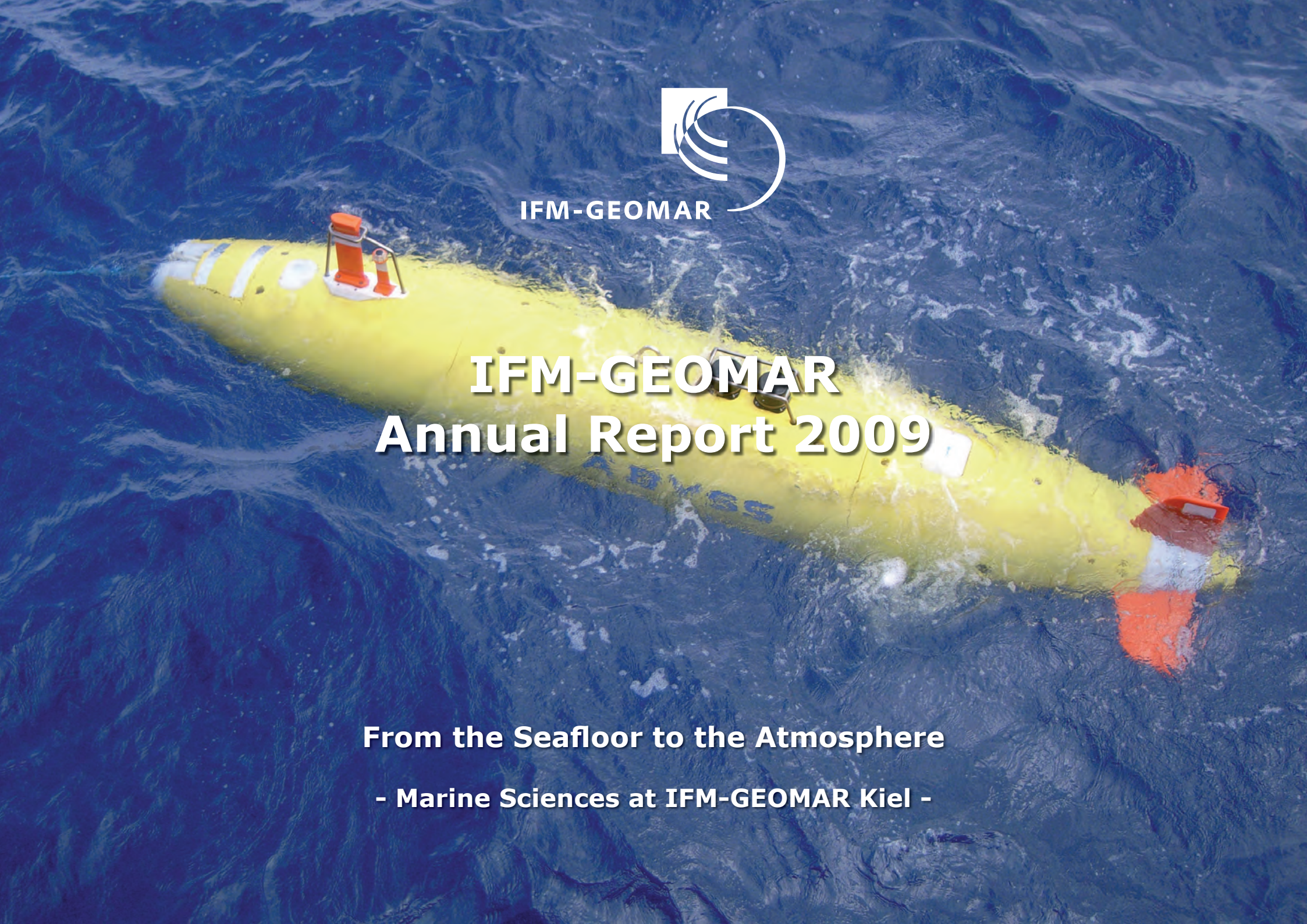
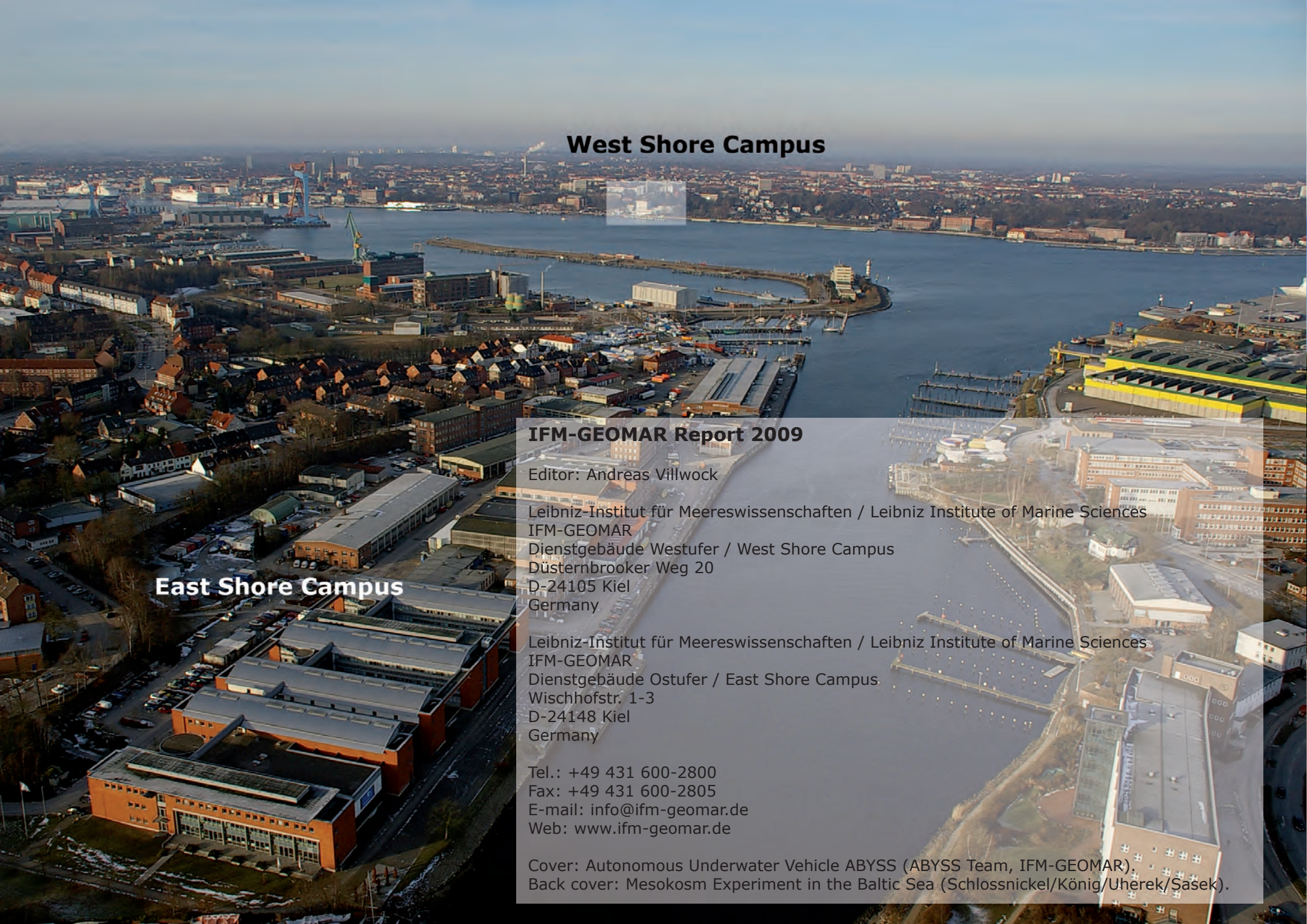


IFM-GEOMAR

IFM-GEOMAR
Annual Report 2009

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -



IFM-GEOMAR Report 2009

Editor: Andreas Villwock

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Cover: Autonomous Underwater Vehicle ABYSS (ABYSS Team, IFM-GEOMAR).
Back cover: Mesokosm Experiment in the Baltic Sea (Schlossnickel/König/Uherek/Sasek).

Contents

Preface

It is a very good sign when one is able to grow and expand against the trend during times of economic recession, and IFM-GEOMAR has now succeeded in doing this for the sixth year in a row. In virtually all areas, including the overall budget and the number of personnel employed, as well as in important performance indicators such as the number of scientific publications, the institute has, yet again, been able to post gains.

The institute's leading position in the area of project funding has also been confirmed by the German Research Foundation, with IFM-GEOMAR again leading the field by a long way in comparison to all other non-university research institutions in Germany. With two collaborative research centres, a "Cluster of Excellence", four Emmy Noether Research Fellowships, and many other projects in progress, the institute is well ahead.

IFM-GEOMAR also stands up well to international comparison. Although project funding from the EU has not attained the same level as national funding, significant growth has also been achieved in this area during recent years. With its broad research spectrum the institute is now one of the three leading marine research institutions in Europe. IFM-GEOMAR has signed a trilateral cooperation agreement with the national marine research centres of Great Britain (National Oceanography Centre, Southampton) and France (Ifremer, Paris/Brest), and is working closely with these partners in the field of European research coordination and planning. The aim of this agreement is to influence the structure of future EU Framework Programmes to include key topics of marine research.

On an international level, IFM-GEOMAR scientists are also involved in planning coordinated global research projects and are, for example, members of international planning bodies for the World Climate Research Programme, the International Biosphere-Geosphere Programme, and the Integrated Ocean Drilling Programme. In addition, IFM-GEOMAR will, from 2011 on, take over the chair of the Partnership for Observation of the Global Oceans (POGO), in which all major oceanographic research institutions around the world are involved.

The increasing visibility of the institute is evident from the number of visitors that it attracts, particularly political decision-makers. A highlight during the past year was the visit of the Cape Verde President in October 2009, which was a result of increased scientific cooperation with institutes on the Cape Verde Islands during recent years and an emphasis on research into various aspects of this archipelago in the Atlantic.

In view of this extraordinary success, special thanks are due to the institute's employees, who now number more than 750. Through their exceptional dedication, whether on expeditions or in their daily work at the institute, it is they who have made this performance possible. Through future measures, such as improving the compatibility of family life with working life, the institute intends

to further improve the general conditions of employment in order to make both the institute and the marine research location of Kiel even more attractive.

This report summarises the main activities of the institute during 2009 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 Report 2009".

Prof. Dr. Peter M. Herzig
Director

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, the oceans 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

750 including 400 scientists (end 2009)

Budget

59,3 million Euros:
- 26,6 million Euros research funding
- 32,6 million Euros institutional funding

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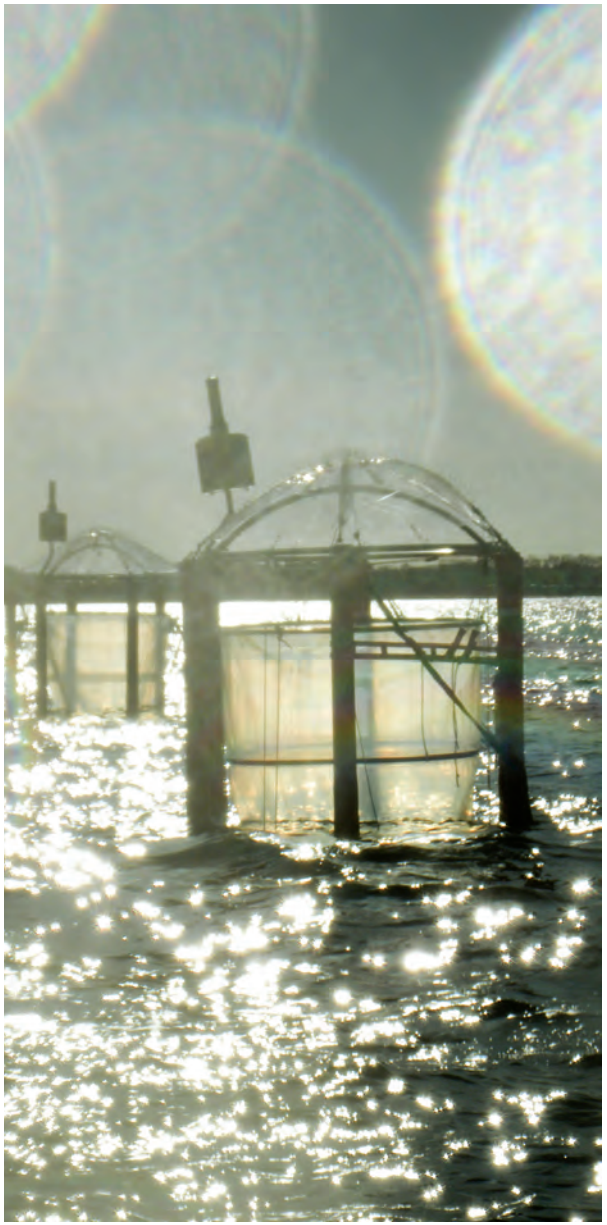


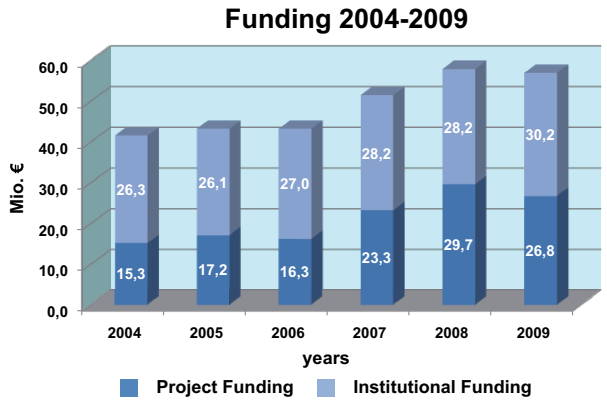
Introduction

In 2009 the institute's overall performance was again very positive, as reflected by increases in the total budget, and in the total number of staff employed which exceeded 750 by the end of the year.

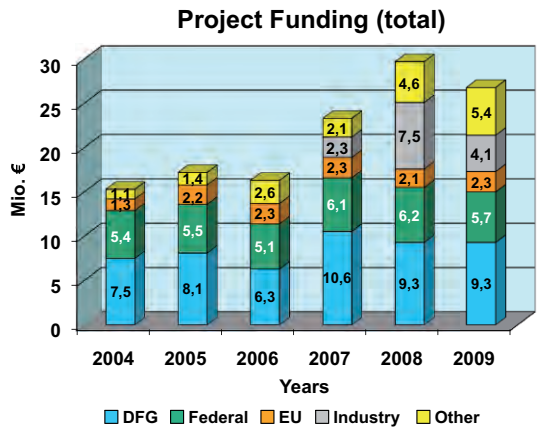
The total budget for IFM-GEOMAR in 2009 was about 59 million Euros (Fig. 1), of which about 27 million Euros was project funding from funding agencies and industry (Fig. 2). The increase in institutional funding over the previous years was due to additional resources being provided for the planning of the extension building on the east shore campus. This new building is now expected to be completed by 2014. Federal and provincial governments have essentially agreed on a public-private partnership model, with a total investment of 90 million Euros.

With respect to project funding, IFM-GEOMAR again underpinned its exceptional position in acquiring funds from the German Research Foundation (DFG). From 2005 to 2007, the DFG provided more than 33 million Euros in research grants to IFM-GEOMAR. This is more than twice as much as any other non-university research institution in Germany has received.

Funding Overview



Institutional and project funding 2004 - 2009



Project funding 2004 - 2009 by sources

New Research Projects

IFM-GEOMAR has been involved in a number of new projects that started in 2009. A complete list of all projects can be found in Appendix 3.2. Selected highlights amongst the new projects are listed below:

I. EU Projects: 7th Framework Programme

1. HERMIONE: Hotspot Ecosystem Research and Man's Impact on European Seas

The HERMIONE project is a collaborative project funded under the 7th European Framework Programme, and is the successor to the highly successful HERMES project. The objectives of the 3-year project are:

- To investigate the dimensions, distribution and interconnection of deep-sea ecosystems;
- To understand changes in deep-sea ecosystems in relation to certain key factors, including climate change, human impacts, and the impacts of large-scale episodic events;
- To understand the biological capacities and specific adaptations of deep-sea organisms, and to investigate the importance of biodiversity in the functioning of deep-water ecosystems;
- To provide stakeholders and policymakers with the scientific information required to support deep-sea governance with the aim of providing sustainable management of resources and the conservation of ecosystems.

The HERMIONE project has more than 30 partners and is coordinated by the National

Oceanography Centre in Southampton, UK. IFM-GEOMAR receives about 300,000 Euros towards this project.

For further information visit:
http://www.eu-hermione.net/

2. MESOAQUA: Network of leading mesocosm facilities to advance the studies of future aquatic ecosystems, from the Arctic to the Mediterranean

MESOAQUA offers a number of activities including networking, transnational access to mesocosm facilities and joint research. MESOAQUA also serves as a virtual transnational pelagic mesocosm centre - a portal of information on mesocosm research within Europe (soon to be worldwide).

The project has six partners and is coordinated by the University of Bergen, in Norway. The IFM-GEOMAR portion of the budget is around 250,000 Euros.

For further information visit:
http://mesocosm.eu/

3. HYPOX: In situ monitoring of oxygen depletion in hypoxic ecosystems of coastal and open seas, and land-locked water bodies

The HYPOX project aims to monitor oxygen depletion and associated processes in aquatic systems that differ in their oxygen status or sensitivity towards change. These include:

- open oceans that are oxic, with high sensitivity to global warming (e.g., the Arctic Ocean),
- semi-enclosed seas with permanent anoxia (e.g., the Black Sea, the Baltic Sea), and
- seasonally or locally anoxic land-locked systems (e.g., fjords, lagoons, and lakes) subject to eutrophication

The HYPOX consortium consists of 16 partners from 11 nations. The project will run for three years (2009-2012) and is coordinated by the Max Planck Institute for Marine Microbiology in Bremen, Germany. IFM-GEOMAR receives about 300,000 Euros in funding towards this project.

For further information visit:
http://www.hypox.net

4. MyOcean: Development and pre-operational validation of upgraded GMES Marine Core Services and capabilities

MyOcean is a project within the GMES Marine Core Service, aimed at deploying the first concerted and integrated pan-European capacity for ocean monitoring and forecasting.

The objective of MyOcean is to set up this new European service within the period from 2009 to 2011, taking advantage of previous investments in research & development, system development, and international collaborations.

The MyOcean service aims to provide the best information available on the oceans, on both a large scale (worldwide coverage) and a regional scale (European seas), based on the combination of observations from space and in situ observations, and their assimilation into 3-D simulation models.

MyOcean has about 60 partners in Europe and North America. The project is coordinated from the Mercator facilities in Toulouse, France. The IFM-GEOMAR portion of the budget is about 350,000 Euros.

For further information visit:
http://www.myocean.eu.org/

5. SHIVA: Stratospheric ozone: Halogen Impacts in a Varying Atmosphere

The SHIVA project aims to reduce uncertainties in present and future stratospheric halogen loading and ozone depletion resulting from climate feedbacks between emissions and the transport of ozone-depleting substances (ODS).
The SHIVA project runs from 2009 to 2012 and has 12 partners. It is coordinated from the University of Heidelberg. The IFM-GEOMAR part of the budget is about 520,000 Euros.

For further information visit:
http://shiva.iup.uni-heidelberg.de/

II. BMBF project (Federal Ministry of Education and Research, Germany)

1. BIOACID: Biological Impacts of Ocean Acidification

The main questions considered by the BIOACID project are:

- What are the effects of ocean acidification on marine organisms and their habitats?
- What are the underlying mechanisms affecting the responses and adaptations of marine populations and communities?
- How are the responses modulated by other environmental stressors, and what are the consequences for marine ecosystems and biogeochemical cycles?

The project operates in close cooperation with the European Project on Ocean Acidification (EPOCA), which is part of the EU 7th Framework Programme.

The BIOACID consortium is comprised of 14 partners in Germany, with a total funding of 8.9 m. Euros, of which 2.5 m. Euros is allocated to IFM-GEOMAR. The coordinator is Prof. Ulf Riebesell from IFM-GEOMAR.

For further information visit: http://www.bioacid.de

III. DFG funded projects (German Research Foundation)

1. Experimental resistance evolution and its genetic basis in the Diplostomum-Gasterosteus host-parasite system (Part of SPP 1399: Host-Parasite Coevolution – Rapid Reciprocal Adaptation and its Genetic Basis)

This project uses artificial selection to uncover the specificity, variability and genetic basis of innate immune defences in a fish host - the three-spined stickleback (*Gasterosteus aculeatus*). This SPP project is coordinated by the University of Münster. The IFM-GEOMAR portion of the project budget (under Prof. Dr. Thorsten Reusch) is 220,000 Euros.

For further information visit: http://ieb.uni-muenster.de/spp/)

2. Emmy Noether Programme: "Global change and the evolutionary genetics of parasite resistance in coastal ecosystems."

The objectives of this research are to (i) characterize the symbiont fauna of two host species/groups and identify pathogenic bacteria shared by both hosts, (ii) determine changes in their pathogenicity under global-change scenarios, (iii) assess the impact of environmental change on quantitative genetic parameters (G matrices of immune and life history traits), as well as on candidate immune genes in order to quantify interactions between genotype and environment (GxE interactions), and (iv) monitor the evolutionary trajectory of bacterial pathogenicity, experimentally evolved on different hosts and under different environmental conditions (GxGxE interactions). The fundamental objective of extending single species GxE interactions to multiple species GxGxE interactions is to explore the evolutionary consequences of parasitism in an ecosystem currently facing global change. The contact is Dr. Mathias Wegner.

3. Atmospheric response to Gulf Stream and Kuroshio variability: its role in the climate system jointly funded by the German Research Foundation (DFG) and the Japan Society for the Promotion Science (JSPS)

The main objective of this project is to understand the way that atmospheric variability relates to changes in two deep western boundary currents - the Gulf Stream and the Kuroshio - so that this can be incorporated into forecasting systems. It is motivated by recent high-resolution data from satellites and model simulations that indicates the atmosphere may respond to mid-latitudinal ocean variability, challenging the traditional view.

In order to achieve these objectives, high-resolution observational data will be analysed, results from several high-resolution models (European and Japanese) will be compared, and tailored predictability experiments will be performed. This joint German–Japanese project takes advantage of the particular expertise available in each of these countries, providing a perfect combination for tackling the project's objectives.

The budget for this two-year (2009-2011) project is comprised solely of travel expenses. The contact is Dr. Noel S. Keenlyside.

For further information visit: http://www.ifm-geomar.de/index.php?id=5111

IV. European Science Foundation

TopoMed: Plate re-organization in the western Mediterranean: lithospheric causes and topographic consequences

The evolution of the western Mediterranean Sea is governed by (i) convergence between the African (Nubian) Plate and Eurasia, and (ii) subduction-related slab roll-back. Both processes are responsible for the surface features / topography of the Alboran Sea / Rif / Betic domain and deep-seated features related to the consumption of African lithosphere. The TopoMed project forms one of the Collaborative Research Projects in the TOPO-EUROPE programme, within the European Science Foundations's EUROCORES Scheme, studying the interrelationships between convergence, major tectonic fault zones in the Alboran Sea (Trans-Alboran Shear Zone – the Alboran Ridge and Yusuf Ridge pull-apart basin), and Miocene subduction / deep-seated seismicity (40-150 km depth). Monitoring networks with ocean bottom seismometers (OBS) and hydrophones (OBH) will be installed in the area to record local and regional earthquakes. Two deployment periods of 6-8 months each were planned, requiring three voyages. The data collected will be used for tomographic inversion and receiver function analysis, providing seismic constraints on the structure of crust and mantle within the Gibraltar arc area and the

Alboran domain.

This 2-year project has 7 partners; IFM-GEOMAR's share of the budget is 290,000 Euros. The contact is PD Dr. Ingo Grevemeyer.

V. WGL project (Leibniz Association)

TransBrom: Very short lived bromine compounds in the ocean and their transport pathways into the stratosphere

This project aims to investigate the contribution of marine emissions of very short-lived bromine compounds to stratospheric bromine using a new transport model and hot-spot measurements in the western tropical Pacific. Additional bromine in the stratosphere could account for the observed, but as yet unexplained, stratospheric ozone loss at mid-latitudes. The questions of where this bromine comes from, how rapidly it reaches the stratosphere and in what quantities, have so far not been answered and will be addressed within the TransBrom project.

TransBrom is a Leibniz Association project under the competitive "SAW Procedure", within the framework of the Joint Initiative for Research and Innovation 2009. The project is funded through the "Women in academic leadership positions" funding line, aiming to increase the presence of female scientists in leading positions. The 2-year project has a budget of about 600,000 Euros. Contacts are Prof. Dr. Kirstin Krüger and Dr. Birgit Quack.

For further information visit: http://www.ifm-geomar.de/index.php?id=4609&L=1

VI. Volkswagen Foundation

Evolutionary costs and benefits of trans-generational immune priming in a sex-role reversed

The transfer of genetic information across generations is a prerequisite of evolution. However, information can also be transferred to offspring non-genetically. Such trans-generational effects are particularly relevant in host-parasite interactions where, e.g., vertebrate mothers transfer antibodies to their offspring via eggs, blood or milk. Given the fitness costs and prevalence of parasites, such trans-generational immune priming may profoundly affect coevolutionary dynamics. This project studies the costs and interactions of trans-generational versus genetic determinants of parasite-resistance in a fish with sex-role reversal. In the pipefish Syngnathus typhle the male carries the eggs in its placenta-like brood pouch. The project investigates the following hypotheses: (i) under sex-role reversal, males rather than females transfer antibodies or other immune components to the offspring, (ii) these should then vary with the MHC (major histocompatibility complex) genotype of the parents, (iii) immune priming is costly for parents (what costs do offspring pay for immune activation?), (iv) under rapidly changing genotypes of an abundant trematode parasite (Cryptocotyle lingua), immune priming is less beneficial than under a genetically constant parasite regime.

This 3-year project has a budget of 250,000 Euros. Contacts are Prof. Dr. Thorsten Reusch and Dr. Olivia Roth

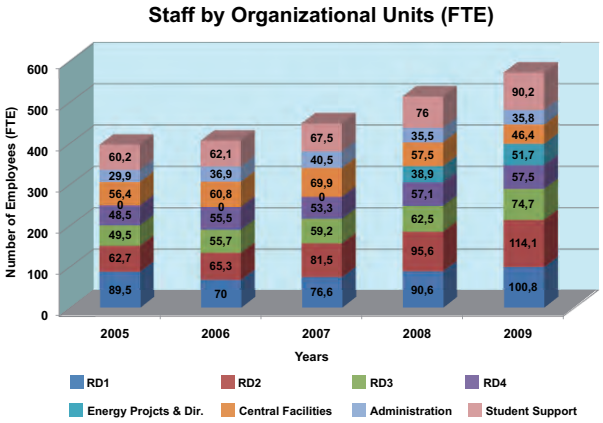
Further details about all projects can be found in Appendix 3.

Personnel

By the end of 2009, IFM-GEOMAR had about 753 employees. Of these, 396 were scientists (60% project-funded) and there were about 358 scientific support staff (including students) in central facilities and research divisions. The number of women employed was 359 (48% of the total), of which 196 were scientists (i.e. 55% of female employees and 49.5% of all scientists), but none were full professors. In order to improve the position of women in academic positions the institute has started a gender initiative. In addition to existing rules such as, for instance, that women should be preferred if they have equivalent qualifications, a number of new actions are planned to improve the compatibility of the family with professional demands, which often result in problems, particularly for women.

The following changes in senior personnel occurred during 2009:

- Dr. Uwe Waller (RD3 / Aquarium), Director of the Aquarium, left the institute for a professorship in aquaculture at the Univer-



sity of Applied Sciences of the Saarland, in Saarbrücken.

- Prof. Dr. Dietmar Dommenget (RD1, Junior Professor in Maritime Meteorology) accepted a position as a senior lecturer at Monash University, Australia.
- Prof. Dr. Andreas Macke (RD1, Maritime Meteorology) accepted an offer from the Institute for Tropospheric Research in Leipzig, Germany and will become a new director of the institute by April 2010.
- PD Dr. Silke Voigt (RD1, Paleooceanography) accepted the offer of a W3 professorship at the University of Frankfurt.
- Dr. Syee Weldeab (RD1, Paleooceanography) left for a faculty position at the University of Santa Barbara, Los Angeles, USA
- Dr. Mathias Wegner (RD3, EV) received an Emmy Noether Fellowship. Dr. Wegner studied in Göttingen, New Zealand and at the MPI for Limnology (now MPI for Evolutionary Biology) in Plön. His last affiliation was with the ETH Zürich.

Further details with respect to personnel can be found in Appendix 2.

Passing of Wolfgang Krauß

Prof. Dr. Wolfgang Kraus, former director of the Institute for Marine Research and Dean of the Faculty of Mathematics and Natural Sciences at the University of Kiel, passed away on July, 3rd at the age of 78. Prof. Krauß was one of the leading international scientists in the field of theoretical oceanography. He studied meteorology at Kiel and, in 1967, became full professor at the University of Kiel where he headed the new research unit on theoretical oceanography at the Institute for Marine Research (IfM). During his professional career he had a significant influence on the development of the curricula for oceanography, turning Kiel University into one of the world's leading educational centres for marine sciences. From 1970-71 he served as Dean of the Faculty of Mathematics and Natural Sciences and influenced the development of the university during difficult times. From 1982-88 Prof. Krauß was a director of the IfM. During his time as spokesman for the Collaborative Research Project entitled "Warm water sphere of the Atlantic" he provided important guidance concerning the understanding of the North Atlantic Current and its significance for the European climate. The scientific work of Prof. Krauß focused mainly on the circulation system of the Atlantic Ocean. His innovative ideas for coupling new observational methods with mathematical modelling of complex circulation systems were the key to an improved understanding of the global oceanic circulation.
Prof. Krauß received a number of high honours and awards. With Prof. Krauß, IFM-GEOMAR and the oceanographic community have lost a scientist, friend and colleague with the highest international reputation.

Honours and Awards

IFM-GEOMAR Director Prof. Dr. Peter Herzig (r) reveived the Presidential Medal of Merit of the Republic of Cape Verde from the President of Cape Verde, Pedro Verona Rodrigues Pires (l), in the presence of Prime Minister Peter Harry Carstensen (m).

In recognition of the institute's excellent cooperation in encouraging marine research in Cape Verde, IFM-GEOMAR has been awarded the Cape Verde Presidential Medal of Merit. The award was presented to Prof. Peter Herzig on the occasion of the visit by President Pires to IFM-GEOMAR.

Prof. Dr. Mojib Latif received the first Deutsche Bank / IFM-GEOMAR Marine Research Award for his outstanding scientific work in the field of climate research and communicating the results to the general public. The award is funded by the Deutsche Bank and has a value of 10,000 Euros.

Overview

Prof. Dr. Mojib Latif with Johannes B. Kerner (r), Till Keulen and Prof. Dr. Peter Herzig.

The Deutsche Bank also sponsored five publication awards with a value of 1,000 Euros each. With these awards IFM-GEOMAR honours outstanding publication records in the past year. In 2009 the following scientists were honoured: Dr. Arne Biastoch (RD1), Dr. Julia Wohlers (RD2), Dr. Birte Matthiessen (RD3), Dr. Cord Papenberg (RD4), and Dr. Lothar Stramma (SFB 754).

Dr. Arne Biastoch, Dr. Cord Papenberg, Dr. Birte Matthiessen, Prof. Dr. Peter Herzig, Dr. Julia Wohlers und Dr. Lothar Stramma.

For 2009 and 2010 the Prof. Dr. Werner Petersen Foundation has sponsored (or will sponsor) five high-level lectureships to the value of 20,000 Euros each. The recipients are: Prof. Dr. Steve Scott (University of Toronto, Canada), Prof. Dr. Jonathan Erez (Hebrew University of Jerusalem, Israel), Prof. Dr. Boris Worm (Dalhousie University, Halifax, Canada), Prof. Dr. Chris German (Woods Hole Oceanographic Institution, USA), and Prof. Dr. Sallie Chisholm (M.I.T, USA). These scientists spend a couple of weeks at IFM-GEOMAR, offer short courses for students and give a public lecture on their scientific research.

Prof. Dr. Ralph Keeling from the Scripps Institution of Oceanography, San Diego, USA, received a prestigious Humboldt Research Award for his outstanding contribution to research on carbon dioxide. He spent one year (August 2008– July 2009) at IFM-GEOMAR, working with colleagues in the SFB 754 project on issues related to oxygen in the oceans. The Humboldt Award is a research grant to support a long-term sabbatical in Germany for exceptional foreign scientists.

Dr. Heidemarie Kassens (RD1) received a Ministerial Award of the Russian Federation from the Ministry for Natural Resources and Ecology, for her outstanding contribution to Russian-German Cooperation.

Dr. Karen Volkmann-Lark (RD1) received an award from the Federal Agency of Hydrometeorology and Environmental Monitoring of the Russian Federation's Ministry for Natural Resources and Ecology, for her significant professional contribution to the development and operation of the Institute of Arctic and Antarctic Research.

Dr. Christa Marandino (RD2) received an invitation to the annual meeting of the Nobel Laureates in Chemistry and was awarded a Humboldt Research Fellowship for Postdoctoral Researchers.

The following students received awards for outstanding presentations and posters at various meetings, documenting a combination of excellence in science, and creative and innovative presentations:

Katja Lindhorst (Excellence Cluster: Submarine Geohazards) for her presentation at the Annual Meeting of the German Geophysical Society entitled: "Sedimentary and tectonic evolution of ancient Lake Ohrid (Albania/Macedonia)".

Nicolas Glock, SFB754, for his poster at the Annual Meeting of the Geologische Vereinigung entitled: "The sensitivity of pore density in tests of Bolivina spissa to ambient oxygen and/or nitrate concentration in sediment bottom water".

Meike Stumpp (Excellence Cluster: Ocean Acidification) for her poster at the European Molecular Biology Organization Workshop "Evo-Devo Meets Marine Ecology: new frontiers in ocean science through integrative biology" entitled: "Impacts of ocean acidification on physiology and gene expression patterns during sea urchin larval development".

Tobias Steinhoff (RD2 / Chemical Oceanography) for his poster at the 8th International Carbon Dioxide Conference entitled "Separation of air-sea gas exchange and biological drawdown of CO_2 by a combined dataset of CO_2, N_2O and dissolved oxygen in the Mauritanian upwelling".

Wiebke Mohr (RD2 / Biological Oceanography) and Annette Kock (RD2 / Chemical Oceanography) were both awarded poster prizes during the 4th International SOLAS Open Science Conference. W. Mohr's presentation was entitled "High variability in single-cell nitrogen fixation rates", and A. Kock's presentation was on "The contribution of turbulent mixing to the N_2O flux into the mixed layer of the Mauritanian upwelling system".

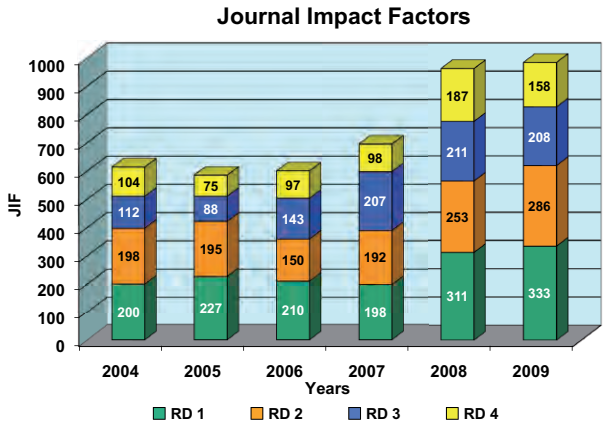
Further details about honours and awards can be found in Appendix 7.7.

Scientific Results and Publications

Nature cover of Biastoch et al. paper.

In 2009 the scientific output in terms of peer-reviewed scientific publications continued at high level. This was documented by an overall increase of the journal impact factors as well as in the number of articles published in high-profile journals such as Nature (3) and Science (1), as well as in other leading journals in specialised fields. Some of the key results are presented in the scientific highlights section (Chapter 2) of this report.

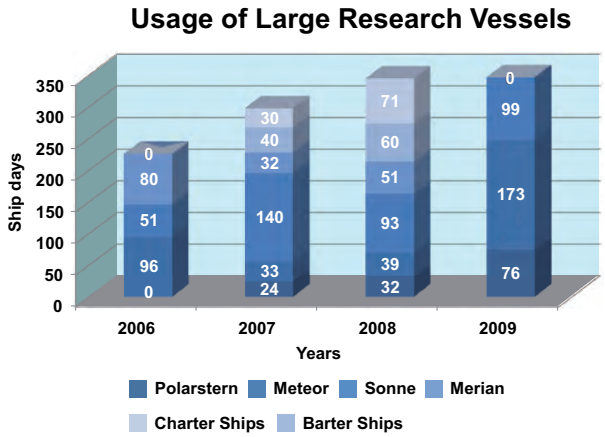
For a full list of publications see Appendix 5.



Journal impact factors by research division (RD) for the period 2004-2009.

Major Expeditions and Sea-going Activities

A total of 11 expeditions with 348 ship-days on large research vessels (i.e. almost one ship-year with a principal investigator from IFM-GEOMAR on a global research vessel), plus a number of expeditions with mid-sized vessels such as RV POSEIDON and RV ALKOR, document a very active year once again for the sea-going groups of IFM-GEOMAR.



Ship usage of large research vessels 2006-2009.

Examples of IFM-GEOMAR activities worldwide: Helicopter expedition in the high Andes (top), on the sea ice of the Laptev Sea (middle), Mesocosm experiment in the Baltic (lower), JAGO expedition to historic coral reefs in Tahiti (left) and POLARSTERN meets METEOR in the Atlantic, both under IFM-GEOMAR leadership (right).

Highlights were the investigation of the oxygen minimum zone in the eastern equatorial Pacific (M77, continuation from 2008), a charter cruise on RV BRAVEHEART with the JAGO submersible in the Pacific, and another JAGO expedition on Poseidon to cold water coral reefs in the subpolar North Atlantic. For the first time the ROV KIEL 6000 and AUV ABYSS underwater vehicles were used together on a METEOR cruise to the Mid Atlantic Ridge (PI Seifert, Univ. HH). During the summer, the ROV KIEL 6000 explored cold seeps in shallow waters of the southern North Sea, on a charter cruise with RV CELTIC EXPLORER. In December, the AUV ABYSS performed high-resolution mapping in the Woodlark Basin (Western Pacific). *See also Chapter 2 for further details.*

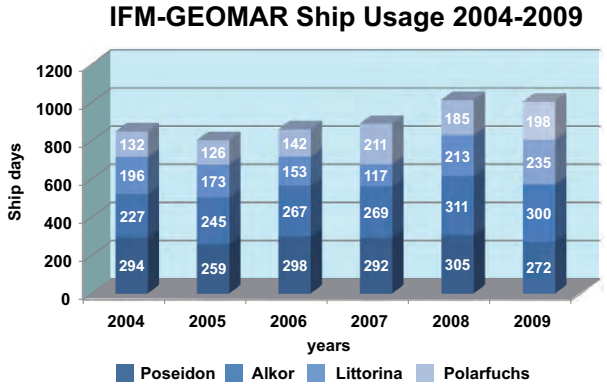
In addition to ship-borne expeditions, two major land-based excursions were undertaken during 2009. In February / March scientists from the SFB 574 project undertook an expedition to the high Andes to investigate the origin of volcanic ash from the subduction zones in South America. Subsequently, a six-week joint German-Russian expedition in April explored the impact of climate

AUV ABYSS and ROV KIEL 6000 in board of RV METEOR on a mission to the Mid-Atlantic Ridge.

change on the Laptev Sea, an area in which a significant proportion of the Arctic Ocean's sea ice is formed.

A total of more than 1,000 ship-days on the four IFM-GEOMAR vessels POSEIDON, ALKOR, LITTORINA and POLARFUCHS again demonstrates the high demand for ship time in the Baltic and North Sea, and also in the North Atlantic and adjacent seas (POSEIDON).

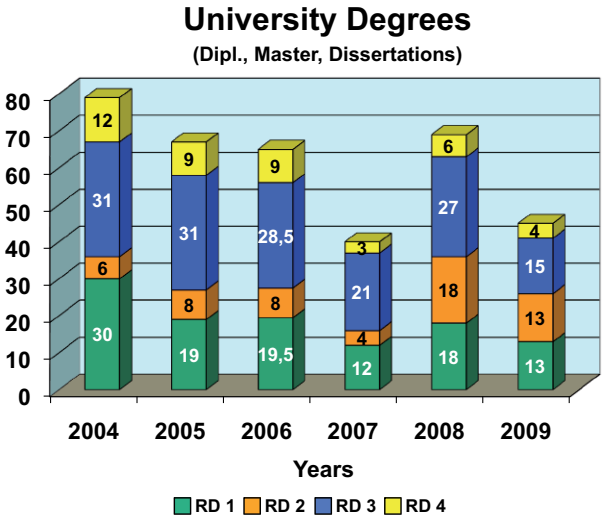
For further details see Appendix 4.



Ship usage of IFM-GEOMAR research vessels for the period 2004-2009.

Teaching & Curricula

The transition process from the Diploma degree to the Bachelor / Master system is now almost complete for the curricula in marine sciences, although most of the degrees are still being awarded according to the previous Diploma standard.



University degrees by research units, 2004-2009.

In total, 13 dissertations and 32 diploma or master's degrees in various marine science disciplines were completed during 2009 (*see Appendix 5.6*). At the end of 2009, IFM-GEOMAR had a total of 156 Ph.D. students from 26 different countries. IFM-GEOMAR staff also supported a number of external students from other universities, e.g. through the international GAME project.

Participants of the first Summer School on Biotechnology with students from the Hochschule für Life Sciences der Fachhochschule Nordwestschweiz (FHNW) in Muttenz, Switzerland.

Together with institutes from the Christian-Albrechts University of Kiel (CAU), IFM-GEOMAR offers the following curricula:

Bachelor's degree courses:

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

Master's degree courses:

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

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

IFM-GEOMAR staff also held guest lectures at various other universities, including contributions to the 5th Sino-German Summer School on "The Coastal Zone and its Management" in Qingdao, China.

Further details about all teaching and curricula can be found in Appendix 8.

International Cooperation and Events

In the area of international cooperation, several attempts were made to foster scientific exchange and cooperation and to develop future research strategies and planning.

Representatives of the G3-Institutes met on occasion of the 25th anniversary of Ifremer in Paris: Jean-Yves Perrot, President of Ifremer, Prof. Peter Herzig, Director IFM-GEOMAR, the French Minister of Research Valérie Pécresse and Prof. Edward Hill, Director of NOC. Photo: Thomas Déron.

Participants of the G3 meeting at the National Oceanography Centre in Southampton, December 2009.

The so-called G3-Cooperation of the three leading marine research institutes in Europe (Ifremer in France, the National Oceanography Centre in Southampton, UK, and IFM-GEOMAR) held two planning meetings, one in Brest (June) and one in Southampton (December). Issues discussed were a deep-sea frontier initiative, a joint gas hydrate project, and cooperation with China.

Participants of the Taiwan-German Workshop on Marine Gas Hydrates in Taipeh, November 2009.

The Submarine Gas Hydrate Reservoirs (SUGAR) project held a first German-Taiwanese workshop on gas hydrates and carbon capture and storage (CCS) technologies in Taipei during November, and a German-Japanese Workshop in Kiel during December.

The Kiel Earth Institute (a collaborative project between IFM-GEOMAR and the Institute for the World Economy) held an international workshop on different methods relating to geo-engineering during the month of June.

A preparatory meeting for a joint German-Saudi Arabian project, known as the "Jeddah Transect Project", was held in Jeddah in November.

Award ceremony during the 10th anniversary meeting of the Otto-Schmidt Laboratory, November 2009.

The Otto-Schmidt Laboratory (OSL) in St. Petersburg, Russia, a joint Russian-German initiative, celebrated its 10th anniversary in November 2009. It was named after the Russian polar researcher Otto Yulievich Schmidt, who conducted several polar expeditions during the 1920s and 1930s. The OSL was opened in the year 2000 at the Arctic and Antarctic Research Institute (AARI) in St. Petersburg. It provides a basis for co-

Overview

ordination and development of the research projects carried out within the framework of the Bilateral Agreement on Cooperation in Polar and Marine Research between the Russian Federation and Germany, which aims to support young scientists through the OSL's "Changing Environments" Fellowship Program.

Other important scientific workshops and meetings with international participation included the 2nd SOPRAN Annual Meeting, the 4th German KALMAR Workshop, the 69th annual meeting of the German Geophysical Society (contribution), the Aquashift Workshop, a planning workshop for the Integrated Ocean Drilling Programme, and the BIOACID "kick-off" meeting.

Participants of the BioAcid Kickoff Meeting, October 2009.

A number of additional scientific workshops and meetings took place at IFM-GEOMAR or were organized by staff members of the institute.

About 70 scientists from 21 nations stayed at IFM-GEOMAR during the year, on research visits.

Additional information about scientific exchange and cooperation can be found in Appendix 7.

Visits

IFM-GEOMAR welcomed a number of high-level visitors during 2009. Among these, the visit by the President of Cape Verde was certainly the most important, and an outstanding event. During his first visit to Germany, President Pires visited IFM-GEOMAR and honoured the institute with the Presidential Medal of Merit.

In addition, several members of the state and federal governments and parliamentary representatives conducted information-gathering visits to IFM-GEOMAR. Amongst these were Dr. Werner Marnette, the Minister for Science, Economy and Transportation for the State of Schleswig-Holstein, Dr. Cornelia Pieper, a member of the Federal Government's Committee for Science and Education, and Reimer Böge, a member of the European Parliament and chairman of the EP Budget Committee.

Visits: Minister for Science, Economy and Transportation of the State of Schleswig-Holstein, Dr. W. Marnette (above); Member of the European Parliament and the chair of the Budget Committee, Reimer Böge. Member of the Committee for Science and Education of the Federal Government, Dr. Cornelia Pieper (left col.)

Other important visitors were the famous scuba diving legend Prof. Hans Hass, a group of American honorary consuls, and the spouses of foreign diplomats and ambassadors in Germany.

Public Relations and Outreach

IFM-GEOMAR was involved in a broad range of public relations and outreach exercises during 2009. Together with the cluster of excellence "The Future Ocean", a "children's university" on marine science was organized for the second time. Contributions by IFM-GEOMAR staff included "Messages from stars in the ocean", "Earthquakes, submarine slides, tsunamis and other natural hazards", and "Black Smokers in the deep sea"; between 200 and 400 children aged 6-14 attended.

For the third year in a row the cluster of excellence and IFM-GEOMAR provided an exhibition for the State of Schleswig-Holstein's contribution to the German Unity Day national holiday celebrations. In 2009, these celebrations took place in Saarbrücken in the southwestern part of Germany, close to the French border. In addition to the presentation for the State of Schleswig-Holstein, an exhibition entitled "The Future Ocean" was also presented over a five-week period on a barge towed along the Mosel River.

Left column: Visits part 2: Top: Diving legend Hans Hass, centre: American honorary consuls, bottom: spouses of diplomats and ambassadors in Germany. Right Column: Top: Children's University. , centre: Opening of the exhibition "The Future Ocean" on a towed-ship in Saarbrücken, bottom: Award Ceremony 365 Days in the Land of Ideas for the Centre of Marine Substances (KiWiZ): left: Tim Keulen (Deutsche Bank) and Prof. Johannes F. Imhoff, KiWiZ.

Overview

The Lithothek during the Day of Open House.

During the open day at IFM-GEOMAR several thousand visitors explored the institute and were informed about specific aspects of marine research. The Centre for Marine Substances Research (KiWiZ) also had an open day for the presentation of the "365 Landmarks in the Land of Ideas" award. This award has been presented on a daily basis in Germany since 2006 for new, innovative ideas. The ROV Team provided another open day, at the International Maritime Museum in Hamburg, on which they presented the ROV KIEL 6000 to the general public.

"Culture meets science" was the motto for two events during the past year. On Cape Verde Day, traditional folk music from the Cape Verde islands was performed, in conjunction with presentations on marine research by IFM-GEOMAR. During Kiel Week ("Kieler Woche") the Muthesius Academy of Fine Arts and Design, together with the "cluster of excellence" and IFM-GEOMAR, presented a so-called "Performative Lecture" with video impressions from scientific expeditions, together with talks and scientific presentations, which created a unique atmosphere.

A number of events were especially dedicated to school children: the previously mentioned "children's university", the 3rd Summer School in Marine Geosciences (attended by 20 pupils), and two special "research days" for pupils from a region in the southwest of Germany co-sponsored by the Fielmann optics company. IFM-GEOMAR also contributed with the traditional special pro-

Art meets Science: Top: Performative Lecture in the Kiel Art Gallery, bottom: Cape Verde folk music during the Cape Verde Day in the Kulturforum Kiel.
Left column: Top: Summer School in Marine Geosciences, centre: special "research day" with pupils, bottom: open ship on ALKOR during the Kieler Woche 2009.

Top: Kids Festival, below: young visitor of the aquarium. Photo: M. Gulyas / S. Paasch.

gramme for young children during the "Kids Festival" and an open-ship day during the "Kieler Woche".

Since 2009 the two collaborative research projects, SFB 574 & 754, have a special public outreach activity. Its objective is to convey the research performed in the SFBs via new and innovative methods (e.g. YouTube-like videos produced by pupils). This 3-year project has a volume of 350,000 Euros.

IFM-GEOMAR's public aquarium welcomed more than 85,000 visitors during 2009. Since the major renovations in recent years the number of visitors has been steadily increasing. The aquarium again participated very successfully in the "Long Night of the Museums" event in Kiel: more than 2,500 visitors were welcomed on this special occasion. The aquarium also joined a new initiative to attract more visitors, organised as a joint marketing effort by several museums for the harbourfront in Kiel, and aimed in particular at the more than 100 cruise liners that visit Kiel every year.

In addition to the previously mentioned exhibition project of the cluster of excellence, IFM-GEOMAR is currently involved in planning a permanent exhibit on marine sciences for the "OZEANEUM" in Stralsund, the most frequented marine museum in Germany.

Top: Prof. M. Latif, on a public event with the Dalai Lama, below: TV Interview with Prof. P. Herzig.

Other activities related to public outreach included more than 50 lectures for the general public held by IFM-GEOMAR scientists on various occasions, such as during the "Kieler Woche" or on the institute's open day. Furthermore, mentions of IFM-GEOMAR and topics related to marine research have increased, not only in newspapers and other print media, but also through more than 80 TV and radio interviews and other contributions. Finally, several groups, with a total of more than 1,500 people, attended guided tours through the institute.

Details of public talks and media presence can be found in Appendices 6.4 and 6.5.


The End

Scientific Highlights

A selection of short scientific reports in this section provides an overview on IFM-GEOMAR research activities and results throughout 2009. 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.

- Deep Echoes: An interdisciplinary approach to investigate the Oceans
- Modelling El Niño - Southern Oscillation
- Present and past calcium isotope fractionation in marine calcifying organisms
- Changes in biogenic carbon flow in response to sea surface warming
- From Microbial Ecology to Marine Biotechnology
- Genetic markers trace the origin of *Mnemiopsis spp* in Eurasian waters
- Reading stress from crystals
- Fieldwork on the seafloor: We are getting close

Deep echoes: an interdisciplinary approach to investigate the oceans

Gerd Krahmann, Ocean Circulation and Climate Dynamics - Physical Oceangraphy,
Cord Papenberg, Dynamics od the Ocean Floor - Marine Geodynamics

Seismic oceanography is a new field in marine research combining expertise of proven geophysical methods with classical physical oceanography to get more insight into physical processes in the water column. An interdisciplinary working group at IFM-GEOMAR has sucessfully used the in-house expertise for deep ocean investigations.

Physical Oceanography (PO) and Reflection Seismics are two fields that until recently had little to share. Although using the same platform, a research vessel, marine seismologists would gladly empty the world's oceans to gain direct access to their primary target, the interior of the earth, while oceanographers had no use for information below the ocean sea floor. This strong separation was shattered when in 2003 Holbrook et al. described structures within the water column seen by seismic methods. Why were oceanographers so interested in these observations? It was because of the extremely different horizontal resolutions typically sampled by the two communities. PO data is collected from research vessels at discrete locations distanced 10 km or more, while seismic multi-channel-streamer (MCS) data provides information at horizontal scales down to 5 m; four orders of magnitude better. Since Holbrook et al.'s publication the race has thus been on to extract meaningful PO information from MCS data. IFM-GEOMAR's interdisciplinary research group on Seismic Oceanography (SO) participated in the EU-project GO (Geophysical Oceanography) that had the evaluation and development of SO as its goals.

With the Gulf of Cadiz GO picked one of the world ocean's most promising spots to study the possibilities of SO. The outflow of the Mediterranean into the Atlantic Ocean creates a distinct regime in which the different water masses mix through interleaving and create a wealth of layers that can be imaged in seismic data. Additional funding from the DFG allowed in spring 2007 for the first time the use of two research vessels (RRS Discovery and FS Poseidon) to simultaneously collect PO and MCS data. The fruits of the combined measurements are now being collected.

PO yoyo measurements in which a CTD was lowered and raised repeatedly from FS Poseidon (see Figure 1) were converted into information comparable to that collected by the MCS system. The close similarity proved that MCS is indeed imaging oceanic structures. Further analyses of the CTD data showed that the depth variations of seismically reflecting layers closely follow the excursions of isopycnals (Krahmann et al., 2009), a finding that underpinned the calculation of internal wave spectra from MCS reflection sections (Krahmann et al., 2008).

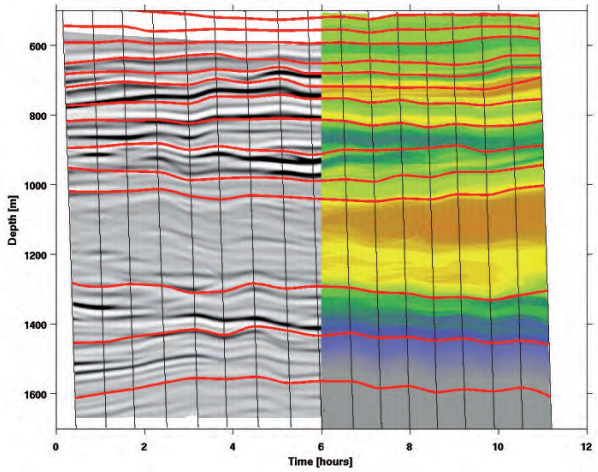


Figure 1: Reflectivity (grey) and temperature (color) of parts of the water column (colorscale is similar to Figure 2) derived from a Yoyo CTD in the Gulf of Cadiz. Also shown are isypycnals (red lines) for the same data. Depth variations of reflectivity and isopycnals go largely hand in hand and allow the use of reflectivities observed with seismic methods as a proxy for isopycnal depth variations.

A major step forward for SO was the combination of MCS and lower accuracy PO data collected with expendable temperature probes (XBT). These two can be collected at the same time from a single ship. The key to the combination lies in the different parts of the variability spectra sampled by the two systems. MCS data is, depending on the configuration of the seismic sound source, restricted to vertical wavelengths between

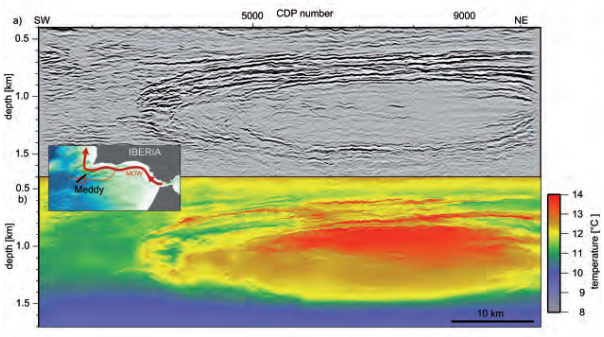


Figure 2: Seismic reflection image (a) and corresponding temperature field (b) derived from seismic-oceanographic data. The seismic section cuts a warm saline Meddy, detached from the main vein of Mediterranean Outflow Water and generating a clear acoustic contrast against the cold Atlantic Water.
The data from Figure 1 compares to about CDP 4000.

about 10 and 200 m. It does, however, collect this data at a very high horizontal resolution. XBTs in contrast sample the ocean at a much lower horizontal resolution but collect temperature measurements every 2 m in the vertical with no limit at the long wavelength end of the spectrum. Using the horizontally coarse resolution XBT data to estimate the long wavelength part of the ocean temperature field and combining this with the horizontally high resolution but bandwidth limited MCS data, we arrived at a combined data set with high resolution in both the horizontal and vertical domain (Papenberg et al., 2010). The resulting images of the ocean‘s temperatures are truly stunning (see Figure 2). In particular intrusive features that occur when two water masses of different thermohaline properties but similar density mix, can with this new type of data be closely followed over long horizontal distances. The details seen in these images might allow us to answer such open questions as what the horizontal aspect ratios of intrusions are or how intrusions radiating away from an eddy are wrapped by its rotation. Further analyses showed that the MCS data was even able to provide information on the dynamics (flow direction) of oceanic water layers (Klaeschen et al., 2009).

Seismic oceanography has made big steps over the past years and already yielded many valuable insights into e.g. the spatial patterns of oceanic fine structure. Some of the challenges even lead to new and unexpected results like e.g. the dynamic movement information that can now be extracted from seismic data. Further opportunities arise from the combination of SO data with that from other recent measurement tools such as microstructure probes and autonomous gliders. In spring 2010 we will conduct such a combined experiment in the Tyrrhenian Sea. We expect that the resulting data will lead to a more quantitative connection between seismic and ocean mixing data.

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Modelling El Niño - Southern Oscillation

Mojib Latif, Wonsun Park, and Noel S. Keenlyside
Ocean Circulation and Climate Dynamics - Maritime Meteorology

El Niño-Southern Oscillation (ENSO) is the strongest natural climate phenomenon on timescales from months to a few years. Sucessfully modelling and subsequently forecasting ENSO is still a challenge although significant progess has been made during the past decades. IFM-GEOMAR scientists developed a new model which is currently being tested for ENSO applications.

The El Niño/Southern Oscillation (ENSO) phenomenon is associated with extreme weather conditions around the globe, and hence of major socioeconomic importance. It originates from ocean - atmosphere interaction in the Tropical Pacific. Although its basic nature is understood, climate models still struggle to simulate it faithfully. A major reason for this is ocean - atmosphere interaction, as it amplifies errors intrinsically existing in component general circulation models. Here we describe results for the Tropical Pacific from the first version of the Kiel Climate Model (KCM, Park et al., 2009), a model that will serve as the dynamical core of the earth system model being developed at the Leibniz Institute of Marine Sciences. The model simulates Tropical Pacific climate relatively well: Sea surface temperature (SST) biases are generally less than 1°C and the annual cycle of SST along the equator matches observations well. Simulated ENSO variability and associated atmospheric patterns are in agreement with observations. Experiments with KCM indicate that ENSO variability will become stronger in response to global warming.

ENSO is characterized by quasi-periodic variations of the Equatorial Pacific SST with a period of about 4 years. Its warm and cold phases are referred to as El Niño and La Niña, respectively. ENSO impacts are felt globally. The record El Niño event of 1997/1998, for instance, "helped" to make 1998 the warmest year to date globally. El Niño events have impacts on almost every aspect of human life: disease outbreaks, low and high agricultural yields, natural disasters, availability of water resources, energy demand, disruption to hydropower generation, price fluctuations, fishery catch fluctuations, animal movements, forest fires, the economic well-being of nations, and many others.

Coupled air-sea feedbacks in the Tropical Pacific influence its annual mean state, annual cycle, and interannual variability. For instance, the existence of an annual cycle in the eastern equatorial Pacific, which is unexpected since the sun crosses the equator twice, is due to such coupled interactions. Also ENSO is an inherently coupled air-sea mode, and its predictability is derived from its coupled nature (Latif et al. 1998). The simulation of Tropical Pacific climate and its variability, however, proves a challenge for global climate model and a wide range of behaviour is simulated. This applies also to the response of the Tropical Pacific to global warming (e. g., Latif and Keenlyside 2009).
In contrast to many models, KCM (Park et al. 2009) simulates Tropical Pacific climate reasonably well. KCM consists of the ECHAM5 atmospheric general circulation model coupled to the NEMO ocean-sea ice general circulation model. No form of flux correction is used. In the Tropics simulated biases are generally not greater than 1°C, except for the warm biases – common to most models – along the west coasts of South America, North America, and Africa. The annual cycle in the eastern Pacific along the equator in KCM agrees well with observations in terms of strength and westward phase propagation indicating its proper representations of coupled air-sea feedback, which is not the case in many other models.

ENSO variability is also reasonably simulated. The spatial pattern of SST standard deviation generally agrees well with observations, but is stronger (not shown). The standard deviations of observed and simulated Niño3 (150-90°W, 5°S-5°N) averaged SST anomalies is 0.79 and 0.93, respectively. As observed, KCM's ENSO variability has a dominant periodicity of four years. Associated sea level pressure patterns are well represented

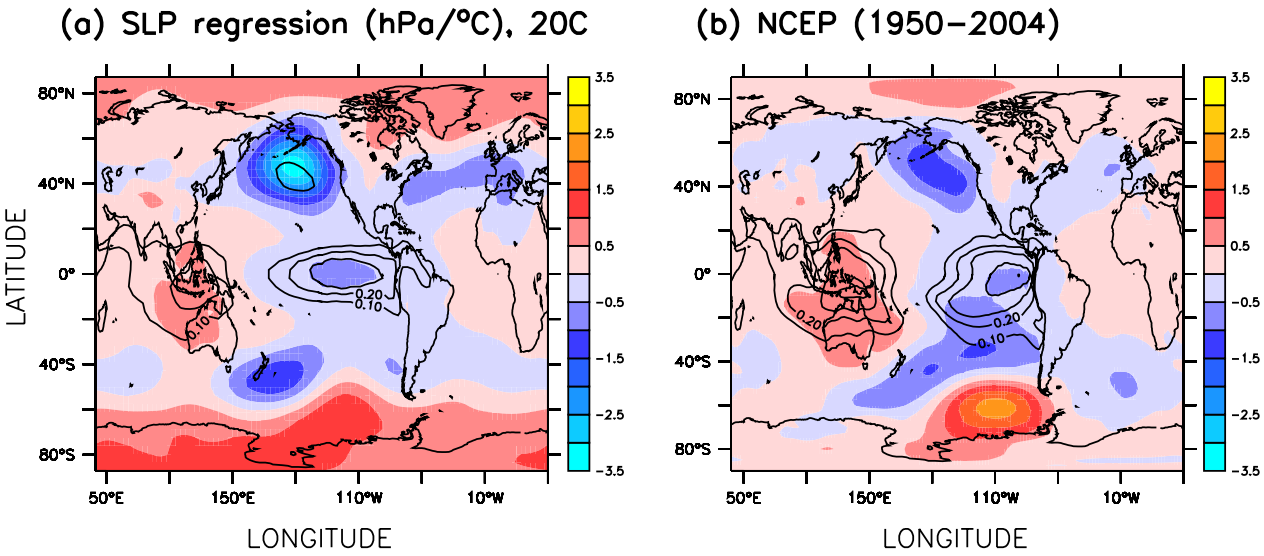

Figure 1: Regression (shading) and explained variance (contour) of monthly anomalies of Niño3 SST onto sea level pressure (hPa/°C): (a) simulated, and (b) observed. From: Park et al. 2009.

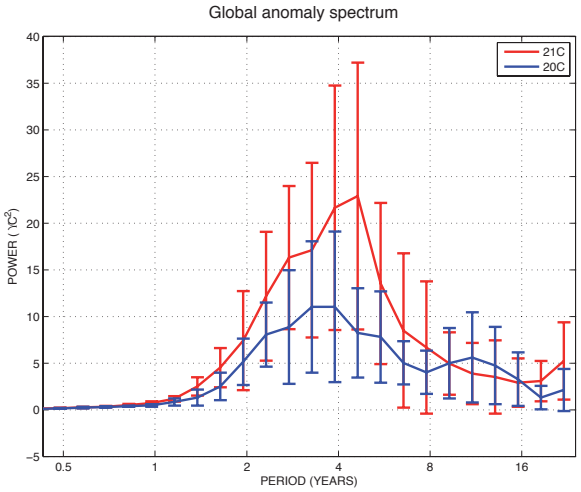

Figure 2: Ensemble-mean spectra [°C²] of Niño3 SST anomalies. Bars indicate the ensemble one standard deviation range. From: Park et al., 2009.

(Fig.1): during warm events the model simulates the typical Southern Oscillation pattern in the Tropics, the intensification (deepening) of the Aleutian low over the North Pacific, enhanced pressure over the eastern South Pacific, and the weak teleconnection over the North Atlantic.

The ENSO response to global warming was investigated in ensemble simulations with CO_2 concentration increasing at 1%/year (compound). The ensemble mean spectrum (21C) displays an increase in variability relative to that derived from the control run (20C) that is most pronounced at interannual timescales (Fig. 2). At the ENSO peak period of about 4 years the increase in power amounts to about 70%. The overall shape of the spectrum does not change much and the ENSO period remains almost constant at about 4 years, although a small shift to a longer period is simulated. The distribution of Niño3 SST anomalies (not shown) becomes wider in the global warming (21C) integrations indicating an overall enhanced variability. Of particular interest, both extreme warm and extreme cold events become more frequent, with stronger changes in the warm extremes.

Next steps will involve the extension of KCM by adding other components of the earth system. Special emphasis will be put on the coupling of ocean biogeochemistry and the investigation of the coupled physical/ocean biogeochemistry response to global warming.

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Present and past calcium isotope fractionation in marine calcifying organisms

Anton Eisenhauer, Marine Geosystems - Marine Biogeochemistry

Precise isotope analysis has developed to one of the most important tool in marine geochemistry. Accurate isotope fractionation is used for climate reconstructions for millions years back into the Earth's history.

Recent advances in thermal and plasma mass spectrometry have allowed the precise measurement of small differences in Ca isotope composition in $CaCO_3$. As a result, recent isotope studies of Ca biomineralization have been able to test whether Ca isotopes can provide an environmental indicator - e.g. of *T* - using marine $CaCO_3$ as an archive. It was hoped that development of this tool would provide information complementary to that gained from more traditional marine *T* data, such as Mg/Ca in foraminifera and Sr/Ca in corals. For both calcite and aragonite—two out of six polymorphs of $CaCO_3$—precipitation experiments have shown that $\Delta^{44/40}Ca_{CC\text{-}BS}$ (CC: Calcit; BS: Bulk Solution) for inorganic aragonite correlates with *T* (~0.02‰/ºC) (Fig. 1). However, aragonite displays an offset of ~-0.5‰ relative to calcite. In contrast, Ca isotope fractionation in biogenic $CaCO_3$ depends on more factors than simply polymorphism. Aragonitic sclerosponges and pteropods secrete skeletons with a fractionation factor similar to that for inorganic aragonite, whereas aragonitic scleractinian corals, calcitic coccolithophores, and calcitic planktonic foraminifera have comparable degrees of isotope fractionation, lying between the values for inorganic calcite and aragonite (Fig. 1). Two species of planktonic foraminifera, *G.s sacculifer* and *N.pachyderma* (sin.), show greater dependence of $\Delta^{44/40}Ca_{CC\text{-}GS}$ on T (Fig. 1). Given their different habitats (tropical versus polar surface ocean), both species show surprisingly similar T sensitivity (~0.24‰/ºC). This was observed in laboratory cultures and in planktic foraminifera collected from the ocean with tow samplers. However, other studies involving these same species failed to reproduce the large *T* dependence (Griffith et al., 2008a), suggesting an influence of salinity and *T* thresholds for the various species (Hippler et al., 2009). Latter observation indicates a complex and unpredictable physiological control on Ca uptake by calcifying organisms prior to $CaCO_3$ formation challenging its use as paleo-temperature proxy.

Calcium is provided to the ocean by rivers that drain mineral-weathering areas on the continents and by hydrothermal activity in the oceans. An additional source of Ca flux in the geological past was dolomitization (Heuser et al., 2005), in which Ca in $CaCO_3$ was replaced by Mg. In the modern ocean, the most important sinks for Ca are biogenic precipitation and sedimentary deposition of $CaCO_3$. Less important is the formation of $CaCO_3$ during low *T* alteration of ocean crust. The actual isotope compositions of Ca sinks and sources are similar, so the modern ocean is close to or at steady state (Schmitt et al., 2003). However, the situation must have been different in the geological past. For example, De La Rocha and DePaolo (2000) showed that

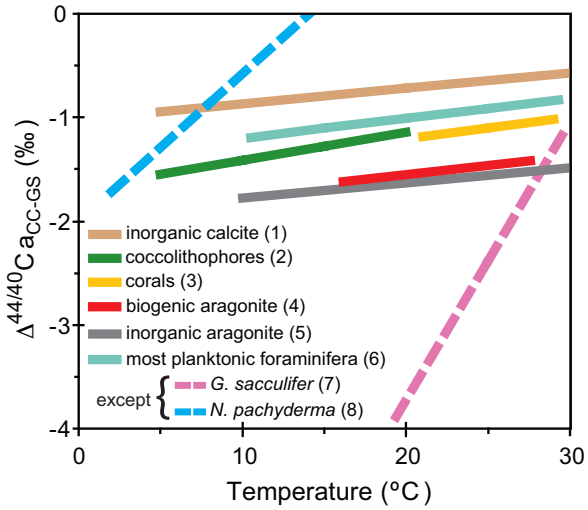

Figure 1:Temperature dependent Ca isotope fractionation in: 1) inorganic calcite 2) calcite of coccolithophores 3) aragonite skeletons of sceleractinian corals 4) aragonite shells of sclerosponges and pteropods 5) inorganic aragonite, 6) calcite of most planktonic foraminifera, 7) planktonic foraminifer Globigerinoides sacculifer, and 8) planktonic foraminifer Neogloboquadrina pachyderma (sin.).

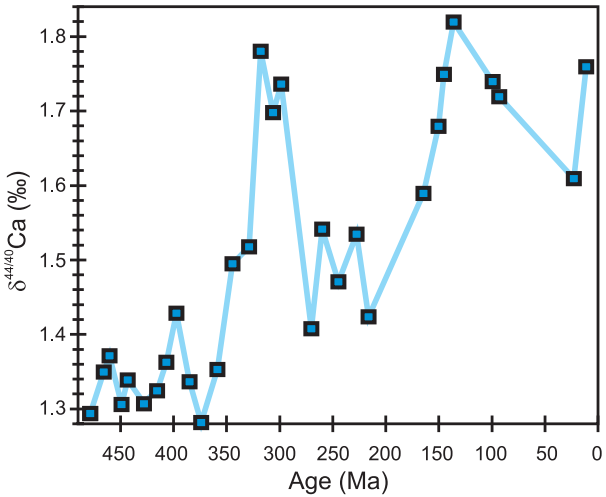

Figure 2: Phanerozoic history of seawater calcium isotope composition ($\delta^{44/40}Ca$) recorded in marine fossils (brachiopods and belemnites) and planktic foraminifera) are averaged in 10 million year bins. The record shows a general increase with time from low values in the Early Paleozoic (540 to 360 Ma) to high values in the Early Cretaceous (146 to 100 Ma) and Neogene (23 to 0 Ma). A sharp rise during the Carboniferous (360 to 300 Ma) and a second rise occurred during the Late Jurassic (160 to 145 Ma).

$\delta^{44/40}Ca$ varied considerably during the last 80 My. During the early Paleogene, relatively high $\delta^{44/40}Ca$ values reflected the fact that Ca input flux was ~80% of the output flux for a period of ~25 My, causing Ca concentration in seawater to decrease. Further studies confirmed that substantial fluctuations in the $\delta^{44/40}Ca$ of seawater occurred during the Neogene (c.f. Griffith et al., 2008b) and earlier in Earth history. Variations much longer than the Ca residence time (Fig. 2) cannot be explained by imbalances in the ocean Ca budget. In this regard, Heuser et al. (2005) suggested that the formation of dolomite [$MgCa(CO_3)_2$] leads to isotope fractionation as Ca is replaced by Mg in marine $CaCO_3$. The enrichment of dolomite in heavy Ca isotopes enriches seawater in lighter Ca isotopes. In contrast, diminishing dolomitization in the ocean enriches seawater in heavier Ca isotopes possibly explaining the gradual increase in the Ca isotope composition of seawater from the Miocene Climatic Optimum (time interval of high atmospheric and seawater temperatures also characterized by large continental shelfs and sub- to anoxic conditions in ocean water between 17 and 15 Ma) to the present.

A sudden increase of the Ca isotope values, such as the one at the beginning of the Late Paleozoic (350 Ma; Fig. 2), correlate with a shift from the Early Paleozoic calcitic sea to the Late Paleozoic aragonitic sea. Ca isotope fractionation is offset by about 0.5 ‰ between calcite and aragonite, so the shift from a calcite- to an aragonite-dominated ocean would be expected to cause a shift in the seawater Ca isotope composition.

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Changes in biogenic carbon flow in response to sea surface warming

Julia Wohlers and Ulf Riebesell, Marine Biogeochemistry - Biological Oceanography

Human-induced climate change is causing a warming of the surface ocean. Due to widely differing temperature sensitivities of key biological processes, this may have profound implications for marine food web interactions and the biogeochemical cycling of key elements such as carbon. Using a novel indoor-mesocosm approach, we show that rising sea surface temperature shifts the balance between photosynthetic production and respiratory consumption of organic carbon in a plankton community. This may weaken the ocean's capacity to sequester atmospheric CO_2, hence providing a positive feedback to anthropogenic climate change.

Throughout Earth's history the ocean has played a dominant role in the climate system through the storage and transport of heat and the exchange of climate-active gases, such as carbon dioxide (CO_2). While these processes have helped to mitigate the human-induced rise of atmospheric CO_2 and the associated global warming since the beginning of the industrial era, they are in turn also causing profound alterations of the ocean's chemical and physical properties. For instance, the upper 700 m of the ocean have already warmed by 0.1°C within the last 40 years, whereas surface pH values have dropped by 0.1 units. In the next decades, these changes are likely to accelerate with, for instance, a predicted increase in global mean surface temperature between 1.1°C (low CO_2 emission scenario B1) and 6.4°C (high CO_2 emission scenario A1FI) until the end of the 21st century.

Sea surface warming will affect the pelagic ecosystem in two ways; directly through the effect of temperature on the rates of biological processes, and indirectly through reduced surface layer mixing, causing decreased nutrient supply and increased light availability for photosynthetic organisms suspended in the upper mixed layer. It is expected that these changes in the physical and chemical environment will have drastic effects on the marine biota. Concerning the direct temperature effect it has been shown, that key biological processes of the pelagic ecosystem differ greatly regarding their temperature sensitivities. Most prominently, autotrophic growth and photosynthesis of phytoplankton typically display a weaker response to changes in ambient temperature than heterotrophic processes, such as the bacterial degradation of organic matter. Accordingly, surface ocean warming is expected to shift the balance between the sources and the sinks of organic matter. Ultimately, such alterations in the interplay of key processes involved in ocean carbon cycling may affect both pelagic food web structures and the functioning of the biological carbon pump, which transports surface-bound organic carbon to the deep sea and hence contributes to the ocean's capacity to take up atmospheric CO_2.

Figure 1: The indoor-mesocosms at the IFM-GEOMAR. Photo: J. Wohlers.

To investigate how rising sea surface temperature will affect the cycling and fate of organic carbon within a natural spring plankton community we conducted an indoor-mesocosm study using a novel set-up available at the IFM-GEOMAR in Kiel. This approach consisted of eight water tanks with a volume of 1400 L each, so-called mesocosms, which were distributed onto four temperature-controlled climate chambers (Fig. 1). After filling the mesocosms with unfiltered seawater from Kiel Bight (Baltic Sea), the plankton community was exposed to four different temperatures: the *in situ* temperature (T+0), following the natural seasonal temperature regime observed in Kiel Bight, as well as three elevated temperatures according to the projec-

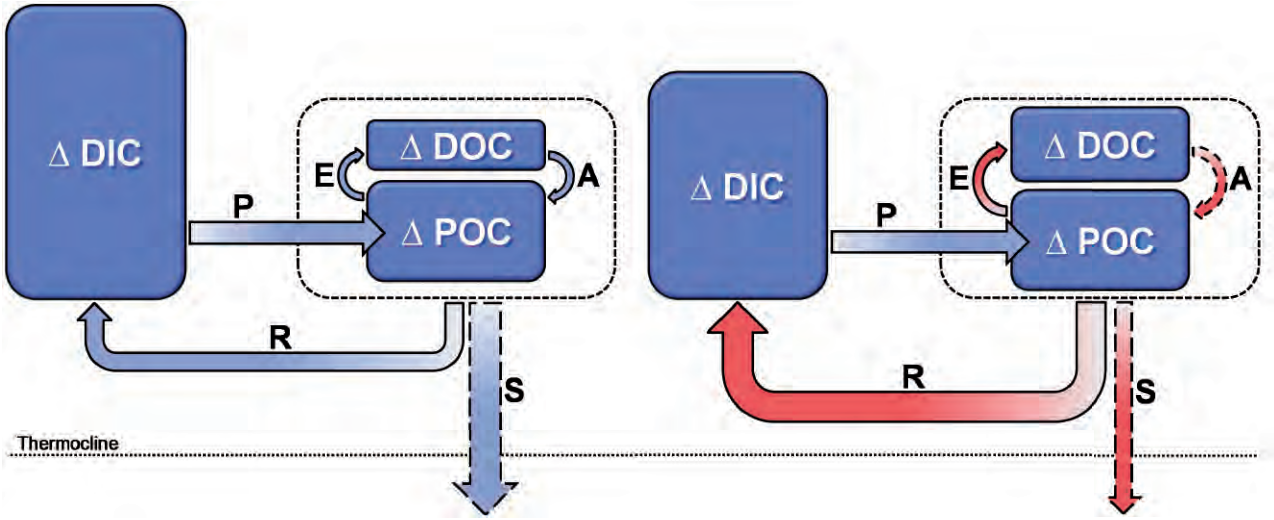

Figure 2: A schematic illustrating the surface layer carbon flow during an algal spring bloom under present (left) and elevated (right) sea surface temperature. Boxes (ΔDIC, ΔPOC, ΔDOC) represent the change in the reservoirs of dissolved inorganic carbon (DIC) and dissolved and particulate organic carbon (DOC, POC) over time. Arrows depict processes (P = primary production, E = exudation, R = respiration, S = sinking, A = aggregation). Processes found to be sensitive to warming in this study are marked in red in the right panel. According to our findings, rising sea surface temperature leads to enhanced respiratory consumption of organic carbon relative to its photosynthetic production. This results in a decline in net DIC consumption, enhanced accumulation of DOC and a lowered availability of organic carbon for export processes.

tions of the Intergovernmental Panel on Climate Change (IPCC), i.e. *in situ* +2°C (T+2), *in situ* +4°C (T+4) and *in situ* +6°C (T+6). In each of the mesocosms the build-up and decline of the spring bloom was closely monitored over 30 days.

In line with theoretical considerations, rising sea surface temperature clearly stimulated both the bacterial decomposition and the respiration of the plankton community relative to the photosynthetic production of organically bound carbon by phytoplankton cells (illustrated in Fig. 2). This led to a rapid replenishment of CO_2 at elevated temperatures, hence reducing the biological net drawdown of dissolved inorganic carbon (DIC) significantly by up to 31%. Moreover, warming markedly shifted organic carbon accumulation from the particulate (POC) to the dissolved form (DOC). Together, these changes in the biologically-mediated flow of carbon within a natural plankton community indicate an enhanced organic matter flux through the microbial loop, hence reducing the transfer of energy and matter to higher trophic levels of the food web, and decreasing the availability of POC for export to depth. In concert, sea surface warming thus has a strong potential to alter pelagic food web structures and to reduce the efficiency of the biological carbon pump in sequestering carbon from the surface to the deep ocean, with implications for the sustainability of global fisheries and the ocean's mitigating effect on anthropogenic climate change.

Based on our findings, surface ocean warming is indicated to be one of the most powerful drivers of future changes in ocean productivity, biogeochemical cycling and air-sea CO_2 exchange. Additional effort of both experimental and observational scientists and modellers is needed to further improve our understanding of the sensitivities of upper-ocean, biotically-driven processes to global change and their feedback potential to the climate system.

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From microbial ecology to marine biotechnology

Johannes F. Imhoff, Marine Ecology - Marine Microbiology

The Kieler Wirkstoff-Zentrum KiWiZ (Centre for Marine Natural Products) at IFM-GEOMAR is investigating opportunities to use substances from microbial communties for medical and other applications. The new field of Marine Biotechnology is an emering area in Marine Sciences.

In recent years, communities of microorganisms associated with various marine macroorganisms have received much attention. In particular, microbial communities associated with sponges, macroalgae or bryozoa were intensively studied both by genetic analysis with the 16S rRNA gene as marker molecule and by pure cultures investigations. The microbial potential to produce biologically active secondary metabolites was determined with emphasis on metabolite-driven interactions between different organisms in these communities.

Bacterial communities of the alga *Laminaria saccharina,* which were one of the major study objects, not only are highly diverse but also harbour specific bacteria. One example is the new bacterium *Kiloniella laminariae* which is the first known representative of a completely new phylogenetic line, a new order of the Alphaproteobacteria (Wiese et al., 2009a). Specifically different bacterial communities are found on the surface of the rhizoid, cauloid, phylloid, and thallus tip of *Laminaria saccharina* (Staufenberger *et al*., 2008). This finding and the specific association of bacteria with algae in general (Lachnit et al., 2009) strongly indicates interactions between the algae and the bacteria shaping the community structure in a specific manner. Small molecules with biological activities are considered to play an important role in these interactions. An interesting example is a *Pseudomonas* strain isolated from the thallus of *Laminaria saccharina* (Wiese et al., 2009b) which produces four different biologically active substances: 2,4-diacetyl phloroglucinol and pyoluteorin are inhibiting other bacteria, phloroacetophenone and rhizoxin S1 inhibit fungi. The production of these substances is in favour of the producer by inhibition of competing microorganisms but also in favour of *Laminaria saccharina* by protecting the alga from overgrowing microorganisms and from pathogens.

Another research focus is dealing with sponge-associated microorganisms and possible interactions between these microorganisms and the sponge. To a great part, bacteria associated with the sponge *Halichondria panicea* are able to produce antibiotically active substances and the analysis of actinobacterial isolates from this sponge demonstrated their ability to produce a great number of known bioactive substances but also revealed many so far not identified possibly new compounds. Quite interestingly there are multiple interactions between these bacteria based on their excreted secondary metabolites, though these interactions are poorly understood. Interestingly, low concentrations of the antibiotic bacitracin, which is produced by a *Bacillus* species, stimulated the production of new biological active substances in a *Streptomyces* strain isolated from the sponge (Mitova et al., 2008). These substances, different streptophenazines, in turn inhibited the growth of various *Bacillus* strains. Representatives of both genera, *Streptomyces* and *Bacillus*, co-occur in the bacterial communities of *Halichondria panicea* and therefore the findings in the laboratory may very well be of relevance in the environment. These few examples demonstrate the importance of interspecies interactions in the microbial communities associated with sponges and

Figure 1 (left): Examples of different marine organism such as sponges, algae, bacteria and fungi.

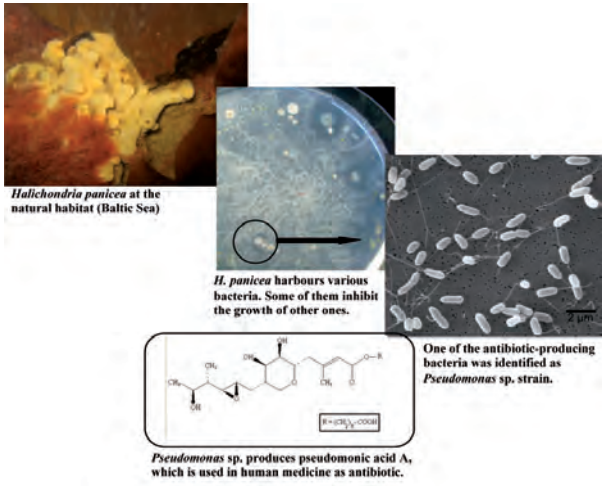

Figure 2: From the habitat to the biologically active compound.

other marine macroorganisms.

Despite of their presumed ecological relevance, biologically active substances from marine microorganisms represent a great potential for biotechnological application. Therefore, in the Research Unit Marine Microbiology and the Kieler Wirkstoff-Zentrum (KiWiZ) classical and molecular approaches are combined not only to evaluate the ecological significance of secondary metabolites produced by marine bacteria and fungi but also to establish their biotechnological potential. This is a promising approach because marine microorganisms have only recently been attained significant interest in this respect, many of these represent specific marine forms of life and a particularly high percentage of microorganisms associated with various marine macroorganisms is able to produce biological active substances. One of the most promising applications of such secondary metabolites from marine microorganisms is their use as drugs in the treatment of human diseases. Because there is a strong need for the detection of new drugs, e.g. for the treatment of infectious, cancer, inflammation or metabolic diseases such as diabetes, research on natural products as performed at the KiWiZ is highly demanded. In particular a project on the establishment of a substance library of marine natural products is of great significance, because it is supposed to meet the urgent demand for new chemical structures for drug development. The KiWiZ is well established for this research: it uses a great collection of biologically active strains of marine bacteria and marine fungi derived from different marine habitats, has profound technical equipment for microbiological and chemical analyses, uses a number of established bioassays for activity measurements, and has an engaged interdisciplinary team for laboratory work and networking with local, national and international partners. Interesting substances are promoted for applications in cosmetics, plant protection and pharmacy and the application of most promising candidates is protected by patents. Patent protection was achieved for cyclodepsipeptides produced by a sponge-associated fungus *Scopulariopsis brevicaulis* (Imhoff et al., 2008, 2009). Recently, also antitumoral drug candidates, new benzanthrins from a sponge-associated *Streptomyces* strain, were patented (Schneemann et al., 2010).

We are therefore convinced, that small biological active molecules from marine microorganisms provide great perspectives both for in depth ecological studies and for biotechnological applications.

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Genetic markers trace the origin of *Mnemiopsis* spp in Eurasian waters

Thorsten Reusch, Sören Bolte, Jamileh Javidpour, Experimental Ecology - Evolutionary Ecology of Marine Fishes, and Experimental Ecology - Foodwebs

Changing environmental conditions, worldwide transport by commerical ships provide the basis for the increasing rates of marine invasions with substantial impact of marine ecosystems. Here we focus on the comb jelly Mnemiopsis leidyi one of the most prominent marine invaders. worldwide.

Marine invasions continue at an ever increasing rate. The driving forces are the transport of propogules, larvae or adults of non-indigenous marine organisms, predominantly via ballast waters of cargo ships. This unintentional globalization leads to local reassembly of marine biodiversity, with coastal areas often being the host of more non-indigenous species than native ones. More importantly, the homogenization of marine habitat has the potential to completely restructure food webs and to alter ecosystem functioning. One striking case in point is introductions of the comb jelly *Mnemiopsis leidyi* (Fig. 1) from American coasts of Atlantic to Eurasia, starting in the 1980s. This zooplanktivorous species is able to consume the complete secondary production when it reaches high densities in its native habitat along the US east coast. Hence, when some years after the first observation in Black, Azov and Caspian Sea, the zooplanktivorous fish stocks collapsed, with concomitant severe socio-economic consequences. However, additional anthropogenic influences for the jellyfication of these seas such as overfishing, eutrophication and climate warming cannot be dismissed.

One first key information in invasion biology are the questions (i) from where the inoculum originated (ii) whether the invasion has had single or multiple origins and (iii) whether or not the invader species in its new location is genetically depauperate compared to the native habitat. In particular the two latter questions refer to a role of genetic and evolutionary processes that can determine the success and hence, the impact of an invasive population. For example, there is evidence that upon mixing of several genetically distinct invasion waves (hybridization), 'super'-genotypes with a much stronger ecological performance and environmental tolerance may exacerbate the effects of the newcomers. As a counteracting process, the loss of genetic variation through a genetic bottleneck, as expected in an invasion with a small inoculum size, should decrease the adaptive potential of invaders.

We set out to address above questions in the recent invasion of Mnemiopsis spp into North- and Baltic Sea, where the species was first recorded four years ago. Given the history of earlier Mnemiopsis invasion, the ecological consequences of this species in its new habitat are of high concern to marine ecology and management. As a prerequisite to answer above questions, we first developed high-resolution molecular genetic markers (microsatellites) that are able to measure population affiliation, genetic distinctness and genetic diversity in population samples. For the first time in the *phylum Ctenophora* (comb jellies), these microsatellites were applied to samples coming from 13 native and invaded locations collected in 2008 and 2009.

Figure 1: Mnemiopsis leidyi from the Baltic Sea, Photo: J. Javidpour.

With respect to the origin of invasion, the genetic patterns revealed a very clear-cut picture (Fig. 2). There were clearly two major invasion waves, one earlier with an origin close to the Gulf of Mexico, which then reached the Black and Azov Sea in the 1980s. From there, in a stepping-stone manner, specimens reached the Caspian Sea in the late 1990s. In contrast, the recent invasion to the North- and Baltic Sea had an independent origin. With a completely independent source

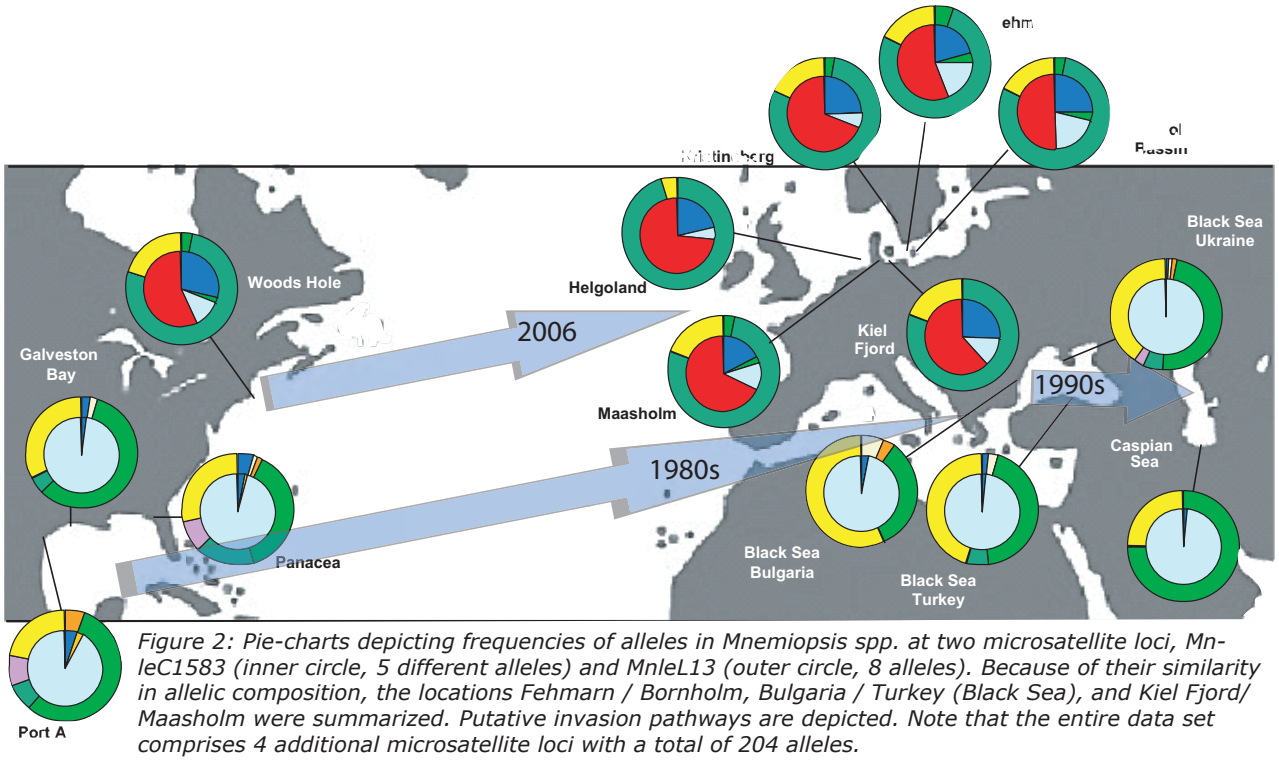

Figure 2: Pie-charts depicting frequencies of alleles in Mnemiopsis spp. at two microsatellite loci, MnleC1583 (inner circle, 5 different alleles) and MnleL13 (outer circle, 8 alleles). Because of their similarity in allelic composition, the locations Fehmarn / Bornholm, Bulgaria / Turkey (Black Sea), and Kiel Fjord/ Maasholm were summarized. Putative invasion pathways are depicted. Note that the entire data set comprises 4 additional microsatellite loci with a total of 204 alleles.

population, individuals were transported from a location in New England to Northern European shores. In fact, we cannot measure any genetic differentiation between the samples taken in Woods Hole versus the south-western Baltic near Kiel. Interestingly, the North Sea is comprised of a somewhat different and genetically less diverse gene pool which clearly indicates that the Baltic Sea population is not a spill-over of the North Sea. At present, there is no indication that these two invasion waves have mixed. Nevertheless, new reports of Mnemiopsis from the western Mediterranean Sea indicate a potential mixing area, a question that we will closely monitor in the near future.

As for the genetic diversity, it is interesting that the earlier invasion revealed a classical reduction in both the number of alleles at the microsatellite markers, and of the heterozygosity. While the source populations in the Gulf of Mexico region reveal on average 9.6 alleles / locus, this drops to 6 alleles in the Caspian Sea population. However, there is no indication that the genetic diversity in the Baltic Sea is reduced compared to New England. These results demonstrate that even within the same taxon, the comb jelly Mnemiopsis, we find a genetic bottleneck in one invasion wave, but not in the other.

Moreover the identification of two rather distinct source gene pools along the US East coast has taxonomic implications. The Gulf coast is inhabited by a morphologically identified different Mnemiopsis species, M. mccradyi (Meyer 1900), which has recently been questioned based on DNA barcoding sequences. Our microsatellite data, in contrast, call for a reconsideration of two different species that occur along the US East coast, a more northern one (*M. leidyi*), and a southern one (*M. mccradyi*). Clearly, more taxonomical, ultrastructural and molecular genetic work needs to be done before the taxonomic status of the Mnemiopsis taxa can be resolved.

Our future work will address the question of rapid adaptation of invasive populations to their new habitat. Can we already find molecular genetic adaptation in selectively relevant genes between individuals from the native habitat, and after either 20 yrs, or 4 yrs of selection in the Black or Baltic Sea, respectively? These data will shed light on the amazing ecological and evolutionary adaptability of many invasive species that seem to contradict the concept of a tight match between a species niche and its environment.

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Reading stress from crystals

Michael Stipp, Dynamics of the Ocean Floor - Marine Geodynamics

Tectonic stresses lead to the deformation of the Earth's crust and upper mantle. They are the driving force behind plate motion and mountain building, and they control earthquake distribution and intensity. These stresses can be measured from deformation microstructures of previously deeply buried rocks using paleo-piezometers. A new assessment of microstructural data from naturally deformed quartz-bearing rocks indicates that the mechanism of recrystallization fundamentally affects the piezometers. Our findings point out major inaccuracies of stress estimates published in the last 40 years, and it prepares the field for a new piezometer generation that will provide a significantly improved assessment of the stress states in lithospheric plates and plate boundaries.

Understanding the Earth´s deformation, from seismic rupture on discrete faults to aseismic plastic deformation in shear zones, requires careful quantification of the controlling parameters. Stress is the most critical parameter, but it is very difficult to measure. Direct stress measurements in the Earth´s upper crust can be made in boreholes and from GPS monitoring of Earth's surface deformation. At greater depths, only indirect measurements are possible. The most powerful tool is the examination of crystal microstructures in rocks exhumed from paleo-shear zones. The most reliable and widely used stress indicator (piezometer) is the dynamically recrystallized grain size resulting from dislocation creep, the dominant plastic deformation mechanism within the middle and lower crust and the upper mantle. Plastic deformation in shear zones is accommodated by a few rheologically critical minerals. In the crust, for example in the deeply subducted rocks at convergent plate margins, these are quartz, plagioclase, calcite, and mica. In the mantle, these minerals are olivine and pyroxene. To understand why deformation is localized in shear zones, how shear zones develop, and under which conditions the transition from aseismic to seismic behavior occurs, it is necessary to study deformation microstructures of these minerals.

Plastic deformation causes dynamic recrystallization in rocks. The microstructures formed in this way are "frozen" when the rocks are brought up to the Earth's surface by tectonic uplift and exhumation. Structural geologists and metamorphic petrologists can read this microstructural memory, and reconstruct the depth and temperature at which the rocks were deformed. Overprinting relationships and geochronology further allow dating of the deformation at depth. Most importantly, however, microstructures indicate if deformation was brittle (seismic) or plastic (aseismic). In the latter case, the paleostress and thus rock strength can be determined from the dynamically recrystallized grain size of

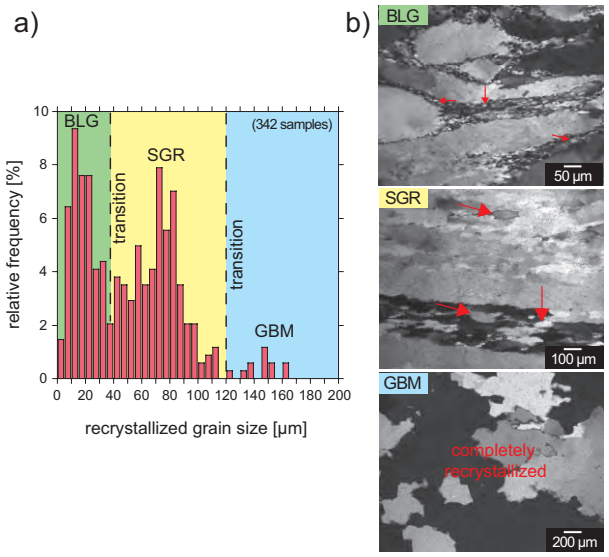

Figure 1: Dynamic recrystallization of quartz in crustal shear zones worldwide. a) Distribution of the mean recrystallized grain size in the range from 0 to 200 µm and related microstructural transitions.
b) The three characteristic recrystallization microstructures (light-optical microscope images, polarized light): bulging recrystallization (BLG; low temperature), subgrain rotation recrystallization (SGR; intermediate temperature), grain boundary migration recrystallization (GBM; high temperature, completely recrystallized). The size of the recrystallized grains (arrows) is inversely proportional to the stress.

the rheologically critical mineral, using piezometer equations. In this way, the temperature and stress conditions are known for the change from aseismic to seismic deformation in the so-called "seismogenic zone", because dynamic recrystallization is persistent until the rocks start to fracture. In addition, plastic deformation during postseismic creep is part of the seismic cycle. Hence, stresses from piezometers characterize not only the plas-

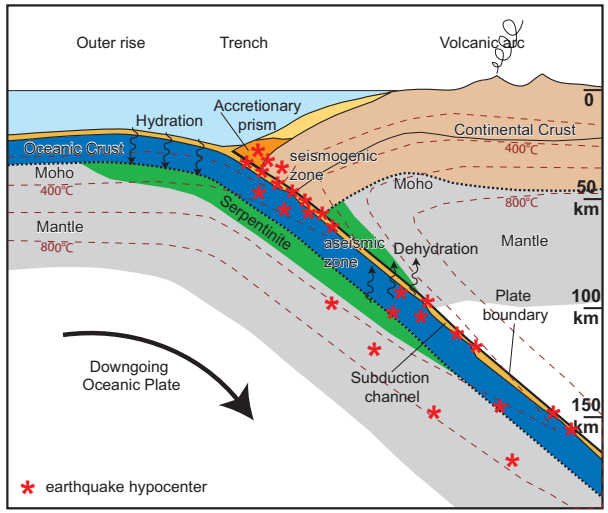

Figure 2: Schematic cross section through a subduction zone (e.g. Chile) displaying sediment transport into accretionary prism and subduction channel. The occurrence of seismic and aseismic deformation and the intensity of earthquakes are controlled by tectonic stresses.

tic deformation, but also represent minimum estimates of the stresses required for fracturing and generation of earthquakes.

Numerous studies have attempted to experimentally calibrate piezometer equations for the most important minerals: quartz, olivine, calcite, and feldspar, along with theoretically derived piezometer equations. These have been applied by hundreds of researchers working on shear zones worldwide for the past 40 years. One quite obvious microstructural feature, however, has largely been neglected: that new grain formation and growth by dynamic recrystallization is not a single process, but the result of different interacting processes. In quartz, for example, three characteristic mechanisms can be determined based on the interaction of three basic processes. Because recrystallization in nature is very slow, it is impossible to reproduce the full range of dynamic recrystallization mechanisms in laboratory experiments. Crucial information has to come from quartz microstructures found in natural shear zones. While a qualitative description of microstructural changes is quite straightforward (Fig. 1), related quantitative parameter changes are yet to be defined. Global analyses on the size-frequency distribution of dynamically recrystallized materials are completely lacking. This prompted a group of researchers from IFM-GEOMAR and Brown University (USA) to undertake the first systematic investigation of recrystallized grain size distributions of quartz by analyzing the data of 555 samples from 31 studies on shear zones worldwide. In our statistical analysis we discovered a remarkable grouping in recrystallized grain size distribution, which is directly correlated to the three different recrystallization mechanisms (Fig. 1). The observed discontinuous distribution calls for distinct piezometer calibrations for different recrystallization mechanisms of quartz. This forces a reassessment of stress estimates published so far. As recrystallization mechanisms in other minerals controlling the plastic behavior of rocks, metals and ceramics, and also in water ice, are very similar to quartz, our findings will change the general understanding on dynamic recrystallization processes and the related stresses.

The rheology of quartz is not only important for intracrustal shear zones, but also for plastic flow and stress in subduction zones, in the buried rocks filling the so-called subduction channel (Fig. 2). Deep seismic imaging indicates that in addition to downgoing mantle lithosphere and oceanic crust, continental slivers and marine sediments are transported deep into the Earth´s mantle. In most of these materials quartz is the mineral defining the plastic behavior of the whole rock. In the rare cases where such rocks were later exhumed by tectonic processes (e.g. in the Alps or the Norwegian Caledonides), stress estimates provide crucial information on the physics of subduction processes. Experimental data show that quartz can suffer dramatic strain-hardening by small parameter changes, e.g. strain rate increase due to more localized deformation or dehydration at high pressures. This in turn forms mechanical asperities near the deep end of the seismogenic zone or deeper in the subduction channel where earthquakes are generated. Hence, the new findings on recrystallized grain size distribution of quartz allow for a better understanding of the plastic to brittle transition and thus earthquake nucleation in the subduction channels at convergent plate boundaries.

Reference

Stipp, M., Tullis, J., Scherwath, M. and Behrmann, J.H., 2010: A new perspective on paleopiezometry: Dynamically recrystallized grain size distributions indicate mechanism changes. *Geology*, **38**, 759-762, doi: 10.1130/G31162.1

Fieldwork on the seafloor: we are getting close

Colin Devey, Dynamics of the Ocean Floor - Magmatic & Hydrothermal Systems

Marine scientists studying the seafloor always have to deal with the fact that the research vessel they are sailing with will be separated from the object they wish to study by several kilometers of water. Technological developments are helping IFM-GEOMAR scientists to overcome this problem and producing astounding results.

Imagine asking someone to describe the environment and culture of the Alps while at the same time forbidding them to go within three kilometres of what they should describe. Ridiculous, you might say. But it is exactly the situation faced by scientists studying the seafloor. Even making a decent map of the seafloor is a difficult task - the best ship-mounted sonars in the world cannot overcome the physics of sound travelling in water so the resolution of such sonars (the "pixel size") is at best in the range of 10´s of metres.

The only solution is to use deep submergence technology to bring sensors close to or onto the seafloor where they can study the environment in much more detail. IFM-GEOMAR is using a three-pronged approach to this problem - landers for long term observations at one seafloor site, remotely operated vehicles ("hands and eyes on the seafloor") for carrying out experiments and precise sampling and visual observation of the seafloor and the newest addition to the fleet, an autonomous underwater vehicle ("AUV") named ABYSS.

ABYSS is a cigar-shaped vehicle approximately four metres long and weighing 900kg in air (see photo). It is powered by lithium batteries which deliver about 11kWh of power, allowing the vehicle to operate for up to 24 hours without recharging.

On board the vehicle are numerous sensors for measuring, for example, the seafloor bathymetry (with a resolution of much less than 1 metre), the acoustic hardness of the seafloor (enabling a distinction to be made between soft sediment and hard rock, for example) the temperature, salinity, clarity and Eh (a measure of the oxidizing or reducing nature) of the water. The vehicle can also be re-configured to take still photographs of the seafloor and measure sediment thickness.

The first scientific deployments of ABYSS have concentrated on mapping the seafloor in great detail and have returned amazing scientific results. As the vehicle was acquired as part of the DFG Priority Programm 1144 which focussed on mid-ocean ridge processes, it is hardly surprising that ABYSS went to the ridge areas first.

Figure1: ABYSS in its Launch and Recovery System, ready to start a new dive to the seabed.

The initial scientific dives were in the Atlantic in an area known as Lilliput. This area had previously been mapped by the AUV "ABE" from the Woods Hole Institution and so the area was a good place to go to test just what ABYSS was capable of. The results were astounding. ABYSS collected data with its state of the art RESON 7125 multibeam sonar at both 200 and 400kHz, enabling us to produce maps which for the first time allowed volcanological interpretation of the seafloor based on its bathymetry. An example is shown in Figure 2.

The second scientific mission saw ABYSS deployed in the Woodlark Basin, east of Papua New Guinea. Here again the target was a spreading axis, this time dominated by small

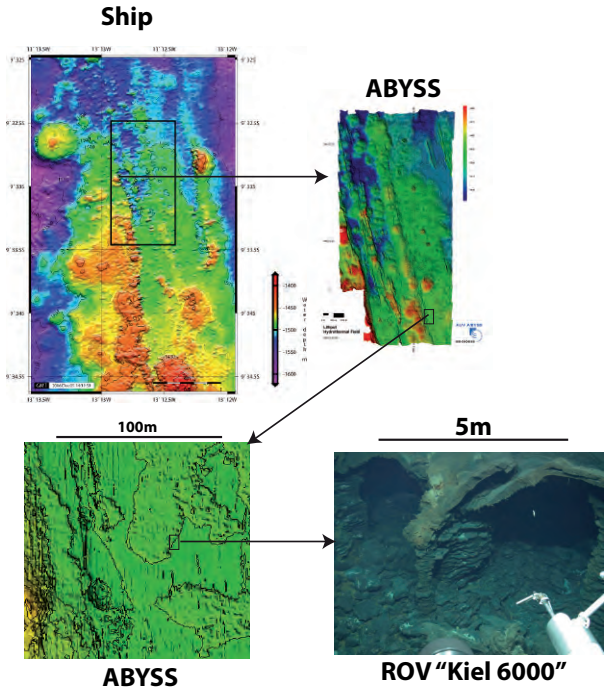

Figure 2: The advantages of getting close to the seafloor: ABYSS´s high-resolution map of the seafloor (top right, compare to best available ship-based map, top left) shows unprecedented detail (bottom left, contour interval two metres). The small "steps" visible on the map are in fact collapse structures in sheet lava flows, as seen on ROV images made in the area.

volcanic edifices. One such edifice, Franklin Seamount, was mapped in great detail (Figure 3).

The resulting map shows a volcanic summit plateau about 800 metres across with a central crater. The plateau shows several volcanic features known from land, where they are associated with moving lava flows. The central crater has irregular margins suggesting it was filled with magma capped by a solidified crust during the eruption and that when the eruption ceased, magma drained back into the sub-surface and the crust collapsed. Towed video observations in the crater show it to be full of volcanic rubble, supporting this interpretation. No evidence to support the prevailing view that such craters are of tectonic origin (and so bounded by ring-faults) was found demonstrating the power of high-resolution mapping in seafloor research.

The discoveries in the deep being made by volcanologists from IFM-GEOMAR continue apace, thanks to these new technologies. We can expect major breakthroughs in the next few years as it really becomes possible to do "fieldwork on the seafloor".

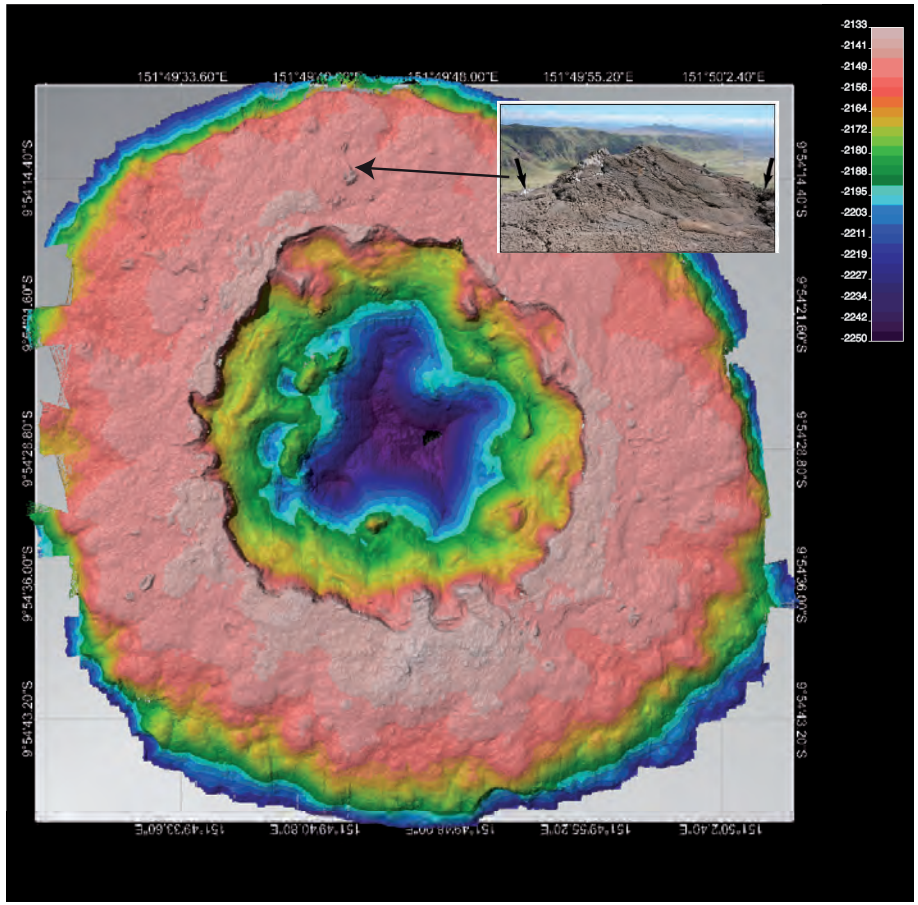

Figure 3: The summit plateau of Franklin seamount. Features such as "tumuli", known from subaerial volcanoes and caused when magma pressure increases below an already hardened volcanic carapace, are clearly visible on the seafloor (see inset).

Contributions to *Nature* and *Science*

In 2009, IFM-GEOMAR scientists published 345 peer-reviewed papers. Amongst them a number in high-profile, internationally recognized journals such as Nature and Science.

Nature

Biastoch, A., **Böning, C.W.**, **Schwarzkopf, F.** and Lutjeharms, J.R.E., 2009: Increase in Agulhas leakage due to poleward shift in the southern hemisphere westerlies. *Nature*, **462,** 495-498. doi:10.1038/nature08519

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Bower, A.S., Lozier, M.S., Gary, S.F. and **Böning, C.W.**, 2009: Interior pathways of the North Atlantic meridional overturning circulation. *Nature*, **459**, 243-248. doi:10.1038/nature07979

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John, T., Medvedev, S., **Rüpke, L.**, Andersen, T.B., Podladchikov, Y.Y. and Austrheim, H., 2009: Generation of intermediate-depth earthquakes by self-localizing thermal runaway. *Nature Geoscience*, **2**, 137-140. doi:10.1038/ngeo419

Karas, C., **Nürnberg, D.**, Gupta, A.K., Tiedemann, R., Mohan, K. and Bickert, T., 2009: Mid-Pliocene climate change amplified by a switch in Indonesian subsurface throughflow. *Nature Geoscience*, **2**, 434–438, doi:10.1038/NGEO520

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Moore, C.M., Mills, M.M., Achterberg, E.P., Geider, R.J., **LaRoche, J.**, Lucas, M.I., McDonagh, E.L., Pan, X., Poulton, A.J., Rijkenberg, M.J.A., Suggett1, D.J., Ussher, S.J. and Woodward, E.M.S., 2009: Large-scale distribution of Atlantic nitrogen fixation controlled by iron supply. *Nature Geoscience*, **2**, 867-871. doi:10.1038/NGEO667

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Science

Watson, A.J., Schuster, U., Bakker, D.C.E., Bates, N.R., Corbière, A., González-Dávila, M., Friedrich, T., Hauck, J., Heinze, C., Johannessen, T., **Körtzinger, A.**, Metzl, N., Olafsson, J., Olsen, A., **Oschlies, A.**, Padin, X.A., Pfeil, B., Santana-Casiano, J.M., **Steinhoff, T.**, Telszewski, M., Rios, A.F., **Wallace, D.W.R.** and Wanninkhof, R., 2009: Tracking the Variable North Atlantic Sink for Atmospheric CO_2. *Science*, **326** (5958), 1391-1393. doi:10.1126/science.1177394

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

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