



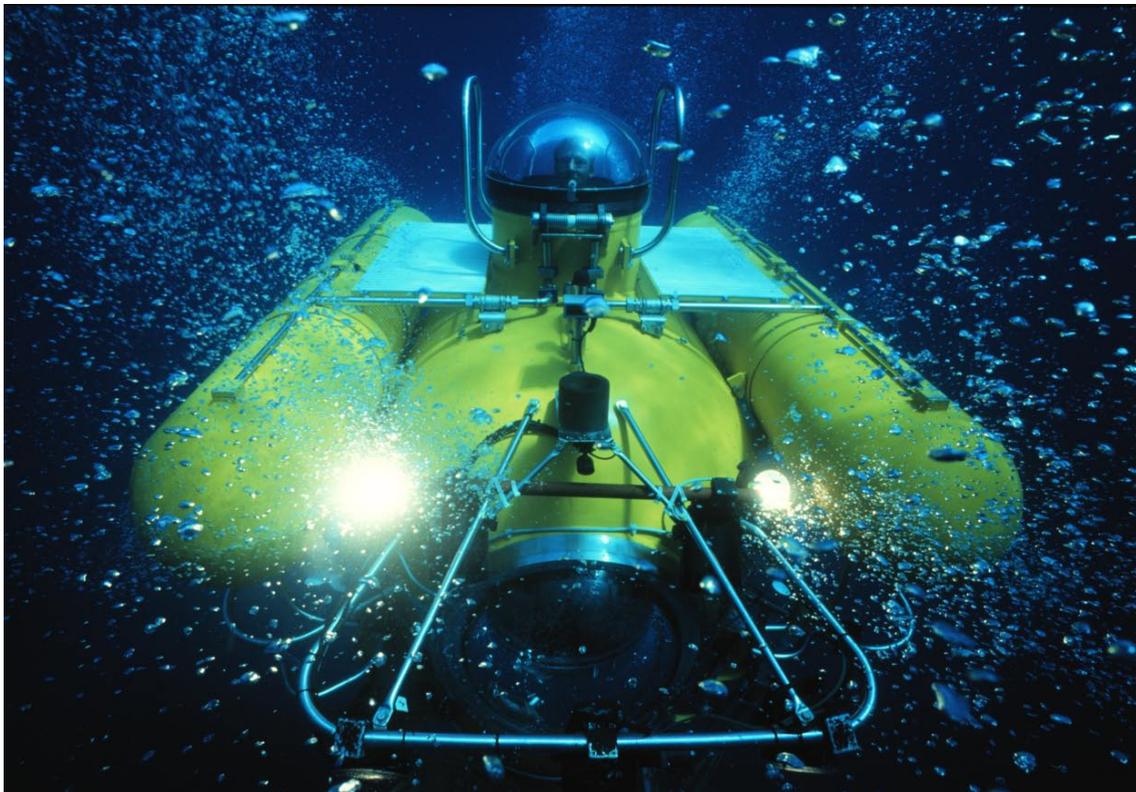
**IFM-GEOMAR**

Leibniz-Institut für Meereswissenschaften  
an der Universität Kiel

# **IFM-GEOMAR Report 2006**

**From the Seafloor to the Atmosphere**

**- Marine Sciences at IFM-GEOMAR Kiel -**



## **IFM-GEOMAR Report 2006**

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Cover photo: Submersible JAGO diving in the Indian Ocean (Jürgen Schauer, IFM-GEOMAR).  
Inner cover: s.a.

## Preface

Three years after the merger of IFM and GEOMAR, the decision to merge the two institutes has proven to be a strategic and scientific success. The reputation and profile of IFM-GEOMAR has increased tremendously and has established Kiel as a major centre of marine sciences in Germany and Europe. One indicator of the success of the new institute is the so-called "DFG-ranking", published by the German Research Foundation (DFG). For the period 2002-2004, IFM-GEOMAR was by far the most successful non-university research institute in terms of DFG-project funding. An important milestone for the strategic development of the institute is represented by the positive funding decision for the excellence cluster "The Future Ocean". In this project, IFM-GEOMAR cooperates with six different faculties of the University of Kiel, the Kiel Institute for the World Economy and the Muthesius College of Fine Arts. The cluster, which has a budget of 36 Mio. Euros for a 5-year period, will cover a wide range of topics including chances and risks of the future ocean such as ocean acidification, marine resources and the consequences of climate change. Four of the 14 new junior research groups will be located at IFM-GEOMAR. The generous funding of "Future Ocean" will enable the creation of about 100 new high-profile jobs in Kiel.

Progress has also been made in the area of research infrastructure. The new Technology and Logistics Centre (TLC) of IFM-GEOMAR opened as the new central basis for the development and maintenance of instrumentation, as well as for the technical preparation of seagoing expeditions. The first large device that found its new home in the TLC is the submersible "Jago" the only manned research submersible in Germany. "Jago" was acquired by IFM-GEOMAR in January and provides an attractive platform for multi-disciplinary marine research. In addition, the construction of a Remotely Operated Vehicle (ROV) with a diving capability of 6000m started recently. The ROV will be available for the marine research community in late 2007. Other large-scale facilities such as offshore mesocosms and an Autonomous



Underwater Vehicle (AUV) are also being developed.

On the scientific side, plans for a new collaborative research centre (SFB) on "Climate-Biogeochemistry Interactions in the Tropical Oceans" are well developed. The review of the pre-proposal was very encouraging and the on-site review and the funding decision are expected for 2007.

Overall, the developments in marine sciences in Kiel and particularly at IFM-GEOMAR have been extremely positive during the past year. Due to successful proposals and generous additional support by the State of Schleswig-Holstein, the institute now enjoys a solid foundation with which it can strive for continued excellence in marine research. We are confident that we can further strengthen our leadership position over the next few years in order to establish IFM-GEOMAR as a "National Centre for Marine Sciences" with high international visibility.

This report provides a short overview of the major developments and scientific highlights during the past year. Detailed statistical information can be found in the appendices. I hope that you will enjoy reading the "IFM-GEOMAR Highlights 2006".

Kiel, October 2007

A handwritten signature in black ink, appearing to read "P. Herzig". The signature is stylized and written in a cursive-like font.

**Prof. Peter M. Herzig**  
**Director**



## Overview

### Funding & Projects

#### Excellence Cluster "Future Ocean"

In 2006, IFM-GEOMAR was awarded a grant together with six faculties of the University of Kiel, the Kiel Institute for the World Economy, and the Muthesius School of Arts to establish the Excellence Cluster "Future Ocean". The proposal was selected from more than 150 applications together with 16 others. The cluster, funded for a 5-year period with a budget of 36 Mio. Euros, started formally in November 2006. It covers a wide range of topics in the framework of scientific and legal aspects of the future ocean. The cluster will provide about 100 scientific positions in 14 junior research groups. Part of the leading positions will be tenure tracked to sustain successful new research fields in this area. The funding of the cluster confirms the leading position of Kiel in the marine sciences in Germany (see box page 3).

#### DFG-ranking

The so-called "DFG-ranking" published by the German Research Foundation (DFG) in 2006 underscored the leading national position of IFM-GEOMAR. For the period 2002-2004, IFM-GEOMAR was by far the most successful non-university institute in terms of DFG-project funding compared with 84 other Leibniz institutes, 80 institutes of the Max-Planck Society and 15 of the Helmholtz Association. The institute received a total funding of 18.9 Mio. Euros from the DFG during this 3-year period.

#### Evaluation process

In autumn 2006, the Leibniz Association published the results of the IFM-GEOMAR evaluation which took place in September 2005. The official report attests IFM-GEOMAR very good to excellent research qualities, with a leading role on the national and European level. Furthermore, the institute enjoys high visibility and influence at the international level. The report also stated the need of an expansion of the facilities on the east shore in the time frame of 2009/2010. Overall, the evaluation recommended the continuation of the joint federal - state funding over the next seven years. The report passed the senate of the Leibniz Association in November 2006.

#### New initiatives

A number of new major research initiatives were launched in 2006. The proposal for a new Collaborative Research Programme (SFB) dealing with "Climate-Biogeochemistry Interactions in the Tropical Oceans" under the leadership of Prof. Douglas Wallace (Research Division 2) passed the pre-evaluation of the DFG in June 2006 and resulted in the recommendation to submit the full proposal in spring 2007.

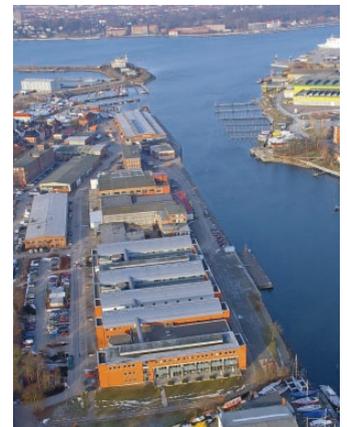
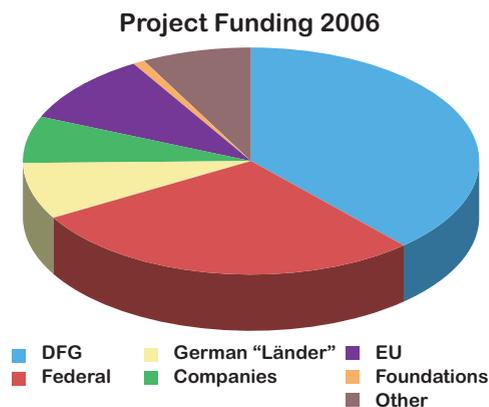
In the field of gas hydrate research, a joint proposal with industrial partners (e.g. E-on Ruhrgas, RWE-DEA, etc.). The purpose of this initiative is to explore the possibilities of underwater gas hydrate exploitation simultaneous to the storage of CO<sub>2</sub> below the seafloor. The proposal was submitted to the Federal Ministry of Economics (Funding line: "Resources of the sea floor").

#### SFB 460 and follow-up projects

The collaborative research programme "Dynamics of Thermohaline Circulation Variability" (SFB460) ended after a 10-year period. A final scientific symposium will be held in March 2007. As a follow-up, IFM-GEOMAR received funding on the order of 1.5 Mio. Euros for the 3-year BMBF project called "North Atlantic". The IFM-GEOMAR contribution focuses on the role of the equatorial Atlantic as a key region for Atlantic climate variability and fluctuations of deep boundary current circulation at the southern exit of the Labrador Sea.

#### Project funding

The overall project funding of IFM-GEOMAR in 2006 amounted to the same



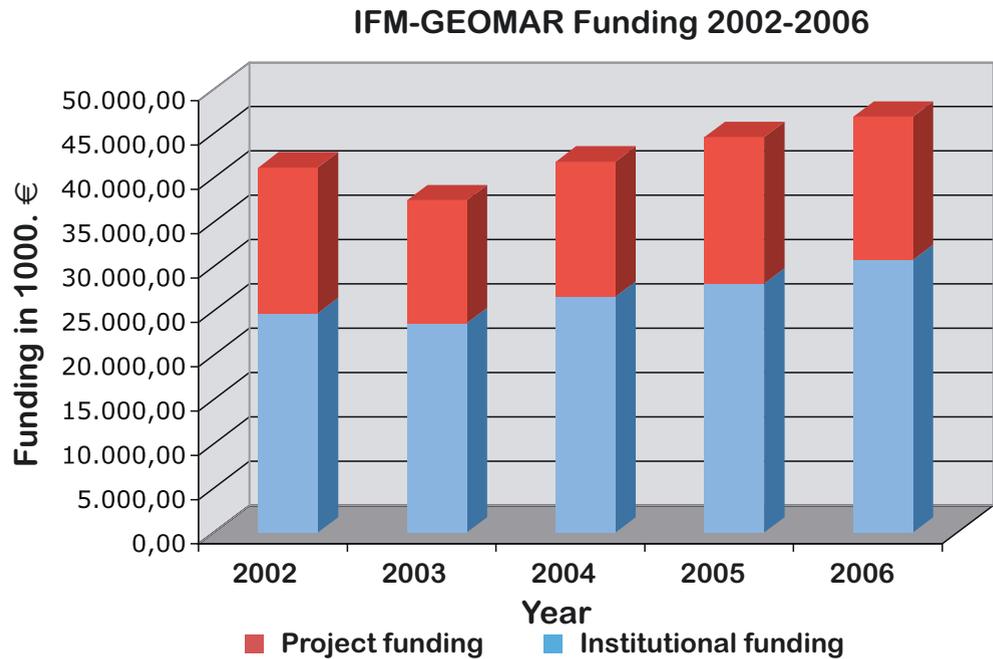
East shore campus, photo:



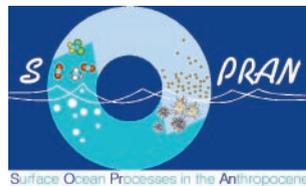
West shore campus

Project funding by sources for the year 2006.

Institutional funding and project funding for the years 2002-2006.



level as in the previous year, whereas the total increased by 5% due to additional funding for the remotely operated vehicle (ROV) by the state government of Schleswig-Holstein. About 34.5% of the total budget of the institute is comprised of projects funds. During 2006, a number of large-scale research projects were funded or started. These include:



**SOPRAN** (Surface Ocean Processes in the Anthropocene)

The SOPRAN project addresses three main aspects of ocean-atmosphere biogeochemical interaction:

1. How do changing atmospheric composition affects the surface ocean;
2. How do changing surface ocean processes can alter oceanic emissions to the atmosphere
3. What are the mechanisms and rates of ocean-atmosphere material exchanges

The project is coordinated by Prof. Douglas Wallace (Research Division 2) with a budget of about 1.3 Mio. Euros.

**Aquashift** – 2<sup>nd</sup> Phase:

The DFG-priority programme 1162 **AQUASHIFT**, "The impact of climate variability on aquatic ecosystems" began in 2004. The goal of the project is to study the impact of climate change on

aquatic ecosystems, in particular shifts in the food chain and the consequences for aquatic ecosystems. The second phase of the programme was funded following a positive evaluation in autumn 2006.



The German-Russian multidisciplinary research project "**KALMAR** - Kurile-Kamchatka and Aleutian Marginal Sea-Island Arc Systems: Geodynamic and Climate Interaction in Space and Time" aims at investigating the climate-affecting system "Kurile-Kamchatka-Aleutian arc" with its adjacent marine parts in the NW Pacific and the Bering Sea. The total budget is 1.3 Mio. Euros for a three year period.

**Research infrastructure:**

**Submersible "Jago"**

In January 2006, IFM-GEOMAR acquired "Jago", the only manned research submersible in Germany. The submersible, built in 1989, can carry the pilot and a scientist to a maximum depth of 400 meters. Due to the relatively low weight of 3000 kg, "Jago" can also be used from smaller research vessels, provided they are equipped with a sufficient crane capacity. In 2006, "Jago" was used to investigate cold water coral reefs at the Norwegian shelf and methane seeps in the North Sea.



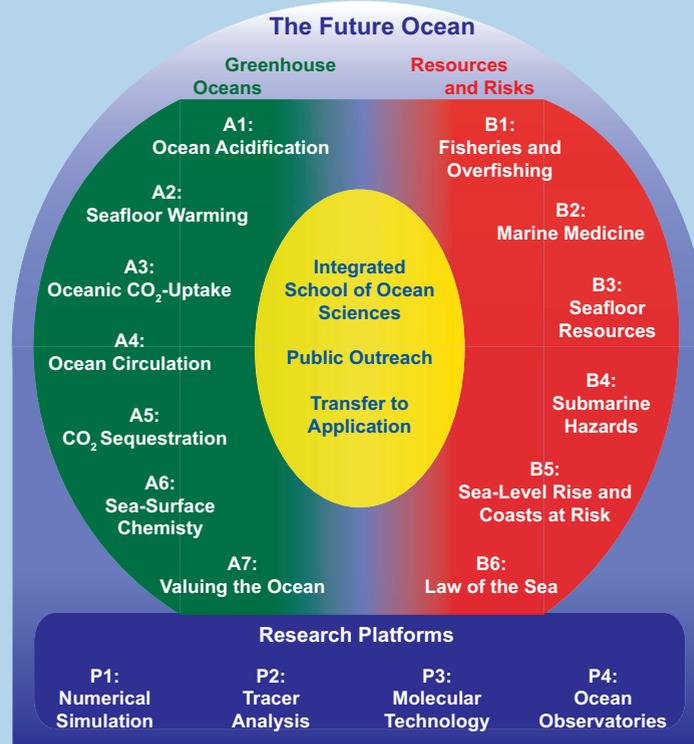
Submersible JAGO during its official launch in the Kiel Fjord.



## The Excellence Cluster "Future Ocean"

The structure of the Excellence Cluster "Future Ocean"

A strategic instrument of the Cluster will be the establishment of new Junior Research Groups (JRG's) in key interdisciplinary research areas (A1 - B6 in Fig. 1). These JRG's will augment the expertise provided by the well-established research groups of the proponents. The positions of the group leaders will be endowed with "tenure-track" positions and thus have the option of being converted to permanent positions (W2/W3) based on a review of merit. The Cluster will provide the JRG's with resources and personnel as well as scientific support through the established research groups of the proponents. The commitment of CAU to establish additional permanent faculty positions in key Cluster research areas implies that the Cluster will have a long-term strategic impact on the fabric of the University. Both the Cluster proponents and the JRG's leaders will be members of the Cluster. They will be eligible to benefit from Cluster resources and will address the emerging new research topics of "The Future Ocean" as identified in the Cluster proposal (Fig. 1). Research within the Cluster will be organized under two themes (A) Oceans in the Greenhouse World and (B) Marine Resources and Risks. Theme A will develop the scientific foundations required to evaluate future oceanic change with respect to energy, water, carbon and chemical cycling. Theme B will address a range of emerging issues regarding marine resources and hazards associated with the Future Ocean. The proposed Integrated School of Ocean Sciences (ISOS) will consolidate in structure, and enhance in scope, multidisciplinary and research-driven ocean education at Kiel University. The JRG leaders will contribute to education in the ISOS and will benefit from the infrastructure provided by the school.



Cluster research will be supported by four overarching research platforms. The platforms will offer a wide range of services including numerical expertise, modeling, and super-computer support, isotope and trace metal analysis, access to high-throughput molecular analysis facilities, and cutting-edge marine technology to explore the global ocean in space and time from the oceanic crust to the air-sea interface. The Cluster platforms permit the more efficient use of resources and will be further developed and strengthened according to the scientific needs of the Cluster.

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For more information visit: [www.future-ocean.de](http://www.future-ocean.de)

### Remotely Operated Vehicle (ROV)

The contract for the remotely operated vehicle (ROV) "Kiel 6000" was signed in June, 2006. The ROV is currently being built by Schilling Robotics in Davis, California. Important supply parts (winch, fiber cable, technical equipment) are added from companies in Germany or Schleswig-Holstein, respectively. The deep-sea test is planned for summer 2007 followed by the first two research expeditions.



Minister Dietrich Austermann (middle), Norman Robertson (Schilling Robotics) and Peter Herzig signing the contract for the ROV Kiel 6000.

### Centre for Marine Substances



New labs of KiWiZ provide a modern environment for blue bio-technology research

The Research Centre for Marine Substances (KiWiZ) moved into new laboratories (Am Kiel Kanal 44) towards the end of the year. These new labs provide excellent working facilities for the

marine microbiologists, who are currently funded for an initial 2-year period. The extension of the funding is currently under consideration.

### Technology and Logistics Centre (TLC)

The Technology and Logistics Centre of IFM-GEOMAR is the hub for the development, testing and preparation of marine technical equipment. All the technical laboratories and workshops



Technology and Logistics Centre on the east shore campus

of IFM-GEOMAR are concentrated in this new centre which is also home base for large technical devices such as Jago and the new ROV. The TLC was officially opened on September 1, 2006.

### Scientific Highlights:

Amongst the IFM-GEOMAR research topics of the past year that proved to be scientific highlights were: investigations of hydrothermal systems (page 10), the detection of long-term changes in the Labrador Sea (page 24), and the invasion of foreign species to the Baltic Sea. The latter topic received major attention both in the general media and in the scientific community, when IFM-GEOMAR first reported the identification of the jellyfish *Mnemiopsis leidyi*, common to the East coast of the United States, in the Kiel Fjord. IFM-GEOMAR scientists became alarmed because the numbers of this invasive species increased steadily during the course of the fall. The discovery and the continued close observation of this phenomenon underscore the importance of the monitoring programme underway in the research division "Marine Ecology". *Mnemiopsis leidyi* proved to be a problem for fish populations in the Black Sea during the nineties, because the jellyfish prefers to consume fish eggs and larvae. Experiences from the Black Sea showed that this species can reduce fish stocks significantly in the absence of natural enemies. Due to low salt concentration, it has no predator in the Baltic. At IFM-GEOMAR, continuous measurements of the jellyfish population fortunately showed a decline over the winter months (for details see page 17).

IFM-GEOMAR scientists also discovered a new foraminiferal species named *Uvigerina celtica*. The discovery of a new species among this group of unicellular-organisms is rare today, since foraminifera have been studied very intensively in the past. *Uvigerina celtica* can be used to study eutrophic processes in coastal waters because of adaptation to high nutrient values. Thus, the new species provides a tool to monitor both past and present environmental changes and the impact on benthic organisms.

Further examples of notable scientific highlights from 2006 can be found in

chapter 2.

IFM-GEOMAR scientists led a number of major sea-going expeditions world-



wide. These include a cruise to investigate mud volcanoes in the Gulf of Cadiz with the new research vessel "Maria S. Merian", the "Alkor" expeditions AL275 to study cold water corals in Norwegian waters and AL290

to investigate methane seeps and an abandoned blow out in the North Sea. On both cruises, the manned research submersible "Jago" provided major new insights and enabled precise data gathering from the seafloor. During the "Merian" cruise MSM03/3, IFM-GEOMAR scientists implemented the new deep-sea drilling device "Rockdrill 2" for the first time in cooperation with the British Geological Survey. Samples were extracted from the Logatshev Hydrothermal Field on the Mid-Atlantic Ridge. SFB 574 started research at a new study area in the deep-sea trench off the coast of Chile with the "Meteor" cruise M67/1. Finally, two "Sonne" cruises led by IFM-GEOMAR staff focused on the subduction zones in the eastern Indian Ocean. Part of the work was related to the Tsunami Early Warning System (TEWS) project. More

details about IFM-GEOMAR cruises can be found in Appendix 4.

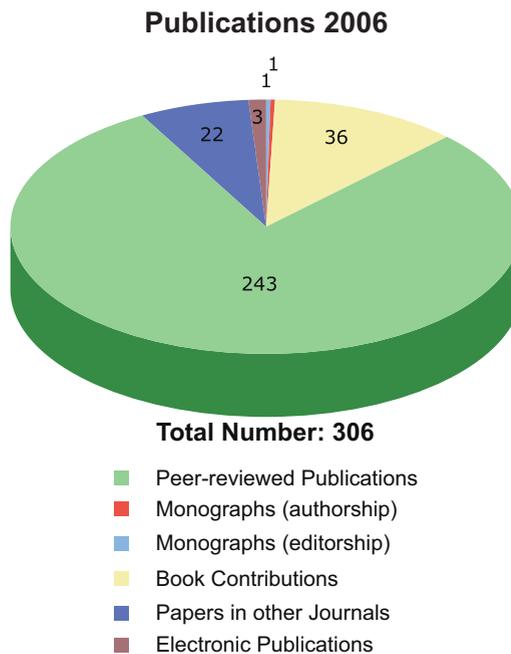
**Scientific Publications:**

One of the key indicators of scientific productivity of a research institution is the number of publication in quality peer-reviewed journals. The number of papers in reviewed scientific journals remained at a high level in 2006 and the relative proportion of peer reviewed publications increased.

**Personnel:**

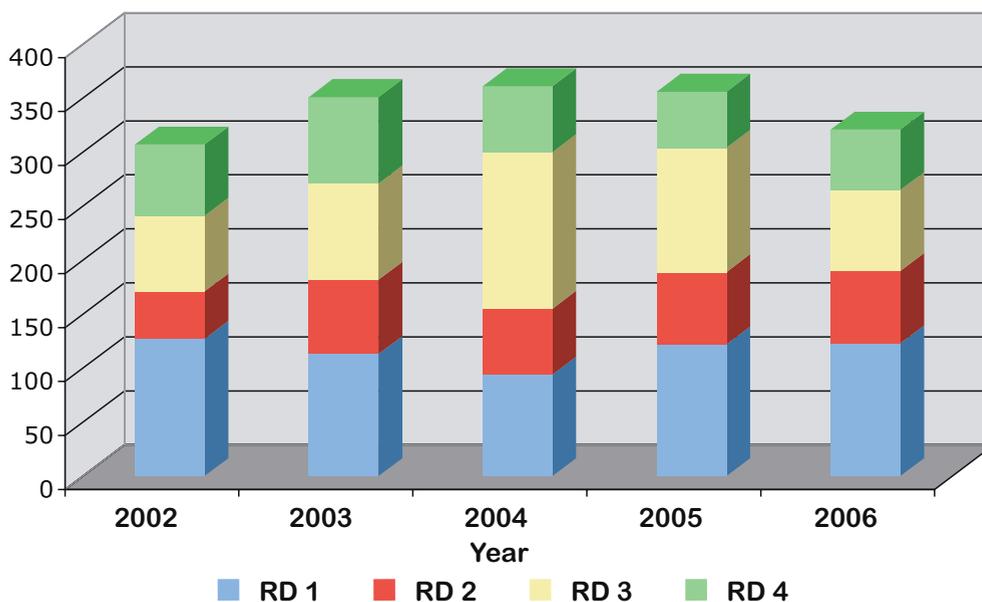
The number of personnel at IFM-GEOMAR increased slightly to 410 in 2006, of whom 240 are scientists. More details can be found in Appendix 2.

*Left: Methane blow-out in the North Sea observed with the submersible JAGO*



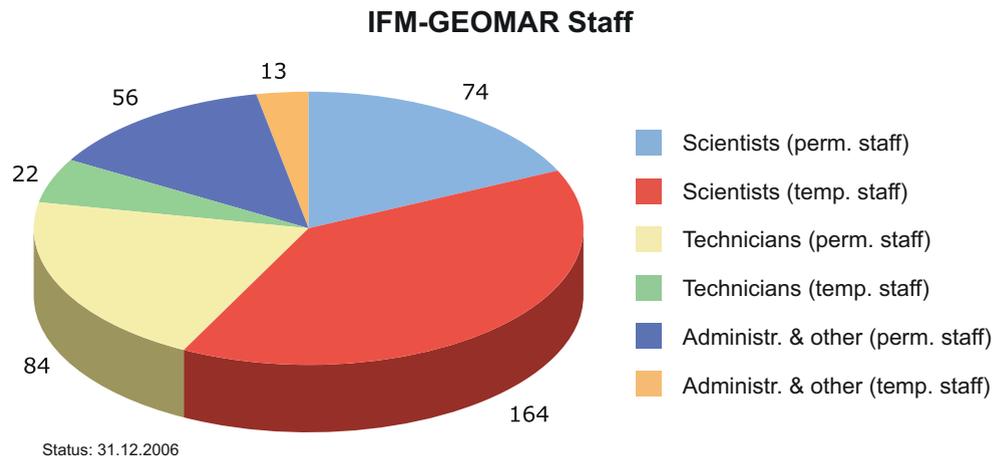
*Publications 2006 by publication type*

**Publications 2002-2006**



*Publications 2002-2006 by research divisions*

IFM-GEOMAR staff by end of 2006



Prof. Jan Behrmann (Univ. Freiburg) took up his Professorship in Marine Geodynamics in May 2006. The Marine Geodynamics research unit is engaged in the study of tectonic processes that shape the Earth's crust. Prof. Behrmann's main research themes are the geology and tectonophysics of active plate margins, from the deep sea trenches to the summits of the highest mountain chains on Earth. His main aim is to help understand the deformation mechanics of rock, a major requirement to find out how earthquakes form, and what governs the stability of sediments on continental margins. Geographically, most of his land-based research was in the Alps, the Betic Cordilleras of Spain, the Variscan Mountain Belt of Europe, and the continental rift zones of Europe and East Africa. His marine research concentrated on the northwest and southeast Pacific plate margins, the Antilles, the Gulf of Mexico and the Mediterranean. He has sailed on three ODP/IODP cruises (Barbados, Chile Triple Junction, Gulf of Mexico Hydrogeology), leading the last two as Co-Chief Scientist.

In August 2006, Prof. Andreas Oschlies (National Oceanography Centre, Southampton) joined IFM-GEOMAR to lead the newly established research unit "Marine biogeochemical modelling". This group will investigate the transport of climate-relevant biogeochemical tracers, in particular carbon, oxygen, and nitrogen, within the ocean and across its boundaries with the atmosphere and the sediments. The quantitative tools implemented range from simple box models to state-of-the-art climate models. As these models require adequate formulations of ecological, biogeochemical and physi-

### Honors and Awards 2006

#### Hoppe, H.-G.:

- 2007 Lifetime Achievement award in Aquatic Enzymology. School of Natural Resources, Ohio State University.

#### Ismar, S.:

- 2006 Nachwuchsförderpreis der ZTS (Zentrum für maritime Technologie und Seefischmarkt GmbH)

#### Krug, S.:

- 2006 Nachwuchsförderpreis der ZTS (Zentrum für maritime Technologie und Seefischmarkt GmbH)

#### Latif, M.:

- Norbert Gerbier – MUMM International Award

#### Lube, G.:

- Gordon-Research Young Scholar's Award of the Queen's College Oxford
- Dissertation summa cum laude
- Alexander-von-Humboldt Fellowship

#### Müller, M.N.:

- Young Scientists' Outstanding Poster Paper (YSOPP) Award 2006 at the EGU in Vienna.

#### Rumohr, H.:

- Service Award in recognition of his contributions to ICES as Chair of Marine Habitat Committee (MHC) from 2004-2006, Internat. Council for the Exploration of the Sea (ICES)

#### Suess, E.:

- Elisabeth-Mann Borgese Award of the State of Schleswig-Holstein.

cal processes, the research unit will closely interact with biological, chemical, and physical oceanographers, as well as with mathematicians and computer scientists. This interaction is already visible in a number of ongoing and planned collaborative research projects, such as the involvement in the Kiel research network "The Future Ocean", in planned European FP7 projects, and in the planned new SFB on climate-biogeochemical interactions in the tropical ocean.

Prof. Timothy Reston (Marine Tectonics, RD4) left IFM-GEOMAR to take up a position at the University of Birmingham. The vacant position has been advertised, the recruitment process is expected to be completed in 2007. The review process for candidates for the positions in Physical Oceanography vacated by Prof. Uwe Send and Theoretical Oceanography, previously filled by Prof. Jürgen Willebrand, are currently under way. Furthermore, initial steps were taken to fill the position vacated through the retirement of Prof. Dietrich Schnack (Fisheries Biology).

A number of scientists were honoured for their achievements in science, science management and public outreach. Amongst them, the "Elisabeth Mann-Borgese Award" of the State of Schleswig-Holstein for Prof. Dr. Erwin Suess, an internationally renowned marine geologist at the former Geomar research institute until 2005.

### Student Education:

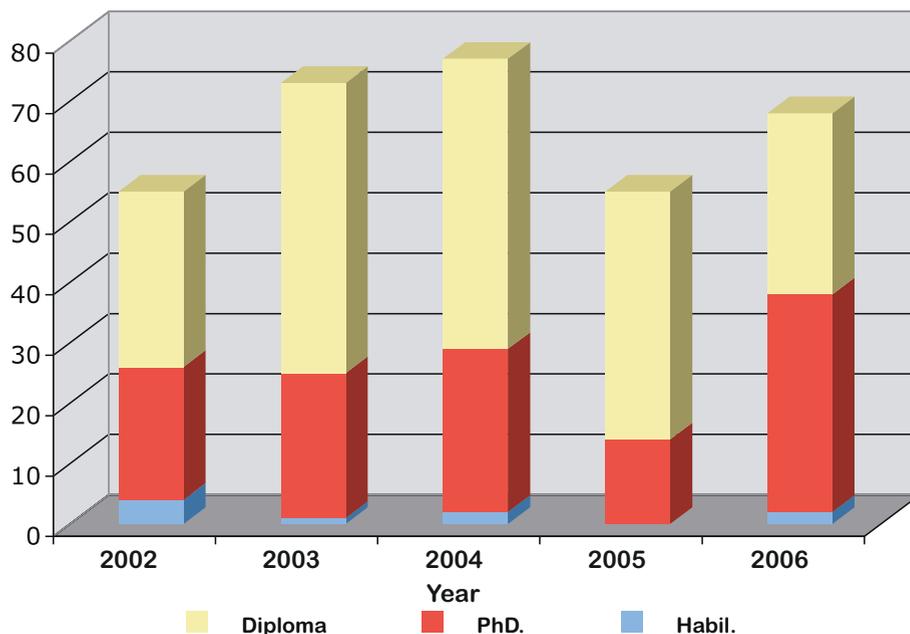
IFM-GEOMAR contributes personnel and facilities for the education programme of the Faculty of Mathematics and Natural Sciences of the Christian-Albrechts-University (CAU) of Kiel. During 2006, 36 PhD theses and 30 Diploma theses were completed (see



Participants of the Sino-German summer school

figure below). IFM-GEOMAR is actively participating in a number of international education programmes. Amongst them is the cooperation with the Ocean University of China in Qingdao, a joint venture with the Universities of Kiel and Bremen. Twenty-one students attended the second summer school 2006 in Germany, this time in Kiel. Currently, the curricula in Oceanography / Meteorology as well as in Biological Oceanography are being revised in order to fulfil the requirements of the new Bachelor / Master curricula, which will be implemented at the end of 2007.

### University Degrees



University degrees 2002-2006

### Events and Public Outreach:

Apart from smaller workshops and project meetings, two larger events were organized by IFM-GEOMAR in 2006: The 36th annual meeting of the "Underwater Mining Institute" of the International Marine Minerals Society. This conference drew about 70 experts in the field of marine mining and resources to Kiel. The second notable meeting was the international symposium "Future Ocean", which was held from October 2-4, 2006. This conference featured topics of the Excellence Cluster and served as a pre-kick-off for the excellence cluster, which received confirmation of funding shortly thereafter.

Furthermore, IFM-GEOMAR contributed to a number of exhibitions and events such as the "Kieler Woche" exhibition "Future Ocean", and various activities at the National Holiday on Oct. 3<sup>rd</sup>, 2006, such as open ship, and a more artistic exhibition "Future Ocean" in "Halle 400". Because of the great success, this exhibit was extended.



Right: One of the renovated tanks in the aquarium.

Exhibition "Future Ocean" in "Halle 400".

In the field of public relations and outreach, IFM-GEOMAR welcomed a number of high-level visitors such as the state minister, Hildegard Müller, the "Science-Attachés" of many embassies in Berlin, Germany, the staff of the International Tribunal for the Law of the Seas and visiting groups of scientists from Japan, China and other countries.



Prof. Colin Devey "testing" self-made volcanos of school children

IFM-GEOMAR scientists contributed to a summer school programme for school children, initiated by the Leibniz Institute for Science Education (IPN) in Kiel. During

a three-week period in summer and another week during the autumn vacation, a class of primary school children were given an insight into various topics in the natural sciences. Four out of 15 themes were hosted by IFM-GEOMAR.

As part of the public outreach effort of the institute, IFM-GEOMAR scientists gave more than 80 public lectures on a broad variety of topics (see Appendix 6).



The aquarium of IFM-GEOMAR reopened to the public after a partial renovation in June 2006. About a third of the basins were replaced. The larger windows reaching almost to the ground allow a much better

view of the marine life, in particular for small children. The second phase of the renovation efforts is planned for 2007.



IFM-GEOMAR produced an image film documenting the breadth of research of the institute in cooperation with a professional film team. The film highlights all major research topics and the re-

search infrastructure of IFM-GEOMAR. The overall length is 23 minutes. The film is available on DVD in German and English.

In cooperation with the research network "Future Ocean", attempts were made to increase the visibility of Kiel as a centre of marine sciences in the nationwide media.

## Introduction

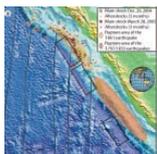
A selection of short scientific reports in this section provides an overview on research activities and results throughout 2006. This encompasses summaries from major expeditions, interdisciplinary activities, technology development and scientific results. These are just a few highlights from the broad scope of marine research at IFM-GEOMAR.

The selected contributions in this section are:

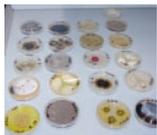
- **“Investigations of seafloor hydrothermal systems”:** Within the frame of the DFG Priority Programme 1144 “From Mantle to Ocean: Energy, Material and Life cycles at Spreading axes” mid ocean ridge systems in the Atlantic were studied.



- **“The Sumatra subduction zone in the wake of the 2004/2005 megathrust events”:** The occurrence of two megathrust earthquakes in 2004/2005 shifted the international research focus to the Sumatra margin.



- **New natural products from marine microorganisms:** In the newly established “Zentrum für Marine Wirkstoffe” (KiWiZ) the potential marine substances are investigated.



- **Invasion ecology:** New species are observed in the Baltic due to warmer ocean conditions caused by global climate change. Examples for such invasions are discussed.

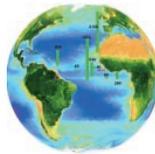


- **Understanding hurricane development:** What are the most important boundary conditions for the development of hurricanes? 2005 was a record year in the Atlantic, 2006 only few storms were observed.

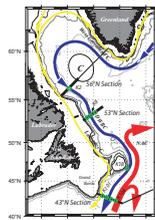


More information is provided on the web pages of IFM-GEOMAR in particular under: <http://www.ifm-geomar.de/index.php?research>.

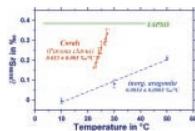
- **Bromine from the ocean and stratospheric ozone:** Marine trace metals affect processes in the middle atmosphere such as ozone depletion.



- **Heating up the Labrador Sea:** Long-term observations of a key region in the North Atlantic shows a continuous warming of the deeper water masses in this key region of the world ocean.



- **Paradigm change: temperature dependent strontium isotope variations:**



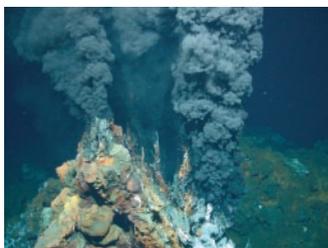
New investigations at IFM-GEOMAR Strontium isotopes can be used as a temperature proxy.

### Highlighted Publications

Moran, K., Backman, J., Brinkhuis, H., Clemens, S.C., Cronin, T., Dickens, G.R., Eynaud, F., Gattacceca, J., Jakobsson, M., Jordan, R.W., Kaminski, M., King, J., Koc, N., Krylov, A., Martinez, N., Matthiessen, J., McInroy, D., Moore, T.C., Onodera, J., O'Regan, A.M., Pälike, H., Rea, B., Rio, D., Sakamoto, T., Smith, D.C., Stein, R., St. John, K., Suto, I., Suzuki, N., Takahashi, K., Watanabe, M., Yamamoto, M., Farrell, J., **Frank, M.**, Kubik, P., Jokat, W., and Kristoffersen, Y., 2006: The Cenozoic palaeoenvironment of the Arctic Ocean. *Nature*, **441**, 601-605.

Wilson, D.S., Teagle, D.A.H., Alt, J.C., Banerjee, N.R., Umino, S., Miyashita, S., Acton, G.D., Anma, R., Barr, S.R., Belghoul, A., Carlut, J., Christie, D., Coggon, R.M., Cooper, K.M., Cordier, C., Crispini, L., Durand, S.R., Einaudi, F., Galli, L., Gao, Y., **Geldmacher, J.**, Gilbert, L.A., Hayman, N.W., Herrero-Bervera, E., Hirano, N., Holter, S., Ingle, S., Jiang, S., Kalberkamp, U., Kerneklian, M., Koepke, J., Laverne, C., Vasquez, H.L.L., Maclennan, J., Morgan, S., Neo, N., **Nichols, H.J.**, Park, S.-H., Reichow, M.K., Sakuyama, T., Sano, T., Sandwell, R., Scheibner, B., Smith-Duque, C. E., Swift, S.A., Tartarotti, P., Tikku, A.A., Tominaga, M., Veloso, E.A., Yamasaki, T., Yamazaki, S., and Ziegler, C., 2006: Drilling to gabbro in intact ocean crust. *Science*, **312** (5776), 1016-1020.

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



A black smoker in the Turtle Pits hydrothermal field. (© MARUM).

## Investigations of seafloor hydrothermal systems

A major research focus within Research Division 4 is the investigation of seafloor hydrothermal systems in various tectonic settings such as arcs, seamounts and mid ocean ridges. Within the frame of the 6-years Priority Programme 1144 of the German Research Foundation (DFG) "From Mantle to Ocean: Energy, Material and Life cycles at Spreading axes" we focused our studies on mid ocean ridge systems in the Atlantic. Other recent and future areas of interest include the Aeolian Arc in the Tyrrhenian Sea (Mediterranean) and the Woodlark rift system northeast of Australia.

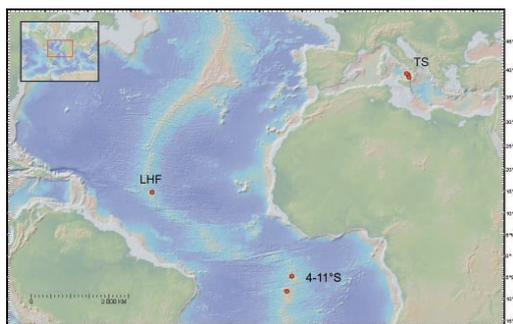


Fig. 1: Location of selected hydrothermal fields currently studied by RD4 (LHF = Logatchev field; TS = Tyrrhenian Sea)

The principal scientific purpose of participants from the research unit Magmatic and Hydrothermal Systems (MuHS) is to elucidate the interrelationship of geological and hydrothermal processes in high- and low-temperature hydrothermal system associated with felsic, mafic and ultramafic host rocks. In the following we will summarize our most recent research:

**Logatchev Hydrothermal Field at 15°N**  
Logatchev is situated on a small plateau within the rift valley of the slow-spreading Mid-Atlantic Ridge (MAR) at 14°45'N. This part of the MAR is dominated by ultramafics (mantle rocks) with subordinate basaltic material – largely in the rift valley. While mantle rocks cover a substantial part of the ocean floor along ultra-slow and slow-spreading ridges their influence on ocean chemistry and hydrothermal activity is not well constrained. The Logatchev field is one of only a few ultramafic-hosted hydrothermal systems found so far.

Extensive bathymetric and video mapping during the HYDROMAR I, II, and IV cruises revealed three factors which

appear to control the location of the Logatchev hydrothermal fields: (1) cross-cutting faults, (2) young basaltic magmatism, and (3) slump structures. Our investigations indicate that hydrothermal circulation takes place through ultramafic and mafic talus material and is most likely related to large slumps. The heat driving hydrothermal convection is probably supplied from magmatic pools associated with intrusions underneath the adjacent rift valley and/or off-axis volcanic structures.

Differences in the morphology of the vent structures and their geochemical and mineralogical composition are related to the different outflow temperatures as a consequence of sub-seafloor mixing and cooling processes and subsequent mineral precipitation. Geochemical and mineralogical investigations of hydrothermal precipitates indicate a three-stage process of mineral formation: 1. precipitation from high-T (ca. 350°C) fluids forms primary Cu-sulfides; 2. cooling of these fluids or reaction of primary Cu-sulfides with medium-T fluids ( $\leq 250^\circ\text{C}$ ) results in Au-rich, and Cu-rich secondary sulfides; 3. reaction of sulfides with cold seawater forms supergene Cu-sulfides. Stages 1 and 2 indicate that the chemical composition of emanating fluids and related precipitates depends on fluid-sulfide reactions in the shallow subseafloor. Osmium isotopes and trace element analyses of sulfides and altered rocks indicate that both mafic and ultramafic host rocks contribute to the geochemical inventory of this hydrothermal field which in turn has major implications for the fluid chemistry and vent fauna. Trace element geochemistry also shows indications for melt rock interaction in this area. Recent drilling has shown that the amount of mafic material at Logatchev is higher than previously thought, and that minor sulfides occur down to 10 m depth, however, it is not yet clear if these are in-situ or transported sulfides. Clay-rich alteration is extremely widespread and their investigation will help to understand the processes taking place in the sub-seafloor.

### New Hydrothermal Fields between 4° and 11°S on the MAR.

Active hydrothermalism along the southern MAR was, until the start of SPP1144, unknown. As was the hydrothermal input of the southern MAR to the global heat and mass transfer to the ocean. The priority programme has distinctly changed this situation. Since its inception, three hydrothermal areas have been identified and sampled. At 4°48'S, in 3000 m water depth, four closely-spaced vent fields (the high-temperature sites "Turtle Pits", "Red Lion" and "Comfortless Cove" and the diffuse low-temperature "Wide-awake" site) occur along a flat (total relief 50 m), volcanically and tectonically active 2 km section of the ridge. Two of these systems, "Turtle Pits" and "Comfortless Cove", seem to be related to recent magmatic activity. The location of individual vent sites seems to be tectonically controlled as indicated in high-resolution bathymetry. Detailed investigations of the "Turtle Pits" sulfides indicate that a dramatic change in the redox-chemistry of the fluids, from oxidizing to reducing conditions, must have occurred in the past (Fig. 2). If these changes, that are distinct from those at other vent sites, are related to the magmatic activity needs to be confirmed.

During our first cruise at the southern Mid-Atlantic Ridge in 2004 we found strong evidence for hydrothermal activity in 2900 m water depth at 8°18'S although black smokers were not directly observed. In 2006, we discovered the active vent site (Nibelungen field) using Eh<sup>-</sup> and photo-mapping capabilities of the autonomous underwater vehicle "ABE" from Woods Hole Oceanographic Institution. ROV dives revealed active and inactive vent sites along a steep slope at 2905 m water depth. The active vent site resembles the ones found in the ultramafic-hosted Logatchev hydrothermal field at 15°N. Mineralogical studies of breccia samples from the crater wall of "Drachenschlund" revealed serpentinites as one of the main components, although the immediate surrounding is largely composed of pillow basalt.

Further to the south, at 9°33'S, hydrothermal activity is located at 1500 m water depth and is associated with fresh pillow lavas, sheet flows, lava

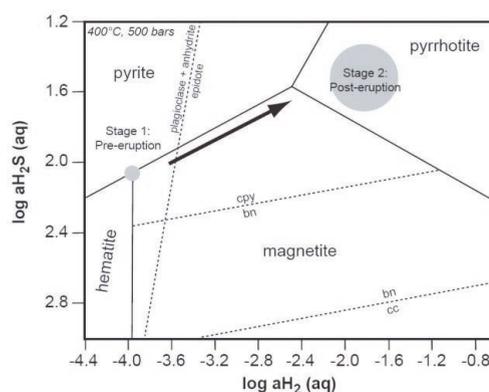


Fig. 2: a) (top) Primary sulfide intergrowth with hematite-magnetite and pyrite from Turtle Pits. b) (bottom) Activity diagram showing possible evolution of the hydrothermal systems with time.

lakes, and collapse structures. This is very unusual, since these volcanic features are commonly found on fast spreading ridges, not slow spreading ridges. This seems to indicate enhanced magma supply to the spreading segment. Low-temperature, diffuse hydrothermal activity is abundant in the area as are large extinct hydrothermal mounds suggesting more vigorous hydrothermalism in the past. All sites are located east of a large NNW trending escarpment flanking horst and graben structures (Fig. 3). Both high- and low-temperature venting on the southern Mid-Atlantic ridge appear to be strongly controlled temporally and spatially by tectonics and recent volcanism.

### Tyrrhenian Sea

Another research topic is the formation of hydrothermal systems in island arc settings. Land-based geology indicates that a large number of economic massive sulfide deposits, the equivalent of modern black smoker systems, formed in a shallow water (< 1000 m) calc-alkalic arc environment. These deposits are extremely valuable because boiling of the hydrothermal fluids enriches the precious metals Au and Ag in these deposits. In many respects, deposition of metals in the shallow water environment can be compared to the formation of epithermal deposits in subaerial

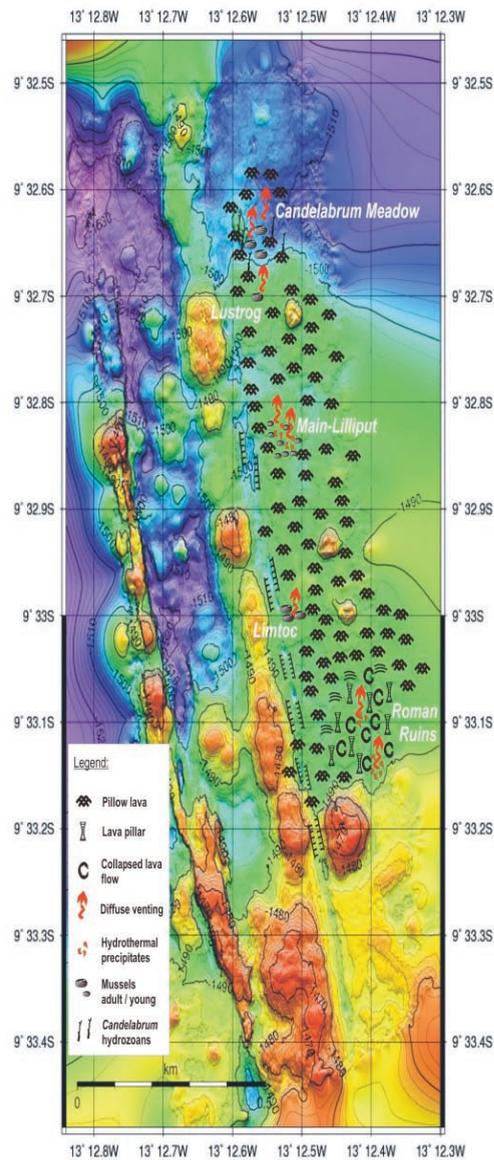


Fig. 3: High-resolution (AUV-mounted) bathymetry of the Liliput site showing tectonic control of individual vent sites.

volcanic arcs on land suggesting that there is a continuum between submarine massive sulfide and subaerial epithermal deposits. This working hypothesis is in contrast to common knowledge indicating a distinction of these deposit types. The southeastern Tyrrhenian Sea represents a prime locality to study the formation of shallow seafloor deposits in such a calc-alkalic arc setting.

Currently three different sites have been recognized in the area, however, geological information (e.g. distribution of vent sites, tectonic, and alteration of the host rocks) is lacking. Detailed investigations on these four sites will provide an ideal basis for the development and testing of new genetic models explaining the formation of shallow water, precious metal-rich marine massive sulfide deposits. In an initial stage a ROV-based expedition was mounted in 2006 to map the geology and the distribution of individual vent fields and to find suitable targets for a drilling cruise in August 2007, which will address the formation of these deposits. Recent hydrothermal activity was observed at Palinuro Seamount, a site previously thought to be inactive (Fig. 4). Some of the hydrothermal activity at the Panarea vulcano is clearly related to explosion craters in shallow water indicating a close hydrothermal/magmatic link (Fig 4).

**Klas Lackschewitz and Sven Petersen**



Fig. 4: Top: Active fluid flow indicated by Vestimentiferan tubeworms at Palinuro Seamount. Bottom: Active gas discharge associated with sulfide deposition and bacterial mats at Panarea.

## The Sumatra subduction zone in the wake of the 2004/2005 megathrust events

The occurrence of the 26 December 2004 Mw 9.3 and the 28 March 2005 Mw 8.7 megathrust earthquakes shifted the international research focus to the Sumatra margin. In the wake of the devastating tsunami generated by the 2004 Sumatra-Andaman earthquake, a suite of geo-scientific data was acquired to help unravel the linkage between earthquake dynamics and margin segmentation. Geophysical investigations of the Sumatra margin were performed from October 2005 to March 2006 using RV SONNE. These investigations revealed that upper plate segmentation of the Sumatra trench system is manifested in varying modes of mass transfer. The margin segments to the northwest of the Investigator Fracture Zone (IFZ), which were affected by the 2004 and 2005 megathrust earthquakes, are subject to extensive surface erosion of the margin wedge. Oversteepening of the lower slope in response to elevated pore pressures and the subduction of pronounced seafloor topography leads to mass wasting processes here. Conversely, neotectonic formation of nascent accretionary thrust folds is limited to the sections of the deformation front southeast of the IFZ and documents the resumption of frontal sediment accretion in the wake of oceanic relief subduction. The distinction in modes of mass transfer from frontal accretion in the south (Fig. 2a) to surface erosion in the north (Fig. 2b) correlates to the increase in frontal slope angle (Fig 2 e-f).

The large-scale morphotectonic segmentation of the Sumatra trench system results from subduction of reactivated fracture zones and aseismic ridges of the Wharton Basin and is also reflected in its seismotectonic segmentation as most recently evidenced by the distinct rupture zones of the 2004-2005 earthquake couplet. Subduction of topographic relief on the lower plate and discontinuities in the geometry of the subduction zone modulate upper plate structure. In addition, geometry variations are closely linked to physical property changes. Heterogeneity in the physical properties of the forearc is associated with a strong lateral variability in age as well as crustal composition and architecture. The topography of the fracture zones represents tectonic segment boundaries and zones of anomalous crust with regards to density, crustal composition and thickness.

The extent of the 1797/1833, 1861/2004 and 2005 rupture zones shows an intriguing correlation to the segment boundaries (Fig. 1). The remarkable correspondence of the slip areas to the fracture zones suggests that earthquake rupture propagation may be inhibited across segment boundaries due to the variation in thrust geometry, material strength, fluid content and pre-stresses. Different sectors along the Sumatra trench show a strong variability in pore pressure, plate coupling and state of stress.

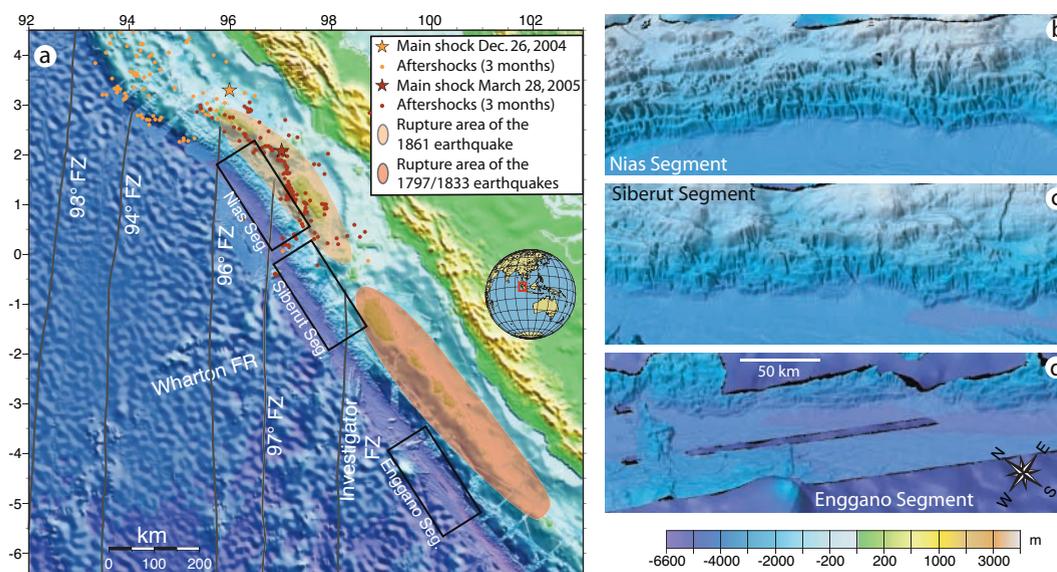
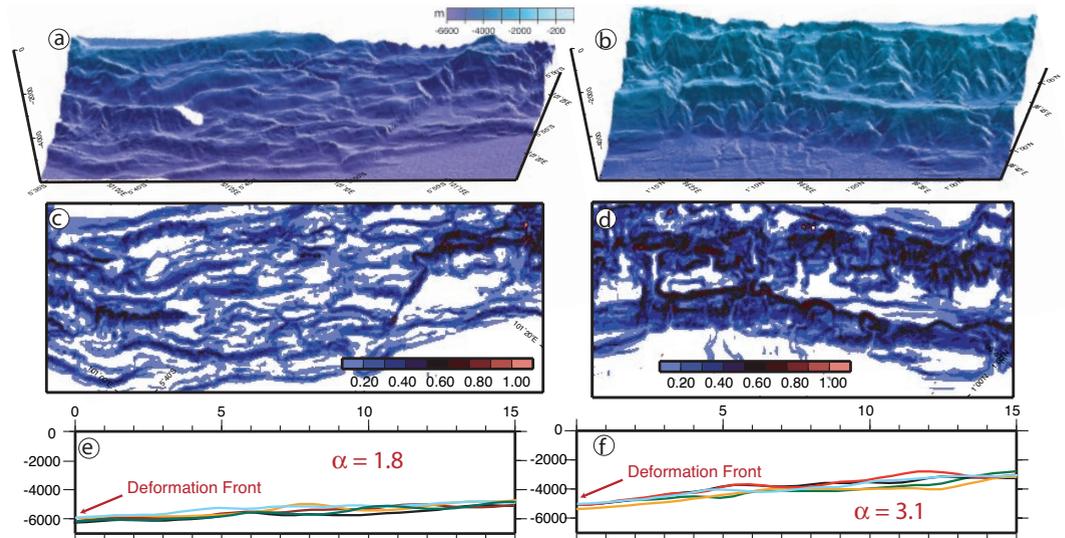


Fig. 1: a) Investigation area off the coast of Sumatra, main earth quakes are indicated by stars, aftershocks by dots, respectively. Rupture zones of historic earthquakes are shaded in brown/orange, black boxes indicate boundaries of detailed sea floor segments shown in Fig. 1 b-d.

Fig. 2: a) southern, b) northern areas of investigation, their vertical structure (c) and (d) and frontal slope (e) and (f) as described in the text.



The aftershock distribution of the 2004 event shows a very sharp southern boundary at the prolongation of the 96°E FZ, implying that rupture did not jump across the anomaly to the stress-reduced adjacent segment. In the wake of the 2004 earthquake, however, the state of stress along the margin was appreciably altered: strain was released along the Andaman trench while the adjacent southern segment was brought closer to failure, which occurred on March 28, 2005. The 2005 event nucleated directly on the projection of the 97°E FZ, which divides the earthquake sequence into two distinct slip patches beneath Nias and Simeulue, respectively. The failure regions of the 2005 and 1861 ruptures largely coincide and are limited to the north by the 96°E FZ and to the south by the projection of the IFZ underneath the forearc, which also marks the northern limit of the 1797/1833 rupture zones.

The distinct rupture zones of the 1797/1833, 1861/2004 and 2005 events suggest that tectonic overprint of the margin by subduction of oceanic relief and lithosphere anomalies leads to the formation of first-order segment boundaries on the upper plate that exert a decisive impact on earthquake rupture dynamics. Though the scientific community is beginning to understand the role of segmentation on the extent and distribution of rupture during megathrust events, we still lack the full understanding of the weight and influence of the physical properties of a margin (i.e. pore pressure, material strength, stress distribution) on its seismic potential compared to its structural tectonic heterogeneity. Fur-

ther analysis of multidisciplinary studies will increasingly close the gap in our ability to assess the impact of different physical-geological parameters on seismotectonic segmentation.

**Heidrun Kopp**

## New natural products from marine microorganisms

Investigations on marine natural products have gained much interest during the past years, mainly because of two reasons: i) It is increasingly obvious that interaction between marine microorganisms and also between microorganisms and macroorganisms are governed by chemical interactions and that cell-cell communication systems play an important role in establishing ecological niches. Often signalling molecules induce the synthesis of substances with antibiotic or other biological activities. ii) A number of secondary metabolites and inhibitors of signalling molecules of marine microorganisms have great potential in pharmaceutical and medicinal applications and are attractive candidates for development of new drugs.

Biological active substances have been known from many marine invertebrates and algae, but only in recent years the role of associated microorganisms came into the focus. Because of their production of biological active substances, in particular marine sponges and their associated microorganisms gained much interest. Sponges, like other sessile marine organisms depend on chemical defence mechanisms against predators, but also against attacks of pathogenic microorganisms. A large fraction of microorganisms living in association with marine sponges have been shown to produce biological active substances. They may contribute to their host's integrity and defence by the excretion of antibiotic and other biologically active substances. One of the substances, which we have identified chemically and also on the basis of genetic sequence information of its biosynthetic pathway, is known as a potent inhibitor also of multiresistant bacteria. Interestingly, the substance is produced by a bacterium isolated from a sponge and the biosynthesis of this substance is stimulated by signalling molecules released by other microorganisms. Therefore, this substance may well play a role in species-species interactions in the natural habitat.

In the Marine Microbiology group, the specific association of microorgan-

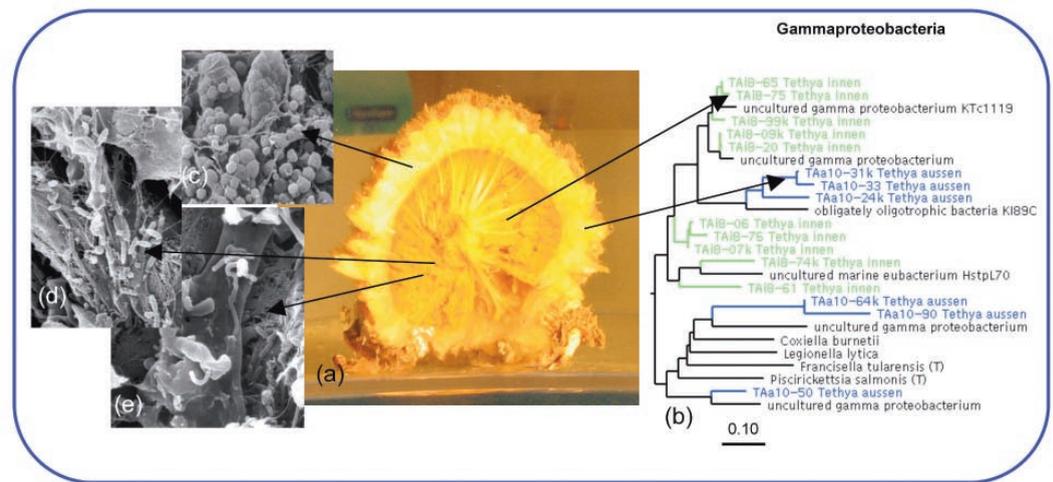
isms with sponges was investigated in selected sponge species which were studied by microscopic and genetic analysis. The microscopic studies revealed large differences in the association of bacteria with different sponges. *Suberites domuncula* e.g. showed only a small number of bacteria on its interior surfaces, while the sponges *Halichondria panicea* and *Ircinia fasciculata* revealed abundant and highly diverse bacterial assemblages. Sponge-species specific association of bacteria was demonstrated by comparison of the bacterial community associated to the Mediterranean sponges *Chondrilla nucula* and *Tethya aurantium*. The latter species even had two clearly distinct bacterial communities associated with exterior and interior cells, which could be differentiated by microscopic studies and genetic analyses (Fig. 1). These findings support the assumption that certain bacteria found in sponges are specifically associated with these animals and may have adapted during evolutionary processes to the sponge environment.

Because marine sponges are considered as one of the most important sources of substances with antibiotic, antitumoral or antiviral activities and a major portion of these substances may be produced by associated microorganisms, the associated microorganisms are a potentially important source of new products for pharmaceutical and medicinal applications. During the past years, we have isolated a large number of bacteria and fungi with antibiotic activities against other microorganisms. Several hundred biologically active marine bacteria and fungi are currently treated in detailed biological and chemical analyses. Some are active against tumor cell propagation and have antiviral activities. New biologically active chemical compounds have been identified. Several compounds were patented and one of these, sorbicillacton A, is in an advanced preclinical stage of the development for anti-leukemic treatment. Sorbicillacton A is produced by a fungus isolated from a marine sponge and is promoted within the national research project "Center of Excellence BIOTEC<sub>marin</sub>". Experiments



Some test probes of marine sponges in the Centre for Marine Substances.

Fig. 1: Specific differences in the association of bacteria with cortex and interior of the marine sponge *Tethya aurantium* (Sea-orange) (a) Cross section of the sponge (b) phylogenetic positions of Gammaproteobacteria sequences found in different cell structures and (c)(d)(e) corresponding electron microscopic (REM) exposure



towards optimization of biosynthetic production of this compound were performed. The chemical structure was elucidated by chemical partners at the University of Würzburg. The biosynthetic pathway was established in joint experiments of the Marine Microbiology at IFM-GEOMAR and the chemical partners, and important biological activities against viruses and cancer cells were established by partners at the University of Mainz.

In 2006 major progress was made in further strengthening the research on bioactive natural products from marine microorganisms and to establish it as a central topic in the Marine Microbiology group at IFM-GEOMAR. Research was extended to bacteria from other marine sources including algae, bryozoa and also extreme habitats from the deep sea and hypersaline brines. The "Zentrum für Marine Wirkstoffe", funded by the Schleswig-Holstein Ministry of Science, Economy and Traffic, has taken major investments into laboratory facilities and instrumentation to establish research facilities and a network of local collaborating partners in science and industry. Both, marine bacteria and marine fungi are principal sources of biotechnological research and development in this "Zentrum". Application of marine natural products is envisaged in infective diseases (bacteria, fungi and viruses), anti-inflammatory processes and tumor treatments. Partners are institutions and groups at the medical clinics and the natural science faculty of the CAU, other research institutions and commercial companies. Together with local, national and international partnerships the "Zentrum für Marine Wirk-

stoffe" will promote the development of new pharmaceuticals from marine organisms and establishes a center of marine biotechnological research in Kiel. In the centre all instrumentation and know how is available to identify and produce natural products from marine natural resources: We isolate, grow, identify and maintain bacterial and fungal cultures. Large culture collections are available and will be maintained. New isolates will be included into these collections. Cultivation and fermentation of the microorganisms, including process development, extraction of secondary metabolites, chemical analysis of the extracts, identification of the chemical structures as well as studies on biosynthesis and genetic studies belong to the basic research work. Most important a large panel of biological assays is used to establish a broad spectrum of biological activities and to identify substances useful for medical treatments, for plant diseases and other applications. Because the increase of antibiotic-resistant bacteria causes severe problems in medical treatment, special emphasis is given the search for substances active against multiresistant pathogenic bacteria.

**Johannes F. Imhoff**

## Invasion ecology

The composition of any given biological community is a sub-sample of the regional species pool, which in its turn is the result of evolutionary and geological processes. Recently, a new player has entered the stage: global change and, in its wake, invasions have become stronger.

One facet of global change, climate change, provokes a shift in environmental parameters. As a consequence, species locally may exhibit reduced fitness. Under the new climatic scenario, these may be less competitive or less well defended. In other areas of the species' range, shifting environmental variables may also improve conditions. In general, we may expect a regional shift in the distribution-range with receding and advancing edges and, consequently, locally unbalanced and, thus, less competitive communities.

In addition, steadily growing global trade leads to an ever more intense and faster exchange of species between biogeographic regions. Notorious vectors for marine species introduction are ballast water and fouled ship hulls, but also overgrown drifting litter becomes increasingly important.

Global (●) and regional (●) modular invasion experiments



Fig. 2: Location of global (green dots) and regional (purple) modular invasion experiments.

Thus, structural changes in local communities are driven by changing dominance of local components, range shifts at the regional scale and large scale invasions. The latter is favoured by intensifying invasion rates and by growing stress on local communities.

Coastal regions are differently impacted depending on ship traffic, similarity between donor and receptor region, and the condition of the receptor communities. More than 300 invasive benthic species have been described from the North American coasts, over 80 from the North Sea, and more than 100 from the Baltic Sea (Schories and Selig 2006). An extrapolation of the invasion rates during the last decades illustrates the dimensions of the prob-

### Successful Invasions in the World Oceans and in the Baltic Sea

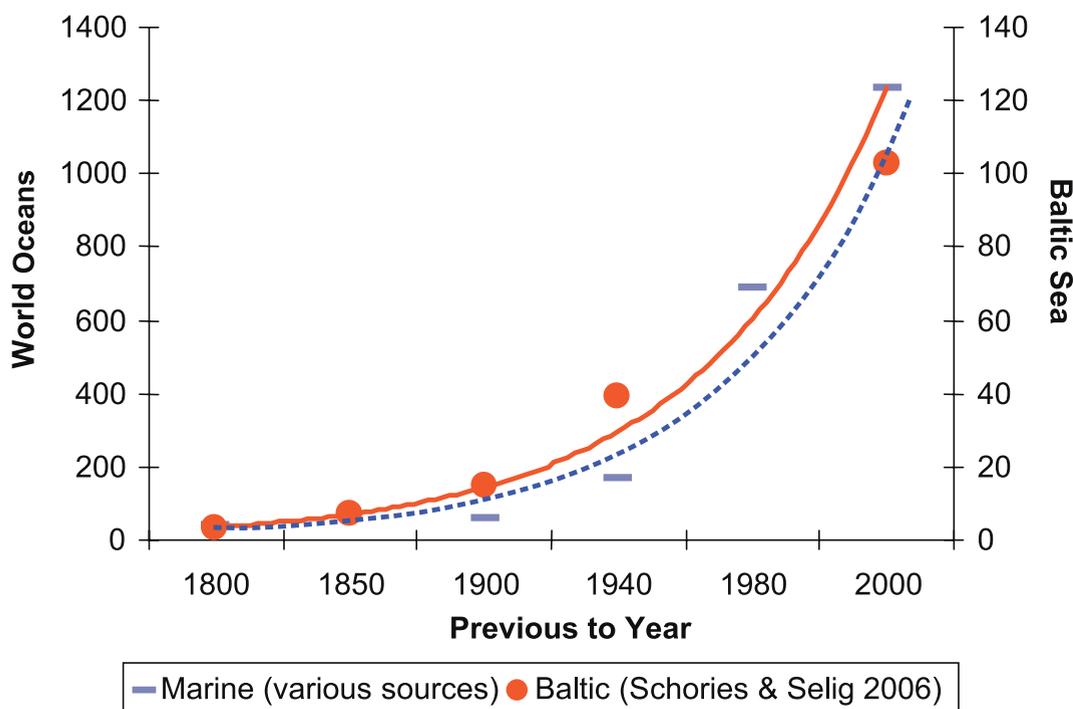


Fig. 1, left column: Successful invasions in the world oceans and in the Baltic Sea throughout the 19<sup>th</sup> and 20<sup>th</sup> century.

*Mnemiopsis leidyi*, a new invasive species in the Baltic.  
Foto by J. Javidpour, IFM-GEOMAR



lem we might be facing.

We are investigating the phenomenon of invasions at different temporal (before, during & after invasion) and spatial scales (local, regional ad global).

1. Early warning system: In collaboration with state and laender authorities we are in the process of establishing a chain of survey stations (50 km grid) along all German and Danish costs. Yearly recruitment studies will reveal both the shift of distributional ranges and the arrival of invasive species. At a later stage, this survey chain may be extended along all European coasts.

2. Simulation of community invasions under different climate scenarios: The fate of intentionally imported communities from different biogeographic regions within local receptor communities is investigated in mesocosm systems (outflow sterilized).

3. Invasibility of communities: In a global approach (5 continents), we try to identify the properties (openness, diversity, age) that determine the stability of the community in an invasion scenario.

4. Impact of invasions: When invasive species (e.g. the red alga *Gracilaria vermiculophylla* or the ctenophore *Mnemiopsis*) arrive, we study their population dynamics and establishment, as well as their ecological impact on our local communities.

These investigation will enable us to quantify the risk, the process and the consequences of invasions.

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**Martin Wahl**

## Understanding hurricane development

The hurricane season of 2005 in the Atlantic sector was the most intense on record, with 28 recorded tropical storms and 15 of them reaching hurricane intensity. It remains controversial, however, as to whether tropical storm activity over the Atlantic has changed in a statistically significant manner. One of the most commonly used indices to measure tropical storm activity is the so called Accumulated Cyclone Energy (ACE) Index which is shown for the Atlantic sector in Fig. 1a. The ACE Index takes into account the number, strength and duration of all tropical storms in a season. The ACE Index shows pronounced multidecadal variability, with enhanced tropical storm activity during the 1890s, 1950s and at present, and mostly reduced activity in between, but no sustained long-term trend. Yet, the last decade appears to be somewhat exceptional in the light of the last 155 years.

The role of tropical North Atlantic sea surface temperature (SST) in driving tropical storm activity was discussed extensively in the literature. Rather strong multidecadal variability in the SST of the Atlantic basin is observed, which is referred to as the Atlantic Multidecadal Oscillation (AMO). The AMO, which has opposite polarities in the North and South Atlantic, is most likely related to variations of the Atlantic meridional overturning circulation (MOC). It modulates the SST of the tropical North Atlantic which therefore also exhibits pronounced multidecadal variability (Fig. 1b). Interestingly, a clear warming trend is seen in the tropical North Atlantic SST which does not seem to influence the tropical storm activity. A clear warming trend is also observed in the surface temperature of the other two tropical oceans, the tropical Indian and Pacific Oceans, which is described in terms of a combined SST index (Indo-Pacific) that averages SSTs over the region 40°E-80°W, 30°N-30°S and also shown in Fig. 1b.

In order to get further insight into the relative roles of the individual ocean basins on the vertical wind shear over the tropical North Atlantic, we analysed the results of an atmospheric general

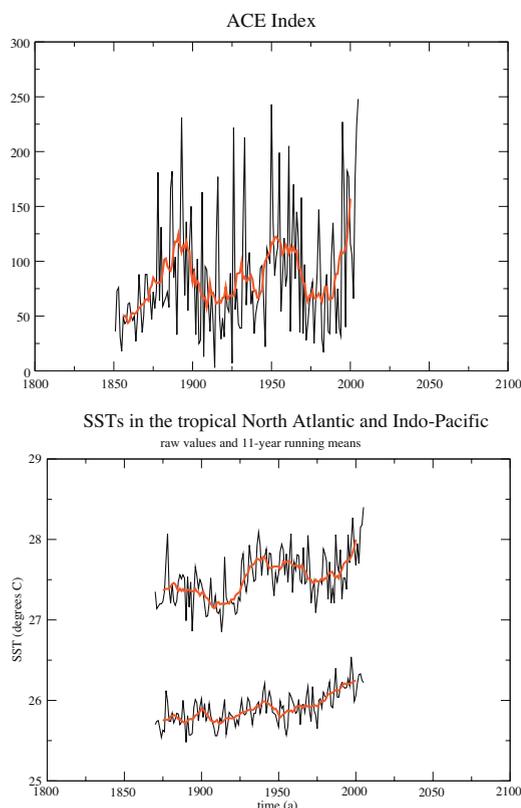


Figure 1: a) Accumulated Cyclone Energy (ACE) Index for the Atlantic basin 1851-2005. The red curve shows the low-pass filtered time series (applying an 11-year running mean).

b) Upper curve: SSTs in the tropical North Atlantic averaged over the region 10-14°N and 20-70°W. Lower curve: SSTs in the Indo-Pacific region (40°E-80°W, 30°N-30°S). The SSTs are computed for the hurricane season (JJASON). The black lines denote the raw values, while the red lines depict the low-pass filtered (applying an 11-year running mean) time series which highlight the multidecadal variations. Units: °C.

circulation model (AGCM) forced by the history of observed global monthly (Hadley Centre) SSTs for the period 1870-2003. The simulated vertical wind shear over the Tropical Atlantic (not shown) is in rather good agreement among the five realisations, indicating a strong role of the boundary forcing. The ensemble mean, a measure of the SST-forced signal, compares well with observations. Furthermore, the variations of the vertical wind shear correspond nicely to those of the ACE Index: Reduced wind shear goes along with enhanced tropical storm activity and vice versa. This indicates the important roles of the vertical wind shear in controlling tropical storm activity in the Atlantic sector during the last 130 years and of the global SSTs in driving the wind shear.

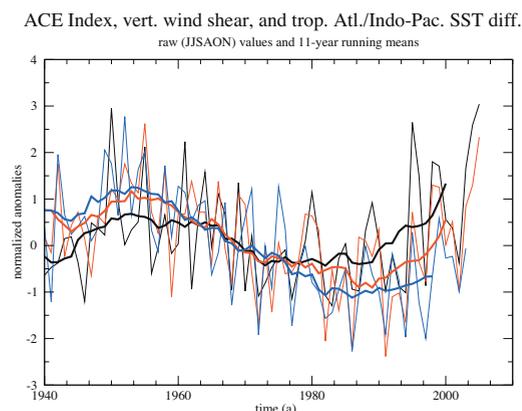
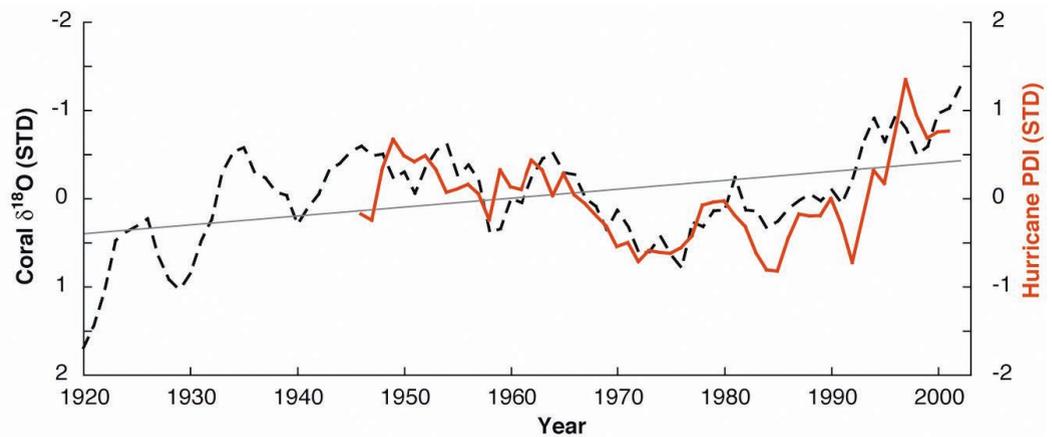


Figure 2: ACE Index (black), inverted simulated vertical wind shear (blue), and tropical North Atlantic/Indo-Pacific SST difference (red). The data were normalized with respect to their individual long-term standard deviations to ease comparison. The thin lines are the raw JASON values. The thick lines denote the low-pass filtered (applying an 11-year running mean) values.

Figure 3: Reconstruction of hurricane activity as measured by the Power Dissipation Index (PDI) using a Caribbean coral (black) and the observed PDI (red). Both time series were normalized to ease comparison.



The question arises, however, why the obvious upward trend in tropical North Atlantic SST (Fig. 1b) is neither reflected in the simulated vertical wind shear nor in the record of observed tropical storm activity (Fig. 1a). It was shown that the Tropical Indian Ocean exhibited a strong warming trend during the last decades which forced global atmospheric anomalies. In particular, it drove enhanced vertical wind shear over the tropical North Atlantic, so that the warming of the Indian Ocean acted to compensate, at least partly, the tendency of the tropical North Atlantic warming to reduce the wind shear. Furthermore, it is known that anomalously high Tropical Pacific SST (El Niño conditions) also drives enhanced vertical wind shear over the tropical Atlantic. The inverted SST difference, tropical North Atlantic minus Indo-Pacific, is plotted in Figure 2 together with the inverted ensemble mean wind shear from the model simulation and the ACE Index. The time series are shown only from 1940 onwards, which is the period of most reliable observations. All three indices show a remarkable correspondence at decadal and longer time-scales. Apparently, the warming trends of the three tropical oceans cancel with respect to their effects on the vertical wind shear over the tropical North Atlantic, so that the tropical cyclone activity remained rather stable and mostly within the range of the natural multidecadal variability. The most recent period is characterized by an increased tropical North Atlantic / Indo-Pacific SST difference indicating that the tropical North Atlantic warmed more rapidly than the Indo-Pacific. This led to reduced vertical wind shear and thus to enhanced tropical storm activity. In contrast, summer and fall of 2006 were characterized by El Niño conditions in the Indo-Pacific, leading

to a rather small temperature difference between the tropical North Atlantic and the tropical Indian and Pacific Oceans, and this explains the weak tropical storm activity.

Overall, however, there seems to be an increase in hurricane destructiveness over the last century, as measured by the so called PDI (Power Dissipation Index). This is seen somewhat in the observations (Fig. 3), but the observational record is rather short. Reconstruction of PDI using a Caribbean coral offers a possibility to extend the record. An example of this work is also shown in Fig. 3 in terms of the  $\delta^{18}\text{O}$ . The coral signal which depends on both temperature and salinity tracks nicely the observational record during the last 50 years. We could extend the PDI record back to 1920 with the coral, and the reconstruction from this coral shows a much clearer upward trend, which is consistent with the evolution of the ACE Index. The latter, however, extends further back in time than the coral-based PDI, and the time period 1875-1900 is characterized by anomalously strong hurricane activity, so that the obvious trend in the coral time series may be due to a sampling problem. We shall use therefore corals that allow reconstructions even further back in time to uniquely answer the question as to whether the statistics of hurricane activity have changed in a statistically significant way.

## References

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## Bromine from the ocean and stratospheric ozone

The oceans supply large amounts of halogens (chlorine, bromine and iodine) to the atmosphere not only in the form of salt but also via naturally-produced organic compounds. When these compounds degrade in the atmosphere, the released halogen atoms drive stratospheric and tropospheric O<sub>3</sub> depletion. Recently, more and more attention has focused on the role of bromine (Br) which is up to 50 times more effective as an ozone-destroyer than chlorine (Cl). Synergistic reactions with Cl released by mankind have caused an increase in the ozone-destroying power of natural Br in the present-day, polluted atmosphere (Figure 1).

Many of the naturally-produced halogenated gases have short lifetimes in the atmosphere. Because of this, and because exchange of trace gases between the troposphere and stratosphere occurs predominantly in the tropics, localised sources in subtropical and tropical oceans are of potentially major importance for ozone chemistry that occurs in the lower stratosphere and upper troposphere.

Bromoform (CHBr<sub>3</sub>) is the dominant carrier compound for Br transfer from the ocean to the atmosphere. In coastal regions seaweeds are an important source of this compound.

Open ocean sources are poorly understood, but the distribution of CHBr<sub>3</sub> has been linked previously to phytoplankton abundance, especially production by diatoms. The overall magnitude of oceanic emissions is uncertain and its spatial and temporal variability unknown. In order to reduce uncertainty in the source strength, distribution and variability of Br emissions to the atmosphere we have been making simultaneous measurements of CHBr<sub>3</sub> and other Br-containing gases in air and seawater: These allow us to estimate fluxes and gain insight into control mechanisms.

We have found that the sea-to-air flux of CHBr<sub>3</sub> is strongly localized. Previously, we identified a connection between biological production in the subsurface ocean, equatorial upwelling, and the supply of Br to the tropical marine atmosphere. These findings contradicted several modeling studies which assumed a spatially uniform oceanic source of CHBr<sub>3</sub> (Figure 2). Further, we measured very high concentrations of atmospheric CHBr<sub>3</sub> in air masses that originated near the Northwest African coast. We hypothesized that these were due to enhanced biogenic production and sea-to-air fluxes in the diatom-rich water of the Northwest African (Mauritanian) upwelling.

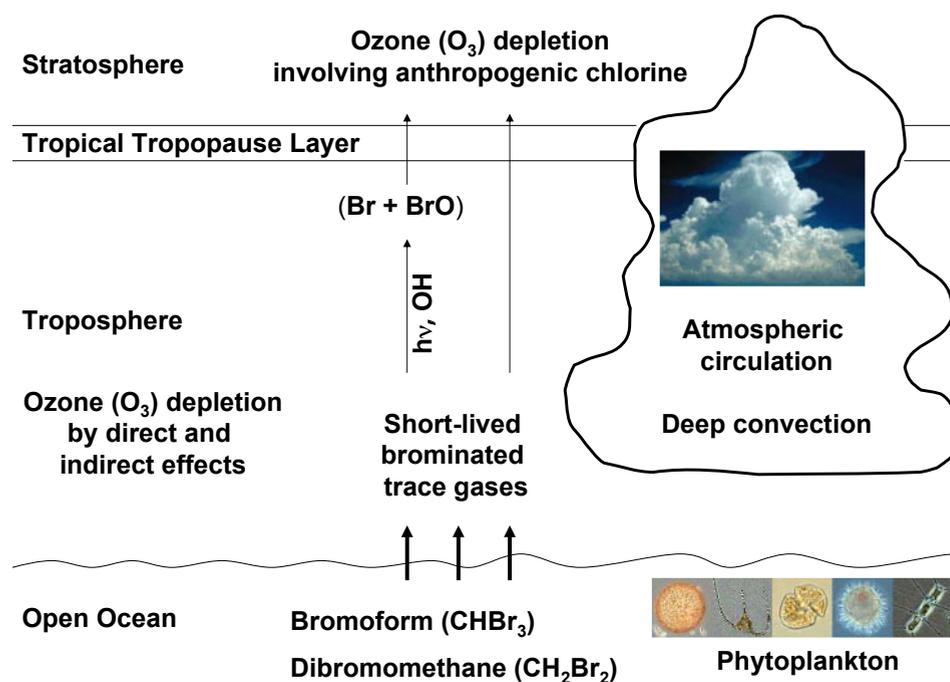
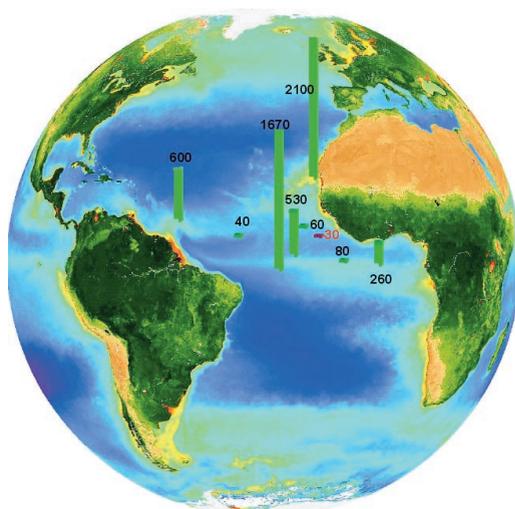


Figure 1: Bromocarbons with atmospheric lifetimes of weeks are produced in the tropical oceans and are an important source of reactive halogen atoms for the troposphere and the lower stratosphere. Rapid transport into the upper atmosphere is promoted by tropical deep convection. The shorter-lived bromocarbons, such as bromoform (CHBr<sub>3</sub>), partly decompose in the troposphere by photooxidation (OH) or sunlight (hv) to inorganic bromine (Br+BrO). This inorganic bromine contributes to stratospheric and tropospheric O<sub>3</sub> depletion, including interactions with anthropogenic chlorine, atmospheric sulfur and nitrate.

Figure 2: Regional emissions of bromoform ( $\text{pmol CHBr}_3 \text{ m}^{-2} \text{ hr}^{-1}$ ) from the tropical Atlantic. High emissions have been found in the Amazon River plume, in the equatorial upwelling region, and the Guinean and the Mauritanian upwelling. The ocean can also act as a sink (red bar) for atmospheric bromoform in certain regions.



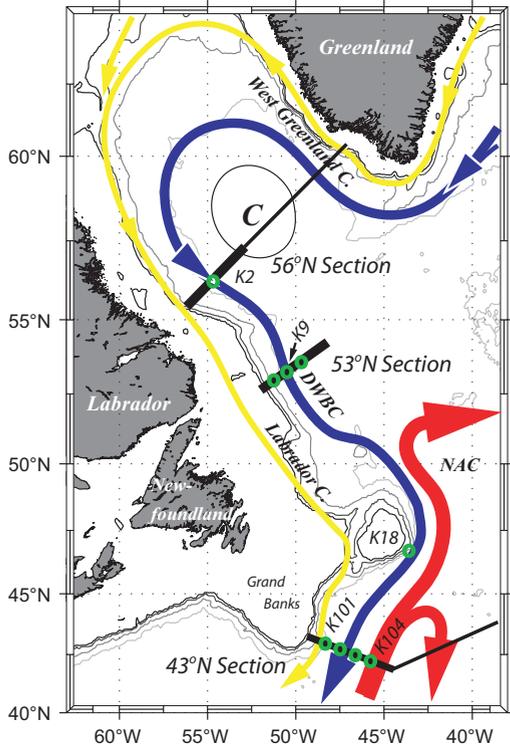
A recent cruise with RV Poseidon to this region confirmed that shelf waters are a strong source of bromoform ( $\text{CHBr}_3$ ) as well as dibromomethane ( $\text{CH}_2\text{Br}_2$ ) for the atmosphere. However the calculated sea-to-air flux from shelf and slope waters was insufficient to explain some very high concentrations that we measured in the atmosphere. Hence additional, and as yet unknown, sources contribute organic Br to the atmosphere of the eastern tropical Atlantic Ocean. Analysis of air mass trajectories for atmospheric samples with high concentrations suggests that these sources must be on land or, more likely, in the nearshore, coastal and highly productive regions of West Africa.

Further investigation into the marine source and atmospheric fate of organic Br-containing compounds is being conducted between the coast of Mauritania and Cape Verde as part of the SOPRAN (Surface Ocean Processes in the Anthropocene) coordinated project funded by the BMBF.

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## Heating up the Labrador Sea

The Physical Oceanography Group at IFM-GEOMAR has been actively involved in climate-related research in the sub-polar North Atlantic since 1996. The Labrador Sea (see Figure



1) between Greenland and Labrador (Canada) represents a major convection area for the production of North Atlantic Deep Water which in turn supplies vast regions of the Atlantic Ocean with freshly ventilated and dense waters rich in oxygen. This production typically occurs during the months March to April. There have been periods of intense convection activity in this area in the early 1990s, but less and less penetration of these newly formed water masses since 1994. This time evolution of temperature with depth for Mooring K1 near 56°N can be seen in Figure 2, indicating the nearly continuous warming throughout the water column. Our moored temperature measurements in the Deep Labrador Current clearly show this development as well (Figure 3a): At the depth of 1500 m where deep cooling was typically observed during winters with vigorous convection, our temperature sensors from various moorings in the

area all display a nearly linear warming trend of 0.05°C/year. These measurements cover the entire region, from the northern convection area at 56°N all the way south to the exit of the Labrador Sea off Grand Banks at 43°N. This warming trend is not an isolated incident.

One of the related questions in the scientific as well as popular literature is whether or not these temperature changes - and subsequently water mass changes - have any effect on the global 'conveyor belt' of ocean circulation. Figure 3b shows the boundary current flow at 56°N and 53°N during the time period of the temperature measurements in Figure 3a, again from moorings located within the strong boundary current exiting the Labrador Sea. Even though there was a slight increase (more southward flow) in 2002, the statistical significance of this increase is lacking.

Even more evidence for this failure of the Labrador Current to convert temperature changes into appreciable flow changes is provided by Figure 3c: Mooring K104, located at the eastern end of the mooring line off Grand Banks at 43°N, measured the outflow of the NADW (North Atlantic Deep Water) at 3000 m and its deepest component, the DSO (Denmark Strait Overflow Water), at 4200 m. Identical measurements had been taken by the Bedford Institute (BIO) in 1993-95, and the time series at these depths (left panel of Fig. 3c), plus the vertical profiles at mooring location K104 (right panel of Fig. 3c) show substantial changes in the deep water masses but no significant changes in the outflow of North Atlantic Deep water along this major route.

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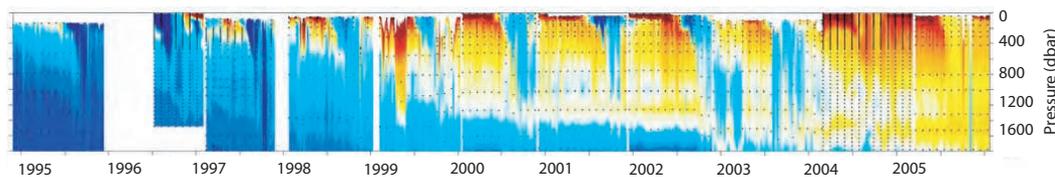


Fig. 1: Schematic map of the circulation in the Labrador Sea. The red arrow represents the North Atlantic Current (NAC) which, as the extension of the Gulf Stream, carries warm water into northern latitudes. The cold upper ocean circulation is shown in yellow, the blue arrows represent the Deep Western Boundary Current (DWBC) carrying deep, cold water from the Nordic Seas overflow regions and adding newly convected water in the center of the Labrador Sea. Current measurements were taken at various times at the locations marked by the green circles along the CTD sections (marked as black lines).

Fig. 2: Time-depth diagram of the temperature development at mooring K2 (56°N) in the upper 1800 m between 1994 and 2006. Blue colors indicate cold water, yellow to red indicates increasingly warmer water. Following deeply penetrating wintertime cooling in 1995 and 1996, the depth of this convection has been decreasing ever since, and the effect of warming at depth is also clearly evident.

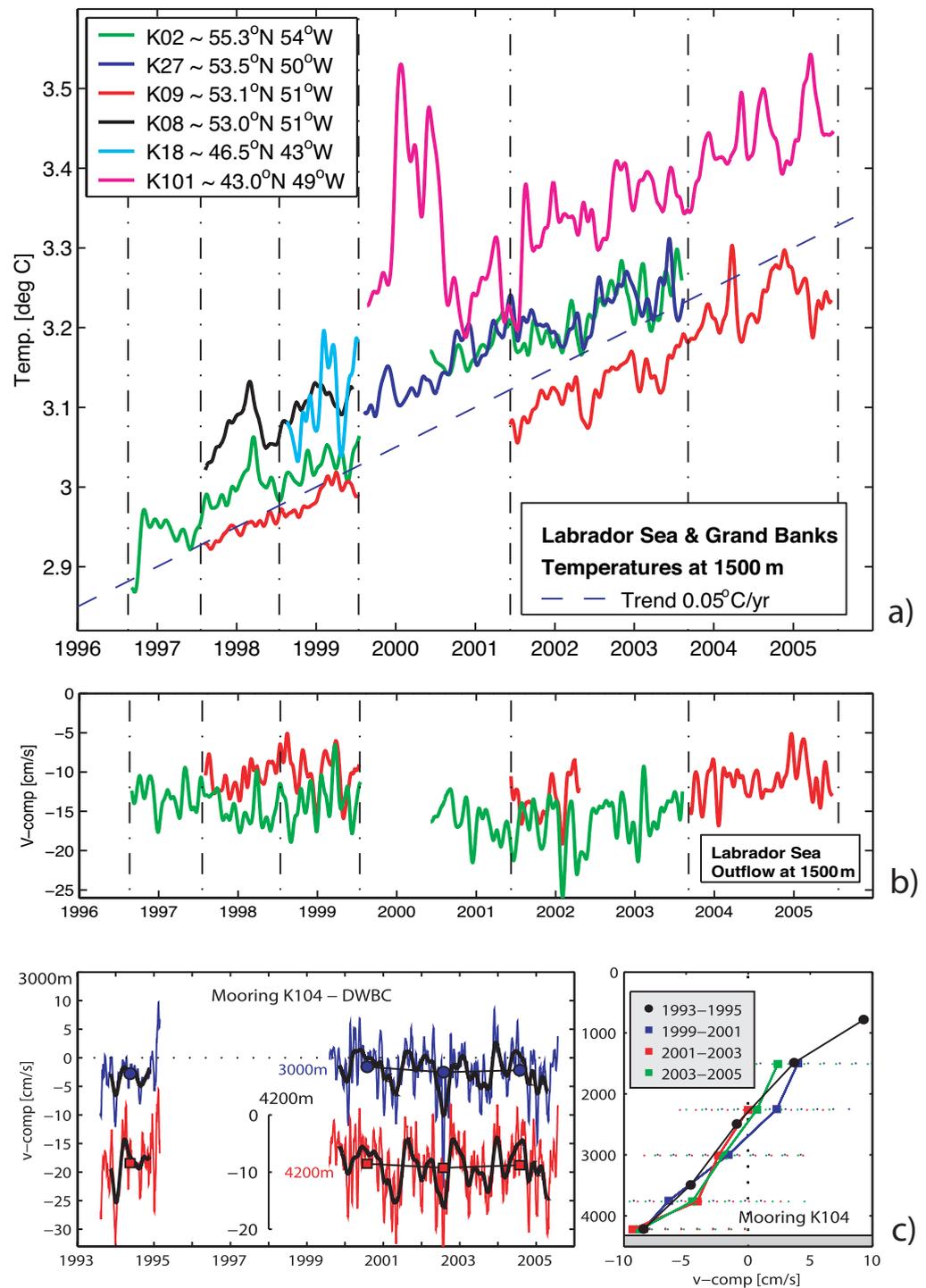


Fig. 3a: Time series of temperature at 1500m at various locations throughout the Labrador Sea, and at the Great Banks (K101). A 50-day lowpass filter has been applied to all time series. This figure shows that the increase of temperature at mid-depth is not confined to isolated regions but covers the entire western sub-polar North Atlantic. The dashed line indicates a linear temperature increase of 0.05°C per year.

Fig. 3b: Time series of outflow from the Labrador Sea at two locations in the Labrador Sea. A 50-day lowpass filter has been applied to all time series. These time series show that the temperature increase from the previous Fig. 3a does not coincide with an increased outflow from the region. Instead we find a minor increase of the outflow in mid-2000 to mid-2002, followed by a return to the previous levels.

Fig. 3c: Time series and profile characteristics of the deep outflow at Mooring K104, located at the eastern end of the mooring line off Grand Banks at 43°N, including NADW (North Atlantic Deep Water) at 3000 m and DSOW (Denmark Strait Overflow Water) at 4200 m. Identical measurements had been taken by the Bedford Institute (BIO) in 1993-95, and the time series at these depths (left panel of Fig. 3c), plus the vertical profiles at mooring location K104 (right panel of Fig. 3c) demonstrate that there has not been any appreciable change in the outflow since 1993.

## Paradigm change: temperature-dependent strontium isotope variations

Strontium (Sr) is used widely to reconstruct the chemical and temperature history of the ocean on various time scales through measurement of the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratio and the Sr/Ca elemental ratios in marine carbonates. Although Sr itself is not radioactive the isotope  $^{87}\text{Sr}$  is supported by the radioactive beta decay of  $^{87}\text{Rb}$  (Rb=Rubidium) which has a half-life of 48 billion years. The primary use of this isotope system in the geosciences is for rock and mineral dating. However, because Sr is enriched in the Earth's mantle whereas Rb is enriched in the Earth's crust, the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio can also be used to distinguish the geological origin of minerals and rocks. Notably, the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of continental rocks and minerals tends to be higher than those originating from the Earth's mantle. One major application of this element and isotope separation process in the marine sciences is to reconstruct changes in the chemical balance of Sr in the ocean and distinguish the relative contribution of Sr from marine hydrothermal sources to that delivered by continental weathering throughout Earth's history. Such studies shed light on past rates of continental weathering and hence on a key process that controls atmospheric  $\text{CO}_2$  levels on geological time scales.

Throughout decades of Sr isotope research it has been assumed that there are no additional isotope fractionation processes which alter the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio established by the radiogenic ingrowth of  $^{87}\text{Sr}$  due to  $^{87}\text{Rb}$  beta decay. In particular, this was assumed to hold true for the  $^{88}\text{Sr}/^{86}\text{Sr}$  ratio, which is used in the calibration procedure for mass spectrometric measurement of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios. However, recent high precision measurements at IFM-GEOMAR of  $^{88}\text{Sr}/^{86}\text{Sr}$  (Fietzke and Eisenhauer, 2006) show that this ratio is not stable, but rather is variable and temperature dependent. The measurements also showed that the presently accepted  $\delta^{88/86}\text{Sr}$ -value for seawater ( $\delta^{88/86}\text{Sr}_{\text{seawater}}=0$ ) is offset by about 0.4 ‰ from its true value (Fig. 1) which in turn implies that the true  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic ratio in seawater is also significantly different (by about

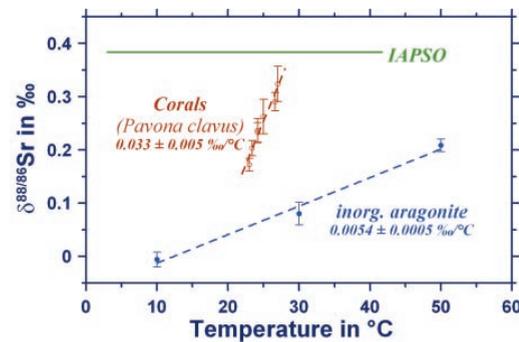


Figure 1: The  $\delta^{88/86}\text{Sr}$  versus temperature data of inorganically precipitated aragonite and natural coral (*Pavona clavus*) samples. For comparison the  $\delta^{88/86}\text{Sr}$  value of IAPSO seawater standard ( $0.381 \pm 0.010\%$  (2SEM)) is plotted as temperature-independent level.

0.2 ‰) from its presently-accepted value ( $\delta^{87/86}\text{Sr} = 0.7091741(24)$ ).

The measurements also revealed, for the first time, that there is a temperature-dependent strontium isotope fractionation during calcium carbonate precipitation. This could be shown both for inorganically precipitated aragonite and for coral samples (Fig. 1). These results require further experimental confirmation but may point to a new tool for reconstructing past seawater temperature variations resulting from climate change. The isotopic ratio has the potential to be less sensitive to post depositional diagenetic alteration, water pressure effects and salinity variability than the traditional proxies for temperature reconstruction. Hence the results from these high-precision measurements both open a new door to past climate change but also, as a result of the insight into Sr-isotope fractionation, suggest that the history of continental weathering as deduced from the  $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of marine carbonate has to be reassessed. First, approximate calculations indicate that about 20 % of the Cenozoic  $^{87}\text{Sr}/^{86}\text{Sr}$ -variations might, in fact, be due to other sources of  $^{88}\text{Sr}/^{86}\text{Sr}$ -variability (e.g. temperature changes).

### References:

Fietzke, J. and Eisenhauer, A., 2006: Determination of temperature-dependent stable strontium isotope ( $^{88}\text{Sr}/^{86}\text{Sr}$ ) fractionation via bracketing standard MC-ICP-MS. *Geochimistry, Geophysics, Geosystems* **7**(8), doi:10.1029/2006GC001243.

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