Volume I

HELMHOLTZ ASSOCIATION

Research Field Earth and Environment

Proposal for a Helmholtz Research Programme

Marine, Coastal and Polar Systems

PACES II: Polar regions And Coasts in the changing Earth System




Participating Helmholtz Centres
Alfred Wegener Institute for Polar and Marine Research
Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research

2014 – 2018 I Coordinating Centre
Alfred Wegener Institute for Polar and Marine Research

Research Field Earth and Environment

Proposal for a Helmholtz Research Programme

Marine, Coastal and Polar Systems (PACES II: Polar regions and coasts in the changing earth system)

for the third funding period, 2014 – 2018

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Volume I

Participating Centres:	Alfred Wegener Institute for Polar and Marine Research (AWI)
	Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research (HZG)
Programme Speaker:	Prof. Dr. Heinrich Miller (AWI) Prof. Dr. Thomas Jung (AWI)

Helmholtz Association

Mission Statement

We contribute to solving grand challenges
which face society, science and industry
by performing top-rate research in strategic programmes
in the fields of Energy, Earth and Environment, Health,
Key Technologies, Structure of Matter,
Aeronautics, Space and Transportation

We research systems of great complexity
with our large-scale facilities and scientific infrastructure,
cooperating closely with national and international partners.

We contribute to shaping our future
by combining
research and technology development
with perspectives
for innovative applications and
provisions for tomorrow’s world.

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Contents

THE RESEARCH FIELD EARTH AND ENVIRONMENT IN THE HELMHOLTZ ASSOCIATION – MISSION, VISION & STRATEGY I

PROGRAMME: MARINE, COASTAL AND POLAR SYSTEMS (PACES II: POLAR REGIONS AND COASTS IN THE CHANGING EARTH SYSTEM)..... 1

PART 1: Overview 1
- Programme: Challenges, Objectives and Strategy 1
- Research Environment 4
- Profiles of the Participating Centres 7
  - Alfred Wegener Institute for Polar and Marine Research 7
  - Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research 7
  - Contribution to Cross-programme Activities and Initiatives 9
- Planned Resources 11

PART 2: Programme Development and Organisation 13
- Challenges 13
- Development and Environment 15
  - Development of the Programme 15
  - Utilization potential and commercial application 19
  - Strategic Partners, Cooperation and Competition 21
- Infrastructures 24
  - Existing Infrastructures 24
  - Planned Infrastructures 25
- Management 28
  - Organisation and Cooperation 28
  - Planning and Controlling 28
  - Talent Management 28

PART 3: Programme Content 31
- Topic 1: Changes and regional feedbacks in Arctic and Antarctic 31
  - Workpackage 1: The polar atmosphere, interaction with sea ice, ocean and frozen land 35
  - Workpackage 2: Ice sheet dynamics and mass balance 39
  - Workpackage 3: Degrading permafrost landscapes; carbon, energy and water fluxes 43
  - Workpackage 4: Arctic sea ice and its interaction with ocean and ecosystems 47
  - Workpackage 5: Southern Ocean physics, biodiversity, and biogeochemical fluxes in a changing climate 51
  - Workpackage 6: Large scale variability and change in polar benthic biota and ecosystem functions 55
- Topic 2: Fragile coasts and shelf sea 59
  - Workpackage 1: Coastal shifts and long-term trends 64
  - Workpackage 2: Species interactions in changing and exploited coastal seas 67
  - Workpackage 3: Evolution and adaptation to climate change and anthropogenic stress in coastal and shelf systems 71
  - Workpackage 4: Biogeochemical provinces of sea floors in the German North Sea sector 75
  - Workpackage 5: Interface processes and physical dynamics of the coastal ocean 79
- Topic 3: The earth system from a polar perspective: Data, modelling and synthesis 84
  - Workpackage 1: Circumpolar climate variability and global teleconnections at seasonal to orbital time scales 88
  - Workpackage 2: Earth system on tectonic time scales: From greenhouse to icehouse world 92
  - Workpackage 3: From process understanding to enabling climate prediction 96
- Topic 4: Research in science-stakeholder interactions 100
  - Workpackage 1: Operational analyses and forecasting 104
  - Workpackage 2: Channelling research data to enhanced data products 107
  - Workpackage 3: Providing information – enabling knowledge 111

Service Topic: Climate Service Center 117
Workpackage 1: Networking, Synthesis of Existing Knowledge and Expert Judgement 121
Workpackage 2: Determination of Stakeholders' Needs 124
Workpackage 3: Development of Demand-Oriented Products and Services 126
Workpackage 4: Establishment of Target Group-Oriented Communication 130
Workpackage 5: Capacity Development 132
Workpackage 6: Institutionalization of Climate Services (inter-/national level) 134

Coverpage description:

Photo 1: Recovery of the gravity corer in heavy weather conditions during RV POLARSTERN cruise ANT-XXVI/2 to the Pacific Southern Ocean (Photo: Y. N. Kim, KOPRI – former PhD student at AWI)	Topic 3
Photo 2: Anthropogenic footprint in the Wadden Sea (Photo: I. Frings, HZG)	Topic 2
Photo 3: Field camp on the margin of a continental ice sheet to collect ice samples in Northeast Greenland (Photo: H. Oerter, AWI)	Topic 1
Photo 4: Knowledge transfer to the next generation: Curious girls at the information desk of the climate office (Photo: I. Frings, HZG)	Topic 4

The Research Field Earth and Environment in the Helmholtz Association – Mission, Vision & Strategy

Coordinators of the research field:
Prof. Dr. Reinhard Hüttl (2011/2012), Prof. Dr. Georg Teutsch (2013/2014)

Humans influence their environment significantly: Climate change, species decline and extinction and other critical developments have been observed for decades, and important resources, such as drinking water or fertile soils threaten to become scarce. This is why the Helmholtz Association is engaged in preventive research. The research regarding Earth and Environment studies the fundamental functions of the Earth system and the interactions between nature and society. The global challenge is to provide the basic and applied knowledge necessary to secure and sustain the foundations of human life on a long-term basis. Key tasks include development of strategies for efficient use of natural resources, research of natural phenomena and their associated risks, and assessment of human impact on natural systems and the repercussions for humanity.

It is our aim to develop strategies for the management of natural hazards and the prevention of disasters, for improved prediction of climate change, for balancing the sustainable and efficient use of geosystems and ecosystems with their long-term protection and for adapting to changes in environmental conditions. Finally, the development of options for political action requires an analysis of the socio-economic consequences of the aspects mentioned.

Addressing these challenges requires an in-depth understanding of the numerous interacting subsystems (atmosphere, biosphere, geosphere, hydrosphere, cryosphere and anthroposphere) and a highly integrated scientific approach suitable for understanding the complexity of the Earth processes. The final goal is to assess anthropogenic influences, determine resilience limits and regeneration potential of terrestrial, marine, climate, and biological systems, and to shape concepts for their sustainable management.

The main challenges for the research field Earth and Environment lie in the following six areas:

- Earth system dynamics and risks,
- climate variability and climate change,
- availability of water and water management,
- ecosystem dynamics and biodiversity,
- sustainable use of resources and
- socio-economic dimension of global change.

The activities in the research field are pursued at eight Helmholtz centres: the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven, the Jülich Research Centre (FZJ), the German Research Centre for Geosciences (GFZ) in Potsdam, the Helmholtz Centre Munich - the German Research Centre for Environmental Health (HMGU), the Helmholtz Centre Geesthacht for Materials and Coastal Research (HZG), the Karlsruhe Institute of Technology (KIT), the Helmholtz Centre for Environmental Research (UFZ) in Leipzig and the GEOMAR | Helmholtz Centre for Ocean Research in Kiel.

The centres of the research field Earth and Environment feature excellently equipped medium-sized and large research infrastructures and platforms (e.g. ships, aircrafts, zeppelins, satellites, observatories, simulation chambers, climate computing centre) as a basis for long-term observation and outstanding research.

The selection of research programmes mirrors the respective challenges. With regard to the regions analysed, these are on the one hand those substantially shaped by humanity, e.g. coastal regions, emission centres, areas with crucial functions in food production or in which people are exposed to special risks (e.g. earthquakes or floods). On the other hand, research will focus on regions that are very sensitive to global or regional environmental and climate changes, e.g. polar regions, tropical oceans, arid or semiarid areas, mountainous regions or permafrost areas.

In the third period of the programme-oriented funding (POF), which will start in 2014, research will be focused in five programmes.

Geosystem: The Changing Earth

This programme deals with process analysis in the geosphere and its interactions with the hydrosphere, atmosphere and biosphere, focusing on the “human time scale”. The long-term objectives are: monitoring and modelling key processes, understanding and assessing the impact of these processes, developing solutions and strategies for avoiding disasters and for their prevention, and developing geotechnologies for use in underground areas.

Marine, Coastal and Polar Systems – PACES II

The programme focuses on observing and analysing changes in the Arctic, the Antarctic and coasts from palaeo to future time scales. It focuses on polar climate change and its consequences, changes of coastal systems and the Arctic deep-sea ecosystem. The programme includes a new topic on the interaction between science and society that examines how findings from research can be turned most effectively into information for decision-making processes in society as a whole.

Oceans: From the Deep Sea to the Atmosphere

Using an interdisciplinary approach, the Oceans programme will investigate the physical, chemical, biological and geological processes of the entire ocean system from the seafloor to the atmosphere. The principal goals are the role of the oceans in climate change, human impact on marine ecosystems, the potential use of biological, mineral and energy resources in the oceans and risks related to geodynamic processes in the ocean basins and their margins.

Atmosphere and Climate

The main objective of this programme is to gain a better understanding of the role of the atmosphere in the climate system. For this purpose it examines key atmospheric processes by means of sophisticated measurements of atmospheric parameters, laboratory investigations and numeric modelling on a cross-scale basis.

Terrestrial Environment

The programme aims to secure the natural bases of human life and health. It examines the impacts of global and climate change on terrestrial environmental systems and works out management strategies and options for sustainable social and economic development. The research work takes place on a scale that ranges from the micro-level to the global level, though in many cases the focus is on regional scales, e.g. catchment scale, selected regions and landscapes.

Approaching the challenges of the research field Earth and Environment presupposes an appropriate **transfer concept** to provide and transfer the acquired knowledge to decision-makers, users and to society. For the forthcoming programme period it is planned to conceptualise and implement a comprehensive transfer approach for the entire research field. This will be based on already existing transfer activities and features of the individual centres, e.g. the Climate Services Centre CSC and the four regional Helmholtz climate offices serving as a platform for climate information. Thus, an "Earth System Knowledge Platform" will be implemented as a contact and focal point to provide a wide range of scientific knowledge for application in practice.

The centres of the research field Earth and Environment maintain an excellent **network within the Helmholtz Association**. Apart from the research fields in which the centres are additionally involved (Energy, Key Technologies, Health), there is also a close link to Aeronautics, Space and Transport. Infrastructure, which is of utmost importance for all centres, e.g. the new research aircraft HALO, is available for all research fields and is also operated **jointly with other research institutions** (MPG, WGL). Particular innovative cross-cutting themes are researched on a cross-programme basis beyond programme and even research field borders. This refers to subjects which are tackled from various perspectives in several programmes and which are considered strategically important. The following cross-cutting themes are already conducted jointly: "Causes and regional impacts of climate change", "Management of water as a resource", "Earth system knowledge platform", "Mineral resources", and "Sustainable bioeconomy". In the upcoming programme period new research objectives of particular significance for "Earth and Environment" are soil research and technological innovation in Earth observation such as new approaches to verification of satellite observation and an innovative deep-sea observatory in the Fram Strait.

Local and regional **cooperations with universities** and other institutions of higher education are highly significant for the centres. Three types of cooperation are particularly important:

- Joint professorships: This instrument is applied to ensure long-term cooperation on a specific strategic research theme, to transfer up-to-date scientific knowledge via teaching, and to gain access to young academics;
- Common training of graduate and junior scientists: this is realised by graduate schools and Helmholtz colleges, which are operated jointly;
- Coordinated research in projects and programmes: The research together with university partners is based on long-term strategic cooperation agreements with complementary contributions from both sides, leading among others to common proposals for funding. In this respect the Helmholtz Association offers competitive funds for so-called Helmholtz alliances to examine specific questions in cross-centre networks with partners form universities and other non-university institutions. Regarding the forthcoming programme period two Helmholtz alliances have been successfully established in cooperation with university partners and the research field Aeronautics, Space and Transport. These are: "Remote Sensing and Earth System Dynamics" as well as "Robotic Exploration of Extreme Environments". These activities are based on long-term interdisciplinary cooperation.

Research Field costs

Research Field costs covered by institutional funding as requested for 2014

T €	AWI	FZJ	GEOMAR	GFZ	HMGU	HZG	KIT	UFZ	Total
Geosystem: The Changing Earth			915	38.760					**39.675**
Marine, Coastal and Polar Systems	54.423					27.318 *			**81.741**
Oceans: From the Deep sea to the Atmosphere			30.726	500					**31.226**
Atmosphere and Climate		14.182		700			22.423		**37.305**
Terrestrial Environment		11.469			19.720			52.895	**84.084**
LK II - Research Vessel POLARSTERN (AWI)	28.424								**28.424**
LK II - Research Vessel HEINCKE (AWI)	4.640								**4.640**
LK II - Polar Research Station Neumayer Station III (AWI)	12.300								**12.300**
LK II - Research Vessel POSEIDON			5.450						**5.450**
LK II - Research Vessel ALKOR			4.889						**4.889**
LK II - Modular Earth Science Infrastructure (MESI) (GFZ)				7.608					**7.608**
Total	**99.787**	**25.651**	**41.980**	**47.568**	**19.720**	**27.318**	**22.423**	**52.895**	**337.342**

Programme: Marine, Coastal and Polar Systems (PACES II: Polar regions and coasts in the changing earth system)

PART 1: Overview

Programme: Challenges, Objectives and Strategy

The polar and the coastal regions both play a key role within the Earth system. The Arctic and Antarctic represent a very special environment, are home to an as yet largely undiscovered biodiversity and exert a great influence on the global climate. The coastal and shallow seas are areas of most intense human activities and at the same time harbour most of the marine food resources. Both regions are subject to substantial environmental change due to human impact and climate change. The programme PACES II addresses both these focal areas with an emphasis on the changing environment.

The polar regions are characterized by very low temperatures, marked seasonality, huge continental ice sheets, large oceanic areas permanently or seasonally covered by sea ice, massive and deep reaching permafrost layers. The polar regions react sensitively to climate change and at the same time they govern global climate evolution on a broad range of time scales and directly influence global sea level change and hence impact on coastal regions. Due to extremely long recovery cycles polar ecosystems are highly susceptible to perturbation. Many polar processes have far reaching effects on the Earth system as a whole, such as effects of melting ice sheets on sea level rise, impact of dwindling sea ice cover on large scale atmospheric processes, or release of greenhouse gases from thawing permafrost regions. Characteristics and circulation of the global deep ocean is determined by deep water formation in the Southern Ocean and Arctic Ocean (only 10% of the surface area of the world ocean) and thus influence 90% of the ocean's volume. Hence understanding of polar processes is of paramount importance in order to be able to predict climate evolution with ever narrower bounds on uncertainties and to analyse incipient or ongoing ecosystem changes.

Human activities are mainly concentrated in shallow shelf seas and coastal areas and result in conflicting interests between two main societal goals: conserving habitats, ecosystems and natural services while at the same time exploiting these services. Sustainable use has to be based on an understanding of the dynamic forces that underlie these systems, which in turn requires a comprehensive understanding of interacting physical, chemical, biological and geological factors across the entire gamut of space and time scales. To identify the potentials for change, sustainability and adaptation, coastal research provides the tools, assessments, and scenarios for managing this vulnerable land- and seascape. Research activities in coastal sciences span both the natural and human dimensions of coastal dynamics, analysing the coastal system in global and regional contexts, conducting assessments of the state and sensitivity of the coastal system to natural and human influences, and developing scenarios of future coastal options.

The open oceans, coastal areas and polar regions are systems linked by a large number of processes and interdependencies. Each of these systems, however, is characterized by unique environments, processes, and challenges which together significantly influence the entire Earth System.

The complexity of these system components needs to be addressed in a manner which allows to cover the regional aspects as well as their global connectivity and temporal development. In order to also strengthen the transfer of scientific insights into society we have chosen to structure this programme into 4 complementary research topics and one Service Topic providing a comprehensive Earth system's understanding from a polar and coastal perspective with special emphasis on vulnerability and resilience in relation to society's needs.

- Changes and regional feedbacks in Arctic and Antarctic
- Fragile coasts and shelf seas
- The Earth system from a polar perspective: Data, modelling and synthesis
- Research in Science-stakeholder interactions
- Climate Service Center

While the first three topics deal with the natural and anthropogenically influenced earth system and have evolved from the present programme the last two topics are newly defined and satisfy the mission of the Helmholtz Association addressing direct service to society. The topic Research in Science-Stakeholder Interaction will define optimal forms for an interactive dialogue between science and decision makers, or society as a whole to allow for the planning of appropriate actions in a changing world. The Climate Service Center was founded to collate all relevant climate information from all agencies and disseminate it to institutional stakeholders and the wider public.

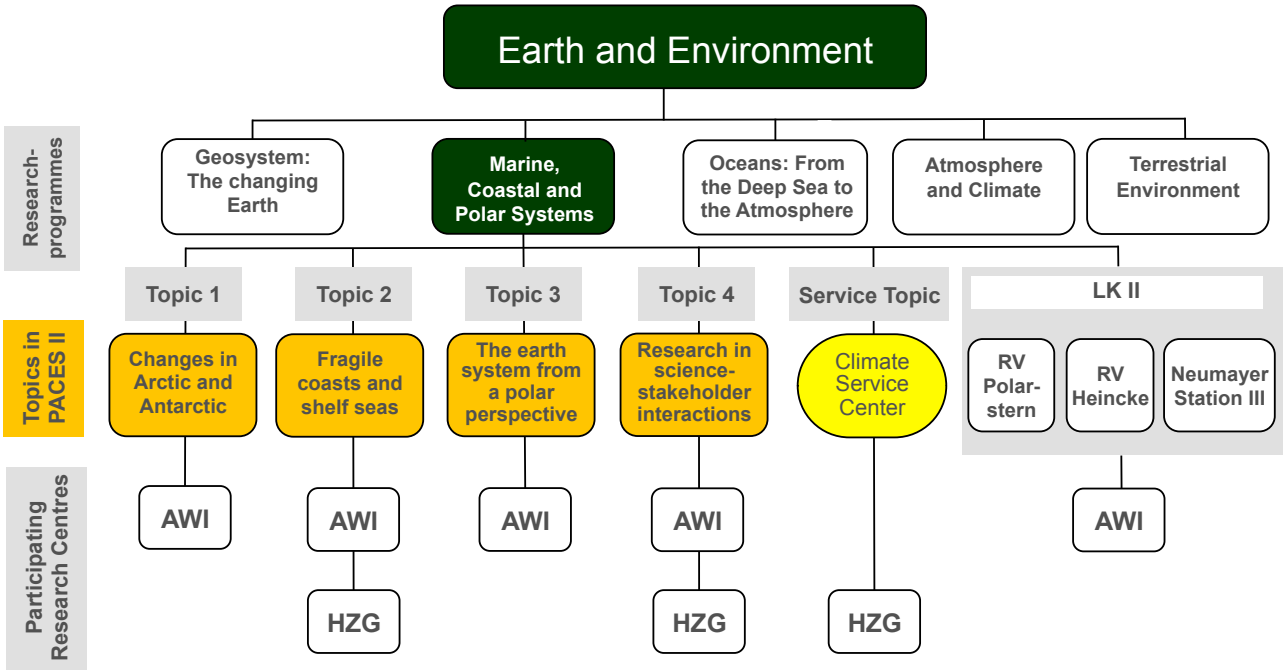

Figure 1: Structure of the research programme

Research in these topics requires a long-term strategy. Natural systems are characterised by high variability and possible trends can therefore only be extracted from appropriate observation strategies and long-term data sets. Similarly, process oriented studies addressing hypotheses derived from observational data require comprehensive and far-reaching research to unravel cause and effects. Such long-term and consistent research approaches are an advantage of Helmholtz Programmes allowing the study of complex topics that go beyond the capacities of most other research institutions. Therefore, PACES II is an evolution of the present programme. It is built upon the experience and outcomes of ongoing research; it focuses on transdiciplinary approaches and includes new aspects and techniques. The aim is to concentrate on questions of high societal

importance, such as e.g. improved assessments of future sea level rise through appropriate studies of ice sheet mass balances, of future development of sea ice coverage on the Arctic Ocean, or of future changes of the coastal ecosystem of the North Sea and polar coasts.

Given the areal extent, the complexities of the research areas, as well as the open boundaries of the polar oceans and coastal seas with the rest of the world's ocean, the PACES programme has to form a strong and leading nucleus and has to be embedded within national and international research efforts. For this end PACES II collaborates closely with strategic partners.

Strategic and cooperative partnerships will widen the scope and interact closely with the PACES II programme of AWI and HZG. A major strategic partner of PACES II is the new OCEANS programme of GEOMAR and GFZ. The second strategic partner is the institutional AMAR alliance of AWI with the University of Bremen (MARUM). A third strategic partner is the KlimaCampus of institutions in Hamburg. Together with strategic partners AWI and HZG will effectively coordinate marine, climate and coastal research as well as the required complex and extensive infrastructure. These partnerships will ensure that existing and future research efforts will be coordinated to develop new joint research projects both within and outside of the Helmholtz Association. The strategic partnerships and their role in the programme are outlined in detail in Part 2 (page 20).

In the course of the POF III period a strategy for joint research of the marine system between the contributing centres will be developed.

Implementing the partnerships addresses the Research Policy Requirements of the BMBF for the research field "Earth and Environment" by making use of the respective and comparative expertise of the participating Helmholtz Centres and establishing a comprehensive research profile with the focus on research institutions in Northern Germany.

Research Environment

This programme will continue to provide essential input to IPCC assessment reports. Furthermore, large parts of the programme will be major contributors to International Global Change Programs such as WCRP, IGPB and IHDP, in particular GEWEX-BALTEX, LOICZ, PAGES, CLIVAR, CLIC, SPARC, IGAC, IMBER, ICED, IODP, IPICS, FRISP and ANDRILL. Evidently this programme is also well positioned within the SCOR and in particular the Arctic (IASC) and Antarctic (SCAR) programme portfolios. In addition, crucial parts of the programme rely on and augment a number of current and planned future satellite missions such as CRYOSAT, GOCE, GRACE and GRACE 2, TERRASAR X and TANDEM X, SWARM and in future also ENMAP, ICESat-2 and TANDEM-L.

The special role of polar regions has been recognized in the framework programme of BMBF "Research for Sustainable Development" („Forschung für nachhaltige Entwicklungen - FONA"[1]), the „EU-Arctic Communication"[2] and the "Grand Challenges in Global Sustainability Research"[3] of the International Council for Science (ICSU)[4]. They have identified major challenges for polar science, which will be addressed in the programme PACES II:

- past, present and future climate change in Arctic and Antarctic regions
- polar ice mass balance and its contribution to sea level rise
- effects of the reduction of sea ice on atmosphere, ocean and ecosystems
- consequences of thawing of permafrost areas
- adaptation of organisms and ecosystems to environmental change

Similarly coastal regions are highlighted as zones of major importance for society by the national programme "Research Agenda for the North and Baltic Seas" (BMBF), by several European programmes and the "Grand Challenges in Global Sustainability Research" (ICSU).

The compliance and synergies with these national and international programme portfolios is ensured by the fact that scientists from AWI and HZG are directly involved in the respective steering committees or that some of these international programmes maintain bureaus at AWI or HZG, such as LOICZ, CRYOSAT and the newly established WWRP Polar Prediction Project.

The present programme has been heavily augmented by funding from EU within Framework 7 and it is expected that the successful attraction of EU funding within the next EU Framework Program "Horizon 2020" will continue in PACES II. The polar components will be mostly embedded in joint projects with our European partners who are organized in the European Polar Board.

On the national level funding by DFG is limited to priority programmes such as the DFG-SPP Antarctic Research with comparative studies in Arctic Polar regions. BMBF funding under the FONA-programme will enable close cooperation of coastal researchers with universities and national agencies in the "Research Agenda for the North Sea and Baltic Sea".

This programme as well as the cooperating partners require specialised infrastructure from high performance laboratories to large-scale research platforms without which the research outlined in this programme cannot be performed.

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[1] Federal Ministry of Education and Research (BMBF) (2009): „Forschung für nachhaltige Entwicklungen - Rahmenprogramm des BMBF", BMBF, Referat 721 – Grundsatzfragen Kultur, Nachhaltigkeit, Umweltrecht, Bonn, Berlin. http://www.bmbf.de/pub/forschung_fuer_nachhaltige_entwicklung.pdf

[2] European Commission (2008): Communication from the Commission to the European Parliament and the Council: The European Union and the Arctic Region. Brussels. http://eeas.europa.eu/arctic_region/docs/com_08_763_en.pdf

[3] ICSU (2010): Grand Challenges in Global Sustainability Research. A Systems Approach to Research Priorities for the Decade. International Council for Science, Paris.

[4] Reid, W.V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y.T., Mokhele, K., Ostrom, E., Raivio, K., Rockström, J., Schellnhuber, H.J. and A. Whyte (2010): Earth system science for global sustainability: Grand challenges. Science 330:916-917.
The citations will be found as full text on the accompanying CD/USB-stick.

In the following some of these infrastructures will be highlighted, which are also available to the wider scientific community.

AWI operates a number of smaller ships or boats especially for deployment in coastal waters, namely UTHÖRN, MYA, DIKER, and AADE. They are suitable for serving repeat measurements and sampling around the islands of Helgoland and Sylt as well as for rapid responses in order to investigate special high-impact events. HZG operates the LUDWIG PRANDTL and STORCH mainly for research in the Wadden Sea, estuaries and coastal North Sea and Baltic Sea.

HZG has designed, has built and is operating the coastal observing and forecasting system COSYNA, to be extended under the Helmholtz strategic infrastructure ACROSS. It has been established in the North Sea and off Svalbard and aims to develop and test analysis systems for the operational synoptic description of the environmental status by integrating real-time observations with models. COSYNA provides knowledge tools that can help authorities and other stakeholders to manage routine tasks, emergency situations and to evaluate trends. Observations comprise a range of in-situ techniques as well as remote sensing with satellite and shore-based radar. Key physical, sedimentary, geochemical and biological parameters are observed at high temporal resolution in the water column and at the water-sediment and water-atmosphere interface. A nested modelling system with different levels of spatial resolution is used for estimating various hydrodynamic and biogeochemical (ecosystem) state variables in near-real time. Of particular importance for COSYNA is the ability to provide forecasts of different parameters concerning ocean waves, circulation, and suspended matter (COSYNA products). By using data assimilation procedures, the reliability of now-casts and short-term forecasts is much improved. Data management organizes the data streams between the observation sites, modelling output, and central storage systems situated at HZG and the partner institutions. Data quality control and documentation are ensured. COSYNA products range from time series at various locations and regular maps of e.g. currents, waves, salinity, temperature, chlorophyll, oxygen, etc., to routine short-term forecasts (days) for these parameters. COSYNA adopts an open data policy, providing real-time or near real-time data and forecasts to the public via the COSYNA data portal (internet).

AWI operates two ski equipped BASLER BT-67 research aircraft that are dedicated to polar research. They are modified versions of DC-3 aircraft and can operate anywhere on the polar ice sheets as well as over the adjacent seas. The modifications are such that a multitude of scientific instrumentation tailored to the respective research mission can be performed.

Furthermore, AWI operates a pool of 80 broadband Ocean Bottom Seismometers in close collaboration with GFZ through the MESI infrastructure.

In the Arctic, AWI operates a year-round base (AWIPEV) in NyAlesund (Svalbard) jointly with the French national polar institute IPEV. AWIPEV serves as a base and provides facilities for coastal marine, permafrost and atmospheric research.

In the Antarctic the Dallman Laboratory operated jointly with Argentina at the Base Carlini on King George Island is a centre for studies of impacts of regional climate change on marine and terrestrial organisms.

On the Antarctic continent itself, Kohnen Station on the interior plateau of the ice sheet serves as a summer base for ice core studies as well as other deep field investigations in glaciology, geophysics and meteorology.

In cooperation with the Arctic and Antarctic Research Institute, St. Petersburg, AWI operates the Samoylov station in the Lena delta. This station has been used for about 5 months each year and from 2013 onwards a new base will allow year-round access and operations.

The Antarctic and Arctic Institute, St. Petersburg, the University of St. Petersburg and AWI jointly run the Otto-Schmidt-Laboratory in St. Petersburg. It serves as a laboratory for advanced sample analysis of joint projects in Siberia and as a training laboratory for the cooperative study course POMOR.

At the Biologische Anstalt Helgoland, AWI operates a school for the training of scientific divers and provides support for external users for special sampling programmes requiring sophisticated sampling procedures.

Furthermore, AWI maintains an extensive guest researcher programme and provides dedicated teaching facilities both on Helgoland and Sylt for German universities to conduct marine field and lab classes for students of biology.

AWI also operates three Helmholtz Research Infrastructures (LK II). They are essential prerequisites for most of the research carried out within this programme. Since they are presented in detail in a different volume and will be reviewed separately, albeit with reference to the research programme, in the following only a brief overview will be given. This special infrastructure consists of

- POLARSTERN
- Neumayer III and
- HEINCKE

The research and supply vessel POLARSTERN commissioned in 1982 is the major research tool of the German polar research programme. She provides ideal working conditions for almost all fields of marine, atmospheric and glaciological research. POLARSTERN is a unique research tool even in an international context. She can break ice up to a thickness of about 2 m and operate up to 90 days at sea, which is a prerequisite for long-range cruises to remote regions.

Through her ability to host up to 55 scientists and a variable laboratory space POLARSTERN is a most effective interdisciplinary research platform. POLARSTERN was designed to stay in the pack ice even during polar winter and this capability has already been exploited in the form of three year-round deployments to the Antarctic and late winter expeditions to the Arctic.

Neumayer III is the permanently staffed German research station located at the Eckstrøm ice-shelf at Atka Bay. The station was commissioned in 2009 and replaced the former station Neumayer II. The station continues to operate scientific observatories for meteorology, atmospheric chemistry, geomagnetics, seismology and underwater sound. Data from Neumayer I to III together allows to study homogeneous time series starting in 1981. In addition it serves as a base for an infrasound array, which is part of the German commitment within CTBT.

HEINCKE is a medium sized multi-purpose research vessel and can be used for a broad range of biological, hydrographic, and smaller scale geoscientific research activities. In addition to serving as a research platform, HEINCKE is used for university courses aimed at combining class and fieldwork. A steering group for medium-sized German research vessels manages ship time allocation.

Profiles of the Participating Centres

Alfred Wegener Institute for Polar and Marine Research

AWI is the national German centre for polar research and is also part of the German marine research effort, with a focus on high-latitude marine areas. It therefore takes a unique position compared to all other German research institutions working in these and related fields. Within an interdisciplinary research environment, AWI scientists study the natural variability of the climate system from short to long time scales. The Arctic and Antarctic are climatologically the most sensitive regions in the Earth System to anthropogenic climate change and in this context they constitute valuable sources of information about possible future global environmental change and its consequences. Key data are obtained on present-day variability of ocean systems and climate, records of their historic variability in the recent geological past, and in the reconstructions of climate history. Methods exploited range from modern satellite-based remote sensing techniques to deep sea and ice core drilling. A priority at AWI is to conduct research on the polar marine regions and their biotas. The role of polar plankton in the global carbon cycle and the effects of changes in temperature and CO_2 in the ocean on the marine macrofauna are examples how biological research at AWI is focused and linked with other scientific disciplines. AWI also carries out terrestrial polar research: it provides key contributions in the fields of atmospheric physics and chemistry; and the dynamics of ice sheets and the palaeo-climate history of polar and periglacial regions and their permafrost soils are explored. Investigations on marine and terrestrial polar regions are closely coordinated, to better understand the critical processes in these regions. In a comparative approach AWI also investigates ecosystem changes in temperate regions (North Sea) and applies the expertise gained in the lower latitude to coastal regions in the Arctic. In summary, therefore, AWI studies important components of the Earth System using a variety of methodological approaches, by combining the collection and analysis of new data and samples with modelling techniques and by conducting applied research in polar and marine systems.

AWI has close ties to many German Universities, not only the Universities of Bremen, Potsdam, Kiel, Oldenburg, Göttingen and the Jacobs University (Bremen) where joint professorships are established and where formal cooperation agreements are signed, but many others such as Hamburg, Heidelberg, Tübingen where active research groups in our fields exist.

As the national polar research institute AWI is well connected with the international polar research scene and has formed many alliances with leading polar institutions and is partner in or leading internationally coordinated research projects.

Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research

The Institute of Coastal Research of the HZG is conducting research on coastal regions - both coastal sea and the inhabited land. Its research specifically aims to improve the understanding of the natural coastal dynamics and its resilience to global climate change and regional drivers in order to establish a rational scientific basis for the management of coastal zones. As such, the work deals with the determination, understanding and assessment of change while embedding perspectives in a societal context. For doing so, three major issues are considered, along with a series of emerging topics. The major issues are

CoastDat: the construction and assessment of regional environmental change in the past, mainly since 1950, and possible future developments. This involves statistical analysis and homogenization of historical data, model development (for the atmosphere, marginal seas - mainly North Sea and Baltic Sea, ocean waves and ecosystem dynamics), dynamical downscaling and scenario simulations.

COSYNA (Coastal Observation System for Northern and Arctic Seas): the development of technology allowing for a detailed and reliable real-time, operational description/analysis of short-term variability and anthropogenic drivers in the coastal environment. “Technology” means here both the instrumental dimension, such as testing gliders in flat tidal basins, but also the development of routine operational data-assimilating models.

CoastMap: documentation of sea floor functions in the North Sea, with special emphasis on their roles in material cycles. This includes elucidation of origins, pathways, accumulation and effects of anthropogenically released substances (such as nutrients or pollutants). Tools are dynamical models of material transport and transformation, state-of-the-art analytical laboratories and geographical information systems.

Emerging work deals with the interdisciplinary dynamics of small and sub-mesoscale processes, understanding of public awareness and valuing coastal zones, and millennial regional change. Several efforts are established dealing with the challenge of interaction with regional stakeholders and helping international co-operations on either globally distributed coasts or the Baltic Sea region.

HZG has particular close ties with the KlimaCampus Hamburg and its scientific kernel, the Cluster of Excellence (CliSAP) in Hamburg (a joint effort of the University of Hamburg, the Institute for Coastal Research of HZG and the Max-Planck Institute of Meteorology) and international partners. HZG introduced a strong component of not only expressly regional and coastal systems science, but also a societal embedding of climate science into CliSAP. Robust links and regular consultations have been established and are maintained with regional universities (Kiel, Hamburg, Harburg, Oldenburg, Lüneburg, Hannover), governmental and managerial institutions (BSH, vTI), as well as companies engaged in coastal and shelf sea research. HZG established the North German Climate Office, which acts as a dialogue partner for interested individuals and groups from the field of agriculture, tourism and coastal protection and is strongly engaged in the Climate Service Centre (CSC). Starting in 2010, the German Climate Computing Centre (DKRZ) operates under the institutional roof of HZG. Furthermore, the Institute of Coastal Research at HZG hosts the International IGBP - LOICZ office, which coordinates coastal research on a global scale.

The Climate Service Center, with its headquarter in Hamburg, was founded in 2009 as an institution of HZG, initiated as a project of the German Government´s "High-tech Strategy for Climate Protection". The CSC is a National Knowledge Transfer Center for Climate Change that assembles, integrates and disseminates products and services to customers primarily in Germany. It also operates at an international level in order to promote international cooperation between climate service providers. Through a network of partner institutions, the center offers advice to decision-makers and other users from the scientific, economic, political communities and from civil society.

Contribution to Cross-programme Activities and Initiatives

REKLIM

Research within PACES II contributes heavily to the Cross-Programme Climate Initiative REKLIM, which has recently been evaluated separately. REKLIM's overarching goal is to bundle the expertise present in the 8 participating Helmholtz centres with respect to regional climate development. The *Helmholtz Climate Initiative* uses regional observations and process studies coupled with model simulations to improve regional and global climate models, which provide a solid basis for climate-related decision support.

Specific objectives of the Climate Initiative REKLIM are to understand and quantify ice and ocean variability and sea level change, processes at high latitudes, the effects of land surface change and feedbacks, the change of atmospheric constituents, extreme events, their impacts on regional climate, and thus to develop knowledge for mitigation and adaptation strategies. In addition rapid climate variations, climate change and air quality, and risk management for adaptation strategies. These activities provide input to the overarching coupled regional climate modelling.

REKLIM, therefore,

- acquires improved process understanding through regional observations and modelling;
- develops improved coupled regional climate models by adopting existing models to enhanced computational power (resolution) and by including more climate-relevant components of the regional Earth system;
- generates data sets of recent, on-going and possible future regional climate change in a number of key areas;
- analyses on-going climate change with respect to causes, regional and local impact, global significance and perspectives;
- provides new information for advanced parameterisations in global coupled models and for mitigation and adaptation strategies for IPCC;

This new knowledge represents a scientific basis for decision making for all levels of society. The outreach will be organized through the HGF Climate Offices and the Climate Service Center.

The documents relating to REKLIM can be found on the attached CD.

Natural Disaster and Warning Systems, Water and Security

PACES II also contributes to Cross Programme Activities "Natural Disaster and Warning Systems" and "Water".

With the multi-hazard modelling framework for storm surges, submarine landslides, and tsunami-genic events and predictions of the fate of oil contaminations in ice-covered seas in topic 4, workpackage 1, AWI contributes as an associated partner to the cross-programme activity "Security" with DLR, FZJ, KIT, and GFZ.

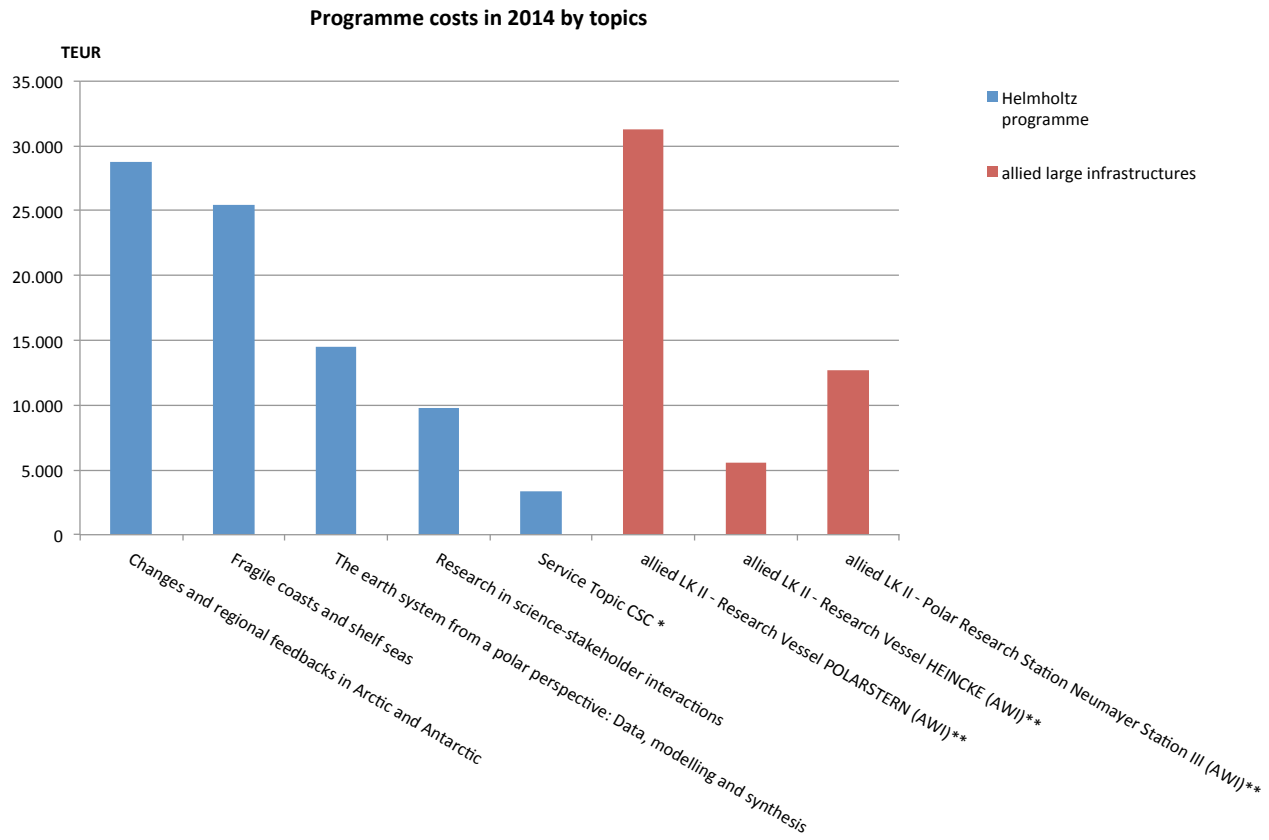
Anticipated Cross-Programme Activity 'Soil'

Soils are of fundamental importance for the functioning of terrestrial systems and consequently, also for the sustainable development of human society. They provide a multitude of essential ecosystem services like the habitat for the majority of the Earth's organisms, the largest terrestrial stock of organic carbon, the filter for groundwater, and the basis for the production of food and biomass. Globally, soils are by far the largest source of biogenic greenhouse gases, strongly affected by management practices and land-use change. As increasingly recognized, soils play a key role not only in the global cycling of organic and inorganic matter but also for water quality, climate and food security. Thus, the sustainable management of soil resources is clearly a global challenge.

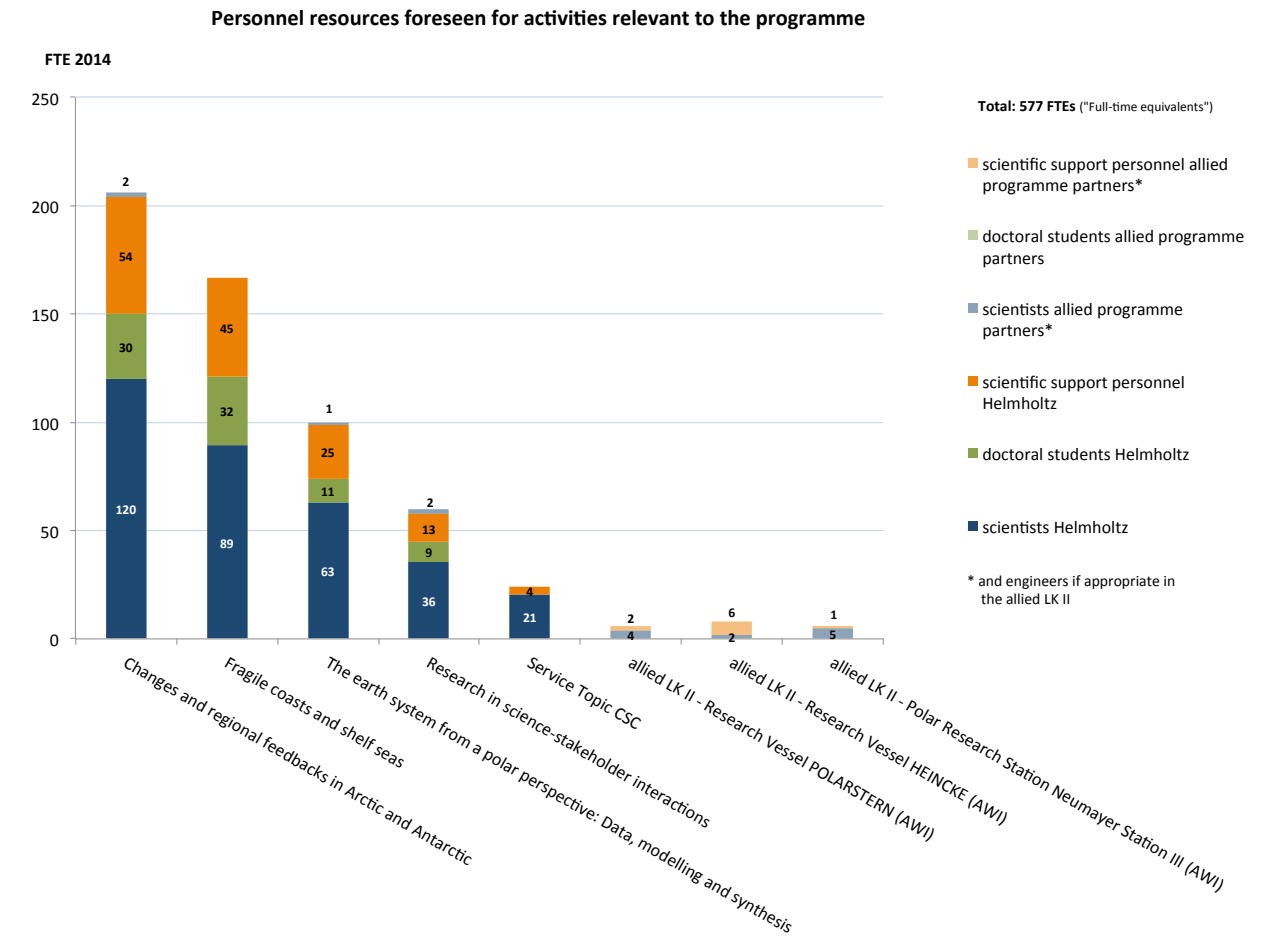
Despite their significance, soils are threatened world wide. This is true in terms of both, quantity and quality given the ongoing urban sprawl and increasing soil degradation through inadequate land use practices. There is a pressing need for scientifically sound sustainable soil management and the development of robust instruments to evaluate and reduce soil vulnerability in response to external forcing be it natural or man made. The main difficulty in establishing a sound scientific basis is the complexity of interacting physical, biological and geochemical processes and their highly non-linear relationships at a wide range of spatial scales. This calls for a system oriented research strategy. To foster the required system perspective, soil research is being developed as a Cross-Programme Activity within the Helmholtz community, where ample and diverse competences, instrumentations and infrastructures exist.

To improve the Cross-Programme coordination and the overall visibility of German soil research, the research directive of the BMBF for POF III is asking for an integrated soil research initiative to be organised by the Helmholtz Association. It further states that this should incorporate the recent activity of Acatech (the German Academy of Science and Engineering) seeking to integrate actual knowledge in soil science with industrial and socioeconomic expertise. Consequently, we foresee a Cross-Programme Activity "Soil" with an annual budget between 1,5 – 2,0 Mio € with the research content to be defined in more detail during 2013.

Planned Resources



* from the beginning of 2015, HZG costs will increase due to the inclusion of the Climate Service Center budget of 5.000 TEUR
** requested costs plus the defined annual growth rate



PART 2: Programme Development and Organisation

Challenges

The Helmholtz-Programme “PACES II” aims at further developing the scientific base for the assessment of observed environmental change as well as sustainable ecosystem utilization. PACES II will be investigating the multiple physical, chemical, biological and geological interactions within the marine and associated terrestrial systems as well as other compartments of the earth system. The programme focuses on two particularly relevant aspects of the Earth system – namely polar and coastal regions. Deciphering processes in the polar regions relevant to global climate, their coupling to lower latitudes and their variability in space and time by observing and modelling of the past and present is thus a central issue within PACES II. On the other hand, coastal regions are relevant as “receivers“ of global change, and key regions for the global socioeconomic systems as well as for global ecosystems – in fact, these two issues meet at arctic coasts, which is a key element in PACES II. Furthermore, the programme aims at the scientific evaluation of possible impacts of observed and expected changes by assessing scenarios of future developments in the Earth system. The above-mentioned goals require a wide range of long-term in-situ and remote sensing observations, as well as regional and global modelling and a high degree of multidisciplinarity. Whenever our accumulated understanding advances existing assessments, these findings are to be used in improved monitoring and management of marine and associated systems. Relevant examples include sustainable use of coastal regions, enhancement of coastal protection, e.g. in view of future sea level rise, safety issues of marine traffic, offshore industries as well as marine nature conservation.

The following objectives reflect the collaborative efforts of the contributing scientists who cover many different scientific disciplines:

Assess the role of the Polar Regions within the earth system by

- Identifying and understanding key processes responsible for recent changes
- Quantifying lithosphere-ocean-cryosphere-atmosphere interaction
- Reconstructing global climate variations from polar archives
- Unravelling the role of climate for evolution, biogeography, and biodiversity

Evaluate natural dynamics and anthropogenic impacts within coastal regions and define knowledge based management tools by

- Identifying key processes responsible for coastal changes
- Developing strategies for the sustainable use of marine living resources
- Augmenting an operational monitoring system for the North Sea
- Describing recent, ongoing and possible future coastal changes

Investigate the polar oceans’ role in global climate variability and change by

- Synthesis of data and models of varying complexity
- Modelling marine biogeochemistry including the functional role of organisms
- Modelling of climate variability over long time scales

Find optimal ways to contribute to society’s information needs by

- Researching how to find appropriate language and information concepts
- Establishing a sustained Service Center on climate change

With these objectives the programme contributes essentially to 5 of the overarching “grand challenges” for the research field “Earth and Environment” of the Helmholtz Association:

- Earth system dynamics and risks
- Climate variability and climate change
- Ecosystem dynamics and biodiversity
- Sustainable use of resources
- Socio-economic dimension of global change

For their realisation these goals require special approaches in the way research is carried out. In this programme a multi-tiered structure will be implemented: Subject-specific understanding of environmental states and processes within different compartments is obtained from within the traditional scientific disciplines; on intermediate levels this information is linked in a multidisciplinary approach wherever relevant; and at the top we have complex views of the studied earth system parts, which will then be integrated into Earth System Models. Particular emphasis will be placed on generating a stronger linkage between individual disciplines and on the atmospheric and oceanic role as mediators between polar and non-polar regions. Moreover, wherever appropriate the outcomes from this programme will be linked to those from other programmes within “Earth and Environment“ in order to obtain a more complete picture of the global system. Obviously this programme must also be transparent at all levels of aggregation to the other programmes and Research Fields, and receive input from them in order to adjust the programme to new findings as they emerge. By employing the structure outlined above new and important knowledge will be generated which will feed into future assessment reports for decision makers.

Development and Environment

Development of the Programme

PACES II contains elements of continuation of the present and previous programme. This seems justified given that it will ensure the continuity of long-term observations, process studies in certain key areas and expeditionary as well as modelling activities. On the other hand, the new programme is sharpened in its structure, strategy and scientific approaches employed compared to its predecessors by taking into account new developments and advances in scientific understanding as well as managerial experience. The elements of PACES II reflect recommendations made during the mid-term review.

Exemplary for this approach is the new Topic 3, which is a merger between the present Topic 3, with provides evidence for climate reconstructions over short and long-term periods in earth's history, and the former Topic 4, which deals with related Earth system modelling aspects. The new Topic 3 in PACES II allows for closer collaboration between data providers and modellers. Furthermore it brings researchers in present-day climate and those in palaeo-climate closer together and fosters a higher level of interaction and transdisciplinary.

Effective research in Polar Regions, especially when it comes to using the required complex infrastructure, needs relatively long planning horizons, which exerts constraints on future developments. However, there remains sufficient flexibility to allow for rapid response should special or even extreme events warrant special attention or investigation.

Current activities are based on research cruises with POLARSTERN, both in the Arctic and Antarctic. They are necessary for process studies of ocean-sea ice-atmosphere interaction, related ecosystem studies both of the sea-ice ecosystem itself as well as pelago-benthic coupling which are a prerequisite to determine potential changes in the total Arctic ocean ecosystem related to the decreasing sea ice cover and thickness. Closely connected to this effort are studies on the ocean-seafloor sediment interaction, which are ongoing in the "Hausgarten" seafloor observatory. Here the effort is increased in the new programme by establishing enhanced observatory capabilities through the proposal for a major investment, namely the FRAM observatory.

The two polar research aircraft POLAR 5 and POLAR 6 share mission time between the Arctic and the Antarctic and provide, for example, new insights into the structure and aerosol load of the Arctic atmosphere, ground truth data for satellite missions such as CRYOSAT, GRACE, GOCE and others by directly measuring sea ice thickness at various times of the year or by providing data for gravity, magnetics, ice thickness, precise surface elevation and surface snow structures over the ice sheets.

Besides participation in international ice core drilling projects such as NEEM, new deep and intermediate depth ice core drilling and related equipment is being developed. It will allow strong contributions to the scientific goals set forth in the science prospectus of IPICS, which includes the search and recovery of "oldest ice" in Antarctica.

Present research has shown that in future there is a possibility of changing ocean circulation patterns in the Weddell Sea leading to enhanced melting underneath the Filchner ice-shelf. Responding to this recent finding, field studies are planned in the area in order to obtain baseline data against which later developments can be compared. This is also closely related to the increased emphasis on ice sheet dynamics within the programme as they are heavily influenced by processes at the grounding zones.

Ongoing permafrost studies in the Siberian and North American arctic have shown that coastal erosion is increasing at an unprecedented rate, that most of the carbon released from terrestrial

as well as submarine permafrost consists of recently biosynthesized matter and that small water bodies are significant as conduits for carbon emission. Research in these areas will continue in close interaction between “polar” and “coastal” scientists, which makes this part of the programme possibly unique in an international context.

Numerous research cruises with POLARSTERN and other research vessels (e.g. SONNE) in the polar to subpolar North and South Pacific as well as the Arctic Ocean have provided a wealth of new insights into past environmental changes and have led to the development of new IODP proposals for the Arctic and Southern Ocean. These data together with the available databases represent a crucial step towards closing the gaps in the array of circumpolar palaeo-climate records.

As contributions to the Earth system model - mainly developed at Max-Planck-Institute for Meteorology in Hamburg - an interactive ice sheet model, various proxy modules, and the Finite Element Sea Ice-Ocean model permafrost have been developed and integrated.

In order to enhance predictive capabilities, modelling efforts will go in step with proxy data acquisition of past environmental states with emphasis on understanding rapid climate transitions. Research on polar predictability based on climate models will be a new element of PACES II. Through these modelling efforts it is anticipated that uncertainties of weather and climate predictions in polar as well as non-polar regions such as Europe could be reduced, which, if accomplished, would be of great socio-economic importance.

For coastal regions and shelf seas ongoing research has been focused on the assessment of change in the physical, biological, chemical and biogeochemical context with the North Sea being the natural laboratory. The unique Helgoland Roads time series has allowed hindcasts of regional climate and ecosystems variables leading to more quantitative estimates of variability and trends in the North Sea and to identify natural response to anthropogenic influences.

New genomic and experimental tools to assess diversity both within and between species have been developed and will be further used to establish links to functional biodiversity and ecosystem functioning with the prospect of contributing to the quantification of ecosystem services.

During the ongoing programme phase the COSYNA distributed observatory system was designed, built and deployed for a synoptic assessment of the geophysical and environmental state of the North Sea and first deployments also took place in coastal regions of the Arctic. Further development and extension of this system from its preoperational phase towards a fully operational system including some of the ACROSS activities will also lead to operational products and services to the outside community. Together with high resolution observational remote sensing techniques COSYNA will provide an important database for the observation and modelling of small-scale physical processes in the coastal ocean and some of its biogeochemical signatures, which will lead to an enhanced understanding of shelf sea ecosystems and their response to gradual change as well as extreme events.

The links between coastal research and society at large with its eminent interest in the subject are currently strengthened by the establishment of the “Norddeutsches Klimabüro” and the “Nordseebüro” which respond to enquiries and provide information on research results in a form accessible to the layperson.

The experience gained from such efforts has led to the establishment of a new topic (TOPIC 4) for the coming programme period. This topic has its origin in the already long lasting cooperation between AWI and HZG during the predecessor programmes MARCOPOLI and PACES where it became clear that there is a strong need for building a communication line with public and private stakeholders in order to facilitate management processes and the public

discussion, specifically in issues related to coastal zones. Topic 4 will consolidate the still somewhat scattered activities, and brings together not only the specific climate issues but also other issues, such as Arctic and coastal monitoring and the maintenance of multiple purpose-data sets and will attempt to develop appropriate tools and pathways to facilitate this interaction.

A completely new topic has been added to the Programme, which is different in scope and intent from the actual research topics. Topic 5 by its nature is characterized as a Service Topic and enables to transfer the Climate Service Center (CSC), a National Knowledge Transfer Center for Climate Change, from project into institutional funding and in this follows a directive from the BMBF. The CSC basically is not a research institution, but assembles, integrates and disseminates products and services to customers in Germany and elsewhere. More precisely, the mission of CSC is *to facilitate the transfer of state-of-the-art and user-oriented scientific information to society*. With this mission the CSC develops and provides science-based products and services in support of society's adaptation and development needs.

CSC makes comprehensive use of the competence of the German climate science, for instance, as bundled in the HGF initiative REKLIM, where PACES delivers contributions for example on the role of and impact on the cryosphere and coastal regions, including global and regional sea level rise. Topic 4 and the Service Topic (CSC) share some similar perspectives, but differ in the terms of approach, focus and intention. In order to clarify these different approaches and the different claims concerning the research and service characters of the work planned, some further annotations are necessary.

CSC as described in the Service Topic, relies in its practice on the scientific competence of all climate-related research institutions in Germany, while the HGF regional climate offices transfer knowledge produced in their own research centres, in particular knowledge generated by the REKLIM Project. The research Topic 4 includes the two scientific contributors to PACES II, AWI and HZG and maintains, analyses and improves their stakeholder interactions with focus on the specific research activities described in Topics 1-3.

To avoid duplication of efforts and to foster a fruitful cooperation between the different initiatives, the tasks of the CSC and of the four regional climate offices at HGF (HZG, AWI, UFZ, KIT) have been distributed as follows: CSC focuses primarily on issues of national and European relevance, while the different HGF centres deal with stakeholders interactions at the regional scales, specifically on issues directly related to their scientific programme.

In summary, both activities described in Topics 4 and Service Topic (CSC) contribute synergistically to the joint goal of improving the usefulness of scientific climate knowledge in public discourse and political and economic decision processes.

In general terms PACES II is developed such that transdisciplinary research is fostered; AWI and HZG together provide the necessary disciplinary expertise. In order to illustrate this we have singled out a particular theme within each Topic and highlight it in a separate box to demonstrate in an exemplary form that contributions from different disciplines are required to fully cope with the theme.

The box below illustrates how the theme of sea level rise, which overarches all the Topics is treated within each Topic with the appropriate in-depth expertise. Much of its origin lies in the polar ice sheets and the ensuing oceanic changes, and its consequences have imminent socioeconomic impact in coastal regions.

Sea Level Change

Major demands of our society on science are the observation of regional and mean global sea level, its variability, as well as projections of future sea level change. Assessing sea level change means quantifying its causes, as well as the spatial and temporal distribution of sea level – a complicate and complex task. We contribute to these urgent needs with a comprehensive interdisciplinary approach, arching across the topics of this program, focussing on different regions and time scales.

Understanding the causes mainly requires understanding the contributions of the ice sheets of Greenland and Antarctica, the ice caps and glaciers, the contribution of glacial isostatic adjustment and the thermo- and halosteric components of the ocean. Observations of the recent mass balance of both ice sheets, as well as modelled discharge on decadal time scale, will be incorporated into ocean models estimating the eustatic response of sea level to increased freshwater input and hence fingerprinting of regional sea level change (Topic 1). Self-gravitation and glacial isostatic adjustment will be investigated with partners in REKLIM at the GFZ.

For assessing the recent and future sea level change over climate cycles, we incorporate qualitative estimates of variations of sea level in the past on millennial and tectonic time scales, using geophysical and geological means and Earth system modelling (Topic 3).

Topic 4 focuses on the regional and local sea level change in the North- and Baltic seas. The analysis of tide gauges and the determination of transfer functions provide estimates of recent regional sea level change. Among the consequence of regional sea level rise is the increased impact of extreme weather events like storm surges and flooding especially in coastal areas. Hence applying multi-hazard modelling of selected areas along the North Sea coast will lead to enhanced storm surge and flood scenarios. Via the “Climate office for Polar Regions and Sea Level Rise” at the AWI as well as the “North German Climate Office” at the HZG the results will be distributed to stakeholders and society.

Utilization potential and commercial application

PACES II comprises also research with potential for public use and value for commercialization.

Beside the very applied approach of Topics 4 and 5 which provide information and data for both public and private stakeholders and which offers also high potential for commercial services (e.g. coastal authorities), knowledge and data accumulated in the other topics have also large utilization potentials. Some examples for such commercial applications are summarized below and more are listed within the detailed description of the topics and work packages (Part 3).

High precision temperature, salinity and density measurements are prerequisite for ocean and climate research and for numerous tasks in applied and environmental monitoring. We develop sensors and integrate systems such as

1) a Precision Salinometer System, which has been brought to a commercial status in cooperation with its manufacturer Optimare Sensor Systems. Its measurement principle is patented and the instrument is built according to a license agreement by Optimare Sensor Systems.

2) A portable winch for use with CTDs or similar instruments on ice floes or small boats is presently under development in a cooperative effort of AWI and Optimare Sensor Systems. The winch is exceptionally small and fits into the cargo of the AWI helicopters. Despite its small dimensions, it allows measurements in the deep ocean up to 6 km depth.

3) During the next years a best precision calibration facility for temperature, salinity, and density will be established and service will be offered.

4) The Ocean Acoustics lab developed the automatic whale detection software “Tashtego“ using data provided by a circumferential thermographic imager, which is commercially available from RDE. The auto detection of whales is of great interest to the oil and gas industry, the offshore windfarm industry and to navies, as their use of hydroacoustic sources has led to increasing concerns that the marine fauna might be harmed through acoustic exposure in the near field of such activities. “Tashtego” has been field tested on numerous expeditions and is now well proven. A patent application is pending and AWI and RDE are currently negotiating a licensing agreement to allow RDE marketing the AWI software together with their hardware.

5) In the framework of COSYNA a novel underwater node for shallow water has been developed. Contributors are HZG and AWI as well as the companies 4H-Jena and Loth engineering. In September 2012, this underwater observatory has been positioned 700 m off Helgoland. It is connected to the island via cable for optical data transfer (1 GBit/s) and power supply (950V, 3A), enabling real time and continuous high frequency measurements of up to 10 remotely controlled sensor units. The data are stored in the HZG database. The Helgoland node is equipped with a CTD and ADCP. A stereo-optical camera system (ReMos2) and a zooplankton recorder (MOKI) will be installed in October 2012. Since June 2012, an additional smaller node system is operated at the AWIPEV station (www.awipev.eu) in Spitsbergen, Kongsfjord, Ny-Ålesund, for year-round measurement in the arctic fjord with CTD, ADCP, and a stereo-optical camera system. Future development includes a buoy equipped with a fuel cell providing access to remote areas; commercialisation is intended.

According to the mission of the Helmholtz Association the transfer of results into societal application is one of the major goals including the commercialisation of innovations. During the last years innovation and knowhow transfer was further developed both on Helmholtz and institutional level. Starting with the motivation of invertors, the technology transfer office (TTO) conducts the protection of intellectual property rights, technology validation projects and technology marketing leading into commercialisation via industry cooperation, licensing and

spin-offs. Several instruments had been established by the Helmholtz Association and the Federal Ministry for Education and Research to support these efforts: The Helmholtz Validation Fund and the BMBF programme “Validation of innovation potentials from scientific research VIP” bridges the gap between basic research and application. The “Helmholtz Enterprise” programme funds early stage spin-off formation whereas the “Helmholtz Shared Services” support smaller TTOs with specific entrepreneurial services. The BMBF programme “Sectoral Exploitation” was designed to professionalise TTOs of non-life science institutions. The mentioned instruments provide important new opportunities to strengthen knowledge and technology transfer.

Strategic Partners, Cooperation and Competition

Strategic Partners: GEOMAR and GFZ

A close partnership exists with the Helmholtz programme "OCEANS: From the Deep Sea to the Atmosphere", conducted by GEOMAR and GFZ. Changes and regional feedbacks in the Arctic and Antarctic, as well as the dynamics and changes in coastal and shelf seas, will be investigated within the PACES II programme. Since the open ocean links the coastal and Polar Regions, the PACES II and OCEANS programmes complement each other very well. Scientists from AWI and GEOMAR have a long record of close collaboration, which will be further strengthened now that GEOMAR also belongs to the Helmholtz Association. To document existing cooperation, avoid duplication, and to coordinate joint future research, AWI, HZG and GEOMAR have developed a cooperation strategy that includes annual meetings of all tenured professors and other key scientists of the three centres. The first two meetings of this series were held in the cities of Stade (2011) and Ahrensburg (March, 2012), which are geographically located between the three centres. The joint declaration of the results of the Ahrensburg meeting is attached to this document, which also includes a list of joint publications (on the accompanying CD). The following research fields were identified for further intense collaboration:

- Climate dynamics, including proxy and paleo-climate model development
- Coastal ecology and marginal seas
- Ocean observatories
- Ocean acidification
- Continental break-up and large magmatic events

It is expected that further synergies in these fields will be gained by the increased AWI-HZG-GEOMAR cooperation that also includes university partners such as the Christian-Albrechts University of Kiel, the University of Bremen and the University of Hamburg. To reach this goal, the three centres also agreed on sharing and joint development of infrastructure (e.g. experimental mesocosm, deep-sea technologies, in-situ experimental ponds and reefs facilities), including the cooperation between AWI and GEOMAR in the Helmholtz Alliance ROBEX. Both programmes will document the effectiveness of this strategic partnership in their evaluation reports, for example, by listing new collaborative projects and joint publications. Finally, to demonstrate the close working relationship between the two programmes and to answer questions about the cooperation, it was agreed that delegates from both programmes will participate at each others on-site Helmholtz programme reviews.

Strategic Partner: Marine Environmental Sciences at the University of Bremen (MARUM)

A further strategic partnership exists between AWI and University of Bremen. Both institutions have a long and successful tradition of cooperation. Most professors at the AWI were jointly appointed with the University of Bremen, where also most PhD students of the AWI are accredited. A central partner in terms of scientific research collaboration is the Research Centre for Marine Environmental Sciences at the University of Bremen (MARUM). Joint research with MARUM includes palaeo-oceanographic, biogeochemical and palaeo-modelling studies that are complementary of the PACES II programme. MARUM projects focus on tropical and subtropical regions and thus are complementary to the polar studies of PACES II.

In 2010, the AWI-MARUM Alliance (AMAR) was established as a competence platform for the strategic further development of scientific and technical cooperation in the medium and long-term. At present, this partnership comprises three research fields:

1) Ocean system North Atlantic – Arctic

The joint work within this field focuses on the interaction between the Greenland ice sheet and the North Atlantic. Utilizing the expertise and experience of MARUM and AWI, the water masses and circulation processes under and in front of glaciers in NE Greenland will be studied. Autonomous measurement systems and tracer measurements underneath and in front of the glacier will be used to detect the influence of ocean circulation on the melting of the glacier and the circulation of the melt water in the ocean. In order to answer the question, whether the strong temperature rise we observe at present in the Arctic has happened before, a number of sediment cores will be drilled at suitable geological locations (e.g. Yermak Plateau and NE Greenland) with the unique MARUM sea floor drill rig (MeBo).

2) Underwater technology and earth observation systems;

At the core of this research field are a number of externally funded projects, which are currently being implemented jointly by the AMAR partners (e.g. H-ROV, ROBEX, FRAM). In addition, proposals for the development of sensor floats and subsea winches are being considered. These devices could for example be used in the FRAM underwater observatory and other important deep sea research sites of AWI and MARUM.

3) data information systems.

The central task of this research unit is the further development and sustainability of the PANGAEA data centre, which is jointly operated by AWI and MARUM. The necessary organizational, technical and infrastructural actions are joint activities to ensure the sustainable operation of PANGAEA and the continuation of data information tasks and systems initiated under the Helmholtz projects MANIDA.

It should be noted that other institutes and research partners from the University Bremen can join the AMAR alliance at any time and that further subjects and new areas of collaborative research will be initiated as required.

Close research and education cooperation is continued with the DFG Research Centre/Cluster of excellence “The Ocean in the Earth System” (MARUM). During the new funding phase approved for 2012 - 2017 the Graduate School GLOMAR will be part of the excellence cluster and will be carried out in conjunction with AWI scientists.

Strategic Partner: KlimaCampus Hamburg

Complex interplays of natural and societal drivers require that coastal science embraces a holistic view of the natural system and the human system acting in the coastal zone, locally, regionally and world-wide. This requires strong scientific and institutional partnerships. HZG is firmly linked in with the KlimaCampus Hamburg, a network of climate research experts in the Hamburg area that includes scientists from 18 different institutes of the University of Hamburg as well as non-university partners such as the Max Planck Institute for Meteorology, and the German Climate Computing Centre. The nucleus of the KlimaCampus is the Cluster of Excellence „Integrated Climate System Analysis and Prediction“ (CliSAP) of the University of Hamburg, which is funded in the framework of the Excellence Initiative of the German federal and state Governments. HZG contributes to the CliSAP Cluster of Excellence by leading research Area B (Climate Manifestations and Impacts) and delegating one member to the Science Steering Committee; 3 HZG scientists are amongst the principal investigators. In addition to that, excellent local services make up further building blocks for the climate research network: the German Weather Service, the Federal Maritime and Hydrographic Agency and the Climate Service Center.

Beyond these very close strategic partnership there will be contributions to this programme from other Helmholtz centres, in particular from GFZ in the fields of sea level monitoring and mass balance of ice sheets by satellite altimetry and gravity, DLR in the fields of remote sensing and robotics, KIT and FZJ in atmospheric physics, chemistry and modelling and UFZ in principles of biodiversity and the field of interactions with society

Beyond Helmholtz this programme, both in the polar components as well as coastal research will benefit from many national and international university groups or other research institutions that participate in joint field work either at sea or on land.

As this programme is well founded within larger international research roadmaps the continuing interest by others is guaranteed. Due to the excellent opportunities for research based on the large scale Helmholtz infrastructure, from ships and aircraft to research bases in both polar regions AWI and HZG is guarantee are very attractive for external research partners.

Infrastructures

Existing Infrastructures

Besides the infrastructures necessary for field observations mentioned above, local lab facilities are available at both HZG and AWI. They include standard analytical equipment for high precision and high throughput of chemical, biogeochemical and biological samples.

A Europe-wide unique facility at AWI are the ice core processing and analysis labs, which are also regularly used by partners from Europe and beyond. This facility also includes a high resolution CT for the analysis of pore space and consequently firn compaction on full firn cores.

Specialized aquaria at AWI allow the caging of polar as well as temperate marine organisms under their normal environmental conditions and also incubation and growth experiments.

Recently developed unique MS and associated lines at AWI allow concurrent Silica and Oxygen isotopic studies on extremely small diatom samples. New clean lab facilities have been established for LA-ICP-MS (femto second Laser Ablation Inductively Coupled Plasma Mass Spectrometry) analysis of very small samples for known proxys but they will specifically allow progress in the development of new proxies.

At AWI, NMR systems are available for structural analysis of natural compounds as well as an elaborate NMR (4.5 Tesla) system for physiological studies on living marine animals under different temperature regimes. It is planned to replace this 15-year old system during the coming period by a 9 Tesla system.

Computing facilities are available as appropriate to individual requirements up to TIER 3 level at AWI. They are well integrated into the overarching Helmholtz computing strategy. The current NEC-SX8 (TIER 3) system needs to be replaced in 2014 to provide the basis for model development and to allow for efficient throughput of medium-sized jobs. Large computing jobs and long production runs will continue to be carried out on external TIER 2 or TIER 1 systems.

COSYNA – Coastal Observation System for Northern and Arctic Seas

HZG has established COSYNA as an operational and integrated observational system for the North Sea. COSYNA achieves large spatial coverage of coherent and real-time measurements with various in situ and remote sensing platforms. The data are integrated in near real-time data-assimilation models providing a unique forecasting system for the North Seas that has been maintained over a long period of time. Several national partner institutions (AWI, BSH, ICBM, HPA, MARUM, NLWKN, IMARE, ZMAW, BAW, LKN, FTZ) are collaborators for measurements and data analysis.

In-situ observations are based on a multitude of sensors mounted on fixed and mobile platforms. Key physical, sedimentary, geochemical and biological parameters are observed at high temporal resolution in the water column and at the water-sediment and water-atmosphere interface. The data is complemented by satellite data of sea surface temperature and ocean color as well as radar current and wave measurements.

A nested modelling system with different spatial resolution levels is used for estimating various hydrodynamic and biogeochemical (ecosystem) state variables in near-real time. Of particular importance for COSYNA is the ability to provide forecasts of different parameters concerning ocean waves, circulation, and suspended matter (COSYNA products). By using data assimilation procedures, the reliability of now-casts and short-term forecasts is much improved.

The COSYNA products thus range from time series at various locations and regular maps of e.g. currents, waves, salinity, temperature, chlorophyll, oxygen, etc., to routine short-term

forecasts (days) for these parameters. Data management organizes the data streams between the observation sites, modelling output, and central storage systems situated at HZG. while performing quality control and providing data documentation.

COSYNA has an open data policy, providing real-time data and forecasts to stakeholders in politics, agencies, science, industry, or public via the COSYNA data portal (internet). COSYNA will be substantially supported by the multiplatform observation approach ACROSS (Advanced Remote Sensing – Ground Truth Demo and Test Facilities).

Planned Infrastructures

The FRAM Ocean observing system

Here AWI proposes the installation of a submarine infrastructure to meet the growing need for ocean data in the framework of Earth System observation. The main purpose of this infrastructure is permanent presence at sea, from surface to depth, for the provision of near real-time data on ocean dynamics, climate variability and ecosystem change. Our ability to understand the complex interactions of biological, chemical, physical, and geological processes in the ocean and on land is still limited by missing integrative observation infrastructure. This infrastructure should be installed at the gateway between the North Atlantic and the Arctic Ocean, which is a rapidly changing, highly climate-sensitive region of the Earth system. It will serve national and international tasks for a better understanding of the effects of change in ocean circulation, water mass properties and sea-ice retreat on Arctic marine ecosystems and their main functions and services. The FRAM ocean observation system includes a defined set of next-generation modular platforms and components allowing synchronous observation of important physical, biological and chemical variables. Products are long-term data with appropriate resolution in space and time and ground truth for ocean models and remote sensing, serving numerous national and international programmes. FRAM will integrate already existing Helmholtz observatories such as the LTER site HAUSGARTEN and the Fram Strait oceanographic array (HAFOS). These are operated by AWI with contributions by Norway and other international collaborators since the late Nineties. They represent valuable long-term data, including recordings of ocean conditions before the accelerated sea-ice decline at the turn of the millennium, and are already embedded in many national and international programmes. FRAM targets the short to intermediate term vision of autonomous underwater infrastructure, representing the first step towards a larger European plan of a cabled underwater observatory network in the Fram Strait region.

High Performance Computing Platform for Model Development and Data Interpretation

AWI has strong activities in modelling, starting from algorithm development over contributions to community models up to in-house developments of entire model components like the ocean model FESOM. Seven research sections of AWI are actively engaged in modelling, model development and application and these tools are required to achieve the goals of almost every work package. It is the aim of this procurement to provide an internal HPC platform for these model developments for the period of PACES II (2014-2018). External production runs of models in the PACES II period will also use national HPC Centres like JSC/FZJ, DKRZ and HLRN.

Currently, the AWI utilizes a NEC SX-8R HPC platform with 14 nodes and 8 CPUs per node, which was installed in 2007 and will be in use until 2014. A replacement is needed for several reasons. First, the present system will be out-dated by 2014 and unable to keep pace to growing demands from the modellers, either due to new numerical techniques (e.g. finite element models), or increased resolution. Moreover, developments on the part of processor architecture turned away from vector techniques. The NEC replacement needs to be able to

host all model codes currently in use at AWI, including finite element models, which are not well suited for vector processors. We aim for a target system with 20,000 to 35,000 cores and 0.2 to 0.5 PFlop/s, being effectively ten times the computational power of the present installation at the application level.

Apart from the computational resources, a strong demand for storage and an integrated data archive arises from the huge amount of data produced, which has to be kept together with metadata for at least 10 years (DFG rules for good scientific practice). The goal of this procurement is therefore also to replace and extend the existing long-term archive, which was part of the NEC SX-8R investment in 2007.

The total capital expenditure is based on the experiences of the investment into the NEC SX-8R and the existing data archive in 2007, i.e. 4.000 T€. Out of this sum, 665 T€ need to be invested into a renewal and extension of the data archive, and 3.335 T€ into the replacement of the high performance computer system.

Nuclear Magnetic Resonance Spectroscopy (NMR)

In a world wide comparison the Nuclear Magnetic Resonance (NMR) laboratory at the Alfred Wegener Institute for Polar and Marine Research (AWI) stands out by being dedicated to marine and polar research questions. This large-scale facility is unique in enabling long-term non-invasive studies of physiological functions of marine macro-organisms, by using a horizontal magnet for their study under unrestrained conditions. During the last 16 years the NMR system has contributed to the unravelling of the physiological background of climate sensitivity and climate dependent evolution in animals. The existing equipment is now out-dated and the expected lifetime of the superconducting magnet already exceeded. The level of resolution and the number of applications have become more and more limited when compared to the newest systems with higher field strength. The new system with field strength of 9 Tesla will greatly enhance resolution and additionally running costs will be reduced by a longer helium refill cycle due to the new magnet technology. Therefore, this application has the goal to replace the horizontal magnet and associated infrastructure and to thereby widen our opportunities for future research on marine organisms under climate change.

REEPON

REEPON is a research platform unique in its focus on marine ponds and reefs for the experimental study of ecological processes in coastal and shelf waters. REEPON will be reproducing coastal and shelf ecosystems, which are impacted or under pressure, for the first time in sufficient size and in realistic variety to be studied and researched in an experimental setting, which closely resembles real world conditions. REEPON will also connect small-scale laboratory experiments with large-scale research (ships & monitoring) as it is intermediate in scale. Moreover, REEPON uses and combines existing information, e.g. from the Coastal Observing System for Northern and Arctic Seas (COSYNA), the EU Water Framework Directive, research expeditions and relevant laboratory work. REEPON will deliver useful ecosystem data, assertions and observations to authorities and modelers alike. It will also stimulate the European research cooperation and promote new technologies e.g. sensors and underwater systems, which in tern will create new economic synergisms.

Technikum

This investment is in line with AWI efforts to upgrade facilities and to allow in concerted fashion the development, construction and testing of instrumentation for field deployment. A support facility for the large demand on technical development work is not yet available but it has become evident that such a facility is needed urgently. Instrumentation required for achieving

the goals of the programme, whether it is an ice core drill or systems for observing the ocean and its boundary with the sea floor and the atmosphere, respectively is large and complex. It It needs adequate facilities for development as well as maintenance and must be tested under the conditions for deployment. Therefore AWI plans for an appropriate building, which can serve these requirements and at the same time will offer space for specialized electronics labs and the necessary machining tools.

Advanced Remote Sensing - Ground-Truth Demo and Test Facilities (ACROSS)

By relating ground truth data with satellite data, ACROSS will lay the foundations for overcoming the technological and methodological challenges of the transfer of proxies, remotely sensed by satellites, into environmental parameters. Furthermore, the ACROSS infrastructure will be deployed to develop, improve and validate monitoring concepts which are likely to facilitate the future usage of satellite data. By closely linking the already existing observatories and remote site observations, ACROSS supports the better integration of the Helmholtz activities across the different marine, coastal and terrestrial systems. Combining the efforts, expertise and capabilities of nine Helmholtz Centres and their partners will create conditions to overcome still existing limits in integrated environmental monitoring and research, e.g., coupling of earth surface ecosystems and atmosphere, connections between terrestrial hydrosphere and estuaries/marine systems as well as ocean surface expressions. The regional focus will be on Europe and its periphery taking advantage of those Helmholtz observatories that are located in this region. AWI and HZG contribute with COSYNA as a multi-scale coastal platform, with the Samoylov observatory for the permafrost regional component and with ground truthing for the oceanic realm, in particular the sea ice component. ACROSS is fully funded by the Helmholtz Association and will start operations in 2013.

large investment (> € 2,5 million) proposals planned in the programme period

	total investment sum in TEUR anticipated plan
AWI: Individual investment proposals planned	**79.513,0**
FRAM - Ocean observing system *)	24.713,0
High Performance Cumputing Platform (NEC)	4.000,0
Nuclear Magnetic Resonance Spectroscopy (NMR)	2.500,0
REEPON **)	23.300,0
Technikum	25.000,0
HZG: Individual investment proposals planned	**2.500,0**
ACROSS ***)	2.500,0
Total investments (AWI & HZG)	**82.013,0**

*) Prioritised by the Helmholtz members for 2014, final funding decision pending
**) Proposal planned to be presented during the programme period
***) All centers start to finance ACROSS in advance from 2013 on, except HZG how starts ACROSS from 2014 on

Management

Organisation and Cooperation

The decision making process started with writing of the programme, which was developed in a bottom up approach and in many discussion rounds with involved scientists - in many cases from both Helmholtz centres, strategic and associated partners as well as other national or international collaborators – the programme emerged in its present shape.

The two Helmholtz Centres contribute in different intensity to the four topics as identified in the topic and work package descriptions. The missions of the centres are well reflected in the new programme and the directorates of the centres are actively involved in the shaping of the major goals of the PACES II programme. This also includes the strategic planning of the infrastructure and future running of the new infrastructures in accordance with the centre development.

As already explained above most of the decision making processes within the programme have a long-term aspect in the sense that the availability of the research infrastructure necessary for fieldwork in polar regions is limited (e.g. time on POLARSTERN is overbooked about two and a half times). Therefore, in discussions amongst topic and workpackage representatives compromises will be sought, which will satisfy as much of the requirements as possible and without loosing sight of the very central themes.

Planning and Controlling

It will be the responsibility of the programme speaker, the topic speakers as well as workpackage coordinators to plan and oversee the progress of the actual programme and together with the centre directorates discuss the most effective distribution of resources. It has proven very effective to have formal annual workshops for each topic in which progress is presented, failures are identified and the way forward is discussed. Results from these workshops are then discussed with the centres management in order to achieve a reallocation of resources, if necessary.

The scientific achievements of the programme are controlled by the regular evaluations of the Scientific Advisory Boards of the centres.

Talent Management

The programme offers ample opportunities for young academics of both genders to train for leadership in particular during expeditions or research cruises, when they are tasked with achieving their own or common goals even as it may happen under adverse conditions. Furthermore special attention is paid to PhD support and supervision on the individual level through the establishment of a PhD committee for each candidate. Furthermore in two graduate schools also additional educational services are provided.

Helmholtz Graduate School for Polar and Marine Research (POLMAR)

The Helmholtz Graduate School for Polar and Marine Research (POLMAR) started its work end of 2008 and has since been growing continuously. It collaborates closely with the universities of Bremen and Potsdam, Jacobs University Bremen, Max Planck Institute for Marine Microbiology (Bremen), Bremerhaven University of Applied Sciences, and Institute for Marine Resources (IMARE).

To date, 135 members are enrolled in POLMAR, equalling about 2/3 of all AWI PhD students and including 21 POLMAR-financed stipends of which three have just finished their thesis. The percentage of female PhD students amounts to roughly 60% and about 10% are parents. 30% of the members come from abroad.

Members choose their course curricula from a wide spectrum of courses. These cover scientific workshops with a strong interdisciplinary component, compact courses given by invited guest scientists, general courses covering statistics, electronics, first aid, or introduction to GIS, as well as the whole range of transferable skills trainings. Amongst these, scientific writing courses range at the top and are offered upon demand. Further highlights include training cruises with POLARSTERN (Parasound Training) and HEINCKE (Maritime Sampling Techniques). Invited guest scientists are chosen both according to students' needs and in order to strengthen existing research activities of the institute, like e.g. the work on sea ice (Prof. H. Eicken, University of Fairbanks and Prof. D. Thomas, University of Bangor/Wales). In 2011, POLMAR organized a total of 80 course days with more than 30 AWI colleagues contributing to the program.

Financial support is provided through travel grants, outgoing scholarships (up to 3 months) and by covering extra costs arising from childcare during workshop or conference participation.

The POLMAR office is the prime contact address for PhD student matters and in this respect works closely together with the student's ombudsmen, the PhD students' representatives, the family office and the equal opportunity officer at AWI. Both POLMAR coordinators contribute to the institute's activities, and are e.g. members of the "Audit Beruf und Familie" or the mediation team. They are also part of various networks and regularly meet up with colleagues from the partner institutions, from the Graduate Centre at the University of Bremen (ProUB) and other Helmholtz Graduate Schools and Colleges.

Earth System Science Research School (ESSReS)

Since the official inauguration of the Earth System Science Research School (ESSReS) at the AWI in October 2008, a first generation of 23 PhD was educated in the field of Earth system sciences, with special emphasis on data analysis and modelling. The group comprised an equal share of female and male doctoral students from 8 different nations (43% foreign PhDs). The common educational programme, which has been successfully completed in collaboration with our partner institutions University of Bremen and Jacobs University, gave insights in all fields of Earth system sciences. The curriculum comprises more than 45 compulsory lecture days and seminars. Transferrable skills were trained in a 3-stage course by the Imperial College London in the framework of the Helmholtz research school network. In contrast to POLMAR, ESSReS education is organized in fixed classes, building a strong network and collaborative atmosphere among the PhDs right from the beginning. By mid-2012, about 50% of the PhDs have successfully defended their PhD with an average duration of 3.25 years (expeditions and research stays at foreign institutes have not been taken into account) and directly found follow-up PostDoc positions at research institutions.

The midterm evaluation by an independent reviewer board in 2010 stated that "with ESSReS a successful bridge between the involved research areas on the one hand and the partner institutions on the other hand has been successfully succeeded". This paved the way to call for a second class, which was established in 2011. The second class comprises 23 PhDs now from 12 countries with a gender ratio of 30% female and 70% male students.

As sustainable documentation a book about the implementation of the research school and with contributions of all PhD projects of the first class has been submitted to Springer publisher and shall give an example for the build-up and establishment of today's educational concepts. This concept also served as the base for the POLMAR graduate school at AWI.

Both, POLMAR and ESSReS, provide a new level with binding rules for doctoral education at AWI, striving to meet our enduring efforts on the improvement of doctoral education in the

Helmholtz Association and additionally provide stipends for graduate students also from foreign countries. Furthermore AWI strongly interacts in international organized by other organisations.

International Graduate Programs

The International Max Planck Research School of Marine Microbiology (MarMic) is a M.Sc. / PhD graduate program for highly qualified and motivated national and international students. MarMic is a joint program of the Max Planck Institute for Marine Microbiology, the University of Bremen, the AWI, and the Jacobs University Bremen. MarMic teaches students to take an interdisciplinary approach to the understanding of marine prokaryotic and eukaryotic microbiology, offering training in physiology, ecology, evolution, molecular biology, bioinformatics, and other related subjects.

The International Graduate School Global Change in the Marine Realm (GLOMAR) is a multidisciplinary, multi-institutional graduate school funded through the 'Excellence Initiative' for German Universities, where AWI strongly participates in 3 of the 4 fields.

Highsea: Leaving School – learning at SEA

AWI aims at providing regular high school education alongside polar research and is offering solid science education not only for university students but also for a larger audience. All efforts towards this goal are interconnected within the project SEA (Science & Education @ the AWI) (http://highsea.awi.de/index.php).

Since the school-term of 2002/03, about 22 high school students (grade 10 or 11) are admitted each year to Highsea spending their last three years of school not at school but at the institute. Four subjects (biology as a major, chemistry, math and English as accessory subjects) are combined and taught fully integrated. Students leave their school for two days each week to study, work and explore all necessary topics at the AWI. We are organizing expeditions for every group of Highsea-students (e. g. to the Arctic or to mid-Atlantic seamounts). For each student expedition we devise a "real" research question and data gathered by the students during "their" expedition contribute to ongoing research projects of different departments of the AWI.

Highsea students usually finish their final exams with way above average results and have excellent starting conditions for taking up university courses in natural sciences. When compared with general German figures, Highsea "produces" twice as many university students of natural sciences. Approximately 13% of the Highsea-students return to the AWI to work on their bachelor-, master- or PhD-theses. This success rate could be also seen as an answer to counteract the unsatisfactory results from the international OECD study PISA (Program for International Student Assessment).

Junior Research Groups

Junior Research Groups are a further component of career development and are positioned in research fields of relevance for the scientific programme. Together AWI and HZG have implemented 9 Helmholtz Junior Research Groups, ERC or Emmy Noether Groups for young academics in the field of polar and coastal science.

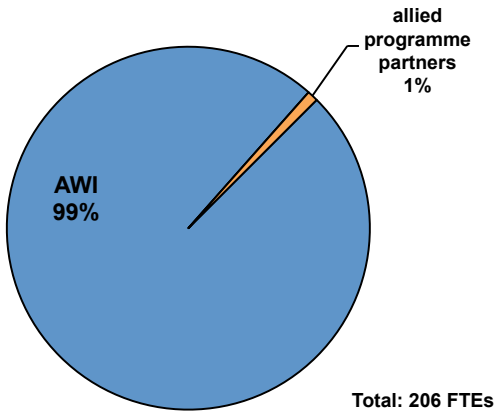
PART 3: Programme Content

Topic 1: Changes and regional feedbacks in Arctic and Antarctic

Coordinators: U. Schauer (AWI), P. Lemke (AWI)

Challenges

The Polar Regions have shown the largest climate change signal in recent decades. Yet they belong to the least understood parts of the Earth system, which is largely due to the harsh environmental conditions that poses special challenges for field studies. Quantifying the contemporary variability and changes and understanding the relevant processes in the cryosphere, oceans, atmosphere and the biosphere in the north and south Polar Regions is, however, a prerequisite to determine the role of the high latitudes in the Earth system and to project its future development (Topic 3).



The high latitudes are ultimately linked to lower latitudes by receiving heat through the atmospheric and oceanic circulation to compensate for the strong negative polar radiation budget. They store huge amounts of fresh water in the continental ice sheets with a strong potential for sea level rise after melting; the sea ice cover constrains heat, momentum and gas exchange between ocean and atmosphere; and the massive terrestrial and submarine permafrost holds one third of the terrestrial global biogenic carbon, which may be mobilized by increasing temperatures. The cooling of polar oceans leads to the ventilation of the global abyssal ocean, which has significant implications for the CO_2 cycle. High latitude changes are believed to belong to the strongest anthropogenic signals on the globe. The stratospheric ozone largely vanished over both poles; the surface temperature in the Arctic has increased twice as much as the global average during the last decades and the Arctic sea ice continues to decrease. On the other hand the Antarctic sea ice cover is slightly increasing, despite the Antarctic Peninsula featuring the worldwide strongest warming. Mass loss of the Greenland and Antarctic ice sheets has accelerated in the last years Substantial effects on the polar marine biota such as shifts in biodiversity, trophic interactions, and ecosystem functioning with consequences for ecosystem services are expected. On the other hand, polar warming opens new possibilities for gas and oil exploration, fishing and sea traffic with unknown impacts on polar ecosystems.

In order to improve our capabilities to assess future developments and to identify potential tipping points we must understand the key processes that drive the changes and their feedback mechanisms. A particular challenge will be to sharpen our abilities to distinguish between natural variations and anthropogenically caused changes.

The following major questions will drive our research in the coming years:

- How is the Polar atmosphere coupled with the sea ice, ocean and land?
- How will dynamic and thermodynamic processes influence the mass balance of the Greenland and Antarctic ice sheets?
- How is the greenhouse gas methane cycling in the atmosphere - cryosphere - ocean - sediment system?

- What are the key processes controlling the vulnerability of the Arctic permafrost carbon pools?
- What are the causes of Arctic sea ice decline and what are the consequences for the ocean circulation, biogeochemical cycles and ecosystem functions?
- How does the Southern Ocean change and what are the processes that link physics, chemistry and ecology, and determine the feedbacks to the global climate system?
- What are expected impacts and risks of an increasing commercial use of the Arctic?
- How can this knowledge be used to make commercial Arctic activities sustainable?

These challenges will be addressed through a wide range of carefully coordinated long-term in-situ and remote sensing observations, process studies, and regional modelling at a high degree of multidisciplinary.

Current Activities and Previous Work

A backbone of research on recent climate change is repeat observations. To capture the variability of the Arctic and Antarctic atmosphere, ice sheets, oceans and permafrost regions and their biota on time scales from seasons to decades long-term observing systems have been developed and implemented in previous HGF programme periods. One of many examples is the outstanding 30 years atmospheric time series from the observatory at Neumayer Station in Antarctica, which has the status of a “climate time series” of the WMO-GCOS program. Another example are HAFOS (Hybrid Arctic and Antarctic Ocean Float System) observatories, which are designed particularly to meet the challenges in ice-covered oceans.

The observational time series are complemented by dedicated process studies and enable an overall understanding and assessment through a range of modelling activities of various levels of complexity and time scales that reach beyond those of the observations.

Surface energy budget, structure and fluxes in the polar atmospheric boundary layer, cloud and aerosol properties, and water vapour and ozone concentrations are recorded at observatories and during aircraft campaigns. The data are used for evaluation and development of parameterizations of sub-grid scale processes in regional and large-scale climate models. It has been shown that the large-scale atmospheric circulation and its variability respond sensitively to theese processes. Simulations with coupled ocean-ice shelf/sheet models suggest that changes in sea-ice and ocean circulation may add considerably to destabilise the Antarctic ice sheet in the near future.

Permafrost studies indicate that most of the carbon released from terrestrial and submarine permafrost consists of recently biosynthesized matter. Results emphasise the significance of small water bodies (ponds) as conduits for carbon emission, which are not yet resolved in climate and ecosystem models.

Systematic surveys using the electro-magnetic ice sensor, an in-house development at AWI, showed that in large areas of the Arctic sea ice thickness has decreased by more than 1 m in recent decades. Sensitivity tests with coupled sea-ice ocean models indicated the crucial role of thickness for the future sea ice evolution. Ocean observatories revealed considerable accumulation of fresh water in the central Arctic and warming of Weddell Sea Bottom Water in the Southern Ocean. Repeated transects document uptake of anthropogenic CO_2 by the ventilated Antarctic deep waters. Southern Ocean iron fertilisation experiments showed that iron supply stimulates organic carbon export from the surface layer to the deep ocean and seafloor. This process is modified by complex interactions between the physical, chemical and biological realms.

Biogeochemical and primary productivity studies suggest an equal importance of sea ice and pelagic system for carbon fluxes but highlight also the dominant role of water mass distribution

in shaping biogeochemical cycles. Biological and physiological studies have provided significant insight into environmental constraints of polar organism behaviour and performance, ranging from phytoplankton through key species such as krill up to mammals.

A hierarchy of coupled biogeochemistry-ocean circulation models is currently being developed to analyse ecosystem-variations from diurnal to glacial-interglacial timescales.

Illustrative for the multidisciplinary approaches within this Topic we have singled out a theme of particular relevance in the Arctic and with global implications.

Methane in the Arctic - Sources, Sinks and Pathways in the Ecosystems

Atmospheric methane in the high Arctic is the highest on earth, about 10% higher than in the Antarctic. This atmospheric maximum is one of the most mysterious phenomena observed in the Arctic and to date no plausible explanation has been suggested. Especially, relatively level periods and large short-time variations are difficult to explain and focus the view on the sources and sinks in the recent methane cycle. Emissions are known to be partially of anthropogenic origin as shown by the rapid rise in atmospheric levels since the beginning of the industrialization. However, the changing Arctic, home to large known methane reservoirs like permafrost and submarine gas hydrates, is a potential driver concerning sizeable shifts between sources and sinks in the atmosphere-sea ice-ocean-permafrost-sediment system. The least known box in the Arctic system is the sea ice and a main impact of sea ice relates to its role as a cap on the ocean influencing the gas exchange. This role, however, is changing due to the rapid decline of summer Arctic sea ice cover. Basic datasets for the Arctic region are needed to model the impact of the ongoing climate warming on the methane cycle.

In an interdisciplinary approach we aim to find linkages in the atmosphere-sea ice-ocean-permafrost-sediment system to understand and quantify the coupling between methane sources and sinks. This networking project will combine the different views on the methane cycle as seen by scientists from different disciplines and will strengthen collaborations in addition to those between the work packages and topics.

The final goal is to understand the pathways and microbial drivers of methane production and consumption triggering methane cycling in the atmosphere-sea ice-ocean-permafrost-sediment system and to quantify methane fluxes from wetlands, shelves and high Arctic regions to the atmosphere on a regional scale.

Objectives

This topic aims to lay the ground for improved predictability by quantifying ongoing changes in the Polar Regions and understanding the underlying processes. The overall objectives are

- To carry out a combination of long-term monitoring and observations of atmospheric key processes on different scales over ice covered surfaces; to improve the current insufficient understanding of the polar climate system through small to global scale modelling (WP1).
- To assess the mass variation of the ice sheets by large-scale mapping of ice thickness and basal topography, adjusting regional models and use them for sensitivity studies, providing input for the modelling of sea level change, to achieve a better understanding of firn densification and deformation and of the role of the warming oceans for destabilization of the Antarctic ice shelves and Greenland outlet glaciers (WP2).
- To observe key parameters and model processes which control the vulnerability of Arctic permafrost and its carbon pools and to quantify the release of carbon in gaseous,

dissolved and particulate form; thereby studying the permafrost energy and water balance, changes in land cover of the circumarctic permafrost regions, coastal erosion, and subsea permafrost (WP3).

- To distinguish between anthropogenically driven changes and natural variability in the evolution of Arctic sea ice, to determine the contribution of the ocean to the Arctic sea ice retreat and its effect on the ocean circulation and fresh water balance and to assess and quantify ecosystem changes from surface to the deep ocean in response to retreating sea ice (WP4).
- To improve our projection capabilities of the Southern Ocean's future role in the cycling of carbon and nutrients and hence its role in global climate and marine productivity; to continue capturing Southern Ocean variability in the physical and chemical environments and in biodiversity through long-term observations; to combine time-series, interdisciplinary process studies and model simulations to identify the main drivers of change in food-webs and biogeochemical fluxes (WP5).
- To analyse and model the present and future role of benthic and demersal biota in key ecosystem functions such as biodiversity, energy flow and biogeochemical cycles of polar oceans (WP6).

Expected Results, Milestones

The research necessary to meet the objectives of this topic will be organised in six work packages. Furthermore, there will be contributions to two networking themes. The overarching approach in all work packages is to combine field studies, remote sensing, lab experiments, theoretical studies and numerical modelling in an interdisciplinary way across the core disciplines of physics, biogeochemistry and biology.

WP1 "The polar atmosphere and feedbacks to sea-ice, ocean and frozen land" will use observations in combination with modelling studies to investigate feedback mechanisms of the lower atmosphere, sea/land ice and ocean. A focus will be on atmospheric boundary layer and cloud processes and their interactions with aerosol, water vapour and baroclinic cyclones. Predictability of chemical ozone loss in the Arctic will be assessed using better understanding of the processes that regulate the stratospheric sulphur and aerosol budget and the role of aerosol variability. WP2 "Ice sheet dynamics and mass balance" will combine modelling and observational research on ice sheets/shelves and their interaction with atmosphere and ocean. Special attention will be given to better incorporate the ice deformation, firn processes and the hydrology to the ice sheet model. The ice sheet-ocean interaction will be addressed by dedicated field studies at the Filchner-Ronne Ice Shelf and at the NEGIS outlet glacier in north-eastern Greenland.

WP3 "Degrading permafrost landscapes; carbon, energy and water fluxes" will study the climate response of permafrost landscapes and submarine permafrost. Budgets of sediment, carbon and nutrient delivery to the Arctic Ocean and greenhouse gas emissions to the atmosphere will be derived by using a range of observations such as local field measurements and large-scale remote sensing on land and along the coasts on several locations in the circumpolar Arctic. The backbone of the research will be the Samoylov station in the Lena Delta, which will be operated year-round as an international network observatory.

Research in WP4 "Arctic sea ice and its interaction with ocean and ecosystems" will provide Arctic-wide estimates of sea ice volume, growth and export rates. Budgets of heat and fresh water will be obtained including exchange rates between the Arctic and Atlantic oceans. Estimates of primary production and vertical fluxes of organic material will be given and links between physical, biogeochemical processes and biodiversity indicators will be studied.

WP5 “Southern Ocean physics, biodiversity, and biogeochemical fluxes in a changing climate” will combine observations with open ocean and laboratory process studies. The data will be merged with models in order to assess the variations and trends in the physical and chemical environment and the response on different levels within the marine ecosystem in the Atlantic sector of the Southern Ocean. Key processes which couple the physical, chemical and biological realms and biogeochemical fluxes will be identified to improve the ability to make reliable forecasts of shifts in the balance of the biological and physical pumps of carbon. WP6 “Large scale variability and change in polar benthic biota and ecosystem functions” will use a macroecological/-physiological approach to identify, quantify and model links between environmental drivers and biological responses with emphasis on the role of benthic and demersal organisms for polar ecosystem functions. It combines experimental, field and modelling activities on hierarchical levels from genes to organisms/populations to ecosystems. Ecophysiological and biogeochemical models will be coupled geostatistically to address spatial and temporal variability of benthic ecosystem functions, such as the organic carbon flux.

The innovation transfer potential arising from Topic 1 includes deep-sea observation systems and underwater sensors for commercial use as well as data and services related to the access to the Arctic and the deep-sea, respectively.

Workpackage 1: The polar atmosphere, interaction with sea ice, ocean and frozen land

Coordinators: K. Dethloff (AWI), U. Wacker (AWI), R. Gerdes (AWI), J. Boike (AWI)

Mission statement

A combination of in-situ process studies, long-term climate process monitoring, regional and global climate modelling will be applied to improve the current insufficient understanding of the polar climate system.

Challenges

The Polar Regions represent the cold poles of the global climate system heat engine. Heat is transported poleward from the lower latitudes by the atmosphere and ocean to compensate for the heat deficit in Polar Regions. Hence, changes in the radiation balance of the Arctic system may have the potential to affect the atmospheric and oceanic circulation for the whole northern hemisphere, including the European region. Attribution of ongoing polar changes is difficult because internally generated variability may be large enough to partially mask anthropogenic influences. The rate of observed sea-ice decline over the last decades is higher than projected in the IPCC AR4 model simulations and its causes as well as regional and global impacts remain to be fully understood. Current regional and global climate models (RCM, GCM) suffer from poorly described processes and regional feedbacks due to the paucity of observations in the remote areas and insufficient parameterizations. To improve simulations of polar processes within the global climate system the parameterizations of sub-grid scale processes must be further developed and enhanced. A combination of in-situ observations and satellite measurements will be used to monitor important atmospheric and surface parameters that are needed to improve model parameterizations with a strong focus on atmospheric processes and their interactions with the snow- and sea-ice-covered surfaces.

- Understand the changes in the coupled atmosphere-ocean-sea and land ice-system.
- Disentangle natural from anthropogenic causes of observed recent climate change.
- Reduce uncertainties in Arctic climate change projections.

Current Activities and Previous Work

Since atmospheric processes, such as those related to the stable Arctic planetary boundary layer, are a source of large systematic errors in atmospheric models measurements must be interfaced with NWP models and regional Arctic climate models (atmosphere-only RCMs, coupled Atmosphere-Ocean-Ice RCMs) to derive appropriate parametrizations. These are implemented in global climate models and tests for the impact of sub-grid scale parameterizations on simulations of large-scale atmospheric circulation patterns in European mid-latitudes and on decadal climate variability are carried out. Atmospheric measurements of the surface energy budget and atmospheric boundary layer structure, heat and moisture fluxes, cloud and aerosol properties, water vapour and ozone are essential for the understanding of key processes in the polar climate system. These measurements are carried out at Arctic and Antarctic observatories and during air-borne measurement campaigns. Processes in polar regions, connected with a variety of feedbacks, including cloud-, aerosol-, ozone-, planetary boundary layer-, sea ice and frozen land processes cause changes on the global scale and are not well represented in numerical weather prediction and climate models as shown by our work.

Objectives

To overcome present deficits in understanding and modelling of polar weather and climate, various observation and analysis strategies in combination with improved model concepts are required. Observations in the Arctic and Antarctic will be carried out to understand the nature and origin of changes in the polar atmosphere, sea ice and frozen land. Measurements will be taken at long-term observatories, from POLARSTERN as well as from the two polar aircraft (Polar5 and Polar6) of AWI with their relatively long-range capabilities; these measurements will be augmented by remote sensing data. The data sets will contribute to study the following physical processes: exchanges of heat, mass, and momentum at the ice-land-atmosphere interface, vertical transfer of heat, moisture and momentum in the atmosphere, inversions, clouds, aerosols, ozone, and baroclinic cyclones. A systematic modelling approach is needed to understand the involved feedbacks of the processes ranging from local to regional and global scales and in the coupled atmosphere-ocean-sea ice-frozen land system and within the subsystems. Arctic climate feedbacks and links to atmospheric teleconnection patterns will be investigated with the goal to reduce the large uncertainties in projected future polar climate change. This requires an improved understanding of regional feedbacks (atmosphere-sea ice-frozen land), investigations of their global impacts and studies of seasonal and decadal-scale climate variability, together with WP3 in Topic 3. The interactions between atmospheric low- and high-frequency baroclinic processes and the impact of polar sub-grid scale parameterizations will be studied. Long time series from observations and from model runs covering the whole annual cycle are required to understand the variability inherent in these processes, particularly as they respond to major climate shifts such as a drastic decrease in sea-ice concentration.

- Understand and model physical processes on local, regional, and global spatial scales and on daily to decadal time scales.
- Investigate polar climate feedbacks and links to atmospheric teleconnection patterns.
- Exploit all in-situ and remote sensing observation techniques.

Expected Results, Milestones

Atmospheric meso-scale processes and interactions with ocean, sea and land ice

To enhance our understanding of polar weather and climate and to quantify exchange of mass (including H_2O and CH_4), energy and momentum between the atmosphere, sea ice and land ice depends we have to improve our knowledge of processes on various scales by a combination of

observations, long-term monitoring and modelling.. To estimate the seasonality of the ABL structure above different surface conditions, in-situ and remote sensing data will be collected during campaigns with Polar 5 and 6 over the northern Fram Strait and inner Arctic regions and from observations at Kohnen (Antarctic Plateau). A maximum benefit will be obtained from these campaigns by combining the observations with model results focussing on interaction processes on local, regional and large scales. The effect of decreasing sea ice concentration and thickness on the structure of the lower atmosphere can be estimated as function of changing forcing (wind, temperature). These studies will contribute to improved parameterizations of sub-grid scale processes with a focus on the dependence of turbulent sub-grid scale processes on sea ice morphology and on clouds. Ongoing monitoring of climate changes and vertical distribution of ozone concentration up to the stratosphere at the Neumayer Station deliver unique data sets, which will continue to be made available to the scientific community.

Arctic Ocean-sea ice interactions

Sea ice regulates the fluxes of momentum, heat and matter between the ocean and the atmosphere. It represents a highly variable interface and is responsible for important feedbacks in the high-latitude climate system. To better understand the role of sea ice as upper and lower boundaries for the ocean and atmosphere, respectively, investigations of the vertical fluxes and the feedback mechanisms with both ocean and atmosphere, are needed. Improved parameterizations of the momentum and heat transfer under different sea ice regimes (see above) will be tested in ocean-sea ice hindcast simulations and validated with sea ice observations from remote sensing, ice mass balance buoys, and aircraft campaigns. This will result in a mapping of sea ice roughness. The sensitivities of the system will be investigated systematically using adjoint modelling techniques.

Aerosol and cloud feedbacks in the Arctic atmosphere

Aerosol and their interaction with clouds remain one of the largest uncertainties in the Arctic climate system. Warmer and more humid Arctic winters will lead to increased wet deposition and removal of hygroscopic aerosol components. In contrary increasing pollution from East Asia, increasing transarctic shipping and an earlier onset of forest fires may increase black carbon (BC) concentration. BC with its absorption will amplify warming both in the atmosphere or deposited on ice or snow-covered surfaces, thereby decreasing atmospheric stability. The AWIPEV research base in Ny-Ålesund has recently been updated with new instrumentation (continuous remote sensing of wind, humidity and temperature) and optimized balloon-borne measurements, which now meet the GCOS Reference Upper Air Network (GRUAN) standard. Thus the station is well equipped to perform aerosol closure experiments, measurements of mixed ice-water clouds, interactions between aerosol, clouds and water vapour or the coupling between the boundary layer and baroclinic cyclones by different ground-based, balloon-borne and airborne sensors. Flights of AWI's Polar 5 aircraft will link boundary layer measurements to aerosol-cloud events, surface properties (interaction of the atmosphere to sea-ice, ocean, land) and the synoptic situation.

Arctic ozone layer feedbacks

The polar ozone holes belong to the strongest anthropogenic signals in the global atmosphere. The Arctic ozone layer is vulnerable to changes in climate, and stratospheric ozone loss is a main driver of climate change. The Arctic ozone layer is also particularly sensitive to variability and changes in stratospheric aerosol. We will continue the observational record of chemical ozone losses in the Arctic based on international Match campaigns. Based on ATLAS (Alfred Wegener InsTitute LAgrangian Chemistry/Transport System) we will improve our ability to predict severe Arctic ozone loss on a time scale of weeks to over a month and will develop a

fast parameterisation for polar ozone loss and the global ozone layer for use in coupled climate models. Variability in the stratospheric aerosol abundance has been shown to have significantly contributed to attenuate global climate warming over the past decade but may contribute to the accelerated warming of the Arctic. The aerosol chemistry is a major driver for Arctic stratospheric ozone loss. The processes regulating the stratospheric sulfur and aerosol budget are poorly understood. The aerosol layer is prescribed in state-of-the-art climate models and hence does not respond to climate change in these models. We will work toward a better understanding of the processes that regulate the stratospheric sulphur and aerosol budget and the role of aerosol variability on Arctic ozone loss. This includes development of model parameterizations to interactively include the stratospheric aerosol layer in coupled climate models with Arctic ozone loss process.

Feedback understanding in Regional Arctic atmosphere and climate system models

The regional climate model HIRHAM5 with a prognostic cloud scheme will be used to interpret atmospheric measurements and to improve process understanding with respect to water vapour and cloud feedbacks. The coupled Arctic atmosphere-ocean-sea ice model system HIRHAM-NAOSIM will be applied to understand the origin of changes in sea ice cover. The impact of Arctic land surface and frozen soil feedbacks will be investigated with the coupled atmosphere-land surface soil model HIRHAM-CLM. Regional effects of improved Arctic process parameterizations will be studied with the Regional Earth System Model (HIRHAM-NAOSIM-CLM) of the Arctic. This model system will be developed on the basis of the already available regional coupled models HIRHAM-NAOSIM and HIRHAM-CLM. This includes the comparison with frozen land measurements at the AWIPEV and Samoilov station. Decadal-scale simulations will be carried out to understand the external and internal drivers of Arctic climate changes.

Arctic climate feedbacks and their links to atmospheric teleconnection patterns

The main focus is on a better understanding of the role of regional Arctic processes and feedbacks on atmospheric teleconnections. The spatial and temporal variability of teleconnection patterns in IPCC AR5 models and ERA-Interim data will be analysed. Dynamical relations between changes in sea-ice and snow cover and atmospheric changes and impacts on baroclinic processes and planetary teleconnections will be explored. The impact of an interactive stratospheric ozone chemistry, sea ice and snow cover feedbacks on atmospheric teleconnections and high-latitude troposphere-stratosphere interactions will be investigated with a coupled Earth system model.

Milestones

- Mapping of sea ice roughness for the Arctic Ocean.
- Estimates of mass (including methane), energy and momentum exchange between atmosphere and ice in dependence of surface morphology.
- Monitoring of climate changes including vertical distribution of ozone concentrations at the observatories.
- Improved understanding of synoptic-scale atmosphere-sea ice processes and the role of aerosol-cloud-water vapour feedbacks.
- Estimates of stratospheric ozone-climate change interactions.
- Determine internally versus externally generated forcing factors of Arctic climate change.
- Possible commercial applications include consulting and accompanying field research for environmentally compatible (low BC) shipping via arctic sea routes and ice dynamic surveys based on observations and modelling.

Workpackage 2: Ice sheet dynamics and mass balance

Coordinators: A. Humbert (AWI), F. Wilhelms (AWI)

Mission statement

To further quantify driving factors for changing ice dynamics by performing theoretical, numerical and experimental process and system studies and contribute to refined mass balance estimates.

Challenges

In order to quantify the polar contribution to sea level change, the key challenge is to determine the time scale and magnitude of changes in dynamics and mass balance of the Greenlandic and Antarctic ice sheets. This requires an interdisciplinary observational, theoretical and modelling approach on all levels, from process understanding to system studies. This goes along with the following challenges:

- Capturing changes of the polar ocean circulation and the associated response of Greenland and Antarctic ice shelves and ice streams in order to identify the complex mechanisms leading to change and to model these mechanisms adequately.
- Increasing the spatial resolution of modeling ice mass geometry, internal structure, net surface mass balance to a level required for profound studies of ice dynamics and stability.
- Gaining knowledge of the distribution of water underneath the Greenland and Antarctic ice sheets, the characteristics of its temporal variability and quantification of the contribution of subglacial water to ice sheet dynamics and mass balance.
- Improving the understanding of glaciological and oceanographical processes and to provide physical descriptions, as well as model parameterisations.
- Establishing a suite of numerical models capable of treating grounding line dynamics, subglacial water and calving adequately.

Current Activities and Previous Work

Mapping the geometry, structure and dynamics of oceans and ice sheets and monitoring their change with time is a long-term task that requires large scale infrastructure such as POLARSTERN, the polar aircrafts and continental stations as scientific platforms. During PACES the focus in the workpackage Role of Ice Sheets in the Earth System was on processes at the ice sheet interfaces. IPCC scenario (A1B and E1) runs with two independent sea ice-ocean models predict a redirection of a coastal current in the South Eastern Weddell Sea around the middle of the 21st century. This leads to the inflow of a relatively warm coastal current into the Filchner Trough and hence into the cavern of the Filchner-Ronne Ice Shelf. As a consequence of the heating the basal mass loss shifts from 80 Gt/a to 1600 Gt/a – which amounts to about 60% of the present-day ice accumulation on the Antarctic plateau.

There is the possibility of comparable mechanisms for ice shelfs in North-Eastern Greenland as the East Greenland Current carries relatively warm Atlantic Water southwards along the Greenland continental slope that is recirculating from Fram Strait. Results from a long-term observation program in Fram Strait (see Topic 1 WP4) showed an increase of the temperature of the Atlantic Water over the last decade by 1K.

We just contributed another several 10.000 profile-kilometres to ice-thickness compilations for Greenland within the EU funded programme ice2sea as we provided our latest data to updates of the Antarctic BEDMAP2 compilation. With FMCW (snow) radar we link up firn and ice coring sites, which we drill to increase spatial resolution of accumulation data, distribution of

geochemical proxy data (e.g. major ions, water isotopes and dust), but also to parameterize and validate firn densification models that treat the influence of the impurity content correctly and draw a consistent picture of the gas enclosure process even for glacial times (see Topic 3 WP1). We reconstruct the 3D firn structure with an X-ray computer tomograph that scans entire one-metre ice core sections with a spatial resolution of about 10 micron.

(Shot) seismic profiling of deep bore-holes were applied for the first time around the EPICA Dronning Maud Land borehole at Kohnen station. Seismic velocities and anisotropic properties of ice were determined.

Also within the frame of ice2sea we developed the deployment and operation of wireless pressure and temperature sensors in the subglacial environment of West Greenland outlet glaciers in cooperation with the university of Utrecht (NL) to derive a parameterisation of effects of accelerated glacier movement during the melt season.

Remote sensing of ice sheets played a relatively minor role during the former PACES programme. Direct intercomparison of field measurements gathered during the traverses to Kohnen station and satellite data demonstrate the improvement through advanced ice accumulation algorithms, which have been developed in close cooperation with the University of Canterbury (NZ). POLAR 5 and 6 contributed to a more widespread survey within the CryoSat Calibration/Validation Experiment (CryoVEx).

We also lacked manpower in the area of ice sheet modelling during the present programme. In the new programme this area of research is also significantly strengthened, which will allow us to tackle problems and data interpretation with far more advanced tools.

Objectives

The research themes of this work package range from the microscale, where ice deformation takes place, to the macroscale where the mass balance of ice sheets contributes to sea level change. The research themes, ordered according to their spatial scales, are

- ice deformation microstructures
- surface mass balance, firn densification, physical properties
- subglacial processes - ice stream genesis
- ice sheet and ice shelf stability, grounding line migration
- ice sheet mass balance

We aim to determine the active deformation mechanisms of polycrystalline ice with the use of observational and theoretical methods. Using various observational methods for retrieving parameters and variables on the microscale we analyse and re-analyse ice cores, which will provide the basis for the generation of a new theoretical description of ice deformation, using a combination of concepts from thermodynamics, continuum mechanics and materials science.

On scales of centimetres in the vertical and kilometres in the horizontal, we focus on the observation surface mass balance and its spatio-temporal distribution along with the understanding of the mechanism of firn densification. To this end we combine the results of the analysis of shallow and medium deep cores from Greenland and Antarctica with radar stratigraphy and remote sensing based accumulation rates. This advances our knowledge from more pointwise, local information of surface mass balance to a more comprehensive view of its spatial distribution. Related to that is the fundamental research of firn densification mechanism(s). It is of crucial importance to understand the effect of impurities in the ice matrix on the densification and hence on the age of the air, as this is the key for any temperature CO_2 lead/lag analysis (performed in TP3WP1). We thus continue the effort to quantify the processes of signal transfer between atmosphere, snow and firn by means of observation and modelling.

Understanding the role of subglacial processes on dynamics and mass balance of the Greenlandic and Antarctic ice sheets is the goal on spatial scales of hundredth of kilometres. As the base of ice sheets is hardly accessible, we use observational techniques like ground penetrating radar, seismics and remote sensing to retrieve indirect information on locations of subglacial water and the time scale of changes in the subglacial hydrological system. Modelling efforts will advance the capabilities from the level of routing subglacial water to simulating the subglacial hydrology. This includes the lubrication effects, as well the effects on the thermal structure of ice streams.

On even larger spatial scales the stability of marine ice sheets and ice shelves is a matter of importance. We aim to determine the past and present stability of the West Antarctic ice sheet, and particularly the Weddell Sea sector, and to understand crucial factors and processes, which lead to instability. We tackle this issue with both, modelling and observational approaches: continuing the efforts of the former PACES programme, our goal is to model grounding line migration using a hybrid-physics multi-scale approach and high resolution full-Stokes models to quantify its effect on the dynamics of ice streams and hence sea level change. We will develop an observational network for capturing the projected response of ocean circulation and basal melt rates in the Filchner Ice Shelf area to anthropogenic climate change. This will be complemented by radar echo soundings and seismics surveying the area of the eastern FRIS tributaries, as well as surveying ice domes adjacent to Ekströmisen for inferring the ice sheet extent in the Weddell Sea from the shape of internal layers.

Changes in the basal melt regime will also be investigated along the northeastern side of Greenland. The past decades featured the highest increase of ocean temperature in the North-Atlantic and the recently observed rapid retreat of glaciers along the southern and western Greenland coasts has been discussed in this context. We will therefore start to investigate the impact of the ocean on the North-Eastern Greenland ice sheet. This will be done in a regional study comprising ocean observations and modelling in the vicinity of the outlet glaciers of the Northeast Greenland Ice Stream (NEGIS). More specifically, we will carry out observations and ocean model simulations to study the advection of warm shelf water towards the entrance of the NEGIS outlet glacier cavities and the circulation of warm Atlantic water on the shelf and its variability from tidal to seasonal time scales.

Of similar importance on this spatial scale are the factors that contribute to ice shelf disintegration and the role of the buttressing of ice shelves on the flux across the grounding lines in Antarctica. Using remote sensing data, radio echo sounding and modelling, we aim to improve the understanding of the mechanisms of ice shelf disintegration and quantify the effect of inhomogeneities and pinning points on flow dynamics and calving.

On the global scale we aim to determine the current and future contribution of Greenland and Antarctica to sea level change. The reduction of uncertainties and evaluation, which key factors are driving mass loss, are the foci of our studies. To this end, we establish measurement campaigns for surface elevation change using laser scanner onboard of Polar 5/6 and satellite remote sensing over outlet glaciers in Greenland and Antarctica. Modelling studies will employ ice-sheet wide hybrid-physics multi-scale approaches, as well as high-resolution full-Stokes regional modelling in which the sensitivity of the system to crucial parameters will be tested. The mass balance of the ice sheets is then incorporated into the modelling of the thermosteric and halosteric sea level change and serves as input for the modelling of regional sea level change taking self-gravitation and GIA into account.

For our understanding of the dynamics and mass balance of ice sheets, ice streams, glaciers and ice shelves, the mapping of ice thickness, basal topography and surface elevation is crucial. Thus, we will continue the AWI efforts, which started in the mid 1990s, and aim to

increase the spatial coverage, for the benefit of understanding of the dynamics and processes and the reduction of uncertainties in modelling.

Expected Results, Milestones

Milestones

- Retrieving medium deep firn cores and FMCW radar surveys connecting the locations of cores.
- Developing an advanced hydrology component for ice sheet models.
- Implementation of the evolution of calving fronts and advection of physical properties in ice sheet/shelf models.
- Establishing a processing chain for the retrieval of accumulation rates from remote sensing data.
- Performing hot-water drills on the Filchner Ice Shelf and installation of moorings below the ice shelf.
- Installation and recovery of an array of moorings on the East Greenland shelf and a hydrographic survey of water masses in the vicinity of the NEGIS outlet glaciers.

Deliverables

- New models for the coupling of deformation mechanisms, deformation conditions and recrystallization processes in ice sheets, solid understanding on the micro-mechanical mechanisms responsible for the ice flow, as well as grain-scale coupled deformation and recrystallization models for large-scale ice sheet flow models.
- Firn densification model.
- Map of accumulation rates over Antarctica and Greenland and datasets of regional spatial distribution of surface mass balance.
- Maps of subglacial water layer thickness and fresh water fluxes into the ocean by means of modelling, as well as an assessment of the configuration of subglacial drainage systems.
- Assessment and modelling of processes leading to ice shelf instability.
- Calving rates of Antarctic ice shelves and map of drift paths of icebergs.
- Time series of CTD measurements in the vicinity of and under the Filchner Ice Shelf and basal melt rates of the Filchner Ice Shelf.
- Determination of spatial distribution of water masses in the vicinity of the NEGIS outlet glaciers and an assessment of the potential for increased basal melt.
- Quantification of key factors driving grounding line retreat and ice stream/outlet glacier acceleration by means of remote sensing and modelling.
- Quantification of the contribution of Greenland and Antarctica to eustatic sea level change by means of observation and modelling.
- Knowledge transfer could include modelling of the dispersion of hazardous substances in ice-covered regions e.g. for insurance companies.
- Commercial use of new technologies for investigations of deep-temperature behavior of commercial products, FMCW radar-based deformation measurements on technical surfaces as well as x-ray tomography of frozen goods (e.g. avoidance of crystallization in frozen convenient food).

Workpackage 3: Degrading permafrost landscapes; carbon, energy and water fluxes

Coordinators: J. Boike (AWI), H.-W. Hubberten (AWI), G. Mollenhauer (AWI)

Mission statement

To identify and quantify key processes and parameters influencing and controlling the vulnerability of the Arctic permafrost carbon pools to future climate change.

Challenges

About 24% of the northern hemisphere land area is underlain by permafrost containing roughly 1700 Pg of carbon. Permafrost environments extend from inland regions with discontinuous, patchy permafrost at mid- to high latitudes of North America and Eurasia to regions with thick and continuous permafrost deposits at higher northern latitudes along the Arctic coasts and beyond the coastline into the circumpolar shelf seas. Most of these environments are changing, and their permafrost is threatened by continued anthropogenic change. The thawing of permafrost may release carbon (C) and thus influence the global climate system, but there is substantial uncertainty about the sensitivity of the C cycle. Soil C from permafrost can be mobilized in particulate, dissolved or gaseous form and in response to changes in air temperature, water balance, fire, thermokarst, and flooding. Recent modelling studies have suggested that in the geologic past, thawing permafrost may have contributed strongly to global thermal maxima, and a large part of the postglacial atmospheric CO_2 rise can be attributed to mobilization of material stored in permafrost. In order to understand how permafrost reacted in the past, reacts in the present, and will react in the future to climate change and human impact, a better understanding of critical processes is needed:

- The formation and degradation of permafrost with diverse geomorphology and landcover caused by complex interactions and feedback mechanisms between the frozen ground, vegetation, hydrosphere and atmosphere.
- The water and energy exchange processes and budgets as well as freeze-thaw dynamics of the annually thawing active layer as the interface between atmosphere, biosphere, hydrosphere and permafrost.
- Coastal erosion leading to threats to infrastructure and changes in coastal ecosystems through release of organic- and nutrient-rich sediments to and redistribution in the ocean.
- The distribution and state of subsea permafrost in the circumpolar Arctic shelves, which act as a transient cap on gas diffusion. This permafrost consists mostly of relict terrestrial permafrost that has become unstable and is continuously degrading since its inundation following postglacial sea-level rise.
- The mass exchange processes between permafrost and the atmosphere and ocean including emission and consumption of gases (CH_4, CO_2), release and consumption of dissolved organic matter, as well as erosion of particulate organic matter from coasts and river banks, and its subsequent sedimentation in shelf and deep ocean sediments.

Current Activities and Previous Work

Previous and current permafrost research activities at AWI have concentrated on three regions: the Lena Delta and Laptev Sea (Siberia), Spitsbergen, and North America (Canadian and Alaskan Arctic). At most of these locations, observation networks at multiple temporal and spatial scales are operated in order to establish the baseline characteristics (climate, permafrost, land cover). Regular field campaigns for monitoring, mapping and sampling have

been conducted and will be continued in the future. All of these activities rely on the availability of research infrastructure, in particular on the field stations operated and co-operated by AWI.

Extensive surface energy and water balance studies were carried out at different field sites in order to investigate the vulnerability of permafrost to climate change. Results show that the thermal state of permafrost is highly sensitive to landcover heterogeneities, snow properties, winter cloudiness and winter rain events. Long-term heat and water flux measuring stations established in the Lena Delta and on Spitsbergen provide unique observations of current and future permafrost-atmosphere interactions.

The organic matter currently released from permafrost must be characterized and quantified. Since 2009, concentrations of dissolved (DOM) and particulate (POM) organic matter in the Lena Delta have been studied during annual sampling campaigns. These analyses are paired with determination of the molecular composition of these organic carbon pools and their radiocarbon ages. These data are compared with the organic geochemical composition of Holocene and Pleistocene permafrost deposits outcropping in the region and of sediments deposited in the adjacent shallow Laptev Sea. Since 2009, coastal waters in the Laptev Sea have been sampled in summers for suspended sediments, DOC and coloured dissolved organic matter (cDOM).

Previous work on Samoylov Island has added to our understanding of land-atmosphere methane exchange processes and the spatial variability of the fluxes surrounding the micrometeorological eddy covariance measurement site. There, a significant influence of atmospheric conditions on the magnitude of methane fluxes was found for daily averages and attributed partly to the large fraction of open water surfaces in the footprint of the measurements. Methane and CO_2 emissions vary by up to an order of magnitude on small spatial scales. In 2012, these observations were spatially extended by airborne eddy covariance measurements for the first time, using the helicopter-towed meteorological measurement system “Helipod”. Outside Russia, first tests and an extensive airborne campaign using Polar 5 and investigating regional energy and methane fluxes were conducted in 2011 and 2012, respectively. Trace gas emission measurements (CH_4, CO_2, H_2O) using stationary eddy covariance measurements are on-going. The distribution of dissolved methane in the Lena River and adjacent Laptev Sea has been studied since 2009. The related microbial processes, methane production from DOM, as well as methane consumption determine the further fate of CH4 in the ecosystem. Greenhouse-gas emissions from land, in particular methane, are linked with corresponding microbial processes, including characterization of associated microbial communities since 1999.

Land cover classifications and morphometric analyses in northeastern Siberian lowlands using remote sensing and GIS methods have shown that 70 to 80 % of the periglacial landscape is being or has been degraded by themokarst and thermal erosion. Ongoing changes of thermokarst landscapes were detected at the decadal time scale. Since the patterned ground of the polygonal tundra is a sensitive indicator of environmental and climate changes, its state and dynamics under climate variability are analysed. Fossil organic carbon in ice-rich permafrost deposits is an important carbon pool, and its composition, quality and distribution in the subsurface are studied in current research projects.

Objectives

Workpackage 3 will improve our understanding of the vulnerability of permafrost to climate change. Long-term observation and knowledge on permafrost key variables and processes for regional climate models will be exchanged with modelling experts (T1WP4).

Energy and water balance processes between atmosphere and permafrost will be examined to identify the current state as well as processes that degrade permafrost. Particular emphasis will be placed on

- Observing climate, thermal state of permafrost and active layer and annual thaw depths.
- Recording atmospheric and subsurface heat and water fluxes in different permafrost ecosystems.
- Monitoring key hydrological parameters and processes.

Landcover changes influencing the geomorphological and hydrological response will be addressed by

- Mapping of thermokarst and thermoerosion and changes of morphology and surface water.
- Determining interactions and feedbacks of permafrost with vegetation and its spatial distribution.
- Studying subrecent environmental and vegetation changes as recorded in thermokarst lake deposits.

Processes of submarine permafrost, coasts and shelves will be studied. This will include

- Quantification of sediment and organic matter transfer from eroding permafrost coasts to the Arctic coastal zone in the southern Canadian Beaufort Sea and the Laptev Sea.
- Distribution of subsea permafrost and coastal sediment fluxes.
- Measurement and modelling of controls on near shore permafrost degradation, including coastal retreat, sedimentation and heat and mass transfer in the sediment.

Carbon export from permafrost through coastal erosion, riverine export, greenhouse gas emission, and microbial degradation will be characterized and quantified. We will focus on

- Spatial variability of particulate and dissolved organic carbon and nutrient contents in permafrost sediments and ground ice and aquatic environments.
- Molecular and isotopic characterization of the organic material entrained in typical permafrost deposits, river-transported particulate material and permafrost-derived DOM.
- Remote sensing of measured optic-chemical properties in organic-rich arctic coastal waters.
- Quantification of the fractions of mineralized and conserved POM and DOM.
- Measurement of greenhouse gas emissions from permafrost landscapes.
- Linking of environmental parameters to microbial methane cycling activities.

All aspects need to be investigated at multiple scales ranging from centimetre scale field and laboratory experiments, meter scale field observations, to kilometre to continental scale remote sensing and numerical modelling. Observing sites (Siberia, Spitsbergen and Canada) are continued to understand and quantify these processes. The understanding gained from these observation networks will be integrated into modelling frameworks capable of representing how the responses of permafrost C will influence the trajectory of climate in the future.

Expected Results, Milestones

Quantitative estimates of permafrost degradation and processes affecting the vulnerability of permafrost carbon will be gained through understanding of: (i) biogeochemical, thermal and hydrological processes in permafrost and active layer, coastal and submarine environments, (ii) ground and regional flux estimates of carbon, water and heat from permafrost ecosystems to the atmosphere and to water (freshwater and marine systems), (iii) continuation of long term monitoring of permafrost through ground and satellite based measurements.

Expected Results

- Parameterization of the sub-grid scale variability of landscape properties that influence the exchange of water, heat and carbon.
- Transfer of knowledge of permafrost thermal and hydrological processes at site and landscape scales, based on observations and expertise, to numerical models (site, regional, global).
- Conceptual model on the functional relationships between vegetation and climate as well as between permafrost and vegetation particularly for the forest tundra transition area.
- Quantification of subsea permafrost degradation rates in the coastal zone, and an improved understanding of the processes responsible, including effects of changing sea ice coverage, seawater temperature, salinity regimes and sea level rise.
- Flux rates of sediment, carbon, nutrient and contaminants from permafrost watersheds and coastal erosion into the Arctic Seas including a quantification of the mobilization of fossil carbon deposits.
- Validation of Ocean Colour satellite data products (suspended matter, DOC, cDOM) for the organic-rich coastal waters of the Laptev sea.
- In depth molecular characterization of permafrost-derived dissolved and particulate organic matter and quantification of its microbial and photo-remineralization rates.
- Balance of annual greenhouse gas fluxes from permafrost to the atmosphere using regional scale airborne and local scale ground-based measurements.
- Possible commercial applications: Based on the scientific results specific risk assessments and consulting can be offered to local decision makers, building companies and insurances in the context of coastal erosion, infrastructure damages (e.g. harbors, buildings, industrial plants) caused by thawing of permafrost soil in urban areas.

Milestones

- Opening the new Samoylov station with year-round research activities and year round, long term collection of data (e.g., climate, gas fluxes, permafrost temperature) at observational sites.
- Ship based expeditions in the Lena River Delta and the Southern Laptev Sea
- POLARSTERN expedition to the shelf region of the Beaufort Sea in 2014 –2016
- Repeat Polar 5/6 airborne energy and methane flux measurements in the North American Arctic.
- Airborne energy, CO_2, and methane flux measurements by Helipod in the Lena Delta during break-up, peak growing season, and freeze-back 2014.
- Collection and statistical investigation of field data from vegetation plots and pollen data from lake sediment cores collected along a tundra-taiga transect in Northern Yakutia.
- Identification of molecular biomarkers representing changes during transport of organic matter from permafrost and ice complexes through the river into the coastal ocean.
- Implementation of a molecular classification system for the bioavailability of permafrost-derived DOM.
- Establishment of numerical models of terrestrial and marine permafrost heat and mass transfer and of land-atmosphere greenhouse gas exchange.

Workpackage 4: Arctic sea ice and its interaction with ocean and ecosystems

Coordinators: R. Gerdes (AWI), I. Peeken (AWI), A. Boetius (AWI)

Mission statement

To provide evidence and understanding of the causes and consequences of variation in sea ice cover for the hydro-, bio- and geosphere of the Arctic Ocean and beyond.

Challenges

Sea ice provides a dynamic interface between ocean and atmosphere due to its optical, mechanical, and thermodynamic properties. As a reservoir and transport media for fresh water it is an important and highly variable link in the water cycle of the high latitudes. The Arctic Ocean circulation as well as the modification of water masses and deep ocean ventilation are ultimately linked to sea ice processes. Changes in the hydrography of the Arctic Ocean will affect sea level and the fresh water supply of the subpolar North Atlantic, which in turn will alter the large-scale oceanic circulation. Sea ice provides a significant proportion of the Arctic productivity as a habitat for marine life and as is a crucial feeding ground for many consumers ranging from zooplankton larvae to whales. It also influences the biogeochemistry of sea surface atmosphere interaction and is an important factor in the biogeochemical cycles of the Arctic Ocean, particularly the carbon fluxes to the seafloor.

The Arctic is severely affected by global warming with considerable socio-economic consequences. The summer minimum sea ice extent in the Arctic is shrinking and estimates of sea ice thickness indicate a rapid decrease in volume. Climate models show that the increasing warming by greenhouse gases contributes substantially to these changes. But because of the complexity of feedback mechanisms, our ability to predict future changes of the Arctic sea ice is still poor. There are indications that the gradual decrease in sea ice thickness was the prerequisite for the recent extreme summer sea ice retreat in the Arctic. Are individual anomalies in the atmospheric or oceanic forcing decisive for the transition of the sea ice to a more seasonal state or is the preconditioning by declining ice thickness essential? Which effects will the seasonal state have on primary productivity and food webs?

The stable stratification of the upper Arctic Ocean curtails the amount of heat that can reach the sea ice from the warm Atlantic and Pacific Water layers of the Arctic Ocean. Upwelling of the warm waters imported from the Pacific and Atlantic to the shelf seas might, however, affect sea ice in a direct or, via the atmosphere, indirect way. Could turbulent mixing be enhanced sufficiently in a seasonally ice-free ocean to endanger the halocline at least in certain parts of the Arctic Ocean? There is an urgent need to better estimate the effect of these processes for future conditions and to determine the possible changes in the relevant processes when sea ice extent and thickness decrease further.

To assess the future of Arctic ecosystems integrative studies of the physical, biogeochemical and ecological processes operating at multiple scales are important. Questions include as to how primary production, carbon flux and burial will change with sea ice decline, and how this will affect the coupling of pelagic and benthic ecosystems.

- What governs the long-term development of Arctic sea ice compared to interannual changes?
- Is the gradual decline in Arctic sea ice volume essential for the recent dramatic decrease in summer sea ice extent?
- Under what circumstances will the intermediate water heat reservoir be available for melting Arctic sea ice?

- What are the consequences of the sea ice retreat for sea-ice associated pelagic and benthic communities, as well as for biogeochemical processes from surface to depth of the Arctic Ocean?
- How do shifts in Arctic biodiversity alter biogeochemical functions such as the gas exchange between atmosphere and ocean, the recycling and retention of nutrients, and the energy flux to the deep sea?

Current Activities and Previous Work

Regions of interdisciplinary time series studies and field observations at AWI include Fram Strait, Laptev Sea and continental margins, as well as the central Arctic basin. Previous investigations of sea ice properties have established that sea ice thickness has decreased in the central Arctic and north of Fram Strait. Electro-magnetic measurements of sea ice thickness have started in the early 1990s and have recently been intensified with the availability of the research aircraft Polar 5. These data show a reduction of the average summer sea ice thickness from more than 2 m to slightly above 1 m in recent years. POLARSTERN cruises in the central Arctic in 2007 and 2011 showed very similar ice conditions, characterized by the absence of very thick ice, indicating a preferential loss of multiyear ice. These expeditions also revealed an increasing amount of fresh water accumulating in the central Arctic. This may contain the fresh water previously stored in sea ice. This increased fresh water lid has dynamical impacts on the ocean circulation down to the deep sea.

The detailed survey of trace element distributions on these cruises enabled us to assess the shelf water circulation in the central and marginal Arctic. Future studies will extend to changes in ocean circulation and biogeochemical fluxes in response to changes in Arctic Oscillation and sea ice cover. Ocean-sea ice models have been used to reconstruct the trajectory of the ocean-sea ice system over the last 100 years. Advanced data assimilation techniques helped to systematically improve parameterizations and initial and boundary conditions. This effort has also lead to a better initialization of models for seasonal sea ice forecasts. On the Siberian shelves (Laptev Sea) we observe events of southward penetration of upwelled warm ocean waters. They have the potential to influence the sea ice as well as the submarine permafrost

To better describe the sea ice mass balance in the whole Arctic, exports through Fram Strait and thermodynamic growth rates have been estimated. At the Fram Strait observatory we monitored continuous warming of the inflowing Atlantic water over the past decade by 1°C. This warming was not matched by a respective warming of the return flow to the Atlantic suggesting that the budget needs to be closed by warming of the Arctic Ocean or increased surface heat loss. To answer these questions, large scale Arctic Ocean surveys, including the implementation of autonomous buoys (HAFOS) are conducted.

Sea ice surface conditions and optical properties have been another focus of observational studies, including remote sensing by satellite and ground truthing by ship-based sampling and buoys. Light availability under sea ice varies strongly with snow cover, age of the ice, presence and depth of melt ponds and other variables with severe consequence for the sea ice algae and the pelagic ecosystem. Interdisciplinary biogeochemical studies including the use of remotely operated vehicles during TransArc (2011) and IceArc (2012) allowed to extrapolate local findings to regional scale. Primary production measurements of the various pools from the sea ice to the water column highlight the importance of the sea ice system for carbon export in the Central Arctic. A strong contrast in the influence of Pacific and Atlantic water masses on the biogeochemical cycles was observed.

The rapid change in these and other physico-chemical conditions are linked to changes in elemental cycles, trophic relationships and biodiversity in the ocean at all water depths. The AWI combines long-term ecological time series studies with monthly resolution in distinct

regions (e.g. Kongsfjord, Fram Strait, Laptev Sea) with broad scale ship-based missions (e.g. central Arctic transects) to assess current states and changes of Arctic ecosystems from the sea-ice habitat to the deep sea.

Objectives

The development of sea ice volume in the Arctic is determined by the net thermodynamic growth and by the export to lower latitudes. Both processes will be addressed using sea ice observations and model hindcasts and the combination of both by data assimilation and adjoint sensitivity calculation. Does sea ice export act as a negative or positive feedback on the Arctic ice volume? The changes in sea ice properties will affect the momentum exchange between atmosphere and sea ice as well as between sea ice and ocean. Sea ice drift and ocean circulation will both react and interact with consequences for the fresh water transport to lower latitudes. Improved representations of these processes need to be implemented in models and ecosystem assessments.

With decreasing sea ice thickness and probably decreasing sea ice export, liquid fresh water is expected to accumulate in the Arctic Ocean over some time before a new equilibrium is established. Accumulated fresh water in the Arctic Ocean bears the potential for fresh water export events with substantial impact on vertical mixing in the subpolar North Atlantic and consequences for the large scale ocean circulation and biogeochemical processes. Changes in Arctic Ocean circulation and alterations in sea ice export affect regional carbon and nutrient fluxes and hence ocean ecosystems.

Arctic communities are highly vulnerable because they are adapted in their life cycles to strong seasonal forcing and the multitude of factors related to a multi-year ice-cover. Some populations may be failing to reproduce sufficiently due to e.g. temporal shifts of ice melt by a few weeks, warming by a few degrees, loss of certain ice algae as food. These may be replaced by short-lived pelagic plankton blooms accompanied by changes in species composition, cascading effects on the food web and biogeochemical cycles. The entire surface ocean system is likely to be severely affected by these changes, plus a faster rate of ocean acidification than elsewhere, higher UV radiation, invasive species and increasing traffic and human impact. It is conceivable that this environmental change will lead to a massive response of the Arctic ecosystem at all trophic levels, including fisheries, seabirds, and mammals. Due to the tight bentho-pelagic coupling in the Arctic Ocean, and the general energy limitation of the Arctic benthos, large ecosystem shifts can also be expected in the Arctic deep sea, including basins and ridges. Simulations of potential future ecosystem scenarios are needed, but difficult to achieve, due to the complex nature of interactions with diverse and unforeseen feedback effects.

- Clarify the contribution of the ocean to the Arctic sea ice retreat and assess the impact of the ice retreat on ocean circulation and fresh water balance.
- Explore the most important (feedback) processes for temporal and spatial variability in sea ice properties.
- Assess and quantify ecosystem changes from surface to the deep ocean in response to retreating sea ice.

Expected Results, Milestones

The interaction of atmosphere, ice, and ocean is one of the key topics of sea-ice related research at AWI, investigated with various methods. Ocean observation systems are used that comprise modular platforms and components allowing synchronous observation of important physical, biological and chemical ocean and sea ice variables. Products are time series data and observations including ground truthing for ocean models and remote sensing and

biodiversity assessments, serving numerous national and international programmes. Model results are analysed regarding key questions of Arctic change.

New and improved methods are being tested to measure primary production and to estimate algal standing stock and export fluxes. Ice and under-ice buoys will be equipped with biooptical sensors. Sediment traps and seafloor biogeochemical modules will be deployed to determine particle fluxes from sea ice. Biogeochemical studies focus on carbon, nitrogen and silicate cycling within the sea ice and between ocean, sea ice and atmosphere. Biodiversity of microorganisms in sea ice, ocean and seafloor will be studied using up-to-date microscopical and molecular biological techniques. In addition, the effect of sea ice cover changes on primary production on a wide range of temporal and spatial scales will be investigated by combining remote sensing information on sea ice cover and primary production with ice-ocean-ecosystem models.

Sustained observations will be conducted in Fram Strait, a key gateway between the Arctic and the Atlantic oceans, to further document the exchange of oceanic heat and fresh water, but also to estimate the supply of Arctic waters that are relevant for the meridional overturning circulation. In combination with model simulations such observations will improve the distinction between long-term variability and trends in the ocean climate.

Observational studies in the Laptev Sea address the specific processes on the broad Arctic shelf seas where much of the sea ice is produced, where the vast continental fresh water runoff is redistributed and which host the conversion of surface waters to deep and intermediate waters that exit the Arctic to be involved in the global overturning circulation.

High-resolution palaeo-climatic records going back beyond the timescale of direct measurements will help to solve some of the uncertainties in the debate of recent climate change. The incorporation of improved descriptions of sea ice processes in regional and global climate models will be pursued. At the same time, technological advances, new proxies for palaeo-sea ice, and new observation strategies allow the improvement of measurements and their interpretation.

Expected Results

- Arctic-wide estimates of Arctic sea ice volume, thermodynamic growth and export rates for extended time periods.
- Estimates and predictions of sea ice extent and volume as well as of budgets and exchange rates of heat and fresh water between the Arctic and subarctic oceans.
- Better understanding of the interactions between sea ice and ocean in the past and present, and improved scenarios for their future development.
- Arctic-wide estimates of primary production and vertical fluxes of organic material, their variability and likely future behaviour.
- Assessment of links between ocean variables, biogeochemical processes and biodiversity indicators, to monitor ecosystem state and variation.
- The results may provide the basis for commercial services and accompanying research related to the access to Arctic seas including consulting for authorities, ship yards, shipping and exploration companies in the context of a sustainable use of the Arctic.

Workpackage 5: Southern Ocean physics, biodiversity, and biogeochemical fluxes in a changing climate

Coordinators: V. Strass (AWI), B. Meyer (AWI), M. Losch (AWI)

Mission statement

Assess the changes that occur in the Southern Ocean, identify the processes that link physics, chemistry and biology, and determine the feedback mechanisms to the global climate system.

Challenges

The Southern Ocean (SO) is unique because it extends zonally around the globe without any meridional boundaries, giving rise to the mightiest of all ocean current systems, the Antarctic Circumpolar Current (ACC); the ACC governs the exchange of heat, freshwater, nutrients and other dissolved substances and gases between all other oceans. Many of the hypotheses formulated to explain the correlation of atmospheric temperature and CO_2 concentration on glacial-interglacial time scales rely on processes in the SO.

The rate of CO_2 uptake from the atmosphere depends on the balance between the physical and biological pumps of carbon. While the biological pump, driven by phytoplankton photosynthesis in the sun-lit surface layer and the subsequent flow of organic carbon through the food web and the water column, always acts as a sink of atmospheric CO_2, the physical pump works in two directions. Subduction of surface water at the northern rim of ACC creates a CO_2 sink but the upwelling of deep watermasses in the Antarctic divergence to the south constitutes a CO_2 source. Upwelling however also supplies high concentrations of macronutrients to the surface photic layer that could support much higher primary production than currently observed. The physical and biological carbon pumps are linked through the meridional ACC overturning circulation; the details of this coupling, however, are not yet well understood. Controversially debated are also the possible responses of the ACC overturning, and the contribution by eddy fluxes in particular, to changes in the atmospheric forcing.

In-situ ocean iron fertilization experiments have unequivocally shown that the biological pump is influenced by the supply of iron, but the relationships between iron and phytoplankton seasonal dynamics as well as between community composition and export fluxes of carbon and silica are still poorly understood. The interaction of processes could be complicated by the yet unknown effects of ocean acidification, which are stronger in the SO than in other open ocean regions.

Sea ice affects the cycling of carbon and nutrients, limits gas exchanges between ocean and atmosphere, triggers phytoplankton ice edge blooms, and provides a habitat for a wide range of biota. These important functions of sea ice are likely to change during the coming decades. In concert with a decline in winter sea-ice coverage around the Antarctic Peninsula, which is one of the fastest warming regions on our planet, shifts in organism composition (decline of krill, increase of salps) have been already observed. Marine mammals exert both top-down and bottom-up controls, but our understanding of their reactions to environmental changes, their ecological role and potential impact on biogeochemical fluxes is largely unknown.

In order to make reliable projections of changes in the marine ecosystems it is essential to built models based on robust functional understanding of the linkage between organisms and their environment. This requires a quantitative understanding of ecosystem functions in the pelagial, sea ice and the sea-ice water interface, and of the interaction between key organisms. Improved functional descriptions of the coupling between physical and biogeochemical processes is a prerequisite to predict how the physical and biological carbon pumps will shift in the course of climate change and whether the Southern Ocean will amplify or mitigate anthropogenic perturbations.

The main challenges are to

- assess variations in the physical and chemical environment in the Atlantic sector of the Southern Ocean through sustained observations.
- investigate the ecosystems' response to environmental changes for the different biogeographic provinces.
- identify the processes that couple the physical, chemical and biological realms and control biogeochemical fluxes.
- determine the feedback mechanisms of the Southern Ocean system to the global climate.

Current Activities and Previous Work

Changes in physical and chemical properties and in circulation of key water masses in the Atlantic Sector of the Southern Ocean are documented by repeated transects and moored instruments since the late 1980's. These long-term observations are sustained by the establishment of a Southern Ocean Observing System (SOOS), encompassing ice-compatible ARGO floats that are supported by an acoustic under-ice navigation system deployed within the framework of HAFOS in the ACC – Weddell Gyre transition zone. ACC fluctuations off South Africa are monitored by pressure-inverted echo sounders and compared to satellite-borne GRACE/GOCE gravity field solutions since 2006. Those repeat observations reveal a warming of the newly formed Weddell Sea Bottom Water and an uptake of anthropogenic CO_2 by the ventilated Antarctic Bottom and Intermediate Waters. Chemical measurements of dissolved inorganic carbon, CO_2 partial pressure, oxygen, nutrients, trace elements and (radio-) isotopes are complemented by investigations of the role of sea ice for fluxes of CO_2 and methane as well as for the precipitation of $CaCO_3$. Analyses of the buffering capacity (i.e. the neutralisation of the pH decrease through anthropogenic carbon) of $CaCO_3$ sediments on the Southern Ocean shelves show that it is not sufficient to delay acidification in a significant way.

Investigations on phytoplankton and zooplankton abundance and species composition within the water column and the sea ice in different biogeographic provinces are complemented by synergistic hyper-spectral analysis of satellite remote sensing data. Process-oriented studies on the diversity and variability of key diatom species in comparison to "background" species, the life cycle strategies of selected autotrophic and heterotrophic organisms, the response of these organisms to increasing ocean acidity and seawater temperature as well as the large-scale transcriptomics and metagenomics of pelagic and sea ice communities enhance our mechanistic understanding of the relationships between organisms and their environment. The focus on key species such as krill and functional groups such as diatoms enable us to understand population shifts and ecosystem responses due to climate induced environmental changes. Long-term acoustic data records from near- and offshore passive sensors are used to retrieve marine mammal vocalisations, which are analysed in relation to opportunistic visual mammal sightings and data obtained by a newly developed automatic, infrared-based marine mammal detection system.

The iron hypothesis has been tested by three open-ocean iron fertilization (OIF) experiments, EisenEx, EIFEX and LOHAFEX. The experimental design of using transient mesoscale eddies as coherent bodies of water allowed to trace the bloom beyond its end, and made EIFEX of all OIFs carried out world-wide the only one to date that confirms an export of biogenic carbon to the deep water column and sea-floor. The differences between the three AWI-OIFs however are shedding light on the many open questions that exist with respect to phyto- and zooplankton dynamics, influence of growth vs. mortality of key phytoplankton taxa, and food-web interactions and their influence on elemental fluxes and eventually the sediment record.

Results from the lab and open-ocean experiments, and from process studies of multi-scale physical controls on biogeochemical fluxes, are used to improve a hierarchy of coupled biogeochemistry-ocean circulation models, which are developed in order to capture variations on diurnal to glacial-interglacial timescales using different temporal, horizontal and vertical resolutions. Modelling studies suggest that the Southern Ocean carbon cycle reacts to SAM-related inter-annual variability in physical forcing not only with anomalous carbon fluxes, but also with a shift from non-diatoms to diatoms under positive SAM, and a larger vertical carbon export south of the Polar Front. This shift has implications for uptake of nitrogen and silica induced by iron limitation and the distribution of diatom and non-diatom productivity elsewhere (silicic acid leakage hypothesis), which is studied with appropriate numerical modelling tools.

Objectives

In response to the identified challenges, and building on current activities, the time-series observations will be continued to capture physical and chemical changes in the Atlantic sector of the Southern Ocean during the coming years. Measured changes in volume and density of source water masses will be used in the context of large-scale model experiments aimed at understanding possible impacts on multi-annual modes in the Atlantic and global overturning circulation. To discern changes in anthropogenic CO_2 from natural variations, back-calculating techniques, extended Multiple Linear Regression and data-assimilation will be applied. Large-scale spatial information on phytoplankton abundance obtained by satellite will be validated using point-water samples to improve discrimination of phytoplankton groups from space using PhytoDOAS, and adapt satellite-based primary production models to the Antarctic Ocean.

An important task is to identify the processes which couple the physical, chemical and biological realms and control the biogeochemical fluxes on scales that range from microstructure turbulence, which facilitates diffusive fluxes and maintains mixed layer overturning motions transporting plankton cells along vertical sun-light gradients, over mesoscale upwelling of nutrients and subduction of organic matter to basin-wide Ekman pumping and horizontal advection.

Primary production in open waters of the Southern Ocean is limited by iron. The impact of iron fertilization found on phytoplankton bloom development and fate, on nutrient uptake and uptake ratios, and on vertical fluxes, however, varies among existing studies. The reasons for these discrepancies need to be ascertained. Possible explanations include differences in initial conditions (i.g. nutrient concentrations, phytoplankton compositions, grazer populations), in seasonality and in the physical environment. Not only artificial fertilization experiments shall be compared with each other, but also with natural fertilization studies. A new seasonal to inter-annual natural fertilization study is planned in the Georgia Basin, one of the most productive areas in the Southern Ocean, where productivity likely is fuelled by natural iron inputs from the shelves of South Georgia. The role of the Southern Ocean shelves as an iron source and the mechanisms that determine the global distribution of iron and iron-binding ligands will be investigated with biogeochemical circulation models.

To obtain insights into the adaptability of key diatom species and groups to environmental changes, the evolution of gene families in response to environmental changes has to be characterized through establishment of a reference database encompassing taxonomic, nomenclatural, morphological, molecular and biogeographic information. Investigations on the tolerance and adaptability to changing environmental conditions of pelagic key invertebrates such as krill that impact food-web structure, ecosystem dynamics and biogeochemical cycles have to be carried out from an organismic, cellular and molecular point of view, considering all developmental stages. In this respect it is important to identify the cues that have an important impact on the annual life cycle and to understand if these cues are related or unrelated to

climate induced environmental changes (e.g. food quantity and quality and photoperiod, respectively). The incorporation of generated data in individual-based models will enable predictions of population shift and ecosystem response. The deployment of multi-disciplinary moorings (ADCP, hydrophones, sediment traps) at hot spots of marine mammal occurrences such as King George Basin and Elephant Island will unravel interannual variation and long-term changes in marine mammal distribution patterns in relation to their main prey krill. Data systems for the archiving and processing of acoustic data have to be improved for preparing habitat suitability maps – adapted to include dynamic marine mammal behaviour (i.e., migration) - for selected marine mammal species.

Sea ice plays a key role in many oceanic processes that interact with Antarctic climate and biomes. To further the functional understanding of sea ice for the atmosphere-ocean exchange of gases, in particular CO_2, DMSP and methane, the sea ice physical structure and its relation to the biota needs to be assessed in more detail. In addition it is important to determine the genomic potential and phylogenetic affiliation of sea ice associated organism communities, and to quantify pelagic primary production in the marginal ice zones. The Antarctic-specific sea ice research conducted within this workpackage will be coordinated with corresponding work in the Arctic through a common networking theme of Topic 1.

The comprehensive data sets generated by the multi-disciplinary activities outlined above will be incorporated in different model approaches (e.g. circulation models, bio-physical sea ice models and biogeochemical general circulation models) for a synergistic analysis, for obtaining mechanistic insights, for extrapolation from process and survey studies to larger scales, and for enabling projections of future changes in sea ice ecosystems and in populations of pelagic key organisms with respect to productivity, biodiversity, and resource sustainability. Results pertinent to feedback mechanisms between the Southern Ocean and the earth system will feed into WP3 of Topic 3 in order to improve the skills of global models that are used to predict the future climate development.

Expected Results

Building upon the close cooperation of marine physicists, chemists and biologists eager to weld together their specific expertise to meet the overarching challenges, and by combining in-situ observations and satellite remote sensing, by connecting open ocean process studies with laboratory experiments, and by merging data with models we expect to achieve:

- An assessment of the interannual variations and decadal trends in the physical and chemical environment and in the biodiversity of the Atlantic sector of the Southern Ocean.
- An improved mechanistic understanding of the life cycles of pelagic and ice-bound organisms - ranging from the smallest autotrophic algae to the highest trophic levels represented by marine mammals – and their role in biogeochemical cycles.
- An identification of the most important physical-chemical processes that affect the ecosystems in different Southern Ocean biogeographic provinces on time and space scales that range from minutes/centimetres in the turbulent mixed layer, through days/tens of kilometres in mesoscale eddies and fronts, up to years/thousands of kilometres for the basin-wide circulation.
- An improved ability to predict the consequences of future climatic changes in the atmospheric forcing, in ocean temperature, acidity, circulation and seasonal ice coverage for shifts in the balance of the biological and physical pumps of carbon.
- Confirmation/rejection of hypotheses formulated to explain through features that are unique to the Southern Ocean the correlation of atmospheric temperature and carbon dioxide on palaeo-timescales.

- Impact on society: Chances, effects and risks of large scale iron fertilization. The use and development of specific deep-sea and observation equipment offers opportunities for innovation transfer to marine technology firms. Prototypes developed for ocean research can be validated and marketed for industrial monitoring in various offshore applications.

Workpackage 6: Large scale variability and change in polar benthic biota and ecosystem functions

Coordinators: T. Brey (AWI), H.O. Pörtner (AWI)

Mission statement

To identify, understand, and anticipate large scale and long-term change in ecosystem function and services provided by benthic and demersal biota of Arctic and Antarctic marine habitats.

Challenges

Arctic and Antarctic regions are hotspots of global change. The expected environmental change, particularly rising water temperature, acidification, ice shelf and sea ice loss, will affect the marine biosphere significantly and at large scales, albeit with substantial regional differences. In addition, increasing direct human impact such as gas and oil exploration, fishing and sea traffic add a number of threats for polar ecosystems. We anticipate substantial effects on polar marine biota from surface to depth that will manifest in shifts in biodiversity, trophic interactions, and ecosystem functioning with consequences for ecosystem services. Environmental change affects organism performance directly, and indirectly the ecosystem as a whole through subsequent changes in species interactions and in organism impact on the environment. Therefore understanding and simulating the dynamics of on-going and forthcoming change requires a specific cross-disciplinary approach that takes into account all levels of ecological interactions from species-specific responses to environmental forcing to spatial and temporal variability of polar habitats, as well as the partially non-deterministic behaviour of ecosystems.

This work package targets the functional role of the benthic compartments of both polar biospheres (i.e. the sediment-water transition zone, benthic organisms, their demersal and endotherm predators and pelagic prey) in providing ecosystem functions and services, particularly biodiversity, nutrient recycling, and flow of energy and matter. The geographical focus is on regions for which we already built a considerable knowledge base, i.e. the Antarctic Weddell Sea and Peninsula region and the Arctic Fram Strait including the AWI-HAUSGARTEN – Kongsfjord area.

Within this research framework, the major challenges are

- Assimilation of ecological and environmental data relevant for developing an understanding of key polar characteristics and processes into a reference collection.
- Establishing baselines for the function, distribution and diversity of polar bentho-demersal communities and ecosystems.
- Description of the mechanistic links between specific ecosystem functions and the underlying community and key organism traits and performance.
- A reliable benthic carbon flux model for the Southern Ocean south of 60° suitable for inclusion in global carbon budget calculations.

Current Activities and Previous Work

This work package integrates expertise in polar physiology, polar benthic / demersal ecology, deep sea ecology, sediment biogeochemistry, polar oceanography, and ecosystem and spatial modelling. This interdisciplinary competence enables us to combine experimental and field work carried out at local and regional scales into macro-ecological approaches (i.e. the study of relationships between organisms and their environment at large spatial and temporal scale to characterise and explain patterns of ecological properties) and macro-physiological approaches (i.e. the study of variations in physiological traits over large spatial and temporal scale and the ecological implications of this variation). This strategy facilitates the development of scenarios of future polar biota by means of linking empirically as well as mechanistically properties and functions of organisms, populations and communities with the corresponding environmental and biogeochemical settings.

Past and current benthic ecosystem research concentrates on the functioning of shallow coastal ecosystems in Arctic (Kongsfjorden, Spitsbergen) and Antarctic (Potter Cove, King George Island; heavily affected by regional warming and glacier melting), on long-term change in the Arctic deep sea (AWI-HAUSGARTEN, where the benthic system responds directly to year-to-year variability in sea ice extension), and on variability of benthic community structure and dynamics in the high-Antarctic Weddell Sea (where ice-shelve loss causes profound changes in shelf biota) and in the central Arctic. We intend to establish an integrated bipolar baseline dataset by compiling data collected during previous POLARSTERN cruises and other international research activities and filling gaps in time, space and resolution using state-of-the-art in situ and remote sensing methods.

Visible light, UB and temperature are the major environmental constraints of polar macroalgae. We will analyse the underlying mechanisms in close cooperation with the University Bremen (BreMarE), particularly within the AWIPEV long-term research project “Biology of Arctic benthic algae”. Temperature and oxygen availability have been identified as major environmental drivers shaping the functional characteristics and life cycles of polar invertebrates and fishes. Our growing insight into the mechanisms behind thermal specialization as well as the sensitivity to temperature extremes led the formulation of a unifying principle, the concept of oxygen and capacity limited thermal tolerance (OCLTT). This work identified a hierarchy of thermal tolerance from the highest level of biological organisation, the organism, to systemic and molecular levels. Future studies aim at the relationships between the width and position of thermal windows and biogeography as well as the genomic, transcriptomic and functional characteristics of the respective species. Corresponding models are essential for the development of a comprehensive cause and effect understanding and of scenarios of change at the ecosystem level. The associated high confidence in projecting future effects is relevant, especially in assessments of climate change impacts as carried out for the IPCC.

Biogeochemical fluxes and processes in the sediment–water-transition-zone (bentho-pelagic coupling) are essential parts of global carbon and nutrient cycles and constitute a long term objective of AWI research. Fluxes of particulate organic matter and of biogenic silica were investigated in both polar regions. In situ measurements by micro-profiler and benthic chamber systems were carried out at various locations in the Southern Ocean as well as in the Arctic Ocean (Kongsfjorden and off Svalbard). Since the spatial coverage of biogeochemical measurements remains limited, geographical information systems are used to model biogeochemical large-scale spatial variability.

During recent years, GIS expertise has been developed in many working groups at AWI, in particular to facilitate the understanding of spatial variability in ecological and sediment biogeochemical processes. Currently, AWI establishes an internal network of GIS-users in order

to facilitate exchange of knowledge and the development of common standards for data assimilation and management.

Objectives

With emphasis on the primary target areas, the Antarctic Weddell Sea and Peninsula region and the Arctic Fram Strait including the HAUSGARTEN – Kongsfjord area, the major objectives of the WP are:

- to develop a mechanism based understanding of organism and ecosystem change by linking levels of biological organisation from genome and transcriptome to cell and tissue functional capacities and then to whole organism physiological performance and the spatial and temporal distribution of species.
- to develop organism and population models that identify evolutionary and environmental drivers of changing organism functional properties and energy/mass budget dynamics with particular emphasis on ocean warming and acidification.
- to determine factors and processes that define the dimension of the ecological niche (functional traits and environmental conditions) of relevant species empirically and experimentally, and to generate corresponding distribution and prediction maps.
- to identify spatial patterns and temporal trends in relevant benthic community functions (such as biodiversity, metabolism, POM processing, carbon and nutrient cycling), to map corresponding typical seafloor provinces, and to identify potential environmental drivers as well as the links between drivers and ecological response.
- to model spatially explicit future benthic community structures, to characterize these structures by their intrinsic properties and functions, and to test such scenarios for sensitivity to climate change.
- to develop a comprehensive science community reference collection of environmental and ecological observational data, analytical methods and (parameterizations of) models.

Expected Results, Milestones

Advanced experimental laboratory and field studies will identify and quantify links between environmental drivers and biological responses on different ecological levels from genes to organisms/populations to ecosystems. Environmental and ecological constraints on metazoan organism performance will be analysed by means of organism ecophysiological models derived from applications of the OCLTT concept. We expect that differences in response to temperature change between co-existing and interacting species (competition, predator-prey interactions) will constitute a significant part of the mechanistic links between effects at the community level and the respective drivers. Molecular genetic analyses will establish the role of within-species genetic variability and of gene regulation for organism response. Functional analyses of benthic communities and related biogeochemical processes will be achieved using sensor-equipped platforms (ROV, AUV, landers) and scientific diving. These observational approaches will be complemented by in situ measurements and experiments regarding ecologically relevant processes at the sediment water transition zone such as metabolism, nutrient cycling and energy/matter flow.

To establish an ecological baseline, physical, oceanographic and ecological data of the target areas will be compiled into a geo-referenced data management system (GIS). This approach involves the mining and re-examination of existing data as well as filling significant gaps with new data. Particularly little is known about benthic particulate organic carbon fluxes in the Southern Ocean south of 60° and in the Central Arctic basin north of 80°N. Geostatistical and multivariate approaches will identify statistical patterns in space and time and significant

relationships and interactions between environment and biota as well as within the benthic communities.

In general, our geostatistical approach enables us to move beyond the static description of the status quo: (i) we can apply ecophysiological and biogeochemical models on large spatial scales and (ii) we are able to couple these models to high-resolution oceanographic models (e.g., FEOM) in order to assess the effect of future regional change on the spatial and temporal variability in major ecosystem properties and functions.

Milestones

- POLARSTERN expeditions to Fram Strait (Arctic) and Weddell Sea (Antarctic) in 2014 – 2016.
- Integrated ecological database for Arctic and Antarctic ecosystems from shelf to deep sea.
- Operative interface between GIS based dynamic benthic maps and regional ocean-atmosphere models.
- Operative procedures to identify and manage data, analytical methods and models.

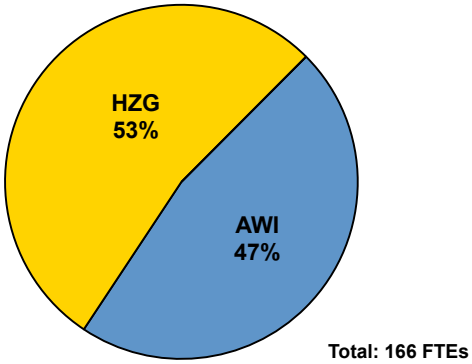
Expected Results

- Macrophysiological models for polar benthic and demersal key species that assess species functional properties and physiological response to environmental forcing at the individual level and its consequences for population spatial distribution.
- Macroecological models for polar benthic and demersal key species, i.e. geo-referenced ecological niche models based on empirical and functional relationships between species properties and the environment.
- Insight into long-term relationships between environmental drivers and marine biota in specific polar (Weddell Sea, Fram Strait) and sub-polar regions.
- Synthesis of biodiversity patterns across all benthic size classes at the HAUSGARTEN observatory.
- Empirical and mechanistic models of interactions between macrobenthic/ demersal communities and biogeochemical processes at the sediment-water interface.
- Maps of benthic integrated properties and functions (biodiversity, community metabolism, POM processing, carbon and nutrient cycling) in specific polar and sub-polar regions (Weddell Sea, wider Barents Sea) and corresponding models to simulate ecosystem responses to future climate and impact scenarios.
- Science community reference collection of relevant data, analytical methods and models
- New underwater equipment developed to perform the foreseen experiments (e.g. diving robots, payloads) might be further developed and transferred to commercial marine technology applications.

Topic 2: Fragile coasts and shelf sea

Coordinators: K. Emeis (HZG), K. Wiltshire (AWI)

Challenges



Coastal and shelf systems are perhaps the most rapidly changing environments on Earth. Concurrently, human future is closely linked to the sustainability of coastal environments and use of their resources. The change is not just confined to globally-induced change such as warming and sea level rise, but superimposed by natural variability and diverse pressures including ocean acidification and anthropogenic effects due to, e.g., overfishing, pollution, transport and the construction of large artificial structures such as wind farms. The allocation of observed change to individual drivers and the detection of combined effects remain difficult. This is, however, prerequisite for the long term management of resources provided by coastal zones and shelf seas.

In this Topic it is aimed to tease out how and on what levels diverse driving forces affect the state of coastal and shelf seas, and how they adjust to pressures. It is a major challenge to differentiate terms of reference with regard to scales, both spatial and temporal. The ability to detect and attribute observed changes to potentially manageable drivers relies on an accurate estimate of the width of the natural corridor of variation, an optimal understanding of causes and effects and their linkages, and resilience to change. Only with a fundament of knowledge of coastal system function, combined with highly resolved observational systems and models, is it possible to develop appropriate management strategies. In a transdisciplinary approach, marrying geological, biological, social, chemical and physical scientific expertise with modeling and observation analyses, five of the major scientific challenges currently facing coastal seas are addressed:

- Identification of drivers
- Evaluation of system states on different scales
- Resilience/sensitivity of systems to different pressures
- Natural variability versus induced variability
- New strategies and techniques for observation and risk assessment

Shelf and coastal seas are subject to different sets of drivers and no two systems will necessarily show the same responses and functionalities. This Topic thus is focused on two geographical regions as examples of areas both subject to immense, albeit different pressures:

The North Sea as an example of a “Service Sea” at the forefront of societal and economic developments and affected by global and regional change drivers, and the Laptev-Lena Delta region in the Arctic as a rapidly changing shelf sea system with primarily global warming trends.

The North Sea is a well studied sea for which extensive databases and models exist (for example from PACES I) serving as a solid foundation to current scientific questions and societal use. A particularly pertinent example of a new impact is the construction of wind farms in the German Bight with an allocated sea floor area of 30%. Such use constitutes a large-scale and long-term disturbance experiment that is likely to have significant effects on the coastal ecosystem. The PACES II proposal period straddles the onset of the wave of activities at this new offshore frontier, and it is essential to investigate the current state of the overall system relative to this imminent development. Topic 2 will devise a strategy for charting possible

consequences for functions and services of the North Sea arising from this experiment. This includes the development and testing of new observational and modelling strategies and tools for identification of anticipated changes with a backdrop of a highly dynamic and variable North Sea system. Skills, techniques and concepts developed and proven here will be adapted to, tested and applied in other coastal environments, for example tropical coasts with specific requirements and problem sets. As in the past, this paves for the transfer of knowledge and technology.

The Lena Delta work overarches Topics 1 and 2. It requires the specialized knowledge of e.g. permafrost experts, oceanographic modellers, climatologists and coastal ecologists to evaluate the rapid changes in evidence in the Arctic. A short exposé is presented in the box below.

The Lena Delta and Laptev Sea - a unique confluence for the study of changing Arctic dynamics

The thawing of permafrost and melting northern sea ice in the Arctic coastal regions as a result of global temperature rise has become an increased focus of world attention. A rapid freshening of the Arctic Ocean is observed and the rate of coastal erosion has increased substantially.

In this overarching focus we will concentrate on the confluence of the Lena River and the Laptev Sea. We will use the huge delta and adjacent sea as a model region and for the study combine expertise and expand findings from Topics 1 and 2. We aim to determine how this arctic coastal region is changing in terms of hydrography including salinity gradients, freshwater budgets, currents and wave action, and changing terrestrial input. This will be combined with an evaluation of the biological productivity including carbon and primary production budgets and the connected higher trophic levels.

Models of hydrography and substance transport in the coastal zone converging with the Lena River Delta will be developed. Scenarios on wave activity based on Radar observations will be considered particularly with an eye on coastal erosion and wave activity in transport routes. Combined with on the ground measurements (e.g. around Samoylov station) linked to satellite images first attempts will be made at evaluating production for this region. The current productivity of the inner coastal area will be estimated.

In this project, which is a close collaboration of German and Russian scientists it is proposed to set up a base-line archive of information for future long term assessments in the Arctic Shelf region. This archive will draw together information on physical, chemical as well as biological parameters relevant to the Lena Region. Scenarios such as increased freshwater runoff and associated input of substances ranging from nutrients to methane both from diffuse and direct sources will be evaluated as these parameters are of particular importance for the dynamics of the ecosystem in the Lena region and Laptev Sea.

The influence of different atmospheric conditions, e.g., anomalies similar to those conditions, which might become more frequent as global change takes hold, on hydrographic conditions will be modelled. The influence of wave action and ice movement on erosion of the coasts could be simulated. The potential for changing pressures on the Delta for example by the increased passage of ships and or transport of goods will be considered together with Russian Partners.

Milestones:

- New model setups for sea ice, bathymetry, hydrography
- Lena Coast, Laptev-Lena connection
- Wave scenario analyses
- River output budgets for carbon (& chlorophyll)
- Productivity estimations for region of freshwater influence

A prerequisite for success in Topic 2 are close links with experts in other Topics, such as regional and global modellers, information systems experts and social scientists. Topic 2 is closely linked to Topic 4, partly an offspring from PACES phase 1, where proven tools and concepts originating from the last program period will be tested in the context of science-stakeholder interaction. Topic 2 is embedded both in PACES II and in the broader HGF-research program. Specifically, it contributes to Cross Programme Activities “Natural Disaster and Warning Systems” and “Water”.

Current Activities and Previous Work

Efforts in PACES focused on the assessment of change. They include an increased state-understanding of the North Sea system and its function in physical, biological and chemical terms. Long-term data analyses, model hind-casts of long-term (60 years) regional climate, sea state, and ecosystems allowed for a greater understanding of variability and trends in the North Sea. Model-based assessment identified possible geophysical risks to coastal zones under impending global change (coastDat), and long-term observational time series were analysed for geophysical and human influences on ecosystem structure and function. Knowledge acquired from PACES includes new approaches for recognising possible consequences of on-going or impending change in global, regional, or even local contexts, including society. Work on coastal change developed and established new genomic and experimental tools and expertise for assessing diversity both within and among species, and successfully linked this to functional biodiversity and ecosystem development and evolution. Biological interactions were found to be a main driver of food-web functioning. Large scale shifts of biodiversity and the influx of neobiota into coastal ecosystems were related to drivers. A number of plant and animal species complexes were analysed on biogeographical gradients spanning polar and temperate regions in both hemispheres, to advance the understanding of how species-specific response capacities and chemical ecology are shaped by extreme environments on the one, and by high environmental variability on the other hand.

Using analytical data and models, the status of the North Sea and other regional seas was evaluated with regard to human-induced eutrophication and pollution. The COSYNA observatory was designed, built and deployed to synoptically asses the geophysical and environmental state of the North Sea. Pre-operational applications, first products and services of COSYNA are now part of WP1 of Topic 4, whereas the continued further development of COSYNA is part of this Topic and will include the ACROSS activities. Research was initiated to build a social-ecological perspective of the German North Sea coast, to map changes in perception of people as a result of various drivers (including offshore wind farms), also in context of national and international governance needs. This motivated enhanced dialogues and communication between coastal researchers and institutional stakeholders, media, and the public, for example via the Northern German Regional Climate Office, and the North Sea Office.

Objectives

Research in Topic 2 addresses the challenges enumerated above in five work packages (WP 1-5):

WP1 “Coastal shifts and long-term changes” will assess and quantify regional environmental change in coastal systems as a basis for development of sustainable and robust adaptation options. This WP is a continuation of the successful cooperation between geophysicists, biologists and social scientists in PACES I. Research will focus on quantitative descriptions of past, recent and ongoing, and possible future changes on decadal time scales. Emphasis will be placed on discrimination of natural variability and anthropogenic driving forces, and the development of comprehensive regional scenarios of environmental change to foster and to

support development of sustainable adaptation options. Products of WP1 (e.g., coastDat and long observational time series) are the cornerstones of other work packages towards defining the natural corridor of geophysical and ecosystem variability in the North Sea, the Arctic, and, for comparison, example regions in Asia. Data products developed are available via Topic 4 for industrial and stakeholder use- e.g. to Aquaculture, Wind Farm Industry management stakeholders.

WP2 “Species Interactions in changing and exploited Coastal Seas” aims to reveal consequences of global and regional change, including new resource usage, on biological functions and diversity of coastal ecosystems. It asks how ecosystem structures and food webs in the coastal ocean are affected by natural climate variations on the one hand, and by developments emanating from human activities on global or regional scales on the other hand. The work package will combine single-species experimental setups, mesocosms, field experiments and dynamic modelling to investigate the structure and function of present ecosystems, and to infer on the effects of future change of species interactions in coastal seas. Results are available for Topic 4 to underpin stakeholder interests including coastal managers of shelf seas. Ecosystem services can be better defined and assessed.

WP3 “Evolution and adaptation to climate change and anthropogenic stress in coastal and shelf systems” aims to understand the genomic and functional strategies, capacities and limitations of organismal adaptation to changing environmental conditions. The work package examines the potential of coastal and shelf species to respond to ecosystem change and contamination, underpinning the experimental and modelling studies on species interactions in WP 2. The limits of organismal adaptation and the potential of species to survive and respond to change, their adaptive strategies and evolution will be studied across relevant temporal and spatial axes. Results are available for Topic 4 to underpin stakeholder interests in shelf seas e.g. to Aquaculture or the Wind Farm Industry.

WP4 “Biogeochemical provinces of sea floors in coastal seas” addresses the role of processes at the sediment-water interface for material fluxes in shelf seas. Through data mining, targeted field work and modeling, a comprehensive georeferenced inventory of biogeochemical seafloor properties and pollution in the German Bight of the North Sea will be created. This provides the compulsory and much-needed boundary conditions for ecosystem models, and will be used to assess the intrinsic ecosystem services of sea floors and to describe the environmental status in national and international contexts.

WP5 “Interface processes and physical dynamics of the coastal ocean” aims to observe and understand the small-scale dynamics of coastal seas. Fronts, waves, or turbulent processes govern air-sea gas exchange, particle dynamics (including biological particles), and exchange processes of matter within the water column or at the sea floor. Many of the features and processes occur on sub-mesoscales (10 m to 10 km), have only recently become accessible to observation. Thus they are only now finding their ways into theory and models. WP5 will use existing COSYNA components and introduce new instrumentation and techniques to elucidate submesoscale dynamics, their effects on energy dissipation, gas and dissolved as well as particulate matter fluxes, phytoplankton dynamics, and the interaction of waves with shallow sea floors.

Expected Results, Milestones

In Topic 2 the driving forces effecting variability and change in coastal and shelf systems will be elucidated, and system states in geophysical, biological and chemical terms will be determined in current and historical contexts. Pressures and their impacts will be evaluated with a major specific example: Wind farms in the German Bight. The responses of two very different systems – the North Sea and Lena-Laptev region – to changed forcing will be analysed in terms of

sensitivity and resilience. Techniques for the detection of state shifts and trends outside natural systems variability in physical, chemical, and biological data and model results will be a focus. Methods for detection of drivers (external and internal) will be used to investigate the mechanisms that ameliorate pressures, and their limits. Topic 2 will test if intensified and modified sea floor use causes a deviation from the corridor of natural variability and shifts in states of the North Sea system. We will establish the nature of variability in the Arctic Ocean as a basis to recognise and evaluate changes and shifts in resilience and sensitivity. Results expected from our work are

- Improved understanding of the interdependency between species inventory, nutrient dynamics and food web structure in coastal ecosystems under pressures from global and regional developments.
- Improved understanding of small-scale physical processes in shelf sea systems, including their effects on material cycles and phytoplankton.
- Inventory of sea floor types of the North Sea, their roles in material cycles and their variability as a basis to establish good environmental status and to estimate their ecosystem services.
- Quantified past, recent and ongoing, and possible future changes in the North Sea by extending the observing capabilities and geophysical regional modelling system. Transfer of scientific approaches developed for the NW European realm, for example to Asia and the Arctic.
- Initial assessment of consequences for shelf seas functions and services arising from large-scale impacts, such as wind farm construction in the North Sea.
- Better assessment of governance structures, user conflicts and management strategies (e.g. Marine Spatial Planning) and their capacity to adapt to new challenges based on the current development in offshore uses.

Milestones

- 3-D-version of coastDat generated, applied to model long-term variability in climate and sea state in the North Sea/Baltic Sea; specific sub-sets implemented for India, the East China Sea, the Arctic. Dossier on the changed biodiversity and assessment of ecosystem interactions in the North Sea. The long-term, homogeneous and consistent geophysical data sets of coastDat are of high interest to and in high demand by institutions and companies in the context of planning and risk assessments (e.g. for offshore wind parks).
- Combined Laptev-Lena Delta geophysical model including productivity evaluations for the Arctic.
- Proxy generation for evaluation of adaptive diversity in ecosystems.
- Observational and model system for high-resolution applications in the coastal zone set up, tested and expanded in order to understand the natural and social dynamics of coastal systems and to quantify consequences of human interventions in coastal systems.
- New technical solutions and services to improve the COSYNA network will be validated and marketed for commercial use in the context of maritime safety and security, and of the various offshore activities in coastal areas.
- The geophysical and ecosystem model system will be an innovative modular system adaptable to diverse needs and will permit both scientific applications and scenaric evaluation of economic and societal developments in the North Sea region. It will open up a multitude of co-operations with industry and agencies engaged in offshore developments.

- Integrated database of sea floor properties in the German Exclusive Economic Zone (EEZ) published as open-access WebGIS and implemented in model system as an interactive seafloor module. Open-access data and knowledge on sea floor properties is of high relevance for decisions on future sea floor uses.
- Status and variability of sea floors in the German EEZ in terms of matter fluxes and pollution established, good environmental status defined, indicators tested and communicated to stakeholders. This is a basis for better description of GES in the context of the MSFD process and is of high societal relevance.

Workpackage 1: Coastal shifts and long-term trends

Coordinators: Ralf Weisse (HZG), Alexandra Kraberg (AWI)

Mission statement

To quantify and to assess regional environmental change in coastal systems to support and to foster the development of sustainable and robust adaptation options

Coastal systems are subject to substantial pressures from natural and anthropogenic environmental drivers and socio-economic change. These comprise of changes in ecosystem composition and dynamics, material fluxes, frequency and intensity of extreme sea level events, or changes in land use and risk perception. WP1 research will focus on 1) quantitative descriptions of past, recent, and possible future coastal changes on decadal time scales; 2) discrimination between natural variability and anthropogenic driving forces; and 3) the development of comprehensive regional scenarios of environmental change to foster and to support development of sustainable and robust adaptation options. This requires homogenization, integration and analysis of available long-term data; tests of feasibility of new techniques for routine generation of long-term data (e.g. molecular probes); extension of available model systems; and creating knowledge for developing assessments of resilience of socio-ecological systems and the mutual impact of changes and disturbances in eco- as well as social systems.

Current Activities and Previous Work

Climate is one of the drivers of long-term coastal change. It is manifested, for example, in changing mean and extreme sea levels or changes in storm climate and their impacts on storm surge and wave climates. Reconstructions of marine and coastal climate during the past decades of years together with scenarios of possible future change until 2100 were developed using a dynamical downscaling strategy. For this purpose a cascade of numerical models ranging from regional atmosphere models to wind wave and storm surge models was developed and is maintained. Data from these reconstructions and scenarios are made available to users via the coastDat database that is now widely used to determine marine climate and its long-term changes and variability. The added value of this approach has been studied broadly, and received international attention. Examples are publications on sea level rise in the German Bight or determination of pressure-based proxies of storm activity. There are presently more than 60 external users of this database covering a wide range of applications. For example, coastDat was used during the design process of nearly all of the planned offshore wind farms in the North Sea, the planning of the Fehmarn Belt crossing, or the environmentally based optimization of ship design.

Applications of the model cascade also adressed fluxes of matter in the coastal zone and through the atmosphere. Complementing the effort to describe the physical state of the coastal system, analytical and modelling work identified sources, fate, and effects of eutrophying

nutrients, xenobiotics, and pollutants, and benefits from joint analyses of observational and model data. Simulation of atmospheric transport and the fate of anthropogenic substances were extended by compiling consistent, highly resolved emission fields of key compounds that have been used to generate emission/deposition hindcasts and scenarios. Further the model cascade was applied to elucidate consequences of increasing ship traffic on aerosol concentrations in coastal areas, risks of pollution, deposition of nutrients into coastal waters, and risk assessments of chronic oil pollution and oil accidents at sea for adjacent coasts.

Joint efforts linking the internally consistent and homogeneous model data with complex observational time series such as at Helgoland Roads and hydrodynamics with biological processes were highly successful. For instance, we reproduced alongshore spring bloom dynamics in ecosystem model simulations of the German Bight between 2002 and 2005 and quantified the effect of hydrography on larval supply of an invasive species in the Wadden Sea.

Merging results from conventional time series analyses with results from models on long time scales remains a challenge, because both observational data and modelling approaches are imperfect. Techniques have been developed to address such issues for both geophysical and biological data.

The provision of detailed long-term observations is of paramount importance to model calibration and provides the basis for recognising and assessing long-term changes as basic input. In the North Sea such time series comprise, for example, the measurements at Helgoland Roads encompassing phytoplankton, zooplankton counts and physico-chemical data, the plankton and nutrient time series in the List tidal basin, and a range of benthic time series maintained and co-ordinated at AWI. These data sets are available to all stakeholders and data are supplied on average three times a week to users.

Recent work based on these data revealed considerable shifts at an ecosystem level such as a regime shift in 1988, or shifts in phenology (the timing of seasonal occurrence) of key species, the appearance of new species in the coastal North Sea and related to this increase in coastal biodiversity. This phenomenon has been observed in both plankton and benthos time series. Data were applied further to successfully establish relationships between physical/chemical drivers and the magnitude and timing of plankton blooms and in a Wadden Sea wide perspective between riverine nutrient loads, nutrient cycles and phytoplankton dynamics. Until recently these biological time series were generated predominantly by manual counts and measurements. However, increasingly, they also incorporate high frequency data from automated measuring devices and molecular tools. While these latest high throughput sequencing methods hold much promise for refined high resolution assessments of biodiversity at all levels, they can only be incorporated into routine monitoring programmes if this does not interrupt the integrity of existing long-term data. Feasibility studies e.g. of the applicability of “Phylochips” for the assessment of picoeukaryotes (Prasinophytes) were already performed over three annual cycles and monitoring for pathogenic bacteria has begun at Helgoland Roads but these systems need to be further tested and calibrated. Therefore a pilot study is planned to test the scope for the introduction of molecular monitoring into this already very detailed time series.

Climate change effects were put into context with other drivers of coastal change and research was initiated to develop innovative adaptation strategies. Here, the Elbe estuary served as an example: It has undergone massive changes in terms of storm surge heights and sediments transport, because of massive water works in the recent decades of years. Using models, we explored optimal strategies for waterways management. The societal dimensions of changes in the coastal zone were explored by determining the self-image of coastal inhabitants (“Heimat”) and their perception of climate change. The societal and political dimensions of change were also explored in the context of offshore wind farming (OWF), in particular the impact of OWF on

ecosystem service provision and the challenges for the governance system, in particular for Marine Spatial Planning.

Objectives

Building on the results from PACES I, the overall objectives are the quantification and assessment of regional environmental change in coastal systems supporting the development of sustainable and robust adaptation options. Comprehensive scenarios of coastal regional environmental change will be developed. Examples are regional sea level change comprising changes in mean and extreme sea levels (storm surges, waves) together with quantification of uncertainties, impacts, and vulnerability assessments to support development of adequate adaptation options. This includes

- Development and application of techniques to discriminate between changes due to natural variability and changes caused by anthropogenic driving forces.
- Assessments of long-term changes in geophysical hazards and in physical and chemical drivers on biological communities at different spatial and temporal scales, and
- Analysis of perception and cognition of natural hazards, use conflicts in coastal communities as well as new governance mechanisms as the basis for developing future adaptation measures.

These objectives require continuation and advanced evaluation of detailed long-term observation systems, optimization of presently used techniques and successfully developed approaches, but also necessarily demand extension of analysis capabilities and tools such as analysis of available long-term measurements, extension of available model systems, and developing assessments of resilience of socio-ecological systems. In particular the development, comparison and transfer of scientific approaches linking researchers to decision makers and communities are envisaged through links with and supply of information to Topic 4.

Expected Results, Milestones

Comprehensive scenarios of future and reconstructions of past regional environmental change will be provided. This requires the complex analyses of time series such as the measurements at Helgoland Roads or in the List tidal basin combined with the extension and upgrading of the modelling system developed and used during PACES. Together data from these modelling efforts and measurements will provide the basis for quantifications of observed and potential future long-term changes and the discrimination between natural variability and changes caused by anthropogenic forces. This will, in combination with sociological studies, provide a basis for assessments of observed and expected changes and eventually provide a rationale for developing robust and sustainable adaptation measures.

Significant contributions will be made in the context of the interplay between environmental conditions and large-scale offshore wind farms. In particular, research carried out in this WP creates the basis for assessing the environmental conditions and their long-term changes to be expected at the installation sites, a prerequisite for optimizing designs and maintenance procedures. In fact, data provided in coastDat were already used during design of most of the planned offshore wind farms in the North Sea such as for determining statistics of weather windows needed to optimize operation and equipment required for maintenance.

Substantial efforts will be put into promoting the development of generic approaches that may be applied to other coastal regions, for example in Asia or the Arctic and particularly the Lena Delta (see Box). This includes extension of modelling systems as well as integration of biological and chemical data from various regions taking into account different methodological

and sampling strategies as well as differing cultural (planning) contexts. More specifically, expected milestones can be summarized as follows:

- Quantitative description of past, recent and ongoing, and possible future coastal long-term changes in particular of regional mean and extreme sea levels including quantification of uncertainties and discrimination between natural variability and changes caused by anthropogenic drivers.
- Transfer of methods and approaches to other coastal areas with specific applications in the Lena Delta.
- Assessment of resilience of socio-ecological systems and the mutual impact of changes and disturbances on these. In combination with Topic 4 the analysis of the perception and cognition of natural hazards and use conflicts in coastal communities as the basis for future adaptation and management measures.
- Assessment of national, regional and international institutions and governance structures, user conflicts as well as differing management strategies in the offshore area (e.g. Marine Spatial Planning) and their capacity to adapt to new challenges based on the current development in offshore uses.
- Information from regional climate models for dissemination through the International BALTEX and LOICZ secretariats and the North German regional climate office and North Sea Office for both public and private stakeholders.
- Based on all available time series: A more detailed description/understanding of the range of ecological responses and interacting effects to underlying drivers acting at different geographic and temporal scales/ periodicities.
- More detailed knowledge of differences in biogeography of different species, including the influence of hydrography on species distribution.
- Pilot study for the introduction of new methodologies (e.g. molecular tools) for routine deployment in coastal ecological time series.
- The aforementioned issues offer various options for commercial services such as consulting for coastal authorities, insurances, building companies, wind park planners. Knowledge and data accumulated here exhibit a major asset also important for private public partnerships and industry co-operations, respectively.

Workpackage 2: Species interactions in changing and exploited coastal seas

Coordinators: Maarten Boersma (AWI), Kai Wirtz (HZG)

Mission statement

To reveal consequences of global and regional change, including new resource usage, on functioning and diversity of coastal ecosystems

Challenges

Currently, climate change and direct human interference are causing substantial alterations in our coastal ecosystems. These are beyond the normal ranges of variability. In particular, concurrent changes in the environment (increase in temperature and CO_2-availability, decrease in pH and nutrient loads, altered wind and stratification characteristics) cause reactions of different magnitudes or even in different directions for different players in the system. This in turn can cause shifts in species distributions, which may lead to mismatch phenomena of previously matched (in time or in space) interactions, or new matches of previously mismatched ones. New species may profit from these changing conditions, all of which are likely to affect the flow of energy and matter through the system. One prominent economically relevant example is

the temperature-driven shift in distributions of Calanus species and its effects on cod reproduction in the North Sea and North Atlantic.

Anthropogenic activities generate effects on widely different scales. For example, on the small end of the spectrum, microplastic particles continuously increase in abundance in Earths´ seas. These particles act as substrates for bacteria, thus potentially facilitating the introduction of new species.They might alsochemically or mechanically interfere with trophic interactions as they collect toxicants and potentially even affect food uptake in smaller organisms. Larger scale human interventions into coastal and shelf seas include new structures such as coastal defences and offshore wind farms that substantially alter local habitats. Changed turbulence in the direct vicinity of these structures might affect sediment-water interactions and sediment dynamics, and generate new habitat availability of substrate for bottom-dwelling organisms. The under-water structures provide a large array of hard-substrates in an environment otherwise characterized by soft-bottomed sediments. This will promote those organisms, which are dependent on hard substrates, during at least part of their life-cycle, such as many jellyfish species. Moreover, at least on a local scale, wind farms will modify the physical properties of passing water bodies (mixing intensity, turbidity, and under-water light climate), which mediate relevant ecosystem processes. Wind farms represent new opportunities, as it is planned that these areas will be designated as no-harvest zones, which thus they could serve as a functional equivalent to marine protected areas (MPAs), safeguarding important ecosystem goods and services, in particular related to fish recruitment. Furthermore, offshore wind farms areas hold the potential as multi-use systems, by for example integrating aquaculture in these areas. Thus, the composition of the benthic and pelagic communities and, as a result, the interactions in the food web and ultimately the functioning of the ecosystem is likely to be affected by all these indirect and direct inferences, and the aim of this work package is to investigate major specific and integral responses.

Altered resource usage and, more generally, global and regional change continue to modify the physico-chemical marine environment as well as the probabilities of arrival and successful establishment of new species and thus drive major shifts in species composition and interactions. We still know very little on how those compositional changes, sometimes apparent in the rise or demise of individual players, affect the food web and the functioning of the ecosystem as a whole. As until now most studies have focused on small subsets of the system, we cannot assess system effects of changes in large scale drivers. Thus, a more integrative approach is needed, where knowledge on the small subsets is extrapolated and integrated to predict and test effects at the system level. Furthermore, many of the issues at hand have a clear spatial dimension, requiring a precise understanding of multi-scale transport processes in coastal and shelf seas. For example, how do local effects spread throughout larger areas of the North Sea? How do changes in circulation patterns and in the distribution of hard substrates affect the population dynamics of individual key species, which have a multi-stage life cycle? Probabilities of impacts should be assessed in the light of uncertainties, especially since many interactions are non-linear, thus subtle changes in the environment may lead to drastic changes in the seasonality of key species. This might explain the strong inter-annual variability seen in ecological observatories, and we do not know how sensitive ecosystem functions are as a whole to these small modifications. Experimental work on the appropriate scale (mesocosm and field experiments) has to fill critical knowledge gaps in estimating the propensity of key species and functional groups to ongoing or anticipated physico-chemical and ecological shifts. Modelling approaches (e.g. based on functional traits) have to account for such knowledge and should be further integrated with physical models. Such a meta-analysis is needed to achieve a more robust capability to generate response scenarios of the coastal ecosystem to man-made and natural drivers. This predictive capability can already be tested when studying spatial gradients and inter-annual variability in ecosystem dynamics.

In short, our main challenge is to relate long-term change in ecosystem structure and function with intra- and inter-annual variation, and to link this to multi-scale changes in ecosystem functions. This comparison will serve as a reference to understand system responses to long-term drivers. Where, for example, spatial or temporal variation in the external drivers is smaller than the currently changing environment, one might expect a relatively high vulnerability to anthropogenic change, and vice versa.

Current Activities and Previous Work

In PACES I, we focused on the effects of several invasive species (e.g. pacific oyster and the comb jelly Mnemiopsis leydii) on other species, and observed that the impact of these species on the system may not be as severe in the North Sea as feared. The pacific oyster has formed substantial beds in the German Wadden Sea but has not excluded blue mussels. Frequent co-existence of both species is now the rule rather than the exception. In the open North Sea, the voracious planktivore M. leydii has not reached the densities observed in, for example, the Black Sea or the Baltic Sea. Also this species will likely find its niche in the North Sea community. Whether this scenario also applies for the Wadden Sea, where much higher densities are observed, is still under investigation. Other invasive species have actually created new habitats for species that live on and of them (for example wireweed, Sargassum muticum). However, many other invasive species are still in the early stages of their invasion history, and we have to continue this work on the effects of changes in species composition in order to investigate whether and under which circumstances new species might substantially interfere with established food web interactions and fisheries.

One of the main aims of our work in PACES was to identify the changes in the composition of the coastal communities through novel techniques such as genetic methods and new (in situ) observational power. These studies have revealed a much greater diversity than previously expected, as well as direct impact of human interference (dumping of harbour dredging products) on the (bacterial) diversity. Furthermore, potentially pathogenic bacteria are much more common in the entire North Sea than previously believed.

Food web studies have revealed the strong impact of nutrient levels and their ratio changes at the base of the food webon higher trophic levels. Algae grown under different nutrient conditions are of different quality for herbivores, and these quality effects are transferred to secondary consumers. Consumers compensate for differences in food quality by selectively taking up the food that they need and excreting products that are in excess.

Studies on the effects of offshore wind farms (FINO research platform) have revealed substantial changes of benthic communities. Large artificial hard substrates induce alterations on different spatial scales ranging from the immediate vicinity of single turbines to the entire wind farm area. In particular, a high amount of suspension feeders in the fouling assemblage and a significant “jellyfication” of the local benthic community indicate implications for the flow of energy and matter through the food web. Various studies on the combination of wind farms with aquaculture with regard to biology, system design, physics, as well as socio-economic studies and possible co-management scenarios were carries out for in the North Sea region. Furthermore, artificial hard-substrates also affect the distribution of demersal fish species. Tetrapods in the artificial reefs around Helgoland attract fish, leading to an initial accumulation of fish on the reef, but an impoverishment of the surrounding areas. Long-term effects of these structures are not known yet, in particular regarding altered recruitment opportunities of gelatinous plankton and/or fish and concomitant food-web effects.

Ongoing studies pinpoint the sensitivity of nutrient and plankton dynamics to changes in water physical conditions, and how this sensitivity depends on internal traits of functional groups and their adaptation. These studies make use of the Model of Adaptive Ecosystems in Coastal

Seas. This model computes biogeochemical and trait dynamics in 3D. Intra- and inter-annual variability observed within COSYNA and at the Helgoland Roads station could partly be explained by combining plankton trait dynamics and high resolution physical forcing. This ecosystem description couples to other Earth System compartment models, which is currently realized within a new modular community frame (MOSSCO). MOSSCO also integrates models and data employed in other WPs such as benthic models or CoastDat.

Our work benefits from the already existing studies on transport patterns in the North Sea. Referring to model based re-constructions of environmental conditions available from CoastDat, a Lagrangian transport module (PELETS) has been applied to interpret data from either field campaigns (e.g. succession of marine bacterioplankton populations) or long-term monitoringdata (e.g. at Helgoland Roads). Moreover, weather related variability of horizontal particle dispersal can be aggregated to a simplified probabilistic description of chronic oil pollution.

Objectives

From our previous work and the challenges formulated above we derive the following objectives:

- to identify the mechanistic linkages between changes in the environment and changes in ecosystem structure and functioning.
- to determine the causes of changes in species composition by assessing the relevant factors at the individual, population, community and food-web level.
- to identify potential threshold environmental conditions, which shift the outcome of species interactions, and may cause regime shifts.
- to establish how key traits of functional groups are interlinked (e.g., trade-offs between nutritional demands and size/position in the food-web), and how physiology affects ecological significance at the species and assemblage level.
- to integrate knowledge gathered at the laboratory scale to describe variability at the seasonal and inter-annual scale, with focus on key species interactions but also variations in related community traits.
- to put this knowledge in a spatial model framework and to provide ensemble scenarios under different forcing, with new large scale resource usages as explicit drivers.
- to identify potential impacts from different co-uses of offshore stakeholders on the local ecosystem vis à vis the assessment of the overall benefits of such multi-functional uses with regard to i.e. the spatial efficiency of ecosystem use and sustainable utilisation of the coastal seas.

In our studies we use a multi-scale approach to address variability and change from the within-species level to trends in ecosystem structure. We will advance from single species investigations (adaptations/physiology/energy flow) to more complex systems, such as community structure investigations. This up-scaling will make use mesocosm studies (REEPON), field studies on artificial reefs and artificial hard structures, as well as models. Thus, we will combine advanced experimental and modelling approaches. An important tool for up-scaling from ecophysiological to ecosystem responses will be the creation of data-bases which collect existing and newly generated knowledge on species interactions and key functional traits. These data-bases and the meta-analysis they enable can provide direct estimates of system scale responses to natural variability and human made alterations. In addition, data-bases and meta-analysis facilitate the integration of experimental data into the coupled adaptive ecosystem model.

Expected Results

- Characterization of spatial, seasonal and inter-annual variation in contrast to long-term patterns will allow us to evaluate the sensitivity of the ecosystem to changes caused by human pressures.
- Assessment of potential assemblage changes by newly established species and related alterations in ecosystem function.
- A better understanding of immediate, cumulative, cascading, or compensating effects of new structures and substrates (ranging from µm to m scales) in coastal seas.
- Data-bases on physiological and ecological ("Who eats whom") key characteristics of planktonic and benthic North Sea species.
- Meta-analysis of observational data, data-bases, and model simulations leading to an aggregated description of major response modes on the system level: a basis for the formulation of coastal ecosystem response scenarios to changes in the physical climate, chemical loads, and large scale human activities.
- Recommendations on sustainable multi-functional use of offshore areas for wind farms, aquaculture and MPAs.
- The aforementioned issues offer various opportunities for commercial services such as consulting, monitoring and accompanying research for authorities, offshore industries (including wind energy, tourism, mining, aquaculture and fisheries).
- The REEPON system will offer opportunities for contract research for aquaculture firms in the context of the cultivation of new candidate species, marine biofuels from algae etc.

Milestones

- Quantification of population changes of gelatinous zooplankton, and an assessment of the most probable causes of these changes.
- Network and sensitivity analyses of coastal food webs.
- Trait-oriented data-base of major planktonic and benthic North Sea species.
- Establishment of experimental macrocosms facilities (REEPON), first experiments on community effects of changing environmental conditions.
- Identification and description of main system sensitivities to large-scale structural impacts such as wind farms or microplastic particles, based on observations, meta-analysis and coupled ecosystem modelling.
- A dynamic map of food web effects of new offshore structures.

Workpackage 3: Evolution and adaptation to climate change and anthropogenic stress in coastal and shelf systems

Coordinators: Doris Abele (AWI), Allan Cembella (AWI)

Mission statement

To understand the genomic and functional strategies, capacities and limitations of organismal adaptation and anticipate the potential of coastal and shelf species to respond to ecosystem change and chemically mediated interactions

Challenges

Understanding the limits of organismal adaptation and the potential of species to survive and respond to change requires combined analysis of heritable traits and of phenotypic expression studies. In this WP we focus on the adaptive strategies and evolution of organisms via the comparative ecosystem approach across relevant temporal and spatial axes, e.g. along

biogeographic gradients within the water column and associated shoreline systems, including sea ice. We have already established differences in acclimation and adaptive capacities of a number of polar coastal species compared to generalist taxa that colonize climatic gradients or different climatic regions. Our comparative approach does not consider species and populations as in steady state but rather takes into account their evolution over various temporal scales and in response to past and present forcing factors. Interactions between species in the habitat and in communities are fine-tuned by co-evolutionary processes (communication, prey-grazer, parasite-host, etc.). These processes as well as the fitness of the involved species are connected to the (energetic) costs and evolutionary trade-offs required for occupation of a specific ecological niche. Understanding the driving processes of past change is a prerequisite to predicting response to future regime shifts, extinctions, acclimation and adaption of the species and populations under stress.

The WP integrates expertise with respect to ecophysiological, ecotoxicological, chemical ecological, and evolutionary processes at the genomic, organismic, population and species level. The objective of this integrated approach is to interpret the present biogeographical distribution of model organisms and their capacities to respond and adapt to stress depending on their evolutionary history. Our research concept places equal emphasis on separating random change (genetic drift) from adaptive responses to directed change using population genetic techniques, as well as interpreting the responses expressed in physiological, genomic and ecological traits in selected model species. The resulting data will be provided as modules for modelling the ecosystem response to different scenarios of stress, disturbance and environmental change. Within this framework, the major challenges are to:

- Describe the functional and genetic strategies in ecologically important temperate and polar coastal (key or keystone) species to respond to ecosystem change within the framework of their phylogenetic context and based on their adaptive (evolutionary) history and their reproductive strategies.
- Develop an inventory of species-specific allelochemical compounds, and to assess their structural and functional specificities, their implication in species interactions and the genomic basis for their biosynthesis and functional evolution.
- Establish suitable indicator species and develop standardised biomarkers of contaminant impact for environmental health assessments in the Arctic, the North Atlantic, and the Baltic Sea.

Current Activities and Previous Work

As adaptive capacities of organisms are predicated upon their evolutionary history, macro-ecological and physiological comparative approaches involving species groups (different species of similar ecotype) and species complexes (geographically separated subspecies) on large biogeographic gradients are being combined with analysis of their genetic distance/relatedness. This has resulted in the detection of migrations and range shifts of keystone species (e.g. of krill, seaweeds, microalgae, etc.) from temperate towards polar latitudes over decadal time scales. These observations are supported by the results of ecophysiological and ecological field and laboratory studies and by a comprehensive suite of transcriptomic information newly assembled within PACES I. Broad scale investigations of the functional adaptation and genomic diversity within species complexes have highlighted their capacities and strategies to colonize suboptimal habitats and the evolution of specific genomic and functional traits on the edge of species-specific distributional ranges. Our future work will consequently combine studies of species adaptation in biogeographical provinces with molecular phylogeny to highlight the role of contemporary gene flow in niche expansion and stress response.

Species interactions are strong determinants of community structures and the success of species to occupy habitat niches and ecosystems. Past and current research in the WP demonstrated the importance of direct chemical or waterborne cues in these interactions. The ecophysiological impacts of environmental stress (biotic and abiotic, natural and anthropogenic) on species fitness and toxicity can now be quantified and studied at the genomic level. The combination of chemical and molecular ecological approaches, including functional genomics, has delivered new insights into the complex structure of species interactions and has highlighted co-evolutionary signatures in this reciprocal adaptive process. For example, genes involved in the biosynthesis of microalgal toxins have been recently discovered and thereby studies of their role in toxigenesis and consequences to marine ecosystems can be effectively performed. Bioassay-guided chemical analyses have elucidated new structures and yielded potential new sources for bioactive compounds. Our future work will investigate the processes regulating biosynthesis of key bioactive compounds to determine their evolutionary and ecological roles.

The effects of environmental pollution on species, populations and communities vary depending on regional contamination history, species-related evolutionary aspects, and adaptation processes. For example, within PACES I we recently demonstrated that one strategy to detoxify lipophilic chemical compounds in amphipods is via transfer into the eggs - leading to higher rates of embryo malformation on the one hand, but to higher fecundity of the parental generation on the other. Adaptation of species and their reproductive strategies in response to anthropogenic impact and environmental change will be addressed in this WP to elucidate their effects on species sensitivities towards combined stress.

Objectives

The WP deals with keystone species from temperate and polar coastal environments, with a major focus in the North Sea, the North Atlantic sub-arctic, the Baltic Sea, and the Arctic (e.g., Greenland, Iceland, Spitsbergen, Kongsfjord). Southern hemisphere target areas are the Antarctic Peninsula, a hotspot of climatic change, and the South American Magellan region. The major objectives of this work package are to:

- Determine the mechanisms (signalling pathways) of natural bioactive compounds and man-made chemicals in regulating interactions among selected marine organisms, including gene expression and their role in defence, growth, toxicity and metabolism.
- Link the consequences of environmental change or genetic isolation/connectivity of populations as drivers of adaptation in coastal and shelf sea species to make predictions regarding species niche width and adaptive capacities in support of ecosystem modelling.
- Establish the relative importance of adaptive responses and protein evolution at the sequence level versus gene family evolution and transfer in the evolutionary history of genes with ecological relevance.
- Identify suitable indicator species and establish criteria for environmental monitoring and impact assessment (chemical contaminants, anoxia, thermal stress, acidification).
- Determine how species and their reproductive strategies adapt to anthropogenic impact and environmental change, with respect to molecular evolution at the protein and genome level for species adaptation and ecosystem functioning.

Expected Results, Milestones

Studies on behaviour, biogeography and gene flow will be combined with experimental and field studies of the physiological and metabolic capacities of local populations in response to environmental forcing. Heritable changes in gene expression or phenotype caused by

mechanisms other than changes in the underlying DNA sequence (i.e. epigenetic features) will be investigated to determine their role as adaptive strategies. We will focus on genes with high functional ecological relevance, including those encoding key components of regulatory pathways (secondary messenger systems, transcription factors), as well as ones with direct adaptive significance (e.g., secondary metabolism enzymes linked to allelopathy; ice binding proteins linked to adaptation to freezing temperatures; high affinity transporters and storage proteins linked to nutrient adaptation in phytoplankton, etc.). Functional genomic approaches will be applied to yield detailed insight into how environmental changes force adaptation over evolutionary time scales (past-present and for future scenarios). Comparative research with species/groups on different levels of complexity (protists – invertebrates – fish) will allow description of general patterns of eukaryotic evolution. This will include studies of gene family evolution and the role of lateral gene transfer in adaptation.

Adaptive and evolutionary processes will also be addressed by focusing on chemically mediated effects of natural bioactive substances and man-made toxicants, with respect to their potentially synergistic effects on interactions and ecology of marine species. Model organisms from coastal and shelf seas will be investigated for their response to natural chemical and anthropogenic pollution signals on the molecular (transcriptomic, metabolomic), cellular, organism, population and species level. Organismal and (sub-) cellular targets of the stressors will be defined in order to predict their ecophysiological impact. Furthermore, cross-cutting effects of different stressors will be investigated, e.g. species in contaminated areas can be more susceptible to other environmental stressors, such as warming and hypoxia.

We will investigate how high stress and consequent genomic and cellular damage must be balanced or compensated by acclimation and adaptive mechanisms. These strategies may include alteration of feeding behaviour, growth and/or changes in reproduction and life cycles over the short term, but with consequences for genetic variation and speciation over longer time scales. Functional and comparative genomic approaches will yield new discoveries of the adaptive processes, which establish recent community structure and species boundaries, while simultaneously allowing for identification and discrimination of future environmental forcing function for acclimation and adaptation.

Expected Results

- Models of chemically mediated interactions of planktonic species with respect to effects on bloom dynamics and succession over the short term (seasonal and annual cycles) and with consideration of population genetic and evolutionary consequences over longer time scales.
- Conceptual models of chemically mediated interactions between pelagic species, but also between benthic grazers and seaweeds and chemical-ecological modules for incorporation into physical-biological dynamic coupled models. Such models could be transferred into commercial application in order to predict interferences and intolerances in the coastal aquaculture and tourism industries.
- Macroecological description of the physiological response and life history adaptations of seaweeds and macro-invertebrates on global scales (Antarctic, Arctic, NE and SE Pacific and Atlantic) for identification of parameter specific (e.g. CO_2, temperature, hypoxia) effects on growth, physiology and gene expression profiles, and the identification of tipping points in future climate change scenarios.
- Estimates of contemporary gene flow among ecologically important, geo-referenced species groups, using selectively neutral markers and markers under natural selection.
- Identification of putative species with Antarctic and sub-Antarctic distribution that survived the latest glacial maxima using intraspecific molecular diversity estimates.

- Description of contamination indicator species for the Arctic, North Atlantic, and Baltic Sea. Detailed information about differences in species and life stage sensitivities as well as adaptive strategies towards contaminants for environmental modelling.
- Understanding of the roles of adaptive protein evolution at the sequence level versus gene family evolution (gene duplications, losses, polymorphism and functional specialization within gene families) for genes with direct adaptive significance (e.g., digestive and metabolic enzymes, enzymes linked to allelopathy, antifreeze proteins and high affinity transporters) as well as regulatory genes (second messenger systems, transcription factors).
- This opens up a broad range of commercial applications using marine natural compounds, enzymes, proteins and metabolic interactions as diagnostic tools or even – on the long term – for new drug development. Furthermore, new or refined "omic" methodologies arising from this research might be transferred into commercial biotech applications.

Milestones

- Annual summer expeditions to Arctic and Antarctic coastal research platforms between 2014 and 2016.
- Operational tools and technological approaches for determining gene expression patterns, genomic structure and production of natural toxins and allelochemicals in natural planktonic (phytoplankton and micro/meta-zooplankton) and benthic communities.
- Studies of relevant species groups (species complexes) that allow for predictions regarding niche width and adaptive capacities under climate change and take into account the genetic isolation/ connectivity between species and/or populations and their present capacity to respond to environmental stress. Provide species specific tools in support of ecosystem modelling.
- Establish species models and biomarkers for the integrated assessment of (anthropogenic) environmental impact caused by various stressors. New fast detection systems (e.g. gene probes) might be transferred from this research for commercial use in aquaculture and coastal tourism.

Workpackage 4: Biogeochemical provinces of sea floors in the German North Sea sector

Coordinators: Ralf Ebinghaus (HZG), Michael Schlüter (AWI)

Mission statement

To provide a comprehensive georeferenced inventory of biogeochemical seafloor properties in the German Bight of the North Sea as a basis to assess their pollution status and functions in material cycling.

Challenges

There is an ever increasing demand for services provided by sea floors bordering the industrialised countries around the North Sea, be it for exploitation of natural resources, or increasingly for open space that will be used for wind farming. We hypothesise that changed uses of sea floors have the potential to impact on the biogeochemistry of the coastal ocean, and that specific biogeochemical functions of sea floors will be affected. The active functions of the seafloor in geochemical context are benthic processes in shallow seas (including the activities of biota) that regulate the sequestration of carbon and nutrients, the retention or cycling of pollutants, and the recycling of materials back to the pelagic ecosystem. Available information

on these functions is surprisingly limited, but vital for assessing ecosystem services of sea floors. Besides being an active component of matter cycles, the status and functions of sea floors are also a criterion for assessing good environmental status (GES) of the North Sea as demanded by the Marine Strategy Framework Directive (MSFD). Data on pollution status scarce, the inventory of polluting compounds is not up to date and effects of new pollutants largely unknown, and their sources and transport pathways are poorly constrained.

Our aim is a rigorous assessment of functions and environmental status of the sea floor in the German EEZ prior to its large-scale conversion to wind farms. Towards this, WP4 proposes to develop a comprehensive georeferenced inventory of geochemical seafloor properties and fluxes across the sediment-water interface in the German Bight of the North Sea (biogeochemical property database: “MarGIS/CoastMAP”). We will use this to quantify the influence of human activity on seafloor integrity, and to develop a surrogate good environmental status from a biogeochemical perspective. Work in this package underpins a national research activity (“NOAH: North Sea, Observation and Assessment of Habitats”) towards creating a seafloor habitat atlas of the German EEZ in the North Sea. Our work package employs COSYNA technology and advanced instrumentation (benthic landers, autonomous samplers, integrating passive and active samplers), state-of-the-art analytical techniques, numerical process models, model-based long-term reconstructions of environmental conditions (e.g. coastDat), and spatial statistical techniques (GIS) to address the following questions:

- What are typical seafloor provinces in terms of sedimentological and geochemical facies, and what physical boundary conditions determine their spatial distribution and temporal variability?
- What are typical concentrations and which turnover rates (and ranges of rates under variable boundary conditions) characterise material cycling (oxygen, CO_2, nutrients, pollutants) between sediments and water column in representative areas of each province?
- Which factors govern the distribution of pollutants in sediment provinces, and how variable are pollution patterns?
- What are sources, dispersal patterns, and effects of emerging persistent organic pollutants (ePOPs)?
- What are the spatially integrated rates of material exchange across the sediment-water interface in the entire EEZ and what is their temporal variability? How will the sealing of large sea floor areas affect the biogeochemical exchange rates?
- Can we develop a surrogate good environmental status (GES) from biogeochemical flux and pollution perspectives?

Current Activities and Previous Work

Seafloor texture and sediment compositionin the German sector of the North Sea reflect a dynamic equilibrium state of material supply and selective transport or deposition. The seafloor of the German EEZ is dominated by sands of good sorting in fossil river valleys, coarse-grained and poorly-sorted sands and gravels marking relicts of glacial moraines, and localised areas where fines accumulate in low-energy environments at the seafloor. Based on statistical analysis of almost 50.000 grain-size data (mainly provided by BSH), some 6 distinct sea floor types emerge from grain size parameters. The existing geochemical database is considerably less detailed than that of sedimentological parameters, and cannot be realistically brought to the same quality. But many, if not all, of the biogeochemical processes in the sediment surface are strongly influenced by the fluxes of suspended particles into the sediment, by organic matter concentrations and accumulation in the sediment, as well as oxygen and nitrate concentrations at the sediment-water interface. Fluxes of organic and inorganic pollutants to the sediments

(imported from rivers or through the atmosphere) are strongly dependent on their chemical behaviour (partitioning between the dissolved and the particulate phase), and their concentrations in sediments usually correlate significantly with organic carbon. Additional processes (such as burrowing and irrigaton by biota, sediment texture and surface bedforms) affect the rates of nutrient cycling and dispersal, sequestration, or alteration of pollutants at the sea floor. Exchange across the sediment-water interface is significant for the entire shelf sea ecosystem: Nutrient regeneration is highly variable and related to the underlying sediment provinces, so that recycled nutrients can sustain between 5 and 50 % of the pelagic primary production.

Over the past years, we established the isotopic composition characteristic of riverborne and atmospheric nitrate, constrained the contribution of recycled reactive nitrogen from sediments, analysed the factors that determine denitrification rates of Wadden Sea sediments, and used a 3D ecosystem model with an isotope module to reconstruct the input required to match the isotopic composition of reactive N in dated sediment cores for pre-indistrial, early industrial, and modern time slices. This permitted an estimate of eutrophication through time.

Chemical pollution is of continuous concern for the coastal and marine environment. Substance patterns are under constant change due to legislation and/or modifications of productions pathways as well as changing or new consumer demands. We started to analyse concentrations, distribution patterns, and partitioning of ePOPs such as polyfluorinated compounds, as well as traditional and alternative flame retardants, in water, sediment, and biota of the German Bight. This work needs to be systematically continued and extended to selected new elements and element species besides the well known organotin and lead compounds, among them personal care products (linear or cyclic siloxanes and in particular element containing pharmaceuticals such as cytostatica like cisplatinum, Gadolinium based contrast agents etc.). Methods for integrative sampling techniques and specific methods for an ultrasensitive detection have been established and will be further optimized. With the impending erection of wind farms and necessary stabilisation, the nature of sea floors will change over significant areas (e.g. due to usage of geotextiles), and new chemicals are likely to emerge as threats to the ecosystem.

The combination of Geo-Information-Systems (GIS), research data including model results, and multivariate geostatistical techniques permits characterisation and identification of distinct provinces at the seafloor of marine and coastal zones has been initiated at AWI (MarGIS) and HZG (CoastMAP). They provide tool for integration of large environmental data sets, allow visualisation of multiple information layers, and support modelling of temporal and spatial patterns in coastal shelf sea regions.

Objectives

WP4 will identify and classify specific biogeochemical sediment provinces in the German Bight of the North Sea, analyse their specific material turnover rates and pollution patterns, and create a database of sedimentological and biogeochemical sea floor status. This will be done by: 1) analysing and processing existing sedimentological and biogeochemical data to derive statistically distinct sediment provinces. Within these provinces, we will identify homogeneous and representative areas for field work, where 2) new data on concentrations and turnover rates of nutrients, oxygen, and pollutants will be collected at seasonal resolution, and where temporal and spatial variability will be investigated during field campaigns in order to better constrain means and variability in chemical properties. 3) Employing numerical models and statistical techniques, the observed properties (diagenetic flux rates, bed forms, pollutants concentrations) will be extrapolated to similar sediment provinces to map seafloor properties for the entire EEZ of the North Sea. Field campaigns and laboratory measurements numerical models and

statistical techniques will be employed to assess the variability of observed province properties (e.g diagenetic flux rates, bed forms, pollutant concentrations) in space and time. Properties of statistically distinct sedimentological and biogeochemical provinces will then be extrapolated to similar habitats under similar environmental conditions to provide a comprehensive georeferenced inventory of geochemical seafloor properties in the German Bight of the North Sea ("MarGIS/CoastMAP"). We formulate the following specific objectives:

- Identify seafloor provinces based on multivariate statistics of existing sedimentological and geochemical data emended with data on physical character at the sediment-water interface (from coastDat; WP1).
- Measure benthic sediment-water oxygen and nutrient fluxes (using in-situ measurements, landers, benthic chambers) in appropriate spatial and temporal resolution to establish means and variability in representative areas in major sediment provinces; upscale to total area by statistical models.
- Assess and evaluate patterns and levels of existing seafloor pollution; analyse pollutant origin, dispersal, and fate; adapt, validate and use numerical models for scenaric modelling of pollution risks. Explore active sampling techniques to assess the bioavailability and body burden of contaminants in biota as well as their biological effects. This contributes to the "Water" Cross Programme Activity.
- Prepare and publish (webGIS; with Topic 4 and external partners) a detailed inventory of habitat character (gridded data set; MarGIS/CoastMap), including sedimentolological character, pollution loads, fluxes across boundaries of environmental compartments in the atmosphere, water, sediment and biota of the German Bight.
- Integrate substance- and effect-related data to evaluate pollution loads; describe and indicate good environmental status to improve the basis for cyclic assessments in the framework of the MSFD process.

Expected Results, Milestones

The result will be an inventory of biogeochemical sea floor provinces and functions in the German EEZ in physical, sedimentological, and chemical terms. The biogeochemical habitat atlas is the central deliverable of our WP and supplements work done with partner institutions for a comprehensive atlas of seafloor habitats that includes biological functions. The observational programme will establish mean states and associated variability (in space and at seasonal resolution) of intrinsic exchange rates across the sediment-water interface and pollution. Modelling will take a pragmatic approach in that existing long-term simulations of environmental conditions (link to WP1) will be employed as predictors for sedimentological and chemical character, establishing statistical relationships between model outputs and observations that include detailed observations at the sediment-water interface in WP5. This will provide full coverage maps of simulated seabed character and an assessment of system variability, thus advancing ecosystem simulations conducted in WP2. Process oriented early diagenesis modelling linked to such maps will allow for sensitivity analyses with regard to anthropogenic forcing (trawling, eutrophication; link to WP2). Our approach will provide detailed data sets on the interaction of sea floors with the water column to be published together with Topic 4.

Expected Results

- Sedimentological and biogeochemical property maps and mass budgets, database on characteristic compositional and cycling aspects of different sediment types. Beside academic use potential commercial application for offshore planning activities.
- Spatially resolved database of organic carbon, nutrient and oxygen fluxes across the sediment-water interface.

- Spatially resolved database of modelled net inputs of nutrients and pollutants from the atmosphere into the North Sea caused by anthropogenic activities, such as shipping and gas oil extraction for today and future scenarios.
- Comprehensive overview of the occurrence, the input and distribution pathways, the fate and possible effects of (emerging) contaminants in the German Bight.
- Identified gaps in current monitoring approaches combined with suggestions for novel monitoring approaches and effect related pollution assessment (MSFD).
- Model system capable of scenaric evaluation of reactions at the sediment-water interface from multi-annual to decadal natural variability, effects of secular trends in sea level and climate, and events (such as accidents) on the shelf sea ecosystem of the North Sea.
- Data and GIS compilations exhibit great values for coastal authorities, and companies active in offshore construction, mining, tourism, fishery and aquaculture, respectively. Services, web tools and consulting could transfer geochemical knowledge to these stakeholders to cope with corrosion, pollution and interferences between sediment, water and technical offshore systems.
- New underwater sensors, samplers and analytical techniques may arise from this WP suitable for commercialization.

Milestones

- Inventory of sedimentological and biogeochemical properties data in gridded data sets created and updated.
- Ship expeditions (2/a) for field investigations of fluxes in representative sediment provinces.
- Spatially explicit database of nutrient and pollutant fluxes across the sediment-water and the atmosphere-water interfaces created, considering anthropogenic activities such as the erection of wind farms and increasing ship traffic.
- Comprehensive overview of the occurrence, the input and distribution pathways, the fate and possible effects of (emerging) contaminants in the German Bight; assessment of environmental status with respect to pollution.
- MarGIS/CoastMAP as the biogeochemical, process oriented, spatially explicit supplement to CoastDat and CoastLab (COSYNA) for the joint evaluation of temporal and spatial dynamics in the German EEZ published as open access database.
- Model system compiled capable of scenaric evaluation of reactions at the sediment-water interface from multi-annual to decadal natural variability, effects of secular trends in sea level, climate, and changing sea floor uses on the shelf sea ecosystem of the North Sea and used to quantify biogeochemical consequences of sea floor sealing.

Workpackage 5: Interface processes and physical dynamics of the coastal ocean

Coordinator: Burkard Baschek (HZG)

Mission statement

Understand the small-scale dynamics of the coastal ocean in connection with fronts, turbulence, and interface processes under present and changing environmental conditions.

Challenges

Many physical and biogeochemical properties of the coastal ocean suggest an essential role of small-scale physics in the dynamics of the coastal ocean and its marine ecosystems. Examples are fronts, micro turbulence, or wave-sediment interaction as contributors to local energy

cascades or mixing processes. The interaction of physical forcing with biogeochemical or biological processes governs a large range of exchange processes through the air-sea interface, fronts, or the pycnocline and play an important role for particle dynamics (including biological particles) or sediment transport. Many of these features and processes occur on submesoscales of 10 m to 10 km with a typical lifetime of minutes to a few hours. Due to their role in local energy cascades and their implications for primary production, submesoscale features have been a recent focus of theoretical and numerical studies. New observational techniques simultaneously resolves the required small spatial and temporal scales and led only recently to the first detailed in situ measurements of these small-scales physical processes and their biogeochemical signature.

Especially in the coastal ocean, the small-scale physical dynamics are significantly influenced by interfaces formed by sharp fronts, the sea surface, pycnocline, or the sea floor. These interfaces are responsible for the exchange of momentum, heat, or cycling matter and therefore have a strong impact on the dynamics of shelf sea ecosystems. The internal exchange processes are governed by local turbulence and mixing processes with implications for biological production and the dynamics of dissolved matter.

WP5 addresses in particular the physical dynamics and interface processes in the coastal ocean on spatial scales of less than 10 km and we propose to explore – with other work packages – the interaction between physical, biogeochemical, and biological processes under present and changing environmental conditions. In this respect, the key challenges to be addressed are:

- Carry out first detailed observations of small-scale physical processes and associated biogeochemical parameters with very high spatial and temporal resolution; develop observational techniques and instrumentation for process studies and coastal observatories (COSYNA – Topic 4 WP1).
- Understand the importance of submesoscale physical forcing and its interaction with biogeochemical and biological signals (with WP3 and WP4); develop a realistic theoretical framework for submesoscale physical dynamics and their role in local energy cascades.
- Understand and quantify exchange and mixing processes across the most important interfaces (e.g. for momentum, heat, salt, cycling matter, or gases; with WP4).
- Identify the key processes in the coastal ocean that are most affected by changing environmental conditions; determine the effect of windparks on coastal ocean dynamics (with WP2 and WP4).

Current Activities and Previous Work

Scientific work on small-scale dynamics of the coastal ocean will be a new activity in PACES II. It will be in particular supported by the recent development of a high resolution observational technique that combines satellite, aerial, and in-situ observations and is ideally suited for the observation of small-scale physical processes in the coastal ocean and some of its biogeochemical signatures. The observational approach and a towed instrument array for fast in situ measurements has led to the first in situ measurements of submesoscale spiral eddies and fronts in the coastal ocean in 2009 and 2011. Measurements in an area of 100 km^2 are repeated every 15min with a spatial resolution of 1m to 25m. Aerial guidance is essential to guide rapid in situ measurements of the upper 45 m of the water column and for the spatial interpretation of the observations. An collaborative effort has delivered first observational evidence confirming the strong connection of physical with biogeochemical processes showing the need to develop and apply observational techniques for interdisciplinary investigations of

submesoscale processes that drive the development of (harmful) algal blooms (with WP3), or the exchange of matter with the sea floor (with WP4).

At the Helmholtz Centre Geesthacht, a variety of techniques and instruments have been developed that will ideally complement these high-resolution measurements and promise to greatly expand the current observational capacity in this field. In particular, a Radar Doppler Current Profiler (RDCP) is ideally suited for surface current measurements with a resolution of less than 20 m within a radius of up to 3 km (with extended range when mounted on a vessel). Acoustic Doppler Current Profilers allow for additional subsurface current measurements. Radar measurements of surface roughness are expected to deliver fine-scale measurements of surfactants (frontal location) and wind. Turbulence and optical measurements on gliders and other platforms will allow us to quantify mixing processes in the associated strong vertical and horizontal gradients. The fine-scale hydrographic structure and optical properties are observed with scanfish tows. Sensors, such as for online pH measurements, or the use of the Ferry Box system or gliders provide the means for determining biogeochemical processes in the water column and at fronts. The in situ measurements will be complemented by infrared and ocean color satellite imagery of sea surface temperature, chlorophyll, and suspended matter.

The coastal observation system COSYNA (Topic 4 WP1), that has been developed under leadership of HZG, provides an extensive observational infrastructure that will be of central importance for the successful observational program of WP5; these observational capabilities will be extended through participation in ACROSS. Operational models and hydrographic measurements will be used to determine background conditions in the German Bight and will help to identify key processes. In return, instrumentation and observational methods tested and developed in WP5 will help to improve pre-operational routine observations of COSYNA/ACROSS and will be essential for an improvement of high-resolution modelling approaches and parameterizations. A better understanding of the relevant and often intermittent physical, biogeochemical and biological processes on different scales will contribute to the improvement of the real-time forecasting of coastal ocean conditions. COSYNA/ACROSS will also provide a platform (associated with portfolio theme “Earth System Knowledge Platform”/ESKP and Cross Programme Activity “Natural Disaster and Warning Systems”) that will be used to communicate the impact of processes that are associated with commercial, health, or environmental risks, such as rogue waves, harmful algal blooms (with WP3) or the impact of wind farms (with WP2 and WP4).

Objectives

WP5 focuses on small-scale physical processes that have significant impact on coastal ocean dynamics, especially if they are directly related to key biogeochemical or biological processes. In particular, we propose to study the exchange and mixing processes across interfaces and the impact of changing environmental conditions and man-made structures on coastal ocean dynamics.

- Submesoscale dynamics: Observe and understand submesoscale physical dynamics in the coastal ocean on scales of 10 m to 10 km. Determine the role of submesoscale processes for the local energy cascade from large-scale motion to turbulence and their influence on coastal and global ocean dynamics. Develop submesoscale theory. (Linked to objectives 2, 3, 4 and COSYNA).
- Phytoplankton dynamics: Determine the role of small-scale physics and interface exchange processes for biogeochemical processes and phytoplankton dynamics under current and changing environmental conditions. Develop observational techniques for cycling matter and the detection of algal blooms; understand the role of physical forcing. (Linked to objectives 1, 3, 5 and WP3, Cross Topic Lena Delta).

- Exchange and mixing across interfaces: Quantify and improve the understanding of the exchange processes of momentum, heat, matter, and gases between atmosphere and ocean as well as the sea floor and water column (linked to WP4). Improve parameterizations of air-sea gas exchange and develop observational techniques for routine observations in observatories (linked to COSYNA). Observe and quantify exchange processes across fronts and thermocline; determine the role of local micro-turbulence.
- Waves, currents, and sediment transport: Understand wave physics and turbulence in shallow water and its role for energy dissipation, sediment erosion and transport, and exchange processes with the sediment. Determine pathways for suspended matter in the coastal ocean and its connection to biogeochemical processes (linked to WP4). Understand the estuarine exchange processes of momentum, heat, salt and suspended matter in shallow coastal areas; study the influence of changing environmental conditions. (Linked to objectives 2, 3, 5; linked to COSYNA).
- Risks and changing environmental conditions: Determine the influence of windparks on waves, mixing, and local coastal dynamics (linked to WP2, WP4). Determine the statistics and physics of rogue wave occurrence in the coastal ocean. Understand the physical and biogeochemical factors leading to a formation of harmful algal blooms (linked to WP3). Provide knowledge of commercial, environmental, and health risks on a publically accessible platform (Linked to objectives 2, 4, ESKP).

While these objectives address some of the most important problems in coastal oceanography, they are regionally relevant to the local coastal waters of North and Baltic Sea and can be applied to a variety of other coastal environments in the world. Several of the underlying processes are crucial for coastal and global modelling efforts and have global significance (objectives 1, 2, 3).

Expected Results and Milestones

Adequate observational techniques only became recently available for processes with small spatial and temporal scales that largely determine the dynamics of the coastal ocean. The latest development of new sensors (e.g. nutrients, pH) has opened new opportunities to investigate the entire range of relevant processes. High-resolution remote and in situ measurements of submesoscale eddies and fronts with infrared camera and hyperspectral sensors flown from a small airplane, high-resolution satellite ocean colour imagery, the further development of a Towed Instrument Array equipped with T/S-and optical sensors, gliders, as well as high-resolution current measurements with a RDCP (Radar Doppler Current Profiler). Additional turbulence measurements will be used for exchange and mixing processes across internal interfaces. Air-sea gas exchange measurements will be carried out with dissolved gas and pH sensors, atmospheric measurements of CO_2 concentration and wind speed, bubble and ambient sound measurements, optical and radar measurements of wave breaking and white cap coverage. Algal blooms will be detected with hyperspectral satellite and aerial measurements supported by in situ measurements from a vessel or fixed platform. Physical parameters will be determined with tools similar to the submesoscale studies, in addition to nutrient, dissolved gas and pH sensors.

Results

- First high-resolution observations of submesoscale physical and biogeochemical processes.
- Estimates of phytoplankton production due to submesoscale processes.
- More physical and accurate description of air-sea gas exchange. Better quantification of exchange processes across interfaces for momentum, heat, salt, or suspended matter.

- Quantification of wave energy dissipation in shallow water under different wave and current conditions. Quantification of estuarine exchange processes in the Wadden Sea.
- Determination of conditions favourable for algal blooms. Routine provision of maps showing algal blooms (as part of COSYNA; link to Topic 4). Potential further development into commercial application.
- Quantification of the effect of wind farms on mixing, local physical dynamics, nutrient pathways, and phytoplankton response.
- Establishment of a public internet platform to present a risk assessment of rogue wave occurrence or the occurrence of algal blooms.
- Innovation transfer from newly developed instruments and measuring techniques and software (e.g. COSYNA modules, RDCP techniques, Ferry Box modules) into commercial application.
- Consulting services for offshore development companies in the determination of current-related load cases, sediment transport, erosion and scouring underneath or nearby offshore constructions, important for the technical layout of offshore and harbour buildings.

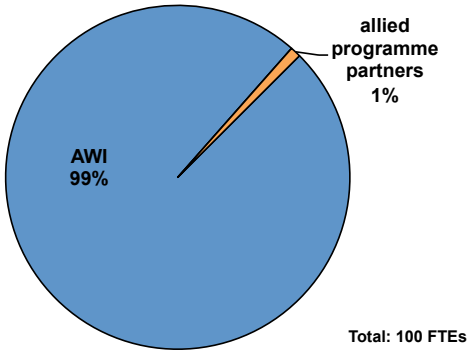
Milestones

- Observational infrastructure and techniques for small-scale physical processes created and tested, including towed instrument array/scanfish, aerial infrared and hyperspectral measurements, radar Doppler current profiler, and turbulence measurements.
- Use of a research zeppelin for aerial studies explored that will allow for continuous remote observations in the coastal ocean over several hours.
- Instrumentation and methods transferred and integrated in COSYNA/ACROSS for long-term measurements of relevant small-scale physical processes.
- Hyperspectral aerial and satellite observations developed to better distinguish algal blooms and suspended matter.
- Theory of sub-mesoscale processes developed.

Topic 3: The earth system from a polar perspective: Data, modelling and synthesis

Coordinators: G. Lohmann (AWI), D. Wolf-Gladrow (AWI)

Challenges



A robust finding from reconstructions of past climate and projections of future climate change is that the high-latitudes are most sensitive to climate forcing within the Earth system. The detection and understanding of trends, the mechanisms for polar amplification, and their role in modulating global climate are central themes in this topic. Enhanced knowledge of processes of past and present climate change is crucial to separate between natural and anthropogenic forcing, to explore the predictability of the polar climate system and to enhance the reliability of future climate projections. Our approach is to generate palaeo-climate data and scenarios obtained from a combination of ice, marine, lake, and permafrost archives in tandem with Earth system modelling and analysis, thus enabling an improved understanding of atmosphere-ocean-land-ice processes at regional and global scales. This relies on a sound expertise in the acquisition and interpretation of data and modelling.

Our research will be guided by the following key questions:

- What are the spatio-temporal patterns, physical and biological drivers and feedback mechanisms of climate variability on decadal to orbital time scales?
- Is it possible to quantify trends at high latitudes on different timescales and are these trends distinguishable from natural climate variability during the Holocene?
- What is the impact of geodynamic-tectonic processes on environmental conditions and glacial evolution in the polar regions during the Cenozoic era?
- How predictable is the climate of the polar regions on seasonal to decadal time scales?
- Is it possible to reduce the uncertainty of climate change scenarios in middle and high latitudes?

Unravelling climate variability at high latitudes requires technical advances in data acquisition, conceptual understanding and numerical modelling. Coupled general circulation models have been utilised to evaluate the magnitude of future climate change. Validation of these models by simulating different climate states is essential for understanding the sensitivity of the climate system to external forcing. The models are clearly unrivalled in their ability to simulate a broad range of large-scale phenomena on seasonal to decadal time scales; their reliability on multi-decadal and longer time scales, however, requires additional evaluation. Climate records derived from palaeo-environmental proxy-parameters allow testing of these models because they provide records of climate variations that have happened in the past. Another critical issue of Earth system models is the representation of key polar processes associated for example with ice sheets, clouds, permafrost, regional ocean dynamics. Besides the physical changes of the climate system, the world ocean also exerts a more indirect control on climate by participating in global biogeochemical cycles that are relevant to the climate system.

Current Activities and Previous Work

Research on the Earth system from a polar perspective has been embedded in our previous programme “Polar Regions and Coasts in a changing Earth System” (PACES) covering the

topics “Lessons from the Past” (Topic 3) with a focus on palaeo-climate proxy data and “The Earth system from a polar perspective” (Topic 4) focussing on global modelling. In new programme these two approaches will be dealt with in a joint topic. In this way it will be possible to foster the collaboration between the research groups, to develop new research themes and to strengthen the synthesis of data and models. Earth system models will be extensively used in Topic 3 to study the dynamics of past climates, as a “surrogate laboratory” for numerical experimentation with the climate system to explore mechanisms of climate variability and change. Finally, it is expected that model improvements will be beneficial for all global model applications including projections of regional climate change for the 21st century.

As an example for the efforts to combine the evidence from palaeo-climate records with modelling we have singled out the workpackage overarching theme described in the box below.

Polar Glacial/Interglacial climate variability – data network and transient modelling

Climate conditions and their variability during cold and warm states and glacial-interglacial transitions are shaped by biogeochemical and ocean-atmosphere-ice related physical mechanisms, internal feedbacks, and their relationship to external forcing. However, the true impact of the different factors, their interaction, and propagation mechanisms in space and time are yet not well known and quantified. Considering that some of most important climate relevant mechanisms are hosted in polar regions, we want to establish climate scenarios based on a yet unique network of the largest possible number of proxy records from land, ocean, and ice archives and combine the proxy reconstructions with transient modelling. The most promising period is the last glacial-Holocene time interval (past 30.000 – 40.000 yrs), which is most completely documented best datable, and highly resolved in marine, lake, permafrost, and ice archives (collaboration with GEOMAR on low-latitude proxy data). Additionally, high-resolution studies of Holocene climate variability offer the possibility to extend the short instrumental records back in time in order to better understand climate dynamics on time-scales relevant for human societies. The approach will also consider innovative proxies for improved reconstruction of past sea ice, hydrological and biogeochemical cycles, as well as water mass structure. The validation/testing of proxy data interpretations and transient numerical palaeo-climate simulations via multiple iteration steps will result in a significantly better understanding of the role, contribution, and interaction of polar processes affecting global climate development and sea level change. This will be supported by improved gas chronologies in ice cores that reduce present uncertainties in the relative timing of greenhouse gas and atmospheric temperature/dust deposition changes. The expected outcome of this large effort is crucial for the understanding of major shifts which have occurred in the past, testing the models under different conditions as today to examine the possible solutions in phase space, and thus presents a baseline for improving forecasts for the coming centuries, a goal also central to IPCC.

Current advances in the documentation of past environmental changes are related to an extensive geoscientific data acquisition, accomplished with POLARSTERN and other research vessels in the polar to subpolar North and South Pacific as well as in the Arctic Ocean. This also provided the necessary baseline for the current development of new IODP-drill proposals for the Arctic and Southern Ocean. Together with geological sampling in the periglacial regions, the marine geological and geophysical sampling represents a crucial step towards the development of a circum-polar array of palaeo-climate records. Glaciological field activities include the participation in international ice core drilling projects. A particular focus is related to timeseries analysis and proxy models. Detailed analyses of the recorder systems provide new interpretations of marine and ice core data. The influence of processes in polar regions on

atmospheric teleconnection patterns have been studied for recent and past climate. Work has concentrated on determining the underlying dynamics, possible changes as a consequence of anthropogenic or orbital forcing and their role in linking polar and non-polar regions.

In the previous programme, we followed a global modelling strategy, which entailed the use of an established Earth system model and to adapt or improve model components for our questions. The Earth system model was developed in an international consortium, mainly at the Max-Planck-Institute for Meteorology, Hamburg (Germany). Our main developments included the integration of an interactive ice sheet model, the development of the finite element sea ice-ocean model as well as isotope modules. It is planed to continue this research strategy in collaboration with national and international partners. These recent model developments are necessary for applications studying past, present, and future climates. Ice sheets are one of the key polar components on long time scales to simulate past climates including the sea level. Interactive isotope modules were developed to allow for a more direct way for data-model comparisons and hypotheses testing with geological records. The finite element sea ice-ocean model system with unstructured grids resolves important phenomena in dynamically active polar and coastal regions and allows studying their implications for the global climate system.

We are strongly involved in national (BMBF-Miklip, DFG-Interdynamic, DFG-Antarctic, Marum) and international projects (IODP, past4future, ice2sea, IGBP-PAGES, WMO Global Integrated Polar Prediction System), as well as in graduate schools with co-supervision of PhD work. One of our strengths is the in-house expertise and infrastructure for research in polar and marine environments which offer on the one hand the possibility to obtain new ice core and sediment core and geophysical data, and on the other hand profound expertise in numerical modelling, understanding of processes (e.g., development of parameterizations) as well as data assimilation schemes.

Objectives

We will focus our investigations in three interdisciplinary work packages (WPs), which are mainly separated by the time scales under consideration:

WP1: “Circumpolar climate variability and global teleconnections at seasonal to orbital time scales”

Profound environmental changes occur when the Earth’s climate shifts between glacial and interglacial states. The generation of scenarios of polar climate and its development during the Quaternary in combination with numerical modelling is a major prerequisite for enhancing our knowledge on climate. For this goal a unique multiproxy approach, which merges a well synchronised network of pan-polar climate records from land, ocean and ice to document climate evolution at the highest possible temporal resolution during the past glacial, the glacial/interglacial transition and the Holocene is required. Such proxy records have to be combined with transient Earth system modelling for the same time intervals. Additionally, high-resolution studies of the Holocene offer the possibility to further extend instrumental records back in time in order to evaluate natural climate variability. Another major objective concerns the assessment of the impact of polar regions to invoke and shape past warmer and higher sea level conditions than present. Such work is closely related with the detailed study of climate-relevant factors typical for high-latitude regions, such as the variability of sea ice, the physical and biological impact of polar oceans on global biogeochemical cycles and atmospheric CO_2 variability, but also on the stability and extent of polar continental ice sheets and the permafrost.

WP2: “Earth system on tectonic time scales: From greenhouse to icehouse world”

The Cenozoic era shows a long term cooling accompanied by abrupt shifts and major reorganizations in the Earth system. The temperature evolution at these key stages towards our

modern ice sheet configuration will be examined by climatic responses to changes in ocean gateways, and other forcing factors such as CO_2. Further refined and novel models for crustal and upper mantle structure and accretion processes at the polar and sub-polar continental margins, spreading ridges and magmatic provinces will be created. The upper crustal and seafloor dynamics approach includes the reconstruction of continental breakup and drift phases, regional palaeo-circulation processes. An improved understanding of continent-to-shelf, shelf-to-slope and slope-to-rise sediment transport, erosion and deposition regimes will be related to palaeo-climatic effects and processes for both the Arctic and the Southern Ocean. Reconstructed past seafloor dynamics and topography will be combined with palaeo-oceanography and palaeo-climate modelling.

WP3: “From process understanding to enabling climate prediction”

Polar regions are also of particular interest because of concerns about amplification of anthropogenic climate change and associated ramifications for the global climate system including extreme events. Furthermore, increased economic and transportation activities in polar regions (particularly in the Arctic) are leading to more demands for accurate polar predictions on synoptic to decadal time scales to support decision-making. It is therefore timely to explore mechanisms, predictability and mid-latitude influences of polar climate variability and change. This work package mainly concentrates on the understanding of polar key-processes such as interactions in the atmosphere-ocean-sea ice-land system and their effects on global climate. Numerical experimentation with climate models will explore polar climate predictability and help shedding light on the physical mechanism behind anthropogenically forced polar climate change.

Expected Results, Milestones

An integrated approach including measurements, palaeo-climate proxy data, and climate modelling will be employed to better understand natural and forced climate variations over a wide range of timescales. Expeditions with POLARSTERN and other ships to the Arctic Ocean and Southern Ocean are prerequisites to obtain necessary geophysical data and geological cores for the palaeo-environmental and palaeo-climatic reconstructions. Such data will be used to support existing and planned proposals for deep (IODP) and shallow drilling (e.g. MeBo) into sediments suitable for palaeo-environmental proxy analysis and provenance studies. Airborne geophysical surveys with Polar 5 and Polar 6 and the usage of equipment from the DEPAS Instrument Pool will provide data for geodynamic studies on the evolution of the ocean basins and polar continental margins. The calibration and further development of proxies will enhance the reconstruction of environmental parameters such as sea ice, hydrological cycle, biological productivity, water mass structure and the carbonate system. These efforts are strongly enhanced by the new femtolaser and opal isotope facilities. New capacities for radiometric dating (^{14}C) will meet the strong demand for appropriate age determination. Earth system models will be further developed and applied to build and test hypotheses and to substantiate the interpretations of the data.

Optimization of Earth system models for present and future super computing architectures will remain high on the agenda to ensure that models can be run at the highest possible resolution and that computing resources are used effectively. Especially the forthcoming new many-core supercomputer architectures with GPU-based accelerator boards make considerable optimization and adaptation work in the field of scientific computing necessary. This includes research on efficient parallel numerical solvers suitable for architectures with more than 10.000 cores per model component, which will be usable in future HPC-Systems. It is also planned to further develop simpler and more efficient as well as more accurate software for coupling

various components of the Earth system. Efficient algorithms are necessary for both low-resolution, long-term as well as high-resolution, short-term applications.

We expect major results from a range of data-based analysis and model simulations especially in the following themes:

- Warm climates: To investigate examples of climate change similar in magnitude to that projected by numerical models for the next century (WP3), we shall look back into past climate (past interglacials, Pliocene and beyond) when global average temperatures were significantly warmer than today (WPs 1-2). Comparing past interglacials, we will be able to examine the climate sensitivity. Of particular importance is the simulation of polar ocean gateway developments, increasing latitudinal thermal gradients at the onset of major ice sheet expansion, and related sea level decrease. Considering that some of the most important climate relevant mechanisms are hosted in polar regions the topic will contribute a key knowledge base for future IPCC assessments.
- Natural climate variability: We will document past polar variability by proxy data to estimate the range of natural climate variability. New proxy data, the compilation of already existing data, and model simulations will provide insights into forcing and feedback mechanisms of climate change. We combine climate archives (marine, ice, land) with Earth system modelling, instrumental and reanalysis data, and statistical data analysis to examine modes of variability for a variety of time scales (WP1 and WP3). Specifically, simulation of geological parameters and statistical models of the recorder systems yield a direct way to compare data with models and opens possibilities for data interpretation and estimates of uncertainty (WP1). Global biogeochemical cycles and sea level variations are particular important for the understanding of long-term trends, millennial climate variability as well as abrupt climate transitions (WPs 1-3).
- Global teleconnections and polar predictability: We evaluate the role of the polar regions in the global climate system on different timescales using high-resolution data and modelling (WPs 1,3). We will improve the representation of polar key processes in Earth system models (in collaboration with Topic 1) and test the models for past, present and future scenarios (WPs 1-3). We will shed light, for example, on the role of Arctic sea ice decline for European weather and climate including extreme events. Furthermore, research will reveal the predictability of the polar climate system on time scales from days to decades (WP3). Data analyses and Earth system modelling will provide process understanding, and insight into forcing and feedback mechanisms for Arctic and Antarctic climate and their global teleconnections (WPs 1-3; collaboration with GEOMAR for the low latitudes).

Workpackage 1: Circumpolar climate variability and global teleconnections at seasonal to orbital time scales

Coordinators: R. Gersonde (AWI), F. Lamy (AWI), P. Köhler (AWI)

Mission statement

We investigate the role of polar regions in past climates by generating a circumpolar synthesis of Quaternary multi-proxy records from land, ocean and ice combined with Earth system modelling.

Challenges

Overarching goal of this WP is to unravel the timing and spatial distribution of Quaternary climate shifts and changing variability in high latitudes and to understand the interaction of

associated processes, global feedbacks and internal and external forcing mechanisms operating at orbital to seasonal time scales. The major challenges of our work include:

- The generation and synthesis of polar sediment and ice proxy records combined with transient models in order to provide a circumpolar Arctic and Antarctic view of atmosphere-ocean-ice climate processes and their link to biogeochemistry and sea level.
- The enhancement of our understanding of the causes and the stability of warmer/higher sea level than present Quaternary time intervals.
- The improvement and further development of proxies describing parameters typical of high-latitude regions, e.g. continental ice, sea ice, water mass generation, biological productivity, hydrological cycle, permafrost degradation.

Current Activities and Previous Work

Extensive marine-geological sampling and acoustic surveying was accomplished in the polar/subpolar North and South Pacific, the North Atlantic and the Arctic Ocean. This also provided the baseline for new IODP-drill proposals for the Arctic and Southern Ocean. Glaciological field activities include the participation in the drilling of the NEEM ice core (Northern Greenland) and the drilling of shallow firn/ice cores in a transect in East Antarctica connecting Kohnen Station, Dome F and Dome A (COFI, COldest Firn). Together with sampling in the permafrost-affected land regions (Northern Hemisphere) and in the fjord region of southern Chile, the marine and ice core sampling represent a crucial step towards the development of a pan-polar array of palaeo-climate records.

Significant progress was made in the establishment and calibration of proxies. The development of the first routine method to measure paired oxygen and silicon isotope on different siliceous microfossil groups allows to better assess changes in surface salinity, nutrient supply and utilization, and water mass structure in combination with other proxies. A novel biomarker approach based on the combination of sea-ice diatom-specific highly-branched isoprenoids and phytoplankton biomarkers enhances quantitative Arctic sea ice reconstructions. New laboratory facilities now allow for geochemical measurements on extremely small samples (e.g. boron isotopes in carbonate) and allow simultaneous measurement of all elements of the periodic system between Li and U opening the gate to look for completely new proxy relationships.

For climate modelling a state-of-the-art comprehensive general circulation model (developed within the framework of a community Earth System Model) was adapted for different climate conditions. It enables an explicit modelling of proxies, e.g. stable oxygen isotopes, thus allows a critical validation of the model simulations with geological records. The model was used to evaluate glacial and interglacial circulation, water mass structures, and atmospheric circulation variability. For glacial climates a strong dependence of the initial water mass stratification for the transient dynamics of the termination was found, indicating the non-stationary nature of climate dynamics. Holocene studies focused on model/data comparisons on SST trends and synoptic-scale atmospheric variability patterns.

Networks of multi-proxy-based climate records are currently established to document and model specific climate conditions, e.g. for the Holocene, the Last Glacial Maximum (LGM), Last Interglacial Optimum, based on marine, land and ice climate archives, at polar and even global scale. These records combined with modelling approaches provide e.g. new insights into high latitude physical and biological mechanisms critical for natural CO_2 variability. In this context, the first glacial-interglacial records of atmospheric circulation, dust input, SST, sea-ice, ocean stratification, water mass formation, and biological nutrient utilization in the South Pacific suggest complex contrasts to other Southern Ocean sectors. Accompanying studies in Patagonia focus on reconstructions of the Southern Westerlies during the present Holocene

warm period. On longer time-scales, Miocene to Pleistocene records from the Ross Sea (ANDRILL project) document significant WAIS oscillations with partly or total WAIS collapses during "warmer-than-present" climate periods. In the Arctic, new marine records constrain the Quaternary ice sheet history and related variations of palaeo-environments. High-resolution palaeo-climate studies with focus on the detection and mechansims of climate tele-connections are currently also being performed in the subpolar North Pacific and on the circum-Arctic continents. Terrestrial archives reveal millennial to decadal-scale variability that is primarily linked to atmospheric tele-connections to the North Atlantic realm. Laminated sediment sequences in the Bering Sea permit reconstruction at up to seasonal resolution for reconstructing atmosphere-ocean changes in the North Pacific realm. Studies on Siberian permafrost deposits formed during glacial periods suggest these are significant carbon sources that release climate-relevant gases during the modern warming.

Objectives

Following the strategic approach to combine data obtained ice, marine, lake and permafrost climate archives with Earth system modelling of ice-atmosphere-ocean processes this WP will address the following objectives:

- Resolve the mechanisms of glacial-interglacial climate variability based on combined reconstruction and transient simulations of the last glacial - Holocene climate evolution at highest possible resolution (seasonal – 100 yr) (see also Box).
- Assess the impact of polar regions to invoke and shape warmer climate/higher sea level conditions than present.
- Short periods in the Quaternary, e.g. Marine Isotope Stages (MIS) 5.5, 9.3, 11.3, are marked by warmer climate and higher sea level than present and by maximum natural greenhouse gas concentrations. Because climate-relevant processes in polar latitudes are particularly sensitive to global warming events it is mandatory to study their potential to invoke and shape warm climate conditions and related sea level change.
- Determine Quaternary sea ice variability.
- Sea-ice is a fast changing parameter that has a large impact on regional and global climate variability. The accurate documentation of the extent and seasonality of this sensible part of the climate system is a most crucial prerequisite for the understanding of polar climate processes and their effect on climate conditions (e.g. abrupt changes).
- Decipher the polar oceans role in global biogeochemical cycles and atmospheric CO_2 variability during the Quaternary.
- Physical and biological processes in polar oceans play a key role for explaining past variability in atmospheric CO_2 concentrations. Atmosphere-ocean interactions largely control upper ocean stratification, deposition of dust and the dust-born micronutrient iron, biological nutrient utilization, and exposure rates of deep-water, and thereby affect the uptake and release of CO_2 in the Southern Ocean.
- Improve the knowledge on Quaternary continental ice and permafrost extent and its relation with the hydrological cycle, deep-water formation and sea-level.
- Detailed knowledge on the extent history and stability of ice sheets and permafrost is crucial for the understanding of past and potential future change of sea level, greenhouse-gas concentration and ocean circulation. This calls for further combined land-based and marine studies in the yet not well-explored polar areas. Knowledge on the hydrological cycle from land, ice and marine records as well as palaeo-ceanographic information from the drainage areas of the ice sheets will support the reconstruction of ice sheet history and provide insight in its stability and impact on global ocean circulation.

Expected Results, Milestones

Milestones to tackle the addressed scientific objectives are:

- Acquisition of new materials. (i) marine: Scotia Sea, Pacific and Indian Southern Ocean, Bering Sea, Arctic Ocean, Nordic Seas; high-resolution records (e.g. POLARSTERN I and II, R/V Sonne, IODP); (ii) ice: shallow firn/ice cores from East Antarctica (COFI) and an very high resolution 800 m ice core from Halfvarryggen, Dronning Maud Land, Antarctica; (iii) land: Patagonia, transect across NE Siberia, Beringia and Alaska/Canada.
- Calibration and further development of proxies: (i) new biomarker proxies for sea-ice (Arctic, Antarctic) and precipitation (hydrological cycle); (ii) biogenic opal stable isotope proxies (^{18}O, ^{30}Si, ^{15}N) for meltwater events, water mass stratification, nutrients, (iii) geochemical proxies for carbonate system reconstruction (^{11}B, B/Ca, U/Ca) using a new femtosecond laser and ICP-MS systems equipment.
- Completion of multi-proxy database of pan-polar climate records (ice, ocean, land) for the past 30-40 kyrs, past warmer than present conditions, selected Quaternary time-series and synchronisation of records. A synchronized evaluation of age models with a mapping of the records on a common time scale will enable the extraction of time slices for modelling and analyses of the related teleconnectivities. Compilation of the records in the data library PANGAEA.
- Analysis of modern analogues of glacial firn from COFI to improve the understanding of firnification and gas enclosure and gas chronologies in ice cores.
- Development of transient model simulations of the last glacial – Holocene climate development with a comprehensive Earth System model (ice-ocean-atmosphere) in a configuration with a closed carbon cycle, including selected simulations with interactive O-18 and other element cycles. Sophisticated pattern analysis of model results, instrumental data and high-resolution proxy data.

We expect the following results accordingly to our objectives:

- A unique bipolar network of land-ocean-ice based multi-proxy records for the past 40-30 kyrs that will provide climate scenarios considering biogeochemical and ocean-atmosphere-ice related physical processes from a polar perspective (see Box).
- Further elucidation of the role of polar physical and biological processes in driving changes in atmospheric CO_2 concentration and global biogeochemical cycles is expected from time-series covering different Quaternary climate mode states and extending back to the Mid-Pleistocene Revolution. Work will be focussed on the yet little studied Pacific Sector of the Southern Ocean and the Indian Ocean sector, but also on the polar North Pacific, all representing prominent HNLC areas.
- The study of polar climate variability at decadal-seasonal resolution in laminated and ultrahigh-resolution marine, terrestrial, and ice archives will extend the understanding of natural climate dynamics, propagation mechanisms, and thresholds beyond the instrumental record on time-scales relevant for human societies.
- Investigating warmer than present Quaternary periods (e.g. MIS 11.3, 9.3, 5.5) and the preceding glacial/interglacial transitions will provide a deeper understanding of polar climate processes and their impact on ice volume and sea level. These data will support the generation of scenarios for future conditions to be expected under global warming scenarios.
- Quantitative reconstruction of Quaternary variability of the Arctic and Antarctic sea ice fields will be based on the application of the new or improved sea ice proxies. A full picture of sea ice seasonality will rely on a combination of numerical simulations and

proxy data. This will provide insight on potential thresholds for significant sea ice change (e.g. total reductions) and profound knowledge on the sensitivity between bipolar sea ice extent/ seasonality and climate development.

- New insight in ice sheets extent and permafrost history will rely on combined land-based and marine acoustic and geological studies. Land-based studies will enhance the mapping of northern Hemisphere glacial ice-sheet expansions (including pre-last glacial conditions) together with marine studies on pathways and provenance of continental ice rafted debris. Land-based observations will highlight the role of short-term atmospheric oscillations, vegetation feedbacks, and the effects of permafrost degradation in past global climate development. In southern-high latitudes the history of WAIS retreat since the last glacial and of the Patagonian ice caps will be in the focus of the studies. Obtained results cannot provide direct information on sea level change related to waxing and waning of continental ice but will, together with information on palaeo-environmental parameters allow for the establishment of scenarios to simulate continental ice extent and volume with comprehensive Earth system modelling.
- From results of land-based and marine acoustic and geological investigations in combination with the comprehension of past ice shield and permafrost dynamics prediction approaches could arise, which are of great value to regional areas affected by expected future changes. In this context, commercial services could be developed e.g. for local authorities, urban developers, insurances.

Workpackage 2: Earth system on tectonic time scales: From greenhouse to icehouse world

Coordinators: K. Gohl (AWI), G. Knorr (AWI)

Mission statement

We study the influence of geodynamic-tectonic processes on palaeo-environmental conditions and glacial evolution at high latitudes in the last 65 million years by data-based reconstructions in combination with modelling.

Challenges

To investigate the evolution of the modern high latitude polar ice sheet configuration, the transition from a hothouse to an ice house world during the last 65 million years can serve as a unique test-bed to form a quantitative, process-based understanding of the underlying mechanisms and feedbacks. Although substantial progress has been achieved in the understanding of climate changes in the past, a complete comprehension of key climate transitions, especially at tectonic timescales as recorded in geological archives, is still a major challenge. We will provide a joint effort of databased palaeo-environmental reconstructions and palaeo-climate modelling to enable an interdisciplinary approach towards a deeper understanding of the interaction of various Earth sub-systems (land, ocean, ice) during the transition to our modern bipolar ice sheet configuration. This approach will help to differentiate between classic hypotheses for glaciations that involve tectonic changes and associated changes in ocean circulation or declining atmospheric CO_2 in combination with the Earth's orbital configuration. The interrelated challenges include the examination of:

- Geodynamics and seafloor processes of the polar oceans and margins.
- Geodynamic influence on key phases of climatic extremes and transitions and the biogenetic evolution at key gateways.

- Long-term global Cenozoic cooling and the response of circum-Arctic and Antarctic ice sheets and deep- and surface water characteristics.
- Palaeo-ice sheet dynamics versus temperature changes.
- Increasing latitudinal thermal gradients at the onset of major ice sheet expansion.

Current Activities and Previous Work

Magmatic processes during the initial phase of basin formation have strongly influenced the ocean's environment. Research in areas of the southern hemisphere has resulted in the reconstruction of the initial continental configuration and an improved understanding of the constraints with which magmatic material was produced during Gondwana breakup. In order to investigate the geodynamic and palaeo-climatic roles of volcanic events causing the formation of Large Igneous Provinces, studies were and are currently performed on volcanic oceanic plateaus in the Indian Ocean and the South Pacific. Several local seismicity studies and seismic profiling at ultraslow spreading across polar and sub-polar oceans provide a first impression of a spatially highly variable crust and magma production and of active spreading processes, which drastically differ from all faster spreading ridges. With a comprehensive multi-scale approach using locally, regionally and globally recorded earthquakes and all available structural information, the accretion processes at several sites along ultraslow spreading ridges of the polar oceans were investigated and compared.

Sediment drifts in polar and sub-polar basins represent the focus of reconstructions of palaeo-oceanographic conditions during the Tertiary and Quaternary. Studies of drift systems in the northernmost Atlantic Ocean provide information on the exchange of water masses between the Arctic Ocean and the Norwegian-Greenland Sea as well as the development of NADW. Sediment drift bodies in the Amundsen Sea off West Antarctica and in the South Atlantic are analysed with respect to variations in sediment input and transport both down-slope and along-slope. The results provide indications for the timing of first appearance of continental-scale ice sheets. For instance, cold conditions leading to deep-water formation in the Amundsen Sea seem to have existed already in early Neogene times.

Studies of the evolution and oceanic gateways, such as Fram Strait of the Arctic Ocean and Drake Passage of the Southern Ocean, and their consequences for palaeo-climate have continued throughout the current PACES programme. As an example, seismic stratigraphic interpretations of prograding sedimentary sequences on the Chukchi Shelf provided indications for high sea level of the Arctic Ocean before the opening of the Fram Strait. The consequences of this finding still remain to be tested by deep drilling and numerical modelling. On the biological aspects of past ocean gateway processes, molecular clocks have been used to calculate the timing of species pairs spanning the Drake Passage separating Antarctic and Patagonian shelves. Ongoing research focuses on shallow-water molluscs, which indicate a strong and recurring genetic exchange across the Drake Passage at times when this barrier was already in place, in contrast to genetically isolated Antarctic and Patagonian limpets today. Current work is aimed to understand which processes, apart from physical isolation, have been governing the evolution of species.

Organic geochemical and palynological proxies have been identified in sediment cores from the northern North Atlantic and the Arctic Ocean in order to reconstruct surface and deep-water characteristics during Palaeogene to Neogene times. In the central Arctic Ocean, for example, sea-surface temperature values indicate a long-term temperature decrease from 25° to 10°C during the time interval of 49–44.5 Ma, coinciding with the global benthic cooling trend (derived from $\Delta 18O$) after the early Eocene climatic optimum. For the late early Miocene, a sea-surface temperature of 11–15°C was determined. Based on biomarker proxies, large part of the Arctic

Ocean in the mid-Eocene was euxinic. The change to currently present oxygenated deep-water masses occurred during the middle Miocene, triggered by the opening of Fram Strait.

For the times after the initial build-up of large continental ice sheets, palaeo-climate and ice sheet modelling have suggested repeated partial and/or full collapses of the Greenland and Antarctic ice sheets during times of warm climate. Indications that such large retreats occurred within the West Antarctic Ice Sheet at times when CO_2 level and temperature were similar to values expected soon come from results of the ANDRILL core analyses from the Ross Sea shelf. Studies of retreat from the last glacial maximum have shown that the retreat rates and times vary between outlet drainage systems around Antarctica and Greenland. The documented retreat of the grounded ice in the Amundsen Sea shelf of West Antarctica occurred rapidly in the first 9000 years after the last glacial maximum back to the inner shelf and slowed significantly until the rates increased in the last decades.

The coupled Earth system model developed within the framework of the COSMOS initiative has been used to test a variety of palaeo-climate hypotheses. An interactive ice sheet model was recently implemented. The model has been used for a wide range of time intervals and processes including a tectonic setting and vegetation reconstruction representative for Miocene conditions. The outcome shows that a warm Late Miocene climate can be reconciled with pre-industrial CO_2 concentrations if vegetation changes are considered.

Objectives

Any complete understanding of relevant primary climate process drivers of the solid earth system requires an understanding of the relationship between tectonic and geodynamic processes at large time-scales from continental drift and ocean crustal formation to sedimentary processes and further to current magmatic activities. Testing hypotheses on the geodynamic and magmatic formation and alteration of the polar ocean basins will play a central role for constraining such Earth system dynamics. This includes an improved understanding of the link between crustal and lower lithospheric structures and the variable magma production in space and time that lays the basis for the topographic and bathymetric development of oceanic basins and its continental margins. As the global scale ocean overturning circulation is linked to the formation of deep and bottom water in the polar basins, detailed reconstructions of the opening histories of key oceanic gateways in the polar regions in time and space are required to constrain the relationship between tectonic evolution and primary palaeo-climatic trends. The Fram Strait, in particular, will be in focus for an improved understanding of how the tectonic, magmatic and sedimentary development is related to changes of ocean circulation and northern hemisphere glaciation. The establishment of consistent age models for Palaeogene to Neogene sections is a prerequisite for all further reconstructions of the palaeo-environment in both the Arctic and sub-Arctic basins. Considered as powerful climate archives, sediment drifts are formed under the influence of such water masses and represent archives of modifications in flow path and intensity of the water masses. Studies of sediment drift systems in polar and sub-polar basins allow reconstructions of changes in the circulation and thus provide boundary conditions for coupled palaeo-climate models. Existing and new data will provide the framework for identifying key locations in the Arctic Ocean and Southern Ocean region for deep scientific drilling that allows more detailed sampling of palaeo-climatic and geological records. Biological aspects have gained significance in reconstructing ocean gateway histories. As the evolution of species has been influenced by major geological events such as continental drift and ocean gateway openings and closures, the deciphering of biological footprints of these events, contained in the genomes of selected species, will provide further constraints of the timing of the development of deep and shallow water passages. Using key species that were separated by the opening of the Drake Passage as a model case, it is expected that boundary conditions can be identified to help improve the constraints for ocean gateway dynamics. As active

magmatic processes have affected the oceanic environment and are continue doing so at present, studies are planned for the observation and deciphering of active accretion processes between magmatic and amagmatic ridge sections along less-known ultraslow spreading ridges.

Reconstructing the past dynamics of the polar ice sheets has two overarching objectives: (1) deciphering the onsets of accelerated growth of ice sheets in the transition from greenhouse to icehouse climate, and (2) understanding the processes, mechanisms and consequences of ice sheets growth and retreat. These objectives address the need to understand the scale and rates of varying climate parameters and sea-level change. As the onset and variability of ice sheets and sea ice are related to changes in surface-water productivity, surface-water temperature as well as surface to deep-water characteristics, a multi-proxy approach must be applied. Of particular interests are geological epochs when atmospheric temperature and CO_2 concentration were close to that or higher of what has been projected by the IPCC for the next decades and centuries. These intervals include time periods from the Oligocene when temperature and CO_2 were substantially higher then today, but some ice sheets existed. Highly relevant are the Miocene and Pliocene with comparable or higher CO_2 conditions than today but with indications for highly dynamic fluctuations of the West Antarctic Ice Sheet and parts of the East Antarctic Ice Sheet. The work objective is focused on investigations of key ice drainage areas of the polar ice sheets by seafloor mapping and sampling of the glacial sedimentary archive from ice-proximal distances on the shelf to ice-distal but more continuous records in the deep sea.

Coupled numerical modelling is necessary to evaluate the various hypotheses that have been proposed to explain the evolution of high-latitude ice sheets, with special focus on changes in continental configuration, including ocean gateways, straits and associated changes in ocean circulation. Modelling of relevant proxies in a variety of Earth system components will be used to disentangle the spatio-temporal climate signature of ice sheets in proxy data, which closes a fundamental gap to understand the evolution of increasing thermal gradients at the onset of major ice sheet expansion.

Expected Results, Milestones

Results can be expected from a range of data-based analysis and model simulations including:

- Development of further refined and novel models for processes at the polar and sub-polar continental margins, spreading ridges and magmatic provinces.
- Reconstruction of regional palaeo-circulation processes coupled with an improved understanding of continent-to-shelf and shelf-to-rise sediment provenances, transport, erosion and deposition regimes.
- Seismostratigraphic correlation and a generation of regional polar and sub-polar palaeo-geographic grids at relevant climatic events will be tested with oceanic circulation responses and biogenetic evolution.
- Studies of glacio-marine stratigraphy and sedimentary dynamics of glacial outflow basins in Antarctica and Greenland/Svalbard will be used to reconstruct ice sheet histories from glacial onset at the greenhouse-icehouse transition to the Pliocene and younger glacial cyclicity with emphasis on times of similar climatic conditions as projected for the near future by IPCC.
- Climate simulations using a comprehensive coupled Earth system model in time slice experiments for the Palaeogene and Neogene with different ocean gateway configurations, orography, greenhouse gases, and orbital configurations. The simulations are used to test hypotheses of long-term cooling and abrupt glaciation.
- Regional geophysical data and model products suitable for commercial utilization will lead to industry collaboration projects and commercial data transfer.

These results are strongly built upon the following milestones in collecting geophysical and geological data, analysing these data and building numerical models for palaeo-climate simulation:

- Geophysical surveys will provide crustal and horizon-stratigraphic data from the polar continental margins and their conjugates to build palaeo-geographical models for the Arctic and Southern Ocean realms.
- Proposed ship-time for POLARSTERN for the northeast Greenland shelf, the Siberian Shelves, the East Antarctic margins as well as the Amundsen and Bellingshausen Sea of West Antarctica will be aimed for the collection of required data for palaeo-ice sheet reconstructions, including the acquisition of site survey data for IODP drill proposals.
- Through the initiation, leading and/or contribution to scientific drilling proposals in IODP, or by using shallow drilling facilities such as MeBo, the stratigraphic, chronological and proxy records of palaeo-climate processes are tied into the seismic databases. New proposed deep and shallow drilling is aimed for the Arctic Ocean, the Amundsen Sea Embayment, the south-eastern and south-western Pacific Ocean, the Weddell Sea as well as in the Ross Sea through participation in the ANDRILL Coulman High project.
- Active and passive seismological surveys using ocean-bottom seismometers will be used to study the active processes of polar and sub-polar spreading ridges and magmatic systems at Arctic and sub-Arctic spreading ridges and in the Laptev Sea.
- Through further enhancement of a coupled Earth system model, including varying orography, ice sheets and isotopes (H, C, O, Si) over long time-scales, simulations of palaeo-environmental and palaeo-climatic scenarios will be tested with geological records.

Workpackage 3: From process understanding to enabling climate prediction

Coordinators: T. Jung (AWI), K. Dethloff (AWI)

Mission statement

Explore mechanisms, predictability and global influences of polar climate variability and change.

Challenges

The polar regions are characterized by pronounced climate variability and change, but many polar processes are still inadequately represented in state-of-the-art climate models, which could explain, for example, the inability of these models to represent the observed decline of Arctic sea ice. The importance of polar regions is further emphasized through the possibility of interactions with the global climate system. While previous research revealed evidence for such linkages more detailed, quantitative knowledge of the underlying mechanisms remains elusive.

Realization of the highly variable character of the polar climate system with its pronounced influence on economic activities has increased the demand for reliable polar predictions. Furthermore, increased risk of environmental hazards and accidents such as oil spills highlight the importance of accurate predictions to support decision-making by stakeholders. However, relatively little is known about how predictable the polar climate system actually is; in fact, exploring the predictability of polar climate and environmental conditions on seasonal to multi-decadal time scales and understanding the underlying mechanisms is nowadays regarded as one of the grand challenges in climate research.

There is evidence that seasonal, interannual and decadal predictions suffer from both initial condition (sparse observations) and model uncertainties, which are strongly amplified

throughout forecasts by internal dynamical and physical processes; on multi-decadal time scales the uncertainty of climate change predictions is dominated by model errors and emission scenario uncertainties. Therefore, to narrow uncertainty of regional climate change predictions, especially in the middle and high latitudes, improving the representation of polar key processes should have a high priority. In summary, this WP will contribute to the following key challenges:

- Unravelling the physics governing polar climate variability and change.
- Understanding the role of the polar regions in the global climate system.
- Determination of the limits of polar climate predictability.
- Narrowing uncertainty of high- and mid-latitude regional climate change predictions.

Current Activities and Previous Work

Climate research activities in PACES had a focus on the description of the most important physical and chemical mechanisms that control the atmospheric and oceanic circulation patterns in polar regions and on the global scale. Furthermore, the consequences of polar processes for decadal scale climate variability as a result of the nonlinear dynamics of the coupled atmosphere-ocean-sea ice-ecosystem under the influence of external forcing factors were explored.

The global Finite Element Sea Ice-Ocean Model (FESOM) has been used in various configurations to explore the polar sea ice-ocean system and its influences on the lower latitudes. For example, Greenland ice sheet melting scenarios have been carried out and the influence of freshwater export through the Canadian Arctic Archipelago on the North Atlantic circulation is under investigation. Furthermore, possible future changes of the Southern Ocean under increased greenhouse gas forcing have been explored by driving FESOM with atmospheric forcing fields from different IPCC scenario runs.

Furthermore, we have studied the impact of the positive phase of the Southern Annular Mode (SAM) on the circulation and biogeochemical cycles in the ocean by using a planktic ecosystem model developed at AWI coupled to an ocean general model. Increased upwelling south of the Antarctic Polar Front leads to further stimulation of biological production and export of organic material from the surface ocean into deeper layers.

Polar prediction research has been started in the framework of the Arctic Sea Ice Outlook. Predictions are carried out by driving the regional sea ice-ocean model NAOSIM with randomly chosen past atmospheric forcing fields. The initial conditions are obtained by using variational data assimilation. Adjoint sensitivity computations for the year 2007 Arctic sea ice minimum have indicated that the slowly changing sea ice volume provides a high potential for skilful predictions of the September sea ice extent minimum several months in advance.

Possible consequences of Arctic sea ice decline for the Northern Hemisphere circulation have been studied using observational data and numerical models. Our results suggest that Arctic sea ice loss in summer and autumn can lead to subsequent winters with a predominantly negative phase of the North Atlantic Oscillation (NAO). Arctic sea ice loss, therefore, serves as a possible explanation for the cold European winters observed in recent years.

Given the possible relevance of atmospheric teleconnection patterns such as the NAO and the SAM in communicating changes between polar and lower latitudes their representation in climate models that participated in the latest IPCC AR4 Report has been studied. Based on newly developed metrics we could show that state-of-the-art climate models are able to describe the spatial structures of teleconnections and atmospheric flow regimes realistically. At the same time they underestimate internally generated decadal-scale variability.

During PACES FESOM has been further developed and coupled to the atmospheric models ECHAM5 and ECHAM6. This new coupled climate model is the first of its kind with a finite element representation of the sea ice-ocean system, which allows for arbitrary large local mesh refinements.

Objectives

It is well established that climate change in polar regions is driven by the depletion of stratospheric ozone, increases in greenhouse gas concentrations and processes internal to the climate system and that the polar response is further amplified by regional feedbacks related to ice and snow as well as the stable stratification of the atmospheric planetary boundary layer. However, many of the mechanisms governing polar climate variability and change remain largely unknown. Since progress in polar prediction hinges on a thorough process understanding, research aimed at unraveling the physical mechanisms governing polar climate variability and change will have a high priority.

Most of the previous studies on polar predictability are based on the rather crude assumptions that the climate models used to carry out do not have errors and that the initial state of the sea ice-ocean system is perfectly well known. We will produce more realistic estimates of the predictability of the polar climate system by more realistically representing model uncertainty and initial uncertainty through the use of stochastic physics schemes and optimal initial perturbation for the sea ice-ocean system based on empirical singular vectors, respectively.

In the face of strong high-latitude natural variability on various time-scales, the initialization of any climate prediction system is of utmost importance. This applies especially to the sea ice-ocean system, which primarily determines the low-frequency part of the spectrum and is believed to be the prime source of polar seasonal to decadal predictive skill. Improved data assimilation methods and new schemes for initializing coupled climate models will therefore be developed and tested in order to carry out seasonal to decadal polar predictions.

Mechanisms that could give rise to linkages between polar and mid-latitude regions will be studied in detail. For the atmosphere, we will investigate teleconnection patterns such as the NAO, AO and SAM; for the ocean-sea ice system circulation changes, advective mechanisms and processes leading to sea level rise will be considered. Emphasis will be put on global implications of Arctic and Antarctic sea ice decline, atmospheric compositions changes (stratospheric ozone, tropospheric aerosols and greenhouse gases) and melting of the Greenland and Antarctic ice shelves along with possible feedbacks with the global climate system. The ability of FESOM to use meshes with vastly different spatial resolutions for the sea ice-ocean system across the globe will be instrumental for this activity.

Regional uncertainty of climate change projections in the middle and high latitudes over the coming decades is known be largely driven by model uncertainty. In order to narrow uncertainty in future projections, therefore, it will be imperative to improve global climate models. Building on the process understanding gained in Topic 1, it is planned to improve the representation of polar key processes such as interactions in the atmosphere-ocean-sea ice-land system, boundary layer process, sea ice dynamics and deep-water formation in global climate models.

Expected Results, Milestones

Unravelling the physics governing polar climate variability and change

Numerical experimentation with ECHAM6-FESOM will shed light on the question to what degree observed polar climate variability and change originates from internal atmospheric or coupled atmosphere-ocean-sea ice processes and which role atmospheric composition changes of CO_2 and O_3 play. The role of coupled troposphere-stratosphere circulation modes

such as the AO and SAM in determining the tropospheric response to ozone changes and the atmospheric response to sea ice anomalies will be determined using a high-top version of ECHAM6-FESOM with an interactive stratospheric ozone chemistry. The response of the Southern Ocean to a further SAM increase in the atmosphere is of major importance for the future development of sea-ice cover and thickness distribution around Antarctica, for the upwelling of nutrients and CO_2-rich waters and the impact on biogeochemical cycles. The simulation of biogeochemical processes will be improved by using a finer resolution for FESOM over the shelves around the Antarctic Peninsula and Patagonia, which are considered an important source region for iron, the limiting nutrient for biological production.

Determination of the mechanisms and limits of polar climate predictability

Research carried out in this WP will provide a deeper insight into the predictability of the polar climate system on seasonal to multi-decadal time scales. Research will highlight the role of different mechanisms in providing predictive skill. Emphasis will be placed on memory provided by the sea ice-ocean system, atmospheric teleconnection patterns such as the AO and SAM, stratosphere-troposphere interactions, influences from the lower latitudes and changes in atmospheric composition (carbon dioxide, ozone and aerosols). Instabilities of the coupled climate system will be identified by computing the fastest growing empirical singular vectors using linear inverse models. Stochastic parameterisations of the polar sea ice-ocean system will be developed to represent the influence of model uncertainty.

Understanding interactions between the polar regions and the global climate system

Experiments with coupled climate models, including studies of the mid-latitude response to Arctic sea ice decline and the global consequences Greenland and Antarctic ice shelf melting, will help to determine the role of the polar regions in the global climate system. Rather than focusing just on the equilibrium response the adjustment processes will also be studied. By considering the initial adjustment it is possible to understand the functioning of the underlying processes before nonlinear interactions start to obscure the response.

Narrowing uncertainty of high- and mid-latitude regional climate change predictions

Parameterization of subgrid-scale processes such as boundary layer turbulence and atmospheric micro-physics will be improved; stochastic parameterizations of polar subgrid-scale processes for the ocean and sea ice will be developed and their influence on the realism of Earth system models will be explored. Research will reveal the influence that increased resolution, especially in dynamically active regions (e.g. deep water formation), has on the realisms of climate models. The improved, optimized and tested version of the climate model will be used to carry out CMIP5-style runs (climate change scenarios, decadal prediction etc.).

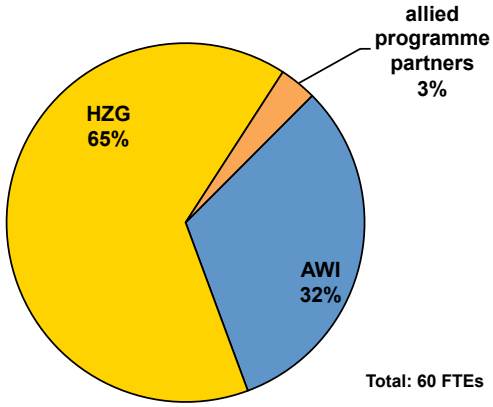
In summary, research carried out in this workpackage in conjunction with progress in other parts of the programme is expected to lead to the following scientific key-results:

- Improved understanding of mechanisms and predictability of polar climate variability.
- Improved methods of initializing climate models for seasonal to decadal predictions.
- Improved knowledge of polar influences on mid-latitude weather and climate.
- Understanding of the Southern Ocean response to the SAM.
- More reliable projections of 21st century anthropogenic climate change.
- Impact to society: Improved models will allow for more precise predictions of ice conditions in arctic regions. Appropriate commercial services could arise from the above-mentioned results providing advice to decision makers, investors, insurances, ship yards, shipping as well as to offshore companies.
- Furthermore knowledge about efficient supercomputing methodologies may be transferred into fields of industrial computing.

Topic 4: Research in science-stakeholder interactions

Coordinators: H.v. Storch (HZG), W. Hiller (AWI)

Challenges



Many aspects of PACES research have a direct bearing on decision processes, by providing analyses of the present state, present changes, forecast of the short term future, and depictions of possible futures via scenarios for decades to come. The instruments are designed to be accessible for decision takers, the type of provided knowledge is prepared for fitting the needs and a science-public/stakeholder dialog is set in motion. The latter is guided by social science knowledge for addressing the societal context, in particular when the overall debate is politicized ("postnormal science"). The overall objective of the topic is to improve the utility of knowledge generated within PACES II for societal needs – both in technological and communicative terms, but also by recognizing the specific challenges resulting from the present post-normal situation of enironmental research in general.

The notion of Stakeholder in the context of Topic 4 is used in the broadest possible sense of the term, to include corporate (market) stakeholders such as companies or different interest groups (e.g. fishing industry, oil industry, wind energy companies), non-market stakeholders with a vested interest in the management of a project (e.g. environmental NGOs, selected local residents), legal stakeholders who have regulating power (e.g. governments, administrations or multi-governmental organisations) and the undetermined bodies and individuals without representation but interest in the trajectory and outcome of the project – the general public

Specifically, the following challenges will be pursued:

- Preparation and provision of methods suitable for operational analyses of environmental conditions, say in the Arctic and in the North Sea, including short-term forecasts (in cooperation with DWD, BSH, Havariekommando and other agencies as well as off-shore companies). While it is not the task of HGF research to *do* environmental monitoring (this is a task of agencies such as DWD and BSH), the topic aims at the development and testing of advanced methodology. *Major challenges* are the organization of routine data access, the availability of applicable multi-faceted system models, development of data assimilation methods, and the combination of these tools in advanced systems, which not only technically but also logistically can be run operationally by responsible agencies. To do so, operational issues such as reliability, utility and costs have to be considered as well.
- Ensuring accessibility of data products that describe homogeneously past developments (palaeo-climatic conditions as well as recent conditions) plus scenarios of possible future conditions (cooperation with DKRZ). *Challenges* concern methods for identifying informational content and inhomogeneities in data sets, IT-technology but also understanding of communication barriers related to different disciplinary cultures.
- Building of a dialog of PACES II with public and stakeholders through various communication offices (regional climate offices at the AWI and the HZG as well as communication offices), and between different scientific cultures making use of project offices (such as BALTEX and LOICZ). Doing so requires the recognition of the

"postnormal" condition of environmental science (inevitable uncertainty, urgency of decisions, high stakes, values in dispute), which typically goes along with an interest-led utilization of science. A major *challenge* is the breakup of the linear "knowledge speaks to power" model of communication, which has been found to be inappropriate but is widespread among natural scientists. This needs input from social sciences.

The topic has significance beyond the PACES II program, as it is dealing with a genuine problem seen at the society/science interface of many programs. Setting up this topic, PACES recognizes that the passage of information and construction of interfaces between science, society and applications is far from trivial and cannot be done along the way by researchers, who may be excellent scientists but usually have little, or mostly naïve understanding about societal dynamics and needs. In this context this topic also challenges the intra- and inter-institutional communication and dissemination of scientific results in order to create, strengthen and establish pathways from scientists within the various disciplines to this topic, building the base for an effective and sustainable science-stakeholder-policy interface.

The topic is embedded both in PACES and in the broader HGF-research program. Specifically, it is related to the risk-management approach of CEDIM, to the climate service concept of the Climate Service Center CSC as well as the ESKP portfolio; also the activities of "Technik, Innovation und Gesellschaft" at KIT offers useful partners.

WP1 of Topic 2 is very relevant because the outlined research activities, where recent decadal changes of coastal conditions, including risks, as well as plausible scenarios are quantified, have found a multitude of applications among economic coastal actors, such as off-shore industry or coastal defense agencies.

Current Activities and Previous Work

While Topic 4 represents a new topic in PACES II, it is assembled from various activities developed during PACES.

Among these activities are

1) Building systems for synoptic "nowcast plus short-term forecast" analysis of the physical, ecological and chemical state of the North Sea, Artic Ocean and other seas. (WP1)

2) Preoperational systems, which combine routine observations (from the PACES partners as well as from other KDM institutions and operational agencies) with advanced numerical models through the process of "data assimilation". This work is done in close cooperation with operational agencies, in particular Bundesamt für Seeschifffahrt und Hydrographie (BSH). One group of applications, under the headline of COSYNA, focuses on the German Bight and the North Sea at large. A first product deals with the analysis of surface currents in the German Bight, utilizing routinely recorded radar data. Further products are presently being tested and in preparation. Another system is focussing on northern shelf seas and the Arctic with high regional resolutions.

3) A somewhat different approach is adopted in case of the German-Indonesian Tsunami Early Warning System (GITEWS). Using an operational tsunami model, a repository of 3400 tsunami scenarios in the warning centre at BMKG, Jakarta, has been built. The TsunAWI model simulates all stages of a tsunami from the source to propagation over the deep sea, shallow coastal water and inland inundation by discretizing the non-linear shallow water equations. Current activities focus on the development of an operational Multi-Hazard model dealing with short term prediction capabilities for storm surges, landslides and tsunamogenic events.

4) Multi-faceted data archives and information systems serve as the core data dissemination and retrieval platforms of PACES II (WP2).

Among them are PANGAEA – a data library for Earth and Environmental Sciences of AWI/MARUM serving as long term archive and preservation tool, MANIDA – a networked approach of AWI, MARUM, GEOMAR, HZG and BSH to distribute German Marine Research data through a user oriented portal, C3Grid - the German Climate Data and Processing Grid, a German Climate Community driven Grid based workflow oriented approach to channel the data deluge in Climate Sciences modelling data and other portals like the Sea Ice Portal - serving enhanced data products to the public, which is currently set up in the REKLIM context. The overall aim of these systems is the aggregation of data and enhanced data products, thereby pacing the paths towards generation of information and of knowledge about regional and local environmental conditions, including biological diversity. Another common feature of these systems is the user friendliness through construction of service-oriented platforms, forming also the basis for knowledge dissemination by the out/in-reach offices in WP3.

5) The homogeneous analysis of regional weather stream from 1948 until today, in terms of marine weather (in particular wind, currents, surges, waves), as well as plausible future scenarios thereof, makes up the data set “coastDat”. These data are used in coastal regions by many national and international stakeholders, from business as well as governmental agencies. The data set is presently extended, both in terms of more variables, but also to cover other marginal seas and coastal regions.

6) PACES II is engaged in various outreach activities, both on climatic and non-climatic issues (WP3).

The science/society exchange about issues of regional climate, climate change and impact is organized through the two regional climate offices at HZG and AWI. At AWI the thrust is on sea level, while HZG deals with coastal issues. This work is associated with social science analysis about communication, knowledge competition and policy analysis – in order to clarify and improve the role scientific knowledge may play in the societal decision forming process. IPCC-like reports on the state of knowledge about regional climate and climate impact have been prepared for the Baltic Sea region (BACC, together with BALTEX), for the Metropolitan area of Hamburg (with CliSAP); new such reports are underway for the North Sea region (NOSCCA) and the Baltic Sea region (BACC).

The international coordination of research activities, including the breaching of disciplinary borders, is the task of international project offices – of LOICZ and BALTEX at HZG. Furthermore, AWI and HZG have undertaken their efforts to professionalise knowledge and technology transfer activities as a cross-sectional responsibility. Technological developments (e.g. observation and deep-sea systems, natural compounds, etc.) have been further developed into commercial applications via licensing, industry cooperation and spin-offs.

Objectives

The objective of Topic 4 in PACES II is the bridging of scientific excellence with societal relevance. This brings in technical challenges such as operational systems, advanced modelling and data storage based on scientific progress obtained mostly in the other Topics of PACES II, but also conceptual issues about knowledge dynamics and aspects of social sciences. With this topic we will help to transfer scientific knowledge and technologies into practical contexts (of marine and coastal operations), but also to link scientific questions to societal questions and demands, which will lead to a better grounding of our science in a societal context (scientific knowledge as a tool for interpreting complex relationships in the earth system).

This Topic provides methods for monitoring marine and coastal activities, collects and analyses data about changing coastal and Arctic environments to be used in practical as well as scientific contexts, and builds platforms of communication between science policymakers, stakeholders

including the private sector and the public at large. Structures for communication will build on principles of sustainability that make scientific results available to stakeholders in a target-group specific, meaningful and conclusive way. As such, the topic will support to integrate natural sciences, engineering and humanities.

Expected Results, Milestones

By integrating observations and modelling, the expected results of WP1 will be improved by preoperational systems for environmental conditions in the North Sea and the Arctic Ocean. Also, data products of synoptic analyses and short-term forecasts will be provided through COSYNA, MANIDA and the Sea Ice Portal. The results encompass the development of a multi-hazard modelling system, predictions of the fate of oil contaminants as well as sea-ice conditions in the Arctic Ocean and synoptic analysis of physical and ecosystem observations. The potential for monitoring strategies of HF radar data, glider observations, and new satellite data like from the Sentinel mission for data assimilation will be assessed.

- Operational synoptic analysis – state of surface currents, seas surface temperature, salinity, suspended matter and other variables in the German Bight (COSYNA) – state of Arctic Ocean (sea ice, currents etc.).
- Multi-Hazard Model for improving operational modelling of coastal and marginal seas.

In WP2, data distributed over different databases will be made accessible through advanced portal techniques and by means of harvesting meta-data from the participating systems. Data aggregation will be more easily achievable with service-oriented technical approaches to provide target-group specific enhanced data products over PANGAEA, coastDAT, and COSYNA. For this, services for data format conversion, thesauri, ontologies and gazetteers will be implemented where appropriate. For data on biological diversity, a workflow-based archiving of high-volume molecular data is envisaged in DIVERSE and integrated with access to distributed biodiversity information from GBIF and within PANGAEA. Data re-use will be pushed by a more effective user-support and data warehousing technique. Improved data ingest processes are developed for projects with well-defined data management. Visualisation will be made available using GIS-services, also included in the user-support.

- Updating of improved analysis of coastal seas in CoastDat 2 for the North Sea and Baltic Sea; inclusion of ecological variables; adopting of the system to other marginal and coastal seas.
- Biological diversity information in/from PANGAEA.
- Adoptable information products from MaNIDA German Marine Research Data Portal
- Sea Ice Portal and other portals.
- Data and information products will be disseminated to users at different conditions to be developed (e.g. free access for academic users, user fees for commercial use).

With WP3 we will establish for the first time in our research programme a structure for research and practical implementation of communication and dissemination of scientific results from the research topics to the public and stakeholders. Aiming at an improved dialog between science and stakeholders in order to generate adoptable scientific knowledge, the socio-cultural dynamics and context knowledge of actors and agents have to be analysed to better understand the perception of lay people as well as the conflicting interests in power structures. At the same time scientific knowledge has to be assessed to discuss specific topics for tailored regional products of coastal and polar systems among different societal groups or actors.

- Socio cultural understanding of stakeholders as potential users
- Regional assessment reports
- Scientific and public dialog network/s

Workpackage 1: Operational analyses and forecasting

Coordinators: E. Stanev (HZG), L. Nerger (AWI)

Mission statement

Develop preoperational systems for environmental conditions in the Arctic Ocean and the North Sea based on the integration of observations and modelling and provide data products of synoptic analyses and short-term forecasts.

Challenges

Major challenges of the work done in this workpackage are:

- Design and implementation of an efficient pre-operational observing system.
- Provision of pre-operational products of societal, economical or scientific relevance.
- Availability of multi-faceted system models and information systems.
- Development of sophisticated data assimilation techniques.
- Operational issues such as reliability, utility and cost efficiency.

With these challenges, the work will focus on three topics:

- Observations, synoptic analysis and forecasts in the North Sea and German Bight.
- Sea ice and contaminants in the Arctic Ocean.
- Multi-hazard modelling of storm surges, landslides, and tsunamogenic events.

Current Activities and Previous Work

Both participating institutions have in the past developed systems for the pre-operational monitoring of coastal Seas, mainly in the North Sea and Arctic Seas. These systems combine theoretical understanding in the form of dynamical models, with empirical in situ and remotely sensed data, using the concept of data assimilation. At HZG the Geesthacht assimilation system (GALATON) is used and at AWI the Parallel Data Assimilation Framework (PDAF).

In the framework of COSYNA (Coastal Observation System for Northern Arctic Seas), a new coastal observing system has been developed for the German Bight. In order to monitor hydrography, currents and biogeochemical conditions, COSYNA operates spatially distributed platforms with a multitude of sensors ranging from FerryBoxes operating on fixed routes, wave rider buoys and remote sensing includes HF and X-band radar stations and satellite data (SAR and MERIS). Observing System Simulation Experiments have been done for identifying suitable instrumentation and observational strategies.

The PDAF approach is used in a joint project with the BSH for pre-operational forecasting in the North Sea and Baltic Sea, where satellite and profile data are assimilated. The system is ideally suited to assimilate dynamic oceanographic topography data to improve estimates of mass transport. Further, PDAF was used for biogeochemical state estimation through the assimilation of satellite chlorophyll concentrations and for the assimilation of sea ice drift data.

Both institutions are engaged in preparing improved observational capabilities; this includes utilization of scanfish and glider systems in shallow seas, as well as two fully cabled underwater observatories at Helgoland in the North Sea and at Spitsbergen (Ny Alesund), also in the COSYNA framework. The underwater fjord observatory in Spitsbergen provides the main hydrographical and ecological data online year round even during the arctic winter under ice.

AWI has participated since 2008 in the international Sea Ice Outlook (SIO), which predicts the Arctic sea ice extent minimum in early autumn starting from the onset of the sea ice melt season at the end of May.

The monitoring and prediction of marine dispersion of pollutants in the Arctic has previously been connected to Arctic Ocean modelling activities (see also Topic 1, WP2). Most investigations concentrated on passive conservative pollutants like long - half-life radionuclides. Simulations included the dispersion of releases from nuclear facilities in Sellafield (UK) and La Hague (France) in the Arctic Ocean and hypothetical releases like from the sunken nuclear submarine Kursk.

The tsunami model TsunAWI was developed for the German-Indonesian Tsunami Early Warning System (GITEWS) and a repository of 3400 tsunami scenarios was provided for the operational warning centre in Jakarta. TsunAWI simulates all stages of a tsunami from the source impact over the wave propagation to the inundation inland. Initial conditions can be taken from geological surveys for hindcasts, prototypic ruptures, or from landslide simulations. Currently, a non-hydrostatic pressure correction is added, which leads to more realistic results in coastal regions especially with steep bathymetry. Tidal forcing is also added to improve hind-casts and risk studies for coastal areas with strong tidal currents. This is the first step towards a multi-hazard modelling system including storm surges and landslides.

Objectives

Synoptic analysis and forecasts generated with data assimilation methods combining routine observations with advanced numerical models are motivated by the need to provide data to various stakeholders in maritime safety and resources, coastal and marine environment, decision making, science and the public. Within PACES, two such systems are in use, GALATON and PDAF. One German stakeholder of this kind, and a strategic partner for this WP, is the BSH. Enhanced coastal observatories like COSYNA already provide synoptic now casts plus short-term forecasts and run pre-operationally at present. In this WP, the existing system will be extended towards new data sources and advanced data assimilation techniques, responding to the mathematical-technological challenge to maximize the synergy between pre-operational practice and research developments and to develop an efficient observing system suitable for long-term use. The capabilities and range of suitable applications of GALATON and PDAF will be assessed by comparison experiments. The generated analysis fields are high-quality products for science-stakeholder interactions. They are also valuable for the planning and interpretation of ship or station based measurements. Here, the work relates to Topic 2 as, e.g., the fields support the need for the understanding of particulate matter transport and the distribution of algal blooms and the associated patchiness related to changing productivity in coastal seas.

The Arctic sea ice extent depends strongly on the slowly varying sea ice volume. Thus, seasonal prediction of sea ice conditions in the Arctic Ocean requires considerable skill when the sea ice and ocean components of a forecast model are properly initialized. The provision of regular predictions beyond the SIO prediction of minimum ice extent by providing predictions throughout the year will support marine operations and economy, such as the shipping or fishery industry, or fighting pollution events. It will be elaborated, which products and services could be transferred free or commercially to public stakeholders and private companies, respectively.

The value of preoperational systems like COSYNA can be maximized by addressing practical issues of economical or societal relevance and by demonstrating the benefit of the system's enhancement with respect to the quality of state estimates needed to accurately simulate or predict risks for the coastal environment, such as oil spills, extreme waves or storm surges. Risk related observations and predictions will be embedded in the Earth System Knowledge Platform (ESKP) to form an interface for information transfer and discussion with stakeholders and the

public. This includes the optimization of drift forecasting methods that are of practical relevance for the management of oil accidents or search and rescue operations.

This WP will provide advanced numerical simulation techniques needed to assess the multiple marine risks in complex geographical settings like the German Bight with its estuaries together with information techniques for rapid access to large indexed scenario databases. The risk analysis itself will be dealt with in Topic 2 “Fragile Coasts and Shelf Seas” while the provision of the data and the communication to the public will be the responsibility of WP2 and WP3 of this Topic 4, respectively.

Expected Results, Milestones

The overall result of this WP will be new knowledge, high quality methods and products for intermediate and end users. The implemented information system will provide support for the complex decision making processes in today’s coastal environmental management. Many of the developed techniques are also applicable to other areas of the world and the activities within this WP can help to place Germany in a leading position, e.g., concerning Europe-wide HF radar operations. The essential characteristic of the implementation strategy is (1) parallel activities in observation and modelling and (2) integrated activities developing new methods and products combining both data and models.

Knowledge based monitoring concepts like smart observational systems will be developed with emphasis on optimal data provision and optimal extraction of information from the observations. Up to date information on the coastal ocean state with objective error estimates will be provided.

For synoptic analysis and forecasts in the North Sea, the GALATON system for the combination of numerical model data with HF radar surface current measurements and Ferry Box SST/SSS observations will be upgraded into the direction of coupling different operational modules, which maximizes the benefit of available and new in situ and remote sensing observations (wind waves, SPM, biogeochemistry variables, light etc.). GALATON will be also extended and tailored for specific applications like drift forecasts. Additional information, like those provided by gliders, will be used to obtain a consistent dynamical picture of the entire water column in the German Bight. This work will also support activities in biogeochemical modelling.

Synoptic analysis fields in northern shelf seas and the Arctic Ocean for decadal time horizons will be generated using the coastal version of FESOM in combination with the PDAF assimilation framework connected to the research of Topic 3, WP3, for the improved understanding of polar predictability. Coupling with the ecosystem model REcoM allows us to also consider biogeochemical variables. Observations for the analysis are satellite SST fields and in situ data ranging from long term monitoring data, to ships and stationary profile data of, e.g., salinity and velocities. Also, ecosystem-related remote sensing data such as chlorophyll concentrations and absorption coefficients will be synoptically analysed.

Strategies for a cost efficient, sustainable and practice-oriented development of a coastal observatory for the German Bight will be developed. The investigation will make use of numerical models and existing observation data. Of particular value in this context are SCANFISH data collected during several ship campaigns. Both OSE and OSSE experiments will be performed looking at requirements from different applications like drift forecast or monitoring of SPM transport processes. Furthermore, optimal sampling strategies, e.g. for gliders will be investigated (adaptive sampling). Benefits for the operational practice of using data from wind platforms will be estimated.

In the Arctic Ocean, the sea ice prediction system will prepare 3-months predictions on a monthly basis for the whole seasonal cycle. The probabilistic forecasts will be initialized using data assimilation methods employing satellite and buoy data of sea ice concentration, drift, and

thickness. Possible pathways of oil spills will be assessed by combining statistical information about predominant weather conditions in different areas of the Arctic with a short term prediction system for the ocean and sea ice. Model hindcasts will be used to assess the variability in contaminant (PCB153, PFOA, radionuclides) transport and deposition patterns.

The AWIPEV fjord observatory in the COSYNA framework will provide hydrographical and ecological data from an arctic fjord system year round allowing to assess and to fully reconstruct the seasonal dynamics of the abiotic and biotic variables even under extreme winter conditions with full ice cover. Together with the COSYNA underwater node system off Helgoland, these data allow a fully comparative research approach of a boreal and an arctic shallow water ecosystem.

The shallow-water model TsunAWI will be extended to allow for the prediction of German Bight storm surges (together with WP3 of Topic 3).

The WP is supported by the Technology Transfer Offices of the participating institutions in order to assess the needs of the specific user markets (e.g. shipping lines, offshore wind, oil & gas, etc.).

In summary, the key results of this WP will be:

- Provision of synoptic analysis fields in the North Sea and northern shelf seas generated using the PDAF assimilation system and the GALATON system.
- Extending the PDAF and GALATON system to cover particle trajectories, extreme events.
- OSSE and OSE experiments assessing the potential of new observational systems (e.g., high resolution altimeter, TerraSAR-X, Sentinel missions, gliders, scanfishes) for data assimilation and development of strategies for future evolutions of the German coastal observatory (cf. Topic 2, WP5).
- Generation of data products for the sea ice portal with the sea ice outlook assimilation system and predictions of the fate of oil contaminations in ice-covered seas.
- Development of a multi-hazard modelling framework for storm surges, submarine landslides, and tsunamogenic events.
- Examination of the utility of cabled underwater laboratories (operated in the North Sea and the Artic) for monitoring purposes.
- Appropriate commercial data and information products according to market needs.

Workpackage 2: Channelling research data to enhanced data products

Coordinators: E. Meyer (HZG), S. Frickenhaus (AWI)

Mission statement

Societal groups are provided with improved technology for a simple access to complex data and information extracted from computer models and observations produced and aggregated in coastal and polar marine research.

Challenges

Interest groups, ranging e.g. from researchers, authorities, industry and science communicators, increasingly require a unified access to complex multi-disciplinary environmental data. To fulfill this need, this WP will further develop and integrate currently existing data and information systems at HZG and AWI (and GEOMAR) to become an integral part of communication strategies in the research of global and regional change, e.g.,

assessment and evaluation of consequences for the Arctic and European coastal regions. Major challenges of this transition are related to consistent automated aggregation of a multitude of discipline-specific data types and limitations of the systems to guide user queries in the context of their disciplines and their profile of demand. Improvements of data ingest processes for data curators and scientists must be accompanied by a set of new services that allow for an efficient re-use of data in research by aggregation of atmospheric and marine data, including data on biological diversity and chemical components. This requires using data warehouse technologies, GIS-formats, web services and ontologies. Efficient access to search results for re-occurring requests is needed in the form of enhanced data products for science communicators. Finally, the web portal of MaNIDA, which acts as a single point of entry/access to the networked data and information systems of the partner institutions, is required for a unification to yield cross-system query functionality and to share visibility of research results, gathering data products from several work packages throughout the topics of PACES II. In short, challenges are

- Harmonizing data and technology by international standards.
- Implementing quality management in workflows, including ingest processes.
- Channelling domain-specific expertise and improving curation support.
- Developing and improving added-value services, incl. statistics/mapping/sequence annotation/data aggregation/overlay.
- Providing enhanced data products by enabling user-specific and thematic data filtering.
- Ensuring data citability via persistent identifiers (DOI).

Current Activities and Previous Work

AWI and HZG put a strong focus on long-term data preservation and publication. For example, the data library PANGAEA - Data Publisher for Earth and Environmental Science is used by various national and international projects for archiving. Since 1997 the system has served 160 projects from which more than 400 000 data sets with 6.6 Billion data items were archived and made available in Open Access. Since PANGAEA is one of the main backbones for HGF marine and geoscientific research data in terms of data archiving and publishing, the seamless integration via the Marine Network for Integrated Data Access (MaNIDA) into the Portal German Marine Research is vital.

The currently emerging DIVERSE information system on biological diversity molecular data will serve the target group of ecological researchers. It is initiated to provide secondary data and derived biodiversity information. Sampling and analysis of molecular sequence data from the marine environment is used as a tool to assess biodiversity information from coastal and polar regions, e.g., in micro-phytoplankton. For this, computational approaches to sequence data processing and storage management have been developed in the runtime of PACES I, supporting publication of statistically justified results and submission of primary data to international sequence data archives. Intensive collaboration with the Hustedt Diatom Study Centre covers aspects of linking molecular-based with classical biodiversity observation data, taxonomic information and to oceanographic contextual data. DIVERSE is planned to develop into a management and publication system for high-volume molecular sequence data and derived information, including repeatable analysis workflows in biological diversity research

An integrated approach for monitoring the marine system is done with the monitoring and observation system COSYNA for the North Sea and Arctic coastal regions. COSYNA is used to combine different methods of in-situ and remote-sensing measurements with numeric pre-operational models. It is the goal to establish an integrated monitoring system for the German Bight and to develop and establish new monitoring methods. A concept for quality assurance to all data including near-real-time-data was developed in COSYNA in coordination with other

international projects like SeaDataNet. COSYNA will contribute to the analysis of environmental, societal, or economical risks that will be made publically accessible as part of the Earth System Knowledge Platform.

Homogeneous and consistent long-term model data from hindcast (1948-present) and scenario (1960-2100) simulations are held in the coastDat database. CoastDat comprises atmospheric and oceanic model data for example from the North-East Atlantic and Europe (Weisse et al., 2008). The database is recently expanded with model data representing South-East Asia that cover the period from 1960 to present (hindcast) and from 2000 to 2100 (scenarios). Also, model results from an atmospheric hindcast (1980 – present) including chemical components and aerosols for Europe are collected. For several applications coastDat data are used, e.g. by the Norddeutsches Klimabüro to develop an atlas for climate or to calculate the changing risks from oil accidents and chronic oil pollution. More than 60 clients, with different interests, have used the data for their problems (e.g. risk assessment, coastal protection, ship design and wind parks construction). Improved user-friendliness of the coastDat database has been obtained using the infrastructure of the DKRZ.

In a similar manner to the coastDat products homogeneous and consistent reanalysis data (NAOSIM-HRA) are available for the Arctic Ocean and the Nordic Sea. These reanalysis data comprise state variables for the ocean and the sea ice for the period of 1948 until 2011. Validation of the reanalysis has been performed as part of published scientific work. The record is available to the public with restrictions.

During the last years, grids have been established as technology for virtual research environments. They can allow a uniform view on heterogeneous data. The Collaborative Climate Community Data and Processing Grid (C3Grid) provides mechanisms to hide the technical details of different archive mechanisms, giving scientists a comprehensive view on distributed data archives. It includes data from archives with a broad spectrum of profiles, ranging from model simulations (DKRZ, AWI, HZG, University of Cologne/FUB, PIK) over measurements (PANGAEA) to satellite data (WDC RSAT, DWD). The scientific user can browse in the data collections. In contrast to traditional downloads, users can specify also subsets of data, which is cut out on the data provider site during a pre-processing step. This option reduces the transferred data volume. Furthermore, C3Grid provides processing capabilities to perform several diagnostic workflows, e.g. calculation of the standard deviation of band pass filtered geopotential height field anomalies (storm tracks) and vertically integrated horizontal moisture flux vectors. The feature catalogue is expanded permanently. Current efforts are focused on interoperability with the ESGF data federation of CMIP5/IPCC AR5.

Currently a marine research data portal is constructed with the purpose of an integrative access of multifaceted observed and modelled marine data, which are collected in different databases. By means of the HGF start-up financing (2012-2014), the Marine Network for Integrated Data Access (MaNIDA) is designed. A networked approach and management strategies are applied to build a long-term sustainable common e-infrastructure for coherent discovery, view, download and dissemination of German marine research data. MaNIDA is linking data products from the federated data libraries PANGAEA (AWI/MARUM), DOD (BSH), COSYNA (HZG), coastDat (HZG) and GEOMAR in the form of a German Marine Research Portal (Portal Deutsche Meeresforschung). Furthermore, within the scope of MaNIDA, homogeneous data descriptions, quality assurance and preliminary processing (ingest) procedures for all major German research vessels are being developed.

Objectives

The mentioned data and information systems require new, concerted developments to turn into a more powerful part of distributed infrastructure. This is a prerequisite for providing services

and information according to the mission statement. Technological approaches to the channelling of data into information by aggregation across the different formats, quality-levels and services are followed in the implementation of this work package. The common objective is to provide data for enhanced data products. These are derived from current and future research activities of the partner institutes in coastal and arctic oceans by means of monitoring, oceanographic measurement, biodiversity observation, forecast modelling and assimilation. Therefore, the following features and services will be made available to the users: integration of contributed data in the data portal created by MaNIDA, services for data format inter-conversion, tools for workflows to process aggregated data to target-group specific data products, faceted search engines addressing the needs of users by their specifications, abstraction and unification of meta-data by the use of standard ontologies, gazetteers and thesauri, access to local and distributed biological diversity data. Furthermore, high-throughput access/processing capacities are offered by means of GRID-technology enabling data life-cycle management, and by data-warehousing. Finally, to give data publication a new impact, user support services will be implemented for simplifying data ingest as well as data retrieval.

Expected Results, Milestones

In MaNIDA, several working groups across all partners have been established to take stock and to create common workflow definitions for integration, harmonization and aggregation of quality-controlled data and related products. Unified workflow development as well as subsequent operational implementations are regularly agreed upon and controlled jointly by the consortium and its steering board. Standardization with international EU-programs is an overall mandatory prerequisite to sustainability. The initial phase concentrates on physical-oceanographic data, underway data and the unification of nationally operated research and monitoring facilities and campaign related data (CSRs, DSHIP, station lists, track lines, and reports) to create one central point of verified information and data. Hence automatic linkage to data retrieval, publications and citability from distributed sources is part of the aggregation effort. Meta-data harvesting across the partner sites, including distributed biodiversity data resources will be implemented in PACES II. MaNIDA will link content from partner sites through the portal in close connection with services offered in PANGAEA, COSYNA and BSH. Accordingly, an extension with interfacing-modules in PANGAEA will be implemented. AWI operates PANGAEA as a public library for the international scientific community. Developing categorized and discipline specific thematic search functionalities via catalogues, faceted search algorithms, interlinked thesauri and international referenced indexing (ontologies & gazetteers) to guide the user to the content of interest. Furthermore, a data warehouse is put into operation to allow the compilation of data subsets to be imported in complementary web services or external software like GIS, models or statistic packages. Added-value services will be implemented for visualization of data in plots, profiles or maps. The focus for data acquisition and ingest will be on the participation of projects with a well-defined data management. Furthermore, the import of supplements to publications will be enhanced through cooperation with scientific publishers. The workflow from the author's data into the PANGAEA system until final publication will be formalized and documented by means of a ticket system. Establishing a data curation centre and a customer support centre constitutes a milestone on the MaNIDA roadmap. For example, help in visualization of data in plots, profiles or maps are provided. MaNIDA has strong connections to partners/users in T2.1, T2.4 and T1.6.

In coastDat and COSYNA results from T2.1, T2.2, T2.4 and T4.1 will be collected and relevant data/results will be offered to the Klimabüros (T4.3), Climate Service Center, other consulting centres and interested groups. In consideration of a needs review of our clients (more than 60 clients with different interests), relevant data will be prepared and result in information offered in knowledge databases. Aggregated information from coastDat and COSYNA (T4.1) will be linked

closely together and data access will be optimized such that societal groups will profit from synergy effects of a novel database. Implementation details are: including coastDat and COSYNA in MaNIDA, selecting relevant data and preparing information for interest groups, develop tools and applications for using data from the database for the public, linking coastDat and COSYNA more closely, and analysing the needs for data (variables, regions).

Concerning biological data, DIVERSE will integrate workflow concepts over web services like GALAXY for data processing using AWI's high performance computational and storage resources. Storage and access to biological diversity data will be implemented as extensions of existing information systems. For example, DIVERSE will extend PANGAEA's event-based concept by a sample-based approach, allowing for meta-data reference to primary data in existing public sequence archives, in connection with offering derived data (secondary data) stored locally. In addition to a close collaboration with PANGAEA in managing biodiversity data, data analysis workflows will harvest primary biodiversity data provided by the GBIF network as implemented in MaNIDA. Main partners in PACES II contributing data to DIVERSE and extracting information are in T1.2, T1.5 and T2.1.

Experiences from C3Grid and ESGF are the basis of an implementation of a data archive for modelling data with user support. The data lifecycle of model output needs specific support. In this work package specific tools will be provided for producing metadata, which are necessary for data reuse and assistance will be given for scientists in the ingest process of high volume model data into long term archives. Further developments will include an enhanced portfolio of distributed processing features. Tools for metadata handling will support users in the data ingest process.

Expected Results summarized:

- Harmonized technology across different information systems in form of a data and information portal, supporting data life-cycle management.
- Integrated tools for the generation of enhanced data products and for an improved data re-use in research, including user and curation support.
- Implementations of and experience in new technologies for channelling data as information to science communicators and interest groups effectively, allowing to support scientific communication with stakeholders sustainably.
- Potential transfer of such new technologies into other commercial fields of the information society.

Workpackage 3: Providing information – enabling knowledge

Coordinators: I. Meinke (HZG), K. Grosfeld (AWI)

Mission statement

This work package provides a structure to enable scientific knowledge of coastal and polar issues in the public. People's perception and understanding of this knowledge are analysed, research results are assessed and adaptable information products for stakeholders based on scientific insights from global to regional scales are developed.

Challenges

The transfer, acceptance and implementation of scientific knowledge among stakeholders and the public at large is facing obstacles:

Competing claims on knowledge, be they interest-lead or culturally constructed, often hamper the dialogue between science and stakeholders. The questions to be targeted are why information does not equal knowledge and why knowledge does not necessarily end up in action. There is clear need for an analysis of the social-cultural system, the predisposition of interests and interest groups, the power relations and governance structures; as well as the analysis of the building communication elements of an exchange between societal needs and values.

The dissemination of existing scientific knowledge within the public and among stakeholders is another challenge. Research activities on specific topics are often scattered and fragmented, which hamper laypersons to assess, and to access scientific results according to their requirements. Also, the research design and thus the research results are mostly not tailored to stakeholder needs nor are they adaptable to the public reception in many cases.

Finally, it can be observed that the confidence in climate science and the described climate impact on Earth system (on global, regional or local scale) in general is diminishing. For example the controversial discussion on errors in the Intergovernmental Panel on Climate Change Assessment Report 2007 raised distrust in climate and environmental science output, leading to a rejection of scientific advice.

These challenges can be tackled by improved communication based on better understanding of the science-stakeholder-policy interface. Given the existence of dialog structures across institutions, the particular aim is to more effectively connect and strengthen those structures. Another important point for this workpackage is to create and establish pathways from the research results of the various other topics to this workpackage.

Current Activities and Previous Work

Two main tasks concerning the science-stakeholder interface can be described. One is to explore the range of perceptions, views, questions, needs, concerns and knowledge in the public and among stakeholders about the coastal and Arctic environment at large and about climate, climate change and climate risks, and to develop appropriate methodologies for doing so. This also includes the analysis of institutional structures and setups at various scales in order to explore how different levels of decision-making interact (e.g. national and international policy contexts).

The other task is to convey the content of scientific knowledge to the public, to the media and to stakeholders. This includes communicating the limitations, risks and chances of such knowledge, the known uncertainties and the unknowable, as well as the limited role of science in complex social decision processes.

The following key elements of the science-stakeholder interface can be assigned:

1) Analysing and monitoring of regional perceptions. For example, two surveys were conducted among people living at the North Sea coast and in Hamburg about their concerns. Both populations share the perception that the major risk of climate and climate change is represented by storm surges (related to increased sea level and intensified storms), but surprisingly, people in Hamburg, who are less threatened by storm surges, are more concerned about climate change. This can be compared to the results obtained in other countries, as similar surveys are currently being conducted in the Netherlands, Spain and the UK.

2) Assessment of the current knowledge about regional climate dynamics, its changes and impacts. So far, one report has been published together with BALTEX for the Baltic Sea basin (BACC) and one together with CliSAP for the metropolitan region of Hamburg.

3) Science-stakeholder dialog maintained by the regional climate offices (Norddeutsches Klimabüro and Klimabüro für Polargebiete und Meeresspiegelanstieg) and the newly established “Nordseebüro”. After six years of experience in regional climate services, certain dialog forms have been established in the science-stakeholder dialog: About every week members of the regional climate offices are invited to contribute to a public event with talks or discussion rounds. Media interest in climate science issues and related changes in coastal and polar regions has been constantly high. Other dialog forms are expert interviews, media relations and answering direct requests on specific regional climate issues.

From this dialog process, public information needs on regional climate change are derived and used to design adaptable information products. One example of these information products is the North German climate atlas, an internet tool, which became operational in 2009. The atlas allows users a direct and interactive access of 12 regionalized climate scenarios. Another example is the sea ice portal, which aims at gathering all important information about sea ice, its formation processes, climate relevance and climate vulnerability for a German audience (e.g. public, teachers and journalists, stakeholders). Knowledge of the actual sea ice situation, of recent research activities on sea ice, and an easy access to archived historical data by use of prepared data products and graphics foster the communication of the public with the scientific community.

Objectives

The objective of this work package is to build up a framework to enable a dialog between science and stakeholders in order to generate adaptable and usable scientific knowledge. This dialog is based on scientific knowledge in consideration of societal (incl. political) needs and cultural values on the one side and scientific insights with partly limited scientific methods on the other side. This structure must be developed on principles of sustainability, making scientific results available to our stakeholders in a target-group specific, meaningful and conclusive way and also generating scientific results based on input obtained from the stakeholders. The dialog feeds back into the scientific process of PACES as a whole, as it clarifies the significant HGF-specific goals of societal relevance of HGF research.

Expected Results and Implementation

The work package contains three main and inter-related elements to be simultaneously performed:

Analysing the socio-cultural dynamics and context knowledge of actors and agents as well as institutions with respect to user conflicts and the current marine policy discourses, including the power structures and governance patterns in which planning and management measures take place. Behind the science-policy exchange, including the determination of competing knowledge claims, the risk perception of laypersons in society and their intrinsic motivation of managing and constructing future development of their environment and life world have to be analysed and evaluated. With the post-normal situation in mind, there is a need to deal with special interests and specific marine and climate change policy. Guiding questions will be: what kind of decision taking and making pressures exist and on which scales are they relevant (private, local community, global)? In which contexts do decision makers have to function? What level of acceptances of planning strategies in the public at large is to be expected? And which information needs are obvious?

Assessment of scientific knowledge: Networks are established and continued to summarise, discuss and assess scientific knowledge for specific regions, dealing with interactions between the participating scientific institutions and the public as well as key stakeholders. In this way,

tailor-made communication products for different target groups based on the science-stakeholder dialogue can be developed.

Science-stakeholder dialogue: Suited dialogue forms are developed to enable two way communications on the basis of scientific insights and public needs. From this dialog information demands are derived to develop adaptable information products.

Expected results are:

- Socio cultural dynamics: Better understanding of public and stakeholder perception of marine and climate change. This includes better understanding of user conflicts, power structures, conditions and benefits of stakeholder involvement and different forms of governance in a coastal management and climate context. Economic, ecological and political issues of coastal management will be explored and related to the role of scientists, scientific data and theories. The results produced in Topic 2, for instance in WP1, can be used in this process.
- Assessment: Global, international and regional research networks dealing with sea levels, coasts, the North Sea, the Baltic Sea catchment and Northern Germany will build regional knowledge platforms for example such as the “Mini-IPCC” reports BACC and NOSCCA to summarise, discuss and access scientific knowledge for specific regions.
- Science stakeholder dialogue: The insights of the first two parts of this work package will help develop and continue suitable dialogue forms and communication products to maintain regional services related to coastal climate and sea level at HZG and AWI (“Regionale Klimabüros”), and to marine ecosystems (“Nordseebüro” at AWI), supported and complemented by the communication departments. As part of the dialogue process, products generated in WP2 are adjusted in terms of specific user needs. For example, user oriented products around research topic ‘sea level change’ will be developed. Both expertises can be combined as the institutes cover different research aspects of sea level change from a local, regional and global aspect.
- Feedback on scientific programme: Stakeholder needs are determined, open and relevant societal questions will be determined, and the value of scientific knowledge for the public and stakeholders will allow adjustments of the scientific programme. This includes improved distribution and availability of targeted information, knowledge and understanding of coastal and polar systems among different societal groups or actors.
- Specific results of this WP associated with private sector stakeholders are used as market analysis for potential further business development (e.g. spin-offs).

Implementation

The work package is implemented in PACES and connected with the broader HGF-research program. In particular, it is related to the HGF Cross-Programme Initiative REKLIM, to the climate service concept of the Climate Service Center CSC as well as to the ESKP portfolio. Also the risk-management approach of CEDIM and the activities of “Technik, Innovation und Gesellschaft” at KIT offer useful partners.

Milestones and Deliverables

Analysing and monitoring of regional perceptions:

Socio cultural dynamics

- Cross-country comparisons of human perception of coastal change and risks.
- A tested concept for identification, description and interpretation of cultural and socially determined Ecosystem Services.

- Analysis of stakeholder interests, governance structures and management strategies (e.g. Marine Spatial Planning).

Assessment

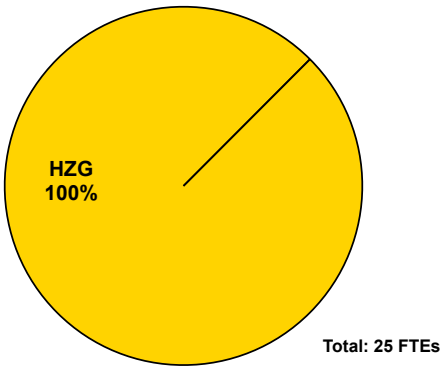
- A second assessment report on climate change in the Baltic Sea catchment (BACC II) is expected to be published in 2014. A first report on climate change in the North Sea region (NOSCCA book) will be published in 2015. A second report on the metropolitan region of Hamburg will be launched in 2014.
- Dissemination of PACES and REKLIM results through regional climate offices, international Earth System Science projects, offices and communication departments.

Science stakeholder dialogue

- Dialog forms and adaptable information products based on PACES research will be developed. Based on this dialog process, operational information products will be established, such as the “sea ice portal”. This should be first realized in German language for our direct stakeholders and can be expanded to other valuable long-term data sets available in PACES. These information products will help to develop e.g. strategies for a sustainable North Sea ecosystem management and appropriate climate change adaptation strategies. International earth system project office/s will provide an interface for exploring their wider application for other global regions.
- Tailored summaries of research results for stakeholders of different sectors: For example, the findings of BACC II, as well as NOSCCA, will be translated into a non-scientific and into the Baltic Sea region languages to reach relevant regional and local managers and the general public in the different countries of the regions. In addition, regular policy briefings and targeted cross-media information products on relevant issues related to changing coastal and polar systems will be published as well as new media products will be tested and – if suitable - established (e.g. social media, web media streams) for pipelining compressed scientific information into the society and to relevant stakeholders.
- Feedback on stakeholder needs to science: Recognizing gaps of knowledge helps to compile scientific targets that are necessary to adapt existing research activities on a rapidly changing Coastal and Arctic Systems. For example, a report on stakeholder research and recommendations for NOSCCA II will be published in 2017. Feedback from international Earth system science projects and their continuous exchange with global scientific peers and stakeholders can be solicited to contribute to a dynamic co-design of research and products.

Service Topic: Climate Service Center

Coordinator: G. Brasseur (HZG/CSC)



Mission Statement

Help society (business, public service) (1) cope with climate risks and opportunities, and (2) develop sustainable living and production systems.

The Climate Service Center (CSC) is a National Knowledge Transfer Center for Climate Change. It is not a research institution, but a Center that assembles, integrates and disseminates products and services to customers in Germany and elsewhere. More precisely, the mission of CSC is *to facilitate the transfer of state-of-the-art and user-oriented scientific information to society*. The Center develops and provides science-based products and services in support of society's adaptation and development needs. Through a network of partner institutions, the Center offers advises to decision-makers and other users from the scientific, economic, political communities and from civil society.

CSC bases the development of its products and services on the scientific methodologies and approaches developed by research institutions in Germany and elsewhere, and specifically by Helmholtz Centers. To facilitate the transfer of scientific knowledge produced by these research institutions, CSC has developed strong relations with different scientific institutions, and several staff members of the CSC have joint positions between CSC and specific research institutes or universities.

To a large extent, the Center acts in response to requests formulated by customers. The majority of the products and services produced and delivered by CSC results from the demand that exists on the market. Therefore, in most cases, they cannot be identified years in advance.

Challenges

Climate and other environmental changes with its risks and opportunities pose major challenges to society. Many of the related policy and business decisions made today will have a profound impact on our future economy and lifestyle. However, decision-makers often lack the necessary expertise to include the climate dimension in their decision-making process. The Climate Service Center, which was started in 2009 at Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research (HZG, former GKSS) addresses this issue and provides stakeholders in the public and private sectors with help to design policy options that include the climate perspective. CSC intends to build a bridge between the climate system research and the users of climate information. As an interface, it brings together local knowledge from various agents involved in climate research with the requirements of the spectrum of users.

Many corporations in the business world recognize the importance of climate-related issues, specifically regarding mitigation issues (i.e., reduction in their greenhouse gas emissions), but have less understanding of their needs neither to adapt to future climate change nor to include the climate dimension in their long-term planning process. An important issue are the time scales involved: companies usually make decisions covering periods of 5 to 10 years, while climate related issues span over several decades and even centuries.

CSC acts as an *independent facilitator* that offers a variety of data and services to users in the public sector and in the corporate world. It disseminates high-quality data and information

resulting from scientific research and presents them in a customized, easily accessible and immediately usable form. The services include interpretation of scientific results provided by research institutions such as the Helmholtz Centers together with an analysis of related uncertainties. Further, CSC supports users to deal with issues related to climate vulnerability, resilience and adaptation.

CSC is a *neutral platform* directly linked to the efforts conducted by the scientific community. The concept of neutrality is central to the credibility of the Center.

Current Activities and Previous Work

The operations of the Climate Service Center started in mid-2009 with the support of three staff members whose role was primarily to establish the foundations for the new institution. Today CSC hosts approximately 30 staff members and 10-15 long-term guest scientists.

The first task was to assemble a strong, enthusiastic and diverse team that could carry the responsibilities assigned to the Center. The department heads were recruited in mid-2010 after an open search and many candidates' interviews. The Center, located in Hamburg, soon moved from a small bureau into larger offices in the building currently occupied by the German Climate Computing Center (DKRZ). It expanded further with the arrival of additional staff members and the participation of CSC in several European and national projects. Again, CSC had to find more space; it moved into the historical Chilehaus located in the middle of the business area of Hamburg.

The second task was to identify the strategic directions for the Center, its place and its role in the German scientific and institutional environment, effective partnerships in the research and business communities, the scientific approaches and methodologies that would generate relevant high quality services, and the target groups that could be best served by CSC. The first relations with customers had also to be established and the first products developed. Since no model for an equivalent climate service was available, innovative approaches and original thinking had to be encouraged. A strategic plan was approved in late 2010. It serves as the basis for today's activities of the Center.

The third task was to demonstrate that knowledge transfer from research to different sectors of society responds to an important need, and that services and products developed at CSC provide added values to the German economy and specifically to important stakeholders in the corporate world and public services. Here again, the development of partnerships and alliances has been a central aspect in CSC's development. To facilitate relations with potential customers, a business plan is currently being developed in cooperation with a specialized company. This plan will constitute the basis on which products and services will be developed, promoted and disseminated in the corporate world and public services.

The BMBF project supporting CSC has been implemented in the HZG and is administrated by PT-DLR. It was favourably reviewed in March 2012 by BMBF and by HGF. This result has opened the way to a long-term institutionalization of CSC: The Center will be integrated in the Helmholtz Association after the first phase of the project is completed. With the first lessons learned, the experience acquired in the last three years, and an entrepreneurial spirit, further business developments are to be expected before the completion of the first phase (until May 2014) directly financed by BMBF including the release of new products to targeted groups of customers.

Several challenging prospects, however, remain. The first one is to consolidate CSC into an institutional setting that offers a rather secure financial foundation, that preserves the high quality and neutrality of services and products, that offers the flexibility and agility required by

the customers in the corporate world and that allows the implementation of an effective business model. Whatever institutional arrangement is adopted, it is important that it preserves the objectivity and neutrality of CSC, and keeps the Center close to the science conducted by the entire German community.

The second, and perhaps less immediate challenging prospect is to broaden our vision towards the growing requirements of a society that is facing unprecedented global and regional problems: the need to redesign its energy system, to develop a new agriculture, food and water model, to deal with a growing world's population and a rapid urbanization process, to reduce poverty and inequalities, and to promote access to health to each citizen of the world. In other words, to move from a development model based primarily on immediate financial returns to a development model that recognizes the price of the common goods and the limit of available natural resources. Since Germany has been at the forefront of these questions and is promoting a transition towards a more sustainable world, CSC could be regarded as the seed for a broader, more inclusive international network focusing on the relations between climate and society and related interdisciplinary sustainability questions. CSC could become a key node in this network and disseminate knowledge to those who will have to conduct the profound transformations facing society during the 21th century.

Objectives

The CSC's long-term objective is the development of an improved transfer of climate knowledge and specifically to provide advice on pressing questions related to climate change, environmental problems and sustainable development. This includes the development of innovative communication processes between a specialized research community and a broad spectrum of actors in society. Transfer of authoritative science-based information is a prerequisite to the development of sustainable adaptation strategies. An important aspect to be captured by climate services is the role of social and economic sciences, cultural behaviour, communication methods and psychological aspects in the dialogue between the scientific community and the societal actors. One of the specific roles of CSC is to help the HGF Centres to initiate a dialogue with stakeholders and to value the societal importance of their research. Even though CSC is part of the "Earth and Environment" Research Field, it can strengthen the transfer of societally important information generated by other HGF Programs of importance for sustainable development. By integrating CSC in one of its important Programs, HGF will deliver services which enable society a) to limit economic damage caused by climate change, b) to build resilience to future climate change and c) to take advantage of opportunities related to climate change.

CSC will focus on themes that are highly interdisciplinary and require cross-departmental approaches and activities. Currently these topics are (for details and future planning see WP1-6):

1: Networking and Synthesis of Existing Knowledge: Integrate climate change research and adaptation practices in Germany. Develop an interdisciplinary network of research institutions that provides an up-to-date and comprehensive knowledge base.

2: Determination of Stakeholders' Needs: Determine the need of the various stakeholders for information on climate, climate impacts and adaptation, and to stimulate practice-oriented climate research.

3: Development of Demand-Oriented Products and Services: Develop demand-oriented products and services in order to raise understanding of climate change and the related

uncertainties, recognize threats and opportunities, and support decisions on adaptation to climate change.

4: Establishment of Target Group-Oriented Communication: Intensify the dialogue among various stakeholders in order to enable all social groups to adapt to climate change.

5: Capacity Development: Develop educational modules and practical learning activities for professionals, decision-makers and other practitioners in Germany and other countries of the world.

6: Institutionalization of Climate Services (inter-/national level): Develop concepts, services and products that facilitate the institutionalization of climate services at the national and international level.

Expected Results

The current *portfolio* of the products and services offered by Climate Service Center to customers and other users is the following:

- Distribution of climate related data including model projections and scenarios at the regional and global scale tailored to the user needs.
- Development of user oriented products based on climate related model data and observations.
- Development of economic assessments of climate impacts.
- Policy advise on climate mainstreaming.
- Network facilitator for climate related institutions and programmes.
- Cross-sectoral advisory service for the use and interpretation of climate related data and information.
- Organization of workshops for professional discussions between scientific experts and decision makers.
- Organization of educational seminars on climate-related issues (climate modelling, climate impacts, climate economics, vulnerability, risk management, adaptation science, climate communication) for professionals in the business and public administration.
- Detailed studies of experts appointed by CSC on specific scientific or societal issues, raised by users and customers.
- Provision of state-of-the-art knowledge on climate-related issues through the publication of educational material (dossiers), synthesis books, brochures, web pages, lectures, scientific reports, etc.
- Periodic publication of a “News-Scan” that highlights important new science
- Organization of an annual conference focusing on a particular climate-related topic open to policy- and decision makers.
- Provision of detailed responses to questions posed by stakeholders on climate-related issues.
- Development through established research institutions of research projects that address complex scientific questions posed by stakeholders.
- Publications in peer-reviewed journals.
- Contribution and support of the community wide klimanavigator.de web portal that provides information about climate research activities in Germany conducted by more than 40 partner institutions.

Workpackage 1: Networking, Synthesis of Existing Knowledge and Expert Judgement

Mission

Integrate climate change research and adaptation practices in Germany. Create a comprehensive knowledge base by developing an interdisciplinary network of research institutions. Develop expert judgement and evaluation of scientific approaches.

Networking and synthesis of existing knowledge occurs through the integration of results produced by scientific research in Germany and elsewhere. CSC brings this information at the interfaces between climate science and society, both top-down (from the results of the research to society) and bottom-up (from the needs of society to the scientific community).

Challenges

Many institutions and research programs are dealing with questions of climate change and adaptation. Perspectives, methodologies and foci are quite different, so that maintaining overview over this complex landscape is a major challenge for many stakeholders. Synthesis, interpretation and expert judgement by an organized network of scientific researchers is key to inform decision-makers.

Stakeholders in business, industry and society are often not able to ascertain the current state of the science that is relevant for their field of action. Decision-makers from administration and government need reliable information on what climate change and adaption means for their business and how to meet these changes. A clear definition of their needs is a necessary prerequisite for an expert advice available from a climate service (cf. WP2)

An important task for CSC is therefore the development of close relations with decision makers in public service and the corporate world, and specifically with professional associations and individual companies affected by extreme climate variability and long-term climate change. Users need guidelines on how to deal with the increasing flood of different climate related information and how to determine the best approach to solve their question. A challenge for CSC is to develop a comprehensive network of German research institutions and of climate service providers. The German landscape is getting more and more complex with different competing institutions at different levels.

Current Activities

CSC sees itself as a “Community Builder”. To develop innovative products of direct interest to different stakeholders, different networks have been established:

--*Network producing Regional Climate Projections for Europe and Germany:* Many customers are requesting climate projections at a rather high spatial resolution. This is the case, for example of the federal states in Germany and environmental administrations and private corporations. CSC participates with other research institutions in Germany (DWD, PIK, University of Cottbus and others) in a network that is developing projections of regional climate change and climate impacts in Europe and Germany. The network will not only provide mean fields, but also a bandwidth that is a good image in the uncertainties associated with these projections. The work conducted in Germany will complement the simulations produced by the WCRP Project CORDEX in the framework of IPCC.

--*Network of Experts producing Synthesis reports*: The Climate Service Center is developing a project through which panels of experts are periodically producing state-of-the-art, authoritative science reports dealing with a question of societal relevance. The panels are composed of the

best world experts representing different disciplines. They offer different perspectives and my have complementary views on a given question. A first example is the synthesis and prospective report on the topic of terrestrial water systems under climate change with the main focus on surface and groundwater related to Germany.

--*Network of German Institutions producing a Climate Assessment for Germany*: CSC has for example initiated joint initiatives with different programme coordinators in the Helmholtz Association: the “Regionale Klimabüros”, REKLIM, TERENO and CEDIM. This cooperation is growing in a constructive spirit. Common studies are dedicated to climate change topics and adaptation measures for the whole of Germany. The network has been extended beyond the HFG to include scientists from the Max Planck Society, the Leibniz Society and universities with the purpose of preparing a *national climate assessment for Germany*.

--*Network of Institution on Climate-Induced Migration:* A network of institutions is working on climate-induced migration. It was designed to create a synergy between various researchers, stakeholders and governmental institutions and as a response to the article 14 (f) of the Cancun Agreement.

--*Network on international Institutions support a German Investment Bank:*To bridge the gap between research and practice, a network dedicated to the “Management of Climate Change Induced Risks“ has been established in cooperation between KfW. The network is being developed to establish a forum of experts from research and outreach institutions. It brings together the international expertise on climate change (climate modelling, impact, adaptation / disaster risk reduction and vulnerability assessment) for developing and emerging countries and will help investment banks who are providing investment funds for infrastructures in these regions.

--*Network of German Institutions developing a National Climate Portal:* As part of its role as a “community builder”, CSC has taken the initiative of creating and supporting a national climate portal. This system called “Climate Navigator” can be accessed on the web at www.klimanavigator.de.Its content is decided by the representatives of the 40 different German research institutions that are affiliated with the project. CSC provides technical support, but leaves the decisions on the content of the site to the community. The site provides an integrated view of the climate research landscape in Germany.

Objectives

The reinforcement of current research network and the development of new networks at the interface between science and society will have several benefits: inform the community about current activities, building a knowledge network and document the sources of information and existing data. The Climate Service Center will become the central location to obtain all information about networks, former and future research as well as experts in specific scientific fields, and - above all - to evaluate the different approaches, methodologies and results.

An illustration of the role of networks is provided by a few concrete examples. The network dealing with climate-induced migration will create a platform for exchange and for the future production of common papers, workshops and conferences. The research forum “Management of Climate Change Induced Risks" will contribute to an assessment of risk analysis and future demand on adaptation activities. Thus the network aims to bring together relevant knowledge for climate change induced action in an international context (see WP5).

On the one side, the different networks and our synthesis of knowledge will help service a client with specific needs for expert judgement, on the other side, establish a network of global experts on climate and climate change.

While most of the current networks connect diverse research community, CSC is currently working at the development of a "Network Forum" that will include the different providers of climate services in Germany. This Network will help coordinate service activities, avoid duplication of efforts and develop more coherent approaches at the National level.

To meet the needs of a globalized economy CSC-networking has even to go beyond Europe but must include all continents. To help developing climate services all around the world an international Climate Service Partnership (CSP) an informal Association of approximately 100 organizations world-wide, that focus on climate services in different countries, was funded (see WP6 for details). Above all the developing countries need detailed information and counselling.

Expected Results

The Climate Service Center will synthesise, evaluate and disseminate existing knowledge. The spread of possible climate change and impacts needs to be considered and communicated in an appropriate way. Special assessments on new vulnerability or impact studies and adaptation strategies will help compare and classify various different approaches. This will enclose the communication and discussion of methodologies and their robustness with the different stakeholder communities, as well as the spread of changes and impacts. Special offers in the field of capacity building (see WP5) will enable decision makers in politics; economy and administration to better estimate the different methodological approaches and draw their conclusions.

Of great importance is the integration of different knowledge platforms. The Klimanavigator should become a central contact point to link all different web sites dealing with climate change and sustainability in Germany. The different offers of UBA-Kompass such as “Klimalotse” and “Datenbank” as well as the “Netzwerkforum zur Biodiversitätsforschung” (http://www.biodiversity.de) or the new PIK platform on climate impact (www.klimafolgenonline.com) will be connected with the Climate-navigator.

Klimanavigator will become the principal gateway to all climate and adaptation knowledge and provides "the synthesis of synthesised information" in a non-scientific language for those who have to respond to climate change. In cooperation with the European Environment Agency (EEA) a network of European climate information and service tools will be established and displayed on www.klimanavigator.de.

The Climate Service Center is the most reliable institution in Germany to enable stakeholders to estimate their vulnerability or even chances resulting from climate change. They learn how to react to climate impact and measure their individual adaptation strategies following the specific needs of their corporation.

CSC is also partner in the following European projects (supported by other financial sources) which contribute to WP1:

- ACCENT-Plus - Atmospheric composition change: a European Network-Plus
- CONGO – “Klimawandelszenarien für das Kongobecken”
- IMPACT2C - Quantifying projected impacts under 2°C warming

Workpackage 2: Determination of Stakeholders' Needs

Mission Statement

Determine the need of the various stakeholders for information on climate, climate impacts and adaptation, and to stimulate practice-oriented climate research.

Consultation with the different sectors of society (various industries, government, public administration, science, educational establishments, civil society, non-governmental organizations, the interested general public) is increasingly required to establish a meaningful and sustainable knowledge basis, which will address their needs and support the decision-making process. The CSC's range of products and services are closely aligned to these different needs. In a first step, the needs of the different stakeholders for information and services are being systematically determined. The aim is to establish and develop a CSC user community from the public and private sectors, and to initiate cooperation and projects with partners from the business, government, administration and science communities.

Challenges

For a climate service to be efficient, a clear understanding of user needs is a prerequisite. However, the concept of climate service is new and largely unexplored. Thus on the one side, until today, many customers know only partly which services and products they need for the sustained development of their business. Therefore, an important task for CSC is to develop a continuous costumer dialogue along various channels, guaranteeing a bi-directional communication with a clear, well-documented understanding of what users expect from climate sciences in terms of future research and the like. On the other side, a marketing concept for climate services to serve costumer needs is required, taking into account public, e.g. freely available, and private, e.g. services with a client-specific prize, aspects of climate services.

When identifying requirements of decision-makers, it is important to document the importance of complex climate issues for the vulnerability of their business, and to recognize that management decisions follow different time scales than the time scales associated with climate change. To be successful, CSC must acquire a deep understanding of the level of knowledge of the customers and analyze the decision-making process that is central to their business.

Current Activities and Previous Work

The determination of stakeholders' needs is a continuous process and demands a sustained dialogue process. Important steps are (1) the identification of key-clients and users of CSC products and services from the industries and various sectors that are particularly affected by climate change and its impacts; (2) the prioritization of the needs of various stakeholders through targeted surveys; (3) the design of products and services together with customers and the presentation of the CSC portfolio at practice-oriented events for direct communication with stakeholders in various sectors and governmental departments.

During the first years, activities were limited to the priority sectors: sustainable agriculture, forestry and food industry, infrastructure, finance, natural hazards and defence as well as international climate policy. Examples of current and previous activities supporting this work package include: A *User Needs Analysis* in the Agriculture and Water Management Sectors, for which more then 1.000 user groups were identified. These received a questionnaire referring to their status of knowledge on climate change and its consequences for their action fields and their information needs on climate impact and adaptation strategies, in particular. In order to detail these needs, a stakeholder workshop for more concrete suggestions of required products

and services was realized. A number of priority issues were elaborated during the workshop and translated into first pilot projects, gradually realized such as a Glossary (Synthesis of existing glossaries and recommendations), the integration of data within interdisciplinary maps (agro-climatic atlas), etc. (see also WP products and services).

In another pilot project aimed at establishing a sustained *User Interface*, the CSC combines the expertise from business and science in a joint expert initiative. A team of interdisciplinary authors will work on closing the gap between climate change knowledge with its underlying uncertainties on one side and the business conditions under which management decisions have to be taken in private and public sectors on the other side. The prominent questions of the enterprises regarding climate change issues are seized individually in order to customize the relevant climate information to the needs of specific economic sectors and business companies. The climate perspectives that will be posing challenges on the enterprises in certain business sectors are presented comprehensively as specialized booklets.

Another pilot project still in the conceptual phase, is a *vulnerability study* for the physical landscape of low mountain ranges in eastern Germany, including the Länder, Saxony and Bavaria, and neighbouring states. This region is expected to be an especially vulnerable region due to projected decreases in (summer) precipitation and increasing temperatures as a consequence of global warming. Based on regionalized, e.g. downscaled climate information, consequences of climate change and extreme events for the water and forestry sector will be assessed, and, together with regional stakeholders, adaptation options developed and communicated, taking into account various economic aspects.

All these pilot projects take place in an environment of various dialogue formats, including regular visits to key-clients and key-players (corporations, associations and governmental institutions), standard networking formats during conferences and individual dialogue formats during stakeholder events, including periodic stakeholder forum meetings. The web-based help-desk system (enquiry system established to respond to questions posed by the public through the web) provides a feedbacks on users needs, categorized by sector and topic (see also WP3 products).

Objectives

CSC aims at establishing a continuous dialogue to better understand and address the needs of various societal actors related to climate change induced risks and related sustainability issues. The implementation of a business model aims at the systematic determination of stakeholder needs in a growing number of sectors, including the communal level.

In order to reduce society's vulnerability to climate change and to enhance its adaptability to unavoidable impacts, business and other actors have to integrate possible climate change issues into their corporate and administrative planning. Adaptation at an early stage helps reduce risks and exploit the opportunities offered by climate change. CSC raises awareness and provides the relevant information, customized to the users' requirements, thus decreasing societies' vulnerability to climate and other environmental changes.

Expected Results

A sustained dialogue is established through an active stakeholder network. CSC is recognized by decision-makers as one of the key providers of climate services in Germany, and functions therefore as a national clearing-house that synthesizes knowledge from different sources for a multitude of users. CSC and its partner network are able to understand the needs from the various societal actors and translate these needs into corresponding services and products. Different user interface platforms are established. Products are developed jointly with users and

address their needs. Succinct information on climate change and its impacts are provided in concise and easily understandable documents (booklets, etc.), that focus on business lines and other special societal needs. CSC and its partner institutions respond to the needs of additional economic sectors, and the number of services and products jointly developed and offered to the customers is growing.

Workpackage 3: Development of Demand-Oriented Products and Services

Mission Statement

Develop high-quality, reliable, and demand-oriented products and services in order to (1) raise understanding of climate change and the related uncertainties, (2) recognize threats and opportunities, and (3) support decisions on adaptation to climate change.

CSC focuses on the development of science-based, high-quality products and services, and deliberately refrains from initiating and conducting *in house* research projects. To facilitate the transfer of knowledge, however, CSC encourages the joint affiliation of some of its staff members with research and education institutions. The Director of CSC, for example, is an External Member of the Max Planck Institute for Meteorology (MPI-M), Professor at the University of Hamburg and Distinguished Scholar at the National Center for Atmospheric Research (NCAR) in Boulder, CO. The Head the Department “Climate System” is a part-time staff member of the Max Planck Institute for Meteorology (MPI-M), where she conducts her research and supervises several PhD students and post-docs supported by this institution. She is also a Professor at the University of Bergen, Norway. The Head the Department “Economics and Politics” is a part-time staff member of the UFZ in Leipzig and Professor at the University of Frankfurt-an-der-Oder. Two staff members in this CSC Department are associated with different universities. The research activities performed by these different groups are directly accessible to CSC for the development of its products and services, and serves therefore the stated objectives of the Center.

Challenges

Society has been informed about climate related problems and their consequences for society. A major challenge for decision-makers is to develop responses that will bring the adequate solutions to the climate problem. Several approaches are possible ranging from mitigation options to geo-engineering to adaptation. Risks will have to be managed in the future, and this requires the authoritative information based on science-based products and services. Another challenge is to design the products that will effectively help decision-makers to respond to expected impacts of human activities. To be at the highest quality and recognized as such by users, products and services have to be generated by scientists who remain closely involved in research activities. A challenge for CSC is to maintain the link of its staff with research groups at the highest level. The products generated by CSC must be world-class.

Finally, the products and services requested by customers require targeted, flexible and interdisciplinary approaches to address the wide array of products needed by the different users. The mode of operation to address the needs of users is not to favour the mass development of a small number of products, but to develop specific products that address the different individual needs a few customers.

Current Activities and Previous Work

--*Regional Model Projections.* Most products developed at CSC are based on a profound knowledge on current and future climate conditions and hence on state-of-the-art climate model simulations. To respond to the demand, CSC contributes to the establishment of this database by performing (or financing/supporting) climate projections and other simulations. An example is provided by the regional model projections performed as part of the EURO-CORDEX initiative and the ReKlies-De project (Climate projection for the federal States including downscaling for Germany of the new IPCC projections). The quality and reliability of CSC's products, services, and expert judgments based on results of climate model simulations will greatly benefit from our involvement in international initiatives through the direct access to multi-model data and through the scientific knowledge gained.

--*Support of the KLIMZUG Project.* The transfer of actual scientific results to subsequent scientific disciplines as well as to stakeholders and customers as data products, synthesis figures and reports is another contribution of CSC. The support of the BMBF-initiated KLIMZUG projects is an example where CSC supports the needs of the scientific community. For this particular project, CSC provides advice and support to regional adaptation projects in different regions of Germany. Here the task of CSC is to act as a facilitator, integrator and communicator.

--*Climate Fact Sheets.* The "Klima-Fact-Sheets" represent a product that provides information on climate characteristics for a distinct area of interest. CSC developed fact sheets based on a dedicated assignment from a customer in the financial sector. The sheets provide information on past, current and future climate traits of individual nations and regions around the globe. The customer requested a short, accentuated and focused product of 3 to 5 pages that is easy to understand and use for investment decisions.

--*CSC Reports*. CSC publishes periodically technical reports that summarize the outcome of projects or studies conducted by the Center or in cooperation with research institutions. An example is provided by the CSC Report on "Regional Climate Simulations for Europe and Germany: Ensemble Simulations for Climate Impact Research" that provides an overview on regional climate projections performed at MPI-M, CSC and other research institutions within the frame of different national and international research programs.

--*CSC Enquiry System.* CSC has developed an enquiry system (or help desk), whereby users can submit queries about particular topics or issues related to climate change. These queries are answered either by in house experts or in collaboration with external partners.

--*Projects conducted in response to an External Request* .When questions posed to the CSC cannot be answered easily with available data and standard products, but need specific analyses and developments, CSC considers the initiation of a research project, very often in cooperation with a scientific institution. An example of such complex question is the request to conduct a climate-risk analysis for international companies, including threats to the whole supply chain. Another example is provided by the "Heavy Precipitation project", initiated in response to questions posed by the "finanzforum/klimawandel". This last study requires the expertise of meteorologists, hydrologists, economists, ecologists, and communication experts and will directly involve external partners from insurances, engineering companies who will assess potential future damages due to heavy precipitation.

--*Support Material for Cities.* The "Stadtbaukasten" will address requirements of municipal stakeholders. It will consist of a modular catalogue that focuses on (1) adaptation measures, (2) climate-proof planning, (3) downscaling of climate projections and (4) public participation.

--*Adaptation Guidebook.* On the basis of the user needs analysis (see WP2), together with our existing knowledge and contacts, CSC has initiated the development of an Adaptation Guidebook that summarizes the key issues, methods and latest thinking in relation to adaptation. The aim of the guidebook is to enable stakeholders to get started, and make progress with adaptation planning.

--*Agroclimatological Atlas*. The Agroclimatological Atlas will provide an online atlas of possible changes in a range of agroclimatological indices across Germany e.g. growing degree-days, soil moisture content. Conducted in collaboration with the DWD, this project builds on existing information, and is conducted in close cooperation with diverse stakeholders from the agriculture sector including farmers, agricultural policy-makers, the insurance industry, and environmental consultancy groups.

--*Guideline Flood Prevention.* The guideline “flood prevention”, which focuses on the risk of small scaled flooding as a result of heavy rain events, is based on the concept of “flood pass”, the equivalent of “Energiepass für Gebäude”. It should strengthen the self-responsibility of landowners and house owners. The main objectives are to raise the awareness with respect to flooding from small brooks and the overloaded sewage systems. In a first step existing knowledge and best practices are merged to give a state-of-the art overview. The following steps contain the close cooperation with stakeholders and municipalities to develop the best communication strategies and to tailor the best tool to develop a spatial vulnerability map, which shows regions with a risk of flooding.

--*Climate Glossary.* A Glossary providing clear definitions of climate-related concepts is now available on the CSC web. It provides comparisons of climate related definitions in areas where many terms without precise definitions exist..

--*Economic Aspects of the Adaptation to Climate Change.* The documentation of two workshops (January and June 2012) synthesizing requirements for future research on „Economic Aspects of the Adaptation to Climate Change” in Germany has been published by CSC. The workshop series - initiated by CSC in joint cooperation with the Competence Centre on Climate Impacts and Adaptation (KomPass) at the Federal Environment Agency (Umweltbundesamt, UBA) and the Helmholtz Centre for Environmental Research (UFZ) in Leipzig - was attended by about 50 highly relevant participants from science, policy and other stakeholders. The workshops focused on case-study-based bottom-up assessments of adaptation measures and on the interplay between qualitative case studies and quantitative modelling approaches.

--*Newscan.*The News Scan is a monthly publication produced by CSC and sent to 8000 stakeholders. The document provides information on the latest papers published in the peer-reviewed literature on issues related climate change, climate impacts, climate adaptation, climate policy, energy and mitigation issues, and the communication of climate change.

--*Vulnerability and Adaptation.* CSC is developing multi-criteria tools for prioritization of adaptation measures. Additional work will concentrate on the development of a climate proofing instrument for adaptation projects. CSC is developing multi-stakeholder partnerships for risk management. The project investigates existing resilience partnerships and establishes protocols for action about social-ecological systems at risk.

To assure the basis and the quality of all CSC products, CSC staff has to be continuously trained and closely linked to science so that it stays up-to-date with the state-of-the art science. Therefore, CSC actively participates in national and international research projects and initiatives and is for example partner in the following projects (supported by other financial sources). These projects directly reinforce the activities in support of WP3:

- PEGASOS – Pan-European Gas-AeroSol-climateinteractionStudies
- C3Grid- Towards an INfrastructure for general Access to climate Data
- TFO – The Future Okavango
- BSH – Project KLIWAS

Future plans

The development of new products will respond to the wishes and needs expressed by actual and potential customers. Thus, it is not possible to foresee all the products and services that will be available in the coming years. Most probably, the existing portfolio of products will be expanded towards the certification of quality-assured datasets, expert judgment, and assessment and valuation of existing information platforms, as well as into the direction of multi-risk assessment.

A standard set of products and services will be the provision of climate change impact, vulnerability and adaptation assessments for individual sectors as well as in an integrated manner (for instance for cities), with full consideration of modelling, data and more general uncertainties. This will include more general syntheses of the current state-of-the-art knowledge about climate impacts, adaptation options and related challenges (e.g. sustainability issues) in the various sectors. We will periodically provide accessible syntheses (e.g. booklets) of existing knowledge, which is of relevance to stakeholders in the real world. Additional services will include user-needs tailored advises on adaptation planning. Risk management will be offered as an overarching strategy to handle climate-related risks. CSC will work with stakeholders to improve adaptation planning and implementation of these approaches to ‘real world’ issues. This activity will draw on a range of different analytical skills and expertise, and will be tailored to specific stakeholder requirements.

Adaptation to climate change requires a broad assessment, considering aspects ranging from the physics of the climate system down to the needs and aspiration of individuals. The interdisciplinarity of CSC allows for products considering the whole chain. For example, the development by CSC of criteria catalogues for sustainable adaptation options can serve as the basis to develop concrete adaptation plans at local, regional and global scale. A major challenge is to include climate-relevant criteria, considering both the resilience of adaptation measures.

The assessment of the economic aspects of the adaptation to climate change has started with a workshop series at CSC (“Economic Aspects of the Adaptation to Climate Change”) and will be further explored, aiming at the provision of products as for example databases of cost and damage functions and model simulations of economic adjustment costs in Germany. The findings will contribute to the criteria catalogue for sustainable adaptation options.

In the context of renewable energies, CSC will contribute to the activities of the Helmholtz Alliance ENERGY-TRANS "Future infrastructures for meeting energy demands; Towards sustainability and social compatibility.” In this context, studies are planned on the vulnerability of the (critical) energy infrastructure to climate change.

Objectives

The long-term objective is to develop a broad range of services that integrates the concept of climate change with other drivers of societal change. CSC will provide advises to help society develop a sustainable future by preserving natural resources and adapting living and production systems. It will contribute to the development and activities of the cross-cutting Earth System

Knowledge Platform (ESKP), originally proposed by CSC to widen its portfolio and now adopted as a new HGF Program.

These objectives call, for example, (1) for strengthening the synergies between climate change mitigation and adaptation; (2) for the integration of the challenges posed by climate change and loss of biodiversity;(3) for developing syntheses between regional climate change impacts and decentralized knowledge; (4) for considering climate change mitigation and nature conservation in issues related to agriculture, forestry, global food security and water resource management.

Workpackage 4: Establishment of Target Group-Oriented Communication

Mission Statement

Intensify the dialogue among various stakeholders in order to enable all social groups to adapt to climate change.

The mission of the CSC is to facilitate access to current results of research on climate and climate impacts for the different stakeholders. Specifically, CSC (1) develops user-specific instruments for communication of complex climate-related issues and of the associated uncertainties; (2) promotes the consultation and services and raise awareness for its partner network, and (3) develops various education and capacity building modules.

Challenges

Communicating complex knowledge on climate and sustainability issues to a broad spectrum of societal actors is an enormous challenge. Because climate change concerns everyone and is thus vividly debated in the media and in partisan circles, providing objective and authoritative information that is understandable by a broad public requires well-defined approaches.

A specific challenge is to communicate the importance of uncertainties that are associated, for example, with climate projections. Multi-model simulations provide a bandwidth of results that needs to be carefully interpreted and communicated to decision-makers who require reliable and directly usable data. There is often confusion in decision-maker's mind about the meaning and importance of model uncertainties.

The scientific community has attempted for many years to communicate knowledge about climate change. It has succeeded to create awareness on this question, but it has not fully convince the corporate world and even public groups that the climate dimension has to be taken into account in the long-term planning process of their business. Another important challenge is therefore to customize knowledge and tailor information to the needs of the corporate world and to the level of understanding of its managers.

Finally, a challenge to be addressed by communicators is the content and the tone of the message that needs to be addressed. In the past, the message has often been negative and alarmist. This has been needed to draw the attention of the decision-makers and of the public on the dangers of climate change. The focus is now increasingly on the solutions to be implemented to address the problem and on opportunities associated with important economic aspects such the reconstruction of our energy system, the development of a green economy, etc. The content of the message produced by CSC must be in line with these emerging broader issues resulting from climate change and related to economic endeavours. This is also an important challenge.

Current Activities and Previous Work

In the first phase of its existence, CSC has developed its corporate identity through a number of public relation events including its participation in a number of events such a “Climate Weeks” in Hamburg, an exhibition in the low energy Hamburg House at the Expo 2010 in Shanghai, etc. It has developed a web site and has produced media material and brochures.

Annual conferences: CSC has organized two large annual conferences for a broad public of stakeholders (around 250 participants). The first one was organized jointly with the Centre for Environmental Research – UFZ, Leipzig on the theme: “Under 2 degrees: How to limit climate change and its impacts“. The second conference was organized together with the Chamber of Commerce of Hamburg on the theme “Resilient cities: liveable – sustainable – climate friendly”. The third annual conference will be organized jointly with a large bank and will address issues at the interface between climate change and economic development. The idea behind the annual conferences is address a specific climate-related topic in the presence of several different groups of experts including scientists, business people, policy makers, administrators and journalists. Each year the event is taking place in a different federal state.

CSC-Website: The website www.climate-service-center.de is dedicated to a wide range of users. It provides a knowledge platform, that includes e.g., a climate encyclopaedia (Klimawiki), e-books, videos and the “news scan” prepared by CSC to alert stakeholders of the latest publications and climate change, climate impact, adaptation, etc.. The website can also be used by any citizen to formulate and transmit questions to which CSC or one of its partners will formulate a detailed response. 5000 different users visit the site by each month (1.3 million hits per year).

“Information campaign about the World Climate Summits in Cancún and Durban”: CSC has conducted two media campaigns about the World Climate Summits in Cancún (2010) and Durban (2011). They included: (1) briefings for representatives of media and of political institutions; (2) a dedicated newsroom on the CSC website with daily news and background material; (3) frequent briefing of the media and (4) special lunches with representatives of the business world to discuss the outcome of the summits. About 50 articles on the last summit were posted on the CSC website and more than 130 short messages on twitter.

Objectives

Many decision-makers are not aware, that they have real needs of climate information for the operation of their business and their long-term planning. CSC wants to make stakeholders more aware of their needs for climate information and will implement a two-way strategy: (1) raise consciousness of climate change and climate impacts (media work) and (2) find new ways to get in touch with important target groups (for example through expert briefings) for decision Climate communication has become a research issue, and CSC should be involved in the process to identify the best communication approaches towards a diverse group of stakeholders. The objective of CSC is to explore new avenues regarding climate communication and to conduct several projects in this regard.

Expected Results

Examples of projects that will support CSC’s strategic objectives on communication are the following:

--*User Interface.* An important channel to convey information on climate-related issues has been through the periodically published IPCC reports. In spite of the great effort conducted by the scientific community, many specific sectors have not been able touse IPCC information very

efficiently because IPCC has focused primarily on global aspects and has provided little information about "how to address the climate problem". CSC will try to address this problem by customizing IPCC information to the needs of well-chosen economic sectors. Decision-makers often need high-resolution (local) climate information and sound advises about how to reduce vulnerability and to adapt to climate change

--*"German Climate Communication Strategy"*: Different experts in Germany are working on Climate communication as a complex research issue. Some of them will become part of the CSC network. Together with such partners the CSC will develop a substantial/academic approach about the concept of climate communication. A first workshop on "Successful Climate Communication", with social scientists, psychologists, communication experts and practitioners from administration and companies was held in November 2011 in Hamburg.

--*"Climate information sheets":* The CSC will publish a series of condensed fact sheets (4 to 8 pages) on important climate-related issues, tailored especially for different target groups, such as the agricultural or the water sector. It will present easily accessible information based on the latest scientific results The printed material will be distributed to schools and other interested parties, and will be also be presented at our website.

Workpackage 5: Capacity Development

Mission Statement

Capacity development programs represent a key factor in helping societies enrich their own capabilities and be able to adapt to possible climatic risks. Capacity development is a corner stone in the UNFCCC context and will build in the future an important pillar for facilitating adaptation to climate change. In this context CSC elaborates user tailored training courses and seminars to transfer the knowledge originated in science to a broader public and specifically to the needed segments of population.

Challenges

In many countries, there is a lack of institutional capacity to address governance and management issues in an adequate and sustainable way when facing climate change. In the past, many donors and projects have been established to respond to these problems. However, responding to these problems is not simple. This is partly due to the complex nature of the climate change impacts, and, to a certain extent, to the little emphasis on long-term capacity building measures towards developing sustainable institutional infrastructures that could support and improve the resilience of societies.

Looking at the complexity of climate change impacts, main aim of CSC for this work package is to provide institutions and decision makers with (1) knowledge resources and guidance to enable them to identify methods of incorporating climate related risks into their management plans and (2) climate adaptation measures after having identified their future climate risks.

Current Activities and Previous Work

CSC is already developing and participating in several capacity development initiatives. One of the includes the collaboration with NCAR (National Center for Atmospheric Research) and IAI (InterAmerican Institute) in the development and implementation of two colloquia on the topic Knowledge Integration at the Science-Policy Interface. Those colloquia have been developed for Latin American Countries aiming at training current and future decision-makers in the integration of social and physical systems at the science-policy interface when facing climate

risks. Other activity involves the development of teaching activities on the management of climate and water related extreme event for practitioners in Spain.

Media training: The CSC has organized a media training for his own staff and a second one for young scientists from the Viadrina university in Frankfurt/Oder. The goal was to train junior scientists to be more at ease and more efficient when they present their results to the press and to the media.

SASSCAL: CSC is contributing to the BMBF funded Southern African Science Service Centre for Climate Change and adaptive Land Management. Capacity development is a prominent topic, and CSC will organize in the project training workshops for African users on regional climate models and of assessment models.

Objectives

CSC will strengthen existing knowledge towards sustainable climate adaptation. It will create a *climate training community of practices* including practitioners from different backgrounds, knowledge and experiences that will provide and support knowledge on adaptation to climate change. This will contribute to three capacity building areas as suggested by the WMO (2011):

- Human resource capacity – equipping individuals with the understanding, skills, information, knowledge and training to enable them to generate, communicate and use decision-relevant climate information for adapting properly to climate change.
- Procedural capacity – defining, implementing and advancing best practices for generating and using climate information for adapting properly to climate change.
- Institutional capacity – elaborating management structures, processes and procedures that enable effective adaptation.

The CSC approach will additionally follow the recommendations of the UNDP. In all cases, the capacity development programme of CSC will undertaken following steps: (1) make a broad assessment of capacity building needs of the particular case; (2) consider the previous and ongoing programmes to assist capacity building; and (3) organize a strategy as a basis for strengthening the climate mainstreaming of a particular area.

The programme will have two components: one at the German level targeted to professionals in public services and private corporations, and one at the international level with focus on development issues. For every user needs, CSC will co-develop together with users several workshops, courses or seminars adapted to their special needs.

Expected Results

CSC intends to strengthen the capacity of governments, non-governmental institutions and private sectors in climate related risks as an essential pillar for reaching their sustainable development goals in the long term. We will establish:

- A catalogue of learning modules including modules on how to understand and interpret climate models, comparisons between dynamic and static downscaling of climate models.
- Procedures and workshops to understand how to analyse vulnerability by sectors and also by regions.
- Workshop on methodologies the prioritization of adaptation measures.
- Learning modules on social vulnerability and risk management.
- Learning modules on adaptive capacity on a change environment.

Additionally and to make sure that our offer is consistent, CSC will conduct a market analysis of training activities with comparable content of competitors; it will develop suitable event formats and learning modules tailored for target groups; it will produce appropriate training material in close cooperation with the growing community of climate trainers. Different lengths of the training sessions will be implemented in order to allow short and long training activities. A special module to "train-the-trainers" will be organized in areas with limited access (as many developing countries).

Workpackage 6: Institutionalization of Climate Services (inter-/national level)

Mission Statement

Develop concepts, services and products that facilitate the institutionalization of climate services at the national and international level.

Motivation for institutionalized climate services has been steadily developing over many years. Awareness of importance of climate on many sectors of societies has grown (agriculture, food security, water, health, energy, tourism, etc); impacts of extremes have been increasingly recognized (human and economic); growth in disasters losses is noted; relevance of managing climate risk is being seen increasingly as a central development issue; preparedness and associated use of climate information has become a mainstream issue of disaster management. Institutionalized climate services must help society to plan for eventual changes (decades-century), prepare for foreseeable risks/opportunities (months-seasons), and manage high impact events (days–weeks). They must address global determinants of climate, regional impacts and local actions. To succeed we will have to connect institutions across function, and across scales from global to sub-national.

Although the CSC is primarily active at a national level, it also acts in international circles. Thus, the CSC works together with international partners by exchanging information, procedures and methods and by initiating joint actions. It takes on a leading role in the development of national and international climate services in concert with the World Meteorological Organization's (WMO) efforts to establish an international network of climate services (Global Framework for Climate Services). This global approach will strengthen the overall ability to adapt to climate change in both industrialized and developing countries.

Challenges

--*The concept of climate service is new and largely unexplored*: Any definition of climate service must recognize the central role of climate information, but to address the primary motivations, the role of climate services must be much broader and address questions such as "*what information? Information for what?".* Meaningful climate services must enable climate informed decision-making and climate-smart policy and planning. They must address many technical issues, but also the *institutional* issues and processes to connect, in a sustained and effective way, providers and users. A learning process is therefore underway. In every setting, demands outstrip services provided.

--*The landscape in Germany and engagement of the scientific community is complex*: Different institutions provide some kind of climate services, which have regarded the creation of CSC as a potential competition. Sometimes there is more interest in avoiding duplication that in generating cooperation. These boundary conditions can complicate the mission of CSC. The Center has only limited incentives to entrain these scientific institutions towards a user interface activity. Other research institutions like to develop their own relations with stakeholders, since

they regard this function increasingly important for themselves. Many contacts, however, have revealed that cooperation will grow in the future. Many universities have indicated their interest to work together with CSC. The development of the “Klimanavigator” project by CSC has been conceived as a first step to build a strong community interested by knowledge transfer.

--*Climate is changing, and this demands innovative solutions:* Many countries in the world are currently developing their own climate services, often with multiple providers per country. Experience shows that, in addition to the services traditionally provided by National Meteorological Services, climate services must address broad interdisciplinary questions that require direct cooperation between physical scientists, engineers, assessments specialists, communicators and social scientists. A major challenge is therefore to create an interdisciplinary team and integrate knowledge to respond concretely to issues associated with vulnerability, resilience and adaptation to climate change.

Current Activities and Previous Work

Detailed discussions within CSC and with the community in Germany have generated the philosophy under which the Center operates. This discussion has led to a clear definition of the overall CSC objectives, the mission, the strategic directions and the target groups for 2011-2014. Since no equivalent model of CSC is available, the model adopted for CSC will necessarily be evolving. CSC is regarded as a model that is often examined by other countries, which may develop similar initiatives. The development of an appropriate business model is a key ingredient for the success of the climate service in Germany.

Numerous discussions have been conducted to develop partnerships with other climate services in Germany. An agreement for cooperation has been signed with the regional Climate Offices of the Helmholtz Association that stipulates the distribution of tasks between the different entities. Discussions are taking place with the German Wetter Service, which is also providing climate services, and with the KOMPASS Program of the Ministry of Environment. The objective is to invite the different groups in Germany to become members of a national Partnership Board for climate services.

At the European level, CSC has initiated the development of a European Alliance for Climate Services. The objective of this initiative is to share experience between different European initiatives, to exchange data, develop joint methodologies and participate jointly in European Projects. Another objective is to reinforce the European participation in the international Climate Service Partnership (CSP).

--*ICCS 2 and CSP*: To help develop climate services all around the world, an international Climate Service Partnership was created in 2011. This CSP explores a wide set of issues, opportunities, and challenges around the climate services enterprise concept, both at national and global scales by planning a second ICCS. CSP, co-chaired by the International Research Institute for Climate and Society at Columbia University (New York) and by the Climate Service Center (Hamburg), includes the participation of about 100 international groups and organizations involved in or interested by climate services. The CSP is an informal, open process based on voluntary efforts that create intellectual resources for partners across the world.

The second international conference sponsored by CSP and hosting 200 participants from 40 countries was organised by the Climate Service Center in Brussels from 5 to 7th September 2012. The agenda retained themes such as knowledge capture, evaluation, economic valuation, good practices, and capacity building in climate services.

Objectives

An important strategic objective is to develop an institutionally and financially stable climate Service on behalf of the entire German research community. The institutional arrangement must therefore allow a strong relation between the center and important research institutions in and beyond the Helmholtz Association. Clear agreements with Helmholtz Centers and other prominent institutions like DWD, PIK, MPI-M will have to be established. The development and implementation of challenging projects and actions together with the implementation of a clear business model will provide a strong basis for a sustainable future of CSC.

The institutional structure under development in the Helmholtz Association will have to recognize important conditions for success: First, the center will have to remain demand-oriented and its program driven by the requests and needs of customers; second, the Center will have to act as a neutral platform, independent of pressures from politically or economically engaged organizations; it will have to remain close to the science. Third, to be productive and adapted specifically to the needs of the private sector, its organization will have to be flexible, exempt of bureaucratic constraints and adaptable to the requests of customers. CSC has certainly a mission of public service, which will have to be conducted with public funding, but it can also provide information that will be financially profitable to the private sector, and in certain cases some income should be generated by the products and services offered by CSC.

CSC is also partner in the following European projects in support of the institutionalization of climate services:

- ECLISE (Enabling Climate Information Services for Europe)
- Joint Program Initiative JPI-Climate
- ENHANCE - Enhancing European Multistakeholder Partnerships

- End of Volume 1 -