 690,000 Euros towards the instrument. It will be used for the first time in 2008.

The new video controlled grab

IFM-GEOMAR received funding from the German Research Foundation (DFG) for an autonomous underwater vehicle (AUV) in the order of 2,3 million Euros. The instrument dives without a cable to a maximum depth of 6,000 meters. It will be available for use in late summer of 2008.

Left: Mesocosms on RV ALKOR ready for their first mission

An AUV similar to the IFM-GEOMAR model

IFM-GEOMAR is well-known for its excellent analytical research facilities. A new mass spectrometer was acquired in 2007, increasing the Institute's capabilities in isotope analysis. The new instrument, a multi-collector ICP-MS, will mainly be used in geochemical and paleooceanographic studies analysing radiogenic (e.g. Nd, Pb, Sr, Hf) and stable (e.g. Mg, Si, Fe) isotopes from sediments and water samples. The new mass spectrometer is highly sensitive, makes possible precise measurements in a wide mass spectrum and it can analyse small samples. The instrument was financed for the Research

The new ICP-MS mass spectrometer

Industry Projects

IFM-GEOMAR started a number of cooperative projects in 2007 with companies in the field of energy and CO_2-sequestration. Some of these projects are basic science (e.g. West Nile Delta Project) while others have an industrial orientation (e.g. CLATHRAT). Although financial support is provided by the industrial partners, the research is not prescribed, apart from the definition of common areas of interest and the results will be published. The following projects have started already or are in the planning process:

1. West Nile Delta Project (WND)

The project will study mud volcanism in the West Nile area. Such volcanoes are common in different continental margin settings, especially in deltaic depositional systems. Fluid formation and fluidisation processes occurring at depths of several kilometres below the seafloor can be monitored in mud volcanoes and act as natural leakages for oil and gas reservoirs. Specific research topics are:

- Chemical and isotopic composition of pore fluids as well as investigation of light volatile hydrocarbon gases and organic biomarkers.
- Geophysical characterization and imaging of fluid migration pathways using electro-magnetic and seismic methods.
- Variability quantification of dewatering and degassing through long-term physical property measurements.

The industrial partner is RWE Dea. The project has a budget of 6,3 Million Euros over a funding period of three years.

More information under http://www.ifm-geomar.de/index.php?id=wnd

2. Fluid and Gas Seepage in the southern German North Sea (SGNS)

This project aims to detect sites of active fluid and gas seepage in the south German North Sea, to decipher and map possible migration pathways in the Pleistocene and Holocene sediments, to quantify gas fluxes in the water column and analyze their chemical composition. The industrial partner is the Wintershall Group. The project has a budget of 1,25 Million Euros over a funding period of 3 years.

More information under http://www.ifm-geomar.de/index.php?id=sdns

3. CLATHRAT - CO_2 storage in marine sediments

The project aims to investigate and assess two potential strategies for storing CO_2 below the seafloor:
(a) as immobile solid gas hydrates in sediments below water depths of ~400 m at low temperatures and
(b) as a dense and gravitationally stable liquid in deep sediment strata in water depths deeper than ~3000 m.
Presently operated and planned geological storage sites include depleted oil and gas reservoirs and onshore and offshore saline formations. CO_2 is also currently used in enhanced oil and gas recovery and enhanced coal bed methane recovery. CO_2 is deposited in a highly mobile supercritical state or as gas in all of these recovery options. Recovery sites are currently operating in Norway, Canada, and in Algeria. The industrial partner is RWE Dea and the FH Kiel is a cooperation partner. The project has a budget of 1,25 Million Euros over a funding period of three years.

More information under http://www.ifm-geomar.de/index.php?id=clathrat

4. JIBA - Joint Inversion with Bayesian Analysis

Started in early 2008, the JIBA project will further develop mathematical concepts of joint inversion which is the simultaneous reduction of marine electromagnetic, seismic and gravity measurements to one common earth model. The joint inversion and the marine electromagnetic method are important technical developments in the field of oil exploration. These new methods can be applied in areas where standard seismic methods fail. Through the use of joint inversion and electromagnetic data, detailed information of the subsurface structures is possible without additional drilling or injury to marine mammals. Partners are University Durham and seven major oil & gas companies. The project has a budget of 0,8 Million Euros over a funding period of three years.

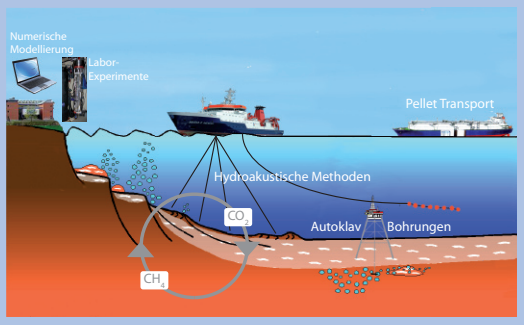
More information under http://www.ifm-geomar.de/index.php?id=jiba

5. TIMBA - Towards the Integration of Multidisciplinary geophysical data in a shelf area: the Büsum-North Area as an example.

The goal of TIMBA, a joint project of IFM-GEOMAR (Dr. M. Jegen) and the Christian-Albrechts University (Prof. H. Goetze) is to find new ways of integrating and jointly inverting various types of geophysical data, a strategy which is particularly important in regions where standard seismic methods fail. The project encompasses development of computational algorithms and shallow water instrument development accompanied by extensive marine and airborne acquisition over a salt structure in the North Sea. The project is supported by Wintershall with a total budget of 5,2 Million Euros over a three year period. IFM-GEOMAR will receive 2,9 Million Euros for a subproject developing the shallow water electromagnetics for sub salt exploration of the Oldenswort salt dome. CAU will receive 2,3 Million Euros for airborne, land data acquisition and data visualization.

More information under http://www.ifm-geomar.de/index.php?id=timba

6. SUGAR - Submarine Gashydrate Resources: exploration, mining and transport



The joint project SUGAR aims to develop new technologies for the exploration and mining of submarine gas hydrate resources and new concepts for the transport of these gases. The mining of hydrates will be coupled with a sequestration of CO_2 in marine sediments. Depending on the material, 2-5 times more CO_2 could be stored than previously and methane is gained through the process. In addition, CO_2 hydrates are more stable than methane in a larger temperature range and thus less sensitive to global warming. The mining concept of SUGAR focuses on deep gas hydrate resources under a sediment layer of more than 50 metres in order to avoid uncontrolled release of methane.
SUGAR will develop an end-to-end approach for the usage of gas hydrates: starting from the exploration to the transport with suitable ships. Industry partners are E.On-Ruhrgas, RWE Dea, BASF, Wintershall and Linde. The project has a budget in the order of 10 Million Euros over a five year period and will start in 2008.

More information under http://www.ifm-geomar.de/index.php?id=sugar

Unit "Chemical Paleo-Oceanography" through a special investment of about 600,000 Euro.

Other infrastructure:

An equipment warehouse was built on the east shore campus next to the Technology and Logistics Centre in 2007.

The new warehouse (left) in the vicinity of the TLC (right)

The Centre for Marine Substances Research (KiWiZ) moved into new laboratories near the Kiel Canal. The initial funding provided by the Ministry of Science, Economy and Transportation was extended by two years.

The second phase of the aquarium renovation started in autumn of 2007. The facility was reopened in time for Kiel Week in June of 2008.

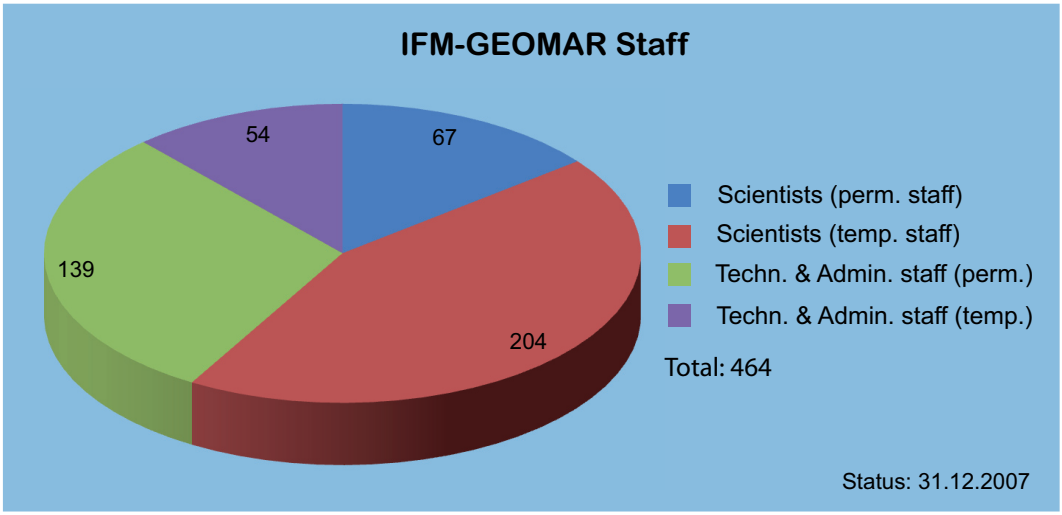
Plans for a new building on the east shore campus are proceeding. After finalising the first cost estimates, the financing model is currently under review. Current plans envisage a completion of the building in 2012.

Personnel

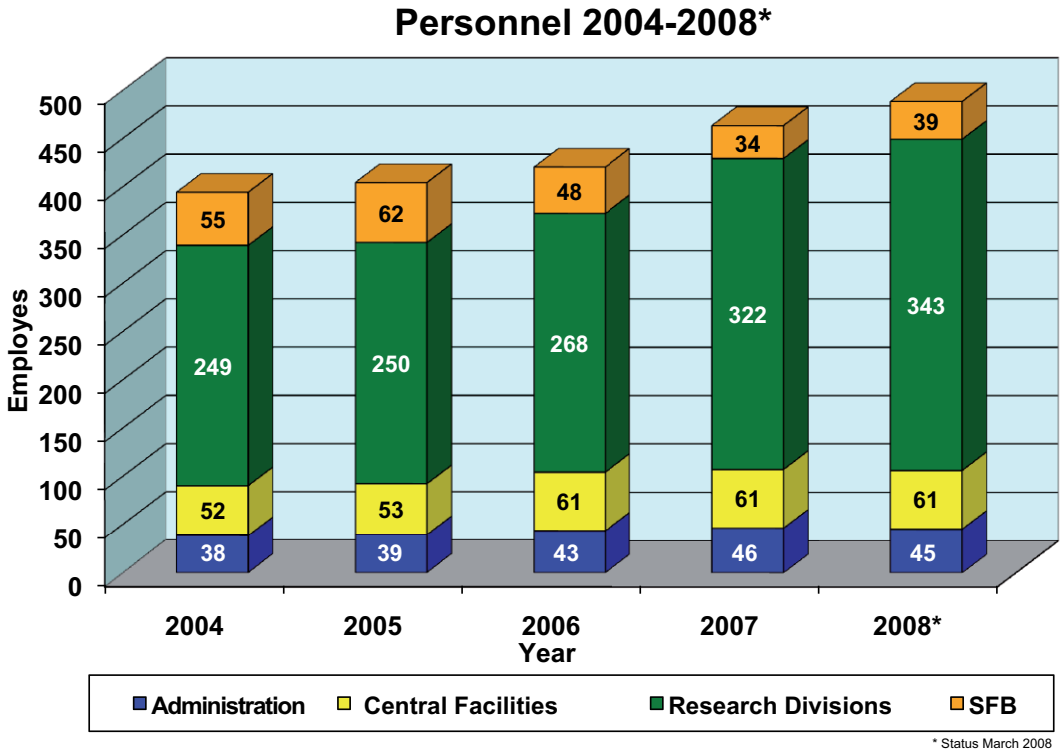
Due to an increase in project funding (e.g. excellence cluster and industry co-operations), IFM-GEOMAR staff also increased significantly during the past year. By end of 2007, IFM-GEOMAR had about 464 employees of which 271 are scientists. The staff has increased since 2004 by about 20%. 56% (75%) of the employees work on temporary contracts. 43% (35%) staff members are female. The numbers in brackets are numbers for the scientific personnel, including Ph.D candidates.

Notable changes in scientific personnel included:

- Prof. Dr. Jürgen Willebrand retired from his position in Theoretical Oceanography at the end of March. A special symposium and scientific conference reviewing the accomplishments of the collaborative research centre "SFB 460: Dynamics of the Thermohaline Circulation Variability" were held in his honor. SFB 460 was a research center from 1996 until 2006. His successor is Prof. Dr. Richard Greatbatch from Dalhousie University in Halifax, Canada.
- Prof. Dr. Karin Lochte, former leader of the Research Unit in Biological Oceanography, succeeds Prof. Dr. Jörn Thiede, as director of the Alfred Wegener Institute for Marine and Polar Research in Bremerhaven.
- The open position in Marine Seismics / Tectonics has been filled by Prof. Dr. Christian Berndt from the National Oceanography Centre, Southampton, UK.
- Prof. Dr. Peter Brandt was offered a position in the Research Unit Physical Oceanography. He also had an of-



IFM-GEOMAR staff by end of 2007



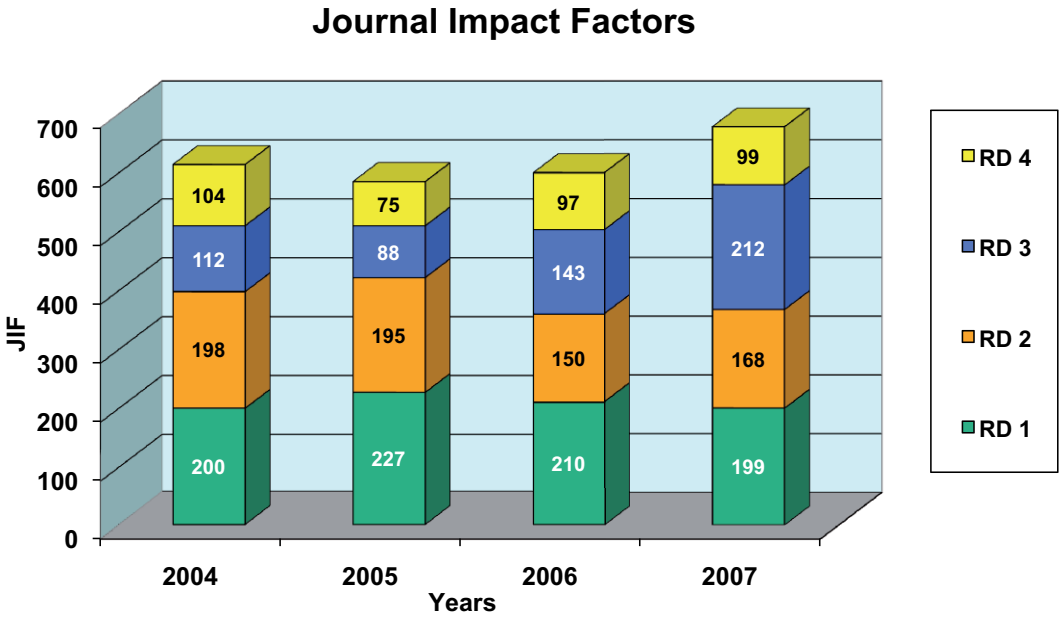
Staff development since 2004

fer from the Institute for Marine Research in Hamburg.

- Prof. Dr. Dietrich Schnack retired in autumn of 2007 as leader of the Research Unit in Fisheries Biology.
- The four leaders of the Junior Research Groups in the excellence cluster are now in Kiel.
- Finally, Prof. Dr. Frank Sommer started a junior professorship in the Research Unit "Experimental Ecology" in 2007.

Honours / Awards

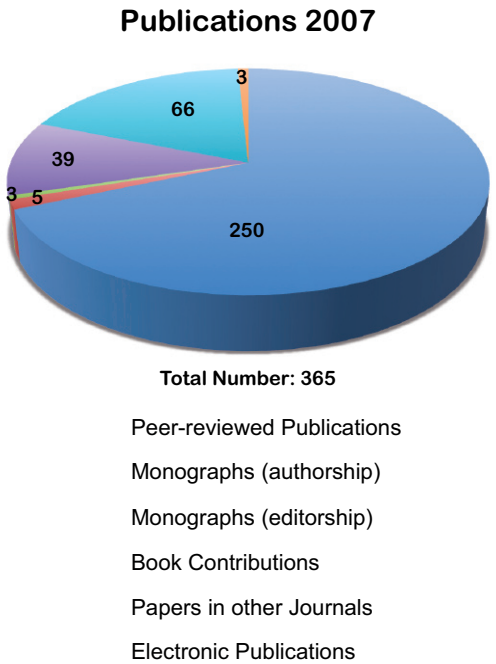
- **Noble prize for IPCC** (major contributions from IFM-GEOMAR): **Prof. Jürgen Willebrand**, lead author of section 5: Oceanic Climate Change and Sea Level.
- **Albert Defant-Medal** of the German Meteorological Society for **Prof. Jürgen Willebrand**, Research Unit "Theory and Modelling".
- **Emmy-Noether Fellowship** "Mechanisms and Predictability of decadal variability in the North Atlantic" for **Dr. Noel Keenlyside**, Research Unit "Maritime Meteorology" (Volume about one million Euros over a time period of five years)
- **2007 Lifetime Achievement Award in Aquatic Enzymology** for **Prof. Hans-Georg Hoppe** Research Unit "Marine Microbiology"
- **Paul-J.-Scheuer Award for Marine Biotechnology** for **Prof. Johannes F. Imhoff**, Research Unit "Marine Microbiology"
- "**Science Award of Kiel**" for **Prof. Klaus Wallmann**, representing the excellence cluster "The Future Ocean"
- **Poster award** for **Dr. Jörn Schmidt** from the Research Unit "Fishery Biology" on the international Zooplankton Symposium in Hiroshima, Japan.
- **Intermedia-Globe Silver Award** for the IFM-GEOMAR Image Film directed by **Mona Botros**
- **Exhibition "The Future Ocean"** was selected as one of the "**365 Landmarks in the Land of Ideas**" of the nationwide initiative "Land of Ideas"
- For the first time outstanding publication records of young scientists were honoured with an internal **IFM-GEOMAR publication award**. This award was funded through a donation of the "Deutsche Bank".



Journal Impact Factors of peer-reviewed publications 2004-2007 by research divisions

More details and statistics can be found in Appendix 2.

IFM-GEOMAR staff members received numerous honours and awards for their scientific work and public outreach projects (see next page). In addition, IFM-GEOMAR scientists serve on national and international advisory boards, research planning and review committees. They are also on the editorial boards of various international scientific journals. More details can be found in Appendix 7.



Publications 2007 by publication type

Scientific results & Expeditions

IFM-GEOMAR scientific accomplishments are well documented by numerous publications in international, peer-reviewed literature. More than 250 papers were published in 2007 (see Appendix 5). A number of papers were published in highly ranked journals with a substantial impact factor. IFM-GEOMAR scientists produced four publications in the leading interdisciplinary journals Science and Nature. A remarkable number of textbooks and book contributions increased the total number to 365. In addition, 41 Ph.D's were published under the topic of marine sciences.

Scientists provided substantial contributions to the fourth, climate assessment report published by the Intergovernmental Panel on Climate Change (IPCC). Prof. Dr. Jürgen Willebrand served as a lead author for the chapter titled "Oceanic Climate Change and Sea Levels," Prof. Dr. Arne Körtzinger and Prof. Dr. Friedrich Schott were also contributing authors to this chapter. In addition, Prof. Dr. Mojib Latif served as one of the contributing authors for the chapter on "Climate Models and their Evaluation." IPCC's work was honoured with the Noble Prize in 2008.

Chapter 2 of this report highlights a number of short scientific contributions on key research topics in the past year (page 13 ff).

Twenty-two major expeditions were conducted under the leadership of

Selected Publications 2007

Jakobsson, M., Backman, J., Rudels, B., Nycander, J., **Frank, M.**, Mayer, L., Jokat, W., Sangiorgi, F., O'Regan, M., Brinkhuis, H., King, J. and Moran, K., 2007: The Early Miocene onset of a ventilated circulation regime in the Arctic Ocean. *Nature*, **447**, 986-990.

Markert, S., Arndt, C., Felbeck, H., Becher, D., Sievert, S.M., **Hügler, M.**, Albrecht, D., Robidart, J., Bench, S., Feldman, R.A., Hecker, M. and Schweder, T., 2007: Physiological Proteomics of the Uncultured Endosymbiont of *Riftia pachyptila*. *Science*, **315** (5809), 247, doi:10.1126/science.1132913.

Riebesell, U., Schulz, K.G., Bellerby, R.G.J., **Botros, M.**, **Fritsche, P.**, **Meyerhöfer, M.**, Neill, C., Nondal, G., **Oschlies, A.**, **Wohlers, J.** and **Zöllner, E.**, 2007: Enhanced biological carbon consumption in a high CO_2 ocean. *Nature*, **450** (7169), 545-548.

Weldeab, S., Lea, D.W., Schneider, R.R. and Andersen, N., 2007: 155,000 years of West African monsoon and ocean thermal evolution. *Science*, **316**, 1303-1307.

IFM-GEOMAR. Highlights included: The SONNE's Expedition 191 in February-March which investigated cold seeps at the Hikurangi complex in the south-western Pacific near New Zealand. The next expedition (SO192) focused on geological and geophysical aspects in this region. During the subsequent expedition (SO193), the Manihiki-Plateau, a "Large Igneous Province" in the western Pacific was observed and the ocean floor was sampled.

IFM-GEOMAR's first off-shore experiment on ocean acidification took place during July in the Gotland Basin (ALKOR 302) using the new mesocosm facilities (page 3). Unfortunately, difficult weather conditions somewhat hampered the study's success.

The new OTIS (Ocean Tracer Injection System) (page 2) was used for the first time during a jointly conducted cruise with the Institute of Baltic Sea Research (IOW) in Warnemünde. IFM-GEOMAR's research vessel Poseidon (P357) injected a chemically inert tracer into the deep layers of the Baltic Sea in order to study mixing and transport processes in the Gotland and Bornholm basins.

The METEOR expedition (M73-2) in the Thyrrenian Sea explored mineral deposits in the vicinity of geologically active zones using the British Geological Survey's Rockdrill facility.

The Rockdrill device of the British Geological Survey

The manned research submersible "JAGO" undertook one commercial and three research expeditions. A chartered cruise for the De Beers diamond mining company off the coast of Namibia was followed by an expedition to cold water habitats in northern Norway. This cruise with the polar research vessel POLARSTERN celebrated JAGO's 1000th dive. In autumn, the submersible was used by a Spanish crew from Instituto de Ciencias del Mar, Barcelona, to investigate marine ecosystems in the eastern Mediterranean. Finally, the boat dived in an Austrian lake to investigate anoxic conditions.

The JAGO Team after the 1000th dive

More details on ship expeditions can be found in Appendix 4.

Education / Curricula

Student education in Paleo-oceanography

The curricula in marine sciences changed from the Diploma degree to the Bachelor / Master system in the 2007/2008 winter semester. Institutes from the Christian-Albrechts University of Kiel (CAU) and IFM-GEOMAR offer the following curricula:

Bachelor courses:

- Physics of the Earth System (Meteorology, Oceanography and Geophysics)

Master courses:

- Climate Physics (Meteorology and Physical Oceanography)
- Biological Oceanography

IFM-GEOMAR staff is also contributing to the curricula in Geology and Geophysics (see Appendix 8 for the complete list).

Following a recommendation resulting from an evaluation by the Leibniz association in 2005, IFM-GEOMAR is negotiating with the CAU to reduce the teaching load of IFM-GEOMAR staff from the present 6 hours per week to 4 hours.

Fifteen dissertations and twenty-six diploma degrees in various disciplines of marine sciences were completed in 2007 (see Appendix 5.7). IFM-GEOMAR had a total of 83 Ph.D students at the end of 2007. IFM-GEOMAR staff also supported a number of external students at other universities, e.g. through the international GAME project (see page 28).

Participants of the summer school in Biogeochemical Modelling

National and international cooperation:

IFM-GEOMAR director Prof. Dr. Peter Herzig joined a delegation to India led by the Prime Minister of Schleswig-Holstein, Peter Harry Carstensen. During his visit to Goa, Prof. Herzig and the head of the National Institute of Oceanography (NIO), Prof. Satish Shetye, signed a memorandum of understanding with the goal of closer cooperation in the fields of gas hydrate research, marine substances research and marine aquaculture.

Right: Prof. Satish Shetye (left) and Prof. Peter Herzig (right) after signing the MoU. Middle: Peter Harry Carstensen, Prime Minister of Schleswig-Holstein

IFM-GEOMAR director and Maritime Coordinator of the State of Schleswig-Holstein Prof. Dr. Peter Herzig, and the former Minister for Transportation, Kurt Bodewig, were appointed "Maritime Ambassadors" by the EU-Commissioner for Fisheries and Maritime Affairs, Joe Borg.

Right: Prof. Peter Herzig (r) with Kurt Bodewig (l)

Numerous IFM-GEOMAR scientists supported research planning on the national and international level through membership on scientific groups and panels. See appendix 7.5 for a complete overview.

IFM-GEOMAR hosted a number of international meetings and workshops. The most important ones were the 20th Latin America Colloquium with about 300 participants and the 42nd Euro-

pean Marine Biology Symposium with 350 participants. IFM-GEOMAR scientists also helped to coordinate meetings and sessions in other locations.

The German Climate Consortium (DKK) is a newly founded strategic alliance formed by the climate research community. Under the guideline: "Climate Research for Society, Economy and Environment," the consortium fosters cooperation on climate research in Germany. Partners in the DKK are non-university research institutes and other university research groups. IFM-GEOMAR is one of the nineteen founding members. More information under http://www.deutsches-klima-konsortium.de/

In order to strengthen marine research on the European level, the three leading institutes in Europe, IFREMER in France, the National Centre of Oceanography Southampton (NOCS) in the UK and IFM-GEOMAR signed a trilateral cooperation agreement.

The Cape Verde Islands will become a centre for several IFM-GEOMAR activities in the coming years. One of the main research areas of the new SFB 754 will concentrate on this region. A new observatory for atmospheric and marine research was officially launched in Sao Vicente, Cape Verde in 2007. The observatory is part of the multinational research programme TENATSO (Tropical Eastern North Atlantic Time Series Observatory) with partners in the UK, Cape Verde and Germany. With IFM-GEOMAR's support, the small Cape Verde research vessel "Islandia" is now able to service an oceanographic station which is also used in the German SOPRAN project.

The Alfred-Wegner Institute for Polar and Marine Research and IFM-GEOMAR are members in the Partnership for Observation of the Global Oceans (POGO). The goal of POGO, originally founded by directors and leaders of major oceanographic institutions, is to promote global oceanography, particularly the implementation of an international and integrated global ocean observing system. The annual meeting took place in Qingdao, China in 2007.

Public Outreach

Left: Prof. Peter Herzig with Dr. Annette Schavan and Dietrich Austermann

In 2007, a number of high-level visitors and more than 30 groups visited IFM-GEOMAR. The Federal Minister for Education and Research, Dr. Annette Schavan, the Maritime Co-ordinator of the Federal Government, Dagmar Wöhrl, the Prime Minister of Schleswig-Holstein, Peter Harry Carstensen, the Minister for Science, Economy and Transportation of the State of Schleswig-Holstein, Dietrich Austermann, the State Minister for European Affairs, Employment and Justice, Uwe Döring, and the spokesmen of the federal and state governments were some of the most prominent guests.

The public relation office released more than 50 media information on various topics. The group provided substantial support to public outreach activities of the excellence cluster "The Future Ocean" (see below) and organized a number of public events. Some of the most notable events included:

Open Day: On September 2nd IFM-GEOMAR supported the celebrations in occasion of the reopening of

Open Day at IFM-GEOMAR

the "Seefischmarkt" which was completely renovated. The Institute's open day and open ship on the research vessel "Alkor" attracted a large number of visitors. More than 3,000 were on board the RV "Alkor" and 25,000 people visited the "Seefischmarkt."

Exhibition "The Future Ocean:" The excellence cluster's "The Future Ocean" exhibition was shown for four weeks during Kiel Week and in Berlin at Schleswig-Holstein's representation in October. The exhibition was developed mainly by the Muthesius School of Arts and IFM-GEOMAR. More than 24,000 visitors and 120 school classes enjoyed the exhibition in Kiel and more than 10,000 people saw the exhibition in Berlin. In addition, a simplified version was presented on October, 3rd for German National Holiday in Schwerin.

Exhibition „The Future Ocean"

Exhibition "The Deep:" IFM-GEOMAR and Knesebeck Publishing presented the "The Deep." The exhibition displayed beautiful, glossy photographs of deep-sea organisms collected by Claire Nouvian.

Claire Nouvain

As part of the public outreach programme at IFM-GEOMAR, 82 placements for school children were organized. A summer school in Marine Geosciences with 24 participants was organized by Research Division 4, "Dynamics of the Ocean Floor" and the

Right: Participants of the international school project

SFB 574. IFM-GEOMAR scientists also contributed to a "young researchers vacation programme" organized by the Leibniz Institute for Science Education (IPN). The NaT "Meeresforschung" programme funded by the Robert-Bosch foundation extended its activities in cooperation with the excellence cluster. Another highlight in 2007 was an international research expedition with school children from Poland, Norway and Germany on board the RV "ALKOR."

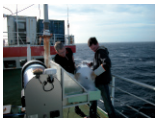
Right: Intermedia Globe Silver Award

IFM-GEOMAR's image film "From the Seafloor to the Atmosphere" received the "Inter-media-Globe Silver Award" from an international film festival.

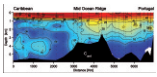
Introduction

A selection of short scientific reports in this section provides an overview on research activities and results throughout 2007. This encompasses summaries from major expeditions, interdisciplinary activities, technology development and scientific results. These are just a few highlights from the broad scope of marine research at IFM-GEOMAR.

The selected contributions in this section are:

- **Innovative observations of ocean - atmosphere interactions in the tropical /subtropical Atlantic Ocean":** This area of particular  importance for climate variability in western Africa but also for the generation of tropical storms as well as a very sensitive region for biogeochemistry interactions.

- **Is modern Arctic Ocean Circulation exceptional?:** Investigations  of marine sediments give new information about the circulation in the North Atlantic in the past.

- **Estimates of anthropogenic CO_2 concentration from repeated ocean measurements made decades apart:** Measurements  taken on a Meteor Cruise were compared to earlier observations to estimate changes in oceanic CO_2 uptake.

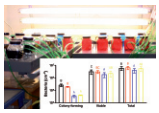
-  **Corals track past Hurricanes:** What are the most important boundary conditions for the development of hurricanes? 2005 was a record year in the Atlantic, 2006 only few storms were observed.

More information is provided on the web pages of IFM-GEOMAR in particular under: http://www.ifm-geomar.de/index.php?research.

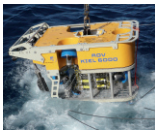
- **Fertilising the surface ocean – the role of volcanoes:** Ash produced by  volcanoes can cause an effective fertilization of the surface ocean as an interdisciplinary project of IFM-GEOMAR has shown.

- **Connecting young scientists: the international programme GAME establishes a unique global research network in marine benthic ecology:** An international  exchange programme for graduate students in marine biology shows successful networking and cooperation in student education.

- **Rapid Sedimentation, Overpressure, Fluid Flow and Slope Instability at the Gulf of Mexico Continental Margin:** Areas with rapid  sedimentation processes are often critical in terms of potential slope instabilities controlled by fluid flow. Submarine slope instability constitute a major geohazard.

- **The molecular basis of algal defense:** The origin of defense  mechanisms of macro algae are investigated to estimate the adaptive potential of enemies in marine ecosystems.

- **Biological mechanism for enhanced carbon consumption in the ocean:** The ocean plays a crucial  role in global carbon cycle. Here, the role of biological processes in the ocean is investigated.

- **ROV Kiel6000: Hands and eyes at the bottom of the ocean:** The new  remotely operated vehicle of IFM-GEOMAR was successfully tested and explored hydrothermal systems in the Pacific and Atlantic.

Innovative observations of ocean/atmosphere interactions in the tropical/subtropical Atlantic Ocean

People on the Indian sub-continent are not the only ones to rely on monsoon-induced changes. West Africa has highly variable seasonal rainfalls as well. Whether certain regions in West Africa will be exposed to major rainfall or near-drought conditions is largely determined by water temperatures in the central and eastern equatorial Atlantic. A comprehensive oceanic and atmospheric measurement and modeling program at IFM-GEOMAR is aimed at improving the seasonal predictability of precipitation patterns in countries adjacent to the Gulf of Guinea and the northeastern regions of Brazil. This in turn might lead to early preventive measures in the fight against climate-related diseases, such as dengue fever, malaria, cholera, and meningitis, and might lead to an improved adaptation of agricultural usage to regional climate conditions.

It has been known for quite some time that the variability of sea surface temperature in the equatorial Atlantic – or more specifically, in the equatorial cold water tongue – plays a special role for precipitation fluctuations across West Africa. It is yet unclear, however, what effect ocean dynamics in comparison to atmospheric driving forces may have for the variability of sea surface temperatures in this region. Due to the time-delayed effects of processes in the ocean's interior on the sea surface, a predictability time scale for sea surface temperatures and thus precipitation in the range of weeks to several months would result.

The equatorial cold water tongue is located along the equator east of 20°W (Fig. 1) and is particularly well developed in boreal summer. The sea surface temperatures are then between 20 and 25°C, thus significantly cooler than the surrounding waters. The cause for this "chilling" effect is the upwelling of colder water from depths of about 100 m. The upwelled waters in turn are supplied by the so-called Equatorial Undercurrent, an eastward subsurface

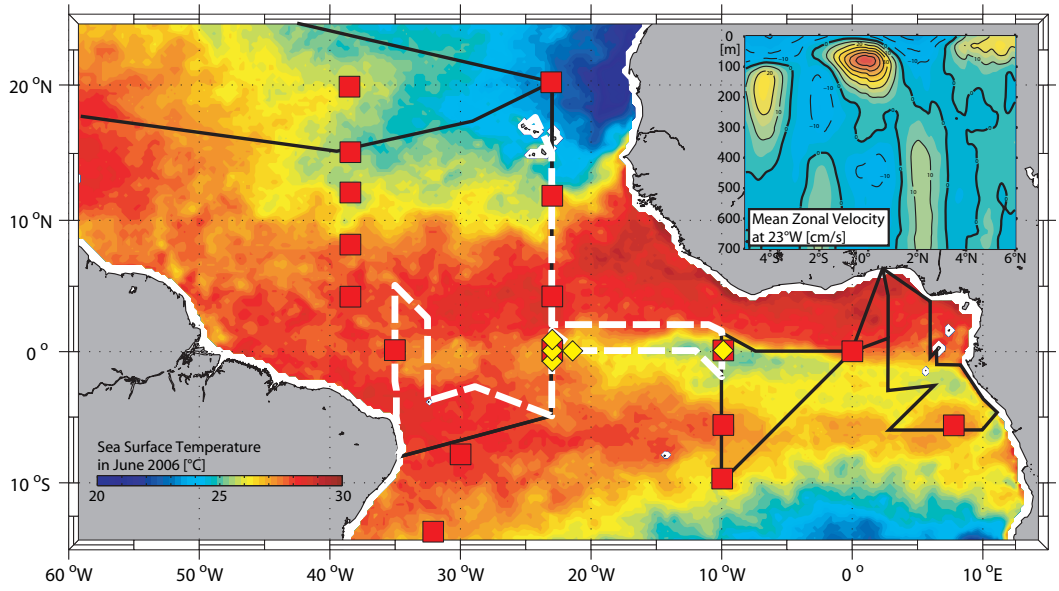


Fig. 1: Sea surface temperature in June 2006, revealing the equatorial cold water tongue (area between 20°W and 0° along the equator). During a R/V "Meteor" cruise in June 2006 (dashed white line), a number of moorings (yellow diamonds) were deployed, intended to measure transport fluctuations of the Equatorial Undercurrent over several years for the first time. This eastward current, concentrated along the equator at about 100 m depth, with current velocities of about 80 cm/s (yellow and red, small insert, top right) supplies water to the upwelling areas within the cold water tongue. Fluctuations in strength and temperature of this current therefore have a direct effect on the sea surface temperature of the cold water tongue. In addition, the map shows cruise tracks of the French R/V "L'Atalante" in the Gulf of Guinea, and of the U.S R/V "Ronald H. Brown" in the central tropical Atlantic (black lines), as well as the PIRATA surface buoy network (red squares). Ocean observations are part of CLIVAR's Tropical Atlantic Climate Experiment, see http://tace.ifm-geomar.de.

flow on the equator that transports water from the oceanic regions off Brazil to the eastern Atlantic (Fig. 1, top right). On average, the transport of the Equatorial Undercurrent amounts to 20 million cubic meters of water per second, about 100 times the volume transport of the Amazon River.

During R/V "Meteor" cruise 68/2 in summer 2006, a series of instruments moored to the ocean floor were deployed in the central equatorial Atlantic. Their task is to measure the fluctuations of ocean currents within the supply path of the cold water tongue over a period of several years (Fig. 1, Cruise track and mooring positions near equator). These measurements are part of the collaborative project NORDATLANTIK, funded by the German Federal Ministry of Education and Research, investigating the oceanic circulation, its transition from warm to cold water phases and its effect on climate. Concurrent to the R/V "Meteor" expedition, there were research cruises aboard the French R/V "L'Atalante" in the Gulf of Guinea, and aboard the U.S. R/V "Ronald H. Brown" in the central tropical Atlantic (Fig. 1). During these expeditions, oceanic turbulence measurements covering the entire region of the cold tongue were carried out for the first time. Turbulence in the ocean is a process that occurs on rather small scales, from meters down to millimeters. It mixes the relatively warm water at the sea surface with colder water below and thus cools the upper ocean. The required energy is supplied by the wind at the sea surface, by the oceanic current system, and from internal waves. Since September 2005, as part of a DFG Emmy Noether Junior Research Group, turbulence measurements have been carried out during six international research cruises within the cold water tongue to study the variability of cooling by turbulence. First results indicate that cooling of the sea surface temperature by turbulence is much larger than expected and amounts to 2-3 degrees per month during summer. Turbulence thus represents one of the most significant processes for the generation of the cold water tongue.

State-of-the art climate models show a particularly large SST bias toward higher temperatures in the tropical Atlantic that strongly reduces the reliability of climate predictions by these models. Aside from oceanic processes not well represented in these models, errors in the radiative forcing might contribute significantly to the model SST bias. Our planet receives and absorbs most of the available solar energy in the tropical and subtropical ocean. Today, our understanding of this radiative forcing is severely hampered due to the diverse effects of clouds. In 2003, the Meridional Ocean Radiation Experiment (MORE) was initiated by IFM-GEOMAR and the P. Shirshov Institute for Oceanology. The research goal is to conduct long-term collocated observations of energy fluxes above the ocean and of the corresponding state of the atmosphere.

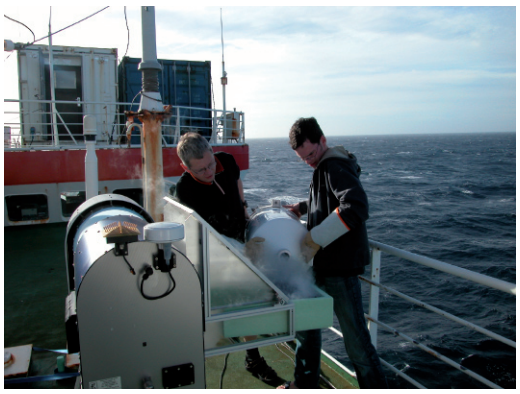


Fig. 2: Filling the HATPRO microwave radiometer with liquid nitrogen for calibration.

In April/May and October/November 2007 the German R/V "Polarstern" carried out the 6th and 7th MORE cruise (Atlantic transects ANT-XXIII-10 and ANT-XIV-1). For the first time, a multichannel microwave radiometer (Fig. 2) was used in the open ocean for continuous observations (temporal resolution of 1 sec) of atmospheric temperature and humidity profiles, as well as cloud liquid water path and precipitable water path.

Additional information on clouds and cloud-free atmospheric conditions from full sky imager and radiosondes, among others, will be utilized to quantify cloud-radiation correlations, and to validate corresponding parameterizations used in coupled ocean/atmosphere climate models. The collected data are used to provide validations of satellite-based retrievals of surface radiation budgets by means of the SEVIRI radiometer onboard the Meteosat Second Generation satellites. First comparisons show a generally good agreement indicating that our present understanding of cloud remote sens-

ing from space is sufficient for a satellite based analysis of cloud-radiative interactions over the Atlantic ocean. As of 2008, MORE will be joined by the WGL-PAKT Initiative OCEANET with participation from the Leibniz Institute for Tropospheric Research, the Alfred-Wegener-Institute for Polar and Marine Research and the GKSS Research Center.

The oceanic and atmospheric measurements in the tropical/subtropical Atlantic provide valuable "ground truth" for the quality assessment of various climate model simulations. An improved model representation of various observed processes, plus the direct assimilation of observations in model runs, are intended to improve prognostics for sea surface temperature, a significant foundation for the successfully projection of climate in the Atlantic sector, and particularly of the monsoon precipitation over West Africa.

Peter Brandt, Marcus Dengler, Mojib Latif and Andreas Macke

Highlighted Publications 2007

Jakobsson, M., Backman, J., Rudels, B., Nycander, J., **Frank, M.**, Mayer, L., Jokat, W., Sangiorgi, F., O'Regan, M., Brinkhuis, H., King, J. and Moran, K., 2007: The Early Miocene onset of a ventilated circulation regime in the Arctic Ocean. *Nature*, **447**, 986-990.

Markert, S., Arndt, C., Felbeck, H., Becher, D., Sievert, S.M., **Hügler, M.**, Albrecht, D., Robidart, J., Bench, S., Feldman, R.A., Hecker, M. and Schweder, T., 2007: Physiological Proteomics of the Uncultured Endosymbiont of *Riftia pachyptila*. *Science*, **315** (5809), 247, doi:10.1126/science.1132913.

Riebesell, U., Schulz, K.G., Bellerby, R.G.J., **Botros, M.**, **Fritsche, P.**, **Meyerhöfer, M.**, Neill, C., Nondal, G., **Oschlies, A.**, **Wohlers, J.** and **Zöllner, E.**, 2007: Enhanced biological carbon consumption in a high CO_2 ocean. *Nature*, **450** (7169), 545-548.

Weldeab, S., Lea, D.W., Schneider, R.R. and Andersen, N., 2007: 155,000 years of West African monsoon and ocean thermal evolution. *Science*, **316**, 1303-1307.

The complete list of publications can be found in Appendix 5.

Is modern Arctic Ocean circulation exceptional?

Arctic Ocean circulation as we know it today is an exceptional situation compared with the geological past. This was shown from geochemical analyses of a unique marine sediment core recovered in the central Arctic Ocean. A major transition from oxygen-poor sediments to well oxygenated sediments 17.3 million years ago indicates that the Fram Strait, which is the only deep water connection of the Arctic Ocean with the Atlantic Ocean, already opened at this time and allowed the establishment of a well-ventilated ocean basin. Isotope geochemical results suggest that the Arctic deep circulation was strongly influenced by sea ice formation during most of the past 15 million years and was not predominantly controlled by inflowing Atlantic waters, as is the case today.

The Arctic Ocean only has a limited exchange with the global ocean, whereby the Fram Strait between Greenland and Svalbard is the only deep water connection to the Atlantic Ocean. It is this connection that allows the supply of oxygen to the deep Arctic Ocean. Most previous studies based on tectonic models suggested that the opening of the Fram Strait for deep water exchange between the two basins occurred at about 10 million years ago. This could not be further investigated because, despite the fact that the Arctic Ocean has been a sensitive responder and potentially an important driver of global climate change, the Arctic's pre-Quaternary oceanographic history (prior to about 500,000 years ago), including the transition from a "greenhouse" to an "icehouse" world, has until recently been inaccessible due to a lack of continuous sedimentary records. This was mainly due to the technical difficulties to drill long sediment cores in an ice-covered ocean.

The central Arctic sediments recovered in summer 2004 during the ACEX expedition (IODP Leg 302) near the North Pole on the Lomonosov Ridge (87°5N, 137°E; 1250 m water depth) provided, for the first time, a continuous sedimentary archive, from which Neogene changes of Arctic oceanography and climate can be reconstructed. The expedition was carried out by a drill platform supported by two icebreakers, which guaranteed that the platform could maintain its position without being displaced by the drifting sea ice. The 428 m of recovered sediments reach back into the Late Cretaceous and for the first time allow investigation of the evolution of Arctic climate and ocean circulation. These sediments are very difficult to date, in particular in the upper 200 m, where detrital sediments essentially barren of any fossils prevail. The sediments of the upper 150 m were dated at IFM-GEOMAR by means of the cosmogenic radionuclide ^{10}Be, which has a half-life of 1.5 million years. The dating showed that the sediments have an age of 12.3 million years at this depth and that the sedimentation rates on the order of 14.5 m/million years were similar to open ocean sites outside the Arctic Ocean (Frank et al., 2008).

Fig. 1: Drilling platform "Vidar Viking" in the foreground. Swedish icebreaker Oden Eisbrecher "Oden" and Russian icebreaker "Sovetskiy Soyuz" in the background smashed the drifting sea ice in order to keep the position of the drilling platform stable.

One of the foci of research was the timing of the establishment of the Fram Strait oceanic gateway between the North Atlantic and the Arctic Ocean, which had previously only been accessible through tectonic modeling. Above a 26 million year hiatus the ACEX sediments have an age of 18.2 million years and are characterized by organic-rich sediments that also prevailed prior to the hiatus and document that the deep Arctic Ocean was not well-ventilated but was rather an enclosed brackish basin which more resembled a large lake. At a depth of 190 m and an age of 17.3 million years there is a sharp transition from the organic-rich, black sediments to organic–poor brownish

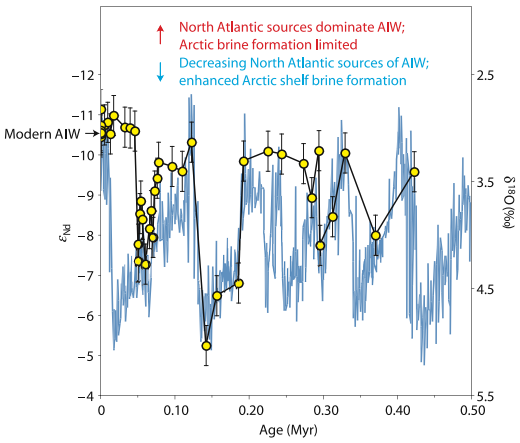


Fig. 2: Nd isotope composition of the past 400 kyr (yellow circles). The blue curve represents the oxygen isotope composition of global sea water showing the cyclic alternations between glacial and interglacial stages of the Late Quaternary.

sediments. This color change documents an increased supply of oxygen and thus the onset of deep ventilation. This ventilation could only be established with the Fram Strait open to an extent that allowed large amounts of salt-rich Atlantic waters to penetrate the Arctic Ocean and supply oxygen to intermediate and deep waters (Jakobsson et al., 2007). The early opening was confirmed by new tectonic information as well as a model constraining the minimum width of the opening strait to allow deep convection. It was also inferred that the Fram Strait fully opened to similar depths as at present of about 2,000 m by 13.7 million years.

Most of the deep Arctic Ocean today is filled with Atlantic waters exchanging through Fram Strait, which today has a sill depth of about 2,500 m. A pronounced and stable freshwater layer at the surface originating from inputs of the large Russian rivers almost completely prevents any significant deep water formation in the Arctic Ocean itself.

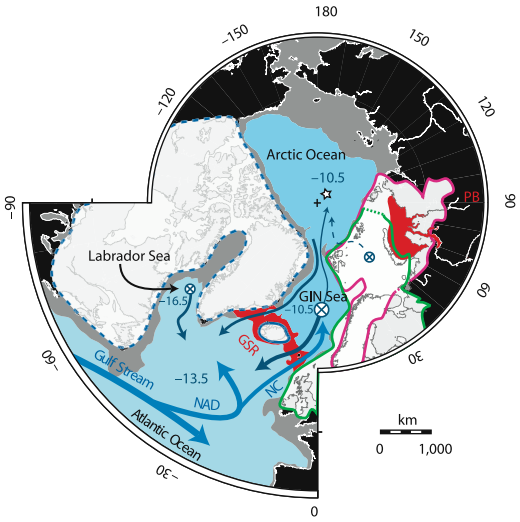


Fig. 3: Schematic Map of the present day Arctic and North Atlantic Oceans. Important currents and their corresponding Nd isotope compositions are given by arrows (blue for surface, black for deep including major areas of deep water production marked by crosses) and the distribution of the ice sheets is marked by white areas (penultimate glacial period - red outline, last glacial period - green outline). The red area marks the distribution of the weathering products of the Putorana Flood Basalts (PB). The location of the investigated sediments is given by the star.

New results obtained from the ACEX core show that this situation was an exception rather than the rule for most of the past 15 million years (Haley et al., 2008). This conclusion was drawn on the basis of the seawater isotope ratio of the element neodymium ($^{143}Nd/^{144}Nd$) that was extracted from the sediments. The Nd, which has characteristic isotope ratios in rocks as a function of their type and age, is transported to the ocean through weathering, where it provides information on the sources of water masses. Surprisingly, the results showed that the Nd isotope signature of the seawater was much higher (more radiogenic) than the present day values, with the exception of the warm periods of the past 400,000 years (Fig. 2). Such signatures indicate a pronounced influence of the weathering of basaltic rocks but on the Circum-arctic landmasses such rocks only exist in the form of the Siberian "Putorana flood basalts".

From this geologically unique setting and taking into account the evolution of the continental ice sheets of the past 140,000 years, it was then possible to reconstruct the circulation history of the deep Arctic Ocean. The signature of the basalts can only have arrived at 1,000 m water depth in the central Arctic Ocean if vast amounts of new sea ice formed near the basalt areas in the Kara Sea area (Fig. 3). During sea ice formation the salt of the sea water freezes out and is rejected, thereby forming highly saline brines, which were denser than the surrounding sea water. These brines sank and transported the dissolved Nd isotope signature of the basalts to the sea floor where the sediment cores were recovered. Further, the obtained Nd isotope variations imply that the inflow of Atlantic waters was significantly reduced during most of the past 15 million years and during the glacial periods of the past 400,000 years despite a fully opened Fram Strait. This also implies that the formation sites of North Atlantic Deep Water, which has been a very important component of global ocean circulation and of heat transfer between low and high latitudes, were most of the time not located in the Norwegian-Greenland Sea, similar to today, but further south, similar to the glacial periods of the Pleistocene.

References:

Frank, M., Backman, J., Jakobsson, M., Moran, K., O'Regan, M., King, J., Haley, B.A., Kubik, P.W. and Garbe-Schönberg, D., 2008: Beryllium isotopes in central Arctic Ocean sediments over the past 12.3 million years: Stratigraphic and paleoclimatic implications. *Paleoceanography*, in press.

Haley, B.A., **Frank, M.**, Spielhagen, R.F. and Eisenhauer, A., 2008: Influence of brine formation on Arctic Ocean circulation over the past 15 million years.- *Nature Geoscience* **1**, 68-72.

Jakobsson, M., Backman, J., Rudels, B., Nycander, J., **Frank, M.**, Mayer, L., Jokat, W., Sangiorgi, F., O'Regan, M., Brinkhuis, H., King, J. and Moran, K., 2007: The Early Miocene onset of a ventilated circulation regime in the Arctic Ocean. *Nature* **447**, 986-990.

Martin Frank

Estimates of anthropogenic CO_2 concentration from repeated ocean measurements made decades apart

Over the past 200 years ~50% of the CO_2 released to the atmosphere via the burning of fossil-fuels or changes in land-use ("anthropogenic carbon") has dissolved in the oceans. This carbon sequestration by natural processes has drastically reduced the global warming effect of mankind's CO_2 emissions. However the dissolution of anthropogenic CO_2 in the future ocean is likely to be reduced due to chemical changes associated with higher CO_2 levels and, possibly, due to changes in ocean circulation associated with climate change. Critical scientific issues for prediction of future carbon sequestration and hence future atmospheric CO_2 levels are the mechanisms underlying ocean CO_2 uptake, the regions of the surface ocean that are responsible, and the depth range within the ocean in which the CO_2 is being stored. This information is also critical to understanding the effects of CO_2-induced ocean acidification.

The paper by Tanhua et al (2007) presents results from a 10,000 km Meteor cruise through the North Atlantic in 2004 (M60/5). The cruise was designed expressly with the goal of directly measuring the build-up of oceanic CO_2 over decadal timescales and we therefore returned to the exact locations that had been sampled by a major US-led expedition in 1981. The earlier US expedition was responsible for collecting the very first high-quality set of carbon and closely-related parameters through an entire ocean basin, and provided the best-available reference for detecting such change over the ocean's considerable natural carbon variability.

Based on our new data, we were able to detect the CO_2 increase over the intervening 23 years with remarkable resolution. However we were able to go even further: and used the result as the basis for a fundamentally new approach to estimation of the total amount of anthropogenic CO_2 in the water column (i.e. the "extra" carbon stored over the ~225 years since CO_2 started increasing in the global environment). The new approach is based directly on measurements of carbon and circumvents several long-standing problems with other methods of anthropogenic carbon estimation. In particular, the new data and their interpretation shed new light on the depth ranges of the ocean in which the anthropogenic carbon is being stored.

To test the new approach, we compared our estimates with simultaneously measured distributions of the anthropogenic tracer CFC-12 and with CCl_4. This included a quantitative comparison with fully independent estimates of anthropogenic CO_2 calculated from the CFC-12 data. For the latter, we used a recently-developed approach that accounts for the mixing of waters of different "ages" within the ocean interior. The treatment of mixing has been a major limitation with earlier attempts to use tracers to infer anthropogenic carbon. The level of both qualitative and quantitative

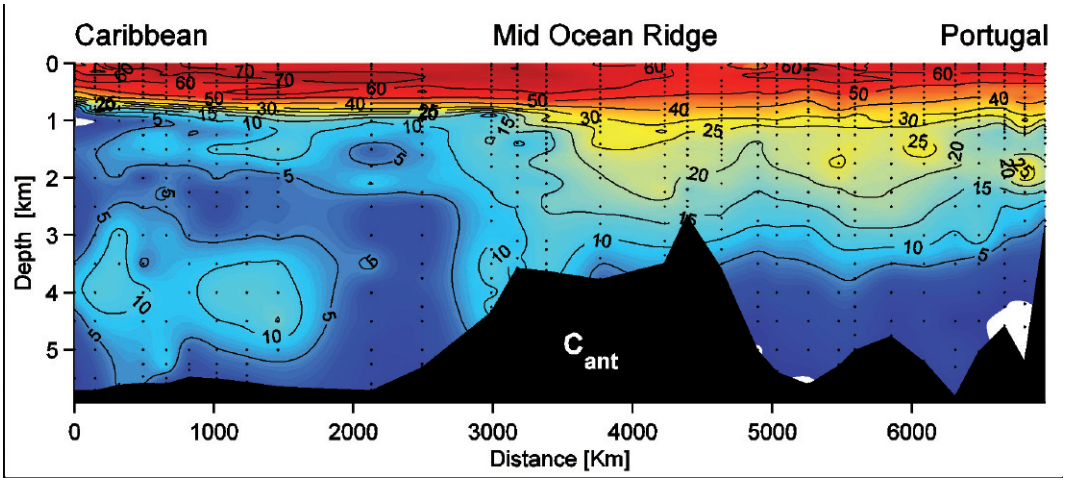


Fig. 1: The content of anthropogenic CO_2 (in µmol kg^{-1}) across the mid-latitude North Atlantic from the Caribbean off Martinique (left) to the coast of Portugal (right) as calculated with the new approach.

agreement between our carbon- and tracer-based approaches is, we believe, unprecedented. We note that, in contrast, nearly every prior comparison of approaches to anthropogenic carbon estimation has revealed large, systematic differences: our result implies that a significant breakthrough has been made.

The overall depth-integrated inventories of anthropogenic carbon were found to be not greatly different between the various approaches which implies that some significant sources of error with earlier approaches cancel each other when averaged over the full depth of the ocean water column. This is encouraging in that it implies that overall global budgets for anthropogenic CO_2 in the Earth system over the past 200 years may be reasonably accurate. (However we note that such "error-cancellation" may not necessarily apply to the critical Southern Ocean, where application of our new approach would now be highly desirable).

Of major significance is the very different depth-distribution of the anthropogenic carbon revealed by our new approach. The depth-distribution of the extra carbon has major implications for projections of future ocean behaviour. If the "extra" carbon is largely stored in the upper ocean and thermocline then future uptake of CO_2 by the ocean will slow down as the chemical buffer capacity of the ocean waters that is upwelled to the surface from intermediate depths is "used-up". On the other hand, storage of a larger proportion of the "extra" CO_2 in the vast, slowly-overturning deep ocean, as revealed by our analysis, implies an extended capacity to store "extra" carbon over longer periods of time.

The deeper input of anthropogenic carbon also has significance for life in the oceans. The preservation and dissolution of calcium carbonate in the oceans, and the ability of carbonate-shell-forming organisms (e.g. deep water corals) to grow in the deep ocean, is dependent on the saturation state of aragonite and calcite at depth. Here one critical issue is whether anthropogenic carbon (and the associated pH change of ocean waters) is impacting the depth and location of the chemical lysocline. Predictions of future change depend on knowledge of where in the ocean the "extra" CO_2 is going: storage above the depth of the lysocline will have little or no effect. Storage near the depth of the present lysocline could drive major changes: the lysocline might shift upwards rapidly. Seen positively, associated dissolution of calcium-carbonate sediments will enhance the ocean's capacity to sequester C_{ant} on long time-scales. On the other hand this will make life more difficult for calcifying marine organisms living in this depth range. Our results reveal significant accumulation of anthropogenic CO_2 at the depth of the aragonite lysocline in the eastern basin of the North Atlantic and closer to the depth of the calcite lysocline in the western basin.

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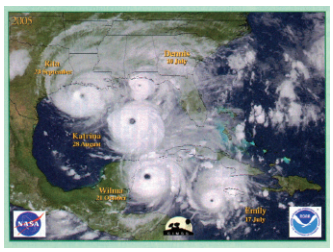
Arne Körtzinger, Toste Tanhua and Douglas Wallace

Corals track past Hurricanes



The strong hurricane activity observed during the last decade fuelled the debate whether global warming is a major force. The crux of the recent debate is the limited length of the reliable instrumental record that exacerbates the detection of possible long-term changes in hurricane activity, which naturally exhibits strong multidecadal variations in association with the Atlantic Multidecadal Oscillation (AMO). We analysed the stable oxygen ($\delta^{18}O$) of a Caribbean brain coral which records both hurricane activity and AMO. This proxy record is equally sensitive to variations in sea surface temperature (SST) and seawater $\delta^{18}O$, with the latter being strongly linked to precipitation and evaporation. The SST and precipitation signals in the coral provide the longest continuous proxy-based record of hurricane activity that interestingly exhibits a long-term increase over the last century.

Massive shallow water corals, characterized by annual density bands, in which seasonally changing environmental signals are incorporated as geochemical traces are well known climate and paleoclimate recorders. The development of *Diploria strigosa* as a reliable archive (Hetzinger et al. 2006) for Tropical Atlantic climate provided the base for this study. Proxies derived from corals so far are biased by variations in growth and skeletal microarchitecture. In December 2004, we drilled a 1.15m coral core from such a hemispherical colony growing in a water depth of 2m in the fringing reef near Cayo Sal (11.77°N, 66.75°W), at the southernmost rim of the Los Rocques archipelago. Micro-samples for oxygen isotope analysis were retrieved in 1mm increments yielding approximately monthly resolution. The monthly $\delta^{18}O$ record extends from 1918 to 2004.

Year-to-year variations in coral $\delta^{18}O$ (Fig. 1A) are significantly correlated with SST at the study site. Both coral $\delta^{18}O$ and SST show pronounced multidecadal variations with a period of ~60 yr (Fig. 1B). However, the magnitude of the multidecadal variations in coral

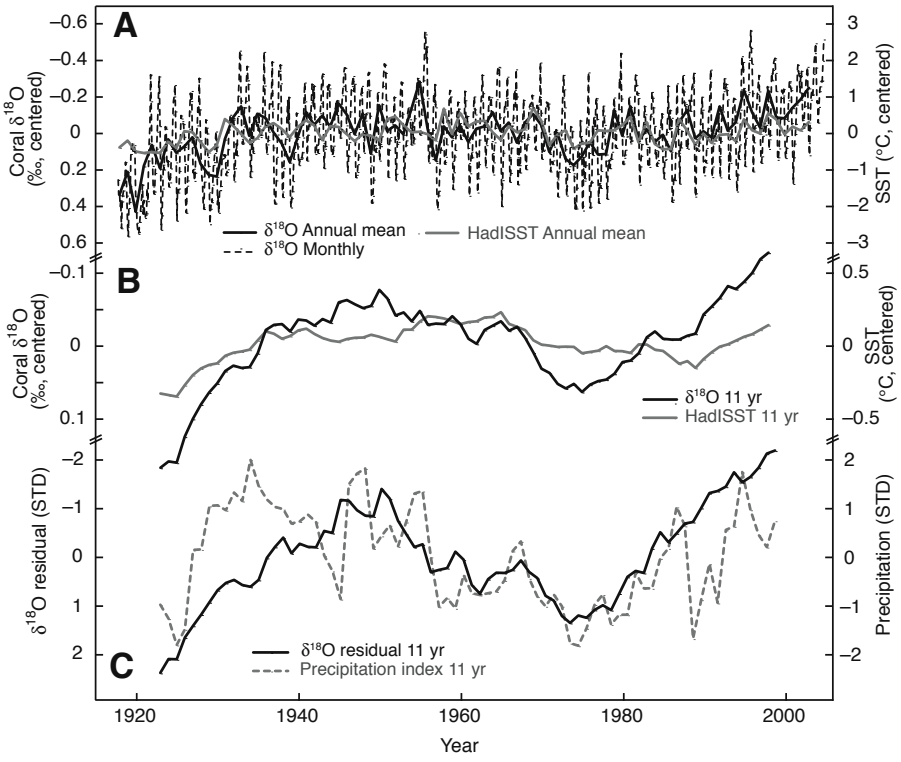


Figure 1: Coral $\delta^{18}O$ chronology and climate parameters. A: Monthly and annual mean oxygen isotopes ($\delta^{18}O$) from the Los Roques coral core compared to annual mean (gridded) SST (HadISSTv.1.1) at the study site (12°N, 66°W). Coral $\delta^{18}O$ and local SST data are negatively correlated ($r = -0.58$ for annual means). The correlation is significant at the 1% level, assuming 83 degrees of freedom.
B: Comparison between coral $\delta^{18}O$ and SST averaged using an 11 yr running filter. The correlation amounts to $r = -0.69$ for the period 1923–1998. Data in A and B were centred by subtracting the mean and scaled so that –0.2‰ $\delta^{18}O$ corresponds to 1 °C.

$\delta^{18}O$ is larger than expected based on SST alone. Subtracting the SST component from the $\delta^{18}O$ of the coral provides the $\delta^{18}O$ residual, a measure of $\delta^{18}O_{seawater}$ which portrays precipitation.

Low-frequency SST variability in the tropical North Atlantic influences the intensity of hurricanes. Los Roques coral $\delta^{18}O$ correlates well with large-scale SST variations in the tropical North Atlantic, especially SST in the south-central part, the main hurricane development region, making this site ideal for detecting past changes in hurricane activity. Vertical wind shear is another important factor controlling hurricane activity (Latif et al. 2007), which is controlled not only by local but also by SST outside the Atlantic. The coral $\delta^{18}O$ correlates also well with multidecadal fluctuations in vertical wind shear. The two are related because the latter are associated with meridional displacements of the Inter-Tropical Convergence Zone (ITCZ). The coral, due to its position, records shifts in the ITCZ through the variations in precipitation. Recording both SST and vertical wind shear, the coral $\delta^{18}O$ variability is an excellent proxy to infer past changes in hurricane activity.

We compared directly the coral $\delta^{18}O$ record with the index of Accumulated Cyclone Energy (ACE), a measure of hurricane activity that takes into account the number, strength, and duration of all tropical storms in a season and which shows pronounced multidecadal variability. Since the typical hurricane peak season is from August to October we selected the corresponding $\delta^{18}O$ data from the coral record and applied an ordinary least squares regression analysis. A strong and statistically significant relationship exists between seasonal mean August-September-October averaged coral $\delta^{18}O$ and the ACE index (Fig. 2A;

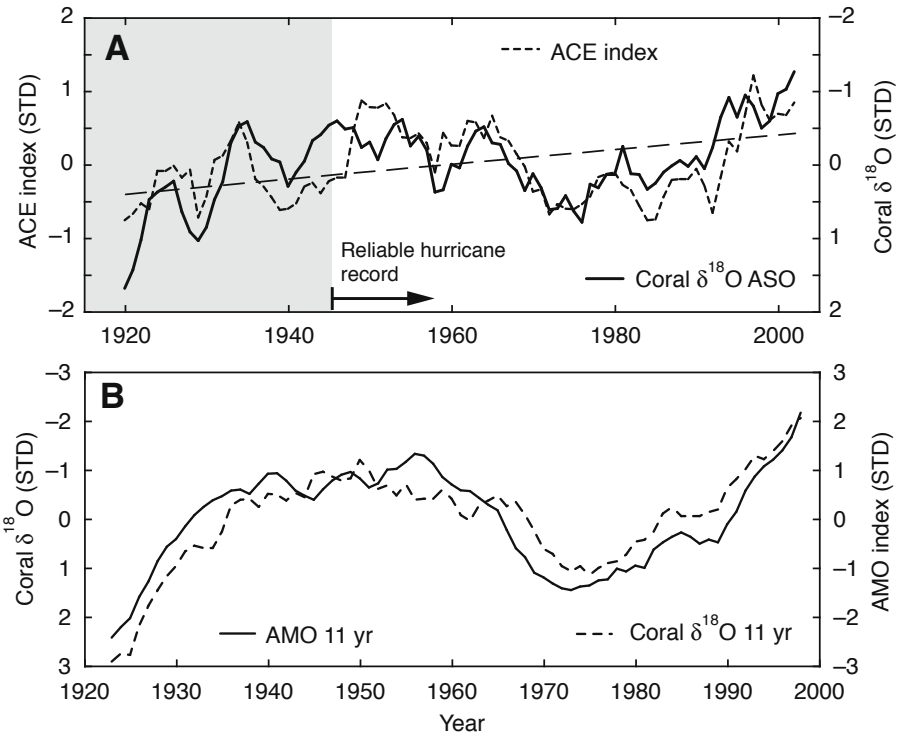


Figure 2: A: Comparison between coral $\delta^{18}O$ and the index of Accumulated Cyclone Energy (ACE) for the North Atlantic. Data shown are for the peak months of the Atlantic hurricane season, August-September-October (ASO), and were averaged using a 5 yr running filter. The correlation is high (r = –0.66) and significant at the 1% level, assuming 14 degrees of freedom (1920–2002); r = –0.52 for unsmoothed ASO data (not shown), 1918–2004. The correlation is also stable for de-trended values (r = –0.50 for unsmoothed ASO data; and r = –0.67 for 5 yr means, same time intervals as above). Dashed line represents the upward trend seen in coral $\delta^{18}O$ during1920–2002. The trend is statistically significant at the 0.1% level, assuming nine degrees of freedom.
B: Comparison between coral $\delta^{18}O$ and the AMO index (North Atlantic SST averaged between 0 and 70°N; Enfield et al., 2001). Seasonal mean values were removed from the monthly data before averaging to annual resolution. An 11 yr running filter was subsequently applied. The correlation is high (r = –0.86) and statistically significant at the 5% level, even with only four effective degrees of freedom. AMO: Atlantic Multidecadal Oscillation; ASO: August-September-October; STD: standard deviation.

r = -0.66; 1920–2002). A comparison with the so-called "power dissipation index", another commonly used hurricane index, revealed similar results. The coral proxy record is a particularly good indicator of decadal to multidecadal swings in the ACE index (Fig. 2A). The relationship to the ACE index is equal to or even better than the relationship between SST and ACE. This is due to the changes in vertical wind shear that are additionally recorded by the coral. In summary our results demonstrate that coral-derived proxy data can be used to reconstruct changes in hurricane activity well beyond the reliable instrumental record beginning in the 1940s with the regular aircraft measurements.

Figure 2A additionally shows a clear and statistically significant negative trend in the coral $\delta^{18}O$ record that is superimposed on the pronounced decadal to multidecadal variability. The trend in the coral $\delta^{18}O$ indicates a significant warming and/or freshening of surface waters in the region of tropical cyclone formation. This indicates a slow increase in hurricane activity over the last century. Such an increase may be expected in response to global warming. However, longer coral records are needed in the presence of strong multidecadal variability to reliably detect a potential anthropogenic impact on hurricane activity.

Furthermore, a close relationship between the decadal to multidecadal variability in the coral $\delta^{18}O$ and the Atlantic Multidecadal Oscillation (AMO) is found (Fig. 2B). The AMO is the major mode of low-frequency climate variability in the North Atlantic Ocean. Despite the fundamental importance of the AMO for Northern Hemisphere climate, most available reconstructions of the AMO are solely based on continental proxies with annual or even lower resolution. So far, coral proxies have failed to show a clear AMO signature. However, our coral data exhibit a strong and statistically significant correlation (r=-0.86) with the smoothed AMO index (Fig. 2B). Both SST and in rainfall in the southeastern Caribbean are driven by the AMO, so that our coral $\delta^{18}O$ index provides an excellent recorder of it.

As *Diploria strigosa* coral colonies are abundant throughout the entire Caribbean and Western Atlantic region and can live up to several hundred years, we are confident that corals of this species will become an important new marine high resolution archive that can be used in future studies to reconstruct ACE and AMO variability beyond the instrumental record.

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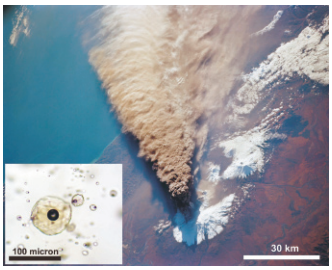
Wolf-Christian Dullo and Mojib Latif

Fertilising the surface ocean – the role of volcanoes



The oceans are by far the largest global reservoir of carbon that is available on climate relevant timescales (< 1000 yrs). A fraction of this oceanic carbon pool, comparable in magnitude with the CO_2 inventory of today's atmosphere, is transformed via biological assimilation of inorganic carbon into dissolved or particulate organic material within the sun-lit surface ocean. Subsequently this material can be respired, returning to the ocean as CO_2, or it can sink to the sediments and this forms the basis of the 'biological pump'. The efficiency of this pump is limited by the availability of nutrients, which are essential prerequisites for the growth of phytoplankton. We now know that vast areas of the surface ocean have extremely low nutrient concentrations limiting productivity. For instance, in the subtropical oceanic gyres, which comprise more than 40% of the Earth's surface, the macronutrients nitrate, nitrite, ammonia and phosphate are depleted to trace levels which limit phytoplankton abundance so strongly such that the term "oceanic desert" was coined for these regions.

In other regions such as the Southern Ocean and the equatorial Pacific, iron is the growth-limiting element. Natural and artificial addition of iron to these oceanic areas can cause massive phytoplankton blooms with an enhanced export of carbon. This process of intentional iron addition has been proposed as a mechanism for sequestering anthropogenic carbon emissions from the atmosphere into the deep ocean. Although this idea is still highly controversial it highlights the need to improve our understanding of the role of natural sources of nutrients and in particular iron in the surface ocean in the Earth's history. Aeolian dust has been studied extensively for almost two decades now for its critical role in supplying iron to the ocean, however other forms of atmospheric iron sources are currently poorly studied.
The potential of volcanic eruptions for the surface ocean nutrients inventory has only very recently attracted the attention of scientists. This is surprising at first sight since the fertilising potential of volcanic soils has been known for hundreds of years and volcanoes are known to be capable of depositing airborne material as e.g. volcanic ash and pumice (during major volcanic eruptions) into even the remotest oceanic areas. While iron concentrations are at the ultra-trace level in open ocean seawater, it is a major element (up to several percentages) in volcanic material. Interaction of relatively iron-rich volcanic material with ultralow-iron surface ocean water could therefore increase iron concentrations and drive considerable phytoplankton growth.

Previously it was not known how much nor how fast volcanic material may release iron and other nutrients upon contact with seawater. Thus we set out to investigate the following questions: (1) does volcanic material release its nutrients in the upper sun-lit (above 200m depth) ocean where the algae thrive or in the darkness of the sea where they cannot have any influence on phytoplankton growth? (2) Will the nutrient release be sufficient and can phytoplankton use these nutrients, so that significant growth can be fuelled? Or are there any processes inhibiting the utilisation of nutrients released from volcanic material? (3) Is there any natural evidence confirming a causal connection between volcanic

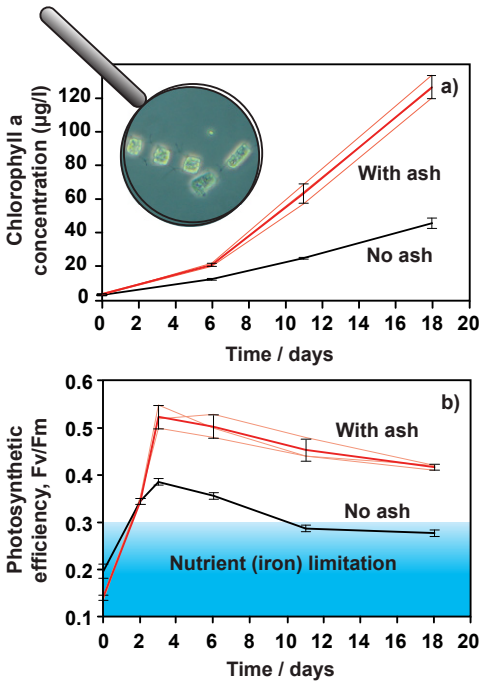


Fig. 1: Results from bio-incubation experiments in marine biology laboratories with/ without volcanic ash and the diatom Chaetoceros dichaeta in natural seawater, showing the increase of (a) chlorophyll a and (b) photosynthetic efficiency through time. Modified rom Duggen et al. (2007) Geophysical Research Letters

eruptions and enhancement of phytoplankton growth? And what is the relative importance of different types of volcanoes and their products, compared to other natural nutrient sources for the surface ocean? To answer these questions a young researcher group NOVUM (Nutrients Originating in Volcanoes and their effect on the euphotic zone of the Marine ecosystem) was formed in 2007 with funding from IFM-GEOMAR. NOVUM initiated this new research field in marine sciences in Germany and several young researchers from different divisions at IFM-GEOMAR combine their expertise in chemical oceanography, igneous geology, marine biogeochemistry, ocean modelling, marine biology and volcanology in order to find the answers to the aforementioned questions.

In our first paper we focussed on volcanic ash for experiments with natural seawater and phytoplankton. The volcanic ash we used should not have had contact with water after deposition (e.g. rain), because very fresh (or unhydrated) volcanic ash particles are covered by salt coatings (formed during the volcanic eruption) that contain nutrients and are easily soluble in water.

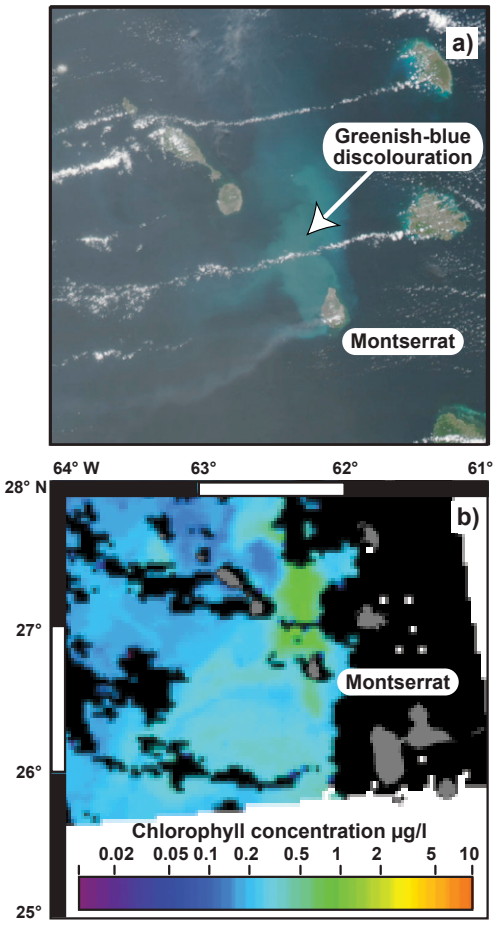


Fig. 2: True colour satellite images showing a greenish-blue seawater discolouration (a) and processed satellite data displaying chlorophyll concentrations in seawater (b), suggesting a phytoplankton bloom around erupting Soufrière Hills volcano on Montserrat (July 2003, Lesser Antilles) Modified from Duggen et al. (2007) in Geophysical Research Letters.

Such ash material is rare but our group has a considerable collection available from numerous volcanoes worldwide and in different tectonic settings. Our geochemical experiments with unhydrated ash and natural seawater show that volcanic ash can release an array of nutrients, including nitrate, nitrite, ammonia, phosphate, silica, iron, zinc and copper. The ash mobilised fixed nitrogen mainly as ammonia, appealing knowledge for marine biologists, as phytoplankton can more easily incorporate ammonia than nitrate and nitrite. We were the first to examine the nutrient mobilisation behaviour of volcanic ash on the minute-scale showing that the strongest release occurs within the first twenty minutes after contact with seawater. These results illustrate that volcanic ash rapidly releases nutrients in the sun-lit surface ocean where phytoplankton exist.

As a next step bio-incubation experiments were designed to examine the phytoplankton response to oceanic volcanic ash fertilisation. We used a diatom species (*Chaetoceros dichaeta*) common in the Southern Ocean, where algae growth is limited by low iron concentrations. After pre-culturing in the marine biology laboratories at IFM-GEOMAR, the diatom culture was split up into two sets of parallel experiments – one in which the diatoms continued to grow under iron-limited conditions and another where the seawater was briefly, for twenty minutes, brought in contact with volcanic ash. In the experiments with volcanic ash fertilisation, compared to those without, the phytoplankton reacts positively with an increase of two biotic parameters: chlorophyll a as a measure for biomass and the photosynthetic efficiency as a measure of how good the algae are to use sunlight for their metabolism (Fig. 1). These are the first experiments showing that marine phytoplankton in iron-limited oceanic areas is able to utilise iron from volcanic sources. Natural evidence comes from true colour satellite images (only available in the NASA archives for the past few years). Pictures from July 2003 show the brownish haze of a volcanic ash plume during the eruption of Souffriere Hills volcano on Montserrat, associated with a large area of greenish-blue seawater discolouration (Fig. 2). Processed satellite data suggest

that the discolouration arises from an increase in chlorophyll and thus a phytoplankton bloom.

Our research activities gained considerable attention by the German press (e.g. Die Welt, Hamburger Abendblatt, Kieler Nachrichten). During an evaluation of the Research Division 4 "Dynamics of the Ocean Floor" our multi-disciplinary study was highlighted by the reviewing committee as an important contribution to improve our understanding of global carbon-cycles. Some important answers have been found by NOVUM in 2007, yet many question as to the significance of volcanoes for the surface ocean nutrient budget, the marine primary productivity, carbon-cycles and eventually climate development are still subject to ongoing and future multi- disciplinary research activities.

Svend Duggen, Peter Croot, Heiner Dietze, Linn Hoffmann, Nazli Olgun and Ulrike Schacht

Connecting young scientists: the international programme GAME establishes a unique global research network in marine benthic ecology

GAME is an international training and research programme for young marine scientists and stands for "Global Approach by Modular Experiments". In the framework of thematically oriented research projects on ecological issues, identical experiments are carried out simultaneously at different locations around the world. This approach is new in ecological science and is as innovative as it is efficient: Only globally comparable findings can provide insights that transcend biogeographical regions and ecosystem boundaries. This innovative new concept was developed by Prof. Martin Wahl (IFM-GEOMAR) and is sponsored by the Mercator Foundation.

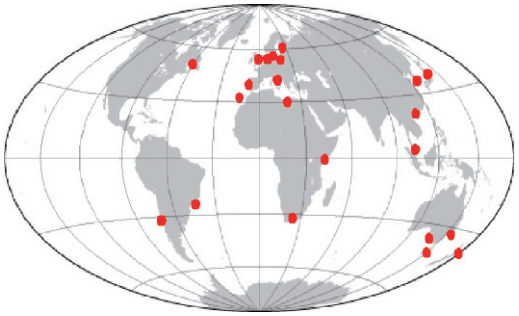


Fig. 1: The GAME global network in 2007. The number of 22 partner institutes on five continents allows the replication of experiments across biogeographical regions and climate zones.

GAME projects are concerned with the structure and functioning of marine benthic communities, their biological diversity, their significance and their potential or actual endangerment. In this context the participants also study the consequences of global change for the marine ecosystems which are among the most important on our planet: coastal waters. These are used by man in many different ways and are subject to continuous change.

GAME was initiated in 2002 and currently co-operates with a total of 22 marine science institutes on five continents. Its unique worldwide network of scientists and institutions, which unites a broad range of competences and research facilities, spans the globe from Australia to Finland, from Chile to Japan. GAME therefore links up scientific expertise and resources across the boundaries of nations and continents.

GAME – accomplished projects

Changes in coastal habitats: Does lack of light reduce the defensive capacity of macroalgae? - 2006-2008

Human activities often lead to an increase in the concentration of microalgae, induced by eutrophication, and suspended particles in coastal waters. This reduces the amount of light penetrating the water column leading to low-light stress for the benthic macroalgae. The latter are important habitat engineers in many coastal systems, e.g. the large brown seaweeds in temperate waters, and provide manifold ecosystem services.

Macroalgae contain active chemical substances which they can use to deter herbivores, such as snails, marine woodlice and fish. It is a widely accepted notion that these defence systems are energy dependent. This GAME project investigated whether seaweeds that are suffering from low-light stress are less capable of protecting themselves against herbivory than less stressed individuals. If impaired algae fall victim to their predators more easily, the structure of coastal habitats could alter dramatically when light regimes change. We studied more

Fig. 2: Installation of an experimental set-up in Kuala Terengganu, Malaysia.

than 20 seaweeds species worldwide and found that most of them show a high capacity to adapt to short-term low-light conditions. Only in 3 cases we observed an influence of low-light stress on algal palatability for mesograzers.

Invasions in the ocean: How stable are fouling communities in the face of environmental change? - 2005 to 2007

Assemblages of organisms living attached to ship hulls are highly mobile and can therefore easily enter new habitats. The speed and distance of their movements are constantly increasing as shipping activity expands. The survival of individual species during transport depends primarily on the stability of the community. In this project we studied the connection between the diversity of fouling communities and their stability towards environmental change. Sheets of plastic were exposed to natural colonization by fouling organisms for four months and were then moved to new locations with different environmental conditions. In all cases, the actual introduction of species into new habitats was avoided by the experimental set-up. In our study younger fouling communities were generally less diverse than older ones and offered more available space for local species to colonise after transplantation. In contrast, the older fouling communities had greater diversity and less available space and native species did not succeed against the introduced community and allowed non-indigenous species to survive. Thus if the dispersal of alien species in the oceans is to be avoided, preventive measures must be taken, e.g. frequent removal of sessile organisms from ship hulls.

Variability in the occurrence of natural disturbances and their consequences - 2004 to 2006

In many ecosystems, disturbances play a significant role in determining the structure of biotic communities. Their role in ecological processes has often been studied, although the emphasis has been on the intensity of disruptive events. However, the occurrence of natural disturbances is often extremely variable in space and time. Global change will increase this variability in the future for many disturbances connected with climate. For this reason we studied the influence of the temporal variability of disruptions on the diversity of marine benthic communities. To this end disturbance events were artificially created in hardbottom communities, and were distributed either evenly or in clusters over a specified period of time.

Fig. 3: Last preparations for an outdoor experiment in Arraial do Cabo, Brazil.

Against expectations, variability in the occurrence of disturbances had an effect on the diversity of communities in only one location, while in two more locations effects on the presence of individual species were observed. The general absence of effects seems to indicate that the temporal variability in disturbance regimes, at least over short periods of time, does not have major relevance for the communities studied.

The interactive influence of disturbance and the availability of nutrients on biotic communities in shallow coastal waters - 2003 to 2005

Disturbances and the availability of nutrients are important factors in

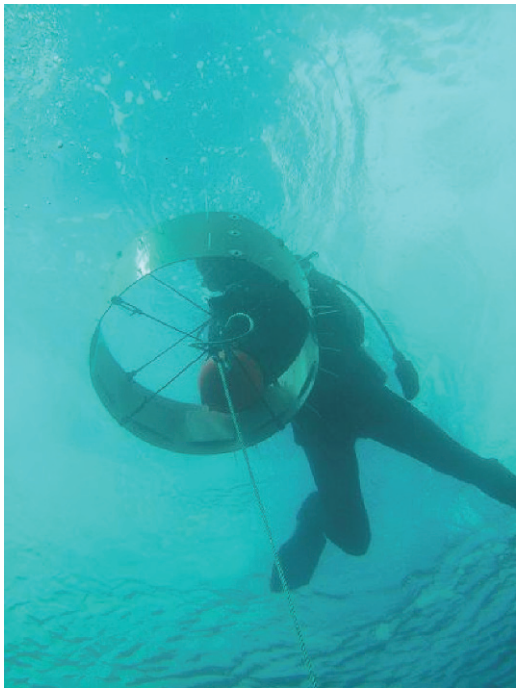


Fig. 4: Sampling near the Leigh Marine Laboratory, New Zealand.

Fig. 5: All data are collected: termination of an experiment in the Bay of Gdansk, Poland.

structuring communities and in coastal habitats both are changing under human influence. Disturbances make resources available and reduce the dominance of strong, competitive species. In this way they help to maintain diversity in biological systems. In contrast, an increased availability of nutrients favours strong, competitive species and counteracts the effects of disturbance. Thus the effects of perturbations should change as the availability of nutrients increases. We tested this hypothesis in nine locations and did not find the predicted interaction between productivity and disturbance in any of the study locations. However, in three of the nine locations we observed a maximum diversity of species at medium frequencies of disturbances what supports one of the central concepts in the theory of biodiversity.

The response of macroalgae to grazing stress: How widespread are inducible defences against herbivores? - 2002 to 2004

It is generally assumed that algal defence systems against herbivory require energy and therefore put a strain on the plants' scarce resources. An adaptable defence strategy based on need would therefore be advantageous. In theory such defences would be triggered by the threat of being eaten and could be shut down in the absence of predators. In this GAME project the taxonomical and geographical distribution of adaptable defences were studied and the findings clearly show that this ability is unexpectedly widespread among macroalgae. Furthermore, it was demonstrated that algae can communicate with each other: by using transmitters they can warn conspecifics over short distances when a grazer is feeding on them. On reception of this information other algal individuals then activate their own defences before they come into contact with the predators.

So far GAME results have been published in 19 peer-reviewed articles.

Mark Lenz

Rapid sedimentation, overpressure, fluid flow and slope instability at the Gulf of Mexico continental margin

Integrated Ocean Drilling Programme (IODP) Expedition 308 studied overpressure and fluid flow on the Gulf of Mexico continental slope. The scientific program examined how sedimentation, overpressure, fluid flow, and deformation are coupled in a passive continental margin setting. The expedition investigated the model of how extremely rapid deposition of fine-grained mud leads to rapid build-up of pore pressure in excess of hydrostatic (overpressure), underconsolidation and continental slope instability. Expedition 308 tested this model by examining how physical properties, pressure, temperature, and pore fluid compositions vary within low-permeability mudstones that overlie a permeable, overpressured aquifer. Three sites were drilled in the Ursa Basin off the Mississippi Delta, using the research drillship R/V JOIDES RESOLUTION (Fig. 1). In the Ursa Basin rapid, late Pleistocene sedimentation was known to be present. Drilling documented severe overpressure in the mudstones overlying the aquifer. The most important achievement of IODP Expedition 308 is to have successfully recorded in situ formation pressure and temperature in an overpressured basin. This is the first time that a coherent data set of such measurements has been obtained.

Rapid sedimentation (>1 mm/y) generates overpressure in many sedimentary basins around the world. When low permeability sediments are rapidly loaded, pore fluids cannot escape and the fluids bear some of the overlying sediment load. In this situation pore pressures higher than the hydrostatic pressure develop. Recent work has focused on how rapid sedimentation and stratigraphic architecture couple to produce two- and three-dimensional flow fields. For example, if a permeable sand is rapidly buried by low-permeability mud of laterally varying thickness (Fig. 2), fluids flow subhorizontally through the sand layer to regions of thin overburden before they are expelled into the overlying sediment. This creates characteristic distributions of sediment properties, fluid pressure, effective stress, temperature and fluid chemistry in the aquifers and the bounding mud (Fig. 2). This simple flow-focusing process can cause slope instability near the seafloor. In the deeper subsurface, overpressures created by flow focusing can drive fluids through low-permeability strata to ultimately vent them at the sea-floor. This is a globally important mechanism for the transfer of fluids from the solid earth to the hydrosphere and the atmosphere.

Fig. 1: R/V JOIDES RESOLUTION, drillship of the Integrated Ocean Drilling Program (IODP), in the port of Mobile, Alabama, before leaving for the Gulf of Mexico.

Ursa Basin is approximately 150 km south-southeast of New Orleans, Louisiana (USA) in about 1000 m of water. The region is of economic interest because of its prolific oilfields that lie at depths >4000 meters below seafloor (mbsf). We were interested in the sediments from 0 to 1000 mbsf. Three-dimensional (3-D) seismic data sets were used to constrain the stratigraphy within the Ursa Basin. Fig. 3 shows the seismic transect along which the three IODP Sites (U1322, U1323, U1324) were drilled. The sand-dominated Mississippi Canyon Blue Unit is overlain by a levee-channel assemblage that is mud-dominated. The most spectacular feature is the sand-cored levee-channel of the Ursa Canyon (Fig. 3), overlain by the muddy eastern levee deposits of the Southwest Pass Canyon, and a hemipelagic drape cover. The post-Blue Unit mudstone package has numerous detachment surfaces that record slumping and attest to a history of repeated continental margin instability.

The Ursa Basin sites provided a west-east transect that tested the flow focusing model of differential loading on a permeable aquifer. Overburden was drilled and sampled to 608 mbsf at Site U1324 (thick overburden) and to 234 mbsf at Site U1322 (thin overburden). Penetrometer measurements (Fig. 4) measured overpressure below 100 mbsf at both sites. Normalized overpressure of approximately 0.6 was determined at the base of each sites (i.e. the pore pressure lies 60% of the way between hydrostatic pressure and lithostatic pressure). Some of the penetrometer measurements at Site U1322 show almost lithostatic pore pressure. These overpressured stratigraphic horizons could be potential detachment surfaces leading to future slope instability.

Average sedimentation rates are considerably faster at Site U1324 than at Site U1322 (10 vs. 3.8 mm/y). The similar overpressure gradients present at both sites in spite of the almost 3-fold difference in sedimentation rate imply a component of lateral flow between them: this flow drives fluids from Site U1324 toward Site U13222, increases the pressure at Site U1322 relative to a system with only vertical fluid migration. The Blue Unit, composed of interbedded sheet sands and mudstones is interpreted to facilitate the lateral transfer of fluids from Site U1324 to Site U1322, which makes the regional pressure field diverge from a simple one-dimensional, compaction system. Core, log and sesimic interpretations document numerous scales of slumping, faulting, and soft-sediment deformation with increased occurrence at Site U1322. This deformation is consistent with prediction of the flow focusing model. Viewed at the basin scale, this type of lateral fluid flow

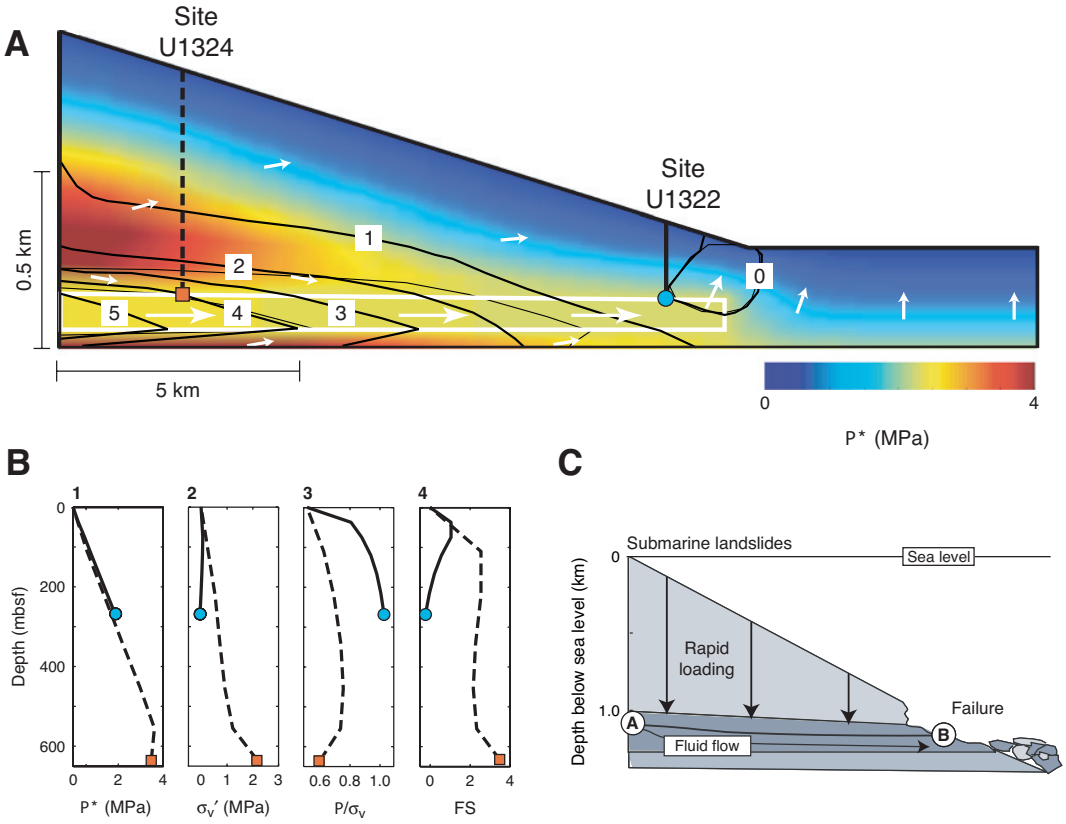


Fig. 2. Flow-focusing model approximating conditions in the Ursa Basin. A) Low permeability sediments are rapidly deposited on a high permeability aquifer (outlined in white). Sedimentation rate decreases from left to right, resulting in the final wedge-shaped geometry. Rapid sedimentation generates overpressures (P; color contours) that are greatest on the left (red). Flow is driven laterally (left to right) along the aquifer and expelled at the toe of the slope where the aquifer ends (white arrows). The vertical effective stress (black contours) is lowest on the right. (B) Predicted overpressure profiles where overburden is thick (Site U1324) and thin (Site U1322). (1) Overpressure at Site U1324 is greater than at Site U1322 for equivalent depths. (2) The vertical effective stress (σ_v') is much lower at Site U1322 than at Site U1324. (3) Pore pressures (P) equal the overburden stress (σ_v) at Site U1322. (4) Slope failure is predicted by infinite slope analysis near Site U1322 for FS < 1. FS relates the failure-driving stress to the available shear strength for shallow failures. Model parameters: low permeability mudstone $k_v < 5 \times 10^{-8}$ m^2 and $k_h < 5 \times 10^{-16}$ m^2; aquifer permeability $k_h = k_v 5 \times 10^{-14}$ m^2; maximum sedimentation rate 3.5 mm/y; minimum sedimentation rate = 0.8 mm/y. C) Cartoon to illustrate how flow focusing drives slope instability. Reproduced from Behrmann et al. (2006).*

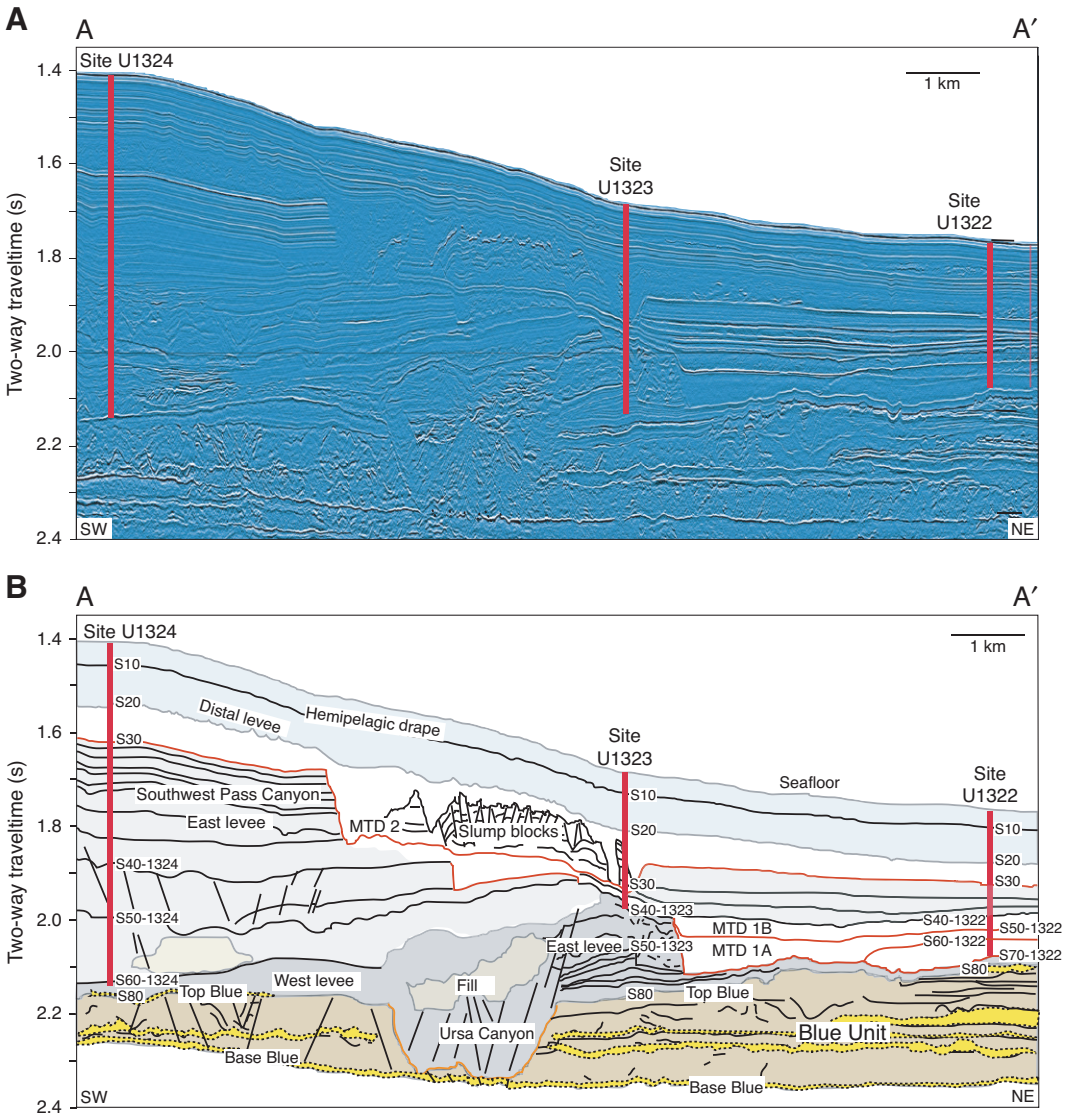


Fig. 3. (A) SW-NE seismic cross-section Ursa Basin. (B) Interpreted cross-section. The sand-prone Blue Unit has been incised by a channel-levee complex and then overlain by a thick and heavily slumped hemipelagic mudstone wedge that thickens to the west (left). The Blue Unit sands are correlated to a distinct seismic facies. Seismic data reproduced with permission of Shell Exploration and Production Company.

may be the prime factor for repeated submarine landslides generating major mass transport deposits.

A fundamental achievement of IODP Expedition 308 is that we directly measured the overpressure profile as a function of depth at Sites U1322 and U1324 in Ursa Basin. These measurements were difficult and we had a high failure rate. However, ultimately we acquired enough data to constrain the overpressure field above the Blue Unit. Preliminary interpretations suggest that flow focusing is occurring in this basin and the process does contribute to deformation and failure of sediments where overburden is thin. To our knowledge, this is the first time in the history of scientific ocean drilling that the spatial variation of the pressure field has been documented at this resolution.

Our data on pore pressure, sediment properties, and overburden stress will provide a basis to assess the potential for slope failure, especially in Ursa Basin, and estimate the conditions that drove previous slope failures. A major component of the ongoing post cruise science is the integration the stratigraphic geometry, physical properties, timing, and pressures associated with these mass wasting processes.

IODP Expedition 308 was the first expedition to monitor downhole pressure and lithology in real time using the Measurement While Drilling approach, and it was the first time that weighted mud has been used as a tool to drill and core overpressured regimes. Real time monitoring allowed us to observe shallow-water flow and to respond to this incident by raising the mud weight in order to hold back flow into the borehole. IODP Expedition 308 science provides the foundation to implement long-term in situ monitoring experiments in the aquifer and bounding mudstones in a future expedition.

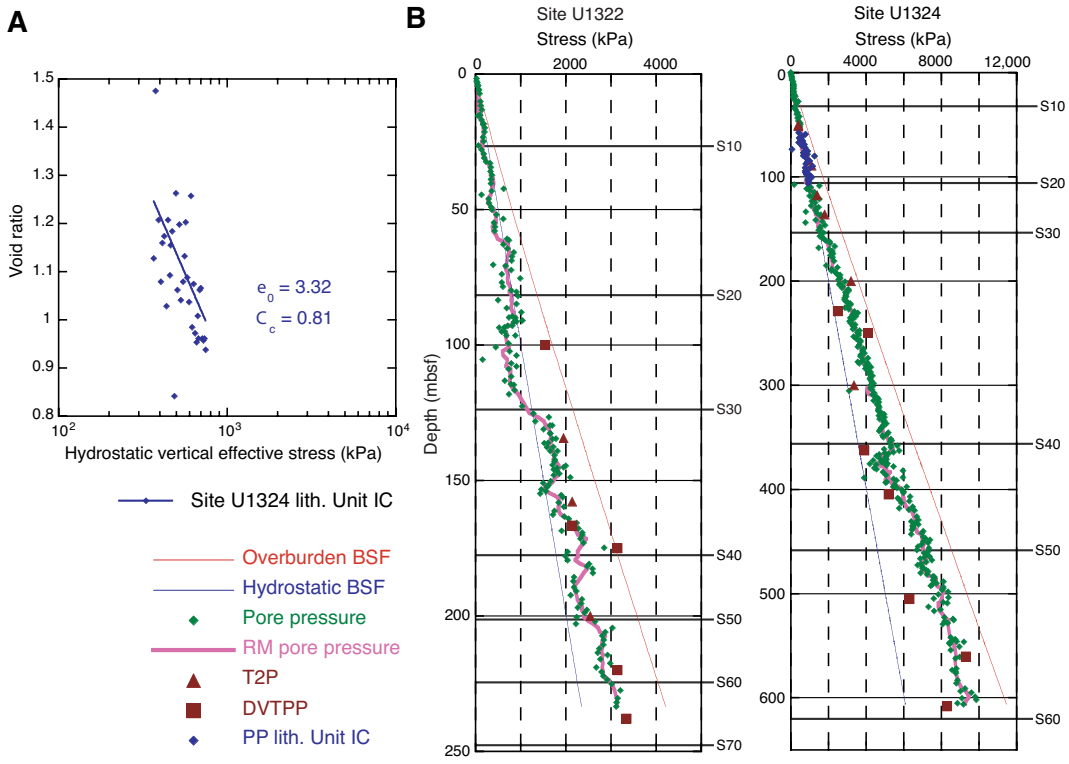


Fig. 4: (A) Void ratio (e) versus hydrostatic vertical effective stress (σ_{vh}) for lithostratigraphic Subunit Ic at Site U1324. The reference void ratio (e_0) and compression index (C_c) are derived from a fit of the type $e = e_0 - C_c \ln(\sigma_{vh})$. (B) Pore pressures for Site U1322 and U1324 are derived from parameters derived in (A) assuming that lithostratigraphic Subunit Ic (blue dots) at Site U1324 is hydrostatically pressured. Pore pressures recorded at the end of temperature and dual pressure probe (T2P) (red triangles) and Davis-Villinger Temperature-Pressure Probe (DVTPP) (red squares) deployments are also shown. BSF = below seafloor, RM = running mean, PP = pore pressure. Reproduced from Behrmann et al. (2006).

We expect research on the cores and data generated during IODP Expedition 308 to break new ground, especially in the field of geotechnical and hydrogeological analysis of continental slopes along passive and active continental margins. We have shown that programmes of in situ measurement of pore pressure in fine-grained sediments can be done with overall success. We have demonstrated that drilling into overpressured formations with riserless technology can be managed using heavy mud, fluid flow into the borehole can be controlled, and operations can be safely concluded without risk to the seafloor environment. Future expeditions in a variety of settings will benefit from the controlled use of weighted mud to stabilize the borehole.

We are grateful for the assistance given to us by the IODP technical and engineering groups, and the TRANSOCEAN marine and drilling staff aboard R/V JOIDES RESOLUTION.

Related Weblink

http://iodp.tamu.edu/scienceops/expeditions/exp308.html

Related Publication

Behrmann JH, Flemings PB, John CM, and the Expedition 308 Scientists (2006) Rapid sedimentation, overpressure and focused fluid flow, Gulf of Mexico continental margin. Scientific Drilling, 3, 12-17. doi:10.2204/iodp.sd.3.03.2006

IODP Expedition 308 Scientists J.H. Behrmann (Co-Chief Scientist), P.B. Flemings (Co-Chief Scientist), C.M. John (IODP Expedition Project Manager / Staff Scientist), G.J. Iturrino (logging staff scientist), Y. Aizawa, N.T.T. Binh, N. De Silva, B. Dugan, T.M. Edeskär, C. Franke, A. Gay, W.P. Gilhooly III, J. Gutierrez-Pastor, S.Y. Jiang, H. Long, J.C. Moore, T. Nonoura, C. Pirmez, M. Reichow, D.E. Sawyer, J. Schneider, A.V. Shumnyk, T. Suzuki, Y. Takano, R. Urgeles, Y. Yamamoto and V. Zampetti

The molecular basis of algal defense

As a measure against the adaptive potential of enemies and for reduction of metabolic costs, defense in multicellular organisms is often regulated. The regulation usually involves molecular perception of enemy presence or activity, followed by activation or induction – either local or systemic - of defense-related proteins. Animals and vascular plants are known since more than a century to defend themselves facultatively against pathogens and grazers. Macroalgal defense, in contrast, has until recently mainly been regarded as "constitutive" in the sense of "permanent" or "unregulated". Indeed, many macroalgae appear to be chemically defended at constantly high levels and this is possibly one of the reasons why the first evidence of enemy-aroused resistance in a macroalga was only detected a few years ago.

For example, the bladder wrack *Fucus vesiculosus* has been shown at IFM-GEOMAR to respond with reduced palatability when it is exposed to herbivorous animals. This brown alga, which is widely distributed in the intertidal North Atlantic and one of the most important habitat forming seaweeds in the Baltic Sea, responds in different ways to distinct consumers. The herbivore *Idotea balthica* induces reduced palatability in grazed *Fucus*, as well as in ungrazed individuals in the neighbourhood of grazed specimens. A water soluble molecular signal obviously indicates the prevalence of *Idotea* grazing within *Fucus* populations. In contrast, the herbivorous snail *Littorina littorea* only reduces palatability in individuals that have been directly grazed and simple mechanical wounding of *Fucus* induces no defensive response. Thus, the bladder wrack differentiates not only between physical damage and natural herbivory, but also between different grazers. Bioassay-guided purification of algal extracts has recently revealed that several different unpalatable metabolites accumulate in *Idotea*-grazed *Fucus*. Some of these compounds are polyphenolics, while the chemical nature of others is still under investigation.

Further evidence of enemy-induced defense comes from the kelp *Saccharina latissima*, another inhabitant of cold temperate waters. Different from populations in the North Sea, *Saccharina* sporophytes in the western Baltic are seasonal, developing during winter and perishing in summer, when water temperatures may raise to 20°C or more. The cell wall matrix of *Saccharina* consists of alginic acid, a polysaccharide composed of guluronic acid and mannuronic acid. On the algal surface alginic acid is constantly subject to more or less intense microbial degradation, which results in a release of oligoalginates. Oligoalginates that are rich in guluronic acid are perceived by *Saccharina*. They activate immediate responses such as an oxidative burst - an enzymatic production of reactive oxygen species like hydrogen peroxide (Fig. 1). These are released into the cell wall free space and the surrounding water, where they drive enzymatic processes such as haloperoxidation. Reactive oxygen species – either alone or in combination with peroxidation products – may directly inhibit certain alginate degraders. In addition, they are suspected to act as secondary signals within the cell, regulating the transcription of defense-related proteins. A study conducted in 2007 at IFM-GEOMAR has shown that a complete loss of the algal capacity to respond to oligoguluronate precedes its seasonal death in early summer, at a time when photosynthesis is still functional. An incapacity for defense against opportunistic pathogens therefore appears as one of the reasons for the death.

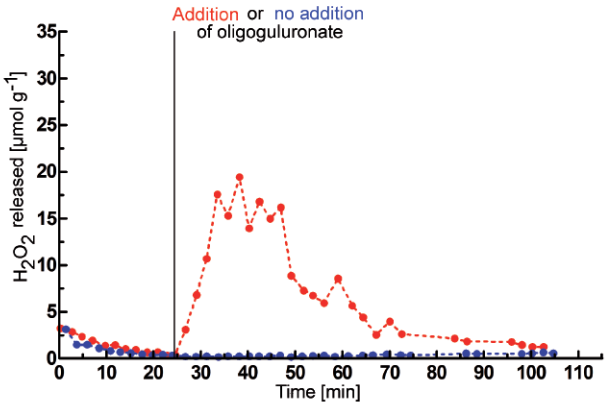


Fig. 1: Release of hydrogen peroxide into the medium by Saccharina latissima exposed and unexposed to oligo-guluronic acid.

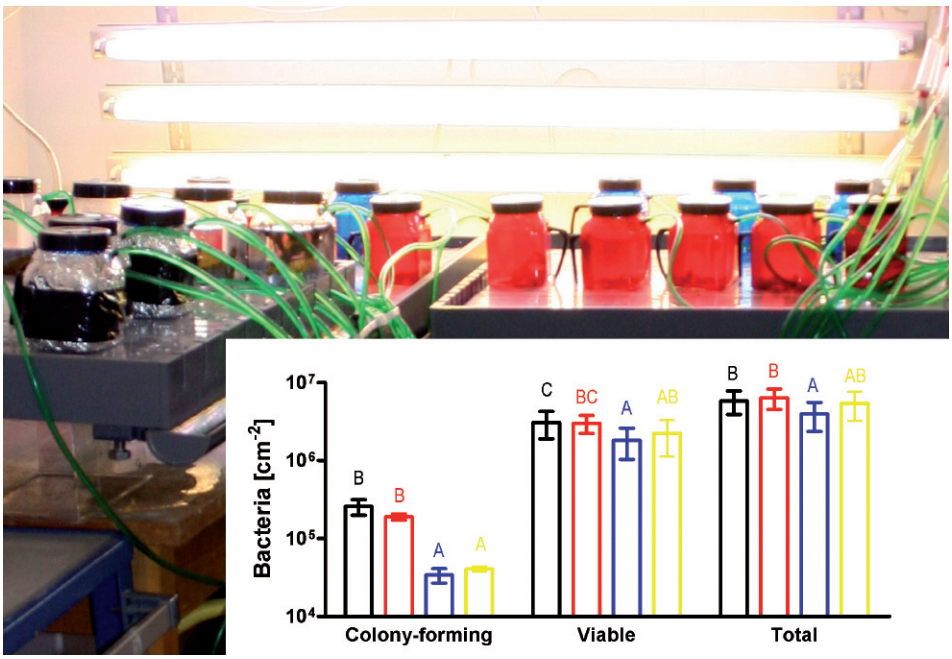


Fig. 2: Numers of colony forming, viable and total bacteria on Fucus vesiculosus incubated for 16 h in darkness, followed by 7 h of incubation in darkness or exposed to 20 µmol m^{-2} s^{-1} of red, blue or white light. Average +/- SE, n = 5. Data marked by different letters are significantly different (Tukey-test, α = 0.05).

Evidence of enemy-induced defense against microorganisms has not been detected in *Fucus* yet. Instead, recent results indicate that blue light controls rapid variations in the defense of this alga against microorganisms. In natural stands, the numbers of bacteria associated with *Fucus* – but not those associated with non-living surfaces - oscillate in a diurnal cycle. Marked decreases of bacterial numbers have been observed during the first hours after sun rise, followed by a rise in bacterial abundance during the following hours. Comparable oscillations were also observed in the laboratory, provided that *F. vesiculosus* was exposed to relatively low irradiances (20 µmol photons m^{-2} s^{-1}) of blue or white light. In contrast, red light exposure and continuous absence of light for more than the usual darkness period did not result in such an effect, and associated microorganisms reached higher numbers than usual (Fig. 2). Regulation of antimicrobial defense in *Fucus* seems therefore to be based in part upon blue light-perception, which apparently triggers pulses of defensive activity.

First hints about the possible nature of this activity come from an other study that is currently conducted at IFM-GEOMAR in cooperation with the microbiology department of Kiel University. This project deals with the identification of algal metabolites that control the overall composition of bacterial biofilms. In order to simulate the excretion of secondary metabolites by seaweeds a device has been developed that allows it to release metabolites at constant pace and over several days through a polysaccharide matrix. The matrix resembles algal cell walls chemically and mechanically. It may be exposed in the marine environment and biofilms that develop on it can be sampled and analyzed. Release of *Fucus* surface extracts from this device results in the development of less dense and less diverse (Fig. 3) biofilms, indicating that *Fucus* has the capacity to control its associated bacterial flora through excretion of specific secondary metabolites.

A newly launched project aims to design a transcript profiling tool for *Fucus* and to identify gene transcripts that are up- or downregulated during enemy attacks. This approach is expected to further improve our understanding of the molecular basis of algal defense.

Florian Weinberger

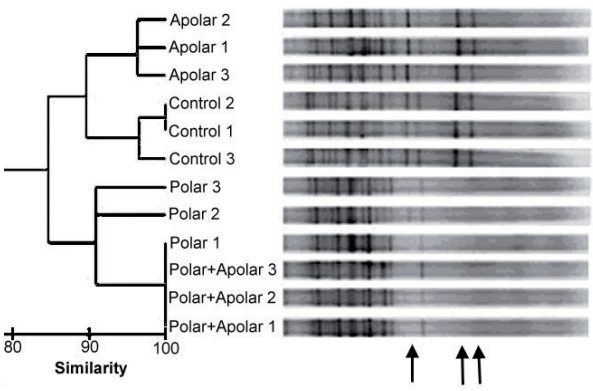


Fig. 3: Similarity of epibacterial communities on phytagel after several days of simulated excretion of polar, apolar or no (control) Fucus vesiculosus surface extract. 16S rDNA was extracted from the epibacterial communities, amplified and separated by denaturing gradient gel electrophoresis. Arrows indicate bands that are missing after treatment with polar extract, representing missing bacterial species.

Biological mechanism for enhanced carbon consumption in the ocean

Throughout Earth's history, the ocean has played a crucial role in modulating atmospheric carbon dioxide through a variety of physical, chemical and biological processes. The same processes are involved in the ocean's response to anthropogenic perturbations of the global carbon cycle. A key process responsible for about three quarters of the surface to deep-ocean gradient in dissolved inorganic carbon (DIC) is the biological carbon pump. This transports carbon bound by photosynthesis from the sunlit surface layer to the deep ocean. Integrated over the global ocean, the biotically-driven surface to deep-ocean DIC gradient corresponds to a carbon pool 3.5 times larger than the total amount of atmospheric carbon dioxide. Hence, small changes in this pool, for example, caused by biological responses to ocean change, would have a strong affect on atmospheric CO_2.

At present, one of the most far-reaching global perturbations of the marine environment is caused by the massive invasion of fossil fuel CO_2 into the ocean, making it the second largest sink for anthropogenic carbon dioxide after the atmosphere itself. CO_2 entering the ocean alters the seawater carbonate equilibrium, increasing seawater acidity and shifting dissolved inorganic carbon away from carbonate towards more bicarbonate and CO_2. For a 'business-as-usual' emission scenario, the CO_2 concentration will rise by about a factor of two relative to the present value (380 µatm) by 2100, and could increase by a factor of three by the middle of the next century. Changes in seawater chemistry of this magnitude in laboratory experiments are found to have adverse effects on calcifying organisms and to stimulate carbon and nitrogen fixation in some groups of photosynthetic organisms. Presently, little is known about the responses of natural marine ecosystems to CO_2 enrichment.

To investigate the effects of rising CO_2 on a natural plankton community, a mesocosm CO_2 perturbation study was conducted in the Raunefjord in southern Norway (Riebesell et al., 2007).

Nine enclosures, each containing 27m^3 of ambient water, were aerated with CO_2-enriched air to achieve concentrations of 350 µatm (1xCO_2), 700 µatm (2xCO_2) and 1,050 µatm (3xCO_2). After nutrient addition, the development and decline of a plankton bloom was monitored over 24 days.

The enclosed plankton community responded quickly to the CO_2 enrichment by increasing photosynthetic CO_2 uptake. The community consumed up to 39% more dissolved inorganic carbon at increased CO_2 partial pressures compared to present levels, whereas nutrient uptake remained the same. The stoichiometry of carbon to nitrogen drawdown thereby increased from 6.0 at low CO_2 to 8.0 at high CO_2, thus exceeding the Redfield carbon:nitrogen ratio of 6.6 in today's ocean. This excess carbon consumption was associated with higher loss of organic carbon from the upper layer of the stratified mesocosms.

The CO_2 fertilization of marine plankton can have a positive effect on climate change in the future. The greenhouse gas consumed by plankton and removed from the surface ocean when the dying cells sink to depth makes way for the uptake of more CO_2. In a way, the tiny organisms act as a biological conveyer

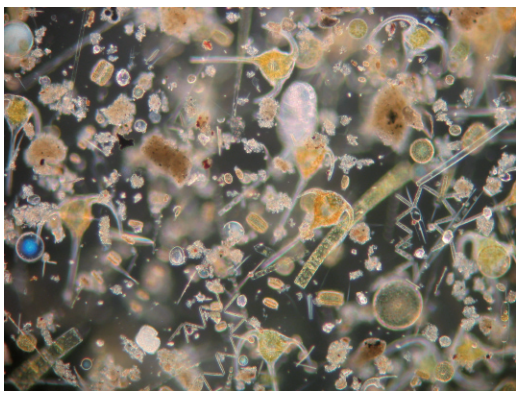


Fig. 1: Mescosm facility in the Raune Fjord, Norway.

Fig. 2: Micoalgae under the microscope: CO_2 consuming plankton. Photo: A. Stuhr, IFM-GEOMAR.

belt for the transport of carbon dioxide out of the surface and into the deep ocean. However, what appears to be a blessing for the atmospheric greenhouse effect may prove to be a curse for deep ocean ecosystems. Decomposition of the increased biomass will consume more oxygen, a major problem for marine animals that occupy deep habitats. Another consequence of the biological conveyer belt is the accelerated rate of ocean acidification in the deep ocean due to more rapid transport of CO_2 to depth. Increasing carbon-to-nutrient ratios would also lower the nutritional value of primary-produced organic matter, which may affect the efficiency of bacterial degradation and zooplankton reproduction, thus having further implications for marine ecosystem dynamics.

The results of this study probably represent only the tip of the iceberg of climate-sensitive biogeochemical processes. Other biotically-driven feedback mechanisms responsive to ocean change are bound to emerge as studies continue. It is essential not only to identify and to understand these mechanisms, but also to quantify their effect on the global climate system, now and in the future.

Ulf Riebesell, Kai Schulz

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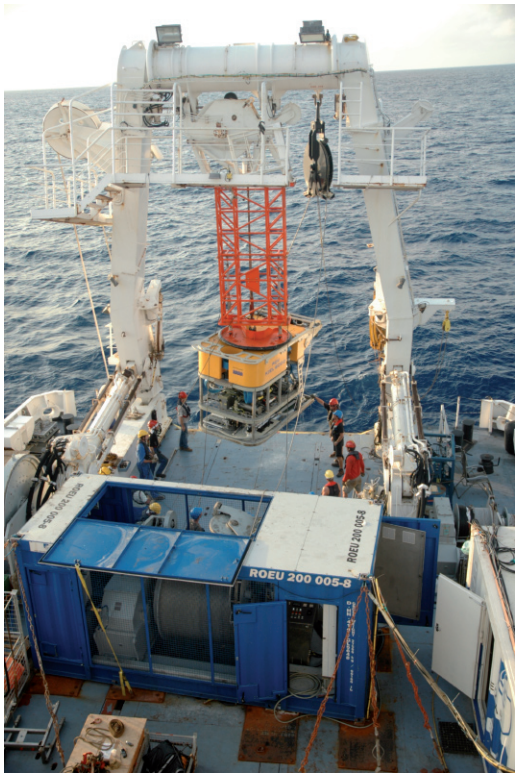
ROV Kiel6000: Hands and eyes at the bottom of the ocean

The year 2007 saw IFM-GEOMAR take delivery of its first Remotely Operated Vehicle ("ROV"), fully financed by the State of Schleswig –Holstein to the tune of 4,7 Million Euro. For that price tag you get 5 containers containing about 50 tonnes of equipment which is all you need to send television cameras, remotely-controlled arms and a host of user-built sampling devices and experiments to the bottom of the ocean, down to 6 km depth. The vehicle which makes the dive is connected to the surface ship via a cable which transmits up to 60 kilowatts of power and transports, in three glass fibres, information between the vehicle and the control van on the ship. The vehicle is equipped with both high-definition (HDTV) and standard video cameras mounted on pan-and-tilt heads (and over 4 kilowatts of lighting) transmitting in real-time to the surface vessel. Onboard sensors include a forward-looking sonar, and depth, temperature and salinity units as well as bottom-tracking doppler sonar. And the front of the vehicle is equipped with two hydraulic manipulator arms for precision work on the seabed, capable of placing samples and equipment in the hydraulically-activated sampling bay. Seven electrical thrusters (with a combined pull of over 500 kilogram-

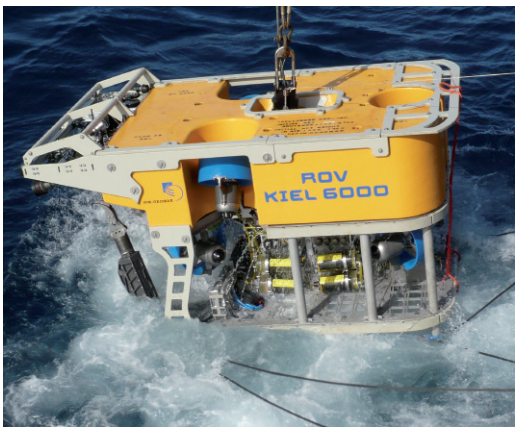


Control and navigation centre for the ROV Kiel 6000.

force) move the ROV at up to 1.5 knots through the water. All of this equipment is controlled via the standard TCP/IP protocol –the ROV is in effect a mobile network. Extra nodes on this network are available for hooking up additional scientific equipment – the standard internet protocol coupled with a flexible vehicle control software makes integrating this equipment into the vehicle a relatively simple task. A team of 8 people, including engineers for the mechanical, electrical, winch and computer systems and pilots to "fly" the vehicle and use the manipulator arms maintain, modify and deploy the vehicle when at sea. As this team stays on the ship and controls the ROV remotely, it is theoretically possible, by working in shifts, to dive indefinitely. Two pilots control the vehicle at any one time from the air-conditioned, darkened control van. They are accompanied by up to three scientists who determine the program to be followed and which samples or observations are to be taken. Via a dedicated network, crew and scientists all over the ship can however "participate" in the dive by watching the video images returned from the seafloor on video projection screens.

So why go to all this effort? Quite simply, the ROV provides unique opportunities for doing science in the deep sea. It carries enough lights and cameras to allow scientists to see exactly what is going on on the seafloor. Thanks to the high-performance software and the bottom-tracking doppler sonar, the pilots can steer and "park" the vehicle with centimeter accuracy, allowing them to position it ideally for the sceintific work. And the two remotely-controlled hydraulic arms mean that

Release of the ROV Kiel 6000 from the French research vessel l'Atalante.



Revovery of ROV Kiel 6000 after the first test dive.

experiments and measurements can be carried out on the seafloor almost as if they were being done in the home laboratory. So sampling, for example, specific individuals in a mussel bed is quite feasible, as is taking samples of the water bathing these mussels and measuring its temperature. Sampling specific parts of seafloor features such as mineralized "chimneys" is possible in unprecedented detail. And the masses of power available through the cable means that the vehicle can lift and move large equipment on the seafloor, a capability which will become increasingly useful in the future as the installation and servicing of seafloor observatories becomes a reality.

Young lava complex at the mid Atlantic ridge.

Delivered in August, the ROV saw its first sea trials in the same month off New Zealand onboard the German research vessel "Sonne" where it dived on hydrothermal vent fields in the Brothers volcano. Following this it was shipped directly to the first scientific cruises on board the French research vessel "Atalante" in December. During these cruises the ROV allowed scientists from such diverse fields as biology, mineralogy and water chemistry to study hydrothermal vents in the Atlantic. At the Logatchev field (15°N) the time-series sampling of vent fluids and their associated biological communities, financed as part of the DFG Priority Program SPP1144, was continued. At 5°S, whilst working at the Turtle Pits vent site, the ROV sampled the hottest vent fluids ever found in the oceans, measuring temperatures well above those thought feasible based on present theories of hydrothermal circulation. These fluids were emerging from a 1-cm-wide hole in the seafloor – unfeasible to sample without clear sight and precise movement of both vehicle and arms.

Mussel sampling near a hot vent in the Logatchev Field.

In the course of over 20 successful dives, the ROV has already proven its worth for the seafloor scientific community and in the process achieved a depth record for a German ROV of 4890m.

Colin Devey