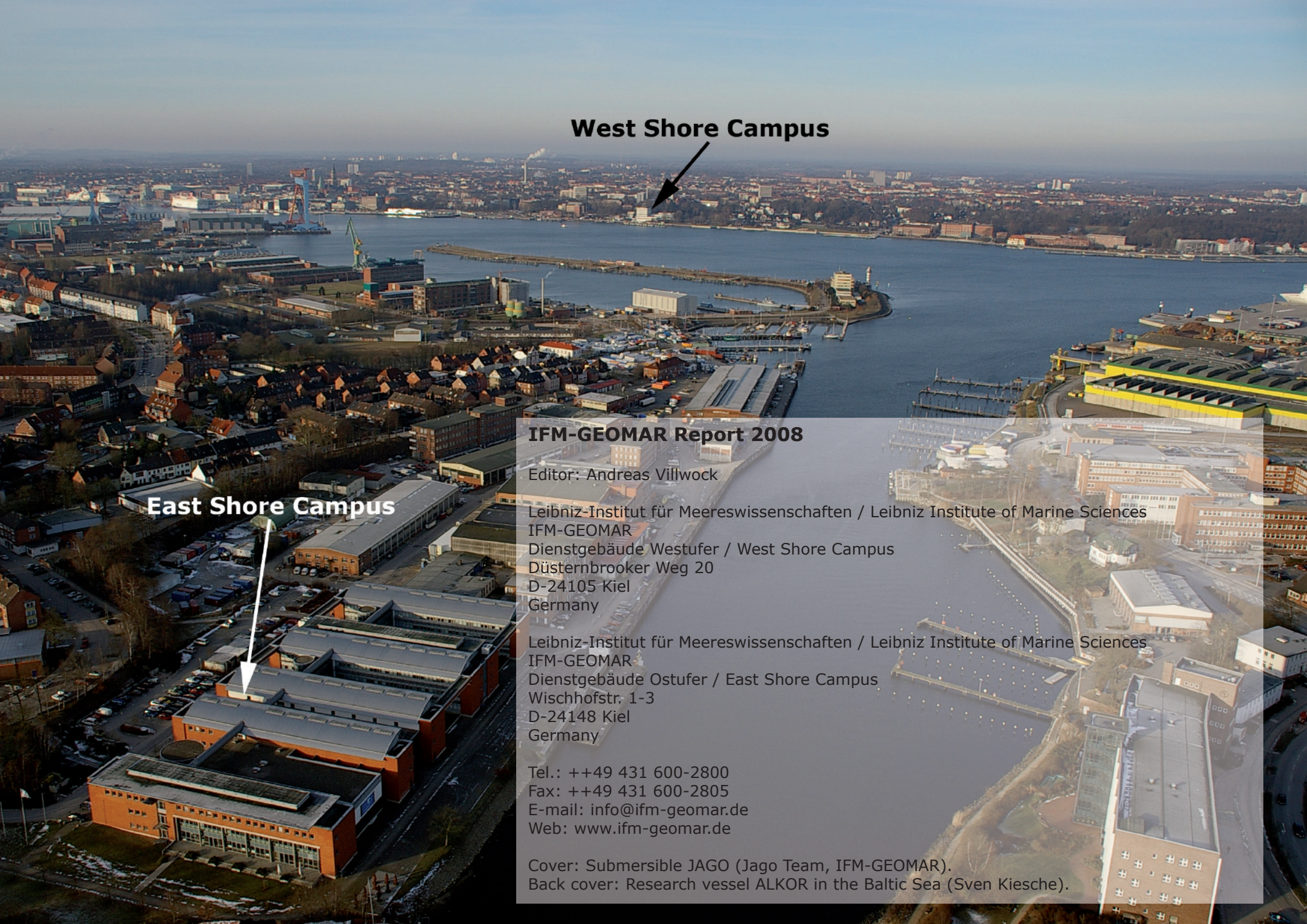
IFM-GEOMAR

IFM-GEOMAR Annual Report 2008

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -



IFM-GEOMAR Report 2008

Editor: Andreas Villwock

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Cover: Submersible JAGO (Jago Team, IFM-GEOMAR).
Back cover: Research vessel ALKOR in the Baltic Sea (Sven Kiesche).

Contents

Preface

In only five years time IFM-GEOMAR has developed to one of the leading institutes in marine research worldwide. This is documented not only by the substantial boost in funding and personnel but also in terms of high-profile research in a wide range of marine disciplines covered by IFM-GEOMAR. Publications in leading scientific journals, participation in the international research planning process and public awareness of research results from IFM-GEOMAR are visible far beyond Schleswig-Holstein or Germany. In addition, IFM-GEOMAR has strengthened its strategic alliances and international cooperation by establishing the "G3-group" consisting of the French Research Institute for the Exploitation of the Sea, Ifremer, the National Oceanography Centre Southampton, UK and IFM-GEOMAR.

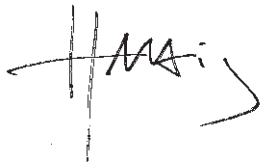
The backbone of basic research with the Excellence Cluster "The Future Ocean" and two Collaborative Research Centers (SFBs) on "Climate – Biogeochemistry Interactions in the Tropical Ocean" and "The Impact of Volatiles and Fluides in Subduction Zones - Climate Feedback and Trigger Mechanisms for Natural Disasters" is expanded by a number of projects on applied research funded by public as well as industry sources. The flagship project SUGAR aims to explore submarine gas hydrate deposits for their potential of carbon dioxide storage and methane recovery. Research on marine substances, onshore aquaculture, and submarine exploration technologies further bridge state-of-the-art knowledge in basic sciences to application.

The success of the merger of the former IfM and Geomar puts even more pressure on the demand for an extension building on the east shore of Kiel Bay. Both, federal and state government already allocated funding for this project. Thus, we are looking forward to this next major step that will strengthen marine research in Kiel in the next decades. Along with the renewal of the research fleet in Germany, now starting with the replacement of RV SONNE, and major investments in marine infrastructure and technologies, the framework for successful marine research is improving significantly. Nevertheless, additional efforts are required to successfully address the important and societal relevant questions of the oceans of the future.

Within this framework, IFM-GEOMAR has again underpinned its leading role at the national and international level of marine sciences. This report summarises the activities of the institute during 2008 and highlights a number of important research topics. All relevant documentation and statistics can be found in the appendices.

I hope that you will enjoy reading the "IFM-GEOMAR 2008 Highlights as much as I did."

Kiel, July 2009



Prof. Peter M. Herzig
Director

Overview

IFM-GEOMAR at a Glance

Overview

The Leibniz Institute of Marine Sciences (IFM-GEOMAR) is one of the world's leading institutions in the field of marine sciences. The institute investigates the chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere. This broad spectrum makes IFM-GEOMAR unique in Germany and one of the three leading institutes in Europe. Additionally, the institute has successfully bridged the gap between basic and applied science in a number of research areas.
IFM-GEOMAR has identified four overarching research themes:

- Role of the Ocean in Climate Change
- Human Impact on Marine Ecosystems
- Living and Non-Living Marine Resources
- Plate Tectonic Processes and Geological Hazards.

In cooperation with the University of Kiel, the institute is responsible for the Excellence Cluster "The Future Ocean" and two long-term Collaborative Research Centres (SFBs) that are funded by the German Research Foundation (DFG).
Four research vessels, large-scale sea-going equipment such as the manned submersible JAGO, the unmanned deep-sea robots ROV Kiel 6000 and AUV Abyss, as well as state-of-the-art laboratories, analytical facilities, and a hierarchy of numerical models provide a unique basis for cutting-edge marine research. With a number of curricula offered in English, the institute actively contributes to the education of young scientists in the field of marine sciences.

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

Director and CEO

Prof. Dr. Peter M. Herzig

Head of Administration

Ursula Frank-Scholz

Public Relations

Dr. Andreas Villwock

Staff

673 including 340 scientists (end 2008)

Budget

57.9 million Euros:
- 29.7 million Euros research funding
- 28.2 million Euros institutional funding

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Overview

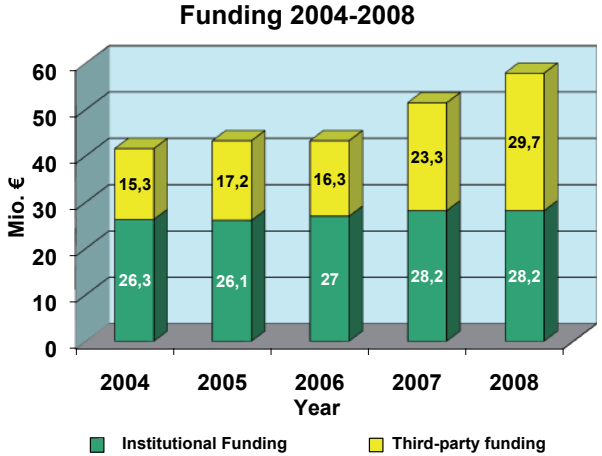
In the fifth year of its existence, IFM-GEOMAR has doubled the amount of third-party funding and increased the number of staff by 60% compared to 2004. These two figures document the success story of the institute.

In 2008 the total budget of IFM-GEOMAR was about 58 million Euros of which nearly 30 million Euros are project funds from funding agencies and industry. Thus, the project funding exceeded for the first time the institutional funding of about 28 million Euros.

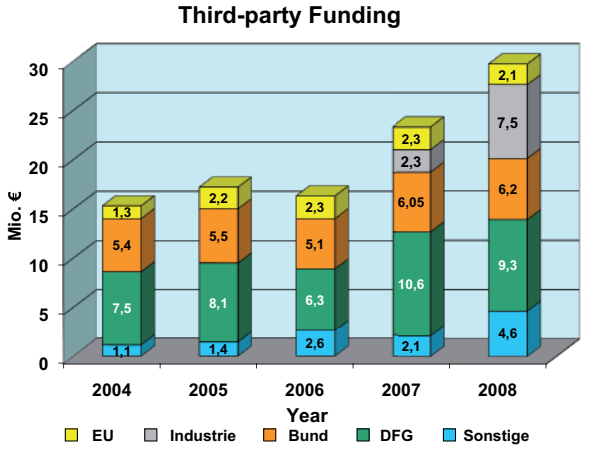
Personnel

By end of 2008, IFM-GEOMAR had about 673 employees. 350 are scientists (60% project funding) and the science support staff encompassed about 320 employees in central facilities and research divisions. Two open faculty positions could be filled in the past year: Prof. Thorsten Reusch (Univ. Münster) succeeding Prof. Dietrich Schnack in the research unit "Evolutionary Ecology of Marine Fishes" (formerly Fishery Biology) and Prof. Christian Berndt (NOCS, UK) in Marine Geodynamics filling the position of Prof. Tim Reston. In addition, Prof. Torsten Kanzow became a new junior professor in Physical Oceanography. Finally, Ursula Frank-Scholz was appointed the new Head of Administration.

Funding Overview



Institutional and project funding 2004-2008

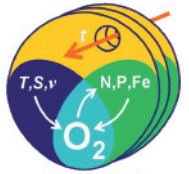


Project funding 2004 - 2008 by sources

Major Projects

future ocean
KIEL MARINE SCIENCES

In basic research, IFM-GEOMAR currently runs three lighthouse projects: The **Excellence Cluster „The Future Ocean"** and two collaborative research centres, SFB 574 "Fluids and Volatiles in Subduction Zones" and SFB 754 "Climate Biogeochemistry Interactions in Tropical Oceans". The built-up of 13 junior research group leaders and subsequent staff within the Excellence Cluster was completed. Four groups were established at IFM-GEOMAR: Ocean acidification (Prof. Frank Melzner), Seafloor warming (Prof. Tina Treude), Seafloor resources (Prof. Lars Rüpke) and Marine hazards (Prof. Sebastian Krastel-Gudegast). The cluster has held its second bi-annual symposium in October 2008. In addition, the cluster organized the first Children's University (lectures to children 8-12 and 12-16 years).
www.future-ocean.de



SFB754 started in 2008. The first phase of this project is funded with 9.2 million Euros (plus 20 % overhead) over a 4-year period. About 50 scientists, 8 post-docs and 22 PhD students participate in this project. Although being a new project, its first year

Overview

was already extremely successful. Two major expeditions, one to the subtropical North Atlantic (MSM 10-1) and the other to the eastern equatorial Pacific (M77) paved the way for successful investigations in the coming years.
www.sfb754.de

SFB574 started its third phase after a successful review in early 2008. In this final phase the focus shifts geographically towards South America and scientifically to interactions between geological processes and climate. Total funding for the last four years is about 6 million Euros (plus 20 % overhead). In 2008, the SFB organised an international symposium with 70 participants and published about 30 scientific papers.
www.sfb574.ifm-geomar.de

In the area of applied sciences, a number of new activities started. Amongst them, the "**Kiel Earth Institute**" (KEI), a joint project of the Kiel Institute for the World Economy (IfW) and IFM-GEOMAR. The Kiel Earth Institute is a virtual research institution concerned with key issues of global change and its socio-economical consequences. Topics are for example carbon capture and storage (CCS) technologies and effects of global change on marine ecosystems. KEI is jointly funded by the Federal Ministry for Education and Research (BMBF) and the State of Schleswig-Holstein for an initial two-year period.The project which was officially launched in October 2008 has a volume of 200,000 Euros over a 2–year funding period.
www.kiel-earth-institute.de

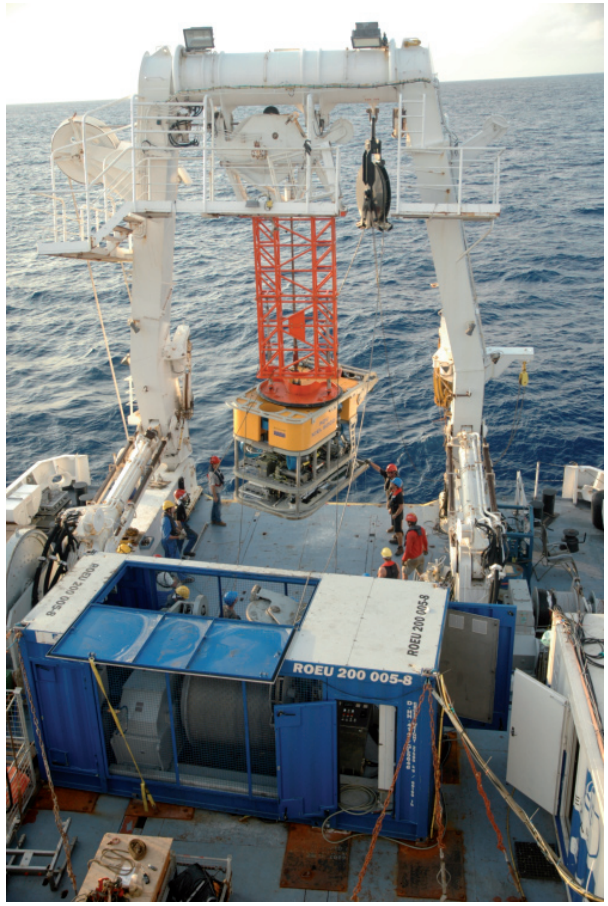
In order to develop closed systems for onshore fish farming, the aquaculture project **NEMO** (Sustainable food from marine organisms) was launched. NEMO is part of the Competence Centre Marine Aquaculture of Schleswig-Holstein with partners at the University of Kiel (CAU), the Research and Technology Centre (FTZ) Büsum and the University of Applied Sciences in Flensburg. IFM-GEOMAR contributes with its expertise in closed circulation systems. NEMO is funded with 1.5 million Euros for a period of three years by the State of Schleswig Holstein.
www.ifm-geomar.de/index.php?id=4685

Research on bio-active marine substances at the **Kiel Centre for Marine Natural Products** (KiWiZ) is further supported by two new projects. The project SUBITO aims at developing a database/library for marine substances. For this project KiWiZ received about 1.8 million Euros from the State of Schleswig-Holstein. The goal of the cluster BIOKATALYSE 2021 (www.biokatalyse2021.de), supported by BMBF, is systematic research on biocatalysts from micro-organisms to identify their potential for industrial application. The state government of Schleswig-Holstein supports KiWiZ in this large-scale coordinated project (about 60 partners) with 450,000 Euro.
www.kiwiz.org

In the area of gas hydrate research the lighthouse project **SUGAR** was launched. Supported by the Federal Ministries of Economics and Technology (BMWi), the BMBF and several industry partners, the project aims at producing natural gas from marine methane hydrates in exchange for carbon dioxide (CO_2) from power plants and other industrial sources. In the first phase of the project, the methods will be tested by laboratory experiments and modelling studies. An off-shore test is planned for the end of the funding period. The project, which involves 20 companies and 10 academic institutes, has a volume of 13 million Euros over a 3-year funding period.
www.sugar-projekt.de

Education of young researchers is supported by the new EU-FP7 Marie Curie Initial Training Project **CALMARO** (Calcification

by Marine Organisms). In the network, 13 research institutes and 4 companies from 8 nations are joining forces to address pressing questions on the future of marine ecosystems. IFM-GEOMAR is coordinating the project which has a total funding of 2.7 million Euro, the IFM-GEOMAR part encompasses 880,000 Euros.
www.calmaro.eu

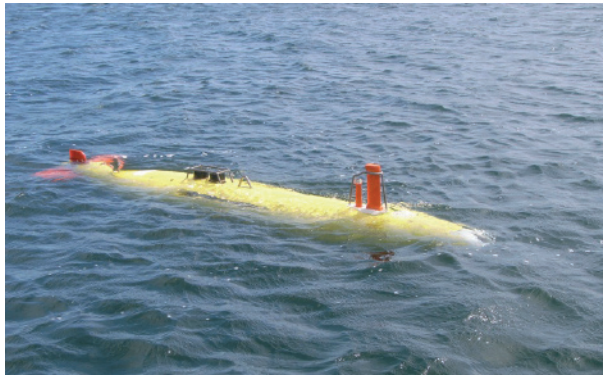


ROV KIEL 6000 on RV L'ATALANTE

Infrastructure

In terms of marine technology and infrastructure, the remotely operated vehicle ROV KIEL 6000 was officially handed over to IFM-GEOMAR on June 16 (see page 9). Before, its first scientific cruise had taken place on the French research vessel L'ATALANTE to hydrothermal vent systems at the Mid-Atlantic Ridge. In 2009, KIEL 6000 will be used on three major expeditions.

In October 2008, the autonomous underwater vehicle (AUV) ABYSS with a depth rating of 6000 m was delivered to IFM-GEOMAR. It is equipped with high-resolution sonar systems, CTD, camera and further sensors. In late autumn the first deep sea tests were performed on board RV POSEIDON. The first



AUV ABYSS

scientific cruise is planned for spring 2009. The renewal of the German research fleet is progressing. In 2008, an agreement for the replacement of RV SONNE was signed and the new ship is expected to be in service in 2013. The budget has a volume of about 110 million Euros (90% BMBF, 10% northern German states). Homeport will be Wilhelmshaven. Although the mid-term plans for the German research fleet are still to be reviewed by the German Science Council, it has already been agreed that RV POSEIDON will be replaced and remain at IFM-GEOMAR in Kiel.

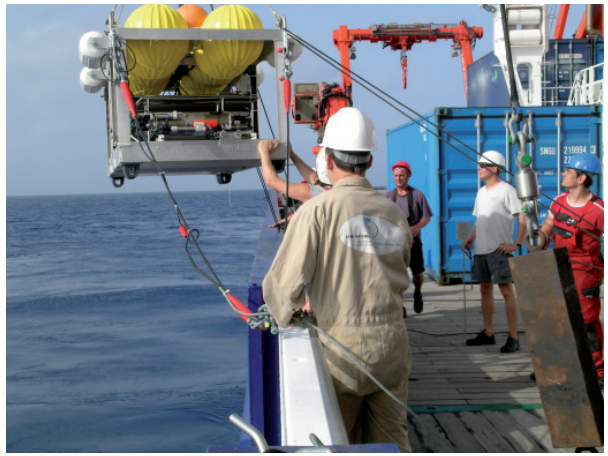
Part of the East shore campus with construction area for the extension building (shaded). TLC: Technology and Logistics Centre of IFM-GEOMAR

The planning process for the extension building on the east shore proceeded. The decision about the finance model (public-private partnership vs. "conventional" building) is expected by end of 2009. The construction will start in spring 2011 with a completion envisaged by the end of 2013. The total cost for a building with a total floor space of about 15.000 m^2 is estimated to 90 million Euros, jointly funded by the Federal Government and the State Government of Schleswig-Holstein.

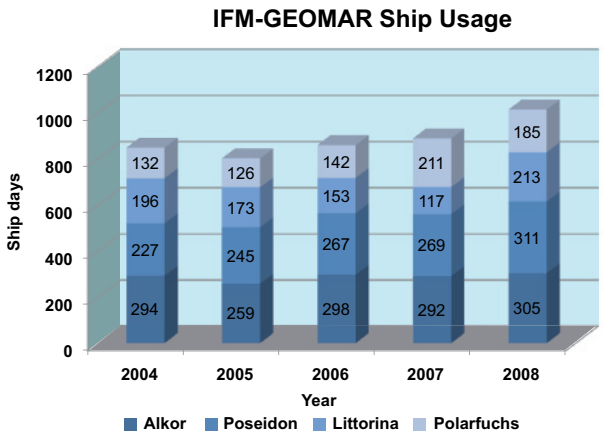
Overview

Major Expeditions and Sea-going Activities

Ten expeditions with 346 ship days on large research vessels (i.e. one ship-year of a global research vessel with principal investigator by IFM-GEOMAR) plus a number of expeditions with mid-size vessels such as RV POSEIDON and RV ALKOR document a very active year of the sea-going groups of IFM-GEOMAR. Highlights were the first ROV KIEL 6000 cruise on L'ATALANTE (replacement for MSM 6-3), the start of a tracer experiment in the subtropical North Atlantic (MSM 8-1 in spring continued on MSM 10-1 in autumn), geophysical and geological investigations in the western and eastern Pacific (SO-199 (CHRISP)) and RSS JAMES COOK for SFB 574, respectively, in the eastern Indian Ocean (SO-195 TOTAL), the investigation of the oxygen minimum zone in the eastern equatorial Pacific (M77) and the AUV ABYSS tests on RV POSEIDON. The submersible JAGO conducted two expeditions: a project on cold water corals / ocean acidification at the Norwegian coast with ALKOR and a charter cruise in the Indian Ocean to investigate the coelacanth, a living fossil fish.



Release of the Ocean Tracer Injection System (OTIS) on MERIAN cruise MSM 8-1 in the eastern Atlantic.



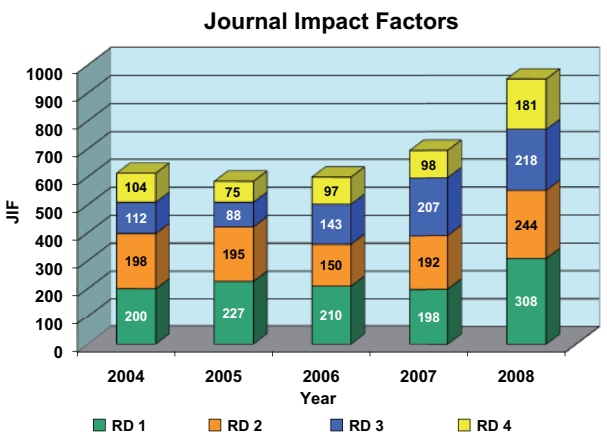
Ship usage of IFM-GEOMAR research vessels for the period 2004-2008.

More than 1000 ship days on the four IFM-GEOMAR vessels POSEIDON, ALKOR, LITTORINA and POLARFUCHS demonstrate the highest operation rate on record.

For further details see Appendix 4.

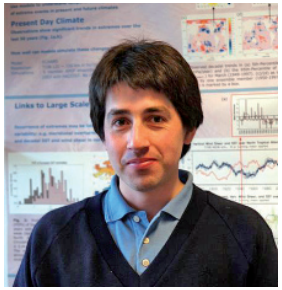
Scientific Results and Publications

In 2008, the scientific output in terms of peer-reviewed scientific publications continues at high level. Both, the absolute number as well as quality have raised. The improvement can be documented by an overall increase of the journal impact factors as well as in the number of publications in high-profile journals such as Nature (3) and Science (2) and in other journals leading in their disciplines. Some of the key results are presented in the scientific highlights section (chapter 2) of this report.



Journal impact factors by research division (RD) for the period 2004-2008.

Honours and Awards

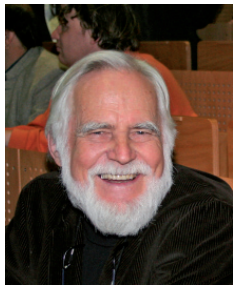


Dr. Noel Keenlyside was awarded an Emmy-Noether Fellowship by the German Research Foundation (DFG). This excellence programme of the DFG is supporting outstanding young scientists with a grant of about one million Euros for five years to build up a junior research group.

In cooperation with the sponsor "Deutsche Bank", IFM-GEOMAR honoured outstanding publication records of the past year with a sum of 1,000 Euros each: Dr. Jan Fietzke, Dr. Noel Keenlyside, Dr. Steffen Kutterolf, Dr. Juan Carlos Molinero and Dr. Maxim Portnyagin.

A number of students received awards for outstanding posters at different meetings documenting combination of excellent science and creative and innovative ways of presentation: Sebastian Krug received the "best student poster award" at the conference "Ocean in a High CO_2 World II" in Monaco. Kirstin Werner and Martin Hieronymi were honoured at the IMPETUS Workshop in St. Petersburg.

A major Deutsche Bank-IFM-GEOMAR Marine Research Award is planned for 2009.

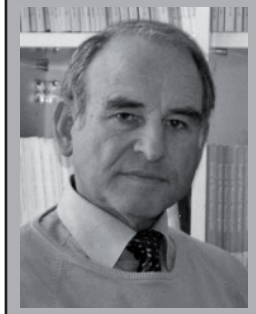


In honour of his 70th birthday, a scientific symposium was held for Prof. Hans-Ulrich Schmincke on February 1. Prof. Schmincke is one of the worldwide leading scientists in the field of Volcanology who was at IFM-GEOMAR from 1990-2003. Many former colleagues, PhD and graduate students with international participation honoured Prof. Schmincke in their scientific lectures. Although officially retired, Prof. Schmincke still contributes to a number of scientific projects.

Prof. Gerold Siedler, one of the best-known physical oceanographers in Germany, celebrated his 75th birthday on August 16. Prof. Siedler did not only had a substantial impact on marine research at the "Institut für Meereskunde" (IfM) but also initiated and led to numerous important national and international research projects.

Obituaries

Passing of Friedrich Schott



Prof. Dr. Friedrich Schott passed away on April 29 following a year-long battle against cancer. With his passing, the IFM-GEOMAR and the University of Kiel lost a nationally and internationally recognized researcher, teacher and colleague.
Friedrich Schott obtained his PhD in Oceanography in Kiel, under the guidance of Professor Günter Dietrich. In 1968, he got a position as Assistant at the "Institut für Meereskunde". He obtained his habilitation in 1974 and in 1978 he was appointed Professor at the Rosenstiel School of Marine and Atmospheric Science of the University of Miami, USA. In 1987, he became full professor for Physical Oceanography at Kiel University.

Passing of Sergej Neufeld

Suddenly and unexpectedly, Sergej Neufeld, technical employee in the Lithothek died on August 30 at the age of 51. Sergej Neufeld was born in Kurgan (former Soviet Union) and moved to Germany in 1987. Sergej Neufeld was one of the first generation members of the former Geomar. He worked as a technical employee in the research unit Paleooceanography and in the Lithothek and participated in many expeditions. In addition, he managed the customs affairs at IFM-GEOMAR. With Sergej Neufeld the institute lost not only a very integer and competent colleague but also a very honest and highly respected person.

Overview

International Cooperation

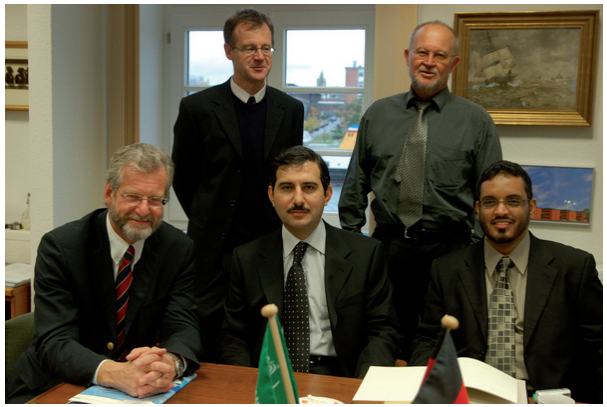
In 2008, IFM-GEOMAR strengthened the cooperation with several international partners.

For a number of projects, in particular SFB 754, the cooperation with the Instituto Nacional de Desenvolvimento das Pescas (INDP) on Cape Verde is of major importance. In order to further strengthen this fruitful collaboration, INDP and IFM-GEOMAR signed a Memorandum of Understanding on May 29 in Kiel.

The three largest marine research institutes in Europe, the National Oceanography Centre Southampton (NOCS), the French Research Institute for Exploitation of the Sea (Ifremer) and IFM-GEOMAR have agreed to further strengthen their scientific cooperation. The institutes signed a Memorandum of Understanding on December 15 in Kiel, Germany in the presence of the Prime Minister of the State of Schleswig-Holstein, Peter Harry Carstensen.

On the occasion of a visit of representatives of the University of Jeddah in Saudi Arabia new perspectives on future cooperation evolved. Opportunities for research in the Red Sea will be followed up.

Since 2008, IFM-GEOMAR is a full member of the Marine Board of the European Science Foundation. The Marine Board is a strategy forum for the marine research community in Europe. Members are marine research institutes as well as funding organizations.



Events

IFM-GEOMAR staff was involved in the organization of a number of meetings, workshops and conferences (for details see Appendix 7.3). The 32nd Annual Larval Fish Conference (ALFC) held in Kiel from August 4-7 was the largest meeting organized by Dr. Catriona Clemmesen-Bockelmann and collaborators. 180 scientists from 34 countries attended. It was the first ALFC meeting in Germany.

Other scientific highlights were the summer schools on Marine Sciences in Qingdao, China (part of the Sino-German Master Programme in Marine Sciences), the biogeochemical summer school BIOCAT and the 2nd summer school in Marine Geosciences for school pupils and students.

Above: Participants of the 2nd Summer Scholl in Marine Geosciences
Left column: top: Signing of the Memorandum of Understanding between the Instituto Nacional de Desenvolvimento das Pescas (INDP) and IFM-GEOMAR.
Middle: Signing of the Memorandum of Understanding between Ifremer, NOCS and IFM-GEOMAR in the presence of the Prime Minister of the State of Schleswig-Holstein, Peter Harry Carstensen.
bottom: Vistitors of the University of Jeddah in Saudi Arabia at IFM-GEOMAR.

Public Relations

The most remarkable public event of the year was the delivery of ROV KIEL 6000 by the Prime Minister of Peter Harry Carstensen and Minister Dietrich Austermann to IFM-GEOMAR on June 16. KIEL 6000 performed a short dive into the Kiel Fjord, placing a Schleswig-Holstein flag on the seafloor. This event had a major reflection in the press, in many TV and radio broadcasts including the major evening news of nationwide TV stations.

Prime Minister of Schleswig-Holstein, Peter Harry Carstensen, watching the official launch of ROV KIEL 6000 from RV ALKOR together with media representatives.

In 2008, about 50 groups with more than 1,500 participants visited the institute in addition to a number of decision makers and politicians. Amongst them, the Federal Minister of the Environment, Sigmar Gabriel, the Federal Minister of Finance, Peer Steinbrück, Minister President of Schleswig-Holstein, Peter Harry Carstensen, the State Minister for European Affairs, Uwe Döring,

and delegations from Malaysia, Thailand and Saudi Arabia. The Minister for Foreign Affairs, Frank Walter Steinmeier, met IFM-GEOMAR representatives at the Otto-Schmidt Laboratory (OSL) in St. Petersburg. IFM-GEOMAR has long and fruitful cooperation with the Russian colleagues. The OSL is currently directed by Dr. Heidemarie Kassens from IFM-GEOMAR.

In the tradition of the "Kieler Woche", an open ship event took place. All four IFM-GEOMAR vessels and, for the first time, the submersible JAGO were present. The submersible was also presented on the "Night of the Museums" as an eye-catcher in front of the Aquarium.

Above: Open ship on research vessels POSEIDON (left) and ALKOR during the Kieler Woche.
Left column: top: Minister for Foreign Affairs, Frank Walter Steinmeier at the Otto-Schmidt Laboratory in St. Petersburg.
Middle: Federal Minister of the Environment, Sigmar Gabriel visiting IFM-GEOMAR.
Bottom: Federal Minister of Finance, Peer Steinbrück in the Aquarium of IFM-GEOMAR.

Overview

The submersible JAGO got a little brother. Trainees from the HDW (Thyssen-Krupp) shipyard in Kiel built a model of JAGO out of customarily available parts. This model can now be used for exhibitions and guided tours.

Shipyard trainees with the model of JAGO.

New home for herring and friends: the public Aquarium of IFM-GEOMAR opened after a major renovation in June. Whereas in the first renovation phase in 2006 only a small fraction of the basins were replaced, the second phase was marked by a major restructuring of the interior. A number of small basins were replaced by two large ones with open surface and better visibility through show windows from aside and viewing options from above. After its reopening, the Aquarium welcomed as many as 50,000 visitors in six months only.The Aquarium participated very successfully in the "Museumsnacht" and offered special book readings for kids in a martime atmosphere.

The Excellence Cluster "The Future Ocean" organized a permanent exhibition in the International Maritime Museum in Hamburg and was present at the German National Holiday (October, 3) in Hamburg. For the first time the "Ocean Explorer", a multi-touch table, was presented.

In cooperation with the Excellence Cluster a very successful children's university was organzised with a series of lectures on various topics of marine sciences. Each lecture was attended by up to 400 pupils.

With a donation by the "Blue Planet - Virginia Böger Stiftung", a 12-minute film on cold water corals was produced.

Left column: Impressions of the "Night of the Museums" in the IFM-GEOMAR Aquarium.
Middle column: top: The exhibition "The Future Ocean" at the German National Holiday in Hamburg.
Middle: German president Horst Köhler with the prime ministers of Hamburg and Schleswig-Holstein Ole von Buest and Peter Harry Carstensen at the opening of the exhibition on marine research in the International Maritime Museum, Hamburg.
Bottom: Prof. Mojib Latif during a lecture at the childrens university.

Scientific Highlights

A selection of short scientific reports in this section provides an overview on IFM-GEOMAR research activities and results throughout 2008. 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.

At the end of this section, a list of publications in the high-profile journals Nature and Science can be found.

Above: German research vessels POLARSTERN and MARIA S. MERIAN meet in the Tropical Atlantic. Photo: Martin Visbeck (IFM-GEOMAR).

- The Agulhas system as a key region of the global oceanic circulation
- Abrupt climate variations during the last ice age – a result of extreme winters
- Simulated 21st century's increase in oceanic suboxia by CO_2-enhanced biotic carbon export
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The Agulhas system as a key region of the global oceanic circulation

Arne Biastoch and Claus Böning, Ocean Circulation and Climate Dynamics - Theory & Modelling

The Agulhas system transports warm and salty waters from the Indian to the Atlantic Ocean and therefore acts as a key element in the global oceanic circulation. Studies have shown that mesoscale processes are not only important for the correct description of the circulation around South Africa itself but also for its impact on the Gulf Stream system in the North Atlantic.

The flow of warm and salty waters from the Indian Ocean to the Atlantic Ocean around the southern tip of Africa is an important element of the global ocean circulation. Under present climate conditions this interoceanic flux, the Agulhas leakage, provides the bulk of the upper, warm limb of the overturning circulation in the Atlantic Ocean. Parts of this water later feed into the Gulf Stream system of the North Atlantic that is responsible for the mild climatic conditions in Europe.

What factors determine the intensity of Agulhas leakage? How will it react to changes in the atmospheric conditions, such as a southward shift in the westerlies which has been indicated by scenario calculations of the recent *Intergovernmental Panel on Climate Change (IPCC)* report? And, what would be the consequences for the Atlantic overturning and the Gulf Stream system?

To examine the role of Agulhas leakage in the global oceanic circulation, an innovative ocean modeling programme has been set up that advances new methodologies developed in international cooperation with French and South African colleagues, based on the European model system *NEMO*. Since the key elements of the circulation in the Agulhas system are dominated by mesoscale processes (Fig. 1) it uses a high-resolution grid for the greater Agulhas region. This regional model is nested in a global ocean/sea ice model of coarser resolution and forced by observed atmospheric conditions during the period 1958 – 2004. Due to an effective and novel "two-way" nesting approach this system for the first time allows us to unravel how the explicitly simulated mesoscale variability in the Agulhas dynamics feeds back to the global ocean.

Due to the high resolution and its state-of-the-art configuration the Agulhas nest simulates all mesoscale features of the current system around South Africa with great verisimilitude (Fig. 2): A strong western boundary current, the Agulhas Current, transports the warm and salty water southward in the Indian Ocean. South of Africa it abruptly turns back into the Indian Ocean, while shedding enormous rings, which transport heat and salt as pulsating elements into the Atlantic Ocean. The simulation also includes small-scale upstream perturbations such as Mozambique eddies as seen in satellite observations. The explicit simulation of those perturbations allows assessing their possible triggering effect on the Agulhas leakage.

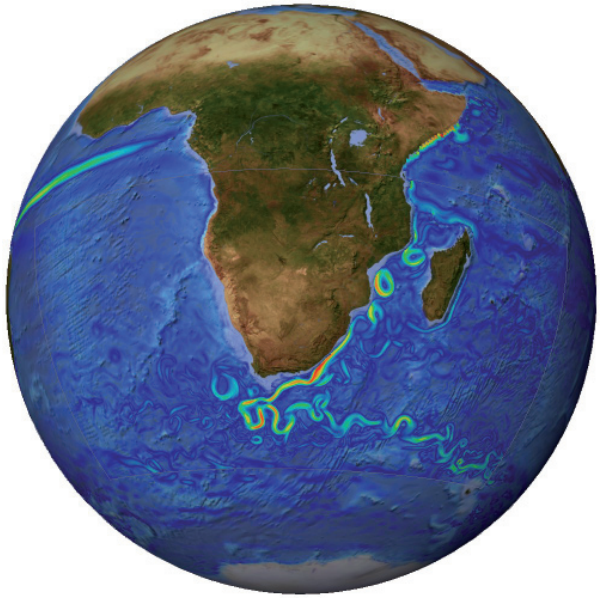


Figure 1: Circulation around South Africa. The Agulhas Current flows along the east coast of South Africa, retroflecting back into the Indian Ocean south-west of Cape Town. During this process Agulhas rings are cut off and drift into the Atlantic Ocean.

The role of mesoscale processes in the net volume transfer between the Indian and Atlantic Ocean was addressed by comparing the reference simulation with an experiment in which the same global model was integrated without the high-resolution nest in the Agulhas regime. The solution of this non-eddying model (Fig. 2a) portrays the inter-oceanic exchange as a continuation of parts of the Agulhas Current as a smooth

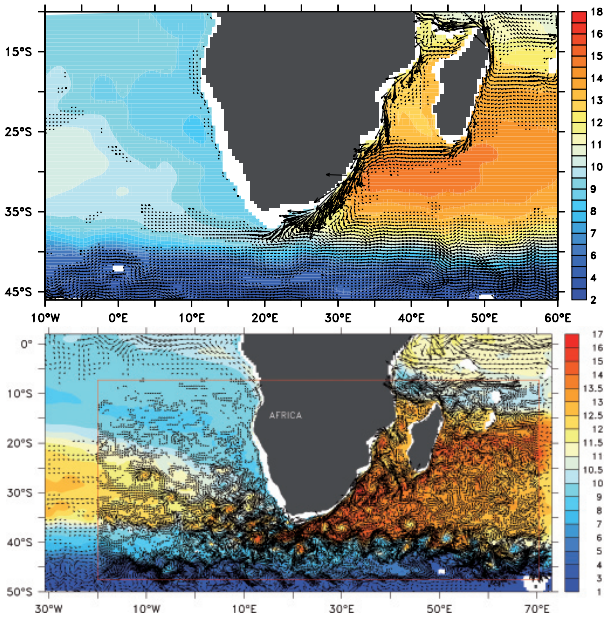


Figure 2: Water temperature and currents around South Africa. The two snapshots show temperatures and velocities at 450 m depth. In the (a) coarse-resolution model the Agulhas Current and the interoceanic transport appear as a broad flow of water. (b) The high-resolution nest (red lines) explicitly resolves mesoscale processes, simulating all important details necessary for a correct description of Agulhas leakage.

current, a solution typical of current climate models. In comparison to observations it strongly overestimates the net exchange from the Indian to the Atlantic Ocean. Only if mesoscale eddies are explicitly simulated, such as in the high-resolution nest (Fig. 2b), realistic interoceanic transports appear in the solution.

What is the effect of the Agulhas Current system on the large-scale circulation in the Atlantic Ocean? By comparing the circulation in solutions with and without the high-resolution Agulhas nest we were able to identify an intriguing contribution of the mesoscale Agulhas dynamics on decadal current fluctuations reaching far into the North Atlantic. The dynamical signal originating south of Africa rapidly travels northward by boundary waves (Fig. 3). In the tropical and sub-tropical North Atlantic the Agulhas-induced variability has similar amplitudes as the variability introduced by sub-polar deepwater formations events, a mechanism that has been known for its climatic impact and that has been extensively studied in the past. This finding highlights the importance for studying the Agulhas regime and its associated interoceanic transport as a prominent key region of the global thermohaline circulation.

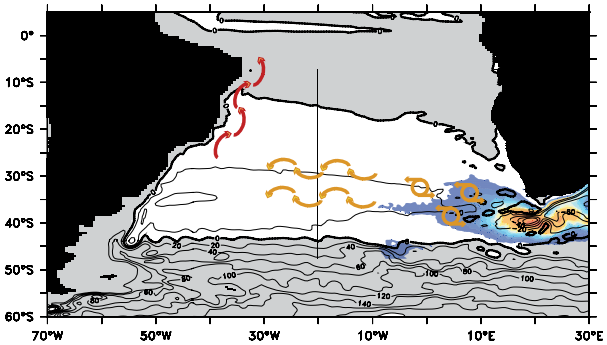


Figure 3: Schematic of the wave processes conveying Agulhas-induced anomalies in the upper limb of the overturning. The contour lines depict the mean horizontal circulation, the color information shows the eddy kinetic energy in the Agulhas region. The arrows give an illustration of the dynamic spreading of Agulhas induced variability by rings and Rossby waves (yellow) and Kelvin waves along the continental slope of South America (red) (from Biastoch et al., Nature, 2008).

IFM-GEOMAR Contributions

Biastoch, A., C. W. Böning, and J. R. E. Lutjeharms, 2008: Agulhas leakage dynamics affects decadal variability in Atlantic overturning circulation. *Nature*, **456**, doi:10.1038/nature07426, 489-492.

Biastoch, A., J. R. E. Lutjeharms, C. W. Böning, and M. Scheinert, 2008: Mesoscale perturbations control inter-ocean exchange south of Africa, *Geophys. Res. Lett.*, **35**, L20602, doi: 10.1029/2008GL035132.

Biastoch, A., C. W. Böning, J. Getzlaff, J.-M. Molines, and G. Madec, 2008: Mechanisms of interannual - decadal variability in the meridional overturning circulation of the mid-latitude North Atlantic Ocean, *J. Climate*, **21**, doi: 10.1175/2008JCLI2404.1, 6599–6615.

Biastoch, A., 2008: The Agulhas Leakage: Role of Mesoscale Processes and Impact on the Atlantic Meridional Overturning Circulation, Habilitationsschrift an der Christian-Albrechts-Universität zu Kiel.

Biastoch, A., C. W. Böning, M. Scheinert, and J. R. E. Lutjeharms, 2008: The Agulhas System as a Key Region of the Global Oceanic Circulation. In: W. E. Nagel et al. (Eds): *High Performance Computing in Science and Engineering '08*, Springer, 459-469.

Siedler, G., M. Rouault, A. Biastoch, B. Backeberg, C. J. C. Reason, and J. R. E. Lutjeharms, 2009: Modes of the southern extension of the East Madagascar Current, *J. Geophys. Res.*, C01005, doi:10.1029/2008JC004921.

Abrupt glacial climate change – a phenomenon of extreme winters?

Dirk Nürnberg, Ocean Circulation and Climate Dynamics - Paleooceanography

Scientists from IFM-GEOMAR and Utrecht University found that the rapid climate variations in the North Atlantic region at the end of the last ice age were mainly a phenomenon of extreme winters. The summer seasons were only marginally effected.

The last glacial period from 70,000 to 10,000 years ago, defined as Marine Oxygen Isotope Stage (MIS) 2-4, was punctuated by abrupt climate changes, switching within a few decades between warm (interstadials) and cold stages (stadials) that lasted for a few thousand years. These abrupt changes – called Dansgaard-Oeschger events named after two Danish resp. Suisse climate researchers - are intensively studied in order to improve our knowledge about the climate system behaviour and especially to provide insights into how climate system responses and interactions can be expected to occur in the future.

In a recent study, published in the journal *Nature Geoscience* in 2008, geoscientists from IFM-GEOMAR and Utrecht University (The Netherlands) suggest that the rapid glacial cooling events in the North Atlantic region are an expression of dramatic winter conditions rather than a reflection of summer cooling. Hence, an extreme seasonality is postulated for the glacial period.

Abrupt glacial climate changes have first been documented in high resolution through the analysis of Greenland ice cores and demonstrate how large and rapid these changes were: the average air temperature warmed by up to 16°C within two to three decades. These abrupt changes were related to changes in the Atlantic meridional overturning circulation, which is part og the global ocean circulation and primarily driven by differences in water density.

In many cases perturbations and even shutdowns in the meridional overturning circulation were postulated in the past during periods of increased meltwater influx from the northern hemisphere continental ice sheets, deepwater formation in the North Atlantic ceased with the consequence that the northward heat transfer to the high northern latitudes was dramatically reduced. The North Atlantic cooled with dramatic effects for the NW-European climate. Based on the recognition of these cooling events a scenario was recently discussed in which a reduction of sea surface salinity and hence, in the overturning circulation in response to anthropogenic global warming may eventually lead to severe cooling in NW-Europe in the near future.

In their new study, the paleoceanographers from Kiel and Utrecht present sea surface temperature (SST) reconstructions from the northeastern Gulf of Mexico for the last 300,000 years to examine the regional and seasonal expression of millennial-scale climate variability. The Gulf of Mexico represents an ideal location to decipher the dynamic evolution of the Atlantic Warm Pool

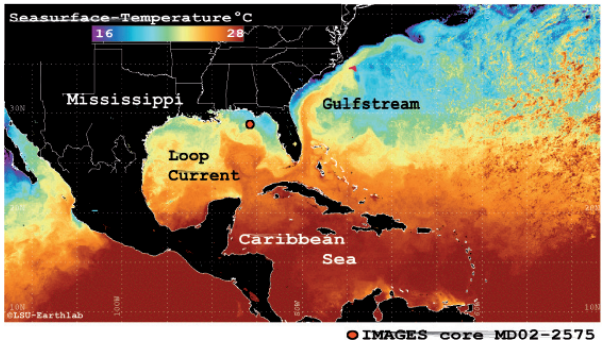


Figure 1. Chart showing sea surface temperatures in the Caribbean and the Gulf of Mexico (from LSU Earthlab). Note the warm water transfer into the gulf via the Loop Current. The location of the paleoceanographic record studied here is indicated.

(AWP), an ocean area in the equatorial western Atlantic and the adjacent Caribbean with extremely high sea surface temperatures. In summer, when warm Caribbean surface waters enter the Gulf *via* the Loop Current, the entire Gulf heats up and forms part of the AWP. The Loop Current transporting ~30 Sv (10^6 m^3sec^{-1}) of water through Yucatan and Florida Straits mediates the oceanic heat and salt flux from the Caribbean Sea into the Atlantic Ocean. Its interference with the Mississippi River discharge is in fact critical for both the regional climate in the Gulf of Mexico area and the heat and water vapor transport towards high northern latitudes.

During boreal winter, warm Caribbean surface water generally does not penetrate into the northeastern Gulf and tropical waters are restricted to a narrow band in the southeastern Gulf. During this time, relatively cool

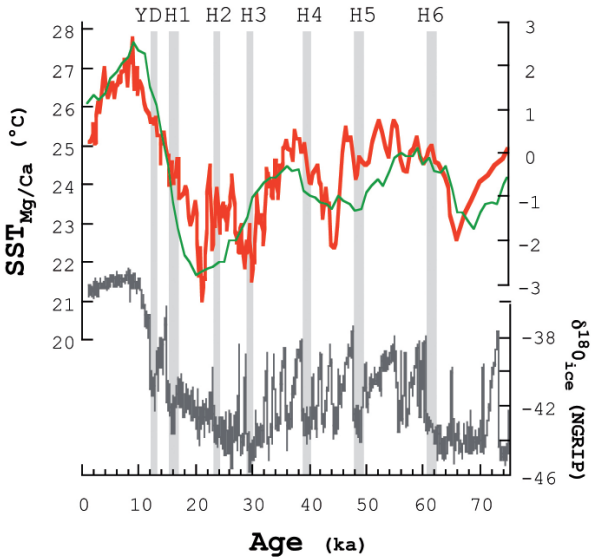


Figure 2. The northeastern Gulf of Mexico SST record (red) over the last 75 ka in comparison to the Greenland climate record (gray). The close match of the SST record to the summer insolation variability (green) implies a persistent summer expansion of the Atlantic Warmpool during abrupt cold events and hence, an extreme seasonality during glacial MIS 3.

Gulf of Mexico Common Water characterizes the uppermost 200 m owing to increased vertical convective mixing induced by cold meteorological fronts that propagate from the North American continent over the Gulf.

The described seasonal contrast is particularly strong in the northeastern Gulf region and results in an intra-annual SST variability ranging from a minimum of 19.6°C in February to a maximum of 29.7°C in August. This variability is closely related to the seasonal position of the Intertropical Convergence Zone (ITCZ), which is the tropical rain belt. Today, both the ITCZ and the northern boundary of the AWP reach their northernmost positions during boreal summer.

The new Nature Geoscience study shows that the expansion of the AWP into the Gulf of Mexico did not respond to the glacial abrupt climate oscillations. This is in contrast to records from the southern Caribbean that do show a strong response to the North Atlantic rapid cooling. These records reflect past (northern hemisphere) winter conditions. The obvious seasonal bias of the Gulf of Mexico SST record towards the summer season supports an idea according to which the abrupt cooling events during MIS 2-4 were predominantly a winter phenomenon.

One possible explanation for this seasonal bias could be that during winter, the North Atlantic was close to a threshold temperature at which sea ice is extensively formed: during the rapid cooling events, the reduced transfer of tropical heat towards the high latitude North Atlantic made it across this temperature threshold and subsequently sea ice grew over large parts of the North Atlantic. The vast sea ice cover and its cumulative effects on the albedo functioned as a fridge for the high latitudes. During summer the threshold, instead, was not passed and therefore the cooling effect was commonly small and compensated.

The study has interesting implications for the effect of a potentially weakened thermohaline circulation in response to the today´s global warming. As the modern "warm" North Atlantic is far from such a winter threshold temperature, the cooling effect will be much less and not comparable to those glacial cooling events. A "Day after tomorrow scenario" becomes, in view of our findings, unlikely. The new study also highlights the need for a comprehensive network of quantitative paleoclimate records monitoring the spatial seasonal change to understand the full variability of the climate system.

How do paleoceanographers in fact reconstruct ocean temperatures and salinities? Since a couple of years, the temperature-sensitive incorporation of magnesium into the calcitic skeletons of marine planktonic microfossils (protozoa, foraminifera) selected from ocean sediments is used to assess SST with an accuracy of approximately ±0.5°C. This geochemical approach was initially suggested by GEOMAR scientists, and became meanwhile a widely applied and internationally accepted paleoceanographic tool. In combination with the detection of stable oxygen isotopes in the same foraminiferal shells it became possible to even reconstruct SSS (sea surface salinity) reliably.

Reference:

Ziegler, M., D. Nürnberg, C. Karas, R. Tiedemann, and L.J. Lourens, 2008: Persistent summer expansion of the Atlantic Warm Pool during glacial abrupt cold events. *Nature Geoscience*, **1**(9), 601-605, doi 10.1038/ngeo277.

Simulated 21st century's increase in oceanic suboxia by CO_2-enhanced biotic carbon export

Andreas Oschlies, Marine Biogeochemistry - Biogeochemical Modelling

At depths between several tens and hundreds of meters, large parts of the tropical oceans are poorly supplied with dissolved oxygen, and are therefore hostile to most marine life. Using a global biogeochemical model, we found that emission-stimulated increases in the carbon content of marine organic matter might lead to a further depletion of oxygen in tropical oceans.

The primary impacts of anthropogenic CO_2 emissions on marine biogeochemical cycles predicted so far include ocean acidification, global-warming induced shifts in biogeographical provinces, and a possible negative feedback on atmospheric CO_2 levels by CO_2-fertilized biological production. In a modelling study we reported a new potentially significant impact on the oxygen minimum zones of the tropical oceans. Using a model of global climate, ocean circulation and biogeochemical cycling, mesocosm-derived experimental findings of a pCO_2-sensitive increase in biotic carbon-to-nitrogen (C:N) drawdown were extrapolated to the global ocean. For a simulation run from the onset of the industrial revolution until A.D. 2100 under a "business-as-usual" scenario for anthropogenic CO_2 emissions, the model predicts a negative feedback on atmospheric CO_2 levels, which amounts to 34GtC by the end of this century. While this represents only a relatively small alteration of the anthropogenic perturbation of the carbon cycle to be expected, the model results reveal a dramatic 50% increase in the suboxic water volume by the end of this century in response to the respiration of excess organic carbon formed at higher CO_2 levels. This represents a significant expansion of the marine "dead zones" with severe implications not only for all higher life forms, but also for oxygen-sensitive nutrient recycling and hence for oceanic nutrient inventories.

A special feature of today's marine oxygen distribution is the presence of extended oxygen minimum zones in the tropical oceans, with suboxic conditions at relatively shallow depths from several tens to hundreds of meters (Figure 1). Besides providing a hostile environment for almost all marine life, these regions are of particular biogeochemical relevance because they allow for anaerobic conversion of fixed nitrogen, a major nutrient essential for biological production, into gaseous N_2 not accessible to most organisms. Sediment records provide evidence that the regional patterns of this oxygen-sensitive nutrient loss have varied on millennial and longer time scales in the past, in concert with changes in the extent of the suboxic ocean areas. Such changes can be driven by variations in biotically controlled local remineralization and associated oxygen consumption, or by changes in the physical oxygen supply via circulation and temperature-dependent oxygen solubility.

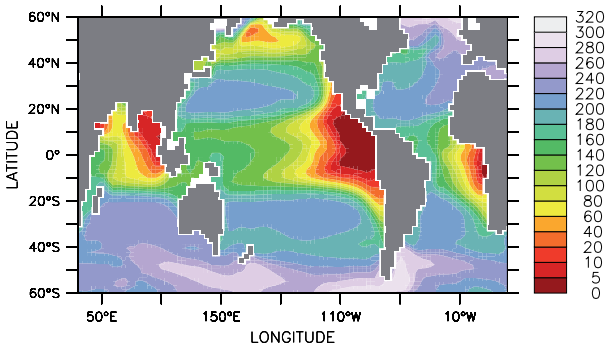


Figure 1: Dissolved oxygen at 300m depth as simulated by the model for year 2100. Units are μmol/kg.

Using a coupled carbon-climate model, the new study suggests that circulation changes expected under a business-as-usual CO_2 emission scenario have relatively little impact on the extent of the oxygen minimum zones. Although warming and reduced ventilation of deep waters lead to a reduction of the overall oceanic oxygen content by about 5% by the end of the 21st century, the volume of the oxygen minimum zones changes relatively little unless possible changes in the marine biology are taken into account. The new study focuses on changes in the ratio of carbon-to-nitrogen drawdown by marine algal blooms, which was observed in recent mesocosm experiments run under different atmospheric CO_2 levels (Riebesell et al., 2007). Based on these experimental

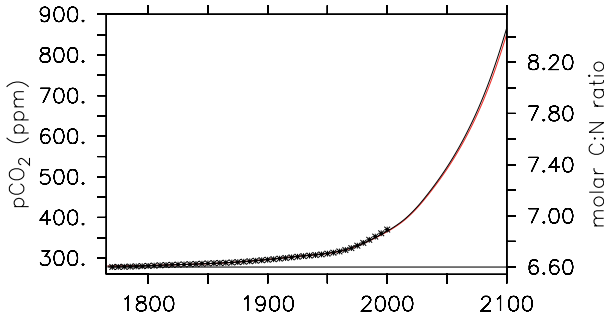


Figure 2: Simulated (lines) and observed (crosses) annual mean atmospheric pCO_2 (left axis). The red curve is for the model with molar C:N varying as a function of pCO_2 according to the right axis. The thin black line just above the red line is pCO_2 simulated by the control run with constant molar C:N=6.6.

results, we assumed that the C:N ratio of organic matter exported from the surface ocean is proportional to the atmospheric CO_2 concentrations simulated by the coupled carbon-climate model (Figure 2).

The inclusion of pCO_2-sensitive C:N ratios has only limited impact on simulated atmospheric CO_2 levels. The enhanced biological carbon drawdown and export lowers atmospheric pCO_2 predicted for the year 2100 by merely 15µatm from 866µatm in the constant C:N run to 851µatm in the pCO_2-sensitive C:N run (Figure 2). This corresponds to an additional oceanic uptake of 34GtC by the year 2100 and thus represents a negative feedback in the anthropogenically perturbed climate system. While this is significant with respect to CO_2 natural changes, including glacial-interglacial swings, the magnitude of this feedback effect is small in terms of the ongoing anthropogenic perturbation, and the difference in atmospheric CO_2 between the two model runs is barely visible in Figure 2.

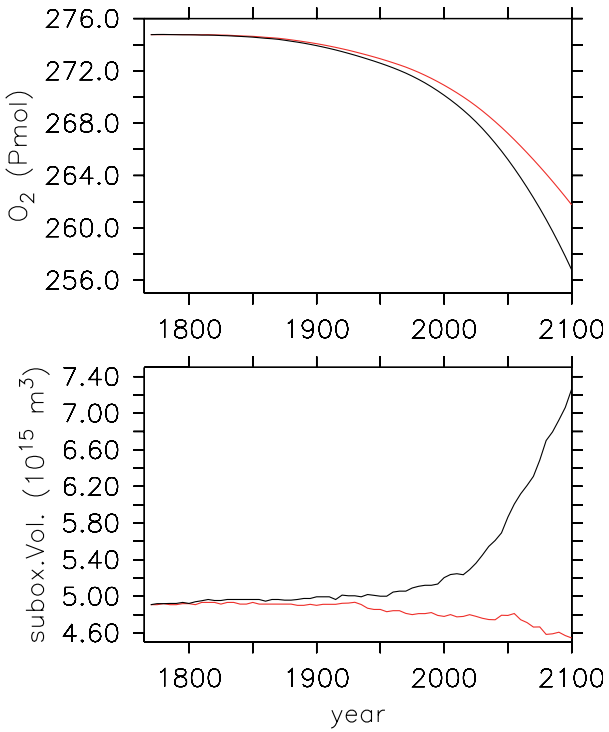


Figure 3: Simulated marine oxygen inventory (top) and suboxic volume (bottom) as a function of time. Black curves are for the model run with constant C:N ratios, red curves for the new run with pCO_2-sensitive C:N ratios.

In contrast to the relatively small impact on atmospheric CO_2, the inclusion of pCO_2-sensitive C:N ratios turns out to generate more dramatic changes in the oxygenation state of the tropical thermocline. Here, our model switches from a net oxygen gain under constant Redfield stoichiometry to a net oxygen loss by the end of this century when C:N ratios increase with pCO_2. Overall, the volume of suboxic waters increases by about 50% until A.D. 2100 in the model run with pCO_2-sensitive stoichiometry (Figure 3). Our model results suggest that relatively small changes in the C:N ratio of organic matter can have profound impacts on the extent of the ecologically and biogeochemically relevant oxygen minimum zones on surprisingly short time scales of decades to centuries. Because of the immediate response of oxygen-sensitive losses of fixed nitrogen, the view of a homeostatic nitrogen cycle may not be anymore appropriate as we move from predominantly astronomical to anthropogenic climate forcing in the 21st century.

References:

Oschlies, A., K. G. Schulz, U. Riebesell, and A. Schmittner, 2008: Simulated 21st century's increase in oceanic suboxia by CO_2-enhanced biotic carbon export. *Global Biogeochem. Cycles*, **22**, GB4008, doi:10.1029/2007GB003147.

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

Silicate weathering in anoxic marine sediments

Klaus Wallmann, Marine Biogeochemistry - Marine Geosystems

Weathering of silicate minerals is the major sink for atmospheric CO_2 on geological time scales. It has commonly been assumed that this process is only occurring on land. New results, however, show that silicate minerals are also reactive within marine sediments. Most of the metabolic CO_2 being produced in marine sediments enriched in organic matter is consumed by this reaction with major implications for the geological carbon cycle.

Chemical weathering plays a key role in the geological carbon cycle. It transforms primary silicate minerals such as feldspars into clays and other particulate and dissolved products. Dissolved metal cations (e.g. Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}) and silica (H_4SiO_4) are released during this reaction while CO_2 is transformed into bicarbonate (HCO_3^-). The dissolved products are transported into the oceans through rivers and groundwater discharge. Silicate weathering is the most important sink for atmospheric CO_2 on geological time scales. It removes CO_2 from the atmosphere and increases the dissolved bicarbonate load of the oceans. Terrestrial silicate weathering depends on climate and the variables of temperature, runoff, and pCO_2. The hydrological cycle –including evaporation, precipitation, and runoff- is accelerated under warm surface conditions while high surface temperatures are usually related to elevated pCO_2 values. Due to this threefold link, silicate weathering is accelerated when volcanoes or other components of the solid earth deliver high doses of CO_2 to oceans and atmosphere. Consequently, the partial pressure of CO_2 reaches only moderate levels during periods of enhanced CO_2 degassing. Conversely, with a reduced source of CO_2, atmosphere CO_2 concentrations do not fall too low as the resulting lower temperatures reduce the removal rate of CO_2 by weathering. Therefore, the climate sensitivity of weathering reactions acts to stabilize atmospheric pCO_2 on time scales of 10,000 to 100,000 years.

Reactive silicate minerals not weathered on land are ultimately deposited on the seafloor in continental margin sediments. In their new paper, Wallmann et al. (2008) showed that these minerals are reactive within marine sediments. They studied a number of sediment cores taken at the continental slope of Sakhalin Island. The evaluation of down-core solid phase and pore water profiles showed that most of the metabolic CO_2 produced during microbial organic matter decomposition is converted into bicarbonate by reaction with feldspars, volcanic ash and other silicate minerals. The evaluation of pore water data from other continental margin sites showed that silicate weathering is a common process in sediments with high organic matter contents. These new data suggest that the rate of marine silicate weathering may be as high as the rate of continental silicate weathering.

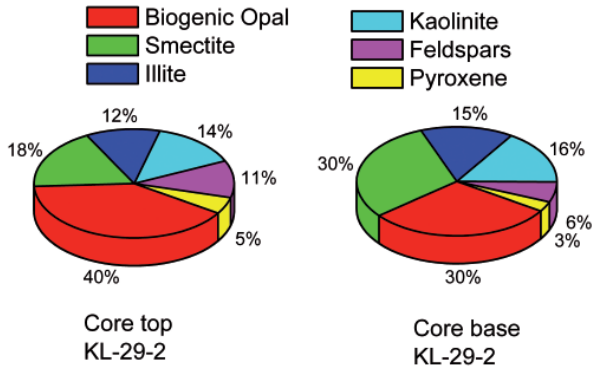


Figure 1. Composition of sediments retrieved at the continental slope of Sakhalin Island. The data show a down-core decrease in the abundance of reactive silicate phases (feldspars, pyroxene).

In contrast to continental weathering, marine weathering is not directly coupled to average global surface temperature and atmospheric pCO_2. Carbon transformations in sediments are rather fueled by the deposition of particulate organic matter and reactive silicate phases. The consumption of CO_2 in these sediments is, thus, controlled by continental erosion and marine productivity. The negative climate feedback established by the temperature- and pCO_2-dependent rate of continental weathering is weakened by marine weathering processes since reactive silicate phases which are not consumed on land may be weathered in marine sediments. Marine weathering might, thus, amplify climate change on geological time scales and could, for example, contribute to the draw-down of atmospheric CO_2 observed during the late Cenozoic and glacial periods of the Quaternary.

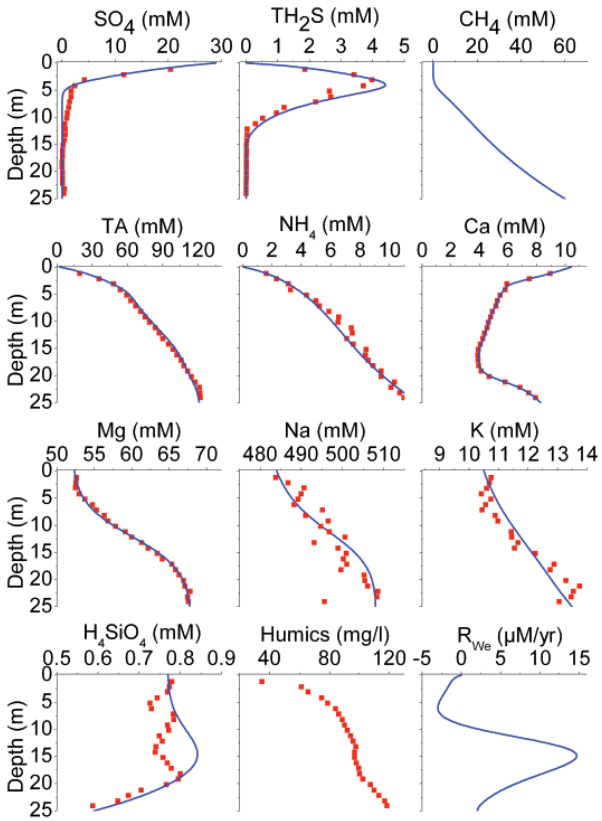


Figure 2. Composition of pore fluids separated from the wet sediments retrieved at the slope of Sakhalin Island. Concentrations of dissolved species measured in these fluids are shown by red dots. The blue lines indicate the results of transport-reaction modeling. TA is total alkalinity which is roughly equivalent to the concentration of dissolved bicarbonate. The rate of silicate weathering (RWE) was derived from the down-core increase in TA and dissolved magnesium concentrations.

The results presented in this study have also implications for applied geosciences. Marine sediments are increasingly used for the disposal of CO_2 separated from natural gas and in coal power plants. The new results imply that terrigenous sediments with high contents of reactive silicate phases might be well suited sites for CO_2 disposal since CO_2 may be rapidly neutralized by marine silicate weathering.

Reference

Wallmann K., Aloisi G., Haeckel M., Tishchenko P., Pavlova G., Greinert J., Kutterolf S., and Eisenhauer A. (2008) Silicate weathering in anoxic marine sediments. *Geochim. Cosmochim. Acta* **72**, 3067-3090.

Ecological thresholds and trophic cascades: implications for the recovery of an open marine ecosystem

Juan Carlos Molinero, Marine Ecology - Food Webs

Michele Casini, Swedish Board of Fisheries, Institute of Marine Research, Lysekil, Sweden

Excessive fishing pressure in overexploited and low diverse pelagic ecosystems may have a large impact in the functioning of marine food webs.

Excessive fishing pressure in overexploited and low diverse pelagic ecosystems may have a large impact in the functioning of marine food webs. This has long been a running subject of debate and is of central importance for the management of marine ecosystems. In pelagic marine ecosystems, food webs are characterized by complex interactions that make identifying trophic cascades, from top-predators to primary producers, in open marine ecosystems difficult. Similarly, evidences of temporal shifts in food web dynamics are not common, and usually have been related to changes in climate. At present, understanding how and under which circumstances marine ecosystems respond to anthropogenic and climate forces bear vast management implications. Without a food web perspective it is difficult to understand why in some cases there is a lack of recovery of overharvested fish species in some parts of the world, despite thoughtful management controls of the fishery. Analysis of field observations through the years 1974 to 2005 in the central Baltic Sea has provided evidence for a reorganization of the ecosystem caused by cascading effects of the top predator collapse, the cod, and has allowed identifying some of the causal mechanisms that have inhibited the recovery of cod in recent years.

In the Baltic Sea, after the decline of seals and other populations of marine mammals principally due of hunting, cod has been the top predator. However, from the early 1980s, cod sharply declined mainly because of high fishing pressure that came along with unfavorable environmental conditions for its recruitment; that is, the lack of salt- and oxygen-rich water inflows from the North Sea into the Baltic basin. In fact, higher salinity of the mid-deep waters not only enhances the buoyancy of cod eggs and prevents them from sinking into hypoxic water layers it also favors the development of the main food sources for cod larvae. Since the late 1980s, the cod stock has been low, and it has not shown any tendency to recover. The low abundance of cod has allowed a substantial increase in the sprat population, a small pelagic fish that mainly feeds on zooplankton. As a consequence, zooplankton, mainly herbivorous crustaceans, declined markedly and phytoplankton increased.
The removal of cod has percolated down through the food web leading to a shift in the structure and functioning of the pelagic

Baltic Cod. Photo: B. Ueberschär, IFM-GEOMAR

food web of the central Baltic Sea. In fact, in recent decades, increased blooms of possibly harmful phytoplankton that may be toxic to people, fish and other wildlife have been observed, and it is thought that the decrease of zooplankton is one of the causes of such phenomena (Casini et al. 2008). In addition, the cod collapse has altered the food web links in the central Baltic Sea during the last three decades. Food web links appeared sensitive to an ecological threshold defined by a total sprat abundance of $17x10^{10}$ individuals that separates two alternative ecosystem scenarios in which the food web links change drastically. Below such an ecological limit, cod controlled the sprat population which does not affect significantly zooplankton biomass, as statistical analyses suggest. In contrast, and more importantly, when

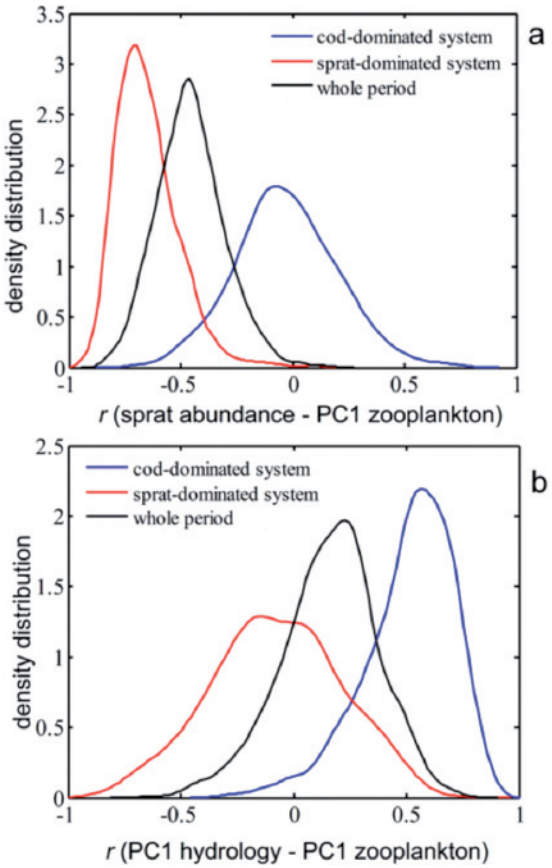


Figure 1: Alternative scenarios of the central Baltic Sea ecosystem related to the dominance and crash of the cod. (a) The two configurations are illustrated by the changes in the relationship between sprat abundance and zooplankton biomass. When cod dominates the system it controls the sprat population, which does not affect significantly zooplankton biomass. This drastically changes in the absence of cod, as sprat heavily controls zooplankton biomass. (b) Changes in the relationship between hydrological factors and zooplankton in the ecological scenarios of dominance and crash of the cod. The cod-dominated scenario prevents the heavy sprat control on zooplankton. In such a case, hydrological conditions are more relevant for zooplankton growth. Conversely, when cod crash and sprat dominates the system, its heavy influence on zooplankton emerges even more relevant for zooplankton growth than the influence of hydrological factors.

sprat abundance was higher than the threshold, sprat controlled not only zooplankton biomass but also their spatial localization. In fact, zooplankton organisms were concentrated in deeper waters. The strength of the sprat control emerged even stronger than the effect of hydrological conditions on zooplankton. In figure 1 the alternative scenarios of the central Baltic Sea ecosystem are shown. These two scenarios are illustrated as the relationship between sprat abundance and zooplankton biomass (Fig. 1a), and the link between zooplankton and hydrological factors (Fig. 1b). These changes in food web links highlight the role top predators may have as ecological buffers in marine ecosystems. In this particular case, it is clear that cod acts as a regulator of sprat abundance being able to buffer high-sprat recruitment events and their severe consequences in lower levels of the food chain (Casini et al. 2009).

In recent years, hydrological conditions for cod recruitment have improved not only in terms of favorable conditions for eggs and larval survival, but also potentially favoring the development of one of the key zooplankton prey for cod larvae, the copepod *Pseudocalanus*. The cod recruitment, however, has failed and the population stock remains low, probably because of the high sprat abundance that continue to be higher than the ecological threshold driving the pelagic food web in the central Baltic Sea (Casini et al. 2009).

This study shows that empirical food web data can provide relevant information for disentangling the combined effects of human-induced disturbances (e.g., overfishing) and climate change on marine ecosystems. It should be noted that harvested species may be seen as part of a large, dynamic, trophic network, with a high probability of being susceptible to top-down control, generating cascading effects through the food web. This stresses that changes in ecosystem functioning, potentially difficult to reverse, can be a result of variations at the higher trophic levels directly affected by human exploitation, and not only the consequence of climate change.

References

Casini M., J. Hjelm, J.C. Molinero, J. Lövgren, G. Kornilovs, M. Cardinale, V. Bartolino, and A. Belgrano, 2009: Trophic cascades promote threshold-like sudden shifts in the functioning of a pelagic marine ecosystem. *Proceedings of the National Academy of Sciences*, **106**, 197-202. doi:10.1073/pnas.0806649105.

Casini M., Lövgren J., Hjelm J, Cardinale M., Molinero J.C., and Kornilovs G., 2008: Multi-level trophic cascades in a heavily exploited open marine Ecosystem. *Proceedings Royal Society B*. doi: 10.1098/rspb.2007.1752.

A genetic perspective on global change

Thorsten Reusch, Marine Ecology - Evolutionary Ecology of Marine Fishes

Heat stress events associated with global climate change may indirectly alter the interactions among marine species, for example among parasites and their fish hosts. At the same time, rapid frequency changes of immune genes, droven by parsite selection, may determine which indiviudals survive, providing an example of "evolution-in-action".

Global environmental change is altering the selection regime for all animal and plant species. The key selective factors are increases in mean temperature and its variability, as well as increase in atmospheric and oceanic CO_2 concentration.

Most studies on the biological effects of global change have thus far focussed on ecology, i.e. the immediate responses or organisms and communities to above changes. Aside from the analysis of the resulting range expansions due to shifting climate zones, there is a growing interest in the genetic basis of critical traits that would allow genotypes or populations to either persist or even evolve under climate change. As one major effect hitting coastal systems, prolonged periods of heat waves impose increasing stress on organisms in these ecosystems, already now leading to severe damage, for example in coral reefs or seagrass based systems. Heat stress may directly interfere with basic physiological processes at the individual level (Pörtner and Knust, 2007), or alter the equilibrium in other 'natural' biotic interactions.

Host-parasite interactions are one of the most important biological interactions, given that all free-living organisms are exposed to multiple parasite species. Hence, one focus of our research is the role of immune defence genes in fish hosts under global warming. We ask whether the fish hosts or the parasites will benefit from global warming. One first goal is to predict the survival of coastal fish as a function of their genotype at those genes that are responsible for recognition and defence against macroparasites such as trematodes, cestodes, protozoans and other metazoan parasites. Therefore controlled enclosure experiments were conducted in which three-spined sticklebacks (*Gasterosteus aculeatus*) were exposed, as a proof-of-principle, to the natural parasite fauna in a lake (Wegner et al., 2008). All experimental fish were descendants from a wild parental generation that gave rise to a first filial (F1) generation. This was necessary to ensure that all experimental animals were parasite free sibships. Subsequently, all fish were genotyped at genes encoding major histocompatibility complex molecules (MHC class II) prior to exposure. MHC class II genes come in several different variants (alleles) within individuals and populations. Their striking diversity is responsible for recognizing a diverse array of up to 25 parasite species present in the system. Interestingly, the immune defence is best when an individual fish carries between 5 and 6 of those variants. Previous data thus allowed us to formulate a prediction, namely that a strong

Sampling on a sea grass meadow in the Baltic Sea. Photo: T. Reusch, IFM-GEOMAR.

selection event, a heat wave, in combination with the natural parasite pressure in, would led to enhanced survival in those individuals that display an intermediate diversity at MHC genes.

This prediction was confirmed in a large exposure experiment across in a among 200 fish coming from 10 different crossings. Those individuals, corrected for sibship differences, that would have around 6 variants per individual had the highest likelihood of surviving a natural heat wave with water temperatures >25°C (Fig. 1). Moreover, it could be shown that possibly, increased parasite pressure, mediated by physiological stress and enhanced vulnerability of individual fish, was the selective agent.

But not only diversity at specific genes determines which genotypes will survive best. In another suite of experiments, the general standing genetic diversity of a habitat

Seagrass Zostera marina. Photo: T. Reusch, IFM-GEOMAR.

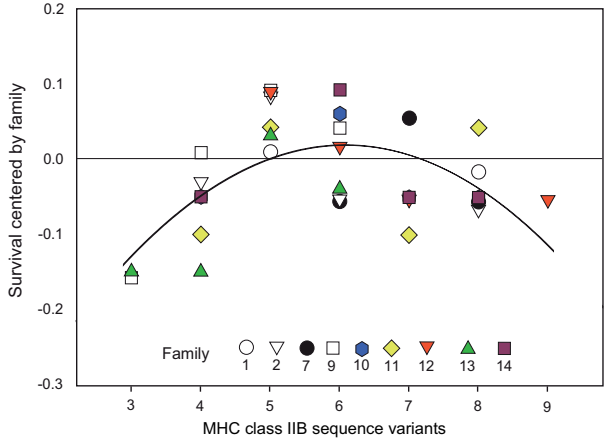


*Fig. 1 . Results of a 14-week exposure experiment of three-spined sticklebacks to their natural parasite fauna during summer heat wave (water temperature >25°C). Survival of three-spined stickebacks as a function of the individual MHC gene variants they carry. The y-axis depicts the residual mortality rate that is corrected for the differences among sibships. The quadratic polynomial (survival = - 0.5595 + 0.1899 * $N_{sequence\ variants}$ – 0.0156 * $N_{sequence\ variants}^2$, R^2 = 0.364, $F_{2,30}$ = 8.601, P = 0.001) shows that within segregating families fish with approximately six MHC class IIB sequence variants survived best. Source: Wegner et al., 2008.*

forming plant, the seagrass *Zostera marina* was manipulated by combining previously genotyped clones using a genetic fingerprint technique. Using scuba diving, experiential patches composed of one, three and six different genotypes were assembled in situ. Following these patches through the 2003-European heat wave revealed that units composed of multiple seagrass genotypes recovered faster than genetic monocultures. Next, we wanted to verify this in mesocosm experiments that involved control temperature conditions and a parallel heat stress treatment simulating the 2003-European heat wave. The results confirmed that the heat wave was responsible for increased mortality under a global warming scenario, and that genotype diversity enhances the resilience of seagrass populations (Ehlers et al., 2008).

In summary, these data provide a glimpse into the complex evolutionary processes that have been triggered by global environmental change. Such studies should complement ecological assessments of the biological effects (Reusch and Wood, 2007). Given that genomic tools are expanding exponentially, rapid progress in the identification of responsible genes for surviving or evolving global change can be expected. One family of these genes, the so-called heat-shock genes are currently being analyzed in mesocosm experiments in coastal fish and the habitat forming seagrass, in order to develop a predictive framework to assess which populations are most vulnerable to global warming.

Argulus spec, a member of a species rich family of crustaceans that are entirely parasitic and live attached to fish, sucking their blood. Photo: M. Kalbe.

References

Ehlers, A., Worm, B. and Reusch, T.B.H., 2008: Importance of genetic diversity in eelgrass *Zostera marina* for its resilience to climate warming. *Marine Ecology Progress Series*, **355**, 1-7.

Pörtner, H.O. and Knust, R., 2007: Climate Change Affects Marine Fishes Through the Oxygen Limitation of Thermal Tolerance. *Science*, **315**, 95-97.

Reusch, T.B.H. and Wood, T.E., 2007: Molecular Ecology of global change. *Mol. Ecol.*, **16**, 3973–3992.

Wegner, K.M., Kalbe, M., Milinski, M. and Reusch, T.B.H., 2008: Mortality selection during the 2003 European heat wave in three-spined sticklebacks: effects of parasites and MHC genotype. *BMC Evol. Biol.*, **8**, 124.

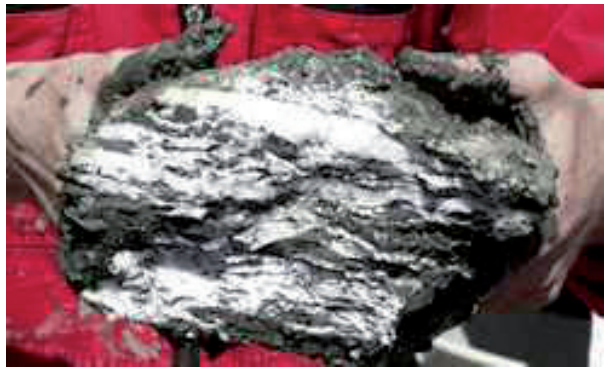
Gas hydrates and slope stability

Christian Berndt, Dynamics of the Ocean Floor - Marine Geodynamics

Global warming affects the seabed in many different ways. One way which causes concern is the effect that bottom water warming has on marine gas hydrates. These ice-like crystals of water and gas dissolve, which changes the stability of continental margins. In a worst-case scenario this may facilitate submarine landslides and associated tsunamis that could reach central Europe.

It has long been claimed that there is a connection between gas hydrates and slope stability. The main reason for this is the spatial distribution of bottom simulating reflectors (BSR), which are a proxy for marine gas hydrates and the head walls of slope failures which frequently occur at the same depth.

As gas hydrates are only stable at high pressures and low temperatures, increases in bottom water temperature or drops in sea level may destabilize hydrates. This may then lead to a weakening of slope sediments either directly because the sediments lose the hydrate cement, which holds them together or by the generation of overpressures when hydrates dissociate and rapidly release free gas.



A typical gas hydrate sample showing the laminated structure of sediments (dark) and hydrate layers (white). Photo: IFM-GEOMAR.

Although modelling studies showed that this is a viable scenario, direct geological evidence for this mechanism remained sparse, and the hypothesis was only supported by circumstantial evidence such as negative carbon isotope excursions during times of rapid warming indicating that gas hydrates dissociated.

In 2008, we have made a couple of observations that elucidate the relationship between hydrates and slope failures. When studying in detail the bathymetry of the Storegga Slide which is one of the world's largest and best studied submarine slope failures, we discovered that there is a pronounced difference between the morphology of areas underlain by hydrates and areas without (Micallef et al., 2008).

In this study we used novel geomorphometric techniques to constrain the submarine mass movements that have shaped the north-eastern Storegga Slide and understand the link between different forms of failure. The northeastern part of the Storegga Slide developed in four major events. The first event was triggered in water depths of 1500 – 2000 m. In this event, the surface sediments were removed by debris flows and turbidity currents, and deposited in the Norwegian Sea Basin. Loading of the seabed by sediments mobilised by the first event resulted in the development of an evacuation structure. Loss of support associated with this evacuation structure, reactivation of old headwalls, and seismic loading have activated spreading in the failure surface of event 1 that extended up to the main headwall. In some areas, spreading blocks have undergone high displacement and remoulding. Parts of the spreading morphology and the underlying sediment have been deformed or removed by numerous debris flows and turbidity currents. We conclude that the higher displacement and remoulding of the spread-

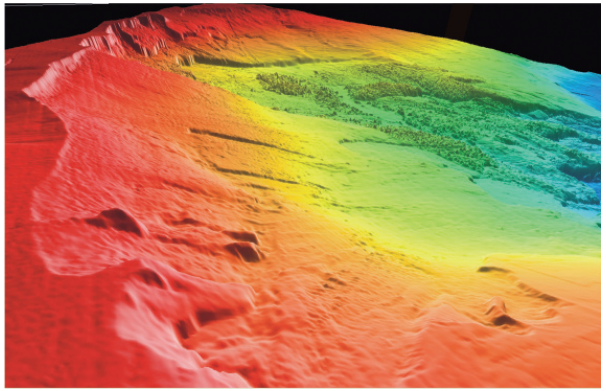


Figure 1: Spatial relationship between morphological units and the distribution of gas hydrate related bottom simulating reflectors show that hydrates control the dynamics of submarine landslides (Micallef et al., 2008). Data courtesy of Ormen Lange license partners.

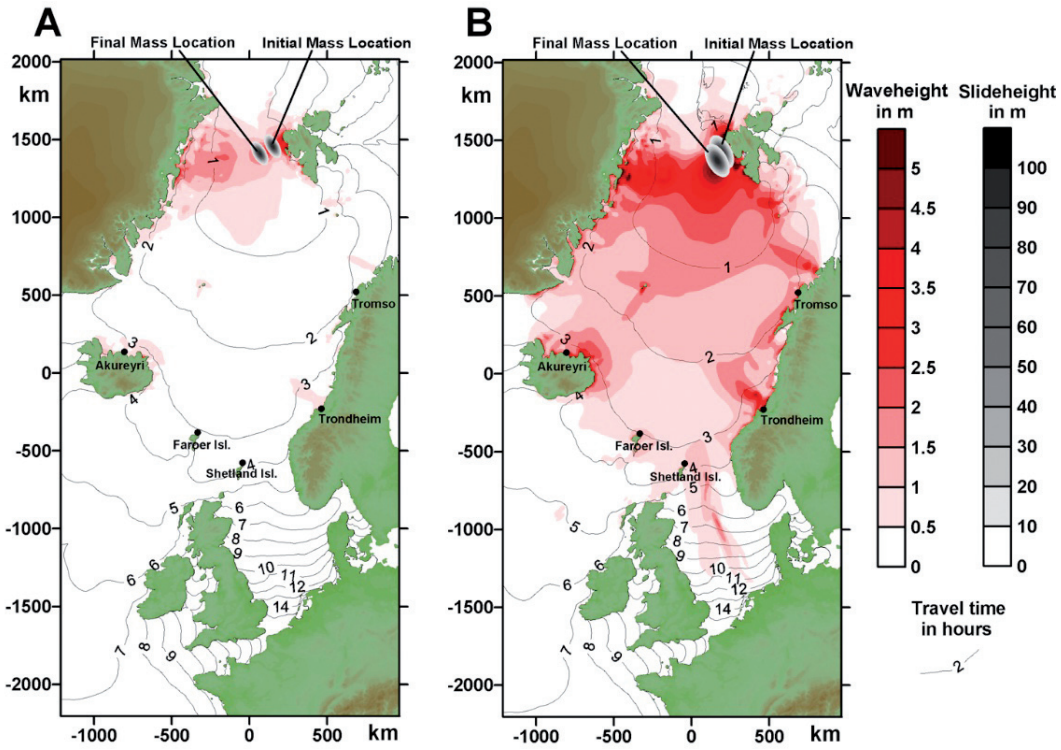


Figure 2: Tsunami heights and travel times for a westward running landslide (A) and a southwestward running slide (B). From Berndt et al., in press.

ing blocks (Figure 1), and their removal by debris flows and turbidity currents, was influenced by increased pore pressures possibly due to gas hydrate dissociation and by lateral variability in the deposition of contourite drifts in palaeoeslide scars. The fourth event entailed the compression of sediment from a large debris flow against the spreading areas and the formation of localised shear zones.

These results do not show that the Storegga Slide was triggered by gas hydrate dissociation, but they do show that gas hydrates have a destabilizing effect on submarine slopes, and that their presence can control how submarine landslides develop once they have started. Therefore it is important to understand how gas hydrates respond to climate change in order to assess if submarine slopes will be less stable as global warming continues.

Last summer we surveyed the western margin of Svalbard where the base of the gas hydrate stability zone intercepts the seabed. At exactly this water depth we found significant release of methane gas from the seabed (Westbrook et al., 2008). The data support that this gas release is due to a decadal scale warming of gas hydrates in the surface sediments. This shows that bottom water warming may induce gas hydrate dissociation, which may destabilize the slope.

From studying the Storegga Slide we know that the landslide has caused an up to 22 m high tsunami on the coasts of NW Europe. Therefore we wanted to find out what will happen if the gas hydrate dissociation of Svalbard should induce a submarine landslide as well. So, we have modeled potential tsunamis in collaboration with the GFZ in Potsdam (Berndt et al., in press). The modeling results indicate that a landslide off Svalbard would be associated with a tsunami that would reach central Europe (Figure 2). The tsunami height would crucially depend on the run-out direction of the landslide. As a consequence we have already proposed to monitor the site of gas hydrate dissociation to understand the scale of this process, and we will propose to install a tiltmeter-based tsunami warning system.

References

Berndt, C., Brune, S., Nisbet, E., Zschau, J. and Sobolev, S.V., 2009: Tsunami modeling of a submarine landslide in the Fram Strait. *G-cubed*, in press.

Micallef, A., Masson, D., Berndt, C., and Stow, D.A.V., 2008: Development and mass movement processes of the north-eastern Storegga Slide. *Quaternary Science Reviews*, doi:10.1016/j.quascirev.2008.09.026.

Westbrook, G.K., Minshull, T., Berndt, C., James, R., Paelike, H., Rohling, E., Chabert, A., Fisher, R., Green, D., Huehnerbach, V., Lanoiselle, M., Thatcher, K., Burchell, A., Piotrowski, A., Aquilina, A., Crocker, A., Bolton, C., and Osbourne, A., 2008: Active gas Venting at the Landward Limit of Hydrate Stability Offshore Svalbard. *Eos Trans*. AGU, **89**(53), Fall Meet. Suppl., Abstract OS31D-03.

Mid-Cretaceous Hawaiian rocks in Kamchatka

Maxim Portnyagin, Dynamics of the Ocean Floor - Magmatic & Hydrothermal Systems

Scientists from IFM-GEOMAR found geochemical evidence for preservation of ~100 m.y. old Hawaiian hotspot rocks in Kamchatka (Far-East of Russia). New trace element and isotope data show that the Hawaiian mantle plume is very persistent in composition during millions of years and originates from a large chemically isolated mantle domain at the Earth core-lower mantle boundary.

The Hawaiian-Emperor Seamount Chain, produced during the passage of the Pacific Plate over the Hawaiian hotspot, extends for 5800 km from the currently active island of Hawaii and Loihi Seamount northwest to the Detroit and Meiji seamounts, seaward of the Kamchatka-Aleutian arc junction (Fig. 1). Despite the extensive data set on the composition and evolution of the Cenozoic Hawaiian magmatism, there is little known about the earlier (>80 m.y.) history of the hotspot. Several studies have proposed that an igneous plateau formed by the plume head at the initiation of the Hawaiian hotspot and that older seamounts formed above the plume tail may have been preserved along the Aleutian Arc, in the Bering Sea or in Kamchatka rather than subducted. There was however no convincing geochemical data which support preservation of older Hawaiian fragments on land or on the sea floor.

During several years scientists from the IFM-GEOMAR together with their Russian colleagues from the Institute of Volcanology and Seismology in Petropavlovsk–Kamchatsky studied geologic structure and composition of rocks preserved in the southwestern part of the Kamchatsky Mys Peninsula (Eastern Kamchatka) (Fig. 1), which consists of ophiolite association of ultramafic rocks, gabbros, dolerites, basalts and sediments of the Late Cretaceous-Eocene age.

Volcanic rocks in the ophiolites occur in the ~1.5 km thick succession together with hyaloclastites and intercalated red jasper and pink pelitomorphic limestone, consistently dated paleontologically as Albian-Cenomanian (120-93 m.y.). Volcanic rocks in the ophiolite association range from trace-element-depleted to slightly enriched mid-ocean-ridge-like basalts (MORB-like) to alkali basalts suggesting that this magmatic assemblage is characteristic of plume-type ophiolites originating from plume-related oceanic ridges and plateaus.

A novel result of the detailed geochemical investigations of the ophiolite rocks, reported in a paper published by Geology in 2008 (Portnyagin et al., 2008) was recognition of a distinctive group of the ophiolite basalts, trace-element-enriched tholeiites cropping out in the northern part of the massif. The rocks are altered olivine-

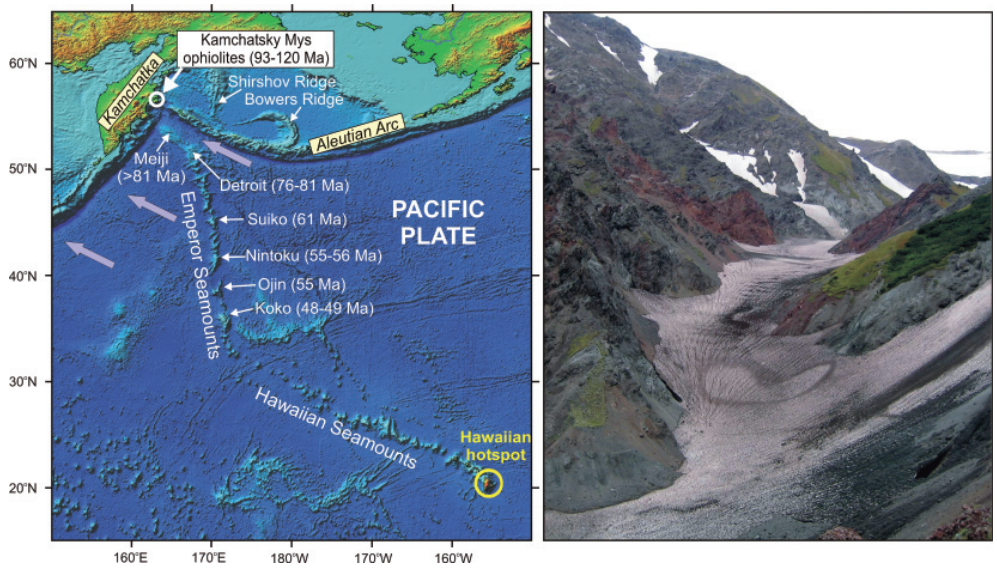


Figure 1. The Hawaiian-Emperor Seamount Chain in the northwestern Pacific, produced by the passage of the Pacific Plate of variable age and thickness over the Hawaiian hotspot, and the position of the Kamchatsky Mys ophiolite complex are shown on the left panel (modified after Portnyagin et al., 2008). Photograph in the right panel illustrates outcrops of oceanic pillow-lavas in the Kamchatsky Mys Peninsula (Photo by Dmitri Savelyev).

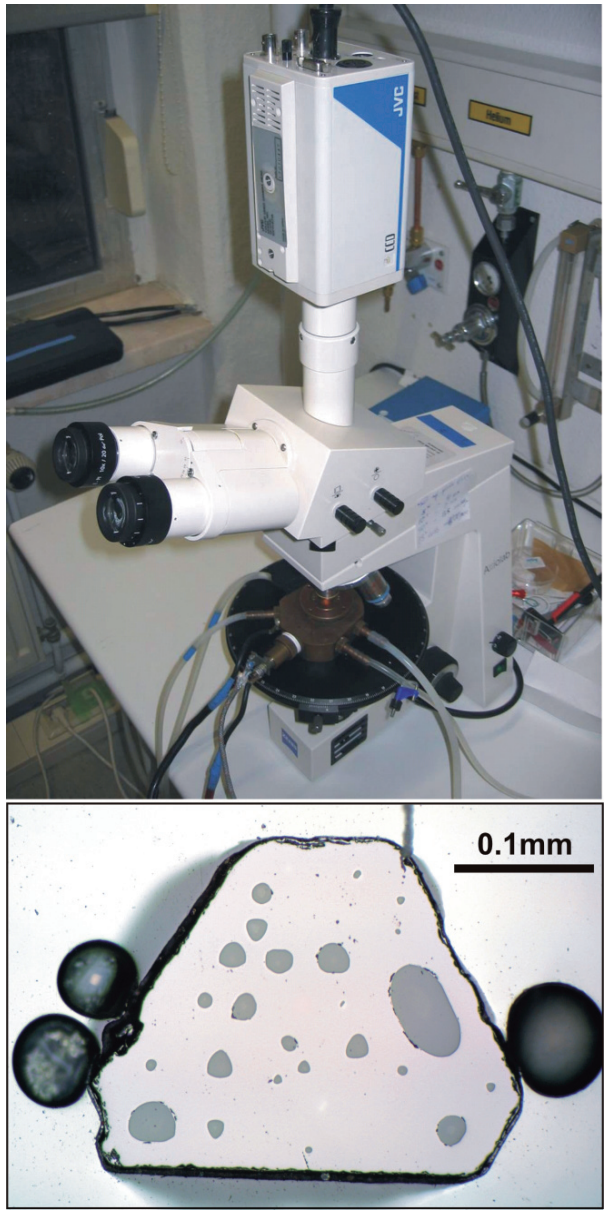


Figure 2 (left column). Vernadsky-type stage for high-temperature experiments under microscope at the IFM-GEOMAR used to homogenize melt inclusions in this study (upper panel) and micrograph of melt inclusions in spinel crystal from the Kamchatka ophiolite basalt after experiment (lower panel).

phyric basalts with very peculiar enriched patterns of incompatible trace elements, Nd and Pb isotope compositions differing from Mesozoic Pacific MORB but falling completely within the compositional range of samples from Detroit Seamount (DSDP Site 1203) belonging to the Hawaiian hotspot track.

In order to collect additional information on the composition of parental magmas of the Kamchatka basalts, this study was extended to include a detailed examination of a mineral chromium spinel (solid solution of Mg, Al, Cr and Fe oxides) in the rocks. Many spinel crystals were found to contain partly crystallized inclusions of 10 to 70 micron in size (Fig. 2), which represent microscopic droplets of melt trapped by spinel during its growth in magma and recrystallized when the magma cooled down. The rocks were hydrothermally altered on the post-magmatic stage. The inclusions inside spinel, a mineral particularly resistant to post-magmatic alteration, remained isolated from the rock matrix by the host mineral and thus preserved information about initial magma composition.

To eliminate effects of crystallization on melt inclusion composition, spinel crystals with inclusions were placed at the temperature of their origin (1250 °C) using the Vernadsky-type stage for high-temperature experiments at the IFM-GEOMAR (Fig. 2). At this temperature crystal phases inside inclusions melted out. Quenched glasses of the melt

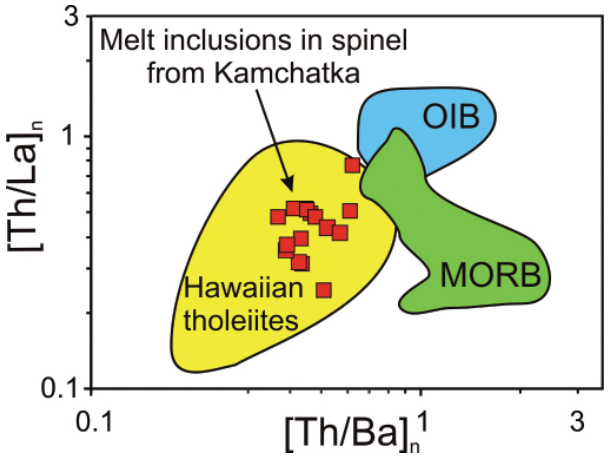


Figure 3. Melt inclusions in spinel from the Kamchatsky Mys ophiolites have Hawaiian-type Th/Ba and Th/La ratios, which are systematically lower compared to the majority of ocean island basalts (OIB) and mid-ocean ridge basalts (MORB). (modified after Portnyagin et al., 2008)

inclusions were analyzed by electron probe and secondary-ion mass-spectrometry for major and many trace elements. These analyses showed that all studied melt inclusions had very low Th/La and Th/Ba and high Nb/La ratios, which are very similar to that of the Hawaiian hotspot lavas and melt inclusions but were not documented for mid-ocean ridge and ocean island basalts from other localities (Fig. 3).

On the basis of these geochemical data the ophiolite basalts were suggested to very likely derive from a Hawaiian-type mantle source, and thus evidence for the existence of the Hawaiian hotspot 120-93 m.y. ago. The studied rocks occur as lava flows in association with slow-accumulated deep-sea sediments (intercalated cherts and limestones) and hyaloclastites. The lavas

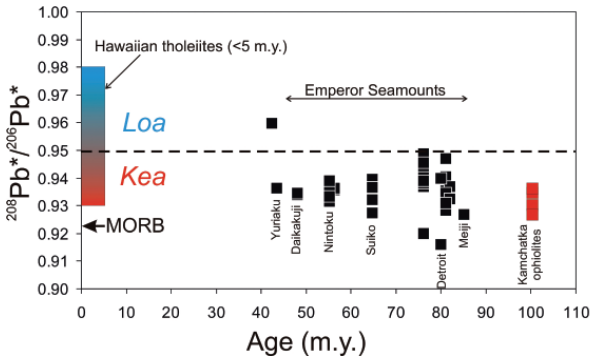


Figure 4. Lead isotope compositions of the Emperor Seamount Chain rocks and enriched tholeiites from the Kamchatsky Mys ophiolites indicate prevailing contribution from "Kea" mantle component ($^{208}Pb^*/^{206}Pb^*$ <0.95) similar to that in rocks of Mauna Kea volcano. "Loa" component ($^{208}Pb^*/^{206}Pb^*$ >0.95) is not common in the Hawaiian hotspot rocks older than 5 m.y. old (modified after Portnyagin et al., 2008). The ratio $^{206}Pb^*/^{208}Pb^*$ represents time-integrated $^{232}Th/^{238}U$ ratio since the formation of the Earth.

could thus have originated on the deep flank of a seamount or on a mid-ocean ridge, strongly affected by interaction with the neighbouring Hawaiian hotspot.

Low Th/Ba ratios in Hawaiian hotspot lavas and studied Kamchatkan melts deviate strongly from typical mantle values and can be explained by melting of low-Th recycled crustal material within the plume source. As evident from the published data and results from this study, a contribution from the low-Th recycled material to the Hawaiian hotspot-derived magmas was persistent over the last ~100 m.y. Moreover, low $^{206}Pb^*/^{208}Pb^*$<0.95 in the least altered Emperor Ridge rocks and lavas from the Kamchatka forearc studied here (Fig. 4) and also unusually high Nb/La in the melt inclusions, similar to inclusions from Mauna Kea lavas, suggest that it was probably Kea-type component, which contributed, together with a depleted plume component to prevailing compositions of Cretaceous Hawaiian hotspot lavas.

A persistent yet heterogeneous composition of Hawaiian hotspot lavas suggests that their source region represents a long-lived prominent geochemical anomaly in the Earth's mantle. Assuming that the volume flux of the Hawaiian plume was similar from the mid-Cretaceous to the present (300 m^3/s) and that the plume originates at the core-mantle boundary, the source region of the Hawaiian plume over the last ~100 m.y. was estimated to cover an area of ≥15% of the core-mantle boundary in the form of a ≤40 km thick layer. Long-lived (≥20 m.y.), complex spatial zonation has also been shown for the Galapagos hotspot and thus also requires a volumetric large-scale geochemical anomaly in the Earth's mantle, which may be an important feature of plume-related hotspot volcanism.

In summary, this work provides evidence that older (than preserved on the NW Pacific seafloor) products of the Hawaiian hotspot have been accreted to the fore-arc of the Kamchatka subduction zone. This study has important implications for the persistence of chemical characteristics of hotspots over ~100 m.y. and the spatial scale of the compositional heterogeneity in the Earth's mantle. This research was supported by the Deutsche Forschungs gemeinschaft (HO1833/14-1) and the Bundesministerium für Bildung und Forschung (KALMAR project). The study of longevity and geochemical evolution of the Hawaiian hotspot is to be continued in the IFM-GEOMAR on the Phase 2 of the KALMAR project focused on the Shirshov and Bowers Ridges in the Bering Sea, possible fragments of the Hawaiian hotspot track.

Reference:

Portnyagin M.V., Savelyev D.P., Hoernle K., Hauff F., Garbe-Schönberg D., 2008: Mid-Cretaceous Hawaiian tholeiites preserved in Kamchatka. *Geology*, **36**(11), 903-906, doi: 910.1130/G25171A.25171.

Contributions to *Nature* and *Science*

In 2008, IFM-GEOMAR scientists published 323 peer-reviewed papers. Amongst them a number in high-profile, internationally recognized journals such as Nature and Science.

Nature

Biastoch, A., **Böning, C.W.** and Lutjeharms, J.R.E., 2008: Agulhas leakage dynamics affects decadal variability in Atlantic overturning circulation. *Nature*, **456**, 489-492, doi:10.1038/nature07426

Bowler, C., Allen, A.E., Badger, J.H., Grimwood, J., Jabbari, K., Kup, A., Maheswari, U., Martens, C., Maumus, F., Ottilar, R.P., Rayko, E., Salamov, A., Vandepoele, K., Beszteri, B., Gruber, A., Heijde, M., Katinka, M., Mock, T., Valentin, K., Verret, F., Berges, J.A., Brownlee, C., Cadoret, J.-P., Chiovitti, A., Choi, C.J., Coesel, S., De Martino, A., Detter, J.C., Durkin, C., Falciatore, A., Fournet, J., Haruta, M., Huysmann, M., Jenkins, B.D., Jiroutova, K., Jorgensen, R.E., Joubert, Y., Kaplan, A., Kroeger, N., Kroth, P., **LaRoche, J.**, Lindquist, E., **Lommer, M.**, Martin-Jezequel, V., Lopez, P.J., Lucas, S., Mangogna, M., McGinnis, K., Medlin, L.K., Montsant, A., Oudot-Le Secq, M.-P., Napoli, C., Obornik, M., Petit, J.-L., Porcel, B.M., Poulsen, N., Robison, M., Rychlewski, L., Rynearson, T.A., Schmutz, J., Schnitzler Parker, M., Shapiro, H., Siaut, M., Stanley, M., Sussmann, M.J., Taylor, A., Vardi, A., von Dassow, P., Vyverman, W., Willis, A., Wyrwicz, L.S., Rokhsar, D.S., Weissenbach, J., Armbrust, E.V., Green, B.R., Van de Peer, Y. and Grigoriev, I.V., 2008: The Phaeodactylum genome reveals the dynamic nature and multilineage evolutionary history of diatom genomes. *Nature*, **456**, 239-244, doi:10.1038/nature07410

Hoernle, K., Abt, D.L., Fischer, K.M., **Nichols, H.**, **Hauff, F.**, Abers, G.A., **van den Bogaard, P.**, **Heydolph, K.**, Alvarado, G., Protti, M. and Strauch, W., 2008: Arc-parallel flow in the mantle wedge beneath Costa Rica and Nicaragua. *Nature*, **451** (7182), 1094-1097, doi:10.1038/nature06550

Keenlyside, N., **Latif, M.**, Jungclaus, J., Kornblueh, L. and Roeckner, E., 2008: Advancing Decadal-Scale Climate Prediction in the North Atlantic Sector. *Nature*, **453**, 84-88.

Other contributions to Nature

Riebesell, U., 2008: Acid test for marine biodiversity. *Nature*, **454**, 46-47.

Nature Geoscience

Böning, C.W., **Dispert, A.**, **Visbeck, M.**, Rintoul, S.R. and **Schwarzkopf, F.**, 2008: The response of the Antarctic Circumpolar Current to recent climate change. *Nature Geoscience*, **1**, 864-869, doi:10.1038/ngeo362

De Lange, G.J., Thomson, J., **Reitz, A.**, Slomp, C.P., Principato, M.S., Erba, E. and Corselli, C., 2008: Synchronous basin-wide formation and redox-controlled preservation of a Mediterranean sapropel. *Nature Geoscience*, **1**, 606-610, doi:10.1038/ngeo283

Haley, B., **Frank, M.**, **Spielhagen, R.** and **Eisenhauer, A.**, 2008: Influence of brine formation on Arctic Ocean circulation over the past 15 million years. *Nature Geoscience*, **1**, 68-72, doi:10.1038/ngeo.2007.5

Mather, R.L., Reynolds, S.E., Wolff, G.A., Williams, R.G., Torres-Valdes, S., Woodward, E.M.S., **Landolfi, A.**, Pan, X., Sanders, R. and Achterberg, E.P., 2008: Contrasting phosphorus cycling in Atlantic Ocean deserts. *Nature Geoscience*, **1**, 439-443.

Visbeck, M., 2008: From climate assessment to climate services. *Nature Geoscience*, **1**, 1-2.

Voigt, S., 2008: Saline water sinking. *Nature Geoscience*, **1** (7), 423-424.

Ziegler, M., **Nürnberg, D.**, **Karas, C.**, Tiedemann, R. and Lourens, L.J., 2008: Persistent summer expansion of the Atlantic Warm Pool during glacial abrupt cold events. *Nature Geoscience*, **1** (9), 601-605, doi:10.1038/ngeo277

Science

Duce, R.A., **LaRoche, J.**, Altieri, K., Arrigo, K.R., Baker, A.R., Capone, D.G., Cornell, S., Dentener, F., Galloway, J., Ganeshram, R.S., Geider, J., Jickells, T., Kuypers, M.M., **Langlois, R.**, Liss, P.S., Liu, S.M., Middelburg, J.J., Moore, C.M., Nickovic, S., **Oschlies, A.**, Pedersen, T., Prospero, J., Schlitzer, R., Seitzinger, S., Sorensen, L.L., Uematsu, M., Ulloa, O., Voss, M., Ward, B. and Zamora, 2008: Impacts of atmospheric anthropogenic nitrogen on the open ocean. *Science*, **320**, 893-897.

Stramma, L., Johnson, G.C., Sprintall, J. and Mohrholz, V., 2008: Expanding Oxygen-Minimum Zones in the Tropical Oceans. *Science*, **320**, 655-658, doi:10.1126/science.1153847

Other contributions to Science

Riebesell, U., Bellerby, R., Engel, A., Fabry, V.J., Hutchins, D.A., **Reusch, T.B.H.**, Schulz, K.G. and Morel, F.M.M., 2008: Comment on "Phytoplankton Calcification in a High-CO_2 World". *Science*, **322** (1466b). doi:10.1126/science.1161096

A full listing of all publications can be found in Appendix 5 of this report or under http://www.ifm-geomar.de/publications.

Appendices (on CD only)

GEFÖRDERT VOM

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Wirtschaft und Verkehr
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