HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

# Coastal Research and Climate Services 2013-2017

## Status Report – Volume 1

HELMHOLTZ-ZENTRUM GEESTHACHT - CENTRE FOR MATERIALS AND COASTAL RESEARCH

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

# Research Field Earth and Environment

## Status Report

## Coastal Research and Climate Services

at

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

2013–2017

Volume I

## Helmholtz Association

We contribute to solving the major and pressing problems of society, science and industry by conducting high-level research in the strategic Programs of our six research fields: Energy, Earth and Environment, Health, Aeronautics, Space and Transport, Matter,and Key Technologies.

We research highly complex systems in cooperation with national and international partners using our large-scale facilities and scientific infrastructure.

We are committed to shaping our shared future by combining research and technological developments with innovative applications and prevention strategies.

We seek to attract and promote the best people and offer our staff a unique scientific environment and comprehensive support in all stages of their development.

# Contents

# 1

# HELMHOLTZ ASSOCIATION – MISSION AND STRATEGY

# 1 HELMHOLTZ ASSOCIATION – MISSION AND STRATEGY

The Helmholtz Association contributes to solving grand societal, scientific and technological challenges, by conducting interdisciplinary strategic research in the fields of *Aeronautics, Space and Transport; Earth and Environment; Energy; Health; Key Technologies;* and *Matter*. It brings together 18 centers that perform research in the natural sciences, technology, engineering, and medicine. With more than 38,000 employees and an annual budget of 4.45 billion €, the Helmholtz Association is Germany's largest scientific organization.

In order to meet the grand challenges and to provide and implement solutions, the Helmholtz Association brings together the resources of its research centers in various disciplines and cooperates with key national and international partners in science, especially from universities and industry. By combining research and development with innovative applications- and prevention-oriented strategies, the Association aims to shape, preserve and improve the foundations of human life. Helmholtz is responsible for planning and operating large-scale facilities and scientific infrastructure within the framework of national and international collaborative research alliances. It strongly promotes high-tech development and raises the international visibility of Germany as a major and attractive hub for science and technology.

Research activities are organized in long-term programs, which strongly build upon synergies between the Helmholtz Centers. These programs are periodically reviewed by international experts. This forms the basis for the funding of Helmholtz's research by the federal government (90 percent) and the federal states (10 percent) that host the Helmholtz Centers. In addition to core funding the Association receives substantial third party funding, primarily through open competition grants such as the European Union's *Horizon 2020*.

The expertise, creativity and motivation of its staff are of utmost relevance for the Helmholtz Association. It therefore offers a large variety of opportunities for professional and personal development, including scholarships and excellent working conditions. The Association promotes equal opportunity, supports young scientists, and contributes to their professional advancement by providing training in its Research Fields. Moreover, the Helmholtz Centers train highly qualified technical personnel. Currently the Centers encompass 250 subject-specific research institutes. Approximately 21,000 of the 38,000 employees are scientists and engineers, 7,800 are PhD students and 1,650 are undergoing vocational training. In addition, roughly 7,500 foreign researchers come to the Centers. Finally, the Helmholtz Association supports the dialog between science and society, by communicating relevant research findings to the public, and promotes decision-making processes.

## SHAPING THE FUTURE WITH CUTTING-EDGE RESEARCH

**Research for mankind and the environment:** Helmholtz's research in the six Research Fields is ultimately directed at securing the foundations of human life in the long-term and creating the technological basis for a competitive economy. The research topics concern future energy systems, integrated research of the Earth System, innovative mobility concepts, preservation of intact ecosystems or treatments for diseases, new materials and substances, new generations of compact accelerator systems as well as information and data science.

**Excellent science from basic research to application:** With over 14,000 scientific publications, over 400 patent applications per year and currently 3,000 industry collaborations, the Helmholtz Association has an excellent track record in both basic research and in developing applications. It has the stamina to drive large-scale projects forward and the capacity to bring together expertise from different areas of research.

**Research infrastructure and large-scale devices:** The Helmholtz Association sets up, operates and further develops excellent research infrastructures and large-scale devices such as observatories, particle accelerators, super computers and research vessels that are unique in the world. Every year, thousands of visiting researchers from all over the world come to the

Helmholtz Centers to make use of the unique research opportunities afforded by these devices.

**Knowledge and technology transfer:** The knowledge transfer activities are extremely diverse, ranging from public advisory services and school laboratories to platforms for dialog at the interface between politics, environmental protection and civil security. Citizens are also integrated more deeply into research planning, research structuring and knowledge transfer in certain cases ("Citizen Science"). Regarding technology transfer, the Helmholtz Centers have been developing successful structures and processes for many years. This is evidenced by the numerous products on the market, license revenues, cooperation agreements, and in particular, a high number of spin-offs. In the last few years, Helmholtz has created additional funding tools such as the Validation Fund, spin-off funding, innovation labs and innovation funds to ensure the success of these undertakings.

**Talent management:** Attracting the brightest minds and providing them with the best environment to develop their potential is a top priority of the Helmholtz Association. Promoting young scientific, administrative and technical talent is a key component of its future strategy. Alongside measures that promote young researchers in the individual Helmholtz Centers, the association has set up overarching funding lines with its Initiative and Networking Fund. These funding tools and the idea behind them have grown into a comprehensive talent management strategy.

**Cooperation:** Networking and cooperating with national and international partners from science, industry and government are a key component of the Helmholtz Association's strategy for achieving outstanding research results quickly and efficiently. Helmholtz's research goes beyond the borders of individual disciplines and countries. This makes it internationally competitive and able to deliver a decisive contribution to solving the major challenges facing society today.

**International project management:** Developing and operating the powerful infrastructures of the Helmholtz Association requires years of experience in the management of large-scale projects. There is good reason why the Helmholtz Association is frequently the hub of major international research projects. As a strong member of the global scientific community, the Helmholtz Association plays its part in shaping the future of modern societies.

## FUTURE RESEARCH AGENDA

In keeping with its mission, the Helmholtz Association has worked continuously to address the complex issues facing science, society and the economy using integrated approaches from basic research through to application, and to provide and implement solutions. This systems expertise is a hallmark of Helmholtz.

Since its foundation, the Association has undergone a dynamic process of development, which will be maintained further developing its research programs, improving its governance structure, and expanding its systems expertise.

Over the coming years, the Helmholtz Association will do everything in its power to fulfill its mission and its tasks within the German science system: as a producer of knowledge, driver of innovation, cooperation partner, talent magnet, and research infrastructure operator.

# 2

# Helmholtz Research Field Earth and Environment

# 2 HELMHOLTZ RESEARCH FIELD EARTH AND ENVIRONMENT

Coordinators of the Research Field since 2013: G. Teutsch/Helmholtz Centre for Environmental Research – UFZ (2013/2014), P. Herzig/GEOMAR (2015/2016), R. Hüttl/German Research Centre for Geosciences – GFZ (2017/2018).

## 2.1 OVERVIEW

Human activity has a significant influence on the environment: climate change, species decline and extinction, and other human-induced pressures have been observed for decades. Important resources, such as drinking water or fertile soils, are increasingly under threat and other essential materials, such as energy resources and critical metals, are increasingly difficult to access. With this in mind the Helmholtz Association is engaged in research to position society for a sustainable future. The Research Field *Earth and Environment* examines the basic functions and interactions of the Earth System and its response to natural and anthropogenic pressures. The global challenge is to provide the fundamental and applied knowledge about our environment needed to secure and sustain human life. This includes the development of strategies for efficient and sustainable use of natural resources, research on natural phenomena and their associated risks, and assessment of the human impact on natural systems and the repercussions for the environment and humanity.

A key aim is to develop strategies for the assessment and management of natural hazards and the prevention of disasters, such as improved projections of climate change. A better balance also is needed between sustainable use of the earth's living and non-living resources and their long-term protection. In addition, strategies for human adaptation to changes in environmental conditions are necessary. A wide range of options for political action is required, including a full analysis of the socio-economic consequences of the risks and the mitigation strategies.

Addressing these challenges requires an in-depth understanding of the numerous interacting subsystems of the earth and its environment (atmosphere, biosphere, geosphere, hydrosphere, cryosphere, and anthroposphere) and a highly integrated scientific approach that provides deep insight into the complexity of Earth's processes. Among the major goals is to assess anthropogenic influences, determine resilience limits of the natural systems, including the regeneration potential of Earth's terrestrial, marine, and atmospheric systems, and to develop concepts and approaches for their implementation and sustainable management.

Thus, the grand challenges for the Research Field Earth and Environment lie in four key areas:

- Earth System dynamics and risks,
- Climate variability and climate change
- Ecosystem dynamics and biodiversity, and
- Sustainable use of resources.

Eight Helmholtz Centers contribute to the joint research in *Earth and Environment*: the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven, the Forschungszentrum Jülich (FZJ), the GEOMAR Helmholtz Centre for Ocean Research Kiel, the German Research Centre for Geosciences (GFZ) in Potsdam, the Helmholtz Centre Munich - German Research Centre for Environmental Health (HMGU), the Helmholtz-Zentrum Geesthacht for Materials and Coastal Research (HZG), the Karlsruhe Institute of Technology (KIT), and the Helmholtz Centre for Environmental Research (UFZ) in Leipzig.

These centers are equipped with state-of-the-art medium- and large-scale research infrastructure and platforms, including research vessels, aircraft, satellites, fixed and mobile observatories, simulation chambers, and climate computing centers, that enable long-term observations and monitoring at high spatial resolution.

The research programs within *Earth and Environment* are designed around the grand challenges. The research foci include regions that are substantially shaped by humans, such as coastal regions, emission centers, areas with crucial functions in food production, and areas in which people are exposed to particular risks (e.g. earthquakes or floods). Regions that are very sensitive to global or regional environmental and climate changes, such as polar regions, tropical oceans, arid or semiarid areas, mountainous regions and permafrost areas, receive particular attention.

In the third period of the Program Oriented Funding (POF) scheme of the Helmholtz Association, which started in 2014, the Centers organized their research into five programs:

**Geosystem: The Changing Earth** This program 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 include monitoring and modeling key processes, understanding and assessing the impact of these processes, developing solutions and strategies for the prevention of disasters, and developing geotechnologies for use in the underground.

***PACES II: Polar Regions and Coasts in a Changing Earth System*** This program concentrates on observing and analyzing changes in the Arctic, the Antarctic and coastal regions from paleo to future time scales. It focuses on polar climate change and its consequences, changes in coastal systems and the Arctic deep-sea ecosystem. The program includes a topic on the interaction between science and society that examines how findings from research can effectively be converted into information helpful for decision-making processes in society as a whole.

**OCEANS: From the Deep Sea to the Atmosphere** Using an interdisciplinary approach, the OCEANS program investigates the physical, chemical, biological, and geological processes of the entire ocean system from the seafloor to the atmosphere. The principal goals are the assessment of the role of the oceans in climate change, of human impact on marine ecosystems, of the potential use of biological, mineral and energy resources in the oceans and of hazards related to geodynamic processes in the ocean basins and their margins.

**Atmosphere and Climate** The main objective of this program 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 modeling on a cross-scale basis.

**Terrestrial Environment** This program 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.

During the POF period a comprehensive approach to knowledge transfer was initiated for the entire Research Field to ensure that research results make their way to decision makers and to society in general. This included existing transfer activities and new approaches of the individual centers, such as the Climate Service Center (GERICS) and the four regional Helmholtz climate offices that have become platforms for climate information. An Earth System Knowledge Platform (ESKP) was also established as a contact and focal point to provide a wide range of scientific information for practical applications, e.g., natural hazards and climate change.

The research centers contributing to the Research Field Earth and Environment maintain a comprehensive network with other centers of the Helmholtz Association. Each center is linked to research initiatives in Energy, Key Technologies, Information, Health, Matter, and Aeronautics, Space and Transport. Key infrastructure within the Helmholtz Association is used by all of the centers contributing to Earth and Environment, such as the new research aircraft HALO, which is operated jointly with other research institutions of the Max Planck Society and

Leibniz Association. Particularly innovative cross-cutting themes are also being advanced within the research networks, including REKLIM and the regional climate bureaus, which tackle strategic questions pertaining to climate change from various perspectives in several different programs.

New research objectives shared with other centers that are of particular significance for Earth and Environment are soil research and technological innovations in Earth observation, such as new approaches to verification of satellite observation data (ACROSS: Advanced Remote Sensing - Ground-Truth Demo and Test Facilities) and an innovative deep-sea observatory in the Fram Strait (FRAM). Further joint initiatives initiated since 2013 focus on Earth System observation, including Modular Observation Solutions for Earth Systems (MOSES), Earth System Modeling (ESM), and data science (Digital Earth - under review).

Close cooperation with universities, locally and regionally, is fundamentally important for the research agendas of all centers contributing to Earth and Environment, and includes:

**Joint professorships** This instrument is applied to ensure long-term cooperation on specific strategic research themes, 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 realized through Helmholtz Graduate Schools and Research Schools, which are jointly operated by the centers and the universities.

**Coordinated research in projects and programs** This is achieved through long-term strategic cooperation agreements with contributions from both partners, including common proposals for funding. The Helmholtz Association offered competitive funds for so-called Helmholtz Alliances to examine specific research questions in networks with partners form universities and non-university institutions. During the POF period two Helmholtz Alliances were successfully established by the Research Field Earth and Environment based on long-term interdisciplinary 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 (ROBEX).

## OUTLOOK

The continuous development of the Research Field Earth and Environment was advanced significantly in 2016, when two science workshops were held in Berlin and Potsdam to consider the program design for the new POF period (POF IV). In January 2017, a four-day summit entitled “Syntegration” concentrated on the development potential of the Research Field and an action plan for the next decade. One of the major results of this event was a new design of the programs focusing on the three major realms relevant to Earth and Environment: “Atmosphere”, “Terrestrial” and “Marine”. The goal of the new programs is to enhance the already strong cross-disciplinary approach to Earth System Observation, Earth System Data Management, and Earth System Modeling, which has been a hallmark of success in the Helmholtz Association. A third science workshop in April 2017 focused on the design of the new research programs, and additional thematic workshops will follow.

## 2.2 PACES II: POLAR REGIONS AND COASTS IN THE CHANGING EARTH SYSTEM

The Earth System is undergoing rapid changes with substantial consequences for humanity. Polar, coastal and shelf sea regions play pivotal roles in this system: The polar regions are unique environments, extremely sensitive to global change and anthropogenic influence. They are home to a largely undiscovered biodiversity and have a critical impact on regional and global climate, as well as on atmosphere and ocean circulation. The coastal and shelf seas harbor most of the marine natural resources and are the interface where effects of terrestrial, oceanic and atmospheric changes culminate. Due to the increasing number of people inhabiting the global coastlines, this land-ocean transition zone is the vital new frontier of economic and social development. Understanding and predicting responses to global change and anthropogenic pressure in these systems, but also of feedback processes in the Earth system, requires major scientific advances to solve these complex problems.

The research program *Marine, Coastal and Polar Systems: **P**olar Regions **A**nd **C**oasts in the **C**hanging **E**arth **S**ystem (PACES II*) focuses on observing, analyzing, modeling, and predicting natural variations and anthropogenic impacts on the Earth System with an emphasis on the polar regions and the coast and shelf sea of the North Sea. This program is rooted in the three disciplines: Geosciences, biosciences and climate sciences, working jointly towards understanding the complex marine, coastal and polar systems and their role in the Earth system. PACES II provides the basis to address pressing challenges to society, based on the expressions of the probable and plausible trajectories, and the expected socio-economic impacts of climate and environmental changes (e.g., of sea level rise, extensive use of natural resources, loss of species, habitats and ecosystem functions). Identifying pathways to a sustainable livelihood, in the face of their complexity as well as societal needs, requires interdisciplinary and cross-sectoral approaches. The interaction between science and society is thus an important component of this research program. Here, scientifically derived data and information products, services, tools and climate services are developed, tested and used to enhance the efficiency of knowledge transfer and technology.

PACES II has the following main objectives:

- Develop a comprehensive understanding of marine, coastal and polar systems and their role in the Earth System, including multi-scale aspects and interaction between compartments;
- Contribute to the assessment of polar and coastal system states through long-term observations and monitoring;
- Improve the capability to simulate the Earth System´s past and present, as well as to predict possible future changes in the polar and marine realms;
- Enhance our understanding of the interaction between natural and anthropogenic processes in the coastal regions to enable a sustainable use of biotic and abiotic natural resources and to minimize risks for the development of a good environmental status;
- Ensure effective transfer of knowledge from science to society by providing products, services, tools and climate services; and
- Provide research infrastructure and expert knowledge to the national and international science community.

The research program PACES II is pivotal to the Research Field Earth and Environment. It encompasses the science of marine, polar and coastal systems and their role in the Earth system. Scientists in PACES II have contributed to three of the six Grand Challenges defined by the Research Field for the period 2013–2017: (1) climate variability and change, (2) ecosystem dynamics and biodiversity, and (3) socio-economic dimension of global change. Furthermore, scientists involved in the research program have been instrumental in coordinating and developing cross-cutting projects in the Helmholtz Association. Prominent examples are the *Regional Climate Change* initiative (REKLIM), the development of *Advanced Earth System Modeling Capacity* (ESM), the *Modular*

*Observation Solutions for Earth Systems* initiative (MOSES), the *Earth System Knowledge Platform* (ESKP) and the Helmholtz working group for knowledge transfer.

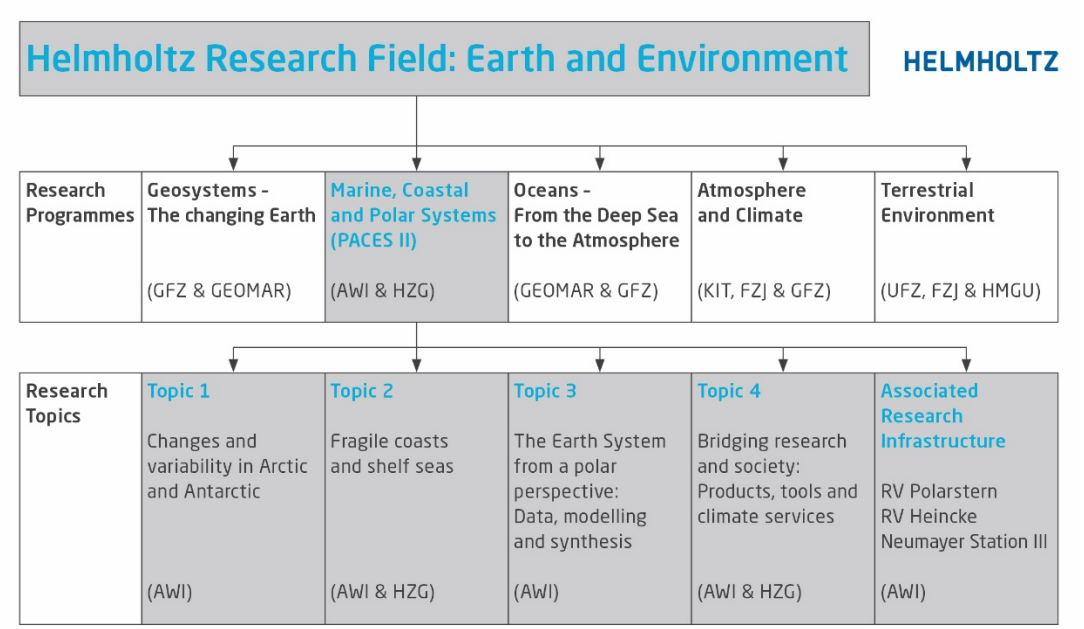


Figure 1: Structure of the Research Program "Marine, Coastal and Polar Systems: Polar Regions and Coasts in the Changing Earth System (PACES II)" and its position within the Research Field Earth and Environment. Note that this is the revised structure, implemented in 2015.

PACES II comprises four Topics along with the associated large-scale research infrastructure (LKII) (Figure 1):

*Topic 1: Changes and variability in Arctic and Antarctic (AWI)*

This Topic focuses on changes in the polar regions, in terrestrial and marine systems as well as the atmosphere, with the aim to *unravel and to quantify the underlying processes determining natural variability and anthropogenic changes*. More specifically, the research focuses on the interaction of the polar atmosphere with sea ice; it addresses the ocean and land; it considers factors influencing ice sheet mass balance and its impact on local, regional and global sea-level and it explores the cycling of the potent greenhouse gas methane, and the vulnerability of Arctic permafrost carbon pools. Research also addresses the causes of Arctic sea ice decline and its impact on biogeochemistry, ecology and biodiversity from fjords and shelf seas to the deep basins. The Topic entails the study of physical, chemical and ecological changes occurring in the Southern Ocean along with their feedbacks on the global climate system and carbon cycle. It also deals with the potential risks of commercial use of the polar oceans and solutions for sustainability.

*Topic 2: Fragile coasts and shelf seas (HZG and AWI)*

Coastal and shelf systems are under multiple pressures from natural variability, global and regional change, and societal factors, resulting in complex systems. The future of humanity is increasingly dependent on the resources offered by coastal environments. Resources and the human environment must be managed in a sustainable manner. Combining fundamental and applied research across relevant disciplines with advanced observation and modeling systems, the Topic *investigates drivers of past, present, and future variability, evaluates system states on a range of time and space scales, and assesses risks associated with regional environmental change and a significant increase in human activity*. Topic 2 is a joint undertaking of HZG's geophysical and biogeochemical scientists together with biologists, ecologists and geoscientists of the AWI field stations on Helgoland and Sylt, as well as polar scientists from Bremerhaven and Potsdam.

*Topic 3: The Earth system from a polar perspective: Data, modeling and synthesis (AWI)*

This Topic aims to *examine the role of polar processes on a global scale for past, present and future Earth system changes*. Its goal is to unravel high latitude climate variability in time and space and to understand the forcing mechanisms and global feedbacks that drive climate change at time scales ranging from the geological past over glacial cycles to the present and future. It entails the use of an integrated approach including observations, paleo-environmental data, and Earth System modeling. New drilling efforts of marine and lake sediments, as well as ice are being undertaken to formulate and test hypotheses explaining the causes, mechanisms and feedbacks of climate change. Using process-based knowledge from ice and geo-archives, we are able to test the applicability of Earth System models under external forcing. We assess recent variability of the Earth System in a long-term context, and use models to enhance climate change projections.

*Topic 4: Bridging research and society—products, tools and climate services (AWI and HZG)*

The Topic deals with the exchange of knowledge, generated within PACES II, with decision-makers and stakeholders. This includes the development and provision of new and advanced forecast and assessment models and products, an effective supply of research data to a wide range of stakeholders, and dialog with societal and institutional players. The contributions by the Institute of Coastal Research (HZG) and AWI are founded in the basic research carried out under Topics 1–3. In addition, HZG's Climate Service Center Germany (GERICS) develops and provides multifaceted climate services, in order to establish a sustained transfer process of appropriate scientific findings in relevant social decision-making processes regarding the adaptation to climate change.

*Associated research infrastructure*

The associated large-scale research infrastructure (LK-II) includes the research icebreaker *RV Polarstern* operating in both the Arctic and Antarctic, *RV Heincke*, which generally operates in the North Sea and the North Atlantic, as well as the *Neumayer III Station* located on the Ekström Ice Shelf in Dronning Maud Land, Antarctica. The large-scale infrastructure is augmented by a smaller class of research infrastructure, including, for example, laboratories, research aircraft and supercomputing facilities.

In order to achieve the objectives of PACES II, our strategy comprises the following key elements:

- Combine excellence in natural sciences with state of the art methodology and interdisciplinary research approaches.
- Assess the states of polar and coastal regions and their role in the Earth system, by considering a wide range of time scales—from the past, to the present and future.
- Increase capacity through strategic cooperation on the regional, national, European and international level.
- Ensure high-level innovative research by effective talent management.
- Maximize societal impact of PACES II-research through knowledge transfer, dissemination of scientific results and climate services by establishing a sustained dialog between science, the public and specific stakeholders.
- Provide excellent research infrastructure and innovative technologies for national and international users.

The overall performance of the research program in terms of high-level indicators during the reporting period 2013–2017 can be inferred from Table 1. PACES II continued to increase its high productivity during the reporting period, as indicated by an increase in the number of peer-reviewed publications by about 30% since 2013. During the same time the number of core staff increased by about 5–10%. The high level of third-party funding remained approximately unchanged throughout the reporting period.

| | 2013 | | 2014 | | 2015 | | 2016 | |
|---|---|---|---|---|---|---|---|---|
| **ISI or SCOPUS cited publications** | **597**<br>495<br>102 | **(PACES II)**<br>(AWI)<br>(HZG) | **585**<br>465<br>120 | **(PACES II)**<br>(AWI)<br>(HZG) | **773**<br>609<br>164 | **(PACES II)**<br>(AWI)<br>(HZG) | **824**<br>642<br>182 | **(PACES II)**<br>(AWI)<br>(HZG) |
| **Third pary funding (Million €)** | **22,6**<br>18,9<br>3,7 | **(PACES II)**<br>(AWI)<br>(HZG) | **25,8**<br>21,9<br>3,9 | **(PACES II)**<br>(AWI)<br>(HZG) | **25,6**<br>21,2<br>4,4 | **(PACES II)**<br>(AWI)<br>(HZG) | **22,6**<br>18,6<br>4,0 | **(PACES II)**<br>(AWI)<br>(HZG) |
| **Core-funded scientists without PhD-Students** | **263**<br>207<br>56 | **(PACES II)**<br>(AWI)<br>(HZG) | **313**<br>229<br>84 | **(PACES II)**<br>(AWI)<br>(HZG) | **322**<br>234<br>88 | **(PACES II)**<br>(AWI)<br>(HZG) | **348**<br>259<br>89 | **(PACES II)**<br>(AWI)<br>(HZG) |

Table 1: High-level performance indicators for the period 2013–2016 and the Research Program PACES II along with the individual contributions from AWI and HZG. Note that GERICS contributed to the indicators from 1 June 2014.

Examples of *outstanding scientific highlights* achieved by the research program during the period 2013–2017, include:

- Modeling studies provide evidence of future irreversible warming of cavities underneath Antarctic ice shelves resulting in increased basal melting and strong impacts on global sea level rise (Topic 1 and 3).
- It is found that Arctic warming results in acceleration of permafrost thaw, including an almost doubling of mean permafrost coastal erosion rates in Northeast Siberia since the 1950s as well as an increased export of organic carbon and sediment to the Arctic ocean (Topic 1).
- Long-term observations reveal profound and rapid ecosystem changes in response to warm-water intrusion into the Fram Strait (Topic 1).
- A mean temperature increase of 1.7°C in the German Bight (North Sea) over the last 50 years is accompanied by increased invasion and persistence of warm water species (Topic 2).
- Construction of offshore wind farms in the North Sea has measureable effects on water column stratification and biological processes on scales of 10´s of km and months for individual parks due to increased turbulence (Topic 2).
- Current state-of-the-art Earth system models realistically simulate inter-annual variability, but underestimate observed variability on centennial to millennial times scales, as revealed by comparing climate simulations, instrumental records and paleo-observations (Topic 3).

Major *methodological developments* include the advancement in the first global climate model (AWI-CM), which features a sea ice-ocean component formulated on unstructured meshes, along with various applications in PACES II, including contributions to the upcoming Coupled Model Intercomparison Project (CMIP6). Furthermore, the Coastal Observing System for Northern and Arctic Seas (COSYNA) now includes nodes in the North Sea, Baltic Sea and the Arctic (Svalbard). Novel underwater hubs, sensors and data-model integration schemes, significantly enhance operation, parameters detected, and utility for nowcasts of coastal system state. Similarly, Arctic observation is enhanced by the infrastructure program of the Helmholtz Association entitled Frontiers in Arctic Marine Monitoring (FRAM), implementing synchronous sea-ice to seafloor observatories in the Central Arctic and Fram Strait.

Important achievements in *knowledge transfer and climate services* in Topic 4 encompass regional assessment reports of climate change and its effects on the North Sea, the Baltic Sea, and the Hamburg Metropolitan region, and a national assessment report for Germany. Furthermore, the prototype concept of toolkits has successfully been implemented as a climate service instrument. Another example is the establishment of the information and data portal meereisportal.de (seaiceportal.de), which has attracted considerable attention.

Scientists involved in PACES II have also been instrumental in *setting the agenda and coordinating large projects* within the Research Field Earth and Environment, as well as at the regional, national, European and international level. Examples include:

- Helmholtz Association: Coordination of REKLIM, ESM, and Reduced Models. The latter two projects are funded through the *Impulse and Networking Fund* of the Helmholtz Association.
- Regional: Joint research with universities in Excellence Clusters of the German Excellence Initiative (MARUM Bremen, CliSAP Hamburg)
- National: Coordination of cooperative projects and overall coordination of the national coastal research agenda process *Küstenforschung Nordsee/Ostsee* (Coastal Research in North Sea and Baltic Sea).
- Europe: Coordination of EU projects in developing a European research agenda (*EU-PolarNet*), identifying drilling sites for the oldest ice core in Antarctica (Beyond EPICA—Oldest Ice), advancing predictive capacity in polar regions and beyond (Advanced Prediction in Polar regions and beyond: modeling, observing system design and LInkages associated with a Changing Arctic climaTE, APPLICATE), determining the impacts of thawing coastal and subsea permafrost (NUNATARYUK), setting up a strategy to meet the needs for marine-based research through the Arctic Research Icebreaker Consortium (ARICE), contribution to the development of the *European Roadmap for Climate Services*, coordination of EU project related to impact, adaptation and climate services (Quantifying projected impacts under 2°C warming, IMPACT2C), contributions to UNFCCC dialogs and the WCRP CORDEX program EURO-CORDEX.
- International: Leadership in the planning and implementation of the Year of Polar Prediction (YOPP) and the Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC). An international Center of Excellence on Oceanography and Ship-Board-training was set up and run in collaboration with German and International Institutes and POGO.

Important activities where *collaboration between AWI and HZG* was critical for a successful outcome, include combined efforts of AWI, HZG and partners from science and policy in shaping the federal research program MARE:N for coastal, ocean, and polar research. This includes a Coastal Research Agenda formulated by the community that entails joint observation, modeling and data structures. Furthermore, significant progress has been made regarding the definition of suitable criteria and performance indicators for the evaluation of knowledge transfer, stakeholder dialogs and climate service activities. These criteria and indicators augment existing methods for evaluating purely scientific work.

A strategy for the forthcoming program-oriented research (POF IV) in the Research Field Earth and Environment is still under development. It is clear, however, that cooperation between Helmholtz Centers, universities and other key players in Earth System research and services will be enhanced. Furthermore, our research will link to several of the Grand Challenges such as climate and biodiversity losses, and will contribute to the respective UN sustainable development goals. At the present level of planning, the following high-level topics are expected to play a central role in program-oriented research during the period 2020–2026:

- *The role of atmosphere, cryosphere and ocean in climate*
- *Coastal transition zones under pressure*
- *Sustaining Marine and Polar Life*

In the development of the research activities, particular attention will be given to the following cross-cutting activities of the Research Field Earth and Environment: REKLIM, MOSES and ESM as well as ESKP, to enhance knowledge transfer. Contributions to international programs such as the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) will also shape the agenda for POF IV. Furthermore, the research will be directed to find new solutions for Earth System data, informatics and digital research environments. Concerning the collaboration between AWI and HZG, there is consensus that strong cooperation will continue in the fields of coastal research, knowledge transfer and climate services as well as Earth System modeling.

# 3

# HELMHOLTZ ZENTRUM GEESTHACHT
# CENTRE FOR MATERIALS AND COASTAL RESEARCH

# 3 HELMHOLTZ-ZENTRUM GEESTHACHT CENTRE FOR MATERIALS AND COASTAL RESEARCH

## 3.1 OVERVIEW

### Mission and Guiding Principles of the Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research

Recent as well as future global and regional development of the Earth System, society, the economy and science raise increasingly pressing questions. Such questions require answers and decisions based on scientifically sound knowledge and innovative technology. The Helmholtz-Zentrum Geesthacht (HZG) provides substantial and effective contributions to the advancement of both science and technology.

As with most scientific work, HZG's specific scientific focus and scope lie in the resulting themes that evolve from inspiring ideas, intense discussions, and also from basic questions that arise from current research work. The latter may lead to evolutionary changes, but sometimes also results in unprecedented themes. Substantial portions of the HZG research connect implementation-inspired basic research with its translation into innovation and application. Thus, research at HZG is conducted along the value chain, or respectively in value-creating networks, and preferably in collaboration with partners from the realms of science and industry. HZG deliberately transfers its know-how and knowledge to society, the economy and to scientific stakeholders, and fosters science-stakeholder dialogs. HZG endeavors to maintain – in the fields of basic research and innovation – a professionally motivated and close cooperation with other non-university research centers and organizations, as well as with industry and, intensely, with thematically-related research units at universities and higher education institutions (formation of regional and nation-wide clusters).

In cooperation with other research centers, HZG is instrumental in shaping the Research Fields involved as well as the Helmholtz Association as a whole, in terms of both the structural and scientific course of development. It is unique to the Helmholtz Centers that the general scope of research is regularly evaluated by international expert panels and is continuously evolving through discussions in the Helmholtz Association´s Research Fields and with the ministry´s funding bodies.

To retain and enhance the talent, expertise, creativity and motivation of its employees, the Helmholtz-Zentrum Geesthacht provides its staff with opportunities for both personal and professional advancement. HZG also provides good working conditions within an exceptional setting. It supports junior scientists and contributes to advancing their professional qualifications by providing them with training in various research fields and by offering them opportunities for scientific independence at an early stage of their career. Moreover, the research center provides training for highly qualified technical personnel. In addition to excellent research conditions, HZG is actively involved in developing measures to ensure equal opportunities and, in particular, a greater compatibility between career and family commitments.

### Profile and competence

The Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, was founded in 1956. It is located in Geesthacht, Hamburg, and close to Berlin. It currently employs 950 individuals, including approximately 650 scientists, engineers, and technicians. Its five research institutes focus on materials and coastal research with a total research budget of approximately 100 million Euros per year.

HZG pursues two major research directions: Research on Materials and Material Systems (approximately 2/3 of the research budget), and Coastal and Climate Research (approximately 1/3 of the research budget).

One major strength of HZG's research is that it focuses the center's expertise, infrastructure and financial resources on carefully selected material systems and processing methods, as well as on the essential questions of coastal and climate research. This allows an in-depth treatment of themes that are quite different in nature. It also provides a basis on which very different research areas can be combined with new, high-level research themes. This combination fosters interdisciplinary and transdisciplinary research. The research themes at HZG are, in general, of a long-term nature.

The research center is structured into scientific and administrative sections. The scientific section consists of four institutes — with a total of ten Research Units — and an independent scientific organizational entity: Climate Service Center Germany (GERICS). The administrative section is comprised of the following: Administrative Staff Unit; the Technical Infrastructure Unit – including the Central Technical Department, which delivers custom engineering and manufacturing services for individual scientific instruments and samples; the Finance and Procurement Unit; the Human Resources Unit; the Staff Department for Technical Compliance; and the Staff Department for Internal Audit.

## HZG in Facts and Figures

<table>
<tr><td>Founded</td><td>1956</td></tr>
<tr><td>Location<br> 
</td><td>HZG is located in Geesthacht near Hamburg;<br>with branches in Teltow, near Berlin (Institute of Biomaterial Science);<br>in Hamburg (GERICS; and operation of instruments using synchrotron radiation at the outstation at DESY);<br>and in Munich (outstation at the FRM II at the Heinz Maier-Leibnitz Zentrum MLZ).</td></tr>
<tr><td>Total Staff</td><td>957 (as of 31-12-2016) employees including approximately 650 scientists, engineers and technicians.<br>The total workforce is as follows:<br>approx. 70% scientific staff<br>approx. 5% trainees<br>approx. 14% administrative staff<br>approx. 11% technical and infrastructure-related personnel</td></tr>
<tr><td>Scientific Staff<br>(31-12-2016, Individuals)</td><td>
<table>
<tr><th></th><th>Materials Research</th><th>Coastal Research and Climate Services</th><th>Total</th></tr>
<tr><td>Scientists</td><td>136</td><td>98</td><td>234</td></tr>
<tr><td>Postdocs</td><td>47</td><td>32</td><td>79</td></tr>
<tr><td>PhD Students</td><td>96</td><td>31</td><td>127</td></tr>
<tr><td>Master's/Bachelor's Students</td><td>28</td><td>8</td><td>36</td></tr>
<tr><td>Technicians</td><td>65</td><td>30</td><td>95</td></tr>
<tr><td>Support / Administration</td><td>43</td><td>27</td><td>70</td></tr>
<tr><td>Total</td><td>415</td><td>226</td><td>641</td></tr>
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</td></tr>
<tr><td>Programmatic Distribution of the Scientific Staff</td><td>Taking into consideration only scientific staff, approximately 65% works in Materials Research (AEM, BIFTM, MML), and 35% in Coastal Research and Climate Services (PACES II).</td></tr>
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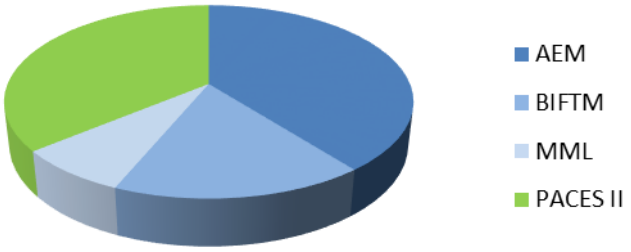
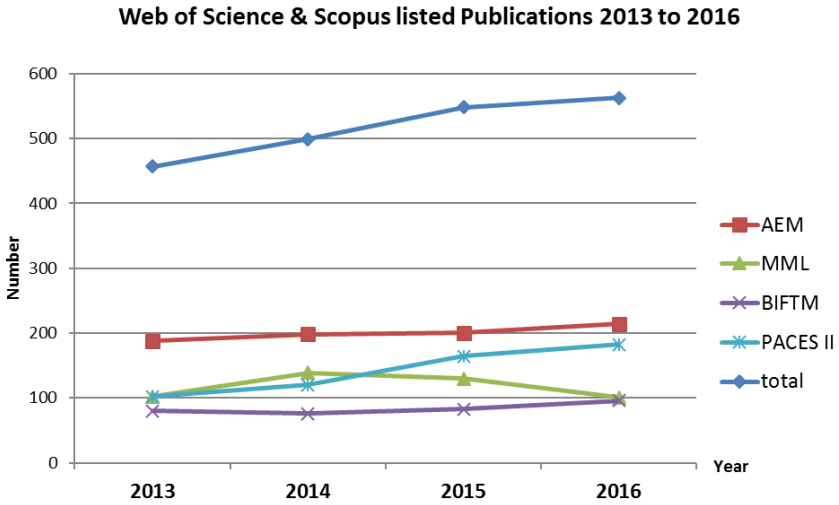
| |  |
| **International Scientists** | HZG maintains numerous strategic partnerships within Europe and all over the world by collaborating with the best research institutions and by working closely with international experts.<br>In 2016, 40% of the scientific staff came from fourty-four countries outside of Germany: the most prevalent countries were China, Russia, Spain, India, Brazil and Portugal. |
| **Institutional Funding (2016)** | 78 million Euro (90% BMBF; 10% federal states of Schleswig-Holstein, Hamburg, Lower Saxony and Brandenburg) |
| **Third-party Funding (2016)** | 22 million Euros were generated through third-party funding, such as EU and national research projects, contract research, and licensing of HZG patents for products and processes. |
| **Publications** |  |

Table 2: Facts about HZG

The Helmholtz Association is organized into six Research Fields. Each comprises several scientific programs. In line with our HZG mission *Science creates benefits*, the main HZG research areas cover materials science (focus on advanced engineering materials, materials research with neutron and synchrotron radiation, active biomaterials and regenerative medicine); climate and environmental research; and climate services. In the current program-oriented funding period (POF III), HZG is actively involved in four programs within three Helmholtz Research Fields: *Advanced Engineering Materials* (AEM) and *Biointerfaces in Technology and Medicine (BIFTM)* in the Research Field *Key Technologies*; *From Matter to Materials and Life (MML)* in the Research Field *Matter*; *PACES II: Polar Regions And Coasts in the Changing Earth System* in the Research Field *Earth and Environment*.

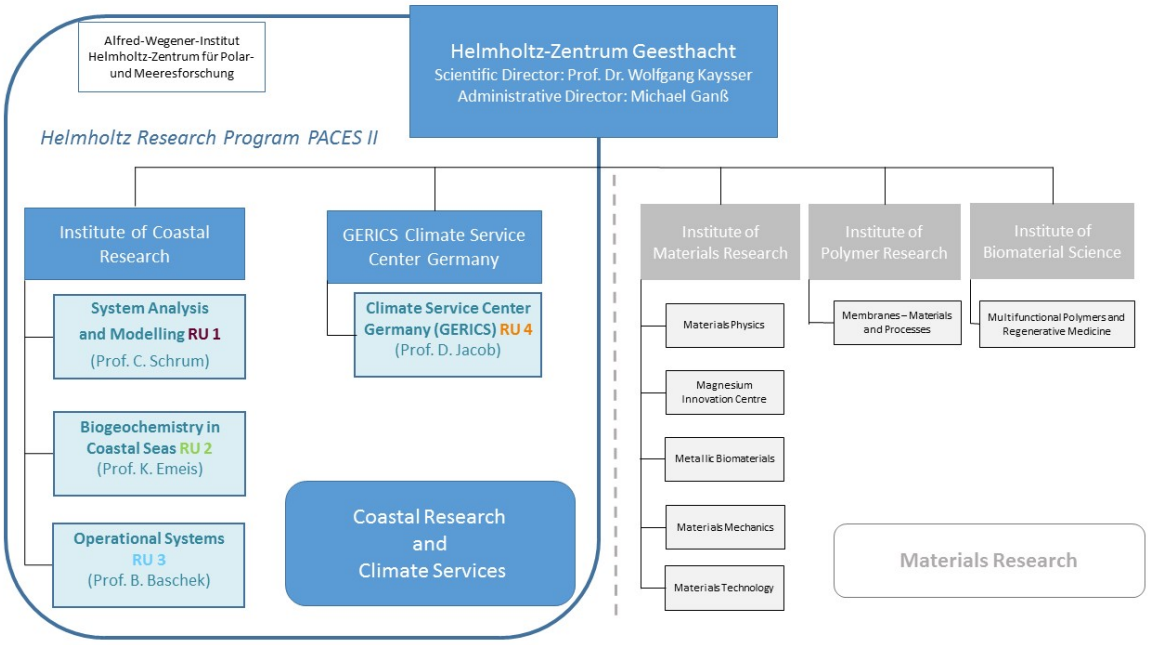



Figure 2: Organizational Scheme of HZG

In the following, we focus on coastal research and climate services, research which is conducted at the Institute of Coastal Research and the Climate Service Center Germany (GERICS).

The Institute of Coastal Research at HZG and GERICS are engaged in the Research Field *Earth and Environment* in a joint program (*PACES II: Polar Regions and Coasts in the Changing Earth Systems*) in cooperation with the Alfred-Wegener-Institute for Polar and Marine Research (AWI).

## Research Units at the Institute of Coastal Research

| | |
|---|---|
| RU 1: System Analysis and Modelling<br>Director: Prof. Corinna Schrum<br>Core-financed scientists: 29 FTE | Exploration of regional and global changes of coastal zones.<br>Developments in operational oceanography. |
| RU 2: Biogeochemistry in Coastal Seas<br>Director: Prof. Kay-Christian Emeis<br>Core-financed scientists: 23 FTE | Investigation of natural and artificial chemical compounds and pollutants in coastal transition zones. |
| RU 3: Operational Systems<br>Director: Prof. Burkard Baschek<br>Core-financed scientists: 16 FTE | Development of the Coastal Observing System for Northern and Arctic Seas (COSYNA); Small-scale physical dynamics. |

Table 3: Research Units at the Institute of Coastal Research

## Research Unit at the Climate Service Center Germany (GERICS)

| | |
|---|---|
| RU 4: Climate Service Center Germany (GERICS)<br>Director: Prof. Daniela Jacob<br>Core-financed scientists: 23 FTE | Think tank for climate services: Development of products, advisory services and decision-relevant information for supporting government, administration and business in their efforts to adapt to climate change. |

Table 4: Research Unit at GERICS

## Research at the Institute of Coastal Research and GERICS, and contributions to the Helmholtz Program PACES II

The central research goal of HZG's Institute of Coastal Research is to understand the complex natural dynamics of coastal systems and their interactions with human drivers. It is the Institute's goal to scientifically explore, detect, and predict consequences of global and regional change at the interface of atmosphere, ocean, land, and society. The Institute of Coastal Research focuses on geophysical, biogeochemical, and chemical aspects of coastal systems. It provides sustained, high-quality observational, modeling, and analytical capacities to address pertinent scientific questions. The Institute strives to enhance the relevance of its research by actively addressing the informational needs through dialog with and knowledge transfer to various stakeholders and the general public. In particular, this understanding often informs institutional partners that are charged with managing the vulnerable and contested land- and seascapes of Northern Europe and elsewhere.

Information needs are central for many actors in the context of climate change. GERICS (RU 4) develops and operates climate services at the interface between society and science. The main objective is to enable decision makers to better cope with the impacts, risks, and opportunities expected from climate change, and to establish links between the science community and societal actors involved. The current priority sectors are water, energy, ecosystems, and the cross-sectoral field of urban areas. The focus is on establishing and providing reliable and comprehensive information related to climate change, based on state-of-the-art scientific evidence from PACES II as from any other research results.

Complementary research portfolios of HZG and of biologists at AWI facilitate a comprehensive systems approach to coastal zone science and climate services in the joint Helmholtz Research Program PACES II. Here, the Institute of Coastal Research is prominently engaged in Topic 2: *Fragile Coasts and Shelf Seas*. Jointly with AWI the Institute of Coastal Research and GERICS (RU 4) also contribute to PACES II Topic 4 *Bridging Research and Society – Products, Tools and Climate Services*. This topic explores and spans the interface between science and society.

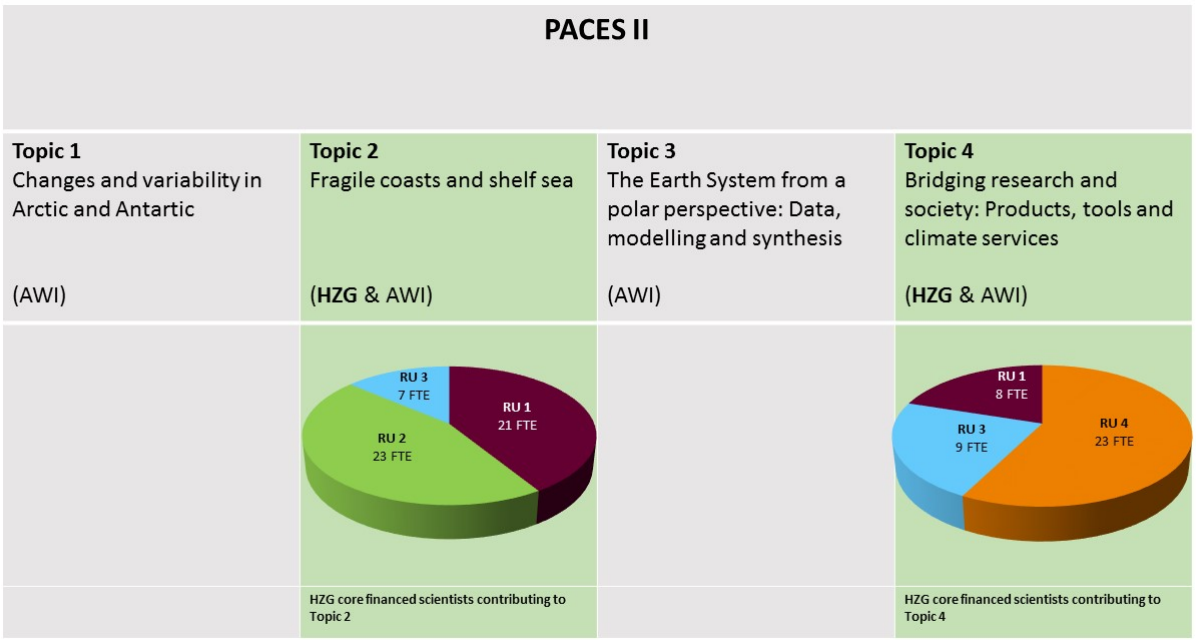



Figure 3: Contribution of HZG-Research Units to the Helmholtz-Program PACES II in 2016.

## Contributions to PACES II, Topic 2. Fragile coasts and shelf seas

Coastal and shelf systems are perhaps the most rapidly changing environments on Earth. Natural variability, directed change (e.g., warming) and single events cause complex system responses. At the same time, human activity increases, and the health of coastal environments and the sustainable use of their resources is of rising societal importance and concern. For coastal science, this calls for efforts to identify and understand human and natural drivers of variability in coastal and shelf sea systems, to define environmental status and corridors of natural variability, and to support low-risk development and management of the coastal environment. In Topic 2, HZG addresses the following research themes by using advanced regional coastal system modeling, analytical expertise and unique capacity for state-of-the-art ocean observations.

Research on ***Coastal shifts and long-term changes*** focuses on model-based descriptions of past, recent, ongoing, and possible future changes on multi-decadal time scales and longer. Emphasis is placed on discrimination between 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 to climatic changes. Products of this research, such as ***coastDat*** http://www.coastdat.de, define 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 made available via Topic 4 for industrial and stakeholder use.

**Work on *Species Interactions in changing and exploited Coastal Seas*** seeks to relate multi-scale variability in physical or chemical drivers to changes in ecosystem structure and function. The HZG develops and deploys mechanistic, trait-based, and coupled models for the southern North Sea including estuaries and the seafloor. The model serve to assess ecosystem responses to, for example, changes in riverine nutrient input or ocean acidification. This activity establishes new concepts in coastal ecosystem modeling and addresses fundamental questions in plankton research. Results are used to provide information for national authorities in the context of European environmental directives.

**Work on *Biogeochemical provinces of sea floors in coastal seas*** investigates the role of processes at the sediment-water interface for material fluxes in shelf seas. Scientists develop ***coastMap*** http://www.coastmap.org, the comprehensive georeferenced inventory of biogeochemical seafloor properties and pollution in the North Sea's German Bight. This provides the compulsory and much-needed boundary conditions for ecosystem models, for pollution assessment, assessing the intrinsic seafloor ecosystem services, and for describing the environmental status in national and international contexts.

Scientists **working on *Interface processes and physical dynamics of the coastal ocean*** observe the small-scale dynamics of coastal seas and elucidate their relevance in energy and matter fluxes. 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. HZG has developed new instrumentation and modeling techniques to better understand the dynamics of the air-sea interface and submesoscale processes, their effects on energy dissipation and phytoplankton dynamics, as well as wave interaction with shallow sea-floors.

## Contributions to PACES II, Topic 4. Bridging research and society—products, tools, and climate services

Climate change and other environmental changes shift baselines in marine, coastal, polar, and terrestrial systems and thus pose major challenges to society. In fact, many related policy and economic decisions made today will have a profound impact on our future economy and lifestyle. The objective of Topic 4 is to improve the benefit of knowledge and developments generated within PACES II by channeling state-of-the-art tools and research findings to decision makers, stakeholders and the public while fostering a dialog between them. Topic 4 develops pre-operational models and tools and provides them to stakeholders, such as operational

national and international service agencies. Moreover, new approaches for effective science-stakeholder interactions and multifaceted climate services are developed. Research-generated model data and data based products are made freely available for further use by research and stakeholder communities and other actors.

**Work on *Operational analyses and forecasting*** addresses the pre-operational development of advanced observations, data analysis, forecast systems, and tools to support marine and coastal operational services and activities. It also supports the further development and provision of existing operational forecast models in close cooperation with national and international operational services and agencies.

**Work on *Channelling research data to enhanced data products*** explores how multi-dimensional observational and modeling data can be made available to users in research and society. New advanced methods and enhanced technological resources in observations and modeling enable deep insights into the (coastal) environment. For example, the observing system COSYNA and regional Earth System models with high resolution in time and space provide enormous data volumes from different model configurations. Integrated observing systems record a variety of data using diverse observational and analytical methods. Challenges in data provision include data storage, metadata standardization, and easy access to the data for interested users, such as scientists with or without similar backgrounds, public authorities, businesses and society.

**Work on *Providing information – Enabling knowledge and climate services*** establishes stakeholder dialogs on coastal issues and regional climate through scientific regional assessment reports, other communication formats and climate services, which are developed and tested in mutual exchange. The overall aim is to build bridges between climate research and (potential) climate information users from the public and private sectors, and to process high-quality information produced by scientific research into customized, pioneering prototype climate service products.

## 3.2 MAJOR HIGHLIGHTS AND ACHIEVEMENTS

The complex interactions and dynamics of the coastal zone combined with the challenges posed by climate change and diverse regional pressures require integrated approaches. The following are highlights of HZG work in the last several years that have been made possible solely due to combining the broad expertise from the four HZG Research Units.

### Highlight 1: Large-scale offshore wind energy development – A case for coastal research

During the program period of PACES II, the North Sea has experienced considerable increase in offshore wind farm (OWF) development. At the end of 2016, the North Sea had a net installed capacity of 9.1 GW with forty-four wind parks and more than 2700 individual piles; by 2020, the total offshore wind capacity is expected to be 24.6 GW. This rapid development is a prime example of increasing conflicts originating from diverging societal goals. The transformation into an energy seascape may therefore compromise environmental development goals stipulated by national and international legislation, such as the EU Marine Strategy Framework Directive. It also bears potential for other natural resource conflicts, such as with fisheries. The physical and biogeochmical effects of OWFs on the North Sea as well as social and planning aspects were examined in a cross-sectional effort that included all Research Units focusing on the North Sea's German Exclusive Economic Zone (EEZ).

*Optimization of design and logistics*

There is considerable interaction between OWFs and the environment, providing challenges and limitations for OWF operability. The latter has been addressed in several HZG studies using the ***coastDat*** database. For example, a climatology of wind energy over the North Sea was developed that also considered potential synergies between different OWF arrays (Geyer et al., 2015). In particular, met-ocean data from ***coastDat*** is used by nearly all planned and operated OWFs in the German EEZ for optimization of design and logistics (overview in Weisse et al., 2015). Furthermore, climate change impacts on key financing aspects of offshore wind energy are investigated in ongoing climate service research at GERICS (RU 4). This is of relevance for climate change adaptation implementation regarding offshore wind energy at the pre-operational planning phase.

*Mixing and wake effects*

Offshore wind farms and single piles create wake effects in the atmosphere and ocean. The wake effects in the atmosphere are created by atmospherically induced turbulence and by the removal of energy. Wind wakes are visible in remote sensing (Figure 4) (Platis et al., 2017), and the size of atmospheric wake effects depends on the size of the wind mills, rotor dimensions and farm size; they scale up to one hundred kilometers and more. The observations show that the wake length of OWFs increases with atmospheric stability due to reduced vertical momentum fluxes. The effects of single wind turbines on wind and friction velocity are observed with high spatial and temporal resolution using HZG marine radars that show strong wind speed shear zones across the wakes.

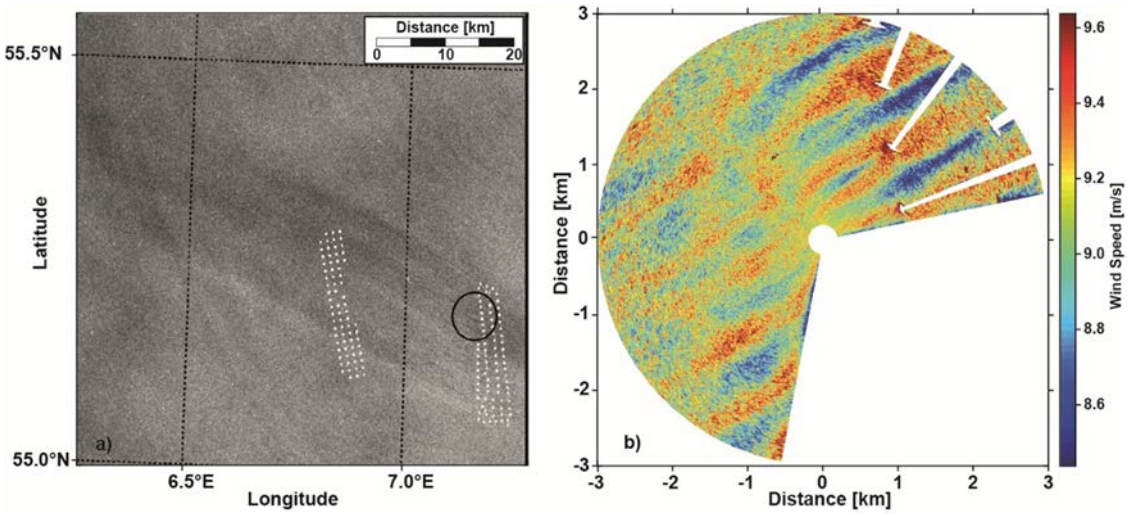



Figure 4: Left: Sentinel-1 SAR image showing the large-scale wind wake of OWF DanTysk located in the southeast corner of the image. Right: Wind field retrieved from HZG's marine radar in the area marked by the circle on the SAR image. Single turbines are marked in white.

An additional impact of wind piles is caused by local generated vertical turbulence through a combination of tidal currents and the pile structure, which lead to the generation of Karman Vortices (Grashorn and Stanev, 2016). Ocean turbulence provides an additional mixing potential for the seasonal stratification that forms throughout large areas of the German EEZ, and for the suspension of sediment. Both of these processes are known to lead to cascading effects on coastal ecosystems. It is also possible for large-scale OWF development to have significant impact on North Sea stratification, as supported by observations and modeling (Carpenter et al., 2016; Floeter et al., 2017). Current work is focused on understanding and quantifying the localized mixing process of a single OWF foundation using Large Eddy Simulations and *in situ* measurements. Initial results suggest that the low thermocline turbulence is expected to be significantly enhanced by OWFs (Schultze et

al., 2017). To support an integrated impact assessment and to explore the economic exploitation potential, OWFs are integrated into regional Earth System models through semi-empirical modeling and OWF parameterization in oceanic, atmospheric and coupled models.

*Biological and pollution effects*

Despite a great number of local impact studies for selected marine populations, the impact of OWFs on regional ecosystems are not yet well investigated or understood. Therefore, the affect of epifauna accumulation on turbine foundation structures (dominated by the filter-feeding mussel *Mytilus edulis*) on pelagic primary production and ecosystem functioning was investigated (Slavik, 2016). The projected distribution of *Mytilus edulis* was integrated by using the Modular Coupling System for Shelves and Coasts (MOSSCO), with state-of-the-art hydrodynamic and ecosystem models. Results reveal non-negligible changes in regional annual primary production of up to a few percent, and larger changes (up to ±10 %) of phytoplankton stock during the bloom period, thus impacting water clarity. The functions and environmental status of the sea floor in the German EEZ prior to the large-scale installation of OWFs are currently being assessed, focusing on material emission fluxes caused by corrosion and scour protection measures. The main goals are to identify potential organic and inorganic pollutants, as well as to develop analytical methods and appropriate sampling strategies to detect and assess potential pollutants.

*Sociocultural and planning effects of OWFs*

Approval and planning processes as well as the societal debate surrounding OWFs are driven by political objectives and sociocultural concerns. Investigations showed that aesthetic and sociocultural perspectives are highly relevant for gaining acceptance by local citizens (Gee, 2013; Kannen, 2014). To make these studies applicable in the planning processes, Fischer & Kannen (2016) investigated the connection of OWFs to ecosystem services, while Busch et al. (2013) analyzed the cumulative impact on bird habitats. Such findings were also transposed into international training and methodological proposals to improve maritime spatial planning, such as outlining a concept for recognizing culturally significant areas (Gee et al., 2017), or looking at them from a socio-ecological system perspective (Alexander et al., 2015).

## Highlight 2: Development and Operation of the Integrated Observing and Modeling System COSYNA

The Coastal Observing System for Northern and Arctic Seas (COSYNA, www.cosyna.de) was established in order to better understand the complex interacting processes in a changing coastal environment. COSYNA (Baschek et al., 2017) is a distributed, automated observing and modeling system to synoptically describe real-time conditions, provide short-term forecasts, data, and data products to help assess the impact of anthropogenically induced change on the coastal environment. In particular, the development and combination of various observing techniques, sensors, integrated modeling, and real-time data provision have fostered our understanding and monitoring capabilities of coastal systems. Observations are carried out by combining satellite and radar remote sensing with various *in situ* platforms. Novel sensors, instruments, and algorithms are developed to further improve the understanding of the interdisciplinary interactions. New modeling and data assimilation techniques are used to integrate observations and models into a quasi-operational system. COSYNA is operated by HZG in cooperation with ten national partner institutions. Particular focus is given to the German Bight (as a prime example for a heavily used coastal area) and to Svalbard and the Lena Delta (as examples of an arctic coast that is under pressure due to global change) (Figure 5).

COSYNA has established and uses several measurement poles, ocean gliders, FerryBoxes, underwater node systems, landers, a ScanFish and GPS telemetry used on sea birds. All *in situ* instruments measure the same basic oceanographic parameters. Remote sensing is carried out with HF radar (e.g. Bruno et al., 2013) and satellite ocean color products and combined with modeling

(Stanev et al., 2015). Numerous measurement devices have been developed, including sensors for underway measurements and for automated collection of samples for molecular analyses and to determine the potential effects of micropollutants on the marine environment and biota (for details see Baschek et al., 2017). As examples, the following instruments and systems developed at HZG are described:

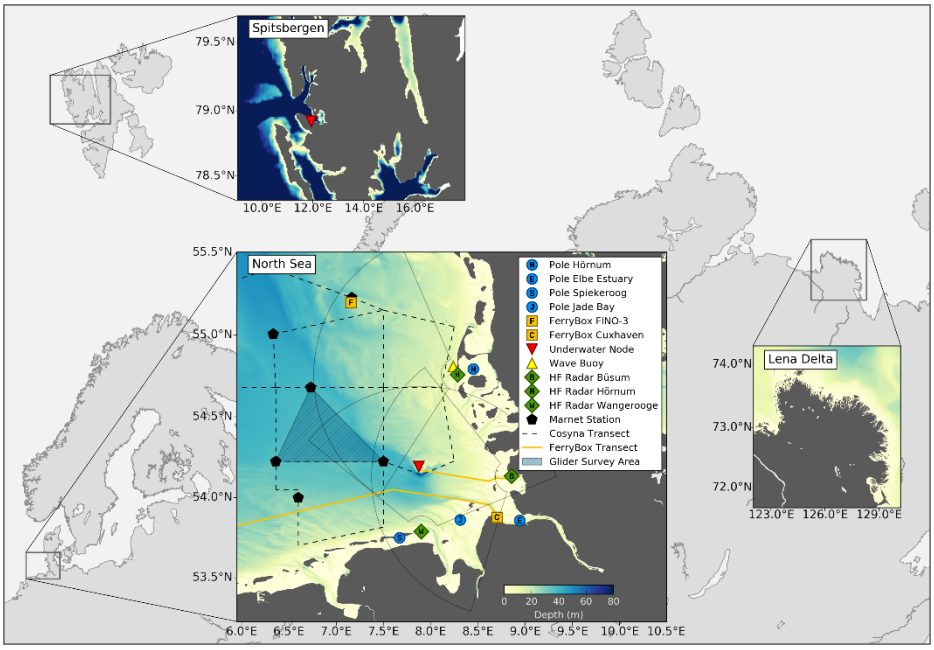



Figure 5: Map showing the pre-operational components of the coastal observing system COSYNA.

- The COSYNA *Underwater Node System* (Baschek et al., 2017; Fischer et al., 2017) was developed in close cooperation with AWI to carry out continuous observations in extreme conditions, such as in storms or during the Arctic winter, and to go beyond the limitations in power and data transmission rates. Several instrument systems can be connected for longer operations. The underwater node off the island of Helgoland is the first installation worldwide in a shallow water environment subject to strong wave forces. At Svalbard, the underwater node allows the first year-round observations beneath the sea ice under harsh environmental conditions. A third unit was deployed in cooperation with GEOMAR to extend the existing Boknis Eck time-series station.
- The *Fluxes on Sands Observatory* (FLUXSO) chamber lander was developed in collaboration with MPI Bremen, AWI and a German company (K.U.M. GmbH) for studying *in situ* solute nutrients fluxes, Dissolved Inorganic Carbon (DIC), and oxygen in permeable, sandy sediments. The purpose of the lander is to study advection-related processes in permeable shelf sediments, benthic-pelagic coupling, and the importance of the seafloor in shelf seas for organic carbon turnover and as sink or source of nutrients and oxygen. The lander is operated on permeable and impermeable North Sea sediments (Ahmerkamp et al., 2017).
- The *European FerryBox Database* (www.ferrybox.org) has been established at HZG. Data collected by European FerryBoxes on ships of opportunity (www.wmo.int), as well as by FerryBoxes from German research vessels and stationary FerryBoxes are processed and provided immediately after transmission. The FerryBox System was originally developed at HZG and is continuously developed further to integrate new sensors or for highly mobile applications (Petersen, 2014).

The integration of observations and models allows the dissemination of data and the development of data products, such as pre-operational current and wave state descriptions, forecasts based on assimilation of HF-radar measurements, modeled temperature maps with assimilated OSTIA satellite data or monthly mean satellite chlorophyll maps. COSYNA has explored different techniques to assimilate data into models: The upscaling problem of connecting smaller to larger scales was addressed by using the North Sea barotropic dynamics (Schulz-Stellenfleth and Stanev, 2016). The impact of small-scale bathymetry perturbations, bottom roughness, wind forcing, and OB boundary forcing was quantified using a novel approach. The impact of different types of perturbations was estimated by inverting the model. A new analysis scheme for data acquired with HF radar was developed (Stanev et al., 2015). The *Spatio-Temporal Optimal Interpolation* (STOI) method blends numerical model data and radial surface current measurements, providing improved short-term forecasts. Model simulations from a free run and radar observations are blended allowing efficient corrections of tidal phase and amplitude errors.

The data collected by COSYNA support several scientific process studies, such as the investigation of nutrient and suspended particulate matter (SPM) fluxes in the Elbe River and the Wadden Sea. They are key processes in the German Bight's land-sea transition. Based on more than five thousand water samples, the ratio between organic and inorganic SPM content was modeled showing a well-defined behavior also at low SPM concentrations. Comparison with other coastal settings prove the general validity of this relationship. A combination with satellite images reveals a transition zone in front of the Wadden Sea characterized by a rapid change from sediment-bound to *fresh* organic material exhibiting considerable variability. This high variability has also been confirmed by an Elbe flood impact study based on FerryBox time series. The flood generated a large influx of nutrients as well as dissolved and particulate organic carbon on the coast, which led to an unusual phytoplankton bloom. As such, large and extreme floods have increased in frequency in recent decades due to climate change and subsequent biogeochemical changes may become more prevalent in the future (Voynova et al., 2017).

Several workshops served to integrate COSYNA activities with the scientific community and other stakeholder groups, such as with the wind energy industry (Eschenbach, 2017). As the success of these activities cannot be measured using traditional methods, COSYNA has been active in developing alternative metrics. COSYNA data and data products are made available for free through the Internet and via the COSYNA app. Users in science, public administration, industry, education, NGOs, and the public stem from fifty-five countries, totaling more than three hundred distinct users per year, with downloads of 250-300 GB. After its original funding ended in 2015, COSYNA has been continuously developed, contributing to the Helmholtz projects ACROSS (Advanced Remote Sensing – Ground Truth Demo and Test Facilities) and MOSES (Modular Observation Solutions for Earth Systems) and will be linked to ESM (Earth System Modeling). COSYNA infrastructure is extended towards a more mobile and cross-discipline usability.

### Highlight 3: Informing climate policy and decision-making at the regional, national, and international levels

This highlight emphasizes different communication formats supporting climate policy discussions and informing decision-making on both the national and international levels. These include coordinating local and regional assessment reports as well as one national climate change report and significant contributions to two international reports. They support increasing demand on region-specific climate information.

In PACES II, four regional assessment reports have been published, coordinated by HZG scientists and with substantial HZG contributions: The *Second Assessment of Climate Change for the Baltic Sea Basin* (BACC II, 2015) was organized by the Baltic Earth Secretariat, hosted at the Institute of Coastal Research. It is an updated, international climate change assessment for the Baltic Sea region and was supported by approximately eighty international scientists. With more than 120,000 downloads by the beginning of November 2017, the BACC II open access e-book was among the top 25% most downloaded Springer eBooks in the relevant collection. The *North Sea Region Climate Change*

*Assessment* (NOSCCA; Quante and Colijn, 2016) was coordinated by the Institute of Coastal Research and developed as an independent international initiative, with contributions by approximately two hundred scientists from fourteen different countries. This open access e-book had close to 60,000 downloads by the beginning of November 2017. The second peer-reviewed regional assessment report for the metropolitan region of Hamburg (von Storch, Meinke and Claußen, 2017) was organized by the Institute of Coastal Research and was published in October 2017. The open access e-book has already been downloaded more than ten thousand times during the first month (as of the beginning of November 2017). A total of 115 scientists were involved in providing an update and new insights on climate change knowledge and its social aspects for regional northern Germany. As a national report, the publication of *Klimawandel in Deutschland* (Brasseur, Jacob and Schuck-Zöller, 2016) was organized by GERICS (RU 4). It is the first peer-reviewed book of its kind for Germany that assesses and summarizes the observed and projected climate changes and associated impacts in a wide range of different economic sectors. The project incorporated more than 120 researchers in Germany and primarily targets decision makers within the country. The freely available e-book or single chapters were downloaded 354,082 times by the beginning of November 2017.

Two further international formats have been developed and published by GERICS (RU 4). In light of the international COP21 negotiations, raising policymakers' and society's awareness of potential climate change impacts under a +2°C global warming is of central importance. This has been the major aim of GERICS (RU 4) in the EU IMPACT2C project (Quantifying projected impacts under 2°C warming), with a focus on the following key sectors: energy, water, tourism, health, agriculture, ecosystems, forestry, coastal and low-lying areas at the pan-European level, as well as for some of the most vulnerable regions in the world. The IMPACT2C web-atlas (https://www.atlas.impact2c.eu/en/) was developed and presents a wide range of potential climate change impacts in an easily accessible manner. It serves in gathering information for decision making on possible adaptation strategies at national and international levels. Based on these findings, GERICS (RU 4) identified the multi-sector *winners* and *losers* in a +2° C world as well as respective hotspots related to the impacts on water, agriculture, and ecosystems. This work is incorporated into the report *Climate change, impacts and vulnerability in Europe 2016* (EEA, 2017). The report supports the implementation and review process of the 2013 EU Adaptation Strategy, which is expected for 2018. It also supports the development of national and transnational adaptation strategies and plans.

Within the EU project ENHANCE (Enhancing risk management partnerships for catastrophic natural hazards in Europe), GERICS (RU 4) developed The Capital Approach Framework in order to assess governmental performance in multi-sector partnerships in the face of risk events. This work resulted in a policy recommendation for implementing the Sendai Framework Article 18 (UNISDR – United Nations Office for Disaster Risk Reduction). It recommends that "risk perception analysis is the first step in understanding how local cultures identify and manage risk. Risk perception drives how people will behave and manage a particular risk. The inclusion of social sciences and their analytical tools in the national platforms is crucial to have a complete vision of the understanding of risk." (http://www.unisdr.org/files/43847_efdrr2015franceoutcomesfinal.pdf).

Several avenues and approaches for informing policy on regional and local levels have been developed and explored by the Institute of Coastal Research (see chapters of individual Research Units). Examples include long-term dialog processes with approximately two thousand registered stakeholders, web tools on coastal climate and protection, and contributions to EU-policy briefings on coastal research, such as the EU-RISES-AM policy briefing and Science for Disaster and Risk Management in 2017.

## 3.3 STRATEGIC PARTNERS AND COOPERATION

The fundamental idea behind the research at HZG — "from application-inspired basic science to innovation" — leads to close cooperation and networking with partners from outside the research center. These close partnerships are a prerequisite for outstanding research and development and inspire basic research, as well as the successful application of innovations. Therefore, the choice of external partners — both for basic research and for its translation into innovation — is a decisive factor for the success of research and development at HZG and, therefore, is an aspect of prime importance. In 2016, HZG maintained 169 contractual relationships with cooperation partners in science and a further 86 with partners in industry.

### 3.3.1 NATIONAL COOPERATION

HZG cooperates closely with the Alfred-Wegener Institute (AWI, Bremerhaven) within PACES II. The cooperation between Helmholtz Centers in research field Earth and Environment is strengthened through Helmholtz initiatives and programs such as the Helmholtz Initiative *Regional Climate Change* (REKLIM), Earth System Knowledge Platform (ESKP), strategic projects such as Earth System Modeling (ESM), Reduced Complexity Models, and infrastructure projects such as COSYNA, ACROSS, and MOSES.

Strategic cooperation in the field of climate research with partners outside of the Helmholtz Association is bundled in activities with the KlimaCampus Hamburg and its scientific kernel, the Center of Excellence CliSAP (https://www.clisap.de), also in Hamburg.

CliSAP is a joint effort of the Universität Hamburg, the Institute for Coastal Research at HZG, the Max-Planck Institute of Meteorology (MPI-M) and the German Climate Computing Center (DKRZ). Together with the Universität Hamburg, the AWI and the Max-Planck-Society, HZG is a shareholder of the DKRZ. HZG introduced a strong component of regional and coastal systems science and their societal embedding into CliSAP. HZG is also substantially involved in the follow-up Excellence Strategy proposal *Climate, Climatic Change, and Society* (CliCCS). The proposal is coordinated through Universität Hamburg's Center for Earth System Research and Sustainability, the MPI-M, HZG and DKRZ. The expression of interest was successfully evaluated in 2017 and CliCCS was invited to submit a full proposal.

A close and binding cooperation with the Universität Hamburg is the subject of existing framework agreements, joint appointments and, last but not least, the long-standing cooperation in the Excellence Initiative and planning for the new Excellence Strategy. In particular, this close cooperation includes topics in the fields of climate and coastal research, climate impact research and research for climate service—for example, through the joint *Helmholtz-Institut Climate Service Science* (HICSS). Robust links and collaborations with several other universities have been established and are also mutually beneficial. Joint professorships are maintained with the universities in Kiel, Hamburg, Hamburg-Harburg, Oldenburg and Lüneburg.

Close partnerships are also maintained with governmental institutions and agencies—in particular, with the *Federal Maritime Agency* (BSH), *German Weather Service* (DWD), *Federal Waterways Engineering and Research Institute* (BAW), *German Federal Institute of Hydrology* (BfG), *Hamburg Port Authority* (HPA), and the *Thuenen Institut* as well as with companies engaged in coastal and shelf sea research and development. Several formalized cooperation agreements are in place in order to increase relevance and timeliness of our research while engaging stakeholders and decision makers in a dialog.

HZG also established the *Northern German Coastal and Climate Office*, which acts as a dialog partner for interested individuals and groups from the fields of agriculture, tourism and coastal protection. The office is part of the Helmholtz network of regional climate offices.

Coastal science in Germany is organized through the *Konsortium Deutsche Meeresforschung* (KDM) in a strategy group and dialog platform that defines future national research priorities and negotiates themes to be tendered by the Ministry of Education and Research (BMBF). The current program

period of the BMBF consortium *Küstenforschung Nordsee-Ostsee* (KÜNO) targets research in the North Sea and Baltic Sea. HZG delegates the speaker for twelve currently funded projects, and coordinates three of them.

The Institute of Coastal Research is further involved in numerous national projects and industry cooperations (see Vol. II). An important key principle of GERICS (RU 4) is that participation in third-party funded projects contributes effectively to the GERICS' main objectives. GERICS (RU 4) is currently a partner in eleven national third-party funded research projects and has different key economic partners (see RU 4).

### 3.3.2 INTERNATIONAL COOPERATION

Close cooperation with international partners takes place through the Copernicus Marine Environment Monitoring Service, the Copernicus Climate Change Service, various EU projects within the framework of ERAnet and H2020 projects, and with international networks, such as Baltic Earth, ICES and EuroGOOS. Strategic partners of the Institute of Coastal Research include several European institutions, such as NERSC and Met.no in Norway, NIOZ in The Netherlands, and MERCATOR in France.

HZG is strongly engaged in two European consortia for research infrastructure in coastal environments. JERICO-NEXT (HORIZON 2020), the Joint European Research Infrastructure Network for Coastal Observatories aims at harmonizing the diverse coastal observatories in Europe and at initializing the coastal portion of a European Ocean Observing System. The *International Center for Advanced Studies on River-Sea Systems* – DANUBIUS-RI, an international Research Infrastructure project now placed on the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap 2016 is currently being implemented as a new pan-European distributed Research Infrastructure for studying river-sea systems. It provides a platform for interdisciplinary research, inspiration, innovation, education, and training. The consortium, currently comprising nine countries, is led by Romania. HZG is responsible for drafting the scientific framework and establishing *the Elbe-North Sea Supersite* and contributes to the DANUBIUS modeling node.

The Baltic Region is also a focus area for international cooperation. HZG currently hosts the international secretariat of *Baltic Earth* and its predecessor *BALTEX,* and HZG scientists have continuoulsy been members of their respective Scientific Steering Committees. *Baltic Earth* brings together a broad international research community to address core scientific issues identified as fundamental for informing societal efforts and for achieving sustainability in the region.

Another international focus is the collaboration with China, based on a long and fruitful partnership with the Yantai Institute of Coastal Zone Research of the Chinese Academy of Sciences, the Ocean University Qingdao in China and various other research institutions in China.

GERICS' activities with regard to coordinating and contributing to many international, European and national networks (e.g., World Climate Research Programme/WCRP, Coordinated Regional Downscaling Experiment/CORDEX, Coordinated Downscaling Experiment – European Domain/ EURO-CORDEX) and initiatives (e.g., international Climate Service Partnership/CSP, Joint Programming Initiative/JPI Climate, ERAnet for Climate Services, Earth League) are important for joint development of high quality climate service products. Different secretariats of various top-level bodies in the areas of sustainability and climate services are based at GERICS (RU 4), including: CSP, the Earth League, EURO-CORDEX, the administrative office of HICSS, and the editorial office for the Elsevier journal *Climate Services*, which was initiated by GERICS (RU 4) and launched in 2015.

Currently, GERICS (RU 4) is partner in twelve third-party funded research projects, which also foster networking between practitioners and scientists.

## EU PROJECTS

As sought-after partners, the Institute of Coastal Research and GERICS (RU 4) actively drive national and international collaborations and are successful in acquiring external funding from European funding programs.

Key motivation of HZG for engaging in EU projects are (1) bringing in HZG's competences to solving international societal challenges and science questions while (2) further improving our competences and enlarging the number of HZG's innovation and research partners in Europe and beyond. Being successful in the highly competitive EU funding constitutes one international benchmarking element of HZG's research and innovation activities. EU projects are ideal for assisting academic partners as well as stakeholders within and outside of EU consortia with observation, data, model infrastructure and innovative climate service products that are otherwise not available to them. The EU projects thus either directly contribute to or complement the research of the Helmholtz Program Oriented Funding (POF).

In the 7th Framework Program (FP7) for Research of the European Union (2007-2013), HZG was active in 48 funded projects with a total of more than 440 partners in 54 countries ranging from science to industry. The present EU Framework Program for Research and Innovation *Horizon2020* started in 2014. Since then, HZG participated in 43 successful project proposals including more than 320 partner organizations in 37 countries. During FP7 and *Horizon2020*, the Institute of Coastal Research and GERICS (RU 4) conducted more than 60 % of all EU projects at HZG. In PACES II, HZG scientists are now also engaged in other EU programs such as Copernicus, INTERREG (European Territorial Cooperation), and the LIFE program of the EU-DG Environment.

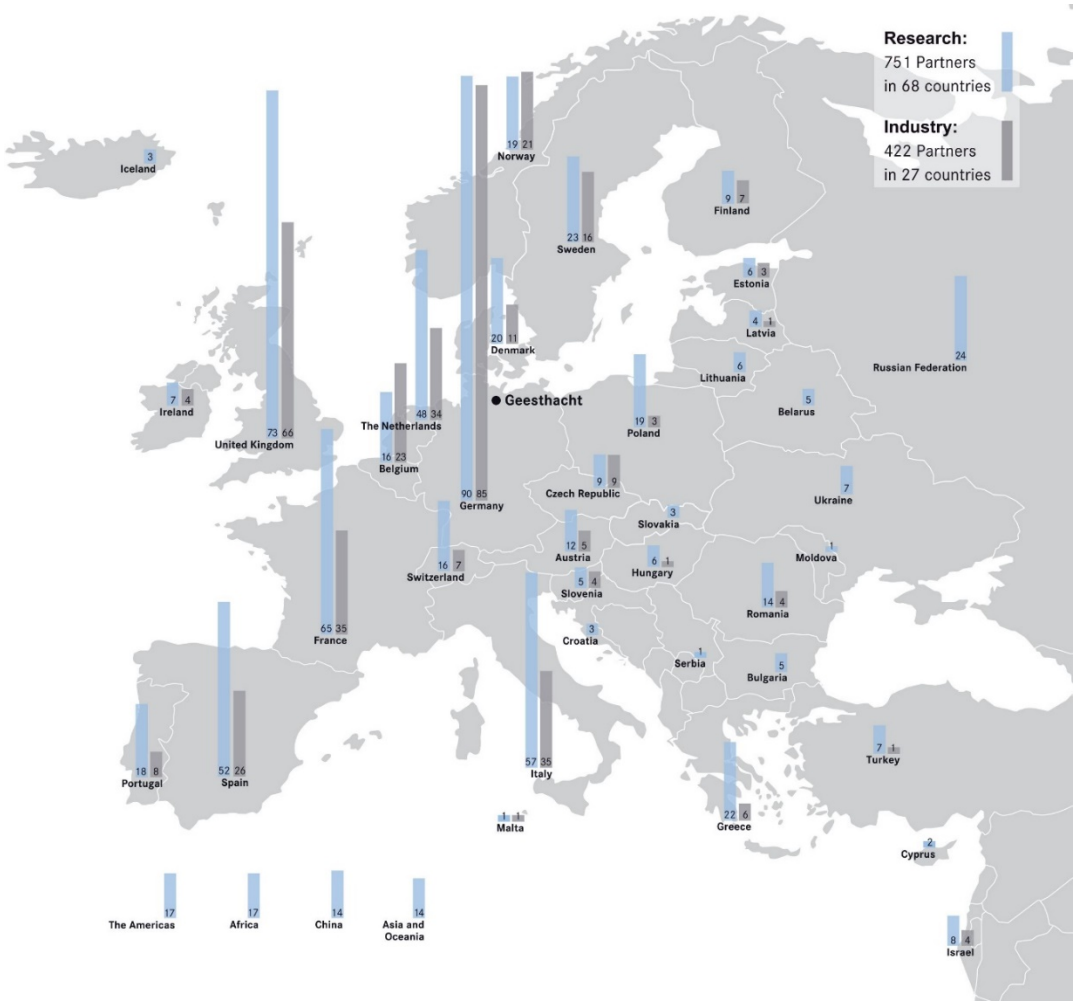



Figure 6: Distribution of partners of HZG in EU projects since 2000. Columns indicate academic (blue) and non-academic (gray) partners.

Examples of ongoing and recently concluded EU collaborative projects with HZG involvement are grouped around the following projects and themes:

- The large scale integrating project IMPACT2C ("Quantifying projected impacts under 2C warming", FP7, 2011-2015) produced timely results as input to the UNFCC COP21 meeting in Paris 2015. It was coordinated by HZG/GERICS (RU 4).
- HZG/GERICS (RU 4) contributes to the development of climate services in a series of EU projects, including ECLISE ("Enabling Climate Information Services for Europe", FP7, 2011-2014), CLIMATEUROPE ("European Climate Observations, Modelling and Services 2", H2020, 2015-2020), EU-MACS ("European market for climate services", H2020, 2016-2018), and LOCAL ADAPT ("Integration of climate change adaptation into the work of local authorities", EU LIFE, 2016-2021).
- HZG (Institute of Coastal Research and GERICS (RU 4)) became a partner in the ERANET Cofund program ERA4CS ("European Research Area for Climate Services", H2020, 2016-2020) and recently succeeded with four funded projects in ERA4CS calls, two of which are coordinated by HZG.
- HZG opens its coastal observation research infrastructure for scientist from Europe and beyond and further develops observational techniques by using several EU projects, such as JERICO (*Towards a Joint European Research Infrastructure Network for Coastal Observatories*, FP7, 2011-2015), JERICO-NEXT (*Joint European Research Infrastructure Network for Coastal Observatory – Novel European expertise for coastal observatories*, H2020, 2015-2019) and DANUBIUS PP (*Preparatory phase for the pan-European Research Infrastructure DANUBIUS–RI: The International Centre for advanced studies on river-sea systems,* H2020, 2016-2019). DANUBIUS-PP is one outcome of the partnership of HZG in the DANUBIUS project placed on the ESFRI (European Strategy Forum on Research Infrastructures) roadmap in 2016.
- HZG engages in research projects to further develop technologies for Copernicus (also earlier referred to as GMES), such as MyOCEAN2 ("Prototype Operational Continuity for the GMES Ocean Monitoring and Forecasting Service", FP7, 2012-2014), CEASELESS ("Copernicus Evolution and Applications with Sentinel Enhancements and Land Effluents for Shores and Seas", H2020, 2016-2019), EUCLEIA ("European climate and weather events: Interpretation and attribution", FP7, 2016-2016), or CLIPC ("Climate Information Platform for Copernicus", FP7, 2013-2016, HZG/GERICS (RU 4)). Since 2015, HZG is also participating in Copernicus contract research with a dedicated approach to develop downstream services for concrete user applications. Currently, the Institute of Coastal Research contributes to three projects of the Copernicus Marine Environment Service (CMEMS), while GERICS (RU 4) is engaged in five projects of Copernicus Climate Change Service (C3S).
- HZG is engaged in several EU projects for the understanding and management of extreme or high impact events, such as ENHANCE ("Enhancing risk management partnerships for catastrophic natural disasters in Europe", FP7, 2012-2016, HZG/GERICS (RU 4)), RISES-AM ("Responses to coastal climate change: Innovative strategies for high end scenarios - Adaptation and mitigation", FP7, 2013-2016), and IMPREX ("Improving predictions and management of hydrological extremes", H2020, 2015-2019, HZG/GERICS (RU 4)).
- HZG became a consortium member in the ERANET Cofund program ERA-PLANET ("The European network for observing our changing planet", H2020, 2016-2021). In the frame of the ERA-PLANET call, HZG succeeded with three funded projects, one of which is iGOSP ("Integrated Global Observing Systems for persistent pollutants", H2020, 2017-2020). iGOSP constitutes a follow-up project of the earlier concluded large scale integrating project GMOS ("Global mercury observation system, FP7, 2010-2015). Both projects contribute to achieving GEO / GEOSS objectives.

- To transfer knowledge directly to stakeholders and to solve environmental issues, such as pollution prevention and cleaner air, the projetcs CNSS (“Clean North Sea Shipping: Competitive Marine Transport Services and Reduction of Emission - a North Sea Model”, INTERREG IVb North Sea, 2010-2013), S@IL (“Hybrid (Freight) Sailing: Sustainable Approaches and innovative Liaisons”, INTERREG IVb North Sea, 2012-2015) and CLINSH (“Clean Inland Shipping”, EU LIFE Environment, 2016-2020) have been and are being carried out.

## 3.4 RESEARCH INFRASTRUCTURE

To achieve an integrated understanding of coastal systems and to provide climate and informational services, HZG operates a state-of-the-art observational, analytical, modeling, and data infrastructure. The PACES II program furnishes the necessary sustained funding for implementation and operation of this infrastructure while enabling dedicated coastal research and climate services at HZG and for its partner institutions.

**Research Vessels** Research vessels are fundamental platforms for observing coastal systems. HZG’s shallow water vessel *Ludwig Prandtl* (Figure) measures 31 m long and has a very shallow draught of 1.7 m. It is therefore particularly suited for research in the tidally influenced areas of the Wadden Sea and associated river systems. The vessel is equipped with a dry lab, wet lab, moon pool, weather station, data communication, ADCP (Acoustic Doppler Current Profiler), FerryBox, A-frames and folding crane. The ship is made available to external users, such as for university practicals. *RV Storch* measures 10 m long and is used for research in the Elbe River and in the Port of Hamburg. Speedboat *Eddy* was outfitted for high-speed towed applications as part of the submesoscale *Expedition Clockwork Ocean* (www.clockwork-ocean.com).


Figure 7: HZG’s research vessels *Ludwig Prandtl* (left), *Storch* (center), and *Eddy* (right).

**Observing System** The Coastal Observing System for Northern and Arctic Seas (COSYNA) was established to detect real-time conditions in the German Bight and provide short-term forecasts, data, and data products to the public. Observations are also provided for Arctic coastal waters at Svalbard, the Lena delta, and the Baltic Sea. COSYNA’s extensive infrastructure and instruments are jointly operated by ten national partner institutions under HZG leadership. For a detailed description, see Chapter 3.2 and Baschek et al. (2017).

Furthermore, a sophisticated infrastructure is supported for very-high resolution observations using planes, a zeppelin, drones, and *in situ* as well as remote sensing observation from vessels or autonomous platforms (Chapter 4.3).

**Seagoing and Laboratory Infrastructure** HZG hosts an extensive seagoing and laboratory infrastructure for physical, optical and biogeochemical properties in air, water, and sediment. It combines *in situ* approaches with state-of-the-art analytical methods in modern laboratories. Examples include trace analytical techniques for determining traditional and non-traditional isotopes, organic and inorganic contaminants, and natural compounds. The *Coastal Competence Center* is an extension of existing buildings with new facilities and offices that will be completed

in December 2017. The two new buildings will greatly enhance the working environments of the research units *Biogeochemistry in Coastal Seas* and *Operational Systems*.

**Computing and Data Infrastructure** HZG is a shareholder of the *German Climate Computing Center* (DKRZ) in Hamburg and extensive user of its networking and high performance computing infrastructure. Thanks to its supercomputer, DKRZ is a national facility and major partner for climate research. It also hosts the climate service infrastructure for GERICS (RU 4) and several of its computer nodes for data analysis.

In addition, the high-performance computer cluster OCEANS II will be installed at HZG in summer 2018. It will be complemented by a high-performance storage infrastructure and additional servers for post-processing, data reduction, and visualization.

Several databases are supported for storing and analyzing the large amount of data generated by extensive *in situ* and satellite observations and numerical modeling. These databases also provide data and data products to the public. In particular, these include the COSYNA real-time observations and model forecasts (Breitbach et al., 2016), the ***coastMap*** geodata, and the marine climate model database ***coastDat***.

## 3.5 CAREER DEVELOPMENT AND EQUAL OPPORTUNITIES FOR WOMEN AND MEN

The success of HZG hinges on attracting or educating outstanding scientists with skills matching the research foci of HZG. In this context, HZG makes special efforts to promote young talents in science and management and routinely applies targeted, effective and customized measures and tools for personnel acquisition and development. In addition to professional qualifications, accompanying professional development is recognized as an increasingly critical and essential aspect.

The personnel development program, which is open to the entire staff, offers a variety of training and education opportunities, such as courses in personnel management/leadership, communication, methods seminars, open seminars, IT seminars, and language training. Furthermore, HZG's employees widely participate in the Helmholtz Management Academy Programs for scientific and administrative personnel at all stages of their career. Tailored professional development aligned with the specific needs of the individual researcher is also provided. This development includes courses on scientific aspects of their research fields as well as generic scientific skills, such as writing manuscripts and research grant applications.

HZG supports researchers at all stages of their scientific education. Leading scientists and young scientists at the research center teach at universities and they particularly encourage talented students to carry out research at HZG as part of their academic degree and doctoral theses.

Students and PhD students are encouraged to take part in HZG's personnel development concept. The junior scientists are also invited to participate in summer and winter schools or in exchange programs offered by HZG's scientific institutes in collaboration with universities.

To facilitate structured training and to provide applied training and networking, HZG is strongly engaged in the following **graduate schools** in coastal and climate research:

- The Graduate School of Integrated Climate System Sciences (SICCS), Universität Hamburg. SICSS is the graduate school for the Cluster of Excellence on Integrated Climate System Analysis and Prediction (CliSAP).
- Coastal Summer School. The summer school is a cooperation between the leading national centres for coastal research in Germany: Helmholtz Centre Geesthacht, Leibniz Institute for Baltic Research Warnemünde, the Alfred Wegener Institute for Polar and Marine Research and the KüNO (Coastal Research in the North Sea and Baltic Sea) consortium. Since 2002, the

- summer school has been held on Sylt and Helgoland, as well as in Büsum, Lauenburg and Warnemünde. The summer schools are listed as follows for the PACES II period:

| | Theme | Main Organizer | Participants |
|---|---|---|---|
| 2012 | Challenges in Changing Coastal Seas | AWI (Ragnhild Asmus) | from 6 countries |
| 2014 | Marine benthic habitats - function of sediments and valuation of their services | HZG (Götz Flöser) | from 8 countries |
| 2015 | System States and Transitions of Tidal Estuaries | HZG (Götz Flöser) / IOW (Hans Burchard) | from 10 countries |
| 2017 | How to govern marine environment: Baltic Sea and sediment services as a case study | HZG (Götz Flöser) / IOW (Claudia Wiedner) | from 16 countries |

Table 5: Summer schools co-organized by HZG

HZG paid and hosted approximately eighty postdoctoral positions in 2016 (thereof 40 % within PACES II). Three candidates received funding through the Helmholtz Postoctoral Program. Excellent postdocs are encouraged to lecture at cooperating universities.

Another instrument to support **young researchers** in becoming scientifically independent at an early stage of their career is the **Helmholtz Young Investigator Groups**, which are co-financed by the Helmholtz Association. HZG has succeeded in establishing three of these Helmholtz Young Investigators Groups in the reporting period, one of which was in the field of coastal research. To promote their personal careers, young scientists are also strongly encouraged to apply for grants. HZG´s Department of European and International Projects provides assistance by identifying suitable funding opportunities and assists in writing and submitting scientific proposals.

Joint appointments at the W2-level between HZG and cooperating universities are an excellent tool to make leadership positions more attractive to promising researchers. Three scientists holding W2 professorships were thus recruited in the reporting period. In addition, three high level female scientists became HZG institute directors: within the research program PACES II one became W3 professor at Universität Hamburg in a *shared professorship* model and one became visiting professor at Leuphana Universität Lüneburg. In the field of Materials Research one became W3 professor at University of Kiel.

As part of the HZG personnel development concept, the individual Research Units have implemented several career development measures as explained in the chapters for each Research Unit.

*Equal opportunities for women and men*

HZG's activities with respect to equal opportunities for both genders are closely connected to career development. It is HZG´s strategic goal for an optimal personnel recruitment and development concept, also aiming at facilitating the path to leading positions. HZG therefore pursues an equal opportunity strategy that is based on three essential pillars:

Firstly, as a research center focusing on materials and coastal research, HZG aims at generating enthusiasm for natural sciences and engineering, particularly among female students in order to recruit more female scientists in the respective fields.

Secondly, HZG offers its employees very flexible organizational working conditions that allow reconciling work and family life. These conditions comprise flexible working hours and home office schemes as well as advanced training courses in career planning. The HZG's kindergarten *Einsteinchen CompanyKids* provides more than forty places for the children of scientists and administrative staff.

Thirdly, HZG implemented an active equal opportunity strategy that is also anchored in its mission statement. HZG continuously refines and further develops this strategy at the highest managerial level.

This strategy has increased the percentage of women in all research areas. The proportion of female executives is also high for a research center conducting science in MINT subjects (mathematics, information technology, natural science and technology). The share of female employees in the entire HZG workforce is about 36%, and about 40% of the PhD students were female; the proportion of women in top management is 36%. In the past three years, five top management positions in the scientific field have been staffed by women and 25% of all W3 professorships and 27% of W2 professorships are currently held by women. In PACES II (Institute of Coastal Research and GERICS (RU 4)), two of four (50%) institute directors, 34% of permanent staff, and 43% of doctoral students are women.

HZG aims to further increase the already high proportion of women in management positions and has set itself a target for the year 2020: the aim is to see 40% of top management postions as well as W3 level positions filled by women. The successful implementation of equal opportunities measures meant that HZG was awarded the prestigious audit certificate *Reconciliation of Work and Family* as early as 2008 and was successfully reaudited in 2011, 2014 and 2017. (See also Booklet on Equal Opportunity for Women and Men www.hzg.de/equal_opportunities_brochure ).

## 3.6 KNOWLEDGE AND TECHNOLOGY TRANSFER

The Helmholtz Center Geesthacht strives to transfer scientific results, data, data products, and knowledge produced by HZG's coastal research and climate services to various stakeholder groups in science, administration, industry, and the public.

For effective and directed **knowledge transfer**, several different formats, channels, and instruments are used as described in the following. Public communication is strongly supported by the Public Relations Department at HZG.

- The school laboratory *Quantum Leap* has been providing a hands-on research experience for 51,500 high school students and 3,750 teachers since 2002.
- The HZG web page reaches 40,000 visitors per month; the center also maintains lively Facebook, Twitter, and Instagram accounts as well as a coastal blog.
- GERICS (RU 4) uses a source-neutral approach, combining Helmholtz Association results with academic and nonacademic research from other national and international institutions. This scientific knowledge is processed, refined, and transferred primarily to national and international decision makers as well as to multipliers in administration, industry, and the public. Products are developed in cooperation with these groups (see Chapter 4.4.). GERICS' homepage provides open access to all GERICS (RU 4) publications. It is available in German, English, and Arabic.
- Through its Northern German Coastal and Climate Office HZG provides web-based imformation tools on coastal climate change impacts and risks to a German audience.
- The Earth System Knowledge Platform is the central knowledge portal for the Helmholtz Research Field *Earth and Environment*. It is co-led by HZG and is accessed by 30,000 visitors per month.
- The award-winning cross-media project *Clockwork Ocean* combines immersive communication formats, such as two fulldome films, a mobile planetarium, and virtual reality content (see Chapter 4.3.).
- Android and iOS apps have been developed for science communication (COSYNA, ***coast****Map*, 360° science).
- HZG maintains regular presence at trade fairs and festivals, such as at the central celebrations for the German Day of Reunification and the UN climate conference COP23. HZG's mobile dome is often used, welcoming 1,200 visitors per day.

- Various brochures are published, such as HZG's journal *In2Science*.
- HZG sees frequent visits by politicians, who wish to be informed of new developments in coastal research and climate services.
- The center provides regular public guided tours of HZG and hosts open house events and an annual open ship tour on the *RV Ludwig Prandtl.*
- Free public access to information and data modeling platforms such as the klimanavigator, ***coastDat***, ***coastMap***, or the GERICS (RU 4) Climate Fact Sheets.
- HZG provides real-time access to COSYNA data, products, and forecasts.
- Preferred scientific publication in open access journals, such as the new Elsevier open access journal *Climate Services* established by GERICS (RU 4) in 2015, or the COSYNA special issue in *Ocean Sciences*.

For a direct **technology transfer** toward application, HZG regularly cooperates with industry. Networks with scientific and industrial partners enable tailored development and future introduction into the market. The transfer to industry is fostered by a strong technical expertise in many departments at the Institute of Coastal Research that is directly driven by scientific application, as well as by a Technology Transfer Support Group, patent attorneys, and HZG's Technology Transfer Fund. The Technology Transfer Fund was established in 2006 in order to bridge the gap between scientific results and commercial innovation. Project proposals can be submitted by scientists at HZG. One funded project, for example, fosters a close exchange between GERICS (RU 4) and commercial users as well as cities to bring about the operationalization of Climate Fact Sheets and *Stadtbaukasten*.

The sophisticated technical workshop *Technikum* supports the broad demand at HZG for technical development and production, with a focus on electro-technical and mechanical development and construction. The scientists' close connection to the *Technikum* enables the development and testing of prototypes leading to commercial application in collaboration with companies. Currently, a total of sixty-five employees work at the *Technikum,* including fifteen trainees.

The Institute of Coastal Research has developed and is continuously improving several unique and worldwide leading technologies. Such technologies (TRL: Technology Readiness Level, 1-9) currently include: High-resolution X-Band radar-measurements of waves, currents, surface features, bathymetry, wind and wind gusts (TRL 7); aerial current measurements with a drone (TRL 7); real-time aerial mapping of sea surface temperature (TRL 7); fuel cells for ocean gliders (TRL 2); shallow-water underwater-node systems with high-speed internet and power connection (TRL 9); benthic Lander systems for biogeochemical observations (TRL 7; patent); FerryBox System (TRL 9); pH and nitrate sensors (TRL 8); Towed Instrument Chain (TRL 7); PIV system for turbulence measurements (based on system from University of Delaware; TRL 5); mobile planetarium (TRL 9). (Chapters 4.2 and 4.3). Many of these instruments are developed in cooperation with companies from the onset or after successful prototype development by HZG. Typically, development contracts provide a framework for collaboration with companies, followed by license agreements for commercial production. Similar procedures apply to software and data applications.

To bring operational methods and tools into application, HZG uses the framework of the Copernicus Marine Service Evolution (CMEMS) projects and bi-lateral research and development collaborations with agencies. Examples include operational wave modeling, coupled wave-current models, COSYNA operational products, and supporting agencies' legal responsibilities in offshore wind farm development. HZG scientists are also actively involved in technical and standardization committees, such as the DIN Standards Committee for adapting to the consequences of climate change.

## 3.7 SCIENTIFIC AWARDS AND APPOINTMENTS

HZG's researchers have been awarded a considerable number of prizes during the reporting period. These awards comprise honors for best papers in renowned journals, best doctoral thesis, best posters as well as awards for most innovative research and for lecturing. Alexander von Humboldt and Fulbright Fellowships were also granted. A significant number of HZG's junior researchers became professors and hold teaching positions at partner universities, including at the Universität Hamburg, the Christian Albrechts Universität in Kiel, Leuphana University in Lüneburg and the Carl von Ossietzky Universität Oldenburg. Moreover, many scientists were appointed members of editorial boards for international journals or as visiting professors – for example in China, the UK, and Sweden.

The following table lists the most important scientific awards and appointments bestowed on scientists from the Helmholtz-Center Geesthacht between 2013 and 2016. These honors and appointments were conferred in coastal and climate research within the Helmholtz research program PACES II. A full list is available at www.hzg.de/scientific-awards .

| Scientific Awards and Appointments | | |
|---|---|---|
| **Name** | **Awards and Appointments** | **Time Period** |
| Burkard Baschek | Special Award for Best in Science Visualisation at the 10th Fulldome Festival in Jena, Germany (together with Clockwork Ocean Project Team) | 2016 |
| Steffen Bender | Adjunct professor (Apl.-Prof.) at the Ruhr University Bochum (Geosciences) | 2017 |
| Svenja Bierstedt | Partner Cities Prize, jointly awarded by The Center for Earth System Research and Sustainability (CEN) of the Universität Hamburg and the Gesellschaft Harmonie von 1789 e.V., worth €5,000, for the best doctoral thesis | 2016 |
| Johannes Bieser | Early Career Researcher Award (International Meeting on Air Pollution Modeling and its Application, Miami, USA) | 2013 |
| Marc Buckley | Postdoctoral Research Fellowship, Atmospheric and Geospace Sciences, National Science Foundation, USA (192.000 USD) | 2015 |
| Ulrich Callies | Associate researcher at the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in Plymouth, UK | 2013 |
| Ralf Ebinghaus | Visiting Professor for Senior International Scientists awarded by the Chinese Academy of Sciences, 2014/2015 | 2014 |
| Markus Groth | Visiting professor for sustainable economics at the Faculty of Sustainability, Leuphana University of Lüneburg | 2014-2017 |
| Tania Guillén Bolaños | Fellow of Alexander von Humboldt Foundation - International Climate Protection Fellowship for young climate experts from developing countries | 2016-2017 |
| Martin Hieronymi | ESA Living Planet Fellowship (80.000 Euro) | 2015 |
| Johanna Irrgeher | Loschmidt Award of the Austrian Chemical Physical Society | 2015 |
| | Agilent RISING STAR PLASMA AWARD at the European Winterplasma Conference in St. Anton, Austria | 2017 |
| Daniela Jacob | Awarded professorship (Prof.) at Leuphana University of Lüneburg, Faculty of Sustainability | January 2016 |
| María Máñez Costa | Visiting professor at University of Barcelona and Guest professor at the Polytech University of Valencia (since 2013) | 2010-2015 |
| Axel Möller | Science Award for the best doctoral thesis of the Annette Barthelt Foundation; title: *Alternative Halogenated Flame Retardants versus PBDEs in the Global Marine Environment – Occurrence, Distribution and Long-Range Atmospheric Transport toward the Polar Regions* | 2013 |
| Beate Ratter von Randow et. al | Wadden Sea Forum (WSF) Service Award 2014 | 2015 |
| Diana Rechid, Claas Teichmann | Guest lecturers at the Faculty of Sustainability/Institute of Ecology at Leuphana University | 2013/2014 |
| Corinna Schrum | Appointed Full Professor (W3) University of Hamburg | 2015 |
| | Appointment Professor II University of Bergen (adjunct professor) | 2016 |

| Scientific Awards and Appointments | | |
|---|---|---|
| **Name** | **Awards and Appointments** | **Time Period** |
| Hans von Storch | Baltic Sea Award of The Åland Foundation for the Future of the Baltic Sea (Baltic Foundation) | 2014 |
| | Guest professor Ocean University of China, Qingdao, for 3 years | Since 2014 |
| | Appointed as second member of the Faculty of Business, Economics and Social Sciences of the Universität Hamburg in addition to the membership in the Faculty of Mathematics, Informatics and Natural Sciences | 2015 |
| | Reinhard-Süring-Plakette German Meteorological Association | 2015 |
| | Certificate of Excellence in recognition of outstanding achievements for the BALTEX and Baltic Earth communities at the BALTEX Conference in Nida, Lithuania | 2016 |
| | Appointed as adjunct professor at the Shanghai Ocean University (SHOU) duration: four years | Since 2016 |
| Zhiyong Xie | Visiting Professor at Shanghai Ocean University, 2016-2017 | 2016 |

## 3.8 MEMBERSHIPS ON INTERNATIONAL BOARDS AND COMMITTEES

HZG scientists are actively involved on several national and international boards and committees serving research organizations and policymaking. These scientists play important roles as steering committee members in renowned professional associations for coastal and climate research within the Helmholtz Program PACES II. Memberships on international boards and committees are often linked with expert activities of particular importance for international research. A selection is listed in the table below; a full list is available at www.hzg.de/scientists-memberships .

| Memberships of HZG Scientists on International Boards and Committees | | |
|---|---|---|
| **Name** | **Board or Committee** | **Time Period** |
| Holger Brix | Member Scientific Advisory Board: NASA Carbon Monitoring System Science Team | Since 2013 |
| Ulrich Callies | Member Independent expert panel on *Impact Assessment of Marine Pollution* which advises the Central Command for Maritime Emergencies (CCME) Cuxhaven, Germany | Since 2013 |
| Ralf Ebinghaus | Co-Editor *Atmospheric Chemistry and Physics*, European Geosciences Union, OA, France | Since 2007 |
| | Editor of Environmental Chemistry, CSIRO Publishing, Australia | Since 2010 |
| | Coordinator of the Evaluation Panel of research proposals in the field of *Environmental Sciences* for the Portuguese Science Foundation (FCT) | 2017 |
| Kay Emeis | Member of EU-ERC Starting Grant evaluation Committee | Since 2016 |
| | Member Editorial Board *Continental Shelf Research* | Since 2010 |
| | Member Editorial Board *Marine Geology* | Since 2003 |
| | Member of the IMBER/LOICZ Continental margins Working Group | Until 2015 |
| Jana Friedrich | Member of the Evaluation Panels of research proposals of the project proposal evaluation panels of the US National Science Foundation, USA and Suisse National Science Foundation, Switzerland | 2013-2017 |

| Memberships of HZG Scientists on International Boards and Committees | | |
|---|---|---|
| **Name** | **Board or Committee** | **Time Period** |
| Johanna Irrgeher | Chairwoman of the Subcommittee on Isotope Abundance Measurements (SIAM) of the IUPAC Commission on Isotopic Abundances and Atomic Weights (CIAAW) | 2015-2017 |
| Daniela Jacob | Member of CORDEX Scientific Advisory Board | 2014 |
| | Member of the Expert Group on Climate Services, European Commission | 2014 |
| | Member of the Expert Advisory Board of the Copernicus Roadmap for European Climate Projections | 2015 |
| | Member of the Met Office Hadley Centre Science Review Group | 2016 |
| | 'Ex-officio member' of the Earth League (international alliance of prominent scientists from world-class research institutions) | 2016 |
| | Coordinating Lead Author, IPCC SR1.5, chapter 3: Impacts of 1.5°C global warming on natural and human systems | 2017 |
| Elke Keup-Thiel | Member of the national standards committee NA 172-00-13AA, Anpassung an die Folgen des Klimawandels, DIN e.V. Berlin | 2016 |
| María Máñez Costa | Executive director of the Earth League (international alliance of prominent scientists from world-class research institutions) | Since 2012 |
| | Member of the Scientific Advisory Board of the ImpAdapt Project of the Ministry for Research and Education, Spain | 2014 |
| Daniel Pröfrock | Advisory Board Member of the Metallomics Journal of the Royal Society of Chemistry | 2010-2016 |
| Markus Quante | Member of the Scientific Steering Committee of the European Research Course on Atmospheres (ERCA), Grenoble, France | Since 2005 |
| Beate Ratter | Member of Steering Committee, Study Group Islands of the International Geographical Union (IGU) | 2015 |
| | Member Trilateral Wadden Sea Forum representing science and research | 2015 |
| | IPCC Lead Author for the Special Report on Oceans and Cryospheres (SROCC) | Since 2017 |
| Diana Rechid | Member of the Advisory Board of the national Norwegian project "HiddenCoasts" at Uni Research in Bergen | 2017 |
| Corinna Schrum | Chair of the Formas Climate Change Panel, Panel member since 2011 | 2012-2015 |
| | Member of the Baltic Earth Science Steering Group and chair of the Baltic Earth Working Group on Regional seas | 2016, 2017 |
| | Member of the Science advisory committee NIOZ | 2016 |
| | Review Panel Member: Soil, Air and water processes, Swedish Research Council | 2017 |
| | Program Advisory Board member for the NERC Changing Arctic Ocean Research Program UK | 2017 |
| Emil Stanev | Member of the Scientific and Technical Advisory Committee (STAC) of the Copernicus Marine Environment Marine Service (CMEMS), European Commission | 2015 |

| Memberships of HZG Scientists on International Boards and Committees | | |
|---|---|---|
| **Name** | **Board or Committee** | **Time Period** |
| Joanna Staneva | Vice chair in EU Horizon 2020 Research Executive Agency (REA) FET-OPEN: NOVEL IDEAS FOR RADICALLY NEW TECHNOLOGIES of the European Commission | 2014-2017 |
| | Member of the Coastal Ocean and Shelf Seas Task Team (COSS-TT) of the GODAE Ocean View forum for national forecasting centers | 2015 |
| | Vice chair in EU Horizon 2020 Research Executive Agency (REA) MSCA-IF of the European Commission | 2016 |
| | NEMO Developer's Committee as "external expert on shelf modeling" | 2017 |
| Claas Teichmann | Co-chair of the Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board for CMIP6 of the European Commission | 2015 |
| Justus van Beusekom | Member of the Evaluation Committee of the Dutch NWO-Program for Coastal and Ocean Research | 2015 |
| Hans von Storch | Member International Advisory Board for the WIREs Climate Change forum | 2013 |
| | Chair of the Technical Advisory Board for the Joint Program Initiative *Connecting Climate Knowledge for Europe* (JPI Climate), European Commission | 2013 |
| | Expert for the Association for German Studies of the City of Qingdao (Gesellschaft für Deutschlandstudien der Stadt Qingdao) | 2014 |
| | Member of the International Advisory Board for the Institute of Oceanography of the Chinese Academy of Science (IOCAS), Qingdao, China | Since 2015 |
| | Member of the Advisory Board *Earth System Modeling Center* Nanjing University of Science and Technology, Nanjing | Since 2015 |
| | Member Advisory Board of GEOPLANET: EARTH AND PLANETARY SCIENCES SERIES | 2016 |
| | Member of the Editorial Board of the journal: Meteorology, Hydrology and Water Management Research and Operational Applications | Since 2016 |
| | Member of the Editorial Board of the journal: Oceanologia | Since 2014 |
| | Baltic Earth (ex BALTEX), Senior Advisory Board | Since 2016 |
| | Editor-in-chief Research Encyclopedia Climate Change, Oxford University Press | Since 2014 |
| | Associate editor: Journal of Climate | |
| | Member of the Editorial Board for (Polish) *Papers on Global Change, IGBP* | |
| Ralf Weisse | Member of the Baltic Earth Science Steering Group and Chair of the Baltic Earth Working Group on Understanding Sea Level Dynamics in the Baltic Sea Region | 2016 |

# 4

# RESEARCH UNITS

# 4.1

# RESEARCH UNIT 1
# SYSTEM ANALYSIS AND MODELLING

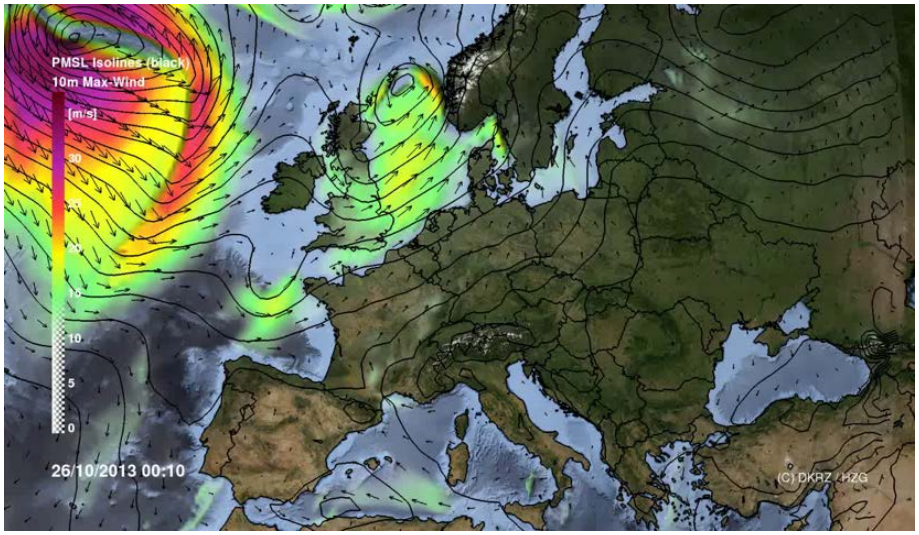
# 4 RESEARCH UNITS

## 4.1 RESEARCH UNIT 1: SYSTEM ANALYSIS AND MODELLING

Director Prof. Corinna Schrum

Climate and weather trigger complex and often non-linear changes in coastal environments. At the same time, human activity in the coastal zone increases continuously, and the health of coastal environments is of rising societal concern. The Research Unit *System Analysis and Modelling* (RU 1) provides an essential theoretical understanding of complex coastal systems and identifies key drivers of variability on various timescales through a combination of mechanistic and statistical modeling and data analysis. Long- and short-term changes in atmosphere, coastal ocean, sea floor, intertidal and estuaries, which together form the coastal system, are closely linked (e.g., Figure 8) and the Research Unit analyzes coastal changes from physical, ecological and socio-economic perspectives to foster a holistic understanding of coastal dynamics.

*A key focus of the unit´s research are climate induced variations of coastal systems on time scales of several decades and longer (Topic 2).* Significant efforts went into the reconstruction of high resolution coastal climate information, and a unique research profile was developed within this field. A key element – to accommodate future societal information needs to assess coastal climate impacts – is the development of new conceptual models and numerical tools, which are tightly linked to observational data and critically validated. These developments are carried out from proof of concept all the way through to application. Based on our research we provide methodological and scientific support for strategic informed decision-making processes of public and private sectors and engaged in knowledge transfer to stakeholders and society. *A second focus of the unit´s research lies in the field of operational oceanography (Topic 4).* The unit contributed research and development in the field of pre-operational modelling, while closly collaborating with operational service providers, both nationally and internationally.



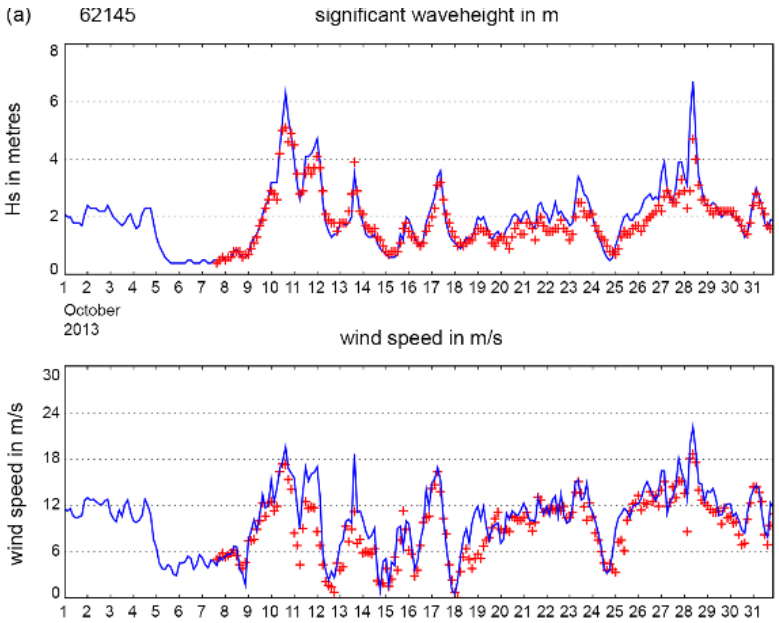




Figure 8: Linking atmosphere and coastal ocean dynamics.
Upper: Storm Christian, 26/10/2013, reconstruction of regional climate; example from the ***coast****Dat* database. Lower: Modeled (blue) and observed (red) wave heights (upper) and wind speeds (lower) during Christian Oct/2013.

### 4.1.1 OVERVIEW

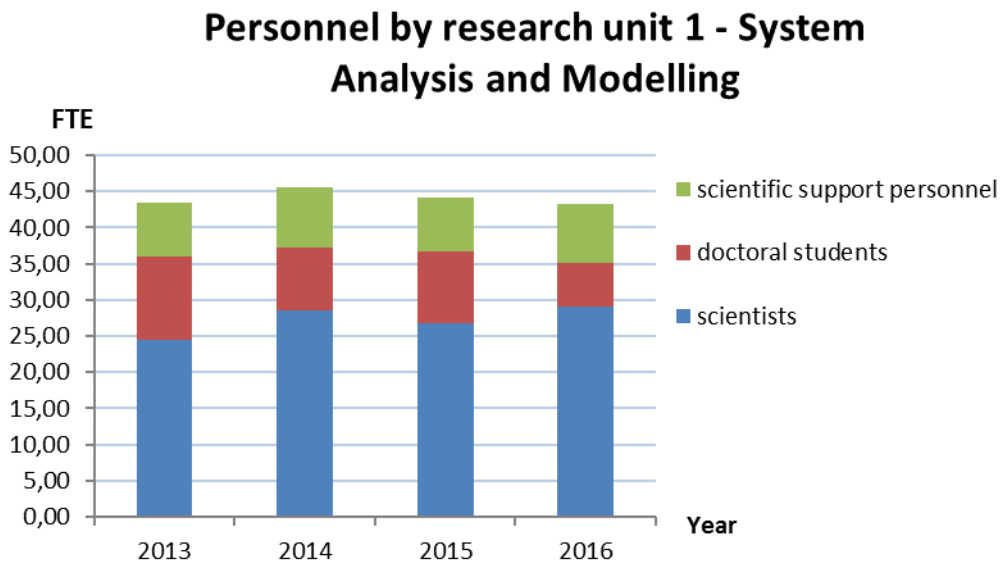



Figure 9: Development of Full Time Equivalent (FTE) Personnel of RU 1. Please see figure 3 for detailed information about the contribution of HZG-Research Units to the Helmholtz-Program PACES II in 2016.

Topic 2+4

During the evaluation period (2103-2016), leadership of the Research Unit *System Analysis and Modelling* changed. In October 2015, Prof. Corinna Schrum took over position as director from Prof. Hans von Storch. In total, the Research Unit 1 holds five shared professorships at the following universities: UHH (Meteorological Institute, Prof. H. von Storch (today only 20% position); Institute of Oceanography, Prof. C. Schrum (UHH, small teaching responsibility, on full secondment); Institute of Geography, Professor B. Ratter- 30% secondment), Christian Albrechts University Kiel (Marine Biogeochemistry, Prof. K. Wirtz) and Carl von Ossietzky University Oldenburg (Institute for Chemistry and Biology of the Marine Environment, Prof. E. Stanev, from Nov 2017 onwards only 40% position). All five professors contribute regularly to teaching at their host universities and actively supervise PhD candidates. The Research Unit has currently 11 PIs, these are Dr. Frauke Feser, Dr. Birgit Hünicke, Prof. Beate Ratter, Dr. Burckhardt Rockel, Prof. Corinna Schrum, Dr. Joanna Staneva, Prof. Emil Stanev, Dr. Insa Meinke (working on science stakeholder interaction and knowledge transfer), Dr. Ralf Weisse, Prof. Kai Wirtz and Dr. Eduardo Zorita.

The Research Unit contributes to both PACES II *Topics 2* and *Topic 4*. Overarching research themes addressed are ***Coastal shifts and long-term trends*** *(Topic 2)* and ***Advancement of coastal modeling capacity.*** The latter includes contributions *to Topic 2* and *Topic 4*. Knowledge transfer is a key element of the Helmholtz strategy and underpinned by RU 1 in various ways, and actively supported by all PIs. To further foster knowledge transfer, the Research Unit established the ***Northern German Coastal and Climate Office***, lead by *Dr. Insa Meinke.* The Northern German Coastal and Climate Office actively carries out knowledge transfer to a wider stakeholder community and to the general public and has established an intensive stakeholder dialog to generate decision-relevant information.

The Research Unit provides and develops joint research infrastructure and products. These are the model results database ***coastDat*** (http://www.coastdat.de) and the coastal modelling framework **GCOAST** (the Geesthacht Coupled cOAstal model SysTem GCOAST). The ***coastDat*** model data are made freely available through the Climate and Environmental Retrieval and Archive (CERA at DKRZ) and are frequently used by other Research Units at the Institute of Coastal Research and beyond.

The GCOAST framework forms an important part of the modelling infrastructure at the Institute of Coastal Research ensuring that flexible interfaces for model codes and setups exist and are maintained. Through GCOAST, we allow for flexible model coupling as well as coupling to observational data products, make codes and setups available and improve access to state-of-the-art modeling tools at Institute of Coastal Research. Moreover, the Research Unit contributes to the coastal observing system **COSYNA** (https://www.hzg.de/institutes_platforms/cosyna) and contributes to the COSYNA product development. COSYNA (cf 3.2 *Highlight 2)* is a cooperation between scientists from the Research Units 1 & 3. Scientists from this Research Unit (RU 1) were responsible for modeling, data assimilation and for generating products.

Active collaboration with the Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (AWI) and GERICS (RU 4) takes place within the PACES II program (further detailed in chapter 4.1.3).

RU 1 is actively collaborating with scientists at the national and international (EU and non-EU) levels through a multitude of collaborative projects, individual collaborations and collaborative workshops. The unit has established strategic collaborations with research institutes, public agencies and universities at the national (e.g. DWD-Deutscher Wetterdients, BSH-Bundesamt für Seeschifffahrt und Hydrographie, Universities Hamburg, Kiel and Oldenburg), EU (e.g. NERSC and met.no, both Norway, UK Met Office MERCATOR) and international levels (e.g. Ocean University China, Sun-Yat-Sen University, china, Virginia Institute of Marine Science and GFDL). Moreover, many RU 1 scientists contribute actively to international networks such as Baltic Earth (secretary hosted at the Institute of Coastal Research), Climate Limited Area Community (CLM-Community), CMEMS, EuroGOOS (European Global Ocean Observing System) or ICES (International Council of the Exploration of the Seas). Here they also take leading roles in working groups (Ho-Hagemann, Kannen, Rockel, Schrum, Weisse, Zorita, Stanev, Staneva).

### 4.1.2 SCIENTIFIC RESULTS AND GOALS

Two major research challenges have been addressed by the Research Unit over the last years: identification of coastal shifts and long-term trends (*Topic 2*) as well as the advancement of coastal modeling capacity. The latter includes development of novel basic theoretical model concepts *(Topic 2*) as well as technological and product developments in the frame of operational oceanography (*Topic 4*). Scientific progress is closely related to the technological advancement and theory and model development. New instrumentation and automatic data gathering provide huge volumes of new ocean observations, which in combination with new advanced modeling capacity allows for novel high-quality operational ocean forecasting, assessment and monitoring tools (Grayek et al., 2015; Stanev et al., 2015a, 2016). The Research Unit therefore follows a long-term strategy to further advance modeling capacity, allowing better understanding of the dynamics and linkages of regional systems and to support current and future societal informational needs.

Topic 2+4

Recent achievements of the Research Unit relate to the development, advancement and application of (1) novel numerical modeling concepts, including unstructured and adaptive grids, (2) modern data assimilation techniques integrating a wide spectrum of newly available observations into models, (3) new advanced ecosystem and impact models (Topic 2) and (4) coupling frameworks, including the coupling of ocean, wave and atmosphere models (Topic 2& 4) and the coupling of physical, biological and chemical models (Topic 2) for the coastal environment. Based on these developments novel insights were obtained into physical, biological and chemical aspects of coastal system functioning (Topic 2) and, in close collaboration with national and international public agencies and other stakeholders, a number of collaborative projects were carried out to develop tools and models as well as to serve data needs for coastal management and operational services (Topic 4). A significant part of these research activities focused on the synoptic description of the coastal ocean and provided methodological support to developing operational oceanography and

advanced monitoring strategies. The developments carried out in Topic 2 and Topic 4 were closely related and cumulated in the coastal system modeling framework GCOAST.

In order to support the HZG mission of "Wissen schafft Nutzen" – "science creates benefits", we actively support problem solving in coastal research through knowledge and technology transfer. To ensure that our research has an impact, we defined target groups and implemented a broad knowledge and technology transfer strategy. These strategies and our activities (*Topic 4 and Topic2*) during the evaluation period are further detailed below.

## Contributions to PACES II Topic 2: Coastal Shifts and Long-Term Trends

Topic 2

Coastal systems are subject to substantial pressures from natural and anthropogenic climate climate change and socio-economic change. Substantial efforts have been made to quantify and to assess regional natural and anthropogenic climate change in coastal systems in order to support and to foster the development of sustainable and robust adaptation. Research during the evaluation period focused on activities aiming at quantitative descriptions of past, ongoing, and possible future coastal changes on time scales of decades of years and longer; on efforts aiming at enhancing the discrimination between natural variability and anthropogenic driving forces for climate change; on activities aiming at the development of comprehensive regional climate impact scenarios; and on analysis of societal risk management and local adaptation strategies.

The assessment of past, ongoing and possible future coastal change was based on two avenues of approach: the analysis of past coastal climate and environmental conditions and the development of scenarios for possible future changes. A cascade of regional numerical models was applied, ranging from regional atmospheric to very high resolution estuarine models. Due to the high resolution of these simulations, phenomena can be examined which are not resolved in global data sets. Examples covered by our studies are polar lows in the North Atlantic (Zahn and von Storch 2010, 2012) and in the North Pacific (Chen and von Storch 2013; Chen et al., 2014); tropical cyclones (Barcikowska et al., 2017); hail (Mohr et al., 2015); and medicanes (Cavicchia et al., 2014). Moreover, to support adaption, the effect of adaption measures was studied through model simulations. Examples comprise investigations into the efficiency of artificial sandbanks in the mouth of the Elbe estuary on storm surge protection (Ohle et al., 2016), risk assessment of estuaries under climate change (Monbaliu et al., 2014), and the assessment of chemical dispersant effects on oil spill drift paths in the German Bight (Schwichtenberg et al., 2017).

*Reconstructing coastal climate for the last decades*: High resolution hindcast simulations for the last decades and future projections have been performed for different parts of the world to enable quantitative description of past, ongoing and future coastal long-term changes. Based on these simulations, our research yielded novel understanding of climate variations on regional scales for different regions. Past atmospheric changes were studied, such as for Southeast Asia (Li 2016; Li et al., 2016c); Europe and adjacent seas (Geyer 2014); and for Siberia, including the Lena Delta (Klehmet et al., 2013). Past and possible future climate change impacts on waves and/or tide-surges were studied for the Bohai Sea (Feng et al., 2016); the North and Baltic Seas (e.g., Gaslikova et al., 2013; Grabemann et al., 2015; Groll et al., 2014, 2017); and globally (Semedo et al., 2013). The geophysical studies were recently complemented by a analyzes based on multi-decadal hindcast for the coupled North and Baltic Sea ecosystem (Daewel and Schrum 2017) using a coupled physical-biogeochemical model (Daewel and Schrum 2013). Based on these simulations, comprehensive assessments of changing environmental conditions were developed and published in peer-reviewed literature. Examples comprise more than fifty publications on geophysical hazards, such as storms (e.g., Feser et al., 2015b), mean sea level rise (e.g., Wahl et al., 2013), waves and surges (e.g., Grabemann et al., 2015) or on ecosystem and hydrodynamic changes (e.g., Daewel and Schrum 2017), which enhanced our understanding of the changing coastal environment. For example, analysis of the coupled physical-biogeochemical hindcast revealed that observed major shifts in ecosystem productivity were introduced by corresponding changes in the wind field (Daewel and Schrum, 2017). Present

knowledge in this area, for example, changes in storm activity over the North Atlantic and Northwestern Europe (Feser et al., 2015b) or mean sea level changes in the North Sea (Wahl et al., 2013, RU 1 scientists contributed), is additionally summarized in a number of review articles. Research under this theme moreover provided a substantial base for this Research Unit regional climate change assessments (3.2-*Highlight 3*), to which RU 1 scientists contributed substantially.

Major efforts were also made to address methodological aspects of the model-based approach in assessing long-term environmental changes. This includes issues such as the homogeneity or added value of regional simulations, optimization of the spectral nudging approach, originally developed by von Storch et al., (2000), or contributions towards enhancing the discrimination between natural variability and anthropogenic driving forces. For example, the publication by Krueger et al., (2013) initiated a discussion on potential inconsistencies in long-term trends derived from Reanalyses and observations and was finally acknowledged as one of the first and few studies which scrutinized the long-term reliability of reanalysis data (Jones et al., 2016). On the climate data guide website, the study by Krueger et al., (2013) is now listed among the five key references in the description of the corresponding reanalysis. We briefly review such methodological issues in Highlight 1. Further efforts have been made to develop coupled atmosphere-ocean climate downscaling (further discussed below).

Topic 2

***Highlight 1: Dynamical downscaling to construct long-term regional weather***

***Data homogeneity*** Even though long-term meteorological records exist, these are often affected by changes in measurement systems or practice over time which may lead to artificial variability or trends. One prominent example is the 20CR reanalysis dataset. Krueger et al. (2013, 2014) showed that long-term storm trends are inconsistent, especially for the first half of the 19th century, which is supposedly due to an increasing station density over time used for assimilation in 20CR. To reduce data inhomogenity problems, we apply dynamical downscaling constrained to the global forcing reanalysis by **spectral nudging**, an approach earlier initiated at HZG. The spectral nudging prevents the regional climate model from deviating from reanalyzed large-scale weather states. A large number of articles in high-impact journals on the topic of spectral nudging have been published during the evaluation period (e.g. Barcikowska et al., 2017, Feser et al. 2015a, Schaaf et al., 2017, Schubert-Frisius et al., 2017, von Storch et al., 2014), manifesting a leading role of HZG as one of the pioneering institutes in this scientific field. A recent overview was given by von Storch et al. (2017).

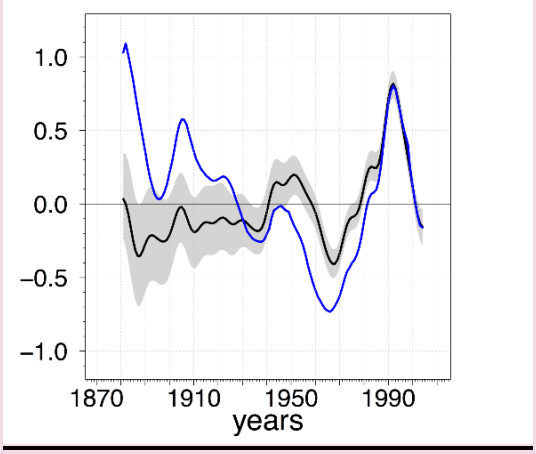



Figure 10: Standardized time series of annual 95th percentiles of geostrophic wind speeds over 10 triangles in the North Atlantic, which have been averaged and low-pass filtered thereafter (Krueger et al., 2013). The black line denotes the ensemble mean of these time series in 20CR, along with the complete associated ensemble spread, which is represented by the minimum and maximum values of the ensemble. The blue line is reconstructed after Alexandersson et al. (2000) for the period 1881-2004.

***Added value of regional climate modeling:*** The main purpose of regional climate modeling is to provide additional detail beyond the resolution of global reanalysis or global climate simulations. Scientists at HZG were among the first to work on the added value topic more than ten years ago and have since published a large number of highly cited articles and review papers (e.g. Li 2016; Feser et al., 2011). These papers dealt with statistical evaluations and suitable techniques to highlight added value of RCMs, such as spatial filtering. By filtering, regional weather phenomena can be separated from large weather states and thus distinctly show improvements provided by the RCM at the spatial scale where added value is to be expected.

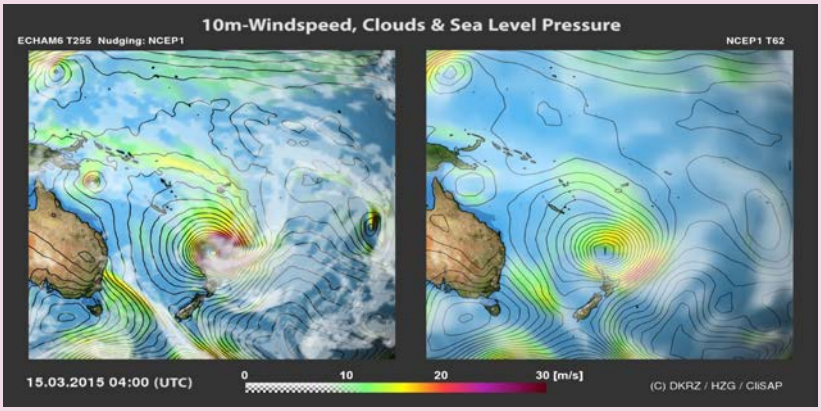



Figure 11: Cyclone Pam north of New Zealand in the new global high-resolution climate simulation (left) and in NCEP reanalysis data (right). Shown are 10m wind speed (colors), clouds (white), and sea level pressure (black isobars). The new simulation shows much higher wind speeds and lower core pressure.

The newest contribution in the field of spectral nudging is the application of this technique for general circulation models. Recently, spectral nudging towards NCEP reanalysis was implemented into the state-of-the-art general circulation model ECHAM6 (Schubert-Frisius et al., 2017) in the framework of the Excellence Cluster CliSAP. An optimal spectral nudging strategy to simulate extreme weather events, such as storms, was developed. The new method was applied to simulate the longest such global spectral nudging simulation to date for the past sixty-seven years. Due to its high spatial resolution, it contains both realistic large weather patterns and regional details, which cannot be resolved by the coarser reanalysis data.

*Reconstructing past regional climate on longer time scales:* Recent anthropogenic climate change is embedded in a background of natural climate variability. Disentangling the purely anthropogenic trends requires a realistic estimation and understanding of past environmental variations. The instrumental record is, however, too short to contain the full range of these variations. Reconstruction of past variability based on indirect archives provides a very useful benchmark to evaluate recent climate trends. These indirect archives comprise biophysical systems, like tree-rings, lake sediments, speleothems corals, but also historical records. A processing of these records to extract the true climate signal, and discard the non-climate noise, is necessary since not all the variations in these records are directly related to climate or environmental conditions. This requires sophisticated and innovative statistical techniques that make use of all the information contained in the archives, sometimes also combining natural archives and model simulations. Together with climate model simulations, such reconstructions provide the base to discriminate between natural variability and changes caused by anthropogenic drivers, how these aspects are addressed is futher described in Highlight 2.

We have developed and/or tested statistical methods to reconstruct several climate aspects over the whole or part of past millennium: the Atlantic Multidecadal Variability (AMV), the spatially resolved variations in the North Atlantic sea-surface-temperature, the climate in North Europe (past 150 years only), and the global air temperature. These reconstructions are based on combinations of natural archives and also on long instrumental records of selected meteorological variables. The reconstruction of the AMV (Wang et al., 2017) is derived from a collection of terrestrial archives under the assumption that the AMV also leaves an imprint on air temperatures in North American and Europe. The method used is a multivariate regression technique that links an AMV index with its terrestrial predictors. The method was also tested under controlled conditions using pseudo-proxies in an ensemble of climate simulations over the past millennium, yielding reasonable reconstruction skill.

The reconstruction of the North Atlantic sea-surface temperature field (Pyrina et al., 2017a) is based on records of growth-layers of *Arctica Islandica* - a very long-lived bivalve mollusc- from a few locations in the Eastern North Atlantic. The statistical method included a variant of principal component regression, which was also satisfactorily tested using pseudo-proxies together with an ensemble of climate simulations. With the help of this test we could establish that the reconstructions are skillful in a wide area in the North Atlantic, but not in the tropical areas. The spatially resolved global temperature (Gómez-Navarro et al., 2017) was derived from the network of terrestrial archives compiled by the PAGES-2k initiative (HZG is also involved) and applying the analog method - an off-line paleodata assimilation method developed at HZG - to an ensemble of past millennium climate simulation. Finally, the climate evolution in Northern Europe at very high spatial and temporal resolution, suitable to be used as a driver of Baltic Sea ecosystem models, was completed for the past 150 years from early long instrumental records of sea-level-pressure and temperature (Schenk 2015). The reconstruction was again based on the analog method, combining the instrumental records with high-resolution simulations with regional climate models. This strategy will be pursued in the future, and by including natural archives and historical information we aim at extending this reconstructions to the last 400 years, which will include the Little Ice Age, a climate regime markedly different than the present, and that may represent a mirror image of the expected warming over the next few decades.

Topic 2

***Highlight 2: Learning from the past: assessing natural climate variability***

The comparative analysis of our comprehensive Earth System model simulations and of climate reconstructions formed the basis of several multi-author publications, five of them in high-impact journals (Nature and Nature Geosciences, highlighted here in bold face). These analyses had global (**Ahmed et al., 2013**; PAGES 2k-PMIP3 group, 2015**; Ljungqvist et al., 2016**) and regional character with the focus on continental Europe and the North Atlantic Ocean (Pyrina et al., 2017a; Pyrina et al., 2017b; **Gagen et al., 2016**). A general conclusion from these studies is that climate models tend to produce a simulated climate that is spatially too homogenous and too sensitive to some perturbations such as volcanic eruptions. On the other hand, the simulated internal variability (not related to external perturbations) is too weak compared to reconstructions (**Wang et al., 2017**). However, in some cases, climate reconstructions and model simulations agree reasonably well in representing long-range links between remote areas, mediated by standing atmospheric planetary waves. An important example that illustrates the relevance of understanding the mechanisms behind large-scale anomalous periods is the climatic period during the 1st millennium AD, during what is known as the Antique Little Ice Age, showing long-distance relationships between Central Asia and Europe (**Büntgen et al., 2016**). The frequency of these reconstructed extremes (pronounced anomalous periods) may be relevant for past societies (Lemmen and Wirtz 2014), and for land use-carbon feedback to the atmosphere (Ruddiman et al., 2016).

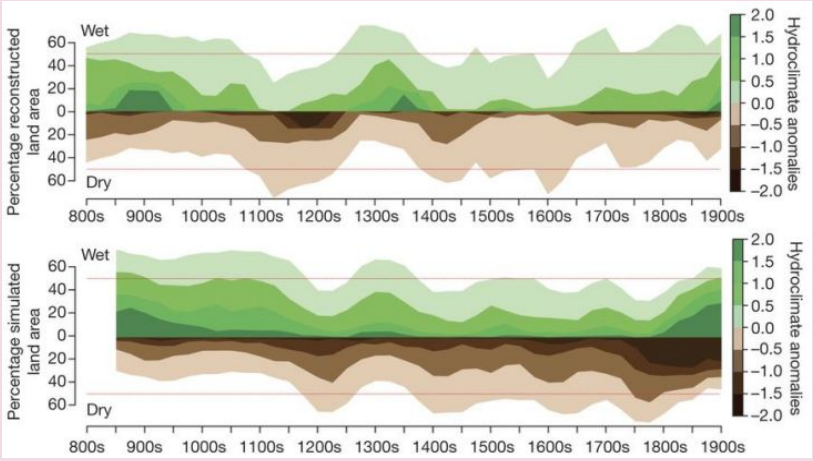



Figure 12: Derived hydroclimate anomalies relative to the average for the millennium selected. Above: values from proxy data. Below: values from climate simulations (from Ljungqvist et al., 2016).

The relationship between temperature and precipitation, and its relevance for climate impacts, is a critical aspect of climate variations and future climate change impacts. In contrast to future climate simulations, which indicate a general intensification of the mean hydroclimatic gradients, the past millennium hydroclimate reconstructions do not show a pronounced link to past regional temperatures (**Ljungqvist et al., 2016**) nor an intensification of hydroclimate extremes during the 20th century. European summer precipitation is mainly driven by the position of the North Atlantic storm tracks and its position also appears to be independent of external natural climate forcings – for example, volcanic eruptions and solar variations (**Gagen et al., 2016**). These results prompted us to initiate a more detailed analysis of the link between wind extremes and the mean climate state in northwestern Europe. In several global and regional models, this frequency is not strongly related either to the mean regional temperature nor to major atmospheric variability patterns, such as the North Atlantic Oscillation (Bierstedt et al., 2015; Bierstedt et al., 2016). For wind extremes, the different parametrizations of the boundary layer dynamics, including deforestation, are more important, with clear implications for future projections of extremes.

*Understanding sea level changes and its impacts to the society:* Sea level changes are driven by a large variety of climatic, meteorological, astronomical, hydrological and geological factors. Consequently, sea level varies across a large range of time scales from seconds to millennia. Traditionally the physical and societal aspects are considered independently mostly, but RU 1 has placed substantial emphasis on addressing sea level changes across times scales including its social dimensions.

Past and possible future long-term changes in wind wave and tide-surge climate at global and regional scales are considered in a number of relevant publications. *Novel findings* from these studies comprise a tendency towards higher waves in the Baltic Sea (Groll et al., 2017) and the eastern parts of the North Sea (Grabemann et al., 2015) towards the end of the 21st century, a poleward shift in mean and extreme wave heights in the mid-latitudes of both hemispheres towards 2100 (Semedo et al., 2013), or a small tendency towards higher surges in the German Bight by 2100 (e.g., Gaslikova et al., 2013). For the semi-enclosed Baltic Sea contributions from seiches or meteorologically induced volume changes were found to substantially contribute to extremes (Weisse and Weidemann 2017).

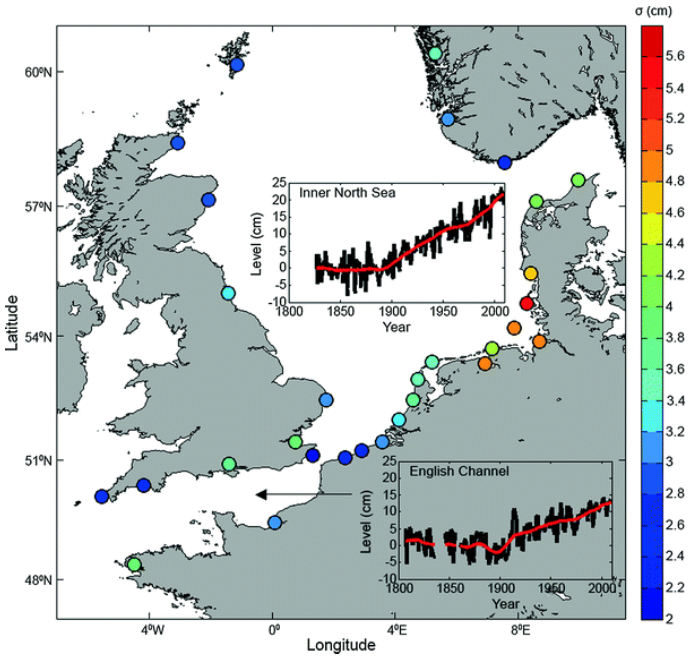



Figure 13: Standard deviation from de-trended annual mean sea level (MSL) time series from thirty tide gauge sites around the North Sea; *upper inset* MSL index for the Inner North Sea (*black*) together with the non-linear sea-surface anomaly (SSA) smoothed time series (*red*); *lower inset* MSL index for the English Channel (*black*) together with the non-linear SSA smoothed time series (*red*) (from Huthnance et al. 2016 (NOSCAA)), after Wahl et al., 2013).

Regional mean sea level changes, accelerations and contributions from atmospheric circulation were assessed for the North (e.g., Wahl et al., 2013) and Baltic Seas (e.g., Hünicke and Zorita 2016). A *novel contribution* was the finding that although recent rates of sea level rise in the North Sea (i.e. over the last two to three decades) are high compared to the long-term average, they are still comparable to those observed earlier in the late 19th and 20th century. We could also identify a small acceleration in Baltic Sea level rise, which may include a contribution related to the Glacial Isostatic Adjustment (Hünicke et al., 2017). Moreover, ground-breaking first estimates on sea-level variability were achieved for mostly unexplored coastal regions such as the western African (Evadzi et al., 2017) or the Indonesian coasts (Kelvin et al., 2017), where hardly any studies had so far existed.

Together with international colleagues we found that the contribution of anthropogenic forcing to global mean sea level rise in the 20th century could have been smaller than previously thought (Ocaña et al., 2016). However, anthropogenic forcing accounts for at least half of the observed global mean sea level rise during the 20th century and therefore represents the dominant forcing during this period (Dangendorf et al., 2015).

Sea level extremes along European coasts, were studied, for example, by Weisse et al., (2014). Extreme sea levels generally show pronounced variability partially associated with seasonal and nodal tidal cycles. Long-term trends are mostly associated with corresponding mean sea level changes while changes in wave and storm surge climate mostly contribute to inter-annual and decadal variability. Changes in extremes become particularly important in estuaries where terrestrial (e.g., rainfall) and oceanic threats (Monbaliu et al., 2014) coincide with socio-economic pressures (Weig and Ratter, 2014). For example, we studied artificial sandbanks efficacys in the mouth of the Elbe estuary for storm surge protection as proposed in the concept for this estuary's sustainable development (Ohle et al., 2016) or the effects of sea level rise on potential flooding in Hamburg's Hafencity (Ge et al., 2014). This latter study found that peak flood levels will increase with rising mean sea level. In some areas, the increase is over proportionally enhanced by non-linear tide-surge interaction and, potentially flooded areas will consequently increase towards the end of the century.

Transdisciplinary research bridging natural and social sciences, planning practitioners and decision-makers in policy development is presently developed further to foster better understanding of climate change impacts and extremes in land-use systems (Gerkensmeier and Ratter 2016). In contrast to traditional linear production of scientific knowledge, the practice-oriented character of transdisciplinarity links theoretical scientific understanding with case specific, practical knowledge in an iterative and reflexive procedure that finds its way into international policies such as the Sendai Framework of Action (González-Riancho et al., 2017).

Dealing with sea level rise in planning and management requires understanding of the public's risk awareness, perceptions and adaptation strategies. To document these, we conduct regular online and interview surveys that include experts and the wider public (Ratter 2017). For example, Hamburg citizens have been queried since 2008 on the perceived impacts of climate change through a regular survey in cooperation with FORSA. Results, published in a frequently cited publication, reveal that the perceived impacts are closely related to respondents' recent experiences and not to the increase in scientific confidence or media coverage (Ratter et al., 2012). Similarly, the impacts expected by different migrant groups were found to depend on the impacts expected or experienced in their home countries (de Guttry et al., 2016). Thus, the success of climate change adaptation is likely to be strongly context-specific and is shaped not only by natural characteristics but also by socioeconomic circumstances, local knowledge, social networks, and non-climatic pressures (e.g., Döring and Ratter 2017).

*The social dimension of past, ongoing and future coastal long-term change* was addressed in a number of studies: these studies include the identification of patterns of socio-cultural values and attitudes of local people concerning offshore wind farms in the German North Sea (Gee 2013), of multiple entrepreneur's role in energy transition (Süsser et al., 2017; Süsser and Kannen 2017), and identification of societal risk management options concerning natural hazards (Gerkensmeier and Ratter 2016; Gerkensmeier et al., 2016; González-Riancho et al., 2015; González-Riancho et al., 2017; Ratter 2017). Based on analyses of marine use and Marine Spatial Planning (MSP) approaches in the North and Baltic Seas, we developed a risk management approach for ecosystem based marine planning (Cormier et al., 2013) and a model on how to perform MSP, including developing stages for scientific advice and stakeholder participation (Cormier et al., 2015; Kannen 2014). Our strategy identifies an ideal process flow, related quality criteria for the process as well as quality criteria for the resulting plan and its potential outcomes. It can also serve as a model for MSP auditing and evaluation. Another concept developed under HZG leadership in cooperation with international colleagues is Culturally Significant Areas. These represents a significant step toward incorporating socio-cultural values into planning (and thereby avoiding or mitigating conflicts) and is based on analysis of the public's cultural attachment to the sea (Kannen 2014; Gee 2013; Gee et al., 2017; Gee 2016).

Topic 2

***Highlight 3: Development of mechanistic trait-based models***

We identified biophysical trade-offs governing the topology *(who eats whom)* and specific rates of trophic interactions in plankton food-webs (e.g., Wirtz 2013, 2014). Using these trade-offs, we devised the first mechanistic trait- and distribution-based plankton model, which displays much lower parameter uncertainty and higher model skill compared to traditional models. Model applications enabled accurate reproduction and understanding of the rise and termination of phytoplankton blooms (Wirtz and Sommer 2013). Concepts and formulations of this mechanistic approach are increasingly used in other ecosystem modelling studies.

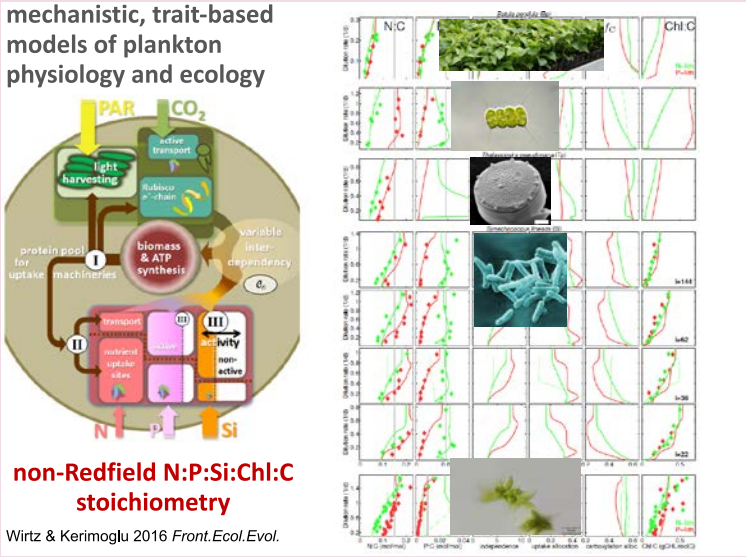



Figure 14: Intracellular compartments relevant for multi- nutrient uptake and photosynthesis as resolved by the trait-based and optimality model. Right: Model results (line) compared to data from chemostat experiments, both for P-limited (red) and N-limited (green) cultures.

Phytoplankton reveals an astounding flexibility in its elemental stoichiometry, with major implications on biogeochemical cycles. Two essential mechanisms underlying the richness in physiological changes were – for the first time – highlighted by another newly developed trait-based model: (1) the co-limitation strength when multiple resources become limiting has been demonstrated to depend on the protein content and hence to vary with environmental conditions. Co-limitation is rather the norm in coastal ecosystems where primary production can be limited by light, nitrogen, phosphorus, and silicate at the same time. (2) Complex physiological changes observed in cultured phytoplankton could be shown to reflect an optimality strategy when also indirect feed-back effects (e.g., of altered protein partitioning) are considered. The combined description of flexible co-limitation and extended optimality regulation displays unprecedented skill in reproducing rich stoichiometric patterns collected from a huge number of published chemostat experiments (Wirtz and Kerimoglu 2016). Again, the model is currently tested by other groups working on phytoplankton stoichiometry (e.g., for describing iron limitation in global models) and constitutes the basis of the biogeochemical model MAECS (Model for Adaptive Ecosystems in Coastal Seas), which has also been extensively tested against field observations for the southern North Sea (SNS) (Kerimoglu et al. 2017). Steep vertical gradients incl. thin-layers reported from regular SCANFISH tracks as part of the COSYNA observatory were reproduced by the trait-based model on its account of adaptive regulation in phytoplankton mobility (Baschek et al., 2017; Kerimoglu et al., 2017). Cross-shore changes in the settling velocity of suspended material was detected, which impact coastal POM and nutrient budgets in conjunction with the estuarine circulation (Maerz et al., 2016; Hofmeister et al., 2017). The seamless transition between the laboratory scale and the coastal ocean during the development of the basic MAECS equations has been specifically made possible by our new concept of modular model coupling.

*Advancing coastal modeling capacity*: Model development and development of new theoretical concepts within Topic 2 was carried out to support the understanding of coastal system changes. We addressed here basically two aspects, (i) advancing regional downscaling models for climate change impacts to regional coupled models and (ii) development of new modeling capacity to address societal information needs on complex coastal system changes. The latter included new ecosystem models as well as new models to resolve the fate and transport of pollutants in the environment.

*Regional climate Downscaling- A coupled atmosphere-ocean challenge:* The role of atmosphere ocean coupling in regional climate downscaling has recently been reviewed by Schrum (2017). Earlier, uncoupled atmospheric models or stand-alone ocean models were thus far used to downscale climatic changes, an approach that is still maintained as the most common on regional scale. However, this approach has some fundamental limitations: regional air-sea interactions remain unresolved and crucial regional feedbacks in coastal zones are neglected (Schrum 2017). To overcome these limitations, regional climate modeling is currently transitioning from uncoupled models to coupled atmosphere-ocean models, leading to fully integrated regional Earth System models. We developed a fully coupled regional atmosphere-ice-ocean model for climate downscaling (Ho-Hagemann et al., 2013, 2015, 2017). We found that air-sea coupling caused a significant improvement in simulations of extreme rainfall events over Central Europe from air-sea coupling. The coupled model is currently augmented by a regional hydrological model to foster improved modelling of regional climate change impacts including coastal flooding events. These activities are closely related to atmosphere-ocean-wave coupling on synoptic scales (*Topic 4)* and will ultimately be combined in the ***GCOAST model framework***.

*Advancing ecosystem model capacity:* The response of marine ecosystems to anthropogenic stressors and to natural climate variability defines a major field of research, but realistic predictions are still difficult. We contributed novel model development to meet future societal informational needs in coastal and estuarine management. Rather than pursuing the usual approach of resorting and adjusting existing model components, we follow a long-term research agenda by developing new, advanced (1) mechanistic, and trait-based ecosystem models – to better resolve biological dynamics- and (2) marine chemistry models for key contaminants and (3) modular coupling framework – to integrate a wider set of models and data in a more flexible manner. The liaison of these innovations was then tailored to meet relevant informational needs for environmental management. We *developed a novel* trait-based approach for plankton growth (Wirtz and Kerimoglu 2016; Kerimoglu et al., 2017, *Highlight 3*), which aimed at reducing uncertainty in plankton modelling and increasing mechanistic understanding of plankton. Another innovative development was the concept of mechanistic controls of macrobenthos communities (Zhang and Wirtz 2017), which is currently further developed to explain benthic variability on basin scale. For the biogeochemical, sedimentological, and ecological integration into *GCOAST*, a novel coupler Modular System for Shelves and Coasts has been developed (Lemmen et al., 2017). The flexible coupling technology allowed us to develop model configurations of varying degrees of complexity and use them to explain variability in coastal ecosystem states as persistently observed *in situ* or by remote sensing *(Highlight 3)*. Using the same physical setup, but extended by geological modules, we quantified - for the first time at the system scale - the control of suspended sediment dynamics by macrobenthic activities (Nasermoaddeli et al., 2017).

The majority of marine ecosystem models target only parts of the trophic food chain. This implies difficulties to consistently simulate the major trophic controls of marine ecosystems that connect primary production with zooplankton, fish and apex predators such as marine mammals. Ecosystem response to climate change covers a wide range of processes from temperature controlled growth and mortality to changes in trophic dynamics triggered by nutrient availability, temperature effects and other environmental controls on marine species through e.g., effects on vital rates and prey availability. To address the scientific questions arising from marine ecosystem responses to climate change the traditional ecological modeling tools do not suffice, and new concepts and modeling tools for ecosystem modeling are required. Keeping that in mind, we developed a novel consistent E2E

ecosystem model on the basis of the functional group approach traditionally used in lower trophic level ecosystem models. The model (ECOSMO E2E) bases on the fully coupled ecosystem model ECOSMO II (Daewel and Schrum 2013; Daewel and Schrum 2017) and includes both, fish and macrobenthos, as functional groups that are connected to the other trophic level via predator–prey interactions (Daewel and Schrum 2016, Daewel and Schrum, in review). For the first time, this allows for estimating energy and matter fluxes on a basin scale in the marine food web from bacteria up to fish. While using this model we were able to conceptually describe the role of macrobenthos and benthic-pelagic coupling for fish production and nutrient dynamics. For the first time, we were able to show that fishing has a footprint on carbon and nutrient fluxes. The integrated modeling approach allows addressing questions regarding trophic interactions in the marine food web and solve the closure term problem identified for marine ecosystem models (Daewel et al., 2014). However, it cannot resolve impacts on targeted marine species, as Individual Based modeling (IBM) species specific approaches can, which allow explicitly resolving climate change impacts on e.g., fish vital rates, match-mismatch dynamics between fish and their prey through larval drift and or changes in ecosystem productivity (Daewel et al., 2015).

*Multi-compartment pollutant modelling:* Modeling of pollutants in the environment was further pursued by the Research Unit through developments in the field of multi-compartment modeling, while closely collaborating with RU 2. We developed a multi-compartment pollutant modeling system, which consists of an atmospheric chemistry transport model (developed within RU 2) and a *novel* marine mercury model developed by scientists of the Research Unit. The latter resolves partitioning, chemical speciation, and bio-accumulation of mercury in water, plankton and sediment (Bieser and Schrum 2017). This allowed us to close the gap in the global mercury cycle currently evident in the modeling community, which is strongly focused on atmospheric chemistry models and global model applications. This high resolution regional modeling system allows us to support industry and policy makers to identify the main pathways of mercury in seafood and to help assess the risks of legacy pollution and unintentional releases. In this regard, HZG is responsible for the regional modeling of mercury transport for the UNEP Global Mercury Assessment Report 2018. Another application is the support of the Swedish Environmental Agency in assessing the risk associated with legacy pollution in the Baltic Sea. Here, we use the model to determine the possible impact of dumped mercury catalyst from a chlor-alkali plant on the ecosystem and help to develop a remediation plan for the area. As mercury was used on industrial scale in the mid nineteenth century and dumping of pollutants was legal until the London convention on the prevention of marine pollution came into force in 1975, legacy pollution is a severe problem which poses a threat to sea food safety. Additionally, in European waters there is still legacy mercury pollution originating from the Second World War where mercury was used widely in military devices.

Topic 4

## Contributions to PACES II Topic 4 Operational Oceanography

*COSYNA Modeling and data products:* Within Topic 4 RU 1 focussed on research and new developments in the field of operational oceanography and pre-operational development. The Research Unit has contributed research to the field of operational oceanography through the strategy for service evolution of the CMEMS and to pre-operational system development. Here, our activities within the framework of COSYNA (Stanev et al., 2015c, 2016; Baschek et al., 2017; 3.2 - Highlight 2) are of utmost importance. COSYNA provides a large variety of coastal observation data, including platform observations and area-covering radar measurements complemented by data-assimilation model products. Data assimilation in the coastal ocean is not currently a routine operational practice, and due to the short memory and the strong nonlinearities of many coastal processes, it is still challenging (Stanev and Schulz-Stellenfleth 2014). However, clear advances were made in the use of HF radar data for the optimization of current forecasts and in the problem of upscaling information gathered by coastal observatories to a larger regional scale. Search and rescue operations can largely profit from this product (Stanev and Schulz-Stellenfleth 2014). Other observations analyzed and/or assimilated include data from tidal gauges, waverider buoys,

FerryBoxes, and vertical profiles from Scan Fish, gliders and Argo floats. Satellite data, including Sentinel data, complement the observational and forecasting system.

*Unstructured grid modelling:* Major advances during the evaluation period were also made in the development of new hydrodynamic modeling capacity. Two-way coupled nested grid modeling was applied to solve a specific cross-scale problem, such as the coupling of the North Sea-Baltic Sea system (Stanev et al., 2015b). Exchange between the two seas is controlled by large-scale basin states and modulated by small-scale dynamics in narrow straits and sounds connecting the two seas (Stanev et al., 2016). As an alternative approach to nested modeling (Stanev et al., 2014, 2015a, b) seamless cross-scale modeling was further developed (Zhang et al., 2016a, b, Jacob et al., 2016; Jacob and Stanev 2017). This computational method integrates and resolves different scales and nonlinear processes in one single model application. Unstructured grid model setups have been developed for a number of case studies connecting open ocean, shelf seas, tidal flats, estuaries and inland harbors. Moreover, the potential for unstructured grid modeling to resolve environmental impacts of offshore constructions has also been explored (Grashorn and Stanev, 2016). These model developments were published in nine scientific papers in journals with high impact. Key aspects are further detailed in Highlight 4. Overall, we conclude that the physical part of the developed unstructured grid modeling system is now mature enough to be coupled with biogeochemical and ecosystem models of different character and complexity to model complex environmental changes in the coastal ocean (Stanev et al., 2016).

*Atmosphere-wave-ocean current coupling:* New developments are also becoming increasingly available for the marine realm in terms of coupled wave-circulation modelling. The Research Unit took a leading role in this field (Staneva et al., 2017). We developed a novel framework for coupling circulation and wave models for operational applications with a focus on regional scales. Staneva et al. (2016, a, b) demonstrated for the first time the improvement in the quality of predictions of wind waves and storm surge simulations during extreme weather cases in the German Bight. Novel contributions to the field were also made through the quantification of the Stokes-Coriolis force's role and the sea-state dependent energy and momentum fluxes for hydrodynamics in regional seas (Staneva et al., 2017; Alari et al., 2016). Contributions were also made through the introduction of interactive atmosphere-wave coupling (Wahle et al., 2017; both aspects further detailed in Highlight 5). These developments had a high international impact, as tools and model versions were shared with the European NEMO developer group and a number of international operational oceanography agencies (details given in chapter 4.1.2.3). These developments form a core contribution to the fully coupled atmosphere-wave-ocean model system **GCOAST**.

Topic 4

***Highlight 4: Unstructured grid modelling***

The framework of the Semi-implicit Cross-scale Hydroscience Integrated System Mode (SCHISM) has recently been fundamentally improved and the cross-scale numerical approach now allows the resolution of estuarine and strait dynamics, shallow water and eddy regimes in one single model (Zhang et al., 2016a).

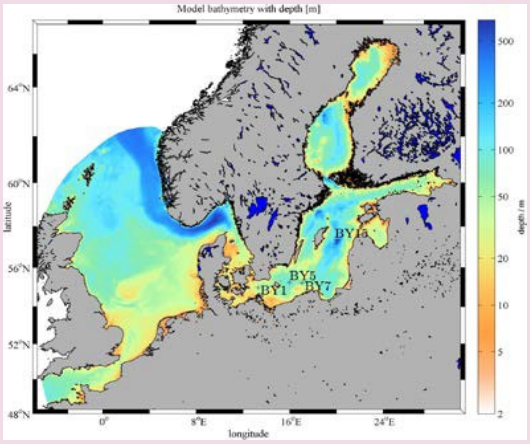



Figure 15: Bathemetry of North and Baltic sea model setup presented by Zhang et al., (2016b).

The SCHISM model framework has been used to create a number of different model setups, for different applications. One example is a model setup for the North- and Baltic Seas, which uses an enhanced resolution in the narrow Danish Straits down to ~70 m (Zhang et al., 2016b). This enabled a realistic simulation of the two-layer strait exchange. The comparison against observed data demonstrated a yet unprecedented realism in a basin-scale model. Processes such as tidal variations along the strait, the two-layer transport reversal and dense water cascading could be simultaneously resolved with basin-scale processes.

Other setups address the coupling of the German Bight, the Wadden Sea and the Elbe, Weser and Ems estuaries (Pein et al., 2014, 2016; Jacob et al., 2016). The challenge here is to resolve tidal amplification and damping, over-tide generation, secondary circulation, baroclinicity and internal mixing asymmetry. Pein et al. (2014) demonstrated that small-scale bathymetric characteristics, which cannot easily be resolved with structured-grid models, forces a complex interplay between these dominant physical mechanisms. The utility of this model system in combination with dedicated observations for environmental assessments was demonstrated by Pein et al. (2016). Other applications demonstrated the realistic simulation of near-shore transport caused by extreme wind waves (Grashorn et al., 2015; Schloen et al., 2017).

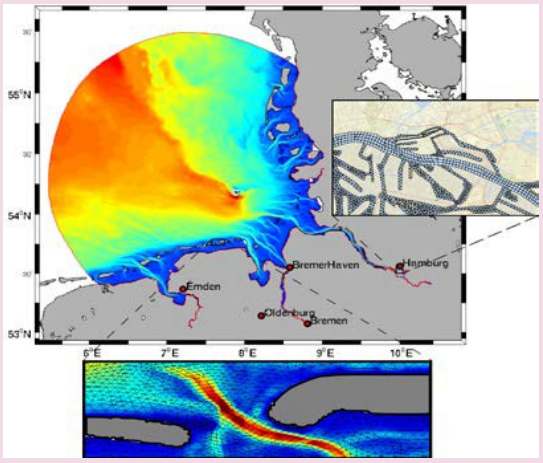



Figure 16: SCHISM setup for the German Bight and of the Weser, Ems and Elbe estuaries, including Hamburg harbor

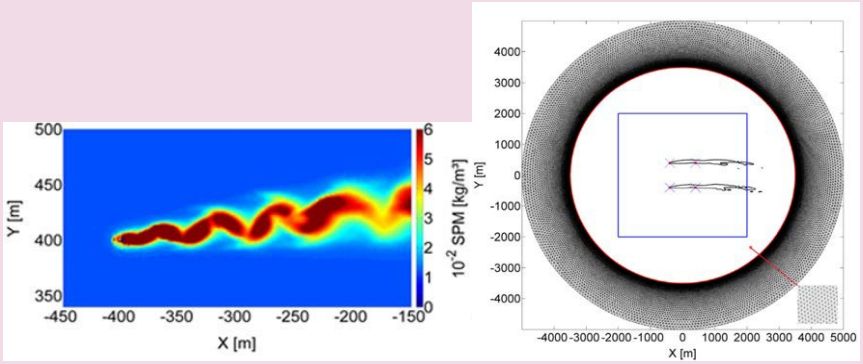



Figure 17: Setup resolving four wind piles in a tidal current regime. Resolution decrease away from the piles, suspended sediment eroded from the bed (Grashorn and Stanev 2016).

The strengths of the model system become evident when modeling impacts of large-scale offshore constructions such as offshore wind farms. Grashorn and Stanev (2016) used an extremely fine horizontal resolution of ~2m combined with larger scale resolution away from the piles in km-scale, demonstrating that these obstacles give rise to vortices similar to Kármán vortices. These enhance sediment remobilization and create wakes, which have been sensed remotely earlier.

Topic 4

***Highlight 5: Coupling of atmosphere and ocean through a dynamic wave interface***

It has been shown by Staneva et al. (2017) and Alari et al. (2016) that wave-current interaction through the Stokes-Coriolis force and sea-state dependent energy and momentum fluxes have substantial potential to also shape the mean circulation and basin wide stratification. It even has the potential to shape the surface temperature pattern in the North and Baltic Seas. This has wide implications for particle transport, biogeochemical processes and air-sea heat fluxes. Hence, wave-current interaction cannot be neglected in search and rescue, oil-spill and larva drift modelling. Moreover, wave-current interaction must also be considered for studying climate processes and ecosystem dynamics on regional scales.

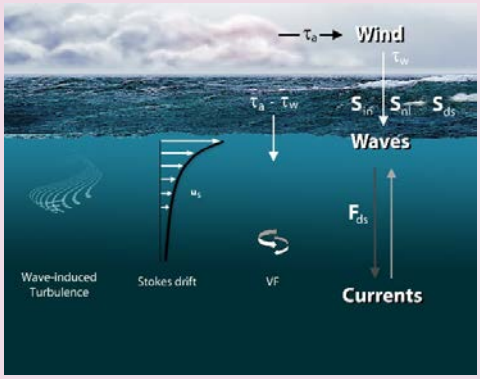



Figure 18: Wave-current interaction.

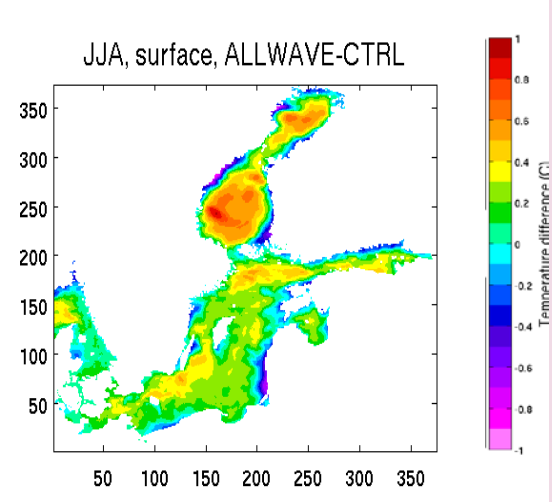



Figure 19: Temperature difference due to consideration of wave-current coupling (Alari et al., 2016).

Consideration of wind waves and coupling between atmosphere and circulation models is increasingly becoming a key element for high quality operational marine-environment information and products. The information and products serve stakeholders and operators in marine safety, marine resources, marine environment and forecasting. Coupling between ocean circulation and wave models has the potential to significantly enhance quality and also provides a new perspective for theoretical basic research on synoptic and climate time scales. A framework for coupling circulation and wave models was developed as the central part of the GCOAST system. Recent advancements in development of the WAM wave model for forecast applications in operational services and climate assessments for the North Sea and the German Bight were presented by Staneva et al. (2014, 2015) and for ensemble predictions by Behrens (2015).

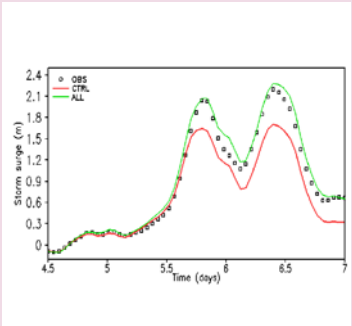



Figure 20: Time series of surge: observations (black circles), NEMO-only (red) and coupled model (green) (Staneva et al., 2017).

Our research contributed to advancing theoretical understanding of regional systems and demonstrated that coupling circulation and wave models could significantly improve model results. Increased demand for improving wave and storm predictions requires improved representation of physical processes. We could prove that coupling between wave and circulation models can significantly enhance the quality of modelled sea level during extreme storm events (Staneva et al. 2016a; Staneva et al. 2017). The impact of wind, waves, tidal forcing and baroclinicity on sea level during extreme storm events in the fully coupled wave-circulation model system was quantified by Staneva et al. (2016b). Moreover, the two-way coupling between wave and atmospheric models is an important stepping stone for adequately resolving interactions and exchanges in the atmospheric boundary layer (Wahle et al., 2017). This proved to be particularly important under severe storm conditions.

## Knowledge and technology transfer goals and related research activities (Topic 2 & Topic 4)

In order to transfer scientific knowledge into practical contexts and to link to societal questions and demands, a broad knowledge transfer strategy has been implemented. We seek to address a wide range of target groups: (i) key federal agencies working in environmental management and forecasting, (ii) regional and local governmental authorities, (iii) a wide range of other regional stakeholder groups, (iv) other science disciplines, (v) commercial enterprises and (vi) the general public. The latter includes target groups such as media, NGOs, decision-makers and education. We have successfully implemented a wide range of different communication channels including publication in key journals, co-developments and collaborative projects with national and international stakeholders, open model data provision through the CERA data portal and we established regular contacts with relevant national German public agencies and initiated dialog processes. Moreover, we initiated and contributed to regional assessments and developed targeted information products. Furthermore, RU 1 scientists actively participated in committee work and transdisciplinary working groups and engaged in capacity building. Our activities are further detailed below. *Knowledge transfer activities were carried out as contribution to Topic 2 and Topic 4 and as collaborative efforts of Topic 2 and Topic 4.*

Topic 4

*Topic 4 Technology and knowledge transfer to support operational services and management:* Within **Topic 4,** we developed tools and methods to support operational forecasting and assessment of coastal environments. Our research and development of new and advanced coastal modeling capacity is in line with research demands formulated by several relevant practically-oriented strategic programs and operational oceanographic networks in the frame of GODAE OceanView, an international forum for national forecasting centers (Kourafalou et al., 2015a, b), CMEMS (Stanev et al., 2016), EuroGOOS (She et al., 2016) and ESA-Sentinel program. A large number of our developments is published in relevant journals (such as Journal of Operational Oceanography) and we contribute to the theoretical base for the future evolution of the coastal forecasting and joint land and marine services through coordination of international publications. One milestone in the transfer of knowledge is the recent Topical Collection on Coastal Ocean Forecasting Science supported by the GODAE OceanView Coastal Oceans and Shelf Seas Task Team (COSS-TT) (De Mey et al., 2017).

The Research Unit *System Analysis and Modelling* moreover closely collaborates with several governmental agencies and other federal stakeholders in Germany and Europe. Model data, codes and other products are made available to interested users and stakeholders in the field of operational oceanography, coastal ocean protection, shipping and other offshore operations. Technical implementation is done conjointly with forecasting agencies in Germany, Europe and world wide. For example, the further optimization of the HF radar assimilation system currently run as part of the pre-operational COSYNA system is done in close cooperation with the Bundesamt für Seeschifffahrt und Hydrographie (BSH) and activities are ongoing to assess a potential inclusion of an HF radar analysis scheme into operation at the BSH. Another example is the ongoing close collaboration in operational wave modeling with the German Weather Service, Deutscher Wetterdienst (DWD). WAM, a (originally developed and continuously updated and improved by Research Unit 1) third-generation wave model is freely available (http://mywave.github.io/WAM/ - model cycle 4.5.4) and provides the base for operational wave modeling at several regional centers in Europe (e.g., for the Black Sea – Research Unit 1-HZG, Mediterranean Sea-HCMR, ISMAR- Italy, Baltic Sea- FMI, Arctic – Meteo Norway). The model is also used by the German Navy for their operational wave forecast system. HZG also provided the model code and support (like organizing training courses) to Meteo-Oman, Muscat. Recent developments in coupling of waves and ocean circulation *(coordinated by the Research Unit 1 – Highlight 5)* were made available to several international research and marine service providers, such as Met Norway and UK Met Office, which successfully implemented recent advances in coupled wave-circulation modeling. These

developments were also made available to other marine CMEMS Partners in Italy and France and to the NEMO developer group (https://www.nemo-ocean.eu/consortium/team/NEMO).

Topic 2

*Topic 2 Transfer of modeling tools* and their specific applications developed in **Topic 2** were also initiated in the field of environmental management and ecosystem modeling. Collaborations have been established on national and EU-level. Collaboration was established and ecosystem model tools were made available to the NERSC, Norway and for further operational use in the frame of the CMEMS Arctic forecasting system. Furthermore, tools and methods developed at the Research Unit (Kerimoglu et al., 2017; Bieser and Schrum 2016) are used to support information needs regarding water quality and risk assessments by national German and international stakeholders, such as national environmental agencies (e.g., UBA, NLWKN) and international corporations (AkzoNobel). The results help to guide ongoing negotiations of the German authorities on the target definition within the Water Framework Directive (WFD) and to evaluate the state of environmental pollution and to determine the impact and risks related to unintentional releases on the marine environment and food safety.

Topic 2

*Topic2 Databases and specific modeling:* Through our research in the frame of **Topic 2** (longterm changes) a number of unique homogenous multi-decadal model data sets were produced. These were made freely available to the research community and other interested users to be used in practical and scientific contexts (http://www.coastdat.de/). The ***coastDat*** database comprises model data from quasi-realistic numerical and statistical model systems. Apart from their scientific usefulness, the database also deemed useful for coastal management and offered different options for commercial services. As of mid-2017 there were more than 100 registered users of these data, with about 40% of them located in private companies, 15% in government and 45% in other research institutes, which have used these data in fields such as naval architecture, offshore wind and more generally renewable energies, shipping emissions, or assessing effects of climate change on coastal flood damages (*Weisse et al.,* 2015, 2014b). For example, based on the hindcast data, climatologies of wind energy for the North Sea and the Bohai Sea were developed (*Geyer et al.,* 2015; *Li et al.,* 2016a, 2016b). Based on power functions for typical wind turbines, the potential was assessed over the hindcast period (as a contribution to 3.2 – *Highlight 1)*. All these studies revealed substantial decadal variability and showed that inferences based on short observational time series may be biased. Multi-decadal met-ocean hindcasts are therefore essential to complement existing observations. With ***coastDat*** several different economic and scientific objectives are investigated. Examples are summarized on http://www.coastdat.de and chapter 4.1.2. Additional curated data and information, such as basic statistics of ***coastDat*** data, are available as maps on vis.coastdat.de.

Topic 2+4

*Topic 2 & Topic 4 Regional Assessments and information products:* As a joint collaborative Institute of Coastal Research activity and a joint contribution of **Topic 2** and **Topic 4**, regional assessment reports are coordinated and supported for three different regions (Baltic Sea region, coordinated by Baltic Earth (BACCII Author Team 2015), North Sea region (NOSCCA, Quante and Colijn 2016) and within CliSAP for the Metropolitan region of Hamburg (v. Storch, Meinke and Claussen, 2017, coordinated by the Research Unit through the Northern German Coastal and Climate Office), see 3.2-*Highlight 3*. The objective of these regional assessment reports is to systematically document the published peer reviewed knowledge about long term trends, its drivers impacts on regional scales. The unit´s research under **Topic 2** provided a solid contribution to the reports and RU 1 personnel has actively contributed to all assessments as lead authors (*Schrum et al.,* 2016; *Hünicke et al.,* 2015; *Meinke et al., 2017)* or contributing author (in *Huthnance et al.,* 2016).

Topic 4

*Topic 4 Dialog processes:* As a contribution to **Topic 4**, a sustainable dialog structure for communication between science, stakeholders and the public at large was built up and established in the Northern German Coastal and Climate Office (www.norddeutsches-klimabuero.de). The main focus of the stakeholder dialog is to support coastal and climate issues in Northern Germany based on our solid research foundation (**Topic 2**) and its relation to the wider state of the art. More than 1850 users from different stakeholder groups have been registered for this service, so far. Major stakeholder groups are interested lay persons (29%) and neighboring scientific disciplines (29%).

Medium sized groups are authorities (10%), NGOs (9%), education (8%) and commercial enterprises (7%), smaller groups are media (4%) and politicians (3%). According to stakeholder needs, different communication formats have been developed and explored. Stakeholder inquiries are answered, interviews are given to media, expert interviews with relevant stakeholders are conducted and talks, information booths, discussion rounds and workshops are provided as contribution to various public stakeholder events. Together with colleagues from RU 1 and other Research Units at Institute of Coastal Research formal as well as informal meetings with government authorities are conducted.

Topic 4

*Topic 4 Information products:* Knowledge transfer about coastal and climate changes to national and international stakeholders and the general public is furthermore performed through various specific communication formats, which have been developed by the Northern German Coastal and Climate Office in the frame of **Topic 4**. Information products are understandable summaries such as booklets, condensing the regional assessment reports and fact sheets explaining the underlying methods such as regional climate projections. Knowledge transfer to the public is further supported through development of effective communication channels such as interactive web tools (e.g., http://www.norddeutscher-klimaatlas.de/, http://www.kuestenschutzbedarf.de) and other user oriented formats. Web tools provide easy access to regionalized and contextualized information on long term variability and changes. For example, http://www.norddeutscher-klimamonitor.de analyzes and interprets recent long term trends of coastal climate for Northern Germany and sub regions using ***coastDat*** data in combination with observations (Meinke et al., 2014). http://www.coastalatlas.org derives possible future climate changes in the Wadden Sea region from more than 120 regional climate scenarios. http://www.kuestenschutzbedarf.de visualizes coastal protection needs in Northern Germany, now and at the end of the 21. century, when water levels may be higher due to sea level rise and possibly changing wind climate (Weisse et al., 2015).

Topic 2+4

*Topic 2 and Topic 4 Committee work and transdisciplinary working groups:* Knowledge transfer through committee work and transdisciplinary working groups is an important element of our communication strategy. RU 1 scientists regularly attend a range of inter- and transdisciplinary science working groups and dedicated workshops, examples are ICES working groups, working groups of the Wadden Sea Forum, Baltic Earth and the Academy for Spatial Research. Several researchers are moreover appointed members of local, regional and international advisory and assessment groups. Current examples are the Regional Advisory Council North Frisia for the Wadden Sea National Park in Schleswig-Holstein (Kannen), the CMEMS Advisory Board (Stanev), the Advisory Board for the trilateral Wadden Sea Forum (Ratter), the IPCC (Special Report on the Ocean and Cryosphere in a Changing Climate: Ratter; AR5: von Storch), European Marine Board policy briefing on ecosystem modeling (Schrum), national German Working Group on eutrophication, nutrients and plankton (Kerimoglu, Wirtz), OceanView Coastal Oceans and Shelf Seas Task Team (Staneva), and the Deutsche Gesellschaft für internationale Zusammenarbeit GIZ (Gee).

Scientists of Research Unit 1 furthermore work together with local actors and governmental authorities through joint national and EU projects (program frameworks H2020, BONUS, ERA4CS, KüNO). A specific type of knowledge transfer is currently used in the frame of the BONUS BALTSPACE project by using an *extended peer review* to specifically enter into a dialog with Baltic Sea government authorities responsible for MSP on tools and approaches for MSP as well as reflection of an analysis of national MSP processes and their implications for future planning processes.

*Topic 2 and Topic 4 Capacity building:* Capacity building is supported on a regular base by RU 1 scientists through university lectures, seminars with different audiences and summer schools. HZG operates on a regular base summer schools on coastal research topics together with AWI, IOW and University of Oldenburg. RU 1 scientists regularly contribute with lectures to these and other summer schools, such as the KüNO summer schools and Baltic Earth summer schools. Moreover, a number of specific training modules are developed and held by RU 1 scientists. These cover the areas of Marine Spatial Planning and technology transfer in atmosphere, ocean and wave modeling.

*Impact - relates to Topics 2 and 4:* Our work created an ***impact*** in the sense that data, models, knowledge and tools developed by us are used in operational work in a range of different institutions. Impact is also seen in the sense that our models and data are used to assess risks in public and economic sectors. Regional assessment reports are internationally visible and frequently downloaded (e.g., the BACC report about 120 000 times, the NOSCCA report so far almost 65 000 times, the climate report for the Meteropolitan region of Hamburg already more than 10 000 times during the first 2 months, all numbers November 2017). Members of the institute are regularly and frequently approached by the media on issues of coastal and climate change and our work also gained visibility in the political process. Regional assessment reports are regularly referenced and scientists are recognized scientific advisers and members in regional, national and international advisory boards. We furthermore contributed to hearings in the Hamburg Senate and Schleswig Holstein parliament and our information material percolates into educational material and books. However, the overall societal impact of our work is difficult to assess and quantify, as this would rather require thorough concomitant research, which has not been carried out during the evaluation period.

### 4.1.3 EMBEDDING IN PACES II

***Contributions to PACES II:*** The Research Unit *System Analysis and Modelling* contributes to *Topic 2 Coastal Shifts and Long-term Trends and Topic 4 Bridging research and society – products, tools and climate services of PACES II (Polar Regions and Coasts in the Changing Earth System),* the joint strategic research program of HZG and AWI in POF III. In Topic 2 and 4, the Research Unit collaborates closely with the other two Research Units at the Institute of Coastal Research, with GERICS (RU 4) and with AWI. The Research Unit is here specifically contributing system modeling expertise, complementing physical and biogeochemical expertise available at the Research Units 2 and 3 and biological expertise at AWI.

Topic 2

**Topic 2:** The Research Unit is responsible for and leads *Topic 2, WP1 Coastal shifts and long-term changes* (led by Weisse/HZG together with Kraberg /AWI) and *WP2 Species Interactions in changing and exploited Coastal Seas* (led by Wirtz/HZG with Boersma /AWI) and contributes furthermore to *WP4* (*Biogeochemical provinces of sea floors in the German North Sea sector,* led by the Research Unit *Biogeochemistry in Coastal Seas* (Research Unit 2). WP1 focuses on quantifying and assessing regional long-term environmental change in coastal systems. Relevant selected contributions are presented as *Highlights 1-2.* Research focus in WP2 is on consequences of global and regional changes on marine biota and coastal ecosystems. A relevant research highlight is presented as *Highlight 3*.

Topic 4

**Topic 4:** The Research Unit contributes research, technology and knowledge transfer in the frame of *Topic 4* (*Highlights 4 & 5*). Here we contribute substantially to all three work packages, which are manifested in (co)leading roles by RU 1 scientists: Stanev (WP1 until March 2017, thereafter Schrum), Meyer (WP2), Meinke (WP3, until March 2017).

***Collaboration within the Institute for Coastal Research:*** The Research Units 1 and 3 closely collaborate on the COSYNA system (3.2 *Highlight 2).* Within COSYNA, the Research Unit 1 is responsible for the modeling work, the integration of data and models through data assimilation and for development of modeling products (*Topic 4, WP1* in collaboration with *Topic 2, WP5*). Another obvious example of synergistic activities is the research done on offshore wind farms *(see 3.2 Highlight 1)*. The Institute of Coastal Research as a whole covers a large range of complementary research topics related to the large-scale development of offshore wind farming in the North Sea. The Research Unit 1 *System Analysis and Modelling* contributes to collaborative Institute of Coastal Research papers (Carpenter et al., 2016) and performs complementary research on impacts of offshore wind farms on changes in the physical environment in the ocean (Grashorn and Stanev 2016), on the data needs for planning of offshore activities (***coastDat***; e.g., *Weisse et al., 2015; Geyer et al., 2015*) and governance issues in Marine Spatial Planning (e.g., Gee et al., 2017, Stelzenmüller et al., 2017, Cormier et al., 2015 and 2016). Close collaboration between the Research Units at the

Institute of Coastal Research manifests further in modeling of contaminants and integrating supporting observations and ***coast**Map* products and model results (WP1, 2 & 4, Research Unit 1 and 2) in ecosystem and coastal biogeochemical modeling (joint Research Units 1, 2 and 3, Maerz et al., 2016; Hofmeister et al., 2017) of pelagic and benthic environments (WP2 & 4).

***Collaboration with AWI and GERICS (RU 4):*** Ongoing collaborations exists with AWI on various topics, such as macrobenthos dynamics, coastal modeling and societal aspects of climate change within *Topic 2 WPs 1 & 2* and within REKLIM (see below). Within *Topic 4, WP3* RU 1 collaborates closely with AWI and GERICS (RU 4), e.g all three units contribute to the web platform klimanavigator.de. An outstanding collaborative effort of all Institute of Coastal Research Research Units and also with GERICS (RU 4) within Topic 2 & 4 are the compilation of international and national climate change assessment reports, which also included contributions by AWI *(3.2 Highlight 3).* Furthermore, RU 1 and GERICS (RU 4) together with AWI build a working group on evaluation criteria for transdisciplinary research. As contribution to this working group RU 1 established together with GERICS (RU 4) and AWI a session at the European Conference for Applied Meteorology and Climatology (2016 and 2017) on *Evaluation and quality assurance of climate services Methods*, criteria *and pitfalls*. Results of this session were contributed to the special issue ***16th EMS Annual Meeting&11th European Conference on Applied Climatology*** (Meinke 2017a, b).

***Collaboration with Helmoltz centers in the research area Earth and Environment:*** RU 1 is considerably contributing to the interdisciplinary Helmholtz Climate Initiative Regional Climate Change REKLIM including an intensive collaboration with the other Helmholtz Centres AWI, KIT, UFZ. Several members of RU 1 act as coordinating Topic Speakers, in Topic 1: Coupled regional climate models (Rockel/HZG with Rinke/AWI), Topic 6: Modelling and Understanding Extreme Hydro-Meteorological Events (Feser/HZG with Kunz/KIT), Topic 7: Risk analysis and risk management for integrated climate strategies (Ratter/HZG with Schwarze/UFZ). REKLIM supports the understanding of climate processes and long-term developments on regional scales and has successfully contributed to improved understanding of large-scale natural climate fluctuations and human impacts. Within the framework of the Helmholtz Network a special aspect is the coordinated collaboration with several Universities (http://www.reklim.de/en/).

***Collaboration with University of Hamburg:*** The collaboration between Universität Hamburg is of crucial importance for RU 1 and cooperation is established on various themes, such as reconstructing past coastal climates, extreme events, predictability of coastal systems and socio-cultural aspects in coastal research. The shared professorship model with the Universität Hamburg fostered a close collaboration with the university, and RU 1 scientists (Prof H v. Storch, Dr F Feser, Dr E Zorita, Prof B Ratter, Prof C Schrum) participated as PIs in the two phases of the Cluster of Excellence CLISAP (Integrated Climate System Analysis and Prediction, 2007-2017). This close collaboration is ongoing and currently CliCCS, a new proposal to the *Excellence strategy of the German Research Foundation* is under way. The proposal is a collaboration between Universität Hamburg, Max-Planck-Institute for Meteorology and HZG. The pre-proposal has successfully passed the first evaluation round and currently a full proposal is prepared. Prof. C. Schrum is a member of the CliCCS coordination group and PI of the CliCCS proposal. Other scientists of the Research Unit 1 are involved in the CliCCS proposal as chairs (Dr. E Zorita, Prof. B. Ratter) and in the role of contributing scientists (Dr. U. Daewel, Dr. F Feser, Dr. A Kannen, Dr. B. Rockel, Dr. J. Staneva).

### 4.1.4 FUTURE FOCUS AREAS (POF IV)

The Helmholtz strategic research plan of the ***Earth and Environment*** research area for the next phase of program-orienting research (POF-4) is currently under development. After intense discussions on scientific and structural aspects of future Helmholtz Earth System Research, the Centers agreed upon structural changes in the program-oriented funding. Currently, the centers are largely organized in research programs within compartments (atmosphere, ocean and geosphere) with only the PACES II program having a research focus on different compartments Polar and Coastal regions. The new

program structure will specifically acknowledge the Earth as an interconnected and interacting system of sub-spheres and all centers in the Earth and Environment program agreed upon a new structure making research across compartment boundaries and co-operations between Helmholtz Centers more effective. For the POF IV phase, research will likely be organized within three major realms and a yet to be specified number of specific topics. One topic will likely focus on Coastal Systems, linking river catchments, estuaries, coastal seas and open ocean dynamics. HZG will take a leading role in this topic and contribute key expertise. RU 1 will specifically contribute expertise in modeling and understanding of changing interconnected coastal systems on various time scales. Linking our expertise with expertise available in other centers such as GEOMAR, AWI, UFZ and KIT will allow for development of new research perspectives. The details of the strategic research program POF IV remain to be developed during the coming year and RU 1 will actively contribute to the future strategic development of POF IV.

The North European Shelf and the Arctic shelves will remain key regions of our interest. However, we also aim to develop a more generic understanding of global coastal systems and their coupling to land and ocean, this will also be one of our research foci within the planned excellence cluster CliCCS. A key role in shaping future research play moreover three strategic collaborative Helmholtz-funded projects (all started in 2017), which provide incentive funding for future research themes at RU 1. These comprise the ***CliCCS Helmholtz-network*** supporting and enlarging collaboration with the Universität Hamburg (coordinated by Prof. Corinna Schrum, with Research Units *Biogeochemistry in Coastal Seas* (RU 2) and *GERICS* (RU 4) and Universität Hamburg as partner), the project ***Advanced Earth System Modelling Capacity*** (***ESM***, http://www.esm-project.net/, coordinated by Prof. Thomas Jung, AWI, RU 1 and GERICS (RU 4) participate), which is strengthening collaboration between Helmholtz Centers in Earth System Modeling in Earth and Environment, and the data science pilot project ***Reduced Complexity Models*** (***RedMod,*** coordinated by Prof. Corinna Schrum, scientist from RU 2 and GERICS (RU 4) participate). Within the ***ESM*** project we will develop the theoretical coastal modeling framework through further development of the GCOAST Geesthacht Coupled cOAstal model SysTem (see 4.1.2). This will enable us to address the urgent research need for a better fundamental understanding of the processes governing the coupling between the ocean, atmosphere and land. Using the GCOAST framework we will focus on resolving and hindcasting energy and matter fluxes between compartments while considering feedback processes in the coastal zone. Future research will link these with regional climate proxies to reconstruct past climate variability on regional scales beyond the period of re-analysis and instrumental records. We will thereby advance understanding on system variability and predictability, a prerequisite for further development of forecasting and assessment capacity to project and forecast future system changes.

The more intensive use of the ocean through activities such as ship traffic, oil drilling, increasing offshore wind energy production and offshore industrialization, aquaculture, fishing and coastal eutrophication furthermore calls for consideration of human impacts in an integrated system modeling approach. Our future research activities will to a significant degree focus on these aspects. Within the ***ESM*** and ***CliCCS Helmholtz-network***, we aim at advancing coastal modeling and data assimilation capacity by considering complex human impacts on coastal systems, such as offshore wind farm developments and their far field effects, fisheries and aquafarming, riverine water management, coastal protection and land use impacts on riverine nutrient loads. These developments will enable us to assess future coastal systems under anthropogenic and climatic pressure and to resolve possible feedbacks in coupled coastal human-environment systems. We will also specifically advance data assimilation with the focus on using new high resolution advanced ocean observations to supplement models with yet unconsidered or unresolved process information to improve model predictions and create synergies between data and observations.

Within the project ***RedMod***, we will focus on exploring the use of advanced data science methods in combination with high resolution 4-d model data for the topics (i) uncertainty quantification while exploring large parameter spaces, (ii) the development of surrogate models to overcome limits inherent to time and storage consuming data mining and (iii) subspace identification in large multi-

dimensional data sets. All three aspects will be of relevance for the research methods and model capacity development within RU 1 to address subjects such as model sensitivity and uncertainty of model projections, data compression and availability of model results to users and finally for combining high resolution model data with longterm records to statistically reconstruct past climates. Within the project, we will closely collaborate with Helmholtz Centers from research areas Earth and Environment, Energy, Health and Aeronautics, Space and Transport.

RU 1 plans to further play a constructive role in identifying high-priority R&D topics for Copernicus programs, in particular in the field of regional and coastal developments. The complementary interests of the Copernicus Land Monitoring Service and Copernicus Marine and Environmental Monitoring Service, as well as long-term European research priorities such as the ESFRI project *Danubius* (RU 1 joined the modeling node) open new research horizons in the direction of land-ocean coupling where RU 1 aims to play an active role.

### 4.1.5 CAREER DEVELOPMENT

Doctoral students in the RU 1 are enrolled at the Universities in Hamburg, Kiel and Oldenburg. During the evaluation period 28 doctoral students were supervised, including students of the China Scholarship Council, which are sent to HZG regularly. The universities run their own graduate school programs. The graduate programs in Hamburg and Kiel are comprehensive, the graduate program in Oldenburg is rather informal. The majority of the Doctoral students enrolled at UHH are members of the Graduate School SICSS (School of Integrated Climate System Sciences). The Hamburg graduate school SICSS offers a career support program, expert courses, annual retreats, and technical and soft skill training. SICSS students are supervised by graduate committees which monitor the students' progress in 6 month´s intervals. Students enrolled at Kiel university have the opportunity to join the Integrated School of Ocean Science, ISOS. However, this has turned out to be practically difficult because of long distance and lacking good public transport connection.

RU 1 trains students and young researchers in state of-the-art concepts and leading-edge research techniques (numerical modeling, data analysis and statistics), with a strong focus on the acquisition of inter-disciplinary knowledge while providing them career-management skills and solid professional connections. All doctoral students at the Research Unit are encouraged and supported to visit national and international conferences and summer schools and students and young researcher present their studies in numerous national international conferences. Several students of the Research Unit have been awarded for their work, e.g. for best conference presentation or for an extraordinary thesis. Young researchers are moreover encouraged to attend courses on communication skills (communicating research to non-experts and media, writing and presentation skills, rhetoric) and research project management. Foreign students and researchers are encouraged to attend language courses.

The Research Unit furthermore supports development of young researchers in various ways. Talented postdocs are encouraged to apply for prestigious national and international funding schemes for young scientists such as applications for their own postdoc position (German Research Foundation), Helmholtz Young Investigator groups (HGF) or ERC starting or consolidator grants. In case institutional funding is required this is ensured by the Research Unit in support of these applications. Moreover, the unit also provides resources to young researchers to support independent research at an early stage of their carrier. Young scientists are supported moreover to develop teaching and supervisions skills through contributing to teaching (currently Dr. C Lemmen at Leuphana University in Lüneburg and Dr. J. Bieser at University of Hamburg) and theses supervision.

Ensuring equal opportunities is an important element of the Research Unit´s career development strategy. During the evaluation period, the unit focused on measures to overcome implicit gender bias and other unconscious attribution and stereotypes. Awareness was raised for implicit

stereotypes and specific measures were applied to encourage female scientists to take responsibilities to overcome the most obvious issue of gender inequality. The strategy was particularly successful and today RU 1 reached gender balance at PI level and tenure scientist positions.

# 4.2

# RESEARCH UNIT 2 BIOGEOCHEMISTRY IN COASTAL SEAS

Topic 2

## 4.2 RESEARCH UNIT 2: BIOGEOCHEMISTRY IN COASTAL SEAS

Director Prof. Kay-Christian Emeis

Estuarine, coastal and shelf systems have been modified by humans for at least 300-150 years (Lotze et al., 2006) and today are among the most rapidly changing environments on Earth. Observed change responds to global trends and processes such as warming, ocean acidification and sea level rise, but is at the same time modulated by natural variability on regional scales. The corridors of regional system evolution are superposed by diverse and regionally distinct anthropogenic pressures, including pollution, eutrophication, alterations of the physical environment, and industrialization on scales of river catchments and shelf seas (e.g., Levin et al., 2015). The coastal zones of Europe and other world regions are of increasing interest to society as a source of ecosystem services and natural living and non-living resources, or simply as a space for offshore developments (Glavovic et al., 2015). Altered matter transports between the Earth sub-systems are a distinct fingerprint of intensifying human activities over the course of the Anthropocene. They are expanding in space and culminate at the coasts (Crossland et al., 2005). Some scientists believe that chemical pollution and unchecked eutrophication compromise safe planetary boundaries (Rockstrom et al., 2009), and they certainly compromise good environmental status of many land-sea-atmosphere transition zones (Figure 21).



Research Unit 2 *Biogeochemistry in Coastal Seas* works in **Topic 2 *Fragile Coasts and Shelf Seas*** (co-lead Prof. K. Emeis/HZG and Prof. K. Wiltshire/AWI) of PACES II and explores matter cycles at the land-ocean-atmosphere interface. The main focus lies on organic and inorganic pollution and nutrients in estuaries and coastal settings. The Unit also investigates and quantifies processes that mitigate adverse effects and that define the natural carrying capacity of the North Sea, notably the role of seafloor/water exchange. This role is defined in Work Package 4 *Biogeochemical provinces of seafloors in the German North Sea sector* in Topic 2 (co-lead Prof. R. Ebinghaus and Dr. S. Kasten/AWI).

Scientific understanding of complex interactions improves the scientific basis for assessing the environmental state, and we strive to generate qualified information to better recognize, appreciate, and manage risks associated with variable and changing matter fluxes in regional land-sea-atmosphere settings. Our portfolio combines experimental (based on field expeditions and analytical work in modern laboratories) with modeling approaches (based on the HZG model systems of physical and biogeochemical processes) and is applied to elucidate origin, transports, modifications, and fate of problematic substances in rivers, estuaries, coastal seas, and in the atmosphere.

Overarching questions of our research are:

- On the one hand, what are biogeochemical expressions and impacts of natural variability? What, on the other hand, are such expressions and impacts of anthropogenic activities on land and in the sea (e.g., estuarine management, pollutants of emerging concern, shipping, construction and operation of wind farms)?
- How do we best characterize sources, transformation processes, and fate of problematic substances in coastal seas and their effects on ecosystems?
- How can that information be used for assessments of environmental status and for recognizing risks to coastal ecosystem health?

These questions are in line with PACES II Topic 2, with national and EU research agendas that increasingly demand topical and applied research, and are a prerequisite and basis for informed management and policy. Although the southeastern North Sea region is a natural priority for these investigations (and most academic and non-academic partnerships in the Unit revolve around research in this area), scientists in Unit *Biogeochemistry* have deep and productive co-operations with partners nationally and internationally. Partners include scientists at the Hamburg KlimaCampus, the Universität Hamburg's Cluster of Excellence CliSAP, other university and institutional partners involved in the German *Coastal Research Agenda*, with international partners

in several ongoing and incipient EU projects, and within several bilateral cooperations worldwide. Examples include projects in support of international conventions (Minamata Convention on Mercury; Stockholm Convention on Persistent Organic Pollutants) or legislation (Marine Strategy Framework Directive/MSFD; EU Water Framework Directive/WFD; and International Maritime Organisation/MARPOL).

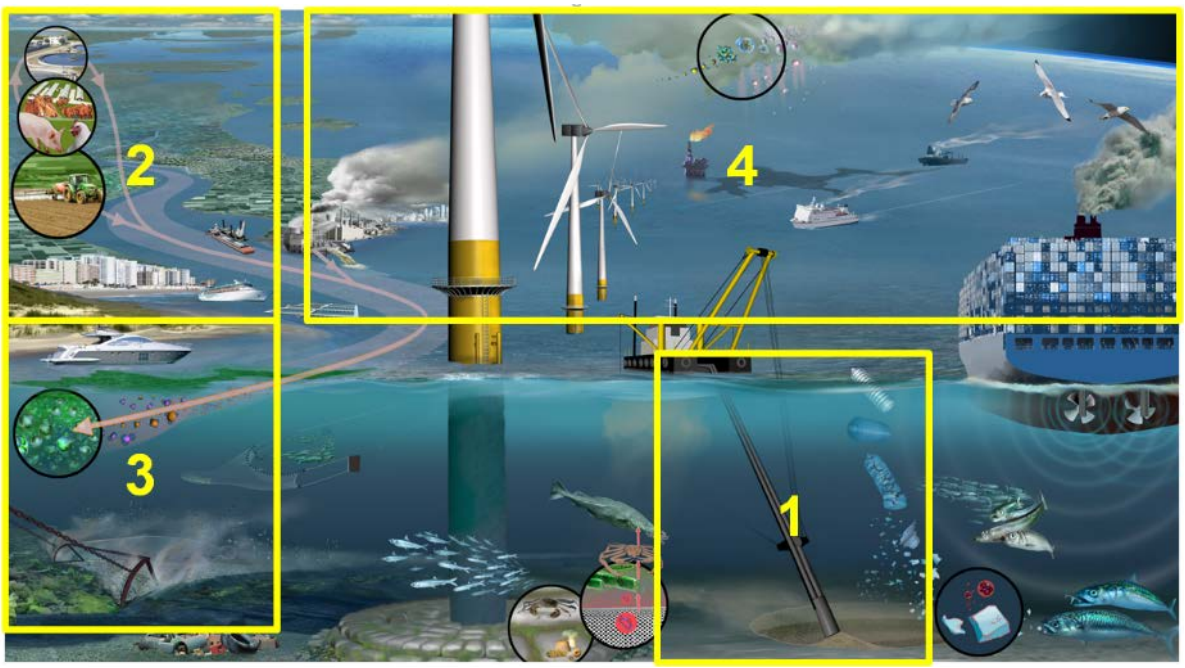



Figure 21: The North Sea is a front-runner of increasingly industrialized *service seas* worldwide. The figure shows some effects of natural processes and human impacts on the biogeochemical state that are studied in RU 2 and are addressed below. 1) Seafloor state and variability in the southeastern North Sea; 2) eutrophication and the nitrogen cycle; 3) pollution patterns and pollution source attribution; 4) synthesis, application, outreach. From the *coastMap* app (http://coastmapapp.hzg.de/ ).



### 4.2.1 OVERVIEW

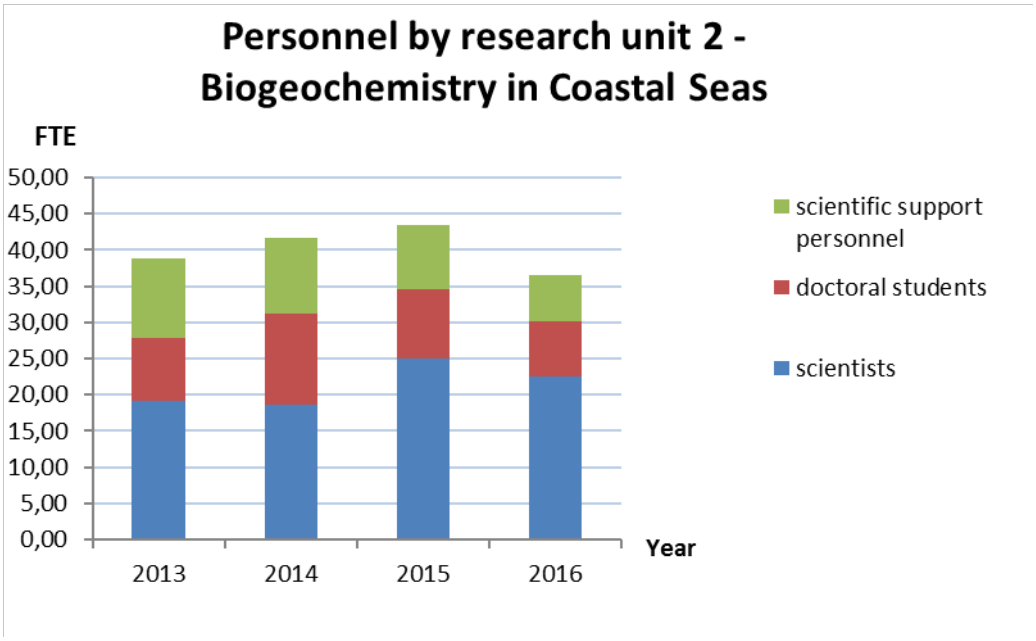



Figure 22: Development of Full Time Equivalent (FTE) Personnel of RU 2. Please see figure 3 for detailed information about the contribution of HZG-Research Units to the Helmholtz-Program PACES II in 2016.

The *Biogeochemistry* Unit of twenty-three full-time scientific staff has three experimental/analytical departments and two departments that employ models. The entire Unit is engaged in work package ***Biogeochemical provinces of seafloors in the German North Sea sector*** of **PACES II Topic 2**. Numerous interfaces exist with the other two Units at the Institute of Coastal Research, ranging from technical (e.g., ***coastDat*** model results and COSYNA instrumentation, data products and model infrastructure) to topical (e.g., the role of wind farms on matter cycles in the North Sea, pollution patterns and dispersal). The Unit was created in 2011 by merging existing groups, following a suggestion by the HGF Senate to strengthen the biogeochemical component of the Institute of Coastal Research. Kay Emeis (currently full professor of Biogeochemistry in Dept. of Geosciences of Universität Hamburg) accepted the director position in a shared-time model that is in effect until February 2021. That arrangement facilitates graduate education at Universität Hamburg and exposure of HZG scientists to teaching. It enables joint research projects and use of facilities, and entrains biogeochemical expertise into Universität Hamburg research structures, such as the Center of Earth System Research and Sustainability (CEN), and the two phases of the Cluster of Excellence CliSAP (*Integrated Climate System Analysis and Prediction*, 2007-2017). At the time of writing, Universität Hamburg has submitted a pre-proposal for an *Exzellenz Strategie* to the German Research Foundation that, in case of success, guarantees continued collaboration between the Institute of Coastal Research, the *Biogeochemistry* Unit, and university research for the next 20 years.



The department of ***Marine Bioanalytical Chemistry*** *(lead: Dr. Daniel Pröfrock)* analyzes elements, their species and their stable isotopes. These are employed to trace sources, transport pathways and sinks of inorganic contaminants and their relationship to processes in the catchments, estuarine and coastal zones. State-of-the-art-sampling techniques and analytical tools are utilized and are continuously developed and improved to allow the accurate determination of target contaminants in different environmental compartments, such as in sediments, water and biota. Development and application of analytical chemistry to environmental research remains attractive for students, and the laboratory accommodates a substantial number of students from partner universities in Germany and abroad. Dr. *Daniel Pröfrock teaches at the Dept. of Chemistry, Universität Hamburg.*

The department for ***Environmental Chemistry*** *(lead: Prof. Ralf Ebinghaus)* focuses on the occurrence, sources, transport, fate and trends of persistent anthropogenic organic pollutants in the coastal and marine environment. Current emphasis is on emerging contaminants such as perfluorinated alkyl substances (PFAS) and alternative flame retardants (FRs). Their occurrence in potential source areas such as in European and Chinese river catchment and coastal areas, and their expanding range towards remote marine as well as polar regions is analyzed as scientific basis for future regulations. A continuing effort embedded in international projects and consortia lies in mercury in the environment. A sub-unit is in charge of monitoring radioactivity in the environment and emission/immission of nuclear power plants within the sovereign mandate of the federal state of Schleswig Holstein. The laboratory has been accredited since 1999 and is financed by the sovereign mandate, as well as by commercial contracts. *Prof. Ralf Ebinghaus teaches at the Leuphana Universität Lüneburg, Faculty for Sustainability Sciences.*

In the department for ***Aquatic Nutrient Cycles*** *(lead: Dr. Jana Friedrich)*, biologists and geoscientists jointly investigate the sources and sinks of nutrients (nitrogen, phosphorus, silicate, carbon) and of oxygen in rivers, estuaries and coastal seas. For process studies on nitrogen turnover and eutrophication, they use natural isotope ratios in nitrogen compounds to trace input and metabolic pathways. Focus lies in the interactions between river catchment and sea, and on water-sediment interactions (pelagic-benthic coupling), which remain a challenge for innovative measurement and *in situ* observations and is a vital contribution to PACES II. Scientists of of this department closely collaborate with the *Observational Systems* Unit in developing underwater technology within COSYNA. *Dr. Justus van Beusekom teaches at Universität Hamburg*.

The department for ***Assessment Modelling of Coastal Systems*** (lead: *Dr. Ulrich Callies*) analyzes model data (RU *System Analysis and Modelling)* to address problems associated with transport in

water and to describe physical forcing in the complex coastal habitat. The department's central project in PACES II is the development of ***coastMap***, a digital inventory and geoportal for the North Sea that collects and merges analytical and numerical model data of other departments to provide integrated data on seafloor characteristics in the form of a Web-GIS (see below; central deliverable to PACES II Topic 2). That portal also curates data from ship campaigns, analytical data from the laboratories of RU *Biogeochemistry* and other RU´s, and serves as a data hub for internal and external projects. Problem-oriented analyses examine risks to good environmental status, for example, to assess the potential deployment of chemical dispersants during a hypothetical oil spill.

Regional atmospheric circulation models of RU *System Analysis and Modelling* combined with an atmospheric chemistry transport model and an emission model are applied by the department ***Chemistry Transport Modelling*** *(lead: Dr. Volker Matthias)* to investigate emissions into, transport through, and deposition of, pollutants, nutrients, and long-lived chemicals from the atmosphere. The model system is used to reconstruct past conditions and scenarios of plausible futures of atmospheric matter fluxes, particularly in the North and Baltic Seas and their coastal regions. Ship emissions have become increasingly important as a source of pollutants in marine environments. Over the few last years, they have been the focus of research on evaluations of management and legislative options. *Dr. Volker Matthias teaches at the Universität Hamburg and at Leuphana Universität Lüneburg; Prof. Markus Quante teaches at Leuphana Universität Lüneburg.*



### 4.2.2 SCIENTIFIC RESULTS AND GOALS

A major thrust of work in RU 2 *Biogeochemistry* over the last few years was to clarify the **role of seafloors in the North Sea** in regard to the exchange of energy, solutes and gases with the water column, their state of pollution, and the role of physical forcing on variations in these properties. Corresponding Work Package 4 *Biogeochemical Provinces of Seafloors in the German North Sea Sector* of PACES II Topic 2 was, on the one hand, motivated by the wave of activities related to offshore wind farm construction in the North Sea. On the other hand, it was prompted by the need to describe and index good environmental status (GES) for the German EEZ in the North Sea as stipulated by national and international legislation (EU Water Framework Directive/WFD; EU Marine Strategy Framework Directive/ MSFD). Although the North Sea likely ranks among the most studied shelf seas on Earth, the status and role of seafloors as active compartments in matter cycling was little known. GES assessment of the seafloor (Descriptor 6 of the MSFD) lacked an empirical basis, as human activity during the past few decades has directly (through fishing, construction, aggregate extraction, waste deposition) or indirectly (through eutrophication, pollution) changed the benthic status, and information was scattered. An additional motive was to create the empirical basis for better including seafloors as active compartments into matter cycles described by regional Earth system models. The work combines dedicated observations of benthic processes; mapping of characteristics and sensitivities of the complex coastal habitat (***coastMap****);* and model-based information on the mean and variability of marine conditions influenced by tides and atmospheric forcing. In terms of observed data, the focus lies in sediment analyses and data from various ship campaigns, in part using COSYNA underwater technology with RU 3 *Operational Systems* (e.g., landers, sliders). In terms of modeling, research draws on existing long-term reconstructions of environmental conditions (***coastDat***), mostly generated in the context of climate research in RU 1 *Systems Analysis and Modeling*.

Pollution and eutrophication are overarching topics in work of RU *Biogeochemistry*, are transboundary issues, and are global in scope. Legacy pollutants that are regulated, in Europe or internationally, continue to pose environmental problems in countries with less well-developed environmental standards. Production facilities simply move elsewhere in response to economic or environmental pressures. Similarly, excess nutrients are transported across borders via rivers, currents, or the atmosphere. This highlights the need for transboundary research that investigates sources and/or processing of pollutants beyond individual coastal regions and across political borders. In line with this need, work in RU *Biogeochemistry* focuses on (a) regional systems that serve as models for pollutant turnover, transformation and storage, and (b) on elucidating sources and

transport of various species of pollutants beyond the coastal zone and globally. Particularly close ties exist with colleagues and institutions in China, most notably with the *Institute of Coastal Zone Research* of the Chinese Academy of Sciences located in Yantai, China. These collaborations are attractive and fruitful due to striking commonalities and differences in economic, environmental, monitoring and legislative evolution in both China and Germany (as part of Europe). The following examples illustrate main areas of research and achievements in RU *Biogeochemistry*.

## Seafloor state and variability in the southeastern North Sea

Milestones are newly compiled data sets that integrate observations and models of conditions at the seafloor and seafloor properties – a central objective in Topic 2 of PACES II. The starting point was to classify sediments in the German EEZ (and in the North Sea) in terms of grain size and organic carbon concentrations. To a first approximation sediment texture expresses energy at the seafloor and sub-seafloor geology and integrates effects of material delivery and activity of benthic organisms. Organic carbon (TOC) is often concentrated in fine sediment fractions, which have large surface areas and ligands that promote binding of inorganic and organic pollutants; it is also the fuel for diagenesis that causes fluxes of solutes and gases between sediment and the water column. Surface sediment distribution in the North Sea has been re-assessed based on a new compilation and re-calculation of median grain size of more than 40,000 seabed samples in more than one hundred individual data sets by kriging, with water depth as an external determinant (Bockelmann et al., 2017) (Figure 23a) errors have also been estimated. Concurrently, an interpolated map of weight % TOC has been compiled and interpolated by kriging based on approximately three thousand analyses, using fraction of mud as an external variable (Figure 23b).



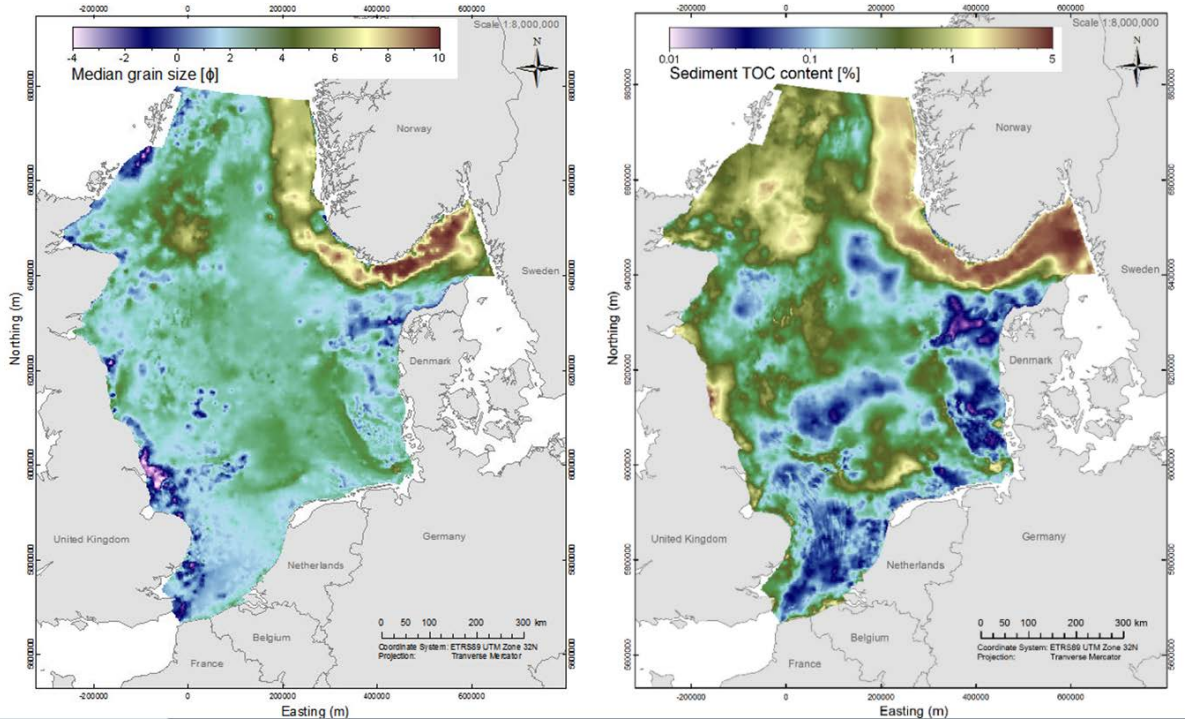



Figure 23a (left): Median grain-size ($D_{50}$) of North Sea surface sedminents predicted by kriging with external drift using log10 (mud%) as trend variable. The underlying data set consists of 40,000 seabed samples in more than one hundred individual data sets. The scale ranges between -4 φ (gravel) and 10 φ (clay) (Bockelmann et al., 2017). Figure 23b (right): Organic carbon concentrations of surface sediment in the North Sea predicted by kriging with external drift using log10 (mud%) as trend variable. Note that the scale is logarithmic (Bockelmann et al., unpublished).

Distribution of sediments (and, in part, of organic carbon and particle-bound pollutants) reflects energy at the seafloor that is time-variable, as are properties of bottom water such as salinity and temperature. To constrain the spatial and temporal variability in these important properties (in the face of sparse observational data), a multi-year (1984-2015) integration of the 3D hydrodynamic

model TRIM (currents) and wave model (WAM) (currently in three spatial resolutions, cooperation with ***coastDat*** of RU 1) provides time- and space-resolved estimates of physical conditions at the seafloor via a web interface. This interface offers data visualization and retrieval to non-modelers (www.coastmap.org). The pertinent data for our purposes include salinity and temperature, and energy at the seafloor (means and extremes). Salinity and temperature are relevant predictors for epi-benthic communities (Neumann et al., 2017a), and the shear stress by combined currents and wave action at the seafloor controls sediment texture, sediment remobilisation, bedform types, character, and frequency of occurrence. These bedforms, in turn, set the level at which solute exchange between sediment and bottom water changes from diffusive (slow exchange rates) to advective (fast exchange rates) fluxes. Permeability and bottom energy thus determine the modes and intensity of solute and particle fluxes at the sediment-water interface. A study by Neumann et al. (2017b) created a high-resolution permeability map of the sediment in the German Bight (North Sea); that permeability map and observed nitrate penetration depths were then used to estimate the denitrification potential in German Bight sediments (Neumann et al., 2017c).

Ongoing work upscales benthic fluxes of solutes and gases established by seasonally resolved measurements of oxygen (Ahmerkamp et al., 2017) and nitrate consumption (Deek et al., 2013; Neumann et al., 2017c) for the entire EEZ (Figure 24). These measurements were performed at locations in the German Bight that have substrate properties representative for the entire EEZ, as determined by a statistical evaluation of grain size and TOC properties, or from comparable settings (Dähnke et al., 2012; Dähnke and Thamdrup, 2016; Dähnke and Thamdrup, 2013). Organic matter reactivity is an important determinant of diagenetic rates and has been analyzed for representative seafloor sediment types (Serna et al., 2014). The upscaling of spot measurements of benthic fluxes is done in collaboration with the *Ecosystem Modelling* department of RU 1. Ongoing work of calibrating the OMEXDIA diagenesis model in the modular setup with observation data (Kerimoglu et al., 2017) will rectify model shortcomings apparent in the differences between observations and data (Figure 24), and will then enable the final step towards generating contiguous and seasonally resolved data set of seafloor fluxes. This is an important deliverable to *Work Package 4 Biogeochemical Provinces of Seafloors in the German North Sea Sector* in Topic 2 of PACES II. Congruent studies were conducted on the NW Black Sea shelf and on the shelf of the Benguela upwelling system.

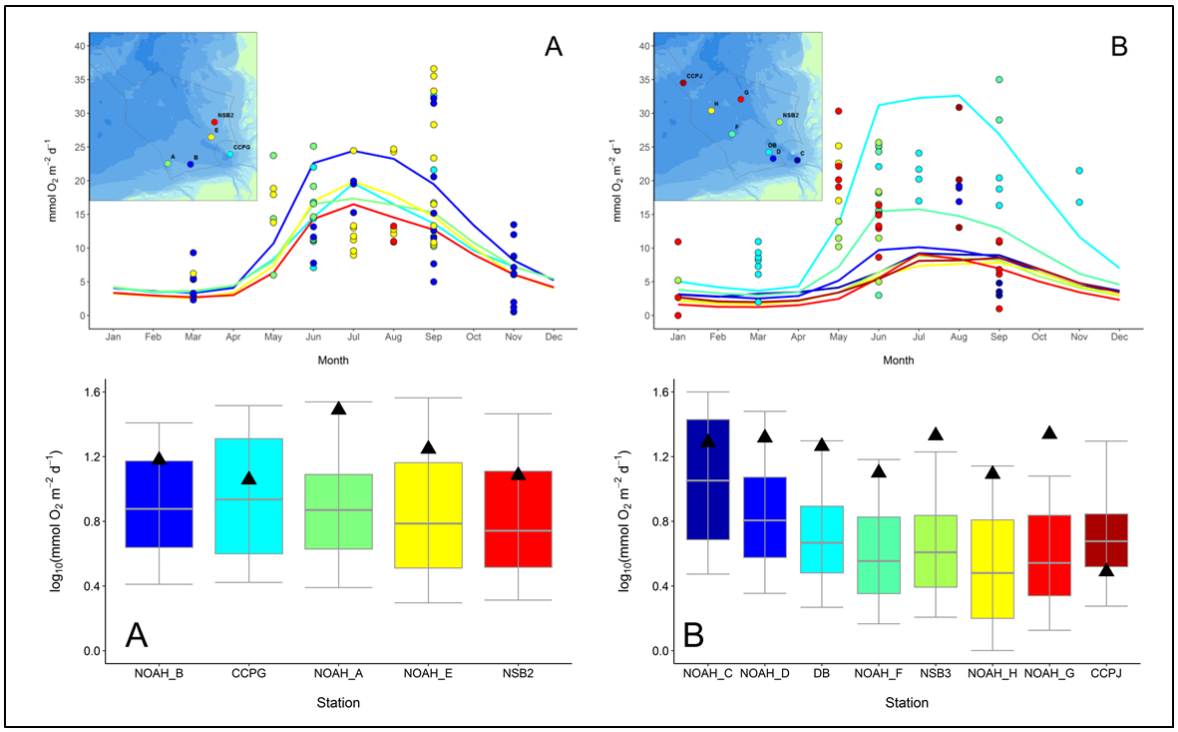



Figure 24: Lineplots A, B: Seasonal variability of total benthic oxygen consumption rates in A) permeable and B) impermeable sediments of reference areas (map inlays for geographic locations and color codings). Compared are data derived from in situ measurements (filled circles) and model results (lines). Observations (n=157) have been taken by benthic lander deployments between 2012 and 2016 (J. Friedrich, unpublished data). The model output has been obtained using the OMEXDIA_P early diagenetic model implemented within the MOSSCO framework (www.mossco.de) (K. Wirtz/RU 1, unpublished). The model data has a temporal resolution of 36 hours sampled between 2009 and 2014 (n=1420). Boxplots: Statistical distributions of total benthic oxygen consumption rates obtained from the OMEXDIA_P (MOSSCO) model results for A) permeable and B) impermeable sediments. Also shown, for comparison, are the medians of the in situ measurements (black triangles) taken in each NOAH reference area between 2012 and 2016 (J. Friedrich, unpublished data). Please note that the data is presented on a log10-scale.

Much of the work toward the deliverables for the habitat map takes the form of repeat ship-based measurements (seasons and shorter) at locations chosen to represent larger seafloor areas. There are also surprises: A series of multibeam bathymetry surveys performed in the course of regular visits to the nine working areas selected to represent typical seafloors in the EEZ revealed the emergence of a large pockmark field characteristic for the release of large quantities of gas from the sediment in the southeastern North Sea (Figure 25). Covering an area of around 915 km$^2$, up to 1,200 pockmarks per square kilometer have been identified. The time of emergence can be confined to three months in autumn 2015, suggesting a very dynamic genesis. Subseafloor structures and high methane concentrations of up to 30 µmol/l in sediment pore water samples suggest a source of shallow biogenic methane from the decomposition of post-glacial deposits in a paleo-river valley. Storm waves suggest the final trigger for the gas eruption. Conservative estimates amount to 5 kt of methane, equivalent to 67% of the annual release from the entire North Sea (Krämer et al., 2017). These observations likely describe a reoccurring phenomenon in shallow shelf seas, which may have been overlooked before due to the transient nature of shallow water bedforms and technological limitations of high resolution bathymetric mapping. An interesting and highly relevant aspect is that the transient pockmark field extends into an area of wind farm construction.

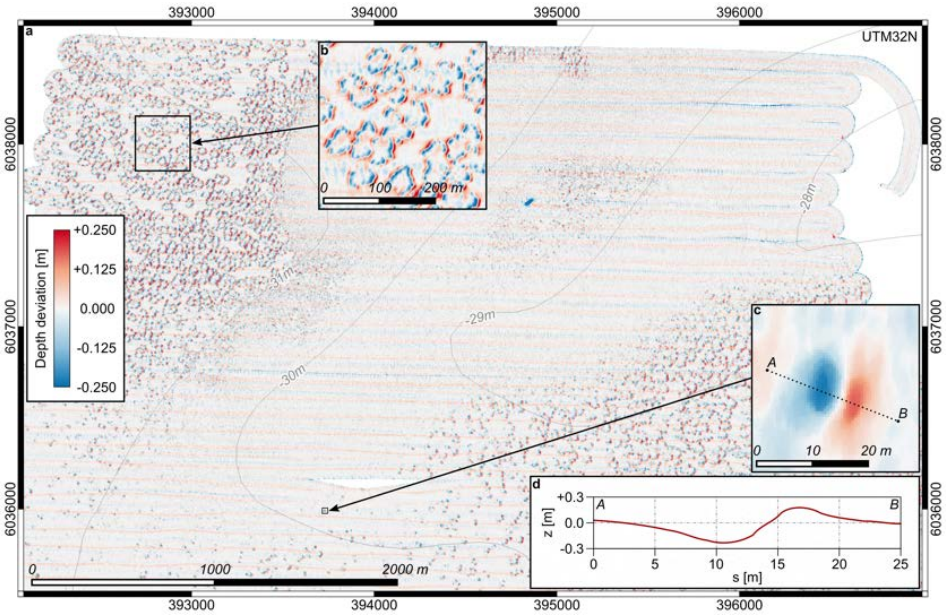



Figure 25: Pockmark density and morphology. (a) Zero-median bathymetry with full seafloor coverage from cruise HE470, August 2016. (b) Detail of pockmark cluster. (c) Detail of an individual pockmark. (d) Cross section along transect A–B. From Krämer et al. (2017).

## Eutrophication and the nitrogen cycle

A central objective of work in the *Biogeochemistry* Unit towards PACES II objectives is to clarify processes that intensify the eutrophication and pollution status (such as the accumulation of organic matter), and those that alleviate the pressure on the ecological status (e.g., denitrification). Significant effort was devoted to analyses of the contemporaneous and past nitrogen cycle in rivers, the atmosphere, and sea floors in the North Sea and other regions (e.g., Benguela System, Black Sea, Arabian Sea, Yellow Sea and Bohai).

A significant source of reactive nitrogen in the North Sea is rivers discharging into the German Bight (Schlarbaum et al., 2011; Serna et al., 2010). Tell-tale isotopic tracers in surface sediment of the German Bight mark the halo of river nitrate (Figure 26). The ratio of two stable isotopes ($^{14}N$, $^{15}N$; expressed as $\delta^{15}N$ relative to air $N_2$ = 0‰) in sediments reflects the origin and history of nitrogen in the water column. Sedimentary nitrogen traces the $\delta^{15}N$ of dissolved nitrate and sedimenting organic matter. In the German Bight and EEZ, the dissolved nitrate originates from two main sources: Nitrate discharged by rivers draining cultivated catchments has high $\delta^{15}N$ values (~ 9‰) characteristic of river loads causing eutrophication of coastal areas. Nitrate in water masses of Atlantic origin advected into the German Bight has low $\delta^{15}N$ values (~5‰). The map of $\delta^{15}N$ values in surface sediments (0-1 cm) collected in the German Bight and German EEZ depicts the halo of high $\delta^{15}N$ resulting from river nitrate (Figure 26).

Environmental legislation has resulted in steadily decreasing river loads over the last several years (Emeis et al., 2015), with partially surprising and unforeseen results illuminated by isotopic indicators: Although river loads from the catchment decrease, and although part of the load is denitrified in the reactive sediments (Deek et al., 2013), enhanced riverine biomass production (enabled by more favorable light climate and a reduced toxicity) results in high nitrification rates and associated oxygen draw-down in Hamburg harbour. Nitrification increases the nitrate generated in the estuary to levels of up to 100% of river concentrations during summer months (Sanders et al., 2017) and also contributes substantially to nitrate loads in the estuary (Jacob et al., 2016). The processes of nitrification and denitrification both generate $N_2O$ as a by-product. $N_2O$ production pathways in the freshwater estuary changed from predominant denitrification in the 1980s towards significant production from nitrification at present. Despite a steady decrease of DIN inputs over the last decades, $N_2O$ emissions remain on a level that is comparable to the mid-1990s (Brase et al., 2017).

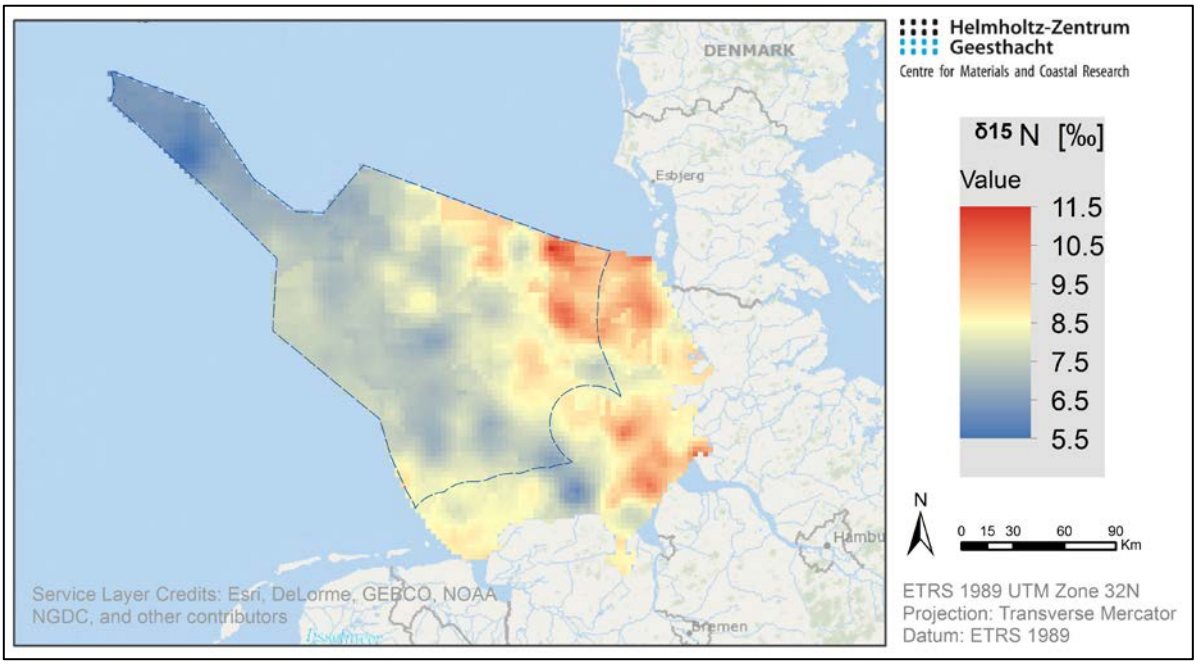



Figure 26: A map of $\delta^{15}N$ in surface sediments of the German EEZ outlines the halo of riverborne nitrate possessing high $\delta^{15}N$ values indicative of agricultural and industrial sources. The map has been compiled from numerous data sets gathered by B.Sc. and M.Sc. students in the course of their theses at Universität Hamburg and HZG. It is one of the digital maps in the Habitat Atlas (www.noah-project.de) (see below).

The reduction of nutrient riverine sources to the coastal environment is well under way, but other pollutant sources have moved into focus. One such source is shipping emissions. These emissions are targeted for reduction in a common agreement among the North and Baltic Sea riparian states. Newly built ships must comply with much more stringent regulations concerning nitrogen oxide ($NO_x$) emissions starting in 2021. Based on a detailed shipping emission inventory, the impact of shipping on current air quality has been investigated with the chemistry transport model system CMAQ (Aulinger et al., 2016). In addition, six different scenarios for the development of technologies and the legal framework for shipping in the North Sea area were generated, and the consequences for air quality in 2030 have been analyzed (Matthias et al., 2016). It found that, due to the slow reduction of specific emissions (per ton of fuel) and the expected further increase in shipping activities, the atmospheric concentrations of nitrogen oxides in 2030 will remain at the 2008 level. Only when most shipping vessels are built according to stringent $NO_x$ regulations will their contribution to air pollution be significantly reduced (Figure 27).

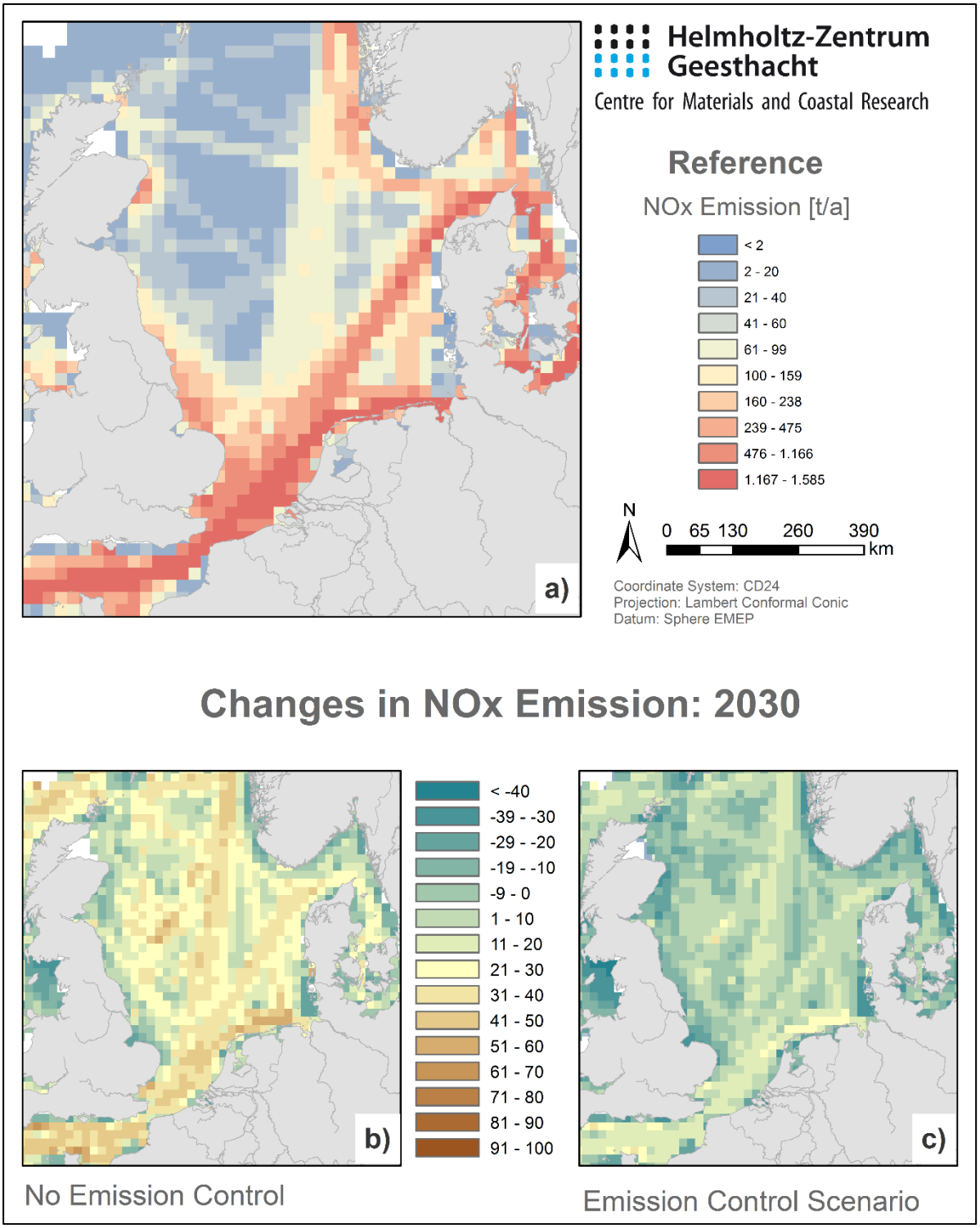



Figure 27: $NO_x$ emissions from shipping in 2008 (a: reference case); scenario for modeled emission changes until 2030 where no emission control is implemented (b: no ECA); scenario where all new ships must comply with more stringent emission limits from 2021 onwards (c: ECA SCR21).

In addition to ship traffic, an atmospheric source of reactive nitrogen to the German Bight is land emission to the atmosphere and advection to the sea. These two sources are isotopically distinct, and have been segregated by combining observational and modeling data (Beyn et al., 2015; Beyn et al., 2014) and have been inventoried (Aulinger et al., 2016; Backes et al., 2016a). More than 90% of all ammonia emissions into the atmosphere stem from agriculture, particularly from manure

management and fertilization. Ammonia is an important reaction partner in the atmosphere that, in combination with sulfur dioxide and nitrogen oxide emissions from other sources (shipping), triggers the formation of very small particles. By considering animal densities, meteorological conditions and existing regulations on animal husbandry and fertilizer application, significantly improved knowledge on the temporal distribution of ammonia emissions in Central Europe is now available (Backes et al., 2016a). The use of the new emission inventory in CMAQ substantially improved representation of atmospheric ammonia and particulate ammonium concentrations. Subsequently, three ammonia emission abatement strategies were analyzed using the model to evaluate their influence on future atmospheric particle formation (Figure 28). Results showed that reductions in meat production have the largest positive impact on particle formation in northern Europe (Backes et al., 2016b).



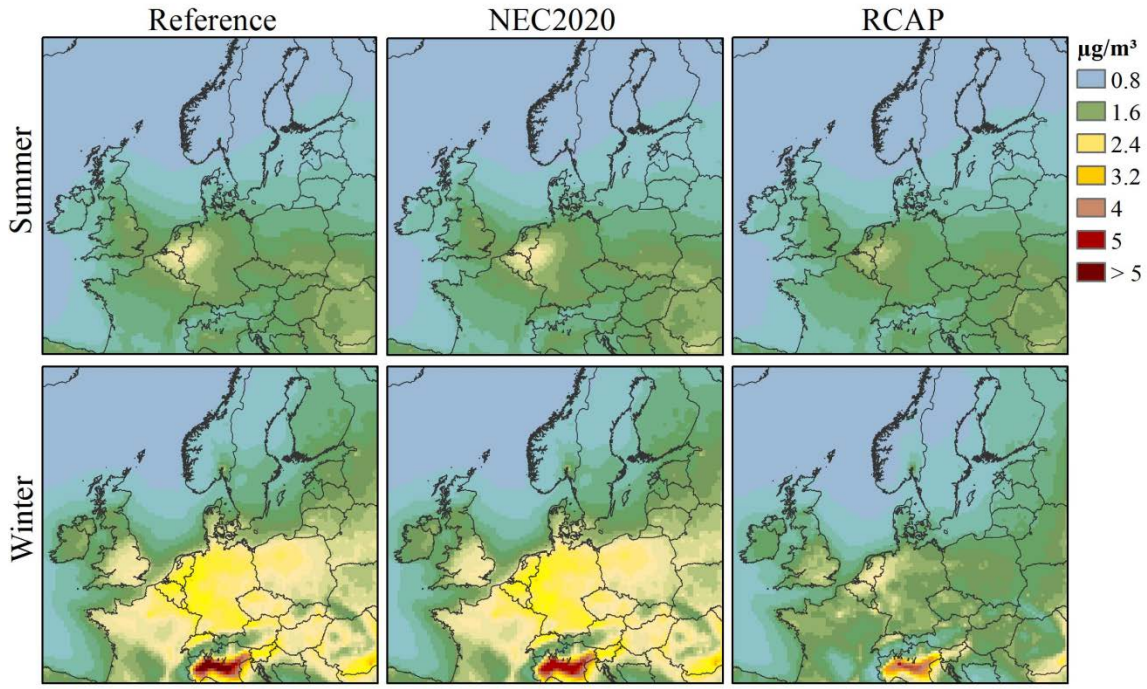



Figure 28: $NH_4^+$ (PM2.5) concentration in the reference case and in two scenarios formulated based on regulation options for ammonia emissions in Europe. The modeled reduction is shown in µg/m³ for winter and summer seasons (Backes et al., 2016b).

## Pollution patterns and pollution source attribution

One of the central questions is where pollution originates, for example as a precondition for managing the sources. The utilization of multi-element fingerprints and isotopic signatures allows to trace origins and transport pathways and to distinguish between natural and anthropogenic sources. Mapping fifty elements and isotopic variations of Sr, Pb, Mo and B commenced in 2014 in the EEZ as part of work in PACES II, including in the German Wadden Sea and the Elbe, Weser, Ems and Rhine rivers. Aquatic isoscapes were created using a Geographical Information System by relating spatial isotopic data with geographical and geological maps. The elemental and isotopic distribution maps show a large variation for different parameters and also reflect the numerous impact factors (e.g., geology, anthropogenic sources) influencing the entire catchment area. Non-traditional isotope systems such as that of Ti are explored to elucidate if isotope fingerprints can be attributed to different possible sources, such as in $TiO_2$ nanoparticles (Reese et al., 2017; Retzmann et al., submitted; Soto-Alvaredo et al., 2016). Currently, possible pollution from anodes protecting offshore wind turbines against corrosion is explored, using their characteristic elemental and isotopic signatures.

A second example of practical relevance is the use of stable isotope fingerprinting for source identification of liquid mud in estuaries – a universal problem for all harbors in Europe. Since the last deepening of the ship channel in the Elbe estuary, Hamburg Port experienced growing oxygen minima and increased suspended and bed loads. One issue in the debate on further deepening the estuary is the risk that it may be pushed into a hyperturbid state. Sofar, however, the origin of material requiring steadily increasing maintenance dredging and offshore dumping has been elusive. Stable isotope fingerprinting suggests that a significant share of surface sediment in the harbor originates from the North Sea (Figure 29), underscoring the need for new concepts for sediment management in step with planning waterways development (Irrgeher et al., in preparation).



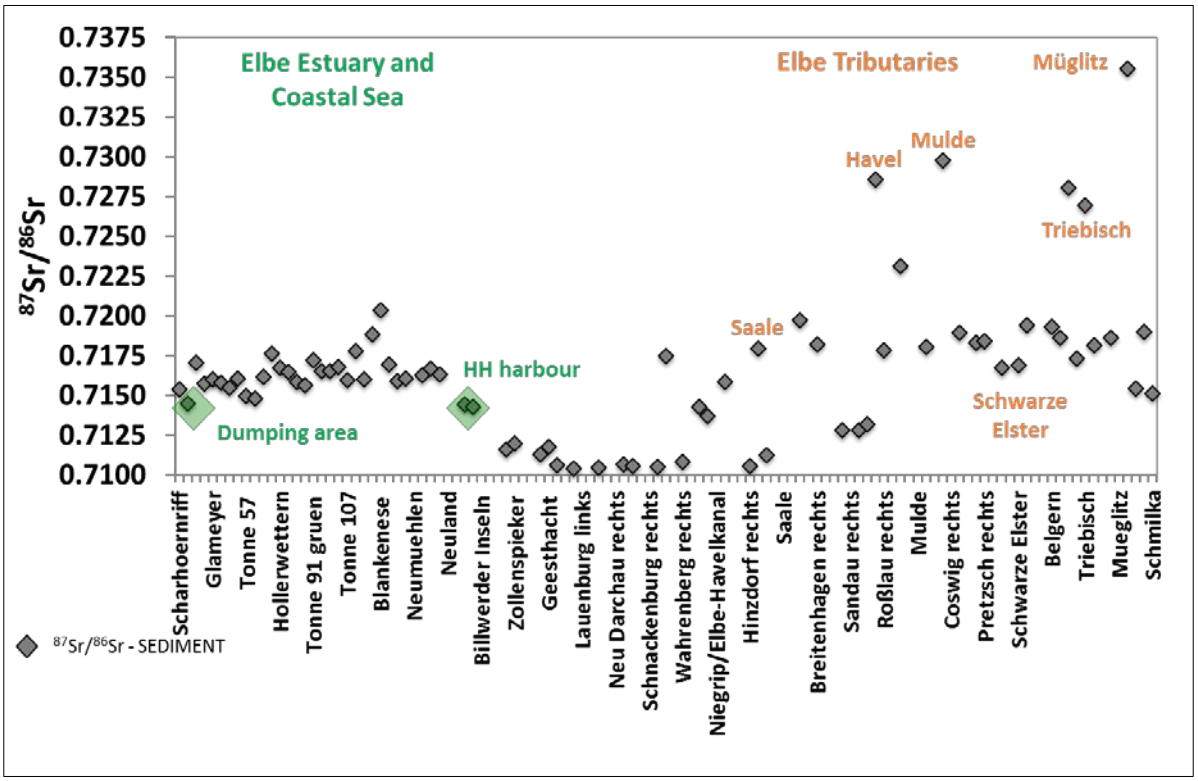



Figure 29: Sr-isotope ratios in surface sediments and water along the course of the Elbe River and its tributaries. Sediment ratios are high in tributaries, low in Hamburg Port samples and increase in the tidal estuary towards the open sea, indicative of import of marine sediments into the estuary. Green diamonds indicate Sr-isotope ratios in the harbor and in a dredge spoil dumping area offshore.

Topic 2

***Highlight: Global Mercury Observation System***

This activity is based on a long tradition of collaboration with international partners. In support of the UNEP Minamata Convention on Mercury and within the framework of the FP7, the EU financed a large-scale integrated project, the *Global Mercury Observation System (GMOS)*. Research aircraft as well as a Lufthansa passenger aircraft (A340-400) have been used to measure the horizontal and vertical distribution of mercury in the global atmosphere. Within GMOS, RU 2 was responsible for the work-package on all aircraft-based measurements and regional modeling, including mercury measurements within the project *Civil aircraft for the regular investigation of the atmosphere based on an instrumented container (CARIBIC)*, coordinated by MPI for Chemistry in Mainz, Germany. Within CARIBIC, the Unit carried out mercury measurements during 390 long-haul flights, covering 3200 flight hours and three million kilometers flight distance. These measurements resulted in the detection and localization of around one hundred large-scale pollution plumes in the global upper troposphere. Based on the wealth of data, source identification (industrial vs. biomass burning) and apportionment (regional) was carried out (Weigelt et al., 2016, 2016b). Generally, it was shown that the major industrial sources are located in East Asia, Pakistan and India, whereas major contributions to mercury emissions from biomass burning are located in Equatorial Africa (Rift Valley) and the Amazon region. Vertical profiles of experimental and CARIBIC flights have been combined to reveal the first complete mercury data set covering the entire tropospheric column, from 250 – 10,000 m altitude (Weigelt et al., 2016a). Published data sets have been applied by HZG modelers (regional and scenarios) (Bieser et al., 2016) as well as international teams, including EMEP MSC-East, Harvard University and MIT (global; emissions) (Song et al., 2015).

As is the case with heavy metals and river nutrient loads, North Sea pollution levels of legacy **organic contaminants** are decreasing. But a multitude of new substances and substance classes are continuously released into the environment, many of which possess all the characteristics of being candidates for regulation: persistence, bio-accumulation potential, toxicity and susceptibility to long-range transport (PBT substances). Flame retardants (FRs) are one of these high-production volume chemicals that are used in myriads of products and goods to reduce their inflammability. Among the halogenated FRs, polybrominated diphenyl ethers (PBDEs) are the most prominent example. Due to their well-known adverse effects on human and environmental health, many PBDEs have been regulated under the Stockholm Convention, resulting in a market-demand for other, non-regulated FRs. Among those replacement substances (alternative flame retardants, aFRs) is Dechlorane Plus, a highly chlorinated compound, and a variety of organophosphorus esters (OPFRs) that are raising equal or even greater concern than the substances they replaced.

Together with Chinese institutions HZG has carried out comprehensive research on the sources, occurrence, fate and transport of aFRs in the coastal, marine and polar environment. This has demonstrated that aFRs are ubiquitous in the global marine atmosphere and in seawater and that several aFRs have long-range transport potential towards Polar Regions (Suhring et al., 2016b; Wolschke et al., 2015). The main source regions that emit aFRs into the marine atmospheric environment are Southeast Asia and Europe, but also Africa. In the North Sea, Dechlorane Plus is the most abundant aFR in German North Sea sediments – although it has never been produced in Europe (Suhring et al., 2015). This problematic substance accumulates to a very high degree in European and American eels, can be remobilized during the maturing process to silver eels, and is redistributed into their gonads and eggs (Suhring et al., 2016a). Clearly, Dechlorane Plus with its documated PBT properties and similarity to highly brominated PBDEs should not be considered a suitable alternative to regulated and banned flame retardants and is thus a candidate for the Stockholm Convention.

Topic 2

***Highlight: Global patterns of poly- and perfluorinated alkyl substances (PFAS).***

PFAS are another group of industrial and consumer chemicals that have been and are still widely applied for an enormous variety of different purposes, such as surface treatment, Teflon production, impregnation of outdoor gear and many others. They are characterized by their extreme persistence and potential for bioaccumulation. Some of them, namely organic acids (PFOA), have been detected in remote and polar environments, although they have almost no volatility and very limited water-solubility, and it had been unclear how these substances could be transported over global distances in such a short time. Regulations in Europe and the U.S. have led to the transfer of production volumes to Asia, in particular to China. Comprehensive analyses of sources, occurrence, fate and transport of PFAS in the coastal, marine and polar environments carried out by RU *Biogeochemistry* together with scientists from China demonstrated that long-range transport of volatile precursor compounds is involved in the rapid occurrence of ionic PFAS in remote and polar environments. In polar areas, air-snow exchange processes can exceed the relevance of atmospheric deposition and explain polar distribution patterns that do not follow atmospheric concentration values (Xie et al., 2015). Whereas regulated PFAS constantly decline in environmental concentrations in European coastal systems (Zhao et al., 2015), they rapidly increase in Chinese river systems (Figure 30). At the same time, non-regulated alternatives such as ADONA (Ammonium 4,8-dioxa-3H-Perfluorononanoate) and GenX concentrations rapidly increase both in European and Chinese river systems, but with much higher levels in China (Heydebreck et al., 2015).

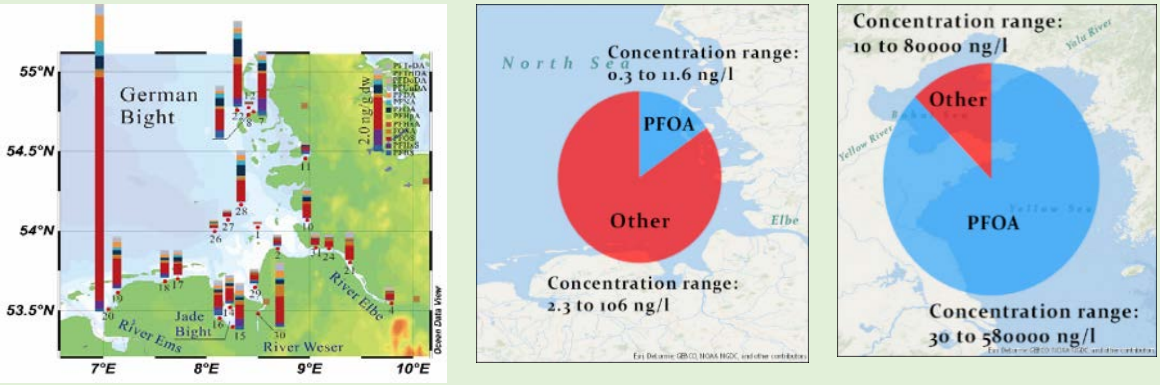



Figure 30: Distribution of PFAS in German Bight sediments (left; Zhao et al., 2014) and relative ratios of regulated PFOA vs. alternative PFAS in German (left) vs. Chinese Coastal waters (right) (Heydebreck et al., 2015).

Heydebreck et al. (2016) were the first to analyse how changes in industrial production triggered by national and international regulations influence emissions into the environment as well as how they influence textile workers to esposure of such emissions in a large Chinese textile manufacturing plant. These compounds are also source-specific: PFAS have very different distributions in different environmental compartments, and changes in industrial production result in changes in substance and compartmental patterns.

## Pollution transport models

Important agents in the dispersal of pollutants in the coastal ocean are **transports in the sea**, and here – as in atmospheric transport modeling – the benefits of collaboration with modelling groups in the Institute of Coastal Research and the societal benefits are best demonstrated. Specific problem-oriented analyses, related to public interest and political debate, examined the potential deployment of chemical dispersants in case of an oil spill in the German Bight's coastal waters (Figure 31) (Schwichtenberg et al., 2017) and of marine litter dispersion (Neumann et al., 2014).

Topic 2

***Highlight: Model assessments for environmental management***

Modeling in RU 2 informs policy and management decisions. Our aim here is to provide scientific information needed to improve societal preparedness for changes in the marine environment. Several approaches scientifically underpin national and international efforts to prevent environmental damages to coastal ecosystems.

One controversial issue is the potential use of **chemical dispersants** in German coastal waters. Facilitating the formation of small oil droplets, dispersants help dissolve a drifting oil slick by mixing it into the underlying water column. This process substantially changes oil drift paths. Drift simulations from model-based, long-term reconstructions of met-ocean conditions led to the development of a map that indicates where it is likely that chemical dispersant application could prevent drifting oil from entering the Wadden Sea. The study was designed in close collaboration with the German Central Command for Maritime Emergencies (Havariekommando). Results are implemented by authorities that provide operational services (BSH) (Schwichtenberg et al., 2017).

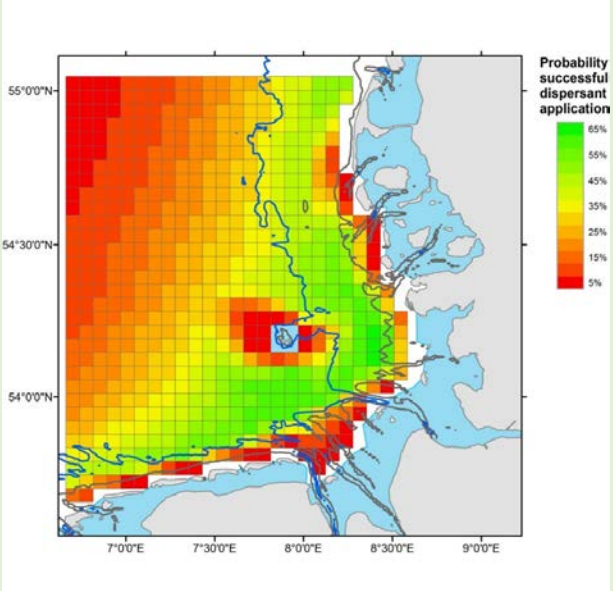



Figure 31: Probabilities for applying a 100% effective dispersant directly after an oil spill would reduce the amount of oil entering sensitive coastal areas by at least 95%. The grey (blue) line indicates the 10m (20m) depth line.

Models are also the tool of choice for scenario-based evaluations of management and management options, for example in the context of **increasing sea traffic,** as described above. Models thus are indispensable to gauge effects of management decisions in advance of implementation.

The former study focused on the influence of dispersion on oil drift behavior, studying millions of hypothetical accidents. It thereby prepared the foundation for a more comprehensive net environmental benefit analysis (NEBA). An innovative aspect of research directed at environmental management is the use of probabilistic tools to bridge the gap between detailed simulations related to specific field studies and the assessment of more long-term conditions, including natural variability. In particular, graphical methods are explored for conveying a clear picture of how different variables interact or influence each other. Such methods comprise analyses of covariance matrices structures (Callies and Scharfe, 2015) and Bayesian networks (BNs) (Stelzenmüller et al., 2015). An example a BN referring to the problem of chronic oil pollution is made available online (http://codm.hzg.de/OilDriftingGUI/). Transports in the sea also must be taken into account when gauging how representative the biological *in situ* observations are, as for instance at the long-term time-series station on the island of Helgoland, operated by our AWI partners in Topic 2. Much of the observed environmental short- and long-term variability there can be attributed to different weather patterns and advected water masses (Callies and Scharfe, 2015; Lucas et al., 2016).

## Leadership in international research consortia and international cooperation

Scientists in RU *Biogeochemistry* take active roles in international research projects and collaborate with institutions worldwide. The RU Biogeochemistry and HZG hosted the International Project Office of LOICZ (*Land-Ocean-Interactions in the Coastal Zone*) for 10 years until it moved to the University College Cork, Ireland, and became *Future Earth Coasts* in 2015. Current international projects (>200,000 EUR funding) include DANUBIUS-PP (preparatory phase for the pan-European Research Infrastructure DANUBIUS–RI, *The International Centre for advanced studies on river-sea systems*) (2016-2019); SHEBA (*Sustainable Shipping and Environment in the Baltic Sea region*) (2015-2018); CLINSH (*Clean Inland Shipping*) (2016-2020). Past examples are GMOS (*Global Mercury Observation Assessment*) (2010-2015); and CNSS (Clean North Sea Shipping) (2010-2013). RU *Biogeochemistry* scientists also maintain intense and productive collaborations with international partners and have visible roles in several EU projects (*ERAPlanet*) and programs within the Helmholtz Association, such as *Digital Earth* (North Sea) and *Earth System Modelling*, and in national cooperative research projects.

Of particular strategic importance are joint activities between Unit *Biogeochemistry* and the *Yantai Institute of Coastal Zone Research in China* (YIC; Chinese Academy of Sciences). HZG and YIC formalized cooperation in a bilateral agreement that dates back to 2007. It was the start of scientific exchange, numerous scientific visits, joint workshops and conferences, and capacity building on the subject of matter cycles in coastal seas. The appreciation of collaborations with leading institutions in China is expressed in invited visiting professorships of Prof. Ralf Ebinghaus and Dr. Zhiyong Xie at leading Chinese institutions. FINBOYEL (Anthropogenic Fingerprints in Bohai and Yellow Sea), a project under the SINO-German Cooperation, has been initialized in 2017 and will facilitate continued scientific exchange in the field of marine bioanalytical and environmental chemistry.

Scientists of RU *Biogeochemistry* took leadership in providing policy advice in support of international conventions (Minamata Convention on Mercury; Stockholm Convention on Persistent Organic Pollutants) and legislation (Marine Strategy Framework Directive/MSFD; EU Water Framework Directive/WFD; and International Maritime Organisation/MARPOL). Prof. Marcus Quante coordinated an international network of climate experts that brought together existing knowledge on climate change in the North Sea region (NOSSCA) (Quante and Colijn, 2016).

## Knowledge transfer: Syntheses, application, outreach

Research activities of RU 2 *Biogeochemistry* are the starting point for scientific information channelled into knowledge for environmental management (e.g., to define good environmental status or to examine management options, see highlight above). These activities were often co-designed with government authorities and institutions in need of scientific assistance. To be effective requires that knowledge must be tailored for diverse user groups. In this regard, *expert* knowledge is different from knowledge created for *non-professionals* or the *interested public*. A newly launched (September 2017) ***coastMap*** portal uses IT functionalities to provide diverse users with data and information on spatially and temporally resolved seafloor conditions and conditions in the overlying water column. ***coastMap*** is designed as the marine geoportal of the Research Unit *Biogeochemistry* and is a sibling to HZG´s existing work in the coastal ocean: COSYNA (Unit *Operational Systems*) and ***coastDat*** (Unit *System Analysis and Modeling*). In the near future, the three systems of the Institute of Coastal Research will be merged into a common portal.

Topic 2

***Highlight: The marine geoportal coastMap***

***coastMap*** is the marine geoportal of the Institute of Coastal Research. It combines analyses and model data relevant to seafloor conditions and those in the overlying water column with a focus on the North Sea. Components are 1) *open-access to data* collected in our own and partners´ field and laboratory work in a searchable, relational database, and including a convenient workflow with the PANGAEA World Data Center for obtaining a DOI for data sets. 2) a user-friendly (target users are non-modelers) interface for *visualizing and extracting data from model data sets*. This interface uses an innovative array database management system for optimized querying of model data sets and is linked to a geographical information system (GIS). The Map Gallery provides a compilation of various thematic maps produced in ongoing and future projects. 3) *Spotlights* are scientific information in the form of short digests of scientific topics that are augmented by map and informational material. The *Spotlight* contents link directly to the access of data and visualization within ***coastMap***, and are targeted towards the public. The portal was launched in 10/2017 (www.coastmap.org). It is the central and growing contribution of RU *Biogeochemistry* to PACES II.



***coastMap*** users and visitors can search and download existing geodata from the HZG and its partner institutions. They can generate or download data-based (model- and campaign-based) information products. *Experts* can use a relational database for ship campaign and analytical data originating from our work and that of our partners. Implemented in this functionality is a seamless workflow for submitting data sets to PANGAEA and obtaining a DOI. Via an interactive data and analytic tool, *non-professionals* can use a variety of HZG model data. The model analysis tool is based on the raster data manager (rasdaman). Rasdaman is an array database management system for optimized processing of large-scale statistics, respectively model data. The array analytics engine allows fast querying of massive multi-dimensional arrays by building *datacubes*, which can reach petabyte size. This big-data technology permits rapid data access, and analyzes and is linked to functionalities of a geographical information system (GIS) that comprises user-friendly data downloads (gridded data and GIS shape files). ***coastMap*** will be home of the Habitat Atlas (http://www.noah-project.de) that is currently hosted by the NOAH (*North Sea Observation Assessment of Habitats*) project website at HZG that collates results of national partners in this project. It will offer a portal to share data and models in future projects of the Institute of Coastal Research and external cooperations.

Matters of marine and environmental relevance have stimulated increasing interest by media and the public, but biogeochemical issues are not easily communicated and often require extra effort to highlight the nature and relevance of scientific work. This is a significant challenge, but progress in bridging the gap from scientific data to information is key. In addition to data access and visualization of data and models as pillars of ***coastMap***, the *interested public* can delve into so-called *Spotlights*. This rubric is an outlet for information on topics of interest in the work of RU *Biogeochemistry* and conveys what those topics and work actually mean. *Spotlights* serve to digest and structure topical scientific information originating from the work in our Unit. Integrated into this information function is a web-based introduction to the RU *Biogeochemistry* research portfolio, the so-called ***coastMap*** app (http://coastmapapp.hzg.de/). This app was designed and developed in collaboration with professional media companies (Figure 32). Over the past two years, this product has received considerable public attention at science fairs, political events, and on the Internet.


Figure 32: Landing page of the ***coastMap***, app (http://coastmapapp.hzg.de/ )



Topic 2

***Highlight: NOSCCA***

The **North Sea Region Climate Change Assessment** (Quante and Colijn, 2016) is an example of joint efforts of all units in the Institute of Coastal Research. It was coordinated by RU *Biogeochemistry* to collate available knowledge for experts, decision-makers and non-professionals. The assessment was finalized and successfully published as an open access book by Springer International in 2016. The assessment was compiled by an international consortium of scientists: Approximately two hundred authors and reviewers representing all North Sea countries were involved in the process. The NOSCCA book offers an up-to-date review of our current understanding of climate change in the North Sea and adjacent areas, as well as an outlook on possible consequences for ecosystems and socio-economic sectors. It provides a comprehensive overview of all aspects of our changing climate, including past, current and future climate change, as well as climate-related changes in marine, terrestrial and freshwater ecosystems. It further explores the impact of climate change on socio-economic sectors such as fisheries, agriculture, coastal zone management, coastal protection, urban climate, recreation/tourism, offshore activities/energy, and air pollution.

### 4.2.3 EMBEDDING IN PACES II

The entire Unit *Biogeochemistry* contributes to Topic 2, *Coastal Shifts and Long-term Trends* of PACES II, HZG´s joint program with the Alfred- Wegener- Institute in POF III. Topic 2 of PACES II, led by Kay Emeis (HZG) and Karen Wiltshire (AWI), aims 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 Topic linking HZG and AWI coastal research, where AWI contributes biological and ecological expertise to supplement physical, biogeochemical and modeling expertise available at HZG´s Institute of Coastal Research. The cooperation with AWI opens up opportunities to extend studies of novel pollutants to Arctic and Antarctic environments (Li et al., 2017; Wang et al., 2015; Wolschke et al., 2015).

RU *Biogeochemistry* is responsible for and leads (R. Ebinghaus/HZG with S. Kasten/AWI) Work Package 4 *Biogeochemical provinces of seafloors in the German North Sea sector*. It produces “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". As pointed out above, this very specific work package aimed at a rigorous assessment of functions and environmental status of the seafloor in the German EEZ prior to large-scale conversion to wind farms. Work Package 4 is therefore developing a comprehensive georeferenced inventory of sedimentological, physical and geochemical seafloor properties and fluxes across the sediment-water interface in the German Bight of the North Sea (biogeochemical property database as part of ***coastMap***). Work in this package underpins a national research activity (*NOAH: North Sea, Observation and Assessment of Habitats*) that is coordinated by Kay Emeis towards creating a seafloor habitat atlas of the German EEZ in the North Sea. Together with partners, thematic coverage is extended to benthic fauna, benthic food webs, and impact of fisheries on seafloor state. In the course of PACES II and NOAH, this state assessment and process understanding will be synthesized to quantify the influence of human activity on seafloor integrity and to develop a set of indicators for good environmental status. Some of the pertinent results of ongoing work have been outlined above and are being aggregated into ***coastMap*** and the Habitat Atlas in close interaction with other Work Packages in Topic 2.

An illustrative example of interaction between the work packages in Topics 2 and 4 of PACES II is research on the consequences of wind farm construction in the German Bight. Such use constitutes a large-scale and long-term disturbance experiment that is likely to have significant effects on matter fluxes in the coastal ecosystem. The present PACES II period saw the onset of the wave of activities at this new offshore frontier, and ***coastMap*** was in part motivated by a need to document the current state of the overall system relative to this imminent development. In the past years, the analysis concentrated on physical and biological effects of enhanced mixing (Carpenter et al., 2016; Floeter et al., 2017), but also included putative pollution by geotextiles used as scour prevention around wind turbines. It additionally included analysis of pollution incurred from corrosion protection (ongoing work).



### 4.2.4 FUTURE FOCUS AREAS (POF IV)

The Program Area *Earth and Environment* of the Helmholtz Association is currently developing its future research plan for the next phase of Program-orientated Funding. After intense discussions on scientific and structural aspects of the Helmholtz Association's Earth System Research efforts in the future, the centers agreed upon a new alignment to make co-operation across centers more effective. The new structure will acknowledge *Earth* as a system of interconnected and interacting sub-spheres, and will consist of interrelated topics that bundle expertise from participating centers. One of these topics will be *Coastal transition Zones under Natural and Human Pressure*, led by HZG with anticipated participation by AWI, GEOMAR, and UFZ.

In current planning, coastal research at HZG will be devoted to bridging the gap between processes on land and in river catchments, in estuaries, and at the coasts. In the context of this concerted effort by observational and modeling groups in the Instiute of Coastal Research, RU *Biogeochemistry* will focus on matter cycling, including pollution in regional land-sea-atmosphere systems along gradients in human impacts. This builds in part on previous joint projects with UFZ in a doctoral twinning program where land-sea transition zones in Europe were jointly investigated (Wolschke, et al., under review; Massei et al., under review). An initial hypothesis here is that there is a qualitative and quantitative difference between the system behavior of highly managed as compared to near-pristine systems. While the details of program planning are yet to be completed, the *Biogeochemistry* Unit with the other HZG units will analyze, model, and reconstruct system states and conditions for naturally and anthropogenically triggered transitions in biogeochemical states of regional river catchments, estuaries, and coastal areas.

This will be done in the framework of an international consortium that has formed to develop, install, and operate a decentralized European research infrastructure (DANUBIUS-RI). In this consortium, the Institute of Coastal Research will be responsible for one of several so-called supersites (Elbe and

North Sea), and will benefit from access to infrastructure at other supersites that differ in natural setting and degree of alteration in catchments and rivers. There is agreement between HZG and UFZ (*Helmholtz Center for Environmental Research*) that pollution and eutrophication in the Elbe-North Sea regional system will be jointly addressed by observation and modeling, including by atmospheric regional and hydrological models, emissions, atmospheric transports, and deposition.

Topic 2

***Highlight: DANUBIUS-RI - The International Centre for Advanced Studies on River-Sea Systems***

International Centre for Advanced Studies on River-Sea Systems

European research on freshwater and marine systems is reknowned worldwide but fragmented, largely discipline-specific and often geographically isolated. There is a particular lack of knowledge and research dedicated to the continuum of riverine, estuarine and marine systems, including estuaries, deltas and the interface with groundwater. The increasing demand to harmonize intensive human use and environmental protection necessitates encompassing research on river-sea systems with enhanced system understanding. **DANUBIUS** fills this gap and will be implemented as a long-term, large-scale and distributed European research infrastructure as was recently decided by the **European Strategy Forum on Research Infrastructures** (ESFRI) after a one-year evaluation. Since March 2016, DANUBIUS-RI has been included in the ESFRI Roadmap, along with five other new infrastructure projects from various scientific areas.

Scientists of Unit *Biogeochemistry* will take leadership in investigations on dynamics of nutrients, particles, oxygen, pollutants and hydro-dynamics as part of a network of eight case study sites on large European river-sea systems developed by sixteen European partner institutes. The goal of the **Elbe-North Sea Supersite** is to observe and understand the dynamics of tidal systems, the effects of extreme events, and to single out natural and anthropogenic cause-and-effect chains to provide scientifically underpinned information for sustainable use.

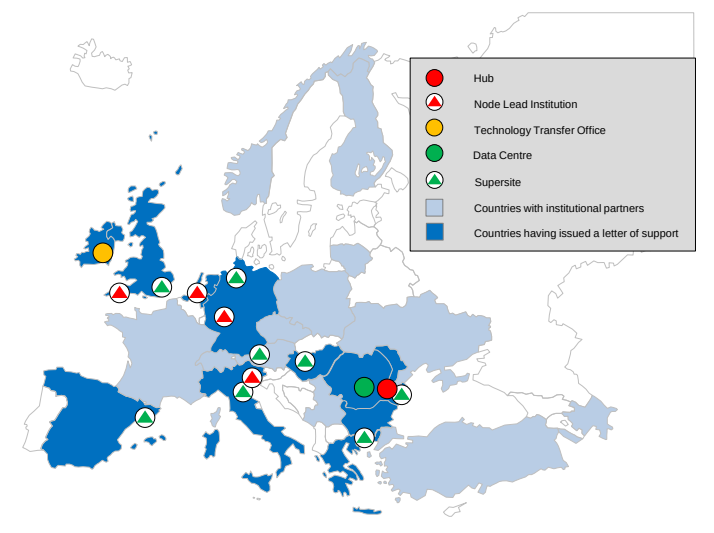



Figure 33: Location of the components of the distributed ESFRI-Research Infrastructure "DANUBIUS-RI". HZG will be responsible for building and maintaining the Elbe-North Sea Supersite.

Other river-sea transitions in Asia (China), in the Arctic, and in the Mediterranean Sea will be evaluated as to their properties and whether they enlarge the range of natural and impacted system states to be studied. Initial investigations are currently under way with partners in China and Israel. These activities will be linked with other international (ERAPlanet), and national (Germany´s Coastal Research Agenda) research agendas. There are large scientific and methodological intersections with the ERA-Net Co-Fund Project ERA-PLANET – *The European network for observing our changing planet*. Particular points of common interest are the advancement of integrated Earth observation

systems, the development of advanced environmental sensor technology, as well as big data science, including the aspects of downstream services and interoperability. Moreover, ERAPlanet connects the observational research with Earth System model development and will support the development of the GCOAST modeling system in RU 1.

The theme *Land-Sea Transitions* is also central to the HZG's contribution to the Universität Hamburg's *Exzellenz Strategie*, the fate of which will be decided in 2018. Ongoing bilateral (e.g., FINBOYEL: Anthropogenic fingerprints in Bohai and Yellow Sea; a project under the SINO-German Cooperation), and Helmholtz programs such as *Digital Earth* (North Sea) and *Earth System Modeling* (RU 1 and RU 4) have been initialized and will facilitate the transition into the new POF.

Continuing effort will be placed on assessing biogeochemical impacts of anthropogenic resource use (e.g., construction of wind farms, estuarine management), the role and state of seafloors in biogeochemical cycles, and the risks associated with pollution, emissions and intensified sea use. The further development of ***coastMap*** as one part of a common data and information portal of the Institute of Coastal Research will accompany these research threads.



### 4.2.5 CAREER DEVELOPMENT

Scientists in RU 2 Biogeochemistry teach at the universities in Hamburg (Department of Geosciences: Meteorology, Geology; Department of Chemistry: Analytical Chemistry; Department of Biology: Hydrobiology and Fisheries Science) and in Lüneburg (Faculty of Sustainability: Environmental Sciences, Sustainable and Environmental Chemistry). The engagement and high visibility of RU *Biogeochemistry* scientists at the universities has the beneficial effect that it ensures a continuous entrainment of undergraduate and graduate students interested in our work, and helps us with our work in the form of qualification theses. Doctoral students enrolled at Universität Hamburg are members of the Graduate School SICSS (School of Integrated Climate System Sciences) in the *Biogeochemistry of the Earth System* track, and are supervised by graduate committees that monitor progress of theses. The school offers a career support program, expert courses, annual retreats, and technical and soft skills training. All doctoral students are encouraged to visit national and international conferences and summer schools (paid by our unit), and to spend time in collaborators' laboratories abroad. A monthly meeting of graduate students with Kay Emeis and Markus Quante serves to provide updates on work progress, to identify problems, and to discuss science. Regular attendance is mandatory, as are courses on scientific writing (held by professional science writers) and statistics (held by Armin Aulinger). The PhD students organize their own brown-bag seminar, where they report on progress of their thesis work.

We are currently in the planning phase to enhance our undergraduate and graduate training (and our attractiveness for drawing prospective doctoral and postdoctoral scientists) by establishing the HZG *Coastal Chemistry Summer School*. Realizing the demand for training of young scientists in environmental chemistry of coastal zones, we are developing an integrated course spanning the land-sea-atmosphere continuum, from sampling to sophisticated chemical and isotope analyzes in our laboratories, to interpretation and evaluation of data in the context of environmental issues. In parallel to this course, we will offer stipends to graduate students from other countries to spend up to three months at HZG as part of their graduate (and postgraduate) project work. That program will be installed in the form of a competitive and open call for applications.

In addition to these in-house efforts, members of the Unit are active in national and international career development activities. The ERCA *(European Research Course on Atmosphere) W*inter School was founded twenty-five years ago by Claude Boutron with the idea that tackling environmentally relevant problems such as climate change, air quality issues and hydrologic cycle perturbations required researchers trained in multidisciplinary approaches and who are able to collaborate on an international scale. The historic core of ERCA is atmosphere and climate, but the scope is much wider, with foci on: (1) the role of the cryosphere and the ocean in the Earth system, (2) surface exchanges

and biophysical feedbacks on environmental evolution, air quality and health issues, biogeochemical cycles, in particular carbon and nitrogen, links between regulation / international negotiation and environmental monitoring (through the problem of GHG emission control). The course is organized by Université Grenoble Alps (UGA) and supported by leading EU institutions in this area (HZG, WHO, Global Atmospheric Watch, Max Planck Institute for Chemistry and Abdus Salam Int. Centre for Theoretical Physics (ICTP). Ralf Ebinghaus and Markus Quante have been regular lecturers since 2003 and have been members of the Scientific Advisory Committee since 2005. HZG is a major sponsor of that school, and numerous doctoral students have attended.

The annual *Coastal Summer School* is conducted in cooperation of some of the leading national centres for coastal research in Germany: *Helmholtz-Zentrum Geesthacht*, *Leibniz Institute for Baltic Research Warnemünde*, the *Alfred Wegener Institute for Polar and Marine Research* (Helmholtz Association of German Research Centers) and the *KüNO* (Coastal Research in the North Sea and Baltic Sea) umbrella project. In 2017, the school was hosted by HZG and is dedicated to lectures, group and field work under the theme *How to govern marine environment: Baltic Sea and sediment services as a case study*. The school has been held annually since 2010 on various topics related to coastal research.

# 4.3

# RESEARCH UNIT 3 OPERATIONAL SYSTEMS

## 4.3 RESEARCH UNIT 3: OPERATIONAL SYSTEMS

Director Prof. Burkard Baschek

Understanding coastal systems is of high scientific and societal value. The quickly expanding world population is concentrated along the coastlines and the effects of global and regional change on coastal ecosystems is becoming increasingly evident. Coastal research has, however, long been hampered by the effort involved in investigating the highly complex coastal systems, the diversity of disciplines, and the difficulties in obtaining long-term and highly-resolved, consistent measurements in an environment with significant variability on many different length and time scales.

Topic 4

The quasi-operational Coastal Observing System for Northern and Arctic Seas (COSYNA) was therefore developed and implemented by Research Unit *Operational Systems* as an integrated system's approach. COSYNA is one of the most extensive coastal observatories worldwide and aims at providing data and data products to stakeholders in science, agencies, industry, politics, and in the public.

While COSYNA provides a long-term framework for coastal ocean sciences and instrument development (Topic 4 in PACES II), the Research Unit also addresses small-scale coastal ocean dynamics (Topic 2). These small-scale processes – such as submesoscale eddies and fronts, the air-sea interface and the impact of man-made structures – cannot be sufficiently resolved by COSYNA and are still poorly understood. They are, however, believed to contribute significantly to the ocean's energy cascade, mixing processes, nutrient transport, phytoplankton dynamics as well as atmospheric and oceanic boundary layer processes. For this purpose, the Research Unit *Operational Systems* develops and uses a unique very high-resolution observational and modeling approach that complements COSYNA research.

Topic 2

Of particular interest are submesoscale processes on scales of 10 m to 10 km, as they are likely responsible for approximately half of the global phytoplankton production – hence affecting the oceanic food web. Energy is brought into the ocean by wind, sun, and tides and must be removed by small-scale processes, such as turbulence. The last step of this ocean energy transport may be greatly enhanced by sharp submesoscale fronts forming strong shear, significant vertical motion on the order of 1 cm $s^{-1}$, instabilities, and increased turbulent motion. In this respect, the impact of man-made structures on the stratification of shallow shelf seas, such as the massive offshore wind farm constructions in the North Sea, must also be considered, as it is driven by small-scale turbulence in the wake of the piles.

HZG's submesoscale Experiment *SubEx II* and in particular the *Expedition Clockwork Ocean* were milestones for observations of submesoscale processes with unprecedented simultaneous spatial and temporal resolution of less than one meter and one second to a few minutes. The *Expedition Clockwork Ocean* took place in the Baltic Sea in June 2016 and included the first-time use of a 75-meter-long research zeppelin in coastal and marine sciences and several planes, speedboats, research vessels, as well as autonomous platforms (see Highlight 1). It was led by this Research Unit and involved six partner institutions.

Topic 4

The coastal observing system COSYNA (www.cosyna.de ) was established by Research Unit *Operational Systems* as a long-term, consistent, and integrated approach aimed at improving the understanding of the complex interdisciplinary processes of northern seas and the arctic coasts in a changing environment (Figure 34). Particular focus is given to the German Bight in the North Sea as a prime example for a heavily used coastal area where significant changes are already visible, and the arctic coast at Svalbard, Spitsbergen and the Lena Delta, that are under strong pressure due to global change. The automated observing and modelling system is designed to monitor real time conditions, provide short-term forecasts, data, and data products to help assess the impact of anthropogenically induced change. Observations are carried out by combining radar and optical remote sensing with various *in situ* platforms. Novel sensors, instruments, and algorithms are developed to further improve the understanding of the interdisciplinary interactions between physics, biogeochemistry, and the ecology of coastal seas. New modelling and data assimilation techniques are used by Research Unit *System*

*Analysis and Modeling* to integrate observations and models in a quasi-operational system providing descriptions and forecasts of key hydrographic variables. Observational and modeling data and data products are publicly available free of charge and in real time. They are used by multiple stakeholder groups in science, federal and state agencies, politics, industry, and the public. COSYNA is coordinated, led, and operated by Research Unit *Operational Systems* in cooperation with Research Units *System Analysis and Modelling* and *Biogeochmistry in Coastal Seas*, as well as with ten national partner institutions (see also Major Highlight in chapter 3.2).

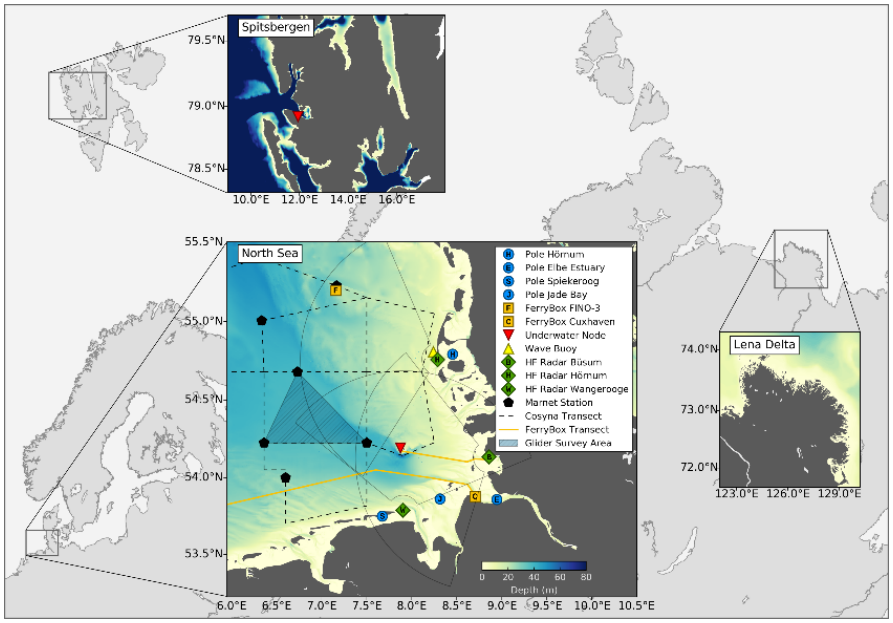



Figure 34: Map showing the pre-operational components of the coastal observing system COSYNA.

Further observations and further development of the instrumentation, will be supported by the Helmholtz project MOSES (Modular Observation Solutions for Earth Systems) that began in 2017 and involves all eight Helmholtz Association institutions that are involved in the *Earth and Environment* research field. MOSES investigates four complex process chains in the ocean, atmosphere and land surface, thus bridging a variety of Earth System compartments. The research unit *Operational Systems* is leading the *Ocean Eddies* process chain and is collaborating in the *Hydrological Extremes* process chain that is targeting a flood event in the Elbe River thereby being related to COSYNA.

While COSYNA's scientific data and results are used by various stakeholders in science, administration, politics, and industry, the Research Unit *Operational Systems* is also dedicated educating the public about processes and conflicts in the coastal ocean. These outreach activities aim to foster acceptance and fascination for the scientific questions and work involved. To reach this goal, a unique award winning cross-media approach is undertaken by using the Research Unit's own mobile 9-meter planetarium (*Mobile Dome*), featuring the fulldome films *Clockwork Ocean* and *Mysterious Oceans: The Eddy Hunt* for an immersive 360° presentation of the *Expedition Clockwork Ocean*. The project also involves virtual reality glasses as well as movies, apps, and a parallax webpage (www.clockwork-ocean.com). According to investigations of a public relations company, the media campaign reached more than 150 million people.

### 4.3.1 OVERVIEW

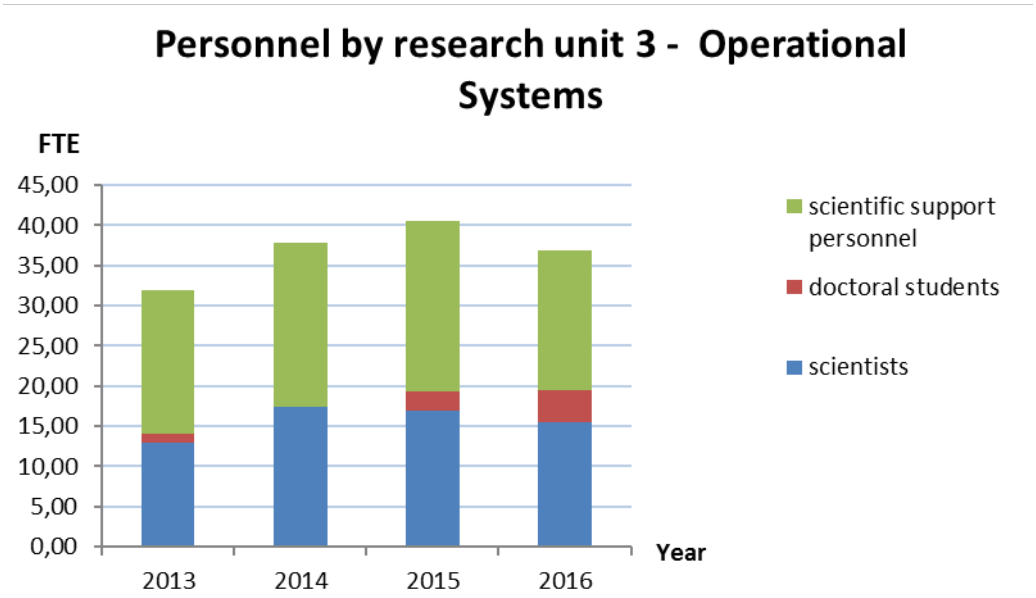



Figure 35: Development of Full Time Equivalent (FTE) Personnel of RU 3. Please see figure 3 for detailed information about the contribution of HZG-Research Units to the Helmholtz-Program PACES II in 2016.

Since 2012, the Research Unit *Operational Systems* has been led by Prof. Burkard Baschek. Since then, the division has established small-scale dynamics as a secondary focus, in addition to developing an operational observing system. Prof. Baschek holds a faculty position at the University of Kiel and teaches undergraduate and graduate courses in physical and coastal oceanography.

Topic 4

The Research Unit consists of six departments. The **New Technologies** department is leading development and implementation of the Coastal Observing System for Northern and Arctic Seas (COSYNA). It is cooperating with other departments within this research unit as well as ten partner institutions in research, public administration, and industry. It is also engaged in stakeholder dialog with a variety of different user groups. Data and data products are provided through Internet services to users from the scientific, administrative, political, and public sectors. Observations and models are applied to study the coastal carbon cycle and its influence on larger-scale processes. The ***In situ* Measuring Systems** department develops and operates cost-effective and reliable observation methods enabling continuous and autonomous oceanographic measurements of *in situ* water quality parameters in order to better understand coastal dynamics with a focus on the carbonate system. Flow-through systems (FerryBoxes) are developed and installed on vessels. Precise biogeochemical sensors are developed for autonomous operation in FerryBox systems.

Topic 2+4

The **Remote Sensing** department is analyzing satellite and aerial remote sensing data by using ocean color to determine seawater optical and biogeochemical properties and to better understand the dynamics of phytoplankton productivity and suspended matter in the coastal ocean. In order to develop improved algorithms, highly precise and complex measurements of optical properties, such as light absorption and scattering in various types of water, are performed in the laboratory and *in situ*. The directly measured information is integrated into optical models to improve satellite and aerial data analysis and processing.

Topic 2

The department **Radar Hydrography** is investigating the dynamics at the air-sea boundary with its various exchange processes between ocean and atmosphere. It has the goal to better understand the interaction between surface waves, currents, and winds as major drivers of air-sea interactions by using *in situ* and remote sensing techniques. The department develops and utilizes different remote-sensing measurement techniques providing observations of the sea surface, simultaneously in space

and time, at scales ranging from centimeters to hundreds of kilometers. The **Submesoscale Dynamics** department is analyzing the dynamics of small-scale processes such as submesoscale eddies and fronts in the coastal ocean or the turbulent mixing caused by wind farms. Very-high resolution *in situ* observations and regional modeling are combined to better understand the interaction of physical and biogeochemical processes and their influence on budgets of the coastal ocean. The **Small-scale Physics and Turbulence** department, which was formed in 2013, works to understand ocean circulation, mixing, and processes that transport important quantities such as heat, salt, oxygen and nutrients. It utilizes ocean gliders for direct field measurements, direct and large eddy numerical simulations, as well as theoretical models to help understand turbulent processes in the oceans. A focus is given to North Sea coastal turbulence, impacts of storms and offshore wind farms on stratification, and turbulent transport of heat in the Arctic Ocean.

In addition to the Institute of Coastal Research's main infrastructure, such as the research vessel *Ludwig Prandtl* or the computer cluster OCEANS II, the Research Unit *Operational Systems* owns the COSYNA platforms and instrumentation. These platforms comprise two underwater-nodes with one head buoy, three lander systems, three ocean gliders, three HF radar stations, several X-Band radar stations, wave rider buoys, nine operational FerryBox systems, a Scanfish, a profiling buoy, several measurement poles, etc. (Baschek et al., 2017). In addition, the division uses its own cooled infrared camera systems, an aerial hyperspectral sensor, two Towed Instrument Chains, three drones, the speedboat *Eddy*, and four dinghies for high-resolution measurements. The division runs an IT infrastructure of several servers used both for data storage and data access, such as the COSYNA server and satellite databases.

The division occupies three buildings with offices and laboratories as well as two multipurpose buildings used for instrumental preparation and development, storage of vessels, instruments and observational equipment. Two new office and lab buildings will be finished in November 2017. The space between buildings will be transformed into a joined campus for the Institute of Coastal Research. The campus will also host the *Mobile Dome*, which belongs to the Research Unit *Operational Systems*.

Within the PACES II program, the Research Unit *Operational Systems* is leading WP 5 of Topic 2 *Interface processes and physical dynamics of the coastal ocean* and has major contributions to WP 1 and WP 2 in Topic 4: *Research in science-stakeholder interactions*. The Research Unit currently has 15.5 FTEs for scientists, four FTEs for doctoral students and 17.3 FTEs in technical and support staff. Costs for instrumentation, logistics, travel, and materials are 1.0 million Euros per year (numbers for 2016). In 2016, the Helmholtz project ACROSS contributed an additional 0.5 million Euros to the observing system COSYNA.



### 4.3.2 SCIENTIFIC RESULTS AND GOALS

Topic 2

A main objective of the Research Unit *Operational Systems* is to better understand the role of small-scale physical and biogeochemical processes that are barely understood, but are highly relevant to the following interdisciplinary and interface processes:

- Submesoscale processes and their role in the energy cascade and phytoplankton distribution
- Turbulence, mixing, and shelf sea transports
- Momentum transfer at the air-sea interface
- Influence of offshore wind farms on the North Sea (see Major Highlight, chapter 3.2)

Topic 4

To address these questions (Topic 2), unique very high-resolution measurement techniques are under development. Observations are also carried out and interpreted in combination with high-resolution numerical modeling (Direct Numerical Simulations, DNS; Large Eddy Simulations, LES; Regional Ocean Modeling System, ROMS).

The second main goal is the development and implementation of an integrated observing system to better understand the coastal dynamics on different time scales and to provide near-real time data and products that can be used by science, agencies, and industry. This comprises the two major research areas (Topic 4):

- Development and operation of the integrated observing and modeling system COSYNA (see Major Highlight, chapter 3.2)
- Optical characteristics of the oceans

While the achievements stemming from the COSYNA observing system and the investigations of the impact of offshore wind farms are described as Major Highlights in chapter 3.2, the scientific results of the other research themes are highlighted in the following.

Topic 2

## Submesoscale processes and their role in the energy cascade and phytoplankton distribution

The global ocean circulation is driven by wind, solar radiation, tides, and the exchange of heat and fresh water with the atmosphere. While the global importance of this large-scale structured flow has been known for a long time, high-resolution model simulations have only recently revealed that the ocean and coastal areas are dominated by variability on multiple spatial and temporal scales. In this context, processes in the submesoscale range (10 m to 10 km, lifetime of hours to days) have gained a great deal of attention recently. One reason for this shift in attention is the significant improvement in observational technology and model resolution now emerging as capable of detecting such small-scale structures. Another reason is the increasing evidence that submesoscale processes significantly alter large-scale budgets (e.g., Thompson et al., 2014) and play a key role in the ocean's energy transfer, vertical transport, and mixing as well as biological and biogeochemical processes. The submesoscale is mediating, for example, up to approximately 50% of the particle export in subpolar oceans (Omand et al., 2015) and contributing to about half of the phytoplankton production in the global oceans.

While a number of highly relevant and interdisciplinary research questions arise, the understanding of submesoscale processes is still hampered by a significant observational gap. In order to *fully* capture submesoscale features with sufficient temporal and spatial resolution, it is necessary to resolve ocean processes at the sea surface and in the ocean's surface layer with simultaneous spatial and temporal resolution of a few meters and a few minutes.

It is therefore the Research Unit's goal to:

- observe single submesoscale features with extremely high resolution using various remote sensing and in situ sensors on airborne and shipborne platforms
- compare the observed submesoscale dynamics with high-resolution regional models
- better understand the role of submesoscale processes in the energy cascade
- carry out the first observations of the physical and biogeochemical interactions on the submesoscale to understand their role in phytoplankton production and export

As a first experiment, the *Submesoscale Experiment* (SubEx) was coordinated by HZG (Ohlmann et al., 2017). It took place in 2014 off the coast of Southern California with six partner institutions and utilized two planes, three research vessels, and several ocean drifters. The goal was to observe submesoscale eddies and fronts in the vicinity of Santa Catalina island and to understand their formation mechanisms and temporal evolution.

**Highlight 1: Submesoscale Dynamics**

In order to better understand the physical submesoscale dynamics and their close interaction with biogeochemical processes and phytoplankton, the Research Unit *Operational Systems* developed a unique multi-platform capability for very-high resolution observations. The *Expedition Clockwork Ocean*, which took place in the Southern Baltic Sea in June 2016, was therefore a great success and showed for the first time the development of a submesoscale eddy from generation to decay – in unprecedented resolution.

Submesoscale features have very short life spans on the order of 6 – 12 h and often measure only a few hundreds of meters in diameter. Measurements were therefore carried out for up to ten hours per day so that submesoscale features could be detected and repeatedly observed before their decay. A motorglider plane was equipped with an infrared camera to find submesoscale processes by detecting their strong surface temperature gradients. Furthermore, a 75-meter-long zeppelin was outfitted with a cooled infrared camera and a hyperspectral push-broom sensor to observe the dynamics and physical-biological coupling of the features. It was the first time, that a zeppelin was used in coastal or marine sciences. It served as a coordination and communication center during the expedition, enabling the near-real time exchange of data crucial for these targeted high-resolution measurements. The real-time data transmission of temperature maps from the zeppelin to several vessels was crucial for measuring fronts and eddies *in situ* and following them during their quick temporal evolution. HZG's research vessel *Ludwig Prandtl*, the research vessel *Elisabeth Mann Borgese*, and the speedboat *Eddy* as well as ocean gliders, autonomous robots, and drifters were used to deliver the most detailed *in situ* observations.

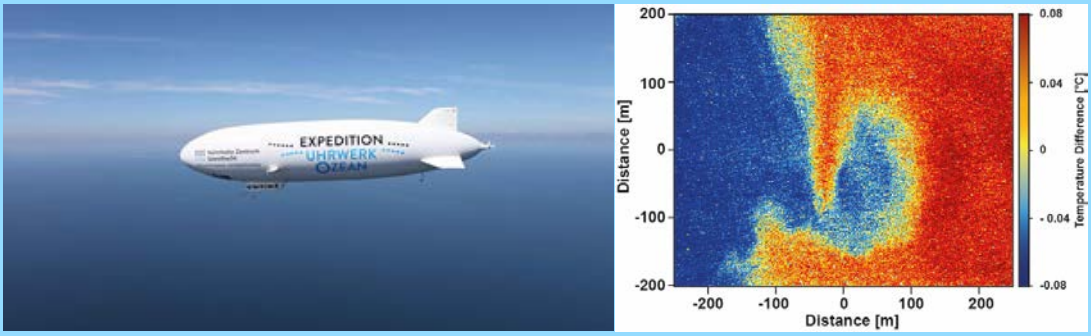



Figure 36: In 2016, a research zeppelin was used for the first time in ocean sciences. Its unique capability for stationary measurements allowed observations of small-scale physical processes with unprecedented resolution. Right: A submesoscale eddy with a diameter of approximately 200 m. The high-resolution temperature imagery showed the first observations of the evolution of a submesoscale eddy from its generation to its decay.

The speedboat *Eddy* was purchased and outfitted with a winch, FerryBox, ADCP, and weather station. In addition to *Ludwig Prandtl*, it served as a platform for a Towed Instrument Chain (TIC) that was developed by this Research Unit for measurements at several depths simultaneously at high speeds. Currently, up to twenty CTDs (with additional chlorophyll or oxygen sensors) can be deployed, even from small vessels, and towed at speeds of up to ten knots covering the upper 45 m of the water column. The real-time data transmission of all sensors is currently under development. Ocean glider operations have been optimized for shallow water environments with heavy traffic. For small-scale observations, they are equipped with turbulence probes and an ADCP (Merckelbach, 2016). Ship-based radar observations were used to detect surface currents (Huang et al., 2016), waves (Carrasco et al., 2017a, 2017b), and surface features, such as fronts (Lund et al., 2017).

The Research Unit *Operational Systems* has built in PACES II a worldwide unique observational multiplatform capability that led to the most detailed observations worldwide of submesoscale processes to date. It is now possible to resolve processes with a 1 – 5 m and 5 – 20 min resolution for areas as large as 10 x 10 $km^2$, or an unprecedented resolution of < 1 m and < 1 s for areas of 0.5 x 0.5 $km^2$. The observations show extreme frontal gradients of typically 1°C over 5 m; vertical velocities of > 1 cm $s^{-1}$; Rossby numbers of 10 – 20; and presumably off California the first observations of hydraulically controlled flow not directly influenced by topography in a two-layer flow with Froude numbers on the order of one. Further highlights are the first observations of a submesoscale eddy generation, through subsequential stationary aerial measurements.

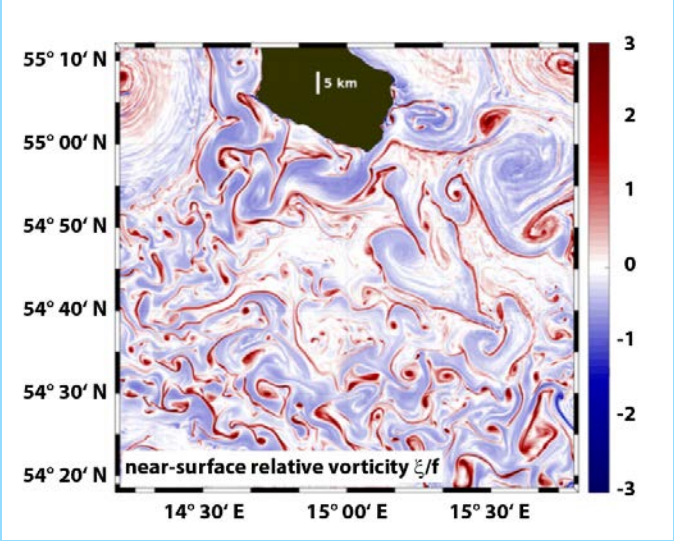



Figure 37: ROMS Model of the Baltic Sea with a resolution of 100 m. High relative vorticity indicates strong submescale activity.

The observations show intense mixing within some submesoscale eddies leading to short eddy life times of approximately 12 h, which is associated in some eddies with a rapid export of waters with high chlorophyll concentration to subsurface waters, indicating an important contribution to the carbon pump. The strong coupling of physical and biogeochemical processes is confirmed by observations showing high phytoplankton concentrations in the immediate vicinity of eddies and fronts. Individual eddies have been tracked to derive first estimates of the dissipation of kinetic and potential energy over their lifetimes. Regional Ocean Modeling System (ROMS) modeling with resolutions of 100 m (Figure 37) and a Large Eddy Simulation (LES) model are currently in use for comparison, and larger-scale interpretation of field measurements.

Further observations will be carried out as part of the Helmholtz project MOSES in 2019 off the Cape Verde Islands to observe the interaction of submesoscale and mesoscale flow as well as in 2020 to investigate the role of submesoscale eddies during deep convection events in the Mediterranean Sea's Golfe du Lion.

Another experiment used for submesoscale analysis is the REP14-MED experiment in the Sardo-Balearic Sea, west of Sardinia, led by the Centre for Maritime Research and Experimentation (CMRE) in June 2014. A vast amount of data was provided by two research vessels, a glider fleet, towed and underway measurements, mooring time series and surface drifters. The Research Unit *Operational Systems* employed ROMS to explore the sensitivity of the forecast skill of mixed-layer properties to the initial conditions (Onken, 2017), boundary conditions (provided by Mediterranean Forecasting System or MERCATOR), and vertical mixing parameterizations. It was shown that the agreement of predicted mixed-layer temperatures and mixed-layer depth with the mooring time series could be improved by nesting ROMS in MERCATOR (Oddo et al., 2016). The forecasted horizontal variability agreed well with ScanFish observations for the mesoscale wave number band.

**Highlight 2: Science Communication Project Clockwork Ocean**

The award winning cross-media project Clockwork Ocean was developed jointly with the Public Relations Office at HZG (www.clockwork-ocean.com) to inform the public about a highly relevant research topic and a unique observational approach to marine sciences. An immersive cross-media approach was used to transport the audience directly into the setting of the experiments and to trigger fascination for scientific discovery in a largely unknown environment.

The project comprises the development of a mobile planetarium, two planetarium films, a virtual reality (VR) media player, the use of 360° videos, VR glasses, and a parallax webpage. Both planetarium films (Figure 38, left) are part of regular program screenings at several planetariums, such as in Hamburg, Berlin, Kiel, or Nuremberg. The film Clockwork Ocean received the special award for "Best of Science Visualisation" at the Fulldome Festival in Jena in 2016 (Figure 38, right).

The mobile planetarium (Figure 38, center) was custom built for HZG and is intended for science communication at festivals. It measures 9.5 m in diameter with a thirty-two person capacity. Its six projectors and tilted dome allow for an exciting immersive media experience. The dome was used at several festivals, such as at the national celebrations for the Day of German Reunification in Berlin 2015, Dresden 2016, and Mainz 2017; the climate conference COP23; at the Representation of the State of Schleswig-Holstein in Berlin 2016; the Greenscreen festival in Eckernförde in 2015. During these festivals, the film typically reaches an audience of 1,200 people per day.


Figure 38: Left: Scene from the fulldome film *Clockwork Ocean*. Center: HZG's Mobile Dome. Right: Best of Science Visualisation Award at the Fulldome Festival 2016 in Jena.

The *Expedition Clockwork Ocean*, however, also received an unusual amount of public attention. During the zeppelin's transfer flight from Lake Constance to Berlin, life Internet coverage by the television channel WDR directly from the zeppelin as well as a flight over downtown Berlin (Figure 39) sparked a great deal of interest, culminating in two top ten spots of Twitter Trends in Germany that day as well as 1100 online articles. The extensive press, radio, and television coverage during the experiment reached more than 150 million people in June 2016. Real-time data transmission during the experiments allowed the public to follow the experiments.


Figure 39: The research zeppelin flies over Brandenburg Gate in Berlin, June 2016.

## Turbulence, mixing, and shelf sea transports

Although ocean turbulence is a very small-scale motion in the ocean on the order of 1 cm, it is a crucial component of large-scale budgets of energy, momentum, and important scalars such as heat and nutrients. It is the process responsible for driving ocean mixing, which is a key ingredient in setting rates of vertical transport in the oceans. The often strong vertical stratification of the oceans is a hindrance to vertical motions and transports, which must be accomplished through small-scale turbulent mixing. Mixing exerts control on many processes that are of paramount importance to coastal and shelf seas; from enabling the supply of nutrients to the sunlit surface layer, to the supply of oxygenated waters to the deep Baltic Sea, and the oceanic heat fluxes delivered to the Arctic sea ice. Recent advances in understanding turbulent mixing and transport in coastal seas have been possible through novel measurement and simulation techniques.

These advancements in observational technology have been made in parallel with advances in computational resources, allowing for a strong interplay between *in situ* field observations and numerical simulations. The use of high performance computer clusters to simulate ocean turbulence with DNS have led to an advancement in heat transport laws in double diffusive convection, with a link to an improved understanding of the energy budget (Hieronymus and Carpenter, 2016). Although normally limited to unrealistically low-energy turbulent events that are not present in the oceans, these simulations have crossed into the realm of geophysical turbulence – simulating conditions present in the oceans. This has enabled a direct, and successful, comparison with *in situ* turbulence measurements (Sommer et al., 2014). These results have been used to understand and constrain estimates of Arctic Ocean heat fluxes due to double-diffusive convection (Shibley et al., 2017). In addition, an investigation is currently underway to identify and quantify these processes in the Baltic Sea, where the ocean gliders were instrumental in discovering double diffusive staircases for the first time.

This combined approach using both simulation and observation is currently being applied to understand the influences of offshore wind farm (OWF) development on North Sea stratification. Preliminary estimates of the turbulent mixing of OWFs suggest that it could provide a significant impact on stratification, with the large-scale construction of OWFs in the North Sea (Carpenter et al., 2016; Flöter et al., 2017). In addition, the glider-based measurements of North Sea turbulence levels suggest that OWFs could contribute to significantly enhanced turbulence in the stratified thermocline region (Schultze et al., 2017). Given these findings, *in situ* measurements using towed instrument chains, and Large Eddy Simulations of the stratified turbulent wake of OWF foundation structures are currently underway.

Topic 2

**Highlight 3: Storm-Induced Mixing**

Storms represent sudden, intense, physical forcing events that are known to have significant impacts on coastal and shelf seas. In particular, storms are known to produce rapid changes in surface chlorophyll, sediment transport and the associated morphological changes, as well as in rapid cooling the surface ocean. Associated alterations in nutrient levels have been proposed to lead to significant changes in net ocean biological productivity, while the rapid ocean surface cooling is being recently linked to forecasting errors in the intensity of tropical cyclones.

All of these storm-induced impacts are driven by changes in ocean turbulence. Yet, despite this enormous importance of turbulence, there are currently little to no observations of turbulence during storm conditions due to difficulties in using traditional ship-based methods, which become too dangerous in extreme conditions. This sampling difficulty has been overcome through the use of autonomous ocean gliders that have been outfitted with turbulence microstructures instruments (Figure 40). Using this new technique for collecting ocean turbulence, has led to long-term (17 day), continuous measurements of coastal ocean turbulence (Schultze et al. 2017a), thus capturing the turbulent ocean response as an extreme storm passed over the North Sea (Figure 40, Schultze et al. 2017b).

From the measurements, background turbulence levels and storm-induced changes have been quantified. In particular, it was found that storm-induced turbulence increases 6-7 fold over normal background conditions within the strongly stratified thermocline. Since the vertical fluxes of heat and nutrients are directly proportional to the turbulence intensity in the thermocline, this increase in fluxes was found to be responsible for rapid sea surface cooling and changes in the distribution of chlorophyll. The physical mechanism responsible for this enhanced thermocline turbulence was found to be the formation of shear instabilities in the thermocline. Using a bottom-mounted acoustic Doppler current profiler deployed close to the glider position, it was possible to show that the thermocline reaches a state of marginal stability during the storm. In this marginally stable state, there is a direct feedback between storm forcing and the mixing of the thermocline that is not present in normal conditions, and it is in this marginally stable state that the enhanced thermocline turbulence is found.

Given the large increases in storm-induced vertical fluxes that have been found, it was possible to estimate the role of storms in an overall seasonal context. The results show that summer storms are expected to produce approximately 30% of the total summer stratified fluxes. This indicates a major influence of storms on the physics and biogeochemistry of coastal seas.


Figure 40: Left: True colour image of Storm Bertha over the North Sea from Aug. 11, 2014, as glider measurements were being made (obtained from NASA World View). Right: Ocean glider on the water surface with microstructure turbulence sensors mounted.

Topic 2

## Momentum transfer at the air-sea interface

Near surface processes in the ocean must be well understood to better comprehend and estimate the momentum exchange between atmosphere and ocean. In this respect, the role of surface waves, their influence on the near surface airflow dynamics as well as wave current interaction are of importance. However, our physical understanding in particular, with respect to their coupling and at higher wind speeds remains incomplete. To better quantify and understand their interactions, several measurement techniques for high-resolution remote sensing of near-surface wind, current, and wave fields were developed. The methods are based on radars, lasers, and video cameras, covering scales between millimeters and hundreds of kilometers:

- Accurate measurements of wind fields at high wind speeds are important for estimating momentum transfer under high-energy conditions when observations are sparse. A large spatial coverage (> 100 km) with a high resolution (up to 1 km) of the sea surface wind fields can only be obtained by spaceborne synthetic aperture radars (SAR). These measurements, however, were limited to moderate winds and resulted in huge errors under extreme conditions such as tropical cyclones. To overcome these limitations, new algorithms were developed, tested, and validated (Horstmann et al., 2013, 2015a; van Zadelhoff et al., 2014). They were applied to spaceborne SARs operating at C-band with either co-polarization or cross-polarization. Comparison with QuikSCAT winds and Stepped Frequency Microwave Radiometer (SFMR) during reconnaissance flights showed that SAR cross-polarization data are, with a root mean square error of 3.8 m $s^{-1}$, significantly better suited for SAR wind retrieval, especially at wind speeds above 20 m $s^{-1}$. This result led to the inclusion of cross polarization in future satellite scatterometer missions.

- In order to estimate the spatial variability of surface wave fields, to observe wave-current interaction, or wave energy dissipation, it is necessary to observe waves with sufficient spatial and temporal resolution over larger areas. For this purpose, radar remote sensing techniques such as the *coherent-on-receive* marine radar with a range of up to 3 km were developed by this Research Unit *Operational Systems*. Utilizing the radar Doppler speed measurements, a robust method for retrieving significant wave heights was developed and validated (Carrasco et al., 2017a, 2017b; Støle-Hentschel et al., 2017). For the first time, it is now possible to retrieve significant wave heights from marine radars without any calibration and with a high accuracy of 0.21 m.

  HZG's coherent-on-receive marine radar system is one of the most reliable systems available worldwide, and have therefore been used by several research partners in numerous campaigns in Germany, France, Norway, Taiwan, and the USA. The systems have proven to measure surface wind, waves, currents, and bathymetry from moving vessels, fixed platforms, and coastal stations. The HZG marine radar systems can now also be used (i) as a Surface Feature Monitoring System (SuFMoS) for real-time observations of fronts, internal waves, wind gusts (Vicen-Bueno et al., 2013; Horstmann et al., 2015b) and sea ice, (ii) for retrieving bathymetry in shallow water, (iii) for retrieving surface winds and gusts, and (iv) current measurements (Shen et al., 2015; Huang et al., 2016; Lund et al., 2017). Ongoing developments at HZG are focused on the retrieval of individual waves (Støle-Hentschel et al., 2017).

- To investigate the role of the wind stress on surface waves (momentum flux) over the ocean, a technique was developed to measure the detailed centimeter-scale airflow in the vicinity of the ocean surface. A combined particle image velocimetry (PIV) and laser-induced fluorescence (LIF) technique was developed at the University of Delaware (Buckley and Veron, 2016, 2017) and used in the laboratory taking into consideration seventeen different wind wave conditions. Dimensional airflow velocity fields were obtained as low as 100 µm above the air-water interface. The data were further analyzed at HZG showing that the mean velocity profile follows the law of the wall when the wind stress is too weak to generate surface waves. With waves present, turbulent structures are directly observed in the airflow, whereby low-

horizontal-velocity air is ejected away from the surface and high-velocity fluid is swept downward. Airflow separation is observed above young wind waves, and the resulting spanwise vorticity layers detached from the surface produce intense wave-coherent turbulence. On average, the airflow over young waves is sheltered downwind of wave crests. The aforementioned PIV technique has been adjusted at HZG to make first measurements in the open ocean, which for the first time, were performed aboard *RV Flip* in October 2017.

- Small-scale physical processes in the ocean are often characterized by sharp fronts that have strong horizontal shear. In order to sufficiently resolve these processes in space (a couple of meters) and time (minutes), the techniques developed for marine radar image sequences were adjusted to the needs of video sequences of water surface waves. Video sequences were acquired in the range of visible light with a small, nadir-looking video camera attached to an off-the-shelf quadcopter drone. The actively controlled gimbal stabilized the video camera. The video data are corrected for lens distortion and are geocoded to a rectilinear coordinate system at water level. The resulting video data allow for measuring wave direction, wave length, and phase velocity. These properties facilitate estimates of surface current vectors (Figure 41) resulting from the difference of the observed phase velocity and linear dispersion relation of surface gravity waves (Stresser et al., 2017).
- A key component of air-sea momentum transfer is in the growth of surface gravity waves from the airflow above. New theoretical advances in understanding this process have been developed and a new physical interpretation of the wind-wave interaction instability has been described (Carpenter et al., 2017). This interpretation breaks the instability down into its simplest form, which consists of a two-way interaction between the surface wave and the airflow critical layer. It also links the physics of the wind-wave instability to those of stratified shear layers, such as the well-known Kelvin-Helmholtz instability. This theoretical basis is also used for constructing an efficient solution method for computations of the most unstable modes likely to arise in different wind profiles.

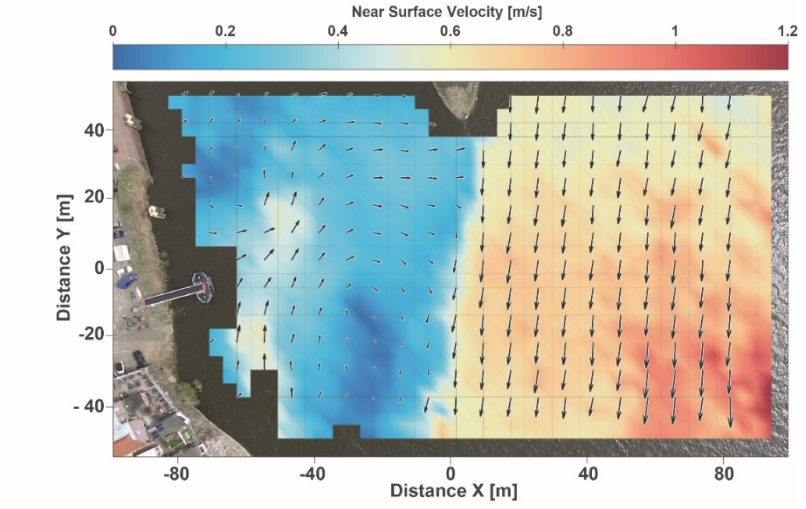



Figure 41: Surface current field in the Elbe River at Lauenburg retrieved with a quadcopter drone.

Topic 4

## Optical characteristics of coastal and oceanic waters

Optical remote sensing data from satellites and airborne platforms provide an excellent spatial overview of processes in the global ocean as well as in coastal environments. These data reveal a strong coupling of physical and biogeochemical processes on many different length scales up to the regional and global scale. These are, for example, the functional types, distribution, and productivity of phytoplankton, the transport of suspended material in the coastal ocean, or submesoscale fronts with their significant influence on the food chain.

Topic 4

**Highlight 4: Coastal Water Algorithms**

To interpret remote sensing data in the optically very complex coastal waters, the optical-physical properties of natural waters and the single constituents (from pure water itself to phytoplankton, and dissolved and particulate organic matter) must be known with the highest possible accuracy. While interpretation involves optical and radiative transfer modeling, the accuracy of the model results is directly influenced by the accuracy of the optical parameters used as model input.

In order to interpret remote sensing data based on accurate *in situ* data, HZG developed regional algorithms for the North and Baltic Seas. Research Unit *Operational Sytems* provides the Baltic Sea algorithm to the Copernicus Marine Environment Monitoring System (CMEMS). The HZG coastal water algorithms originally developed for the instrument MERIS on ENVISAT were adapted to the instrument OLCI on Sentinel-3 to be used by ESA. In addition, a new approach was developed that allows the use of remote sensing data in clear, coastal and optically extreme waters (such as highly absorbing and turbid lakes) with only one processor: the OLCI Neural Network Swarm processor (ONNS) (Hieronymi et al., 2017). HZG is also taking part in preparing the first hyperspectral satellite mission (Environmental Mapping And Analysis Program/ EnMAP, Germany) and has investigated hyperspectral optical data over water surfaces (ocean, coastal waters, and lakes) with respect to the differentiation of phytoplankton and suspended matter types.

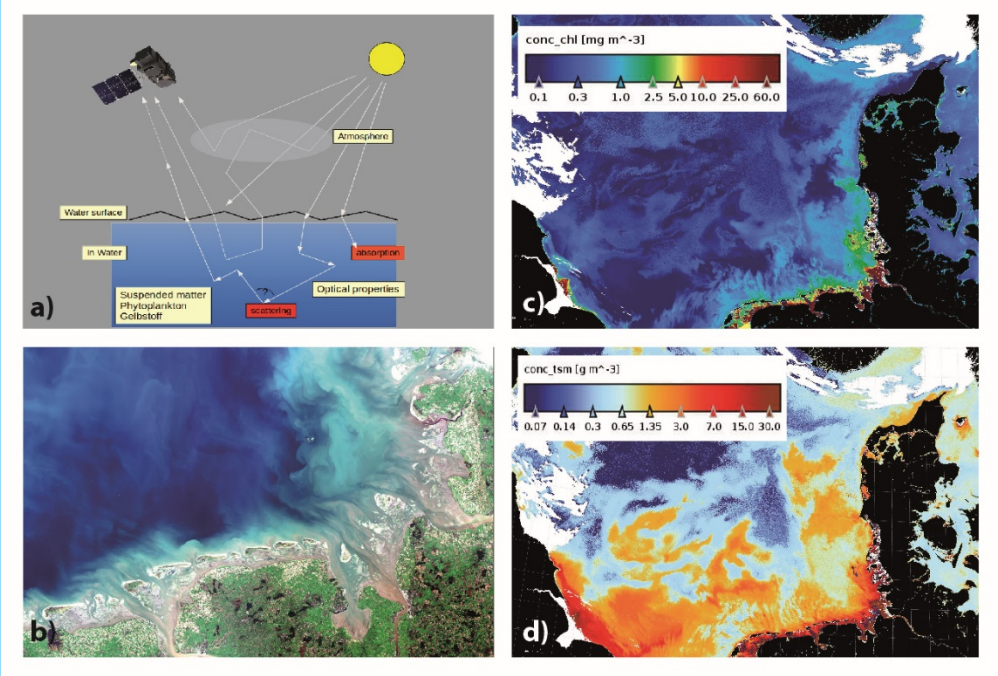



Figure 42: a) The exact knowledge of absorption and scattering effects is necessary to quantify water constituent from optical remote sensing. b) Sentinel-2 scene of the German Bight with structures of suspended sediment visible. c) and d) Processed result of a Sentinel-3 OLCI scene from May 27, 2017, showing the chlorophyll and sediment concentration calculated with ONNS. High sediment concentrations along the Wadden Sea are approximately 5 g $m^3$ (red to brown). Chlorophyll concentrations are with 5 – 30 g $l^{-1}$ also high along the coast.

Small-scale processes play an important role in many oceanic and coastal processes. A significant development is therefore the recent, extensive improvement in the spatial and spectral resolution of satellite remote sensing data, which now offer insights into coastal environments on a much larger scale and with much finer spatial and temporal resolution. The European Space Agency (ESA) and EU-Copernicus provide with the Sentinel program an extended (>25 years) satellite remote sensing framework that includes several optical sensors for coastal waters. Recently, three of these satellites

(Sentinel-2A, Sentinel-3A, and Sentinel-2B) were launched. In particular, Sentinel-3 allows coastal water observations much more frequently now, while Sentinel-2s provides a very high spatial resolution of 10 - 60 m. At the same time, they complement the NASA satellites MODIS-Aqua and VIIRS-Suomi-NPP with their optical sensors.

For observations with very high resolution, a HySpex hyperspectral camera with 1024 spectral bands and a horizontal resolution of approximately 0.5 m was mounted on a zeppelin, alongside a cooled infrared camera during the *Expedition Clockwork Ocean*. The infrared camera can also be flown from a Stemme motorized glider aircraft and delivers unprecedented resolution of submesoscale features in the coastal ocean and their temporal evolution over the course of several hours (see Highlight 1). The observed processes in the Baltic Sea showed a very strong coupling of physical processes (fronts, eddies, and internal waves) with the distribution of cyanobacteria.

The interpretation of airborne and satellite optical remote sensing data, however, demands accurate optical property information for all natural water body constituents. Uncertainties in determining these optical properties, such as absorption and scattering coefficients of particles as well as the water itself (Tan et al., 2013, 2015; Röttgers et al., 2014a, 2014 c), are large and limit remote sensing approaches – especially in coastal waters.

For ground-truthing of remote sensing data with improved precision and accuracy, and to improve bio-optical models, several approaches were taken:

- Instrument development: A Point-Source Integrating-Cavity Absorption Meter (PSICAM), its flow-through counterpart (FT-PSICAM) (Wollschläger et al., 2016), the quantitative filter technique Integrating-Cavity Absorption Meter (QFT-ICAM) (Röttgers et al., 2016), and an Imaging Volume Scattering Function Meter (I-VSFM) were developed at HZG. All of these instruments provide optical data of high quality and accuracy and are unique developments. Due to its very high sensitivity, the PSICAM in particular is used to measure specific properties of pure water that could not be determined before, contributing to HZG's international recognition for high-quality optical data.
- Improvement of water absorption coefficient: The temperature and salinity dependences of the liquid pure water absorption coefficient are a fundamental optical property (Röttgers et al., 2014b). They are difficult to measure, but are required to determine chlorophyll- and mass-specific optical properties for modeling light transfer in coastal waters, to develop optical remote sensing algorithms and to interpret remote sensing data. Seven ship campaigns and five field campaigns were carried out to collect the most accurate optical properties from a range of different environments, such as the German Bight or the Lena Delta (Örek et al., 2013). Using this new method and the aforementioned new instrumentation, mass-specific optical properties of the North Sea and Baltic Sea were determined that are internationally among the most accurate optical data of coastal waters (Röttgers et al., 2014c).
- Optical differentiation of functional or taxonomic groups of phytoplankton: Satellite or aerial information of phytoplankton group distributions over large areas will provide valuable information about the formation processes and distribution of phytoplankton blooms as well as the identification of harmful algal blooms (Xi et al., 2015, 2017; Bracher et al., 2017). This differentiation from remote sensing data and *in situ* methods is possible due to differences in pigment composition of various algal groups and the absorption characteristics of these pigments. For this differentiation, HZG's unique, large database of light absorption spectra for different phytoplanktonic algae from culture work is used. The main outcomes are that the differentiation of specific groups is possible when directly based on reflectance. Other substances, such as suspended matter and gelbstoff, do not interfere with the results as long as they are not optically dominant. Inversion approaches for retrieve algal absorption from remote sensing reflectance are not accurate enough to use absorption-based approaches for

the group differentiation. This work is in preparation for the German ENMAP mission, the first full hyperspectral optical satellite mission.

### 4.3.3 EMBEDDING IN PACES II

The Research Unit *Operational Systems* contributes to Topics 2 and 4 of the Helmholtz program PACES II, with approximately equal parts.

Topic 2

In Topic 2, the Research Unit *Operational Systems* leads work package 5 *Interface processes and physical dynamics of the coastal ocean* (B. Baschek). While all FTEs are placed at HZG, there is an ongoing collaboration with AWI (S. Wohlrab, D. Abele) on the physical-biological interaction in submesoscale eddies, including an AWI-participation in the *Expedition Clockwork Ocean*.

It is the mission of WP5 in Topic 2 to "understand the small-scale dynamics of the coastal ocean in connection with fronts, turbulence, and interface processes under present and changing environmental conditions". The work package focuses on small-scale processes that have significant impact on coastal ocean dynamics. These are described in detail above and are in particular:

- Submesoscale processes: Observe and understand submesoscale physical dynamics, determine the role of submesoscale processes in the local energy cascade
- Phytoplankton dynamics: Determine the role of small-scale physics and interface exchange processes in biogeochemical processes and phytoplankton dynamics
- Exchange and mixing across interfaces: Quantify and improve the understanding of exchange processes between ocean and atmosphere and across fronts and thermocline; determine the role of local micro-turbulence
- Waves, currents, and sediment transport: Better understand wave physics and turbulence in shallow water
- Risks and changing environmental conditions: Determine the influence of offshore wind parks on the North Sea, understand the physical and biogeochemical factors leading to a formation of harmful algal blooms.

Topic 4

The developed methods, instruments, and observational approaches are unique contributions to the PACES II program and provide, in particular, an excellent framework for the integrated study of the impact of offshore wind parks on the North Sea (see Major Highlight, chapter 3.2). As cross-cutting theme of Topic 2, it provides several links to the other work packages in Topic 2 (with Research Units *System Analysis and Modeling* and *Biogeochemistry in Coastal Seas*, as well as with AWI) and to the coastal observatory COSYNA and Research Unit GERICS (RU 4) in Topic 4.

In the framework of COSYNA, the Research Unit *Operational Systems* has significant contributions to WP1 and WP2 of Topic 4. It is the mission of WP1 to "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". As the development and operation of COSYNA are led by research unit *Operational Systems*, the following objectives are of particular importance in this context:

- Design and implementation of an efficient pre-operational observing system
- Provision of enhanced pre-operational products of societal, economical, or scientific relevance
- Availability of multi-faceted system models and information systems
- Harmonizing data and technology by international standards; Implementing quality management in workflows

The Research Unit *Operational Systems* contributes to Topic 4 through COSYNA and the closely connected research theme *Optical Characteristics of Coastal and Oceanic Waters*. The value of a preoperational system, such as COSYNA, can be maximized by addressing practical issues of economical or societal relevance. The benefit of the system's enhancement is demonstrated 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.

The integrated observing system COSYNA (Major Highlight, chapter 3.2) is developed in collaboration with research units *System Analysis and Modelling* (data assimilation and forecasts) and *Biogeochemistry in Coastal Seas (observations of sea floor exchange processes)*. The European infrastructure project DANUBIUS (see chapter 3.2) provides an excellent framework for future expansion of COSYNA towards the heavily used Elbe River. COSYNA is being developed and operated in close collaboration with ten national partner institutions. In particular, AWI has several contributions in PACES II, such as the Automated Filtration System (AUTOFIM) (Metfies et al., 2016) and in particular the joint development of the COSYNA Underwater Node System and its operation off Helgoland and Svalbard. COSYNA and Research Unit *Operational Systems* also contribute to several Helmholtz projects, such as the Earth System Knowledge Platform (ESKP), Modular Observation Solutions for Earth Systems (MOSES), Advanced Remote Sensing – *Ground Truth* Demo and Test Facilities (ACROSS).



### 4.3.4 FUTURE FOCUS AREAS (POF IV)

The focus of the Helmholtz research field *Earth and Environment* for the next program oriented funding period is to improve our understanding of the complex interactions in Earth's subsystems in a changing environment. Particular focus is given to processes bridging compartments as well as different disciplines, ranging from natural sciences to humanities.

The coastal zones are a prime example with strong interactions between ocean, land and atmosphere, very high natural variability and a quickly changing environment due to intensifying regional and global change in addition to an increasing coastal population and use. The land-sea transitional zone is therefore one of nine future focus areas of the Helmholtz Research Area *Earth and Environment* requiring a joint system's approach of HZG in collaboration with the Alfred Wegener Institute, GEOMAR, and the Centre for Environmental Research (UFZ).

The Research Unit *Operational Systems* strives to further expand the integrated coastal observing system COSYNA in collaboration with all Research Units at HZG. In this context, the observational infrastructure project *Modular Observation Solutions for Earth Systems* (MOSES) is a key component. It has started in 2017, and while the initial funding period is for a duration of 5 years, a roadmap process is planned for an even larger joint infrastructure. The Research Unit *Operational Systems* is already strongly engaged in MOSES, leading the event chain *Ocean Eddies* while contributing to the event chain *Hydrological Extreme Events* investigating flood events of the Elbe River, with a strong COSYNA component. A combination with the infrastructure project DANUBIUS (see RU 2, chapter 4.2) and the

Earth System Modeling project (see RU 1, chapter 4.1) will be equally important components toward a system's approach in this land-sea transitional regime connecting the river catchment of the Elbe river with the German Bight and North Sea. Of particular interest are hydrodynamic extreme events, such as severe flood scenarios, and their impact on phytoplankton productivity and carbon fluxes in the North Sea. Continued focus will be also given to the impact of large-scale offshore wind farms on North Sea stratification and circulation.

In order to also carry out observations in other coastal areas of the world, the development of highly mobile observational platforms and autonomous energy supplies is another focus. The observations are part of a long-term plan to expand local and regional results to larger scales and work towards establishing a quantitative base for evaluating the role of coastal regions in a global context, thus evaluating the importance of the "global coast" for carbon fluxes.

Another key focus area is to improve the awareness and understanding of complex small-scale interdisciplinary processes that drive many processes in the coastal ocean and that cannot be resolved with traditional observing techniques or modelling. Currently, the Research Unit *Operational Systems* has a worldwide unique observation capability to target these small-scale physical and biogeochemical processes in an integrated way. Several different studies are currently planned so that the observational techniques will be further improved and expanded.

These are, for example, the coupling of submesoscale and mesoscale eddies in the MOSES event chain *Ocean Eddies*, stationary zeppelin measurements above offshore windfarms, high-resolution *in situ* observations of exchange processes between Wadden Sea and North Sea, or simultaneous PIV measurements of the air-sea interface in and above the water surface. Of particular interest are processes along small-scale and sharp interfaces, such as submesoscale fronts or the thermocline, as well as storm conditions. The measurements will be based on the extensive expertise of the research division in this field and are aimed at closing the significant observational gap at small-scales and high wind speeds. Observations will be compared and interpreted with DNS, LES, and ROMS models. The overarching goal is to better understand the coupling of physical and biogeochemical processes and the role of small-scale processes and extreme events for local energy transport and dissipation as well as phytoplankton distribution and productivity.



### 4.3.5 CAREER DEVELOPMENT

The division Operational Systems is engaged in teaching at the University of Kiel (B. Baschek) and the University of Hamburg (J. Carpenter). Through this teaching commitment, several BSc, MSc and graduate students have been recruited to work on their theses at HZG. In addition, B. Baschek is participating in PhD and MSc Committees at the Alfred Wegener Institute, GEOMAR, and the University of Kiel. J. Carpenter is involved in PhD Committees at the University of British Columbia, Canada, as well as at the Institute for Baltic Sea Research in Warnemünde. J. Horstmann is member of a PhD committee at the University of Alcala, Spain.

Currently 5 PhD and 2 MSc students work on their theses in this research division, with degrees to be awarded through the University of Kiel, the University of Hamburg, and the Hafen-City University in Hamburg. In addition to the official requirements of their universities with bi-annual committee meetings, all students are engaged in very close collaborations with direct advisers at HZG, with daily to weekly interactions. The students shall have at least one internationally renowned scientist on their committees and have the opportunity to visit them at their institutions (e.g. Scripps Institution of Oceanography, Naval Research Laboratory) to broaden their background and network.

In addition, all graduate students are invited to participate in a joint monthly lunch with division head B. Baschek. All students and postdoctoral scientists are encouraged to attend key international conferences at least once a year and are offered strategic career development discussions with the

division head, ideally twice a year. The meetings are aimed at preparing the young scientists for their next scientific career steps early on – independent of their prespective at HZG.

Particular focus is given to the most promising young scientists in their field. At the career stage between PhD and a faculty or permanent research position, the division Operational Systems aims at providing young scientists with an unusual amount of resources for equipment, travel, access to technicians or BSc or MSc students in order to help them develop their careers quickly and in a focused manner. Currently, four postdoctoral researchers are given the opportunity to develop their careers into permanent positions and start their own small research groups. This development takes initially place under the umbrella of an existing research department to reduce the administrative burden and offer guidance.

One young scientist (J. Carpenter) has arrived at HZG in late 2013 and has subsequently developed his new group into a very productive and innovative research department focused on small-scale physics and turbulence with a unique combination of observations and high-resolution modeling.

The annual Summer School is conducted in cooperation with the Leibniz Institute for Baltic Sea Research Warnemünde, AWI, and the KüNO (Coastal Research in the North Sea and Baltic Sea) umbrella project. The school has been held annually since 2010, with various topics related to coastal research. HZG's contribution is organized by G. Flöser.

# 4.4

# RESEARCH UNIT 4 CLIMATE SERVICE CENTER GERMANY (GERICS)

## 4.4 RESEARCH UNIT 4: CLIMATE SERVICE CENTER GERMANY (GERICS)

Director Prof. Daniela Jacob

### 4.4.1 OVERVIEW

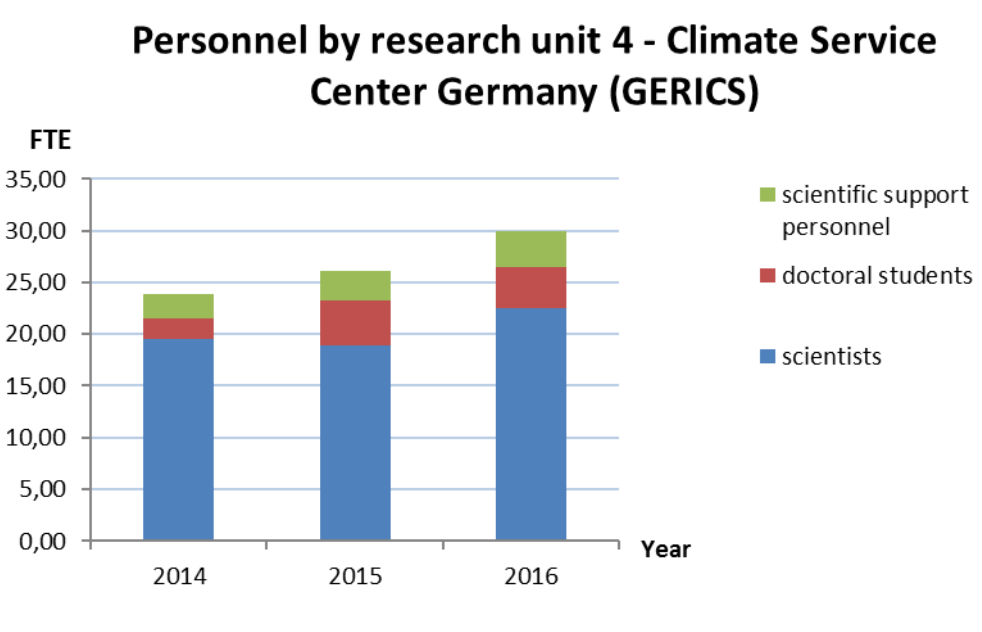



Figure 43: Development of Full Time Equivalent (FTE) Personnel of RU 4. Please see figure 3 for detailed information about the contribution of HZG-Research Units to the Helmholtz-Program PACES II in 2016.

As scientific knowledge related to climate change advances, decision-makers in the public and private sector have an increasing need for information with respect to the impacts of climate change in their specific field of activity. This is precisely where climate services come in. Climate services can be defined as the transfer of decision-relevant climate knowledge to a variety of users in the form of tailor-made products and services. In order to meet these needs, **GERICS' mission is to offer in a scientifically sound manner, prototype products, advisory services, and decision-relevant information in order to support government, administration, and businesses in their efforts to adapt to climate change.**

The German Government, recognizing this need, established the Climate Service Center in 2009 at HZG, initially as a pilot project. The director in these development years was Prof. Dr. Guy Brasseur, and the Center was one of the first of its kind in the world. As such, the Center played a leading, and in many ways pioneering role in developing the field of Climate Services, which continues to this day. In June 2014, the Center became a scientific organizational entity of HZG. Since then climate researcher and former department head Dr. Daniela Jacob took the lead as acting director of the *Climate Service Center 2.0*, and in June 2015, she was appointed as the new director. In July 2015, the Center was renamed the *Climate Service Center Germany* (GERICS). This new name was required for trademark reasons.

According to the existing business model the main objectives of GERICS are:

(1) to clarify the decision makers' current information needs with regard to climate change and related direct and indirect impacts,

(2) to develop prototype tailor-made products and services for different stakeholders, actors and decision makers in the public and private sector, based on state-of-the art knowledge in close cooperation with different partners,

(3) to verify the use of these products, and

(4) to foster their operationalization.

GERICS' climate service products are provided in a customized, easily accessible and immediately usable form. They offer complementarity to one another, and are intended to be applied to a certain region (e.g. a city, mountain region, or delta). They can be used as stand-alone products, or in combination with each other, and they help support the decision making process towards climate-smart development. GERICS' products are characterized as being conceptually generic, such that they may be easily transferred and applied to other applications and/or regions. Intellectually, GERICS' products center around two main themes, one which is termed toolkit-focused, and the other data-focused. The latter product group contains different types of fact sheets, maps, and charts, while the toolkit-focused products comprise different toolkits for consultancy, based on a modular design. While there is a different intellectual emphasis in the two product types, it should be clear that both are based on a variety of high-quality data, including highly spatially resolved regional, and/or local climate data.

At present (October 2017), GERICS has a total staff of 49 (male: 23, female: 26). The scientific staff numbers 44 (male: 23, female: 21, including 7 doctoral students (male: 6, female: 1)) with an additional administrative staff of 5. GERICS (RU 4) is organized in four departments, mainly for administrative purposes. Since an interdisciplinary and cross-sectoral approach is fundamental to the work of GERICS (RU 4) and its success, the working practices of GERICS (RU 4) are almost exclusively organized in cross-departmental, inter- and transdisciplinary projects and project teams.

Over the past few years the strategic direction of GERICS' work has changed from previously being a pure service provider, to a more creative innovation hub today, following the idea of **Science for Solutions**. GERICS, as a multidisciplinary institution, has developed into a central network partner, contributing to putting knowledge and evidence into use. This is done mostly in close cooperation with partners from both science and the public and private sectors. GERICS successfully applied the process of co-development and co-evaluation of products with practitioners from different backgrounds from government institutions e.g. the German Development Bank KfW; cities e.g. Bleckede; and private businesses e.g. BASF SE. To satisfy the different decision makers' needs for information and to put the developed products into use are of paramount importance for GERICS (RU 4).

Another key principle of how GERICS works is that participation in third party funded projects represents an essential element in developing innovative climate service products. Indeed, this is an area in which GERICS has been highly successful during the reporting period, and is currently involved in 22 projects (from funding programs including EU Horizon 2020, EU Life, Copernicus Climate Change Service, and BMBF). During the reporting period, Professor Jacob was also appointed by the EC as member of the expert group that designed the European Roadmap for Climate Services (European Commission, 2015), which has been implemented through EU Research and Innovation Horizon 2020, and beyond.

Overall, GERICS' main task involves developing and providing prototype products and innovative concepts, jointly with different partners and networks from science and application. After having developed a prototype product or service successfully, the prototype can be handed over to third parties who are interested in operationalizing the product. Co-developing prototype climate service products require trust, transparency and quality control, as well as the appropriate scientific and technical climate service infrastructure. All details are described in chapter 4.4.2.

Topic 4

### 4.4.2 SCIENTIFIC AND SERVICE RESULTS AND GOALS

Changes related to weather variability and climate create great challenges for society. Today, in many regions of the world, existing infrastructure is already vulnerable to extreme weather conditions. For example, in the last years unusually heavy rainfall has caused floods also in Germany, resulting in severe damage to infrastructure, households, and businesses. Because the lifetime of infrastructure assets typically ranges from a decade to many decades, it is important that changes in climate are considered at the planning stage of such investments. Many related political and business decisions will have a major impact on how future economies and societies develop. A complicating factor is that decision makers often do not have the necessary knowledge or expertise to incorporate the issue of a changing climate into their decision-making processes, and the use of climate information in specific regions or sectors is often challenged by a lack of suitable information, or capacity to make the information accessible to users.

GERICS supports decision makers to better cope with regional and sectoral impacts, risks and opportunities related to climate change, with reliable and comprehensive information based on state-of-the-art scientific evidence. The priority sectors are water, energy, ecosystems, and the cross-sectoral field of urban areas. To foster the long-term establishment of high quality climate services on the national and international level, GERICS contributes to international climate service networks, for example the Climate Services Partnership (CSP), which was co-founded by GERICS. Moreover, GERICS also advises and supports climate service institutions at the international level, performs training workshops for consultants, and in 2015 established the new open access journal Climate Services (with Elsevier).

Central to the work of GERICS is the development of prototype products and services in cooperation with users. The corresponding development process is based on several years' experience in the field of climate services. It is described in detail in an internal report (Petersen and Seipold, 2017, in German only). Here, the prototypical development of climate services is defined as the development of new and innovative, research based information, procedures and methods, which integrate climate knowledge into decision making processes. **New and innovative** translates to the generation of value adding content through a climate service product. Generally, the prototypical development is performed in a process of co-design and co-development in cooperation with application and research partners, in order to best meet the user requirements for a specific question (Figure 44).

The resulting prototype products can be transferred to other regions, topics, users and/or sectors. GERICS has also developed quality management and evaluation strategies for the development process of the products and the products themselves. During the development process, all prototypes are tested regarding their applicability and fitness for purpose. Eventually, these can be handed over to suitable service providers for operationalization.

However, so far, a number of significant obstacles and barriers have been identified along the chain between having finalized a prototype, its operationalization by external partners, and finally its market launch. In order to overcome challenges and barriers in the operationalization of prototypes, in early 2017 the project **Bridging the gap** (funded by HZG Technology Transfer Funds) was initiated. Two prototype product examples from GERICS' portfolio with different characteristics will serve to analyze relevant obstacles and barriers. Approaches for suitable solutions will be identified and appropriate measures will be developed.

In addition to barriers in the operationalization process, comparable obstacles to climate change adaptation have been illustrated, which include inappropriate institutional structures, limited financial and human resources, lack of awareness and knowledge (Groth and Nuzum, 2016; Weyrich, 2016). Also, barriers in applying climate services (EU-MACS[1]) have been assessed and include technical capacities, and, again, financial resources. GERICS uses this learning to try and develop solutions that may help to overcome or reduce these barriers.

[1]EU-MACS - European MArket for Climate Services (11/2016 - 10/2018), funded by EU H 2020

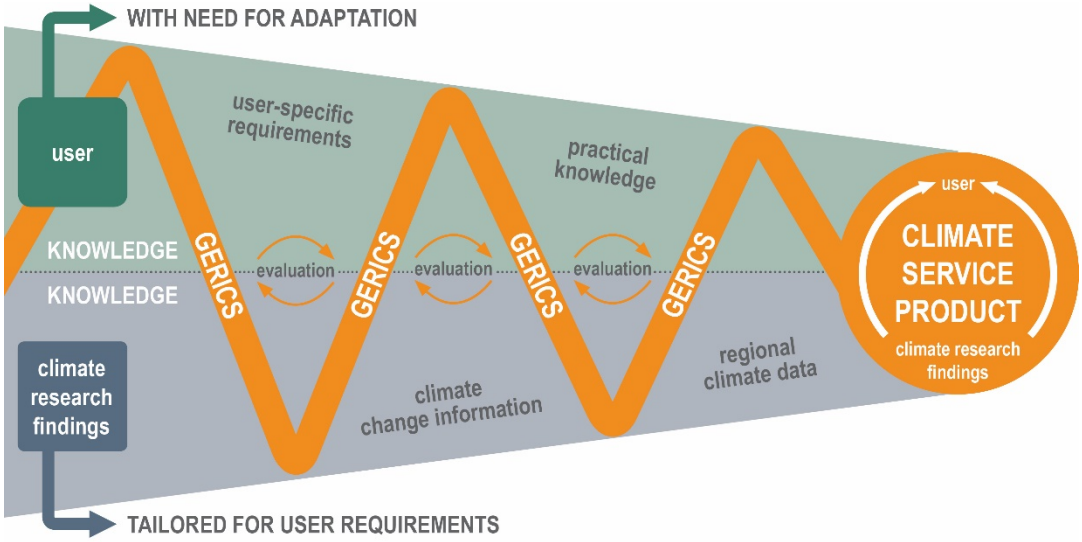



Figure 44: Schematic representation of the process of generating a climate service product, employed at GERICS

Topic 4

## Innovative Prototype Products and Concepts

Regions, for example metropolitan areas, or deltas, are constantly subject to different change processes which puts pressure on them to adapt, such as e.g. demographic and economic change, and of course climate change. The long-term management of such a region requires a comprehensive understanding of the whole system. The development of GERICS tools, methods, products and services is intended to fit within the framework of such a regional system analysis. They deliver in a comprehensive and coordinated manner, facts, data, methodologies, models, toolkits and dialog formats for supporting decisions. Due to climatic and non-climatic drivers, numerous interactions between different sectors and a high number of different interests, integrated and holistic approaches are needed to equally address the different dimensions. With respect to user needs, mostly local or regional solutions are requested. To answer these questions, the combination of local climate information with other local information is essential to develop, design, and finally implement adaptation measures. GERICS focuses on assuring the adequate use of local climate information at the kilometer scale by providing its climate service products. Many of these are tailor-made prototype products and are often based on, or make use of, an unprecedented ensemble of high-resolution climate simulations analyzed and post-processed in the frame of EURO-CORDEX[2] (Jacob et al., 2014). Generally, these products are developed such that they are customized, easily accessible, and are made available in an immediately usable form. Examples for both the toolkit-focused and data-focused products are described below.

*Toolkit-focused products*

*Regions, sectors, and users need scientifically sound, tailor-made climate information, knowledge and support*

GERICS developed the concept of a modular consultation framework to meet individual user needs on a local and regional level. Currently, two modular toolkits are available, the adaptation toolkit for cities (hereafter referred to as the **Stadtbaukasten**), and the adaptation toolkit for companies (hereafter referred to as the **Unternehmensbaukasten**). Both consist of a variety of tools, which can be individually tailored to the specific requirements of the users. The co-development and proof of concept as well as the added value of the products are always carried out with the user. A third

[2]EURO-CORDEX European branch of the international CORDEX initiative, funded by the World Climate Research Program (WRCP)

toolkit, the **Regional Modeling Toolkit**, is under development and will provide the frame for simulating climate change together with its impacts at the regional to local level.

In order to adapt and develop an entire region under changing climatic conditions, a variety of factors have to be taken into account, and various key stakeholders have to be consulted. Sometimes, regional to local climate change information has to be generated using new tools and research. In addition, methods to present new findings and existing information have to be designed. With respect to the development of climate resilient and sustainable urban regions, city planners and all other partners involved need to consider climate change impacts and their interactions with other drivers. It is within this context that the **Stadtbaukasten** has been developed. The main concept of the Stadtbaukasten is the combination of an ensemble of climate information with other data on urban issues using model chains, and a modular approach. In view of the administrative structures in place and due to cost savings, all adaptation processes and actions are implemented into existing planning and decision processes. The Stadtbaukasten is designed to identify the vulnerability of a city, illuminate potential adaptation measures, and associated benefits (see Highlight 1).

Businesses are of course also affected by climate change. Therefore, another modular prototypical product, the **Unternehmensbaukasten**, has been developed to support the company-specific identification, development, and implementation of suitable climate change adaptation measures into relevant business areas. Both toolkits build on presently available climate change information.

The **Regional Modeling Toolkit** (RMT) being developed contributes to the sustainable management of a region by carrying out very detailed local scale modeling to support science-based decision making for adaptation. The RMT is built around a System Dynamics modeling approach, which will be capable of simulating climate impacts for all relevant sectors in a given region, together with cross-sectoral impacts. In addition, the RMT will simulate the effect of stakeholder decisions on the relevant climate impacts. The aim is to identify direct and indirect climate change impacts, where different factors are influencing each other. In order to investigate the interplay between different components of the Earth System (including human systems) in a given region, the flexible tool will consist of modules for modeling regional climate and hydrological impacts, integrated assessment and economy as well as modules representing cost benefit analyses, participatory approaches for stakeholders and prioritization tools. Elements of this work are being undertaken in the recently started project **Advanced Earth System Modelling Capacity** (ESM), which is partly funded by the Helmholtz Association (HGF). Furthermore, parts of the coupling process of socio-economic system dynamics and regional climate/environmental/city/land-use models are conducted within the project IMPREX[3] (see Highlight 2).

*Data-focused products*

*Innovative visualisations ease access to complex climate information*

The **Climate-Fact-Sheets** provide a concise summary of the major information (i) about the climate of a country or region for past, current and future development (ii) with focus on the projected future changes (iii) using short text passages, tables and different diagrams on typically 6 to 8 pages (iv) based on primary data (e.g. projections from global and regional climate models as well as global observational datasets) and literature review. The Climate-Fact-Sheets (developed since 2011) have been updated using the databases of the IPCC AR4 and AR5, and following the success, additional Climate-Fact-Sheets were compiled on behalf of the German Development Bank KfW. A first evaluation based on three prototype Climate-Fact-Sheets was organized in 2011. As a follow up, KfW staff adapted the concept.



[3]IMPREX - IMproving PRedictions and management of hydrological EXtremes (10/2015 - 09/2019), funded by EU H2020

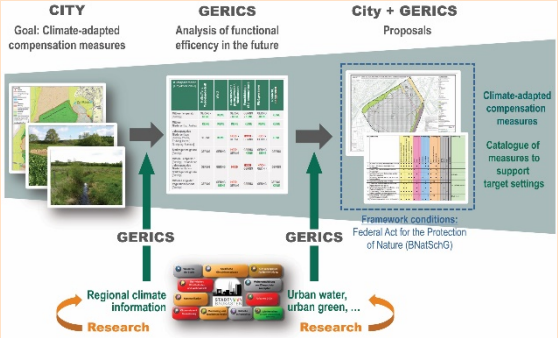
Topic 4

## Highlight 1: Stadtbaukasten – helping cities adapt through a flexible and practice-oriented modular toolkit approach

In order to identify the specific opportunities and challenges arising from climate change for a city, it is necessary to understand all risks related to climate change throughout the entire urban adaptation process. Therefore, the focus of all related activities has to be on the whole system instead of single elements, to avoid misleading action in sectors that were overlooked or otherwise not considered. The Stadtbaukasten provides eleven module groups that cover the most important fields relevant for cities to plan, develop and implement adaptation actions, such as urban water, urban green, climate-resilient urban development or critical infrastructure. The Stadtbaukasten enables cities to exploit opportunities and to reduce risks related to climate change.

- Cooperation with: Kiel (Federal state capital Schleswig-Holstein), Bleckede (small municipality on the River Elbe), Bremerhaven (one of the most important ports in Germany).
- For more information see Cortekar et al. (2016), Bender et al. (2017a).

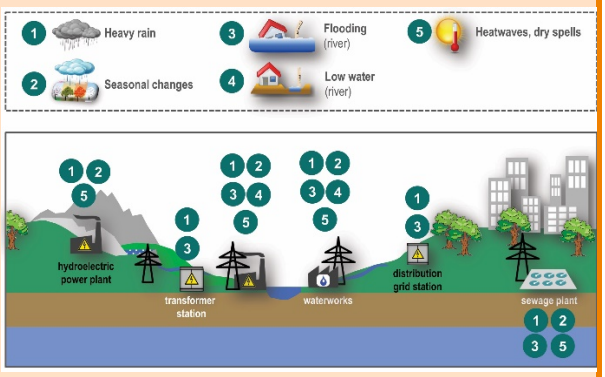
***Case study 1:*** *Stadtbaukasten-module "Climate proofing of compensation measures"*




- Conducted on behalf of the Environment Agency of the city of Kiel.
- Main goal: co-development of compensation measures that are not only climate-proof for today's climate conditions, but also maintain their functionality under future climate conditions.
- Important feature: combination of regional ensemble climate information with local expert knowledge.
- For more detail see Bender et al. (2017b).

***Case study 2:*** *Stadtbaukasten-module "Climate adapted (critical) infrastructure"*

- Conducted on behalf of the German Technical and Scientific Association for Gas and Water (DVGW).
- Main goal: to raise awareness of cities' vulnerability to complex interactions of non-climatic and climatic drivers on all infrastructure elements.
- Focus: impact of extreme weather events on water extraction plants.
- For more detail see Bender and Jacob (2016).



Topic 4

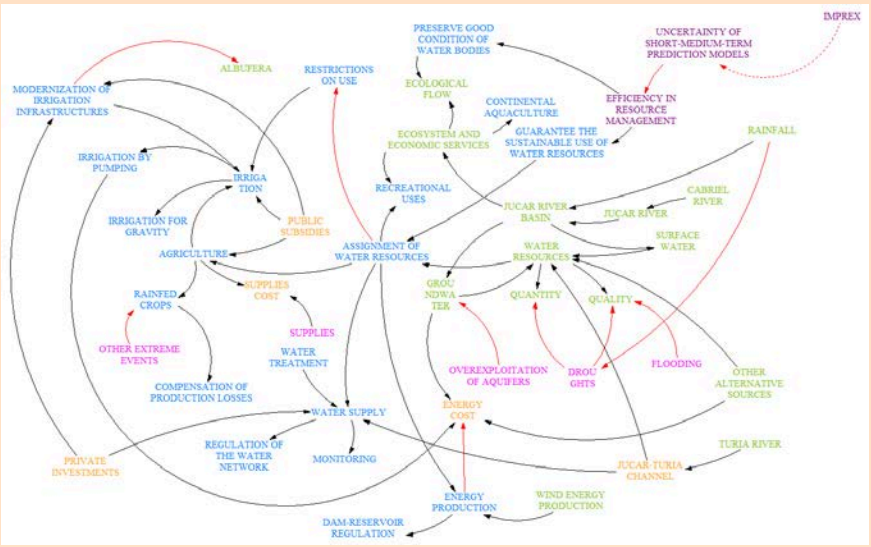
## Highlight 2: IMPREX - building an integrated interdisciplinary model family

The H2020 project IMPREX aims to improve society's ability to anticipate and respond to future hydrological extreme events, e.g. floods and droughts in Europe. The knowledge developed within the project will support risk management and adaptation planning at European and national levels. For more information see: www.imprex.eu.

- Within IMPREX, GERICS leads the work on sectoral integration and climate services.
- Main goal: advising on real-world problems related to climate adaptation and mitigation.
- Tool: integration of interdisciplinary knowledge into the modeling process by coupling socio-economic systems dynamics modeling with natural science models and data.
- Important features: region-specific modeling based on stakeholder experience, natural science expertise, and innovative socio-economic modeling approaches.

***Case study:*** *Júcar River basin*

**Challenge:** to investigate how a change in the provisions of water uptake for the agricultural sector influence water management and adaptation.
**Approach carried out by GERICS:** (i) problem identification and structuring using individual model building exercises; (ii) problem analysis using group model building exercises; (iii) building a family of models to provide results that can be used at the local level for making decisions.
**Partners:** key stakeholders of the Júcar River Basin Authority, e.g. AGROSEGURO, Central Irrigation Board of La Mancha Oriental, EMIVASA.




*Group model (left) and Individual models (right) for the Júcar River Basin (Spain) based on GERICS-interviews with eleven stakeholders representing the use and availability of water resources of the Júcar River.*

Currently an external evaluation by more users is being prepared. Meanwhile, 52 Climate-Fact-Sheets are available. Soon, 14 additional Climate-Fact-Sheets will be produced on behalf of the International Fund for Agricultural Development (IFAD). The Climate-Fact-Sheets are widely used in practice: in addition to the KfW, about 300 additional users from different sectors and regions are registered.

The GERICS Climate-Fact-Sheet concept was used to compile climate change information for the German federal states administration in a fact sheet called **Klimaausblick Brandenburg** developed as a prototype jointly with the state of Brandenburg. In addition, GERICS developed the concept further in the frame of the Copernicus Climate Change Service (C3S) activity CLIM4ENERGY [4]. A collection of sector-specific Climate-Fact-Sheets is currently being co-designed with leading European energy providers focusing on climate impact information for the European energy sector. Driven by the need for local, site-specific climate change information, the so-called **Site-characteristic Climate-Fact-Sheets** were co-developed with the chemical group BASF SE for the BASF production site Ludwigshafen on the Rhine river, also based on the concept of the Climate-Fact-Sheets for regions. Recently, another Site-characteristic Climate-Fact-Sheet was compiled for the Port of Hamburg on behalf of the Hamburg Port Authority (HPA). This fact sheet is summarily described in Highlight 3.

In addition, the format of GERICS' **Climate-Focus-Papers** (CFP) was also originally co-developed with the KfW, primarily for KfW project managers. CFPs provide a short and up-to-date overview of a selected topic. To date, three CFPs have been produced, one on **Global Sea Level Rise**, another on **Regional Sea Level Rise - South Asia**, and one more on **Cities and Climate Change**. Moreover, a fourth Focus Paper which is being produced exclusively by GERICS on **Uncertainty in climate information** is currently being finalized; and one more on **Climate Change and Water Quality**, in cooperation with the UFZ, Leipzig, is in the planning phase. The concept of the Focus Paper has recently been adopted and extended in the project CLIM4ENERGY, to produce a Focus Paper on **Climate Change in the Energy Sector**, together with international partners.

The **Climate Signal Maps** (Pfeifer et al., 2015) are intended to provide easily understandable information about the robustness of projected climate change. Robustness is determined on the basis of the level of model agreement with respect to the direction of change, and the statistical significance of the changes. Climate Signal Maps, however, do not show all available information in the projection ensemble, but rather condense the information. They are thus comprehensible for non-climate experts as well. Climate Signal Maps can be represented based on the model's grid points or on physical or administrative regions. The method has been developed for German administrative districts. It was subsequently applied on European scale for use in the CLIPC[5] web-portal.

GERICS' **Climate Impact Hotspot Mapping** was developed in collaboration with and for the KfW. It is a four-page document, showing areas where climate impacts may be particularly severe, and thus are identified as hotspots of potentially large adaptation need. Three impact sectors were analyzed: water, agriculture, and ecosystem services. This analysis made use of state-of-the-art modeling results from the ISI-MIP[6] project, which provides the most complete data set on which to develop a consistent analysis, where uncertainties in modeling are incorporated, and used to provide preliminary information on the confidence that may be had in the analysis (Warszawski et al., 2013). This work was done at the global level, but three example reports for Brazil, India, and Senegal have been produced.

Together with partners from the German states, GERICS developed the **Rain Map** (referred to as **Regenkarte**), visualizing projected changes of precipitation in a way that they can be quickly grasped while showing the most important user relevant information including the direction and strength of the mean changes and their statistical significance. The Rain Map is based on the most recent high-



[4]CLIM4ENERGY - A service providing climate change indicators tailored for the energy sector (01/2016 - 03/2018), funded by Copernicus Climate Change Service (C3S)
[5]CLIPC - Climate Information Platform for Copernicus (10/2013 - 09/2016), funded by EU FP7
[6]ISI-MIP - Intersectoral Impact Model Intercomparison Project, initiated by PIK and IIASA

resolution ensemble data from EURO-CORDEX and the method can also be applied to other climate parameters.

*Synthesis and dissemination of scientific knowledge*

*Compendia to summarize starte-of-the-art research knowledge for specific topics and regions*

In addition to a large number of scientific papers published in scientific journals, GERICS publishes different formats including reports and studies for a readership with distinct previous or specialized knowledge in different thematic fields. In order to better disseminate scientific knowledge to interested parties, GERICS adheres to the principle of Open Access.

In the frame of the preparation of Assessment Reports, GERICS coordinated and published the book **Klimawandel in Deutschland** (Climate Change in Germany), which required a large community effort. It is the first peer-reviewed book of its kind in the German language, which assesses and summarizes both observed and projected changes in climate, and associated impacts in a wide range of different economic sectors. The book was initiated, coordinated, and edited by GERICS, and contains contributions from more than 120 leading researchers in Germany, and is freely available as an eBook (Brasseur, G. P., Jacob, D. and S. Schuck-Zöller, eds., 2016). The target groups are decision makers in Germany. The book or single chapters have been downloaded from the Internet more than 354,000 times (by the beginning of November 2017).

Inspired by the NRC (National Research Council) Reports, GERICS prepared an assessment report **Der Einfluss des Klimawandels auf die terrestrischen Wassersysteme in Deutschland** (The influence of climate change on terrestrial water systems in Germany; Bender et al., 2017c). The synthesis report summarizes the results of 29 selected studies on this issue and gives an overview of the present scientific knowledge regarding both surface and subsurface systems, from the global to the local scale in Germany. Other subjects addressed were the current knowledge gaps and future developments in the water sector.

Three **policy briefs** were published in the frame of the EU project **IMPACT2C**[7], coordinated by GERICS. The project investigated the impact of 1.5 and 2°C warming above pre-industrial times on various economic sectors in Europe, and for selected vulnerable hotspot areas in Africa and Asia. These briefs were of major policy relevance, especially with regard to the Paris Agreement. Moreover, the impact of the work in IMPACT2C is further evidenced by the inclusion of an assessment of cross-sectoral climate impacts in the European Environment Agency 2017 report (EEA, 2017).

In 2015, instigated by GERICS, Elsevier established the **open access journal *Climate Services***, of which Professor Jacob is the Chief-Editor (https://www.journals.elsevier.com/climate-services). The journal addresses both researchers in the field of climate service research, and practitioners interested in or already applying climate services. This is reflected in a new climate service article type, which contains a classical scientific part as well as a chapter with easily understandable practical implications for policy makers and other practitioners. As such, the journal provides a platform for scientists to present their co-development approaches and results, in a unique style in the field of climate services.

Topic 4

## Engaging with stakeholder communities: practitioners and scientists

The generation of user-driven and science-based highly resolved local climate information for particular regions or applications, and the development of tailor-made information for decision-makers requires an interdisciplinary and transdisciplinary development of knowledge. Access to the best available scientific know-how and high-performance computers is necessary as well. Networking, joint research in active networks and establishing relations of trust are therefore essential to identify users' needs (user-driven) on the one hand, and to provide the respective local climate information (science-based) on the other.



[7]IMPACT2C - Quantifying projected impacts under 2°C warming (10/2011 - 09/2015), funded by EU FP7

*Variety of stakeholder communities*

*Engagement in high-level networks for joint development of climate service prototypes*

The variety of networks in which GERICS is involved, and the close cooperation with a large number of different institutions and practitioners are of particular importance for GERICS' leading role in developing and providing climate services. Due to its own research activities, the participation in national and international research projects, the active involvement in scientific networks and the development of strategic partnerships with other scientific institutions that are working in this field, GERICS has excellent access to state-of-the-art climate knowledge. In addition, GERICS hosts different secretariats, which allows a comprehensive transfer of climate knowledge to stakeholder groups worldwide: the EURO-CORDEX secretariat, the secretariat of the international Climate Services Partnership (CSP) and the Earth League secretariat, the administrative office of Helmholtz-Institut Climate Service Science (HICSS); the editorial office of the Journal Climate Services.

GERICS establishes national and international networking structures that comprise the following groups of actors:

- potential and key customers (and multipliers) with identified demands, including KfW, BASF SE, HPA (Highlight 3), Stiftung 2°, Klimaschutz-Unternehmen e.V., the cities of Bleckede and Bremerhaven,
- scientific partner institutions from different disciplines which provide basic scientific results including Helmholtz Centers, universities, MPI für Meteorologie, DKRZ, and IPSL,
- partners with strong expertise in transdisciplinary processes, consultancy, education, capacity development, and governance including the Leuphana University Lüneburg, Technische Universität Hamburg-Harburg (TUHH), and European Financing Institutions Working Group on Climate Change Adaptation (EUFIWACC).

The networking activities are carried out in different ways and with different aims in order to

- build expert communities that exchange their knowledge internally e.g. the group of regional climate modeling experts in CORDEX and EURO-CORDEX,
- bring together practitioners and scientists and matching them personally to address specific questions e.g. CSP, ENHANCE[8], CLIM4ENERGY, IMPACT2C,
- explore, enhance, and evaluate transdisciplinary research processes, e.g. IMPREX, NAIAD[9] and INNOVA[10],
- develop and publish an up-to-date and comprehensive knowledge base in inter- and transdisciplinary networks, e.g. the web-portal *Klimanavigator*, see: Climate Service Infrastructure, and national assessment *Klimawandel in Deutschland*.

In order to further strengthen GERICS' co-development process, GERICS is continually learning about the range of different users and their different needs with respect to climate service prototypes. This learning has been achieved through a mixed-methods approach, for example with the **Stiftung 2 Grad**, and the **Unternehmensnetzwerk Anpassung**, and also within third-party funded projects, e.g. the C3S projects SECTEUR[11] and DECM[12], and MiKlip II[13]. One finding from this work has been that some users want raw data, while others are more interested in derived products and toolkits.

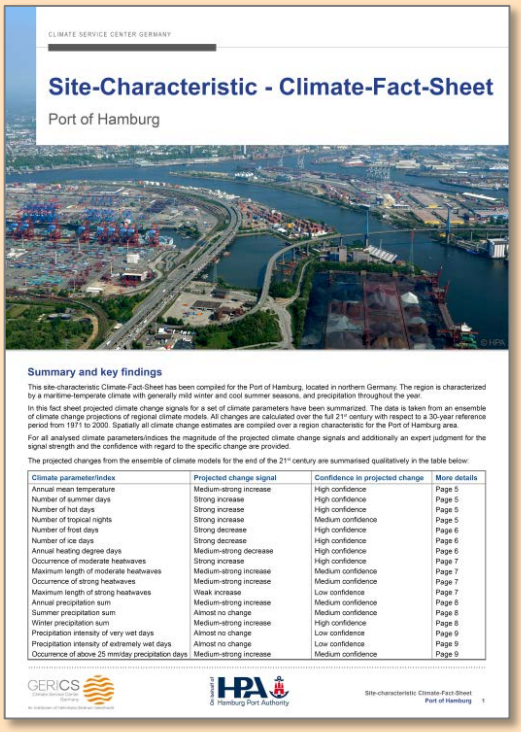
[8]ENHANCE - Enhancing risk management partnerships for catastrophic natural disasters in Europe (12/2012 - 11/2016), funded by EU FP7
[9]NAIAD - Nature Insurance Value: Assessment and Demonstration (12/2016 - 11/2019), funded by EU H2020
[10]INNOVA - Innovation in Climate Services Provision (10/2017 - 09/2020), funded by BMBF and EU-ERA4CS
[11]SECTEUR - Sector Engagement for C3S, Translating European User Requirements (05/2016 - 01/2017), funded by Copernicus Climate Change Service (C3S)
[12]DECM - Data Evaluation for Climate Models (08/2016 - 12/2017), funded by Copernicus Climate Change Service (C3S)
[13]MiKlip II - Mittelfristige Klimaprognosen (11/2015-10/2019), funded by BMBF

Topic 4

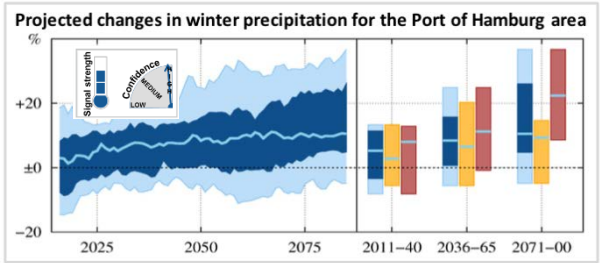
## Highlight 3: Using regional to local climate information for application

Being able to better simulate climate extremes is one of the main motivations for research on developing local climate information at the kilometer scale. GERICS has a very strong engagement in the WCRP CORDEX and in particular EURO-CORDEX research initiatives, and is also heavily engaged in the development of the non-hydrostatic regional climate model REMO-NH. These activities contribute strongly to the pursuit of kilometer scale climate information. The availability of high-resolution climate change data enables new ways to provide practice-relevant local-scale climate information.

***Case study:*** *Identifying the Port of Hamburg area in regional climate models*




- Conducted on behalf of the Hamburg Port Authority (HPA), GERICS has co-developed a Site-characteristic Climate-Fact-Sheet for the port of Hamburg.
- Main goal: estimate robust climate change information for the development and maintenance of the port infrastructure.
- Based on the large state-of-the-art high-resolution EURO-CORDEX ensemble.
- Close cooperation and co-design with the practice partner to ensure usability and relevance of the product.
- Provision of expert judgement for users.




*Climate-Fact-Sheet title page (left) and an example figure from the fact sheet (right).*

Topic 4

*Capacity building*

*From generic to user-tailored formats to enable decision-makers to adapt to climate change*

GERICS' on-going report series covers various topics and provides users with a range of different capacity development tools. The most heavily demanded of these reports are a manual on *Statistical methods for the analysis of simulated and observed climate data* (GERICS Report 13: Hennemuth et. al., 2013; ~15,500 downloads in German, ~294,000 downloads in English, since August 2013) and the guidebook *Adapting to Climate Change: Methods and Tools for Climate Risk Management* (GERICS Report 17: Bowyer et al., 2014, ~8,700 downloads since June 2014). The latter seeks to provide organizations with the information they need to better understand the range of issues involved in adaptation, and to help them make informed decisions with regard to adaptation planning. Further reports in high demand include the *Vergleichendes Lexikon* (Comparative Lexicon; Bender and Schaller, 2014); a compilation of important definitions, thresholds, and indices related to the topics

climate change and its impacts, and the *IPCC made easy*, a document which guides through selected documents from the fifth Assessment Report (AR5) of the IPCC.

Further capacity development activities were conducted in the SASSCAL[14] region (Angola, Botswana, Namibia, South Africa, and Zambia), focusing on the analysis and interpretation of regional climate change projections with respect to uncertainty and robustness measures. Workshops were designed based on the results from a survey in order to meet the needs of the respective users. Similar activities have also been carried out in the projects GLACINDIA[15], ENHANCE and IMPREX.

GERICS also developed numerous user specific capacity development concepts for and in cooperation with institutions or private enterprises. The design of the training program is user specific and includes train-the-trainer concepts, which can be applied both by trainers and multipliers. In cooperation with EUFIWACC, and the German Development Bank KfW, GERICS developed a two-stage training program both for consultants involved in climate risk analyses, and experts of financing institutions. The program aimed at strengthening the capabilities for integrating climate change information into development projects and climate risk analyses. State-of-the-art climate information needs to be considered in the planning process of development projects, which requires sound knowledge on how to interpret climate change information. Training sessions were held for EUFIWACC in Brussels (June 2015), and the KfW in Frankfurt (October 2015 and 2016). A training module for water and environmental engineers related to adaptation to climate change in water engineering is under development (AKWAS[16]).

*Establishing Climate Service Institutions*

*Supporting the development of climate service institutions internationally*

Representatives of several international institutions visited GERICS through the years in order to exchange experiences in planning and developing climate service institutions, among them Australia, Austria, Belgium, Brazil, China, Dominican Republic, Mexico, Nicaragua, Norway, Philippines, Taiwan, the USA, and states belonging to the Alliance of Small Island States (AOSIS). Efforts to foster the development of climate services were undertaken for Central Asia (former Soviet Republic states) within the project Mikroklima[17]. Through collaboration with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), workshops and other capacity-building activities on climate change adaptation and climate services have been organized by GERICS with different ministries and organizations, in countries including México, Nicaragua, Colombia, and the Dominican Republic. Contacts for further collaboration have also been established with different organizations, such as Centro Humboldt (Nicaragua), Adapt-Chile (Chile), and the World Bank.

*Scientifc networks*

*Engaging in scientific networks to be at the cutting edge of scientific developments*

GERICS established cooperation with other Helmholtz Centres in the research field Earth and Environment, including the Alfred-Wegener-Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven (AWI), the Forschungszentrum Jülich (FZJ, including the supercomputing facility), and the Helmholtz Centre for Environmental Research, Leipzig (UFZ). The purpose of this cooperation is the identification of common research interests and joint product development. Furthermore, GERICS is also engaged in different Helmholtz Association activities: in particular in the

[14]SASSCAL - Southern African Science Service Centre for Climate Change and Adaptive Land Management (10/2013 - 10/2017), funded by BMBF

[15]GLACINDIA - Water Related Effects of Changes in Glacier Mass Balance and River Runoff in Western Himalaya, India: Past, Present and Future (01/2014 - 12/2016, funded by BMBF

[16]AKWAS - Anpassung an den Klimawandel in der WASserbaulichen Praxis (10/2017 - 10/2018), funded by BMUB

[17]Mikroklima - Klimawandelanpassung privater Haushalte und KMU in Zentralasien durch Maßnahmen im Mikrofinanzsektor (08/2015 - 02/2017), funded by BMBF

Helmholtz EaE *Earth System Knowledge Platform* (ESKP, communicates contexts and background information related to natural hazards, climate change, and pollutants), in the Helmholtz project *Advanced Earth System Modeling Capacity* (ESM, contributes to the development of innovative Earth System Modeling), and the Helmholtz working group *KnowledgeTransfer* (develops a strategic concept for the strengthening of knowledge transfer in the Helmholtz Association).

A second important pillar of scientific cooperation is the partnership with different universities and research institutions addressing different topics. Scientists from the University of Hamburg and HZG cooperate in the frame of the new Helmholtz-Institut Climate Service Science (HICSS) on topics around knowledge transfer, modeling of complex systems, and evaluation of knowledge. Further network activities in Hamburg relate to the KlimaCampus Hamburg, in which universities, research institutes, and federal authorities have joined forces and formed a unique network; and to the former Cluster of Excellence CliSAP (Integrated Climate System Analysis and Prediction). In order to continue this activity GERICS is fully engaged in an application for a new excellence initiative. GERICS also maintains long-lasting cooperation with the German Climate Computing Center (DKRZ), and the Max-Planck-Institut für Meteorologie (MPI-M). Other strategic cooperation exists with the Technical University of Hamburg-Harburg (TUHH) (developing a training module for water and environmental engineers in the frame of AKWAS), the University of Würzburg (further development of the non-hydrostatic model version REMO-NH including the consideration of land-surface processes and land-use changes), and the University of Freiburg (urban and water quality modeling). Additionally, national and international universities in Europe collaborate with GERICS also in third party funded projects.

*Initiatives shaping the climate service landscape*

*Engagement in various initiatives to boost and promote topics of high relevance for climate services*

GERICS has been engaged in the JPI Climate[18] initiative from its inception in 2011, and in the ERA-NET[19] for climate services since 2014. Both activities aim at strengthening and facilitating networking among the main European players in the field of climate services, be they funders, scientists or public providers. Basically, JPI Climate aims at co-aligning activities mainly related to research funding to avoid heading into different directions or duplication of activities. Based on these activities in JPI Climate, the ERA-NET for Climate Services kicked-off in January 2016. In the spirit of JPI Climate, the in-kind part of the ERA-NET aims at harmonizing methodologies and tools, and brings climate information to the local scale through institutional integration among climate service providers in Europe.

In the frame of the international Climate Service Partnership (CSP), GERICS has a leading role and was substantially involved in establishing the CSP in 2010. The CSP secretariat is hosted by GERICS since June 2015. The basic tasks of the secretariat include, amongst others, the organization of the International Conference on Climate Services (ICCS). In this role, GERICS conceptualized and organized the recent ICCS5 (Cape Town, early 2017) jointly with the local partner, University of Cape Town (UCT). In 2014, GERICS was also actively involved in the foundation of the European Climate Service Partnership (ECSP). At GERICS' initiative, in 2013, the Earth League was created. Earth League is an international alliance of prominent scientists from world class research institutions (currently 17 from 11 countries), who work together to respond to some of the most pressing issues faced by humankind, as a consequence of climate change, depletion of natural resources, land degradation and water scarcity.

Also noteworthy is GERICS' involvement in the project Climateurope[20], which aims at bringing together large European initiatives such as JPI Climate, Climate-KIC[21], Copernicus C3S and facilitating

[18]Joint Programming Initiative *Connecting Climate Knowledge for Europe*

[19]ERA-NET instrument under EU H2020, designed to support public-public partnerships

[20]Climateurope - Linking science and society (12/2015 – 11/2020), funded by EU H2020

[21]Climate-KIC - One of three Knowledge and Innovation Communities (KICs), created by the European Institute of Innovation and Technology (EIT)

dialog among the relevant stakeholders, including climate science communities, funding bodies, providers and users. Here, for instance, GERICS creates dialogs with different user communities not only by the traditional way, e.g. with workshops or bilateral consultations, but rather develops innovative formats. The project is therefore hosting a number of festivals between 2017 and 2020, inspired by the motto **Climate information at your service**. The first was held in Valencia, Spain in April 2017, which GERICS co-organized with the other international partners in the consortium (Kotova et al., 2017). This was a highly successful event which brought together major players in climate services from JPI Climate, C3S, ERA4CS, the European Commission and the main H2020 projects and initiatives including the European Climate Research Alliance (ECRA).

Topic 4

## Climate Services: Trust, Transparency, Quality and Evaluation

*Effective co-development processes result in functional products*

*Co-design and quality*

It is GERICS' experience that a successful process of developing useful and usable prototype products requires a user-centric approach. Throughout the overall process, the user's perspective has to be taken into account, including competencies, capabilities, technical constraints and boundary conditions, human and financial resources. Developing climate service prototypes which can truly inform the climate adaptation decision making process demands a strong and mutual commitment from both providers and users. This process is referred to as **co-designing**, which includes the common definition of the basic problem, the co-production of the climate service product that meets precisely the users' needs, and the co-evaluation of the whole process in order to assure quality over the long term. Building on the work of Brinkmann et al. (2015), GERICS found important guidelines in the concept of **transdisciplinary research** and worked on aspects of **good quality**.

Ten criteria of good quality were identified (Schuck-Zöller, 2018). **Trust building** was shown to be one of the most important aspects (Wall et al., 2017; Schuck-Zöller et al., 2018), and key for the success of climate services. A continuous dialog and the integration of different kinds of knowledge are the basis for the progressive building of trust, confidence and mutual learning between scientists and practitioners. **Transparency** is also one of the core aspects of quality (Schuck-Zöller et al., 2018). Transparency means on the one hand to create open processes of co-creation and to communicate the whole framing. Here, possible limits or constraints regarding the scientific methodology and the application of the scientific knowledge must be addressed frankly. This is a challenge in terms of the uncertainties.

*Quality management*

In order to assure the quality of its own work, GERICS introduced a systematic quality management process to assess and improve work practices and performance. This includes internal quality procedures but also elements of customer feedback. GERICS' **internal quality management** is in line with the holistic approach of the European Foundation for Quality Management (EFQM) and contains, among others, a strategic plan, a structured process management (i.e. established/documented work flows for key processes such as prototype development, Petersen and Seipold, 2017), or publications and other internal reporting procedures. The latter are collected in a manual that is handed over to every new member of staff (**Mitarbeiterhandbuch**).

For quality assurance, GERICS systematically collects feedback from users on some of the current products, e.g. the *Klimanavigator*, EUFIWACC Adaptation Day, Climate-Fact-Sheets and Referenzrahmen Unternehmensstrategien im Klimawandel (framework of reference for business regarding the awareness of climate vulnerability).

*Framework of evaluation criteria and indicators*

Because the co-development of climate service prototype products and knowledge transfer results cannot be evaluated against purely scientific criteria, GERICS instigated and drove the development of an **evaluation methodology**. As a first step, on the basis of a literature review, the different

elements of evaluation applicable to climate services were synthesized and a common terminology was proposed to scale down from evaluation dimensions to criteria, indicators and assessment methods (Figure 45) (Schuck-Zöller et al., 2017).

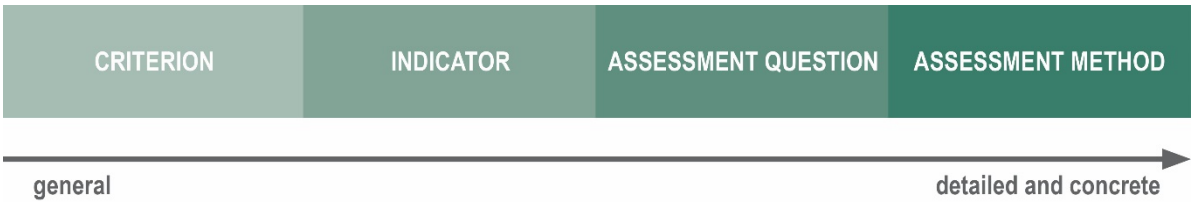



Figure 45: The evaluation cascade enables the assessment of the evaluation criteria (Schuck-Zöller et al., 2017).

Significant progress has been made in bringing together natural and social scientists from AWI, HZG's Institute of Coastal Research and GERICS. To date, a framework for assessing output and outcome of climate service products has been developed, in which output relates to the result of the products, and outcome to the short-term effects on the target groups. The framework includes possible evaluation criteria and respective indicators, which are chosen case specific and adaptive to the project objectives (Figure 46). The results were presented by GERICS in two talks, on behalf of the PACES II working group, one at 17th Annual Meeting of EMS, and another at the International Transdisciplinarity Conference, Lüneburg (Sept. 2017).

GERICS is well aware of the need for evaluating societal impacts too, and intensely follows the discussion in the AESIS network (International Network for Advancing and Evaluating the Societal Impact of Science). Therefore, GERICS has already developed initial approaches for the monitoring of processes and their evaluation.

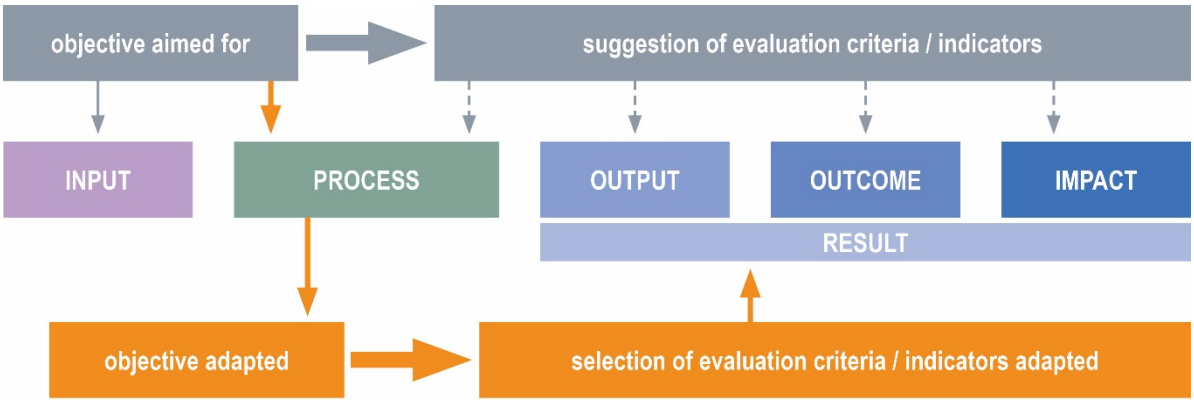



Figure 46: Schematic representation of the GERICS prototype development process, whereby project objectives and associated evaluation criteria/indicators are defined at the start of the process, and updated and modified over time.

*Prototype development*

GERICS also pursues a **systematic monitoring** of product development processes. Following the concept of feedback-loops within the transdisciplinary research or development team, workflows are being developed and implemented for the upcoming product development processes. GERICS **tests its prototypes** with the respective end-user. After having completed the test successfully, the prototype can be handed over to third parties, e.g. consultants, engineering offices or start-ups, who are interested in **operationalizing** the product.

Topic 4

## Climate Service Infrastructure

GERICS' climate service infrastructure provides the framework for generating scientifically sound climate services. On the one hand, it is the basis for many prototype products developed at GERICS, which comprises a sophisticated hardware, software and data infrastructure. On the other hand, it offers interfaces for practitioners and users of GERICS' climate service products. The climate service infrastructure covers five categories: (1) computing infrastructure, (2) models and analysis tools, (3) climate change and climate impact data, (4) interfaces to users and practitioners, and (5) quality management.

### *Computing infrastructure*

#### *Dedicated computing time enables fast response to user demands*

The development of some of the prototype products requires large hardware infrastructures which cannot be maintained by GERICS. Here, the support of external partners is needed. Key partners in this regard are the German Climate Computing Center (DKRZ), and the Jülich Supercomputing Centre (JSC). One of the most important aspects in the cooperation with DKRZ is a guaranteed amount of computing time for GERICS' activities. This was put into effect by an investment into compute nodes at DKRZ's current high-performance computer *Mistral*. Running own compute nodes enables GERICS to perform more service oriented and user demand driven climate simulations. Two major advantages emerge from having dedicated computing time. First, GERICS can react faster to user demands without waiting for the bi-annual application periods. Second, there is no trade-off between pure research and user driven applications on DKRZ's high-performance computer. In addition to climate modeling, the first successful spatially explicit urban form optimization based on a cellular automata has recently been carried out on *Mistral*. This is an important step, because it is envisaged to couple the climate models with three-dimensional urban models in the future.

#### *Long term storage for good scientific practice*

In order to provide high quality climate information, GERICS has to create, analyze and store large amounts of climate data. This requires access to different kinds of computer hardware that fits the purpose of the various activities. Small amounts of data, such as documents or employee backups, are stored on GERICS servers. Larger amounts of data, in particular climate data, cannot be stored and processed within this infrastructure. Therefore, GERICS owns dedicated login nodes in addition to the compute nodes mentioned above and two types of data storage capacities directly at DKRZ. The two types of data storage provide both fast access to data with limited storage capacities on hard disks, and a larger capacity but considerably slower archive on tapes. The fast access storage on hard disks functions as the working storage, where current analysis is done, but also evaluation data, such as observations or re-analysis are stored for fast access. The long-term storage on tape is mainly used for GERICS' climate simulations with a guaranteed storage lifetime of at least ten years in order to fulfil the requirements of good scientific practice.

### *Models and Analysis Tools*

#### *Transparent software assembly line to ensure quality*

As regards the software, the climate service infrastructure builds on models and comprehensive analysis tools. Data analysis at GERICS is highly centralized and done directly on the compute nodes at DKRZ. The advantage of this approach is the use of a common software stack and data pool, which leads to interchangeable scripts and consistency between products. For the most part, well-tested open-source software is used. Developing an in-house software suite fills gaps for specific needs. This software suite is especially important for the visualization of climate data, because in many cases it is user specific (e.g., for the Climate-Fact-Sheets) and often goes beyond *standard* 2D climate change

maps. All in-house developed software is maintained in a software versioning and revision control system and will be verified by a second person in order to support the quality management process.

### *Active model development guarantees state-of-the-art knowledge about strengths and weaknesses of the climate data*

GERICS develops, maintains and uses the regional climate model (RCM) REMO (Jacob et al., 2012). The main motivation for having an in-house RCM is to keep track with current model development. This enables GERICS' scientists to judge the quality, abilities and limitations of the models and their results. A second motivation is to actively contribute to and shape major scientific activities such as CORDEX, which usually provides early and/or better access to regional climate model data which is key to the development of climate services products. For this, a user-friendly desktop version of REMO (called EasyREMO) has been developed, which aims specifically at users in those parts of the world without access to a high-performance computing (HPC) service. Some illustrative results from EasyREMO are shown in Figure 47. A major development of the previous years for HPC is the non-hydrostatic version of REMO, called REMO-NH, which was partly supported by third-party funded projects such as NHCM-2[22]. This step enables GERICS to bridge the gap between state-of-the-art climate information and the growing demand for local climate information at the kilometer scale. The added value of e.g. higher resolution convection permitting modeling in REMO is shown in Figure 48.

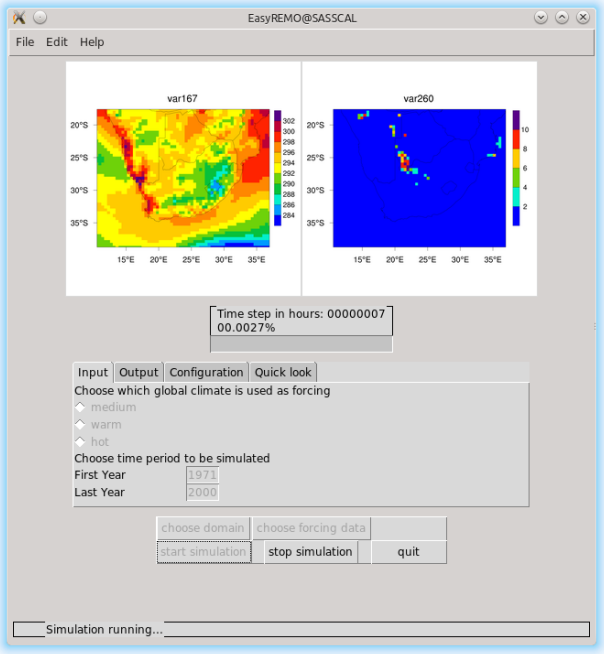



Figure 47: Screenshot of EasyREMO showing on-line simulation results for two variables: 2m surface temperature in kelvin (left-hand panel var167), and hourly precipitation in mm (var260 right-hand panel).

## *Climate Change and Climate Impact Data*

### *Engagement in scientific activities to advance local climate information*

GERICS is currently active in many CORDEX initiatives. The major focus is on coordinating the non-funded EURO-CORDEX activity initially founded by Daniela Jacob in 2011. Moreover, GERICS is a partner in CORDEX Africa, CORDEX South America, and active in CORDEX South-East Asia on atmosphere-ocean coupling activities. In order to head towards local climate information, EURO-

[22]NHCM-2 - Non-Hydrostatic Climate Modelling (01/2013 - 06/2017), managed by Wegener Center for Climate and Global Change (WEGC), Graz, Austria, funded by the Austrian Science Fund (FWF).

CORDEX co-leads two CORDEX Flagship Pilot Studies (FPS), which tackle some of the most relevant scientific questions in regional climate modeling when going to the local scale. The FPS on convective phenomena at high resolution over Europe and the Mediterranean investigates convective-scale events, their processes and their changes using convection-permitting RCMs, statistical models and available observations. The FPS LUCAS (Land Use & Climate Across Scales), which is co-led by GERICS (Rechid et al., 2017), investigates the impact of land use changes on climate in Europe across spatial and temporal scales.

*Better access to climate data to support the VIACS community*

Another important aspect to spatially better-resolved climate data is the need for finer temporal resolution. Especially for investigating extreme weather events such as heavy precipitation, sub-daily resolution is needed. GERICS is currently working on a web-service, which will host the most frequently requested variables from EURO-CORDEX by the VIACS[23] communities in hourly resolution. For the first time, there will be a centralized database for highly relevant data, which is so far only available by asking each individual modeling group.

*Interfaces to Users and Practitioners*

*Organizing the Klimanavigator activity to establish a climate community network*

Key interfaces to users and practitioners are the GERICS web-services. The main gateway is the homepage, which is available in German, English, Arabic (only main pages) and soon in Spanish and Chinese, and offers all GERICS publications with open access. It was relaunched in August 2016 showing a new and interactive product finder with two different gateways on the entry page (*products by region* and *products by sector*). The web-portal *Klimanavigator* (www.klimanavigator.de), initiated, hosted and coordinated by GERICS, is still unique as a community-driven partnership portal. In 2014, Leuphana University Lüneburg carried out a survey of users, potential users and partners of *Klimanavigator*. Following the resulting recommendations, the concept was clarified in the texts on the web, a new search mode (faceted search) was implemented to simplify navigation, and a closer cooperation with partners was instigated. Independent of this scientific evaluation, further sections have been developed (e.g., a document repository for KLIMZUG[24] documents). Currently GERICS is conceptualizing an extension of the *Klimanavigator* portal to Austria and Switzerland. The IMPACT2C web-atlas (atlas.impact2c.eu; Preuschmann et al., 2017) is another important communication platform for GERICS. It makes a large range of sector specific climate impact information, e.g. agriculture, energy, water and health, from the project IMPACT2C accessible to a wide audience. The generic atlas concept will soon be transferred to other regions such as Africa.



[23]Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board for CMIP6 (WCRP)
[24]KLIMZUG - Klimawandel in Regionen zukunftsfähig gestalten (2008 - 2014), funded by BMBF

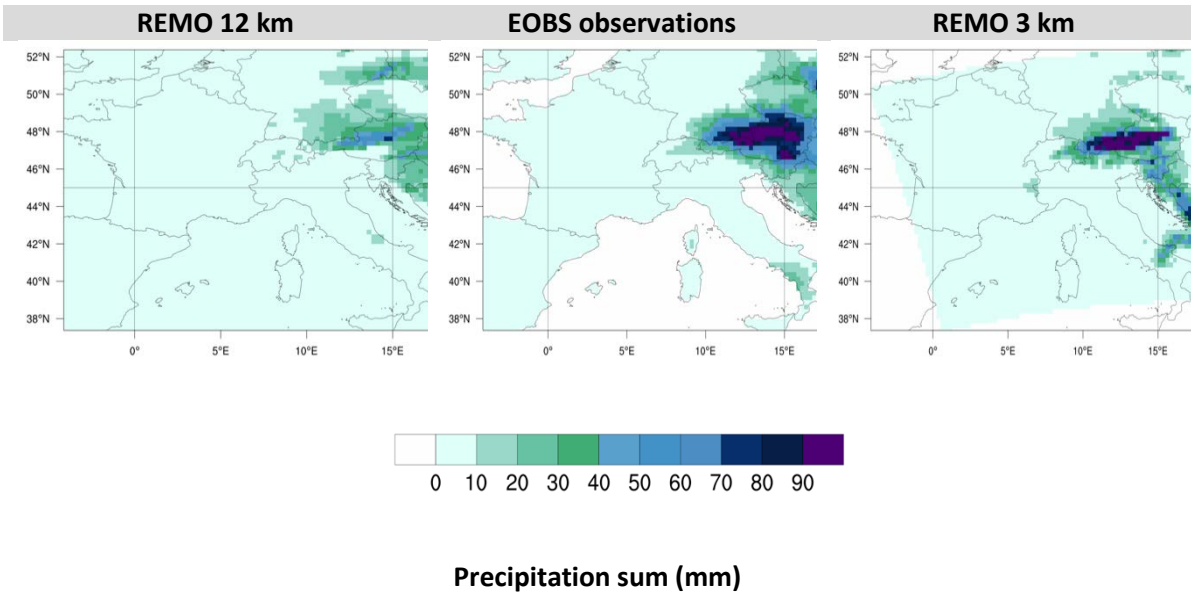



Figure 48: Sums of a heavy precipitation event 22.-24.06.2009 in Austria in observations (middle), REMO with 12 km (left), and 3 km (right) horizontal resolution. All data is interpolated or aggregated to a common 12 km grid. From WCRP CORDEX *FPS on convective phenomena*.

### 4.4.3 EMBEDDING IN PACES II

Topic 4

Since June 2014, GERICS has been part of the Helmholtz EaE program PACES II. The PACES II evaluators, however, indicated that Topic 5 of the proposal (*Service Topic: Climate Service Center*) was sub-optimally positioned in this program. Consequently, in response to the evaluators' recommendations the *Service Topic* was integrated into WP3 of Topic 4. Topic 4 was renamed *Bridging research and society – products, tools and climate services*, and WP3 was renamed *Providing information - Enabling knowledge and climate services* (see also chapter 5 *Recommendations of the Helmholtz Senate*). The new WP3 focuses on providing multifaceted climate services, and establishing a sustained transfer process of appropriate scientific findings in the field of climate change and climate change impacts into relevant social decision-making processes. GERICS director Professor Daniela Jacob became one of the speakers in Topic 4 (jointly with an AWI representative). Dr. Irene Fischer-Bruns (GERICS), became one of the three WP3 coordinators, together with colleagues from HZG's Institute of Coastal Research and AWI. This structural change has been recognized by the Senate Commission as highly effective and useful for strengthening the visibility of the new Topic 4.

The overall objective of Topic 4 is to improve the benefit of knowledge generated within PACES II for societal needs. That is to establish a sustainable dialog between science, the public and specific stakeholders by dissemination of scientific results in order to build steady bidirectional pathways between science and society. Priorities are to reach key stakeholders by knowledge transfer, and to establish a sustained transfer process, whereby appropriate scientific findings are integrated into relevant social decision-making processes. This is precisely in line with GERICS' tasks and mission which includes the development, testing and evaluation of prototype climate service products. The prototypes are designed in a transferable way, which means that they are developed on a case specific basis, but can also be transferred to other regions, topics, or sectors. For example, the toolkit-focused product *Stadtbaukasten* has been developed for cities and will now be transferred to coasts, and eventually to vulnerable regions, for example the polar region (PACES II related region). The global sea level rise Focus Paper has been developed (PACES II related topic), and has

been transferred to cities. With this concept, GERICS facilitates the dialog between PACES II topics and other relevant developments in the field of Earth and Environment (EaE).

GERICS works strictly *source neutral*, based on the available scientific knowledge regarding climate and climate impacts. The basic work principle *source neutrality* results in a knowledge transfer from results i) generated in the whole Helmholtz program-orientated research within the framework of EaE, including PACES II, and ii) generated in academic and nonacademic research in Germany (e.g. Max Planck) and internationally. GERICS processes, refines and transfers this scientific knowledge primarily to national and international decision makers and multipliers in public administration and industry, and develops its products in cooperation with these groups. The latter belong to the wide range of stakeholders which is approached by Topic 4 (including different scientific networks, civil society organizations, administrative actors, and economic actors). Educational institutions, the media, political actors and the general public, which are also addressed by Topic 4, are not GERICS' main target groups. The PACES II key milestones for GERICS were achieved successfully:

- 2014: development of *Hot Spot Mapping*; and the development of *Climate Signal Maps* for PACES II relevant topics or regions,
- 2015: finalization of the *IMPACT2C web-atlas,*
- 2016: publishing the *Klimabericht für Deutschland*; *synthesis of experiences from different third party funded projects* with respect to knowledge transfer and stakeholder dialogs in order to be able to foster tasks relevant to PACES II (strategy developed, work currently ongoing),
- 2017: development of *easy to run* climate modeling tools, for example EasyREMO, within the SASSCAL project; implementation of a quality control concept in the frame of building up a climate service infrastructure. The work regarding 2016's milestone 'to carry out a demand analysis and a feasibility study for the development of a *toolkit for coasts* (with key partner HZG's Institute of Coastal Research)' has started, and is currently ongoing.

In the frame of WP3, GERICS also cooperates with the HZG's Institute of Coastal Research and AWI. It was recommended by the evaluators to hold joint workshops (GERICS, HZG, AWI) in the field of product development on the subjects *sea level rise* and *wind energy.* Here the Institute of Coastal Research and GERICS carried out two workshops in the field of wind energy (regarding *offshore windparks*, 3 June 2015; regarding *stakeholder dialogs,* 2 December 2015). A joint workshop in the field of sea level rise was held by AWI in September 2015. Another joint activity, which was also requested by the evaluators, is related to the definition of suitable criteria and performance indicators for the evaluation of knowledge transfer, stakeholder dialogs and climate service activities - in addition to the existing criteria for the evaluation of purely scientific work. With this activity, which is strategically very relevant, HZG and AWI are playing a pioneering role, especially in the field of natural sciences.

### 4.4.4 FUTURE FOCUS AREAS (POF IV)

The validity of GERICS' business model has been proven in POF III and its viability will be enhanced further in POF IV. GERICS will be part of the ocean and coast related program structure. Close cooperation with AWI, GEOMAR and HZG's Institute of Coastal Research is envisaged. Already started efforts towards co-design regarding the coastal toolkit, topic related Fact Sheets and Focus Papers, as well as the joint development of a network of private companies will be continued and further enhanced.

Another viable option is to embed GERICS in the Helmholtz cross-program section. All prototype climate service products that have been developed so far by GERICS can be transferred to issues with regard to e.g. land and atmosphere. The development of a regional system framework can directly be linked to the new POF IV theme *Vulnerable Regions*. Here, new and innovative products can jointly be designed and developed in cooperation with all centers in Helmholtz EaE. The development of local climate information is required for this purpose, which can be undertaken jointly in partnerships with Helmholtz Centers in EaE, the supercomputing centers DKRZ (German Climate Computing Center) and JSC (Jülich Supercomputing Centre). Here, local climate models will play a major role. They can be validated with observations from different Helmholtz facilities e.g. TERENO (TERrestrial ENvironmental Observatories across Germany), and programs e.g. MOSES (Modular Observation Solutions for Earth Systems). One key challenge will be the coupling of these data to social systems for example, in the frame of systemic approaches in order to assess the impacts of, and vulnerabilities and adaptation to, multiple existing stresses – including rapid urbanization and climate change – for specific regions, e.g. coastal cities. Protecting coastal (mega)cities in the future will require sustainable investments and better planning. Important questions like these in the light of transforming societies require groundbreaking solutions and will be of high importance for POF IV. The concept of co-development and the associated dialogs can be extended to future POF themes, since sustainable responses to these challenges will benefit from the experience of all centers in EaE, and require scientific cooperation beyond the established research boundaries.

The development of evaluation criteria will also be continued with partners from EaE in POF IV, and ideally a generally accepted concept for implementation of the evaluation of services will be developed and implemented. GERICS could help to coordinate this effort.

### 4.4.5 CAREER DEVELOPMENT

Career development can be seen as part of capacity development, which has been described above in chapter 4.2.2. Within this section, career development is split into two branches – for GERICS staff, and for stakeholders. GERICS staff are constantly supported to further develop their scientific, organizational, and communication skills, through participation in specialist training courses. Participation in international networks enables staff members to contribute exceptionally to the field of climate services. This is visible through their appointments to international boards, their leading roles in networks, or as the lead scientist in product development at GERICS. Several GERICS scientists give lectures at national and international universities (e.g. universities of Lüneburg, Bochum, Hamburg, and Valencia), and act as supervisors for Bachelor, Masters or PhD theses. In addition, GERICS actively funds or seeks funding for early career scientists through international organizations. GERICS also provides numerous intern opportunities for students to learn new skills and gain valuable workplace experience.

With the International Climate Protection Fellowships, the Alexander von Humboldt Foundation enables prospective leaders in academia and industry to implement a research-based proposal in the field of climate protection, or climate-related resource conservation during a one-year stay in Germany. Up to 20 International Climate Protection Fellowships are granted annually, funded under the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety's (BMUB) International Climate Initiative. Under this program, GERICS was chosen to host Mrs. Tania Guillén Bolaños, M.Sc. (from 03/2016 - 03/2017) as a Humboldt Climate Protection Fellow.

In the frame of the Marie Skłodowska-Curie Actions the EU Research and Innovation Staff Exchange (RISE) funds short-term exchanges for staff to develop careers combining scientific excellence with exposure to other countries and sectors. The project proposal KNOWHOW[25], in which GERICS participated, was chosen for funding (2014-2016). Within this researcher's exchange program, three scientists from the Council for Scientific and Industrial Research, South Africa (CSIR, Pretoria and



[25] KNOWHOW - Knowledge Production, communication and negotiation for coastal governance under climate change (01/2014- 12/2016), funded by EU FP7

Johannesburg) - a world-class research and development organization - visited GERICS. Five GERICS scientists visited CSIR several times in Durban and Johannesburg.

The China Scholarship Council (CSC), a non-profit institution affiliated with the Ministry of Education of the People's Republic of China, provides the financial assistance to Chinese citizens wishing to study abroad and to foreign citizens wishing to study in China in order to develop the educational, scientific and technological, and cultural exchanges between China and other countries. Two young Chinese scientists from Nanjing University of Information Science and Technology, funded by the CSC programs joined the GERICS team, namely, Dr. Jingwei Xu as a guest researcher (09/2015-09/2016), and Mr. Shoupeng Zhu as a visiting PhD student (12/2016-12/2018).

As part of the Earth League Program, GERICS funds talented scientists, who have recently completed their PhD, for an Earth Doc position (2-3 years, each).

Within the MSc course on Water Management of the IIAMA (Institute of Environmental and Water Management), every year a participatory modeling module is offered by Prof. Dr. Maria Manez (GERICS) at the Polytechnical University of València, Spain, teaching how to co-develop and co-design water management procedures for hydroclimatological extreme events.

In the field of climate services, GERICS develops a training program for hydraulic and environmental engineers in cooperation with the Technical University Hamburg-Harburg (TUHH). The program focuses on the integration of climate change and adaptation knowledge into the hydraulic engineering field. The target groups are both graduate students at the technical university as well as trained engineers, instructors, and decision makers in hydraulic and environmental engineering. The close connection between professional and academic education is thus to facilitate developing a novel concept for practice oriented education at technical universities.

In the frame of different projects, GERICS provides worldwide training and education programs. A four-day climate workshop in cooperation with The University of Zambia in Lusaka entitled *SASSCAL short course on regional climate change assessment and uncertainty analysis* in April 2016 and the training course on *Regional climate change assessment and impact analysis* in Stellenbosch, South Africa, were conducted jointly by GERICS, the Council of Scientific and Industrial Research (CSIR), and the Climate System Analysis Group (CSAG) at the University of Cape Town (UCT). Also training programs in participatory modeling techniques have been offered by GERICS in different Latin American Countries, such as Mexico or Nicaragua (from 2014 to 2016).

In the field of transdisciplinary research, GERICS together with Leuphana Center of Methods (Leuphana University Lüneburg) held a one week special training module on mutual learning in urban climate change adaptation in 2014. This module belonged to the *Td Summer School 2014 - Transdisciplinary Research* at the Science - Society interface. In order to support career development in the field of knowledge transfer and climate services, GERICS is developing new standards for evaluating the quality and success of transdisciplinary research. This work contributes to an extension of the value system also rewarding excellent performance of scientists in transdisciplinary research and helps to ensure that this work is visible and valued within the traditional research system.

Moreover, GERICS initiated jointly with Elsevier the new Journal *Climate Services*, which is the first journal in the field of climate services and provides scientists the opportunity to publish articles in this field addressing both scientist and experts in practice.

# 5

# RECOMMENDATIONS OF THE HELMHOLTZ SENATE

# 5 RECOMMENDATIONS OF THE HELMHOLTZ SENATE

The recommendations of the Helmholtz Senate addressed four strategic questions, which have been taken into account during the program period:

(1) Strengthening of the field earth system modelling,

To strengthen the field of Earth System modelling, the HGF Earth and Environment Working Group *Earth System Modelling* was established (lead of Prof. Thomas Jung, AWI) in 2015. The HZG participated with 3 members, Prof. Emil Stanev, Prof. Corinna Schrum and Prof. Daniela Jacob. A first working group meeting was in November, 30 2015 at GERICS. Among other tasks, the working group aimed to develop a comprehensive HGF Earth System Modelling Strategy to address the recommendations of the Helmholtz Senate. As part of this process, a joint project proposal was developed and submitted for funding to the HGF President's incentive and network fund (project coordinator Prof. Thomas Jung). The project was approved and started in April 2017, all Earth and Environment centers and DLR are involved. It was decided to develop the Future Earth System Modelling strategy within the ESM project and the Working Group was suspended.

(2) Extended cooperation between PACES II and the Oceans programs,

Several scientific commonalities resulted in enhanced collaboration. In 2016, GEOMAR´s permanent time-series station Boknis Eck was successfully incorporated into the COSYNA network. AWI, HZG and GEOMAR cooperate in several supportive initiatives and networks in areas such as data management (e.g., MaNIDA) or knowledge transfer (e.g., joint activities in the Science Year Seas and Oceans). The collaboration within the large-scale infrastructure MOSES led to the planning of several larger, joint experiments, such as mesoscale and submesocale eddy studies in the Atlantic and Mediterranean Sea and an Elbe Flood experiment. A collaborative task within the ESM project is focusing on ocean modelling involving participants from GEOMAR, AWI and HZG. As part of this task closer collaboration between AWI, HZG's Institute of Coastal Research, and GEOMAR is planned in unstructured grid modelling (with AWI) and in NEMO modelling (with GEOMAR). Aspects of these collaborations cover the coupled sea ice-hydrodynamic modelling, biogeochemical (including benthic-pelagic) and hydrodynamic couplings and the coupling of waves and currents. Other collaborations are planned in the frame of the ESM project, such as the collaboration with UFZ on coupling the land-ocean systems and on extremes. Frequent exchange and discussions within the ESM project furthermore enabled new methodological perspectives in collaboration within Earth System Modelling, such as with KIT on pollutant modelling, which are currently further explored also beyond the ESM project.

(3) Improvement of research strategy and tasks in Topic 4 and the formulation of performance indicators

The research strategy and tasks in Topic 4 have been consolidated. A new work package integrates the research and service activities of GERICS with the activities of the Climate offices (AWI, HZG-Institute of Coastal Research), the North Sea office (AWI), and ESKP activities (AWI, HZG-Institute of Coastal Research, HZG-GERICS). The work package focuses on providing multifaceted climate services and establishing a sustained transfer process of appropriate scientific findings into relevant social decision-making processes.

For the definition of suitable criteria and performance indicators for the evaluation of knowledge transfer, stakeholder dialogs and climate service activities, a working group of natural and social scientists from AWI, HZG-Institute of Coastal Research and GERICS has been established in close cooperation and direct exchange with the HGF working group on knowledge transfer.

The definition and collection of a first set of criteria and performance indicators are finalized. A joint scientific paper on the development of evaluation criteria and case studies is in preparation.

(4) Clarification of the relations between GERICS and the PACES II program Topic 4

Since 1 June, 2014, GERICS (at that time named Climate Service Center 2.0) is assigned to the Helmholtz Program “Marine, Coastal and Polar Systems - Polar regions And Coasts in the changing Earth System” (PACES II). GERICS’s climate services activities have been integrated in Topic 4, which had been focused and renamed to *Bridging research and society – products, tools and climate services*. Prof. Daniela Jacob became one of two spokespersons of the new Topic 4 (jointly with an AWI representative). This structural change has been recognized by the Senate Commission as highly effective and useful for strengthening the visibility of the new Topic 4.

# 6

# CITED LITERATURE

# 6 CITED LITERATURE

## 6.1 CITED LITERATURE OF CHAPTER 3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