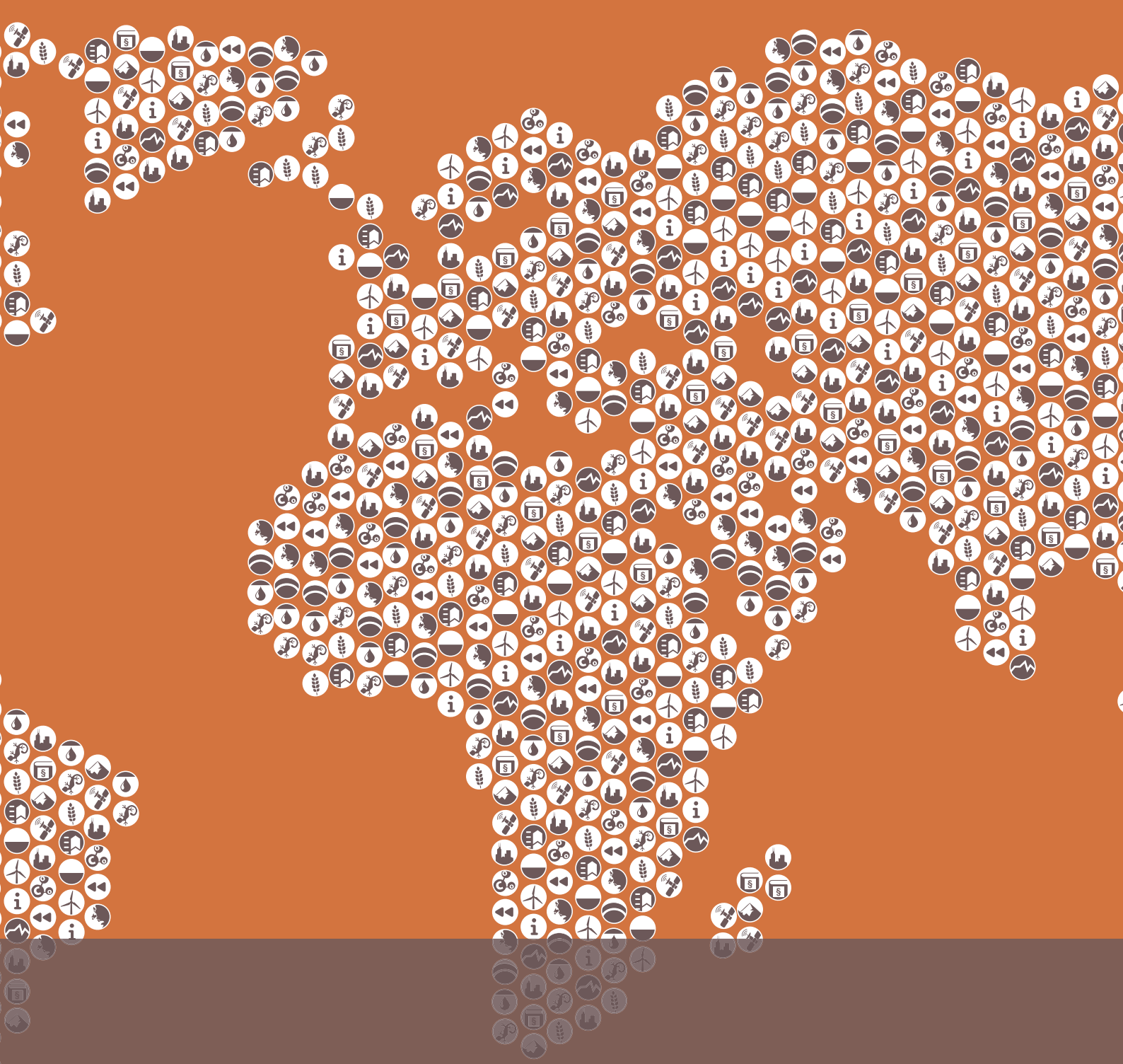


GLOBAL CHANGE RESEARCH IN GERMANY 2011

INFORMATION ON PAST GLOBAL CHANGE | THE CHANGING ATMOSPHERE | OCEANS | CARBON CYCLE | LAND USE CHANGE | BIODIVERSITY AND ECOSYSTEM SERVICES | WATER AVAILABILITY AND WATER MANAGEMENT | COASTAL ZONES | POLAR REGIONS | MEGACITIES | CLIMATE CHANGE - MITIGATION AND ADAPTATION | FUTURE ENERGY CONCEPTS | EARTH SYSTEM GOVERNANCE AND INSTITUTIONS | OBSERVING SYSTEMS | EARTH SYSTEM MODELLING | DATA CENTRE AND DATA AVAILABILITY | KNOWLEDGE TRANFER | EDUCATION | THE INTERNATIONAL GLOBAL CHANGE PROGRAMMES | FUTURE GLOBAL CHANGE RESEARCH | GERMAN RESEARCH FUNDING AND INSTITUTIONS

GLOBAL CHANGE RESEARCH IN GERMANY 2011

edited by
PROF. GERNOT KLEPPER PH.D.
and
DR. BETTINA SCHMALZBAUER

on behalf of the
GERMAN NATIONAL COMMITTEE ON
GLOBAL CHANGE RESEARCH (NKGCF)

KIEL 2011

NKGCF

IMPRINT

AUTHORS AND CONTRIBUTORS:

Meinrat O. Andreae
Marc O. Bettzüge
Katrin Böhning-Gaese
Antje Boetius
Guy Brasseur
Jan Brase
John Burrows
Christoph Böhringer
Peter Dietrich
Klaus Eisenack
Marco Giorgetta
Hannes Grobe
Armin Grunwald
Bernd Hansjürgens
Dierk Hebbeln
Martin Heimann
Venugopalan Ittekkot
Daniela Jacob
Norbert Jürgens
Elisabeth Kalko
Gernot Klepper
Jens Klump
Andrea Koch-Kraft
Frauke Kraas
Elisabeth H. Krüger
Michael Lautenschlager
Peter Lemke
Wolfram Mauser
Axel Paulsch
Ulrich Platt
Bettina Schmalzbauer
Stefan Schäfer
Michael Schulz
Bernd Siebenhüner
Ralf Seppelt
Peter-Tobias Stoll
Georg Teutsch
Frank Toussaint
Martin Visbeck
Thomas Wagner
Michael Zürn

Published by
German National Committee
on Global Change Research (NKGCF)
c/o Kiel Institute for the World Economy
Hindenburgufer 66
24105 Kiel, Germany
Phone +49 (0) 431 8814316
nkgcf@ifw-kiel.de | **WWW.NKGCF.ORG**

ISBN 978-3-9813068-2-8

Concept and Editorial Work:
Bettina Schmalzbauer
Gernot Klepper
Jutta Bachmann (linguistic editing)
WWW.JBACHMANN-CONSULTING.COM

Layout and Type:
Scientific Secretariat NKGCF
(T. Hanke)

Production:
Eurodruck Hamburg

Paper:
Profisilk 135 g/m², chlorine- and wood-free

Editorial Note:
The selection of introduced projects, networks, programmes, link lists and infrastructure represent and exemplify German research activities on global change. Please note that several more projects, networks, programmes etc. address global change.

We gratefully acknowledge the financial support of the Federal Ministry of Education and Research (BMBF) for the printing of this publication.

SPONSORED BY THE

Federal Ministry
of Education
and Research

TABLE OF CONTENTS

INTRODUCTION

GLOBAL CHANGE RESEARCH – CHALLENGES AND STRATEGIES FOR A SUSTAINABLE FUTURE

Global change research summarises the effects of humankind's growing interference with the earth system. Over the last few decades it has become increasingly obvious that this interference has reached a level where the earth system may change in ways that make it difficult to achieve sustainable development. The increased use of the Earth's resources as well as a better understanding of the impact of human activities present societies with a number of challenges for maintaining current living standards in high-income countries and improving living standards in the many countries that have insufficient means to meet the needs of their population. The insights into the process of global change achieved by global change research over the past years and the already observable impacts of global change call for a new phase of research: current activities aimed at understanding global change need to be complemented by research into strategies designed to create a sustainable future for humankind.

Global change research has moved away from more narrowly oriented climate research activities towards a comprehensive view of interactions between different compartments of the earth system where global change is also taking place. Changes in the water cycle, land use change, the increasing loss of biodiversity, and many challenges relating to social systems are increasingly seen as strongly interrelated. Past research has hinted that these phenomena are connected, and current research programmes often take this into account.

The section "Global change issues" of this brochure presents an overview of current research activities in Germany that address many facets of global change: different compartments of the earth system, in different regions, over time and with respect to different management challenges. It has become apparent that strategies for sustainable development under global change require not only global cooperation among international states, but also benefit from the involvement of a large number of academic disciplines which can bring new insights into the many facets of the challenge.

Global change is no longer just an academic research topic but a challenge that concerns society as a whole. Government bodies from the local to the national and supra-national level have expressed the need to have access to information about global change processes that can be used for public decision-making. Over the last few years it has become apparent that the knowledge transfer from academic research results to information which can be used by government bodies is a challenge in itself. A number of institutions have been founded that are specially designed to translate global change research results into services for society on climate change and other global change phenomena. The section "Capacity building and knowledge transfer" presents some examples of such activities including the "Climate Service Center" in Hamburg, the "Regional Climate Offices" of the Helmholtz Association, and the "Regional Science Service Centres Africa". This section also highlights the importance of education programmes to prepare the next generation of scientists for this complex field of research, where close cooperation between scientific disciplines is needed but also stakeholder relevant questions have to be included.

Finally, the last section looks at the international global change landscape. The four international global change programmes (WCRP, IGBP, IHDP, DIVERSITAS) and the cross-cutting Earth System Science Partnership (ESSP) have long been in the forefront of knowledge about global change. However, increasing knowledge about the complexity of global change processes has also led to discussions about a possible future structure of the international global change programmes that can meet the new research challenges. These challenges have been formulated by the International Council of Scientific Unions (ICSU) and the International Social Science Council (ISSC) in their strategy paper "Earth System Science for Global Sustainability – The Grand Challenges". A central theme of this paper is the integration of the many aspects of global change issues. One particular process has been put in place to attempt to find a new institutional structure for the international global change research community which can best serve the activities necessary to meet the grand challenges. The section ends with an overview of the structure in Germany that supports global change research.

GLOBAL CHANGE ISSUES

INFORMATION ON PAST GLOBAL CHANGE

THE CHANGING ATMOSPHERE

OCEANS

CARBON CYCLE

LAND USE CHANGE

BIODIVERSITY AND ECOSYSTEM SERVICE

WATER AVAILABILITY AND WATER MANAGEMENT

COASTAL ZONES

POLAR REGIONS

MEGACITIES

CLIMATE CHANGE - MITIGATION AND ADAPTATION

FUTURE ENERGY CONCEPTS

EARTH SYSTEM GOVERNANCE AND INSTITUTIONS

OBSERVING SYSTEMS

EARTH SYSTEM MODELLING

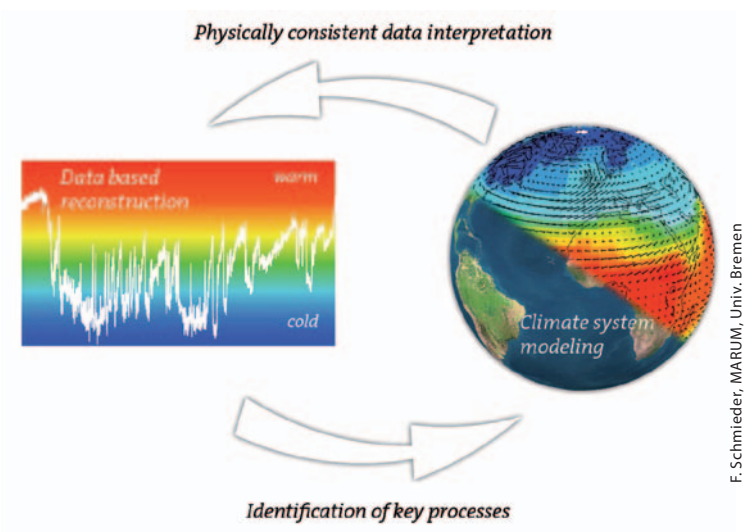
DATA CENTRE AND DATA AVAILABILITY

INFORMATION ON PAST GLOBAL CHANGE

Despite enormous progress in climate research, climate projections for the 21st century are still associated with large uncertainties. The distinction between potential human influence on climate and natural climate variations poses a particular challenge for climate research. Any effort to understand this distinction is hampered by the fact that direct observation of the climate system only covers the past few decades, enabling only a very limited view of natural variability on a longer timescale. Prior to the instrumental period, natural archives provided quantitative information on past regional to global climate variability. Precise and quantitative reconstructions of key climate variables over a wide range of timescales provide information on both the responses of the earth system to its internal variability and to a variety of external forcings. Palaeoclimatic reconstructions thus allow ongoing climate change to be placed in the perspective of natural climate variability. In addition, information from palaeoclimate archives is used to test the response of state-of-the-art climate models to different forcings.

Palaeoclimatic data represent a significant added value for global change research. Accordingly, the 5th IPCC assessment report will include a chapter entirely devoted to the reconstruction and modelling of the palaeoclimate. Recent findings from palaeoclimatic research indicate a notably higher variability in the climate system during warm climate periods (e.g. the interglacials during the last several hundred thousand years) than has so far been considered. Moreover, recent reconstructions of sea-level variations suggest that a sea-level rise of one metre per century during warm climate periods cannot be excluded. Modern approaches in palaeoclimatic research link all available archives containing climate information (terrestrial, marine, ice cores) in order to obtain a comprehensive analysis of past environmental variations at regional to global scales. Furthermore, by linking palaeoclimatic reconstructions with the results of climate models, far-reaching insights into the dynamics of climate variations can be achieved, which are highly significant for projections of future climate changes *(Fig. 1)*.

MARINE ARCHIVES (sediments, biogenic precipitates) contain the chronologically oldest continuous records of natural climate variations as well as information on changes in the marine environment as a whole. Palaeoclimatic reconstructions generated from marine sediment archives offer a unique opportunity to study the ocean as a key component in the climate system continuously in time over a wide range of timescales. Examination of these archives enables the quantification of the effects of climate change on the ocean and the investigation of feedbacks between the ocean and the Earth system's other components. Marine archives from shallow water are ideal for analysing and understanding variations of socio-economically relevant modes of climate variability (e.g. El Niño, North Atlantic oscillation). Apart from providing information about the ocean, marine sediment archives also contain a record of terrestrial environmental variations *(Fig. 2)*. Such information provides excellent opportunities to assess land-ocean interactions in the context of climate change. Moreover, by employing palaeoceanographic depth transects it is possible to create a 3-dimensional view of past circulation changes in the ocean.



F. Schmieder, MARUM, Univ. Bremen

Fig. 1: Combined approach involving palaeoclimate reconstruction and earth system modelling to decipher the dynamics of past environmental changes. (Data source: North Greenland Ice Core Project members 2004, DOI:10.1038/nature02805)

LAKE SEDIMENTS also serve as climate archives. They occur throughout the world and are particularly suited for the assessment of regional aspects of terrestrial climate variability. For example, analyses can be made of climate-induced fluctuations in climatological transition zones (e.g. semi-arid regions) and the associated implications for ecosystems. Seasonally layered sediments are of particular

MARUM
The Ocean in the Earth System

MARUM uses state-of-the-art methods to achieve an understanding of the role of the oceans in the earth system. It examines the significance of the oceans within a framework of global change and provides information for sustainable use of the ocean. The overarching research topics are the role of the ocean in climate and environmental changes, the relationship between geo- and biosphere as well as interactions between humans and oceans. The areas of investigation range from shelf to deep ocean regions. MARUM comprises the DFG Research Center and the "The Ocean in the Earth System" Cluster of Excellence. The Cluster of Excellence comprises the University of Bremen working in close cooperation with the Alfred Wegener Institute for Polar and Marine Microbiology, Bremerhaven, the Max Planck Institute for Marine Microbiology, Bremen, the Senckenberg Institute by the Sea, Wilhelmshaven, the Jacobs University Bremen and the Leibniz Center for Tropical Marine Ecology, Bremen. The project activities are closely integrated with international programmes (e.g. IGBP-PAGES, IODP). MARUM hosts one of the three IODP core repositories, the data publisher PANGAEA and the World Data Center WDC-MARE. MARUM operates a deep-sea drill rig (MeBo) for retrieving palaeoclimate archives from the deep sea, two remotely operated underwater vehicles and an autonomous underwater vehicle. MARUM has thus become a principal centre of ocean research technology and a sought-after partner in international cooperative projects.

Programme Duration: 2007 - 2013
Funding: DFG (Research Center and Cluster of Excellence)
WWW.MARUM.DE

INTERDYNAMIC
Integrated Analysis of Interglacial Climate Dynamics

This priority research programme is aimed at achieving a better understanding of climate dynamics using quantitative palaeoclimate analyses. It is based on an integrated approach, in which climate reconstructions from all available palaeoclimate archives (terrestrial and marine as well as ice cores) are combined and linked with results from earth system models. Key objectives are: (i) to assess natural climate variations on timescales of several years to several millennia, (ii) to evaluate the likelihood of abrupt changes in the large-scale circulation of the Atlantic Ocean during interglacials, (iii) to ascertain which of many biogeochemical feedback mechanisms control the natural limits of atmospheric concentrations of greenhouse gases and aerosols, and (iv) to study potential links between climate and pre-industrial cultures.

Programme Duration: 2007 – 2013
Funding: DFG
WWW.INTERDYNAMIK.DE

importance because they have enormous potential for the study of past climate changes in a seasonal context. Moreover, annual layers enable an exact age determination and a precise assessment of the rate of past climate changes to be made. With this high temporal resolution, changes in the frequency of weather extremes can be detected and the probability of their occurrence can be estimated with a greater degree of confidence.

ICE CORES are the only palaeoclimate archive that enable the measurement of past atmospheric compositions, in particular the quantification of past atmospheric greenhouse-gas concentrations. This is of prime importance for quantifying the role greenhouse gases play as climate forcings as well as investigating the coupling between climate and biogeochemical cycles. Moreover, ice-core archives contain information on atmospheric temperature, precipitation and atmospheric aerosol load (e.g. sea salt, mineral dust, volcanic and biogenic sulphur). In combination with reconstructions from low latitudes, polar ice cores are extremely well suited to the documentation of teleconnection mechanisms between low and high latitudes. Palaeoclimate research based on ice cores can also be carried out on alpine glaciers in the tropics and mid-latitudes. Although such archives cover shorter time periods than polar ice cores, they contribute important insights into the variability of climate conditions at low latitudes.

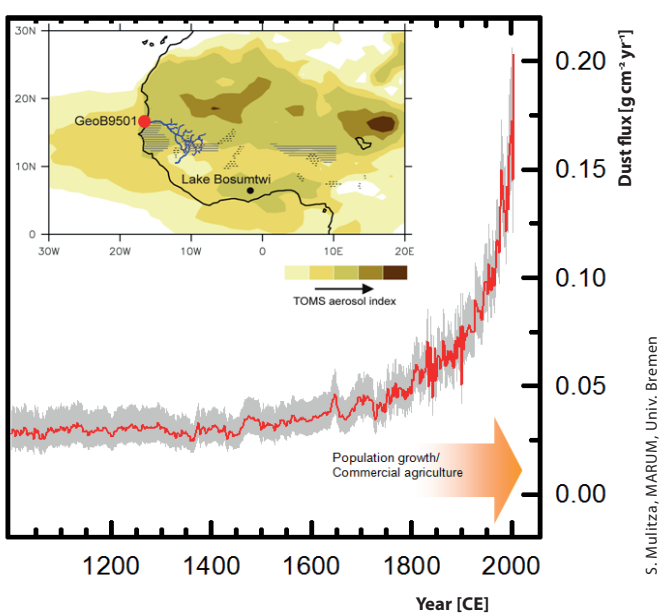


Fig. 2: Reconstructed dust emissions from the Sahara over the last 900 years. Dust flux was reconstructed from marine sediment core GeoB 9501(red dot on map). The significant increase in dust flux over the past 200 years is associated with population growth and the spread of commercial agriculture in northwest Africa (grey band denotes 95% confidence interval of the reconstructed flux). Inset: atmospheric dust loading from satellite data (relative scale; darker colours indicate higher dust loading). (Source: Mulitza et al. 2010, DOI:10.1038/nature09213 and references therein).

THE CHANGING ATMOSPHERE

Ever since the industrial age, the chemical composition of the atmosphere has been changing as a result of human activities, and this change has accelerated during recent decades. This tendency is widely known and extremely well documented for long-lived greenhouse gases, in particular carbon dioxide and methane. What is less well known, but maybe no less important for human well-being, is the fact that the atmospheric burdens and cycles of the reactive trace gases (e.g. ozone or oxides of nitrogen) that control the oxidation capacity of the atmosphere have also been changing. The oxidation capacity, in other words the capability of our atmosphere to clean itself, is clearly central not only to air quality, but it also determines the abundance and vertical distribution of greenhouse gases like methane or tropospheric ozone and affects the production of aerosol particles.

Atmospheric change thus has direct consequences for air quality, the Earth's energy budget, protection from ultraviolet radiation, weather and the water cycle, all of which are primary conditions for life. The atmosphere is a major natural transport system for energy, water, nutrients and pollutants, and influences the earth system on a wide range of space and time scales. It is evident that the atmosphere is a central component of the climate system.

In recent years, the focus of atmospheric research has shifted from a mechanistic understanding of individual processes towards a quantitative assessment of the "system atmosphere". Central to this understanding are observation systems that – ideally – allow a three-dimensional mapping of the physical and chemical properties of the atmosphere.

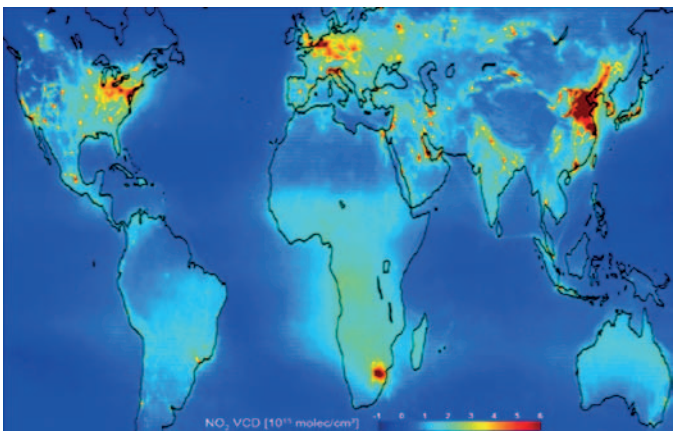


Fig. 3: Mean global distribution of tropospheric NO_2 (2003-2004); data are derived from the satellite instrument SCIAMACHY on ENVISAT. The vertical column density (VCD) is the vertically integrated trace gas concentration. (Source: Max Planck Institute for Chemistry, Mainz)

In this context, advanced ground-based networks, aircraft observations and satellite sensors are powerful tools in atmospheric research. Satellite sensors in particular add a truly global perspective. Based on novel data retrieval techniques, German researchers pioneered comprehensive sensing of stratospheric and tropospheric gases from space. Europe has greatly expanded its capabilities of remote sensing from space thanks to GOME, ENVISAT and the GOME-2 family (see example in *Fig. 3*).

Observations of atmospheric composition at all time and space scales through in-situ measurements using aircraft, ships and ground stations are a mainstay of German atmospheric science. Of particular note is the operation of long-term atmospheric observatories, such as the observatories at Schauinsland and Lindenberg in Germany, or at Zotino in Siberia. The new High-Altitude Long-Range (HALO) research aircraft is expected to start scientific operations in the near future.

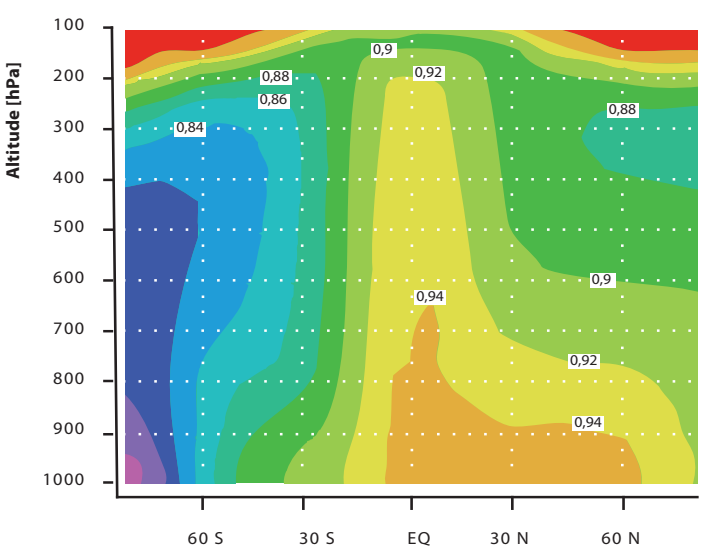


Fig. 4: Possible reduction of tropospheric ozone due to bromine monoxide-catalysed destruction. Shown here is a latitude-altitude plot of the modelled ratio of the ozone concentration without tropospheric bromine compared to a scenario with tropospheric bromine. (Source: v. Glasow et al. 2004, DOI:10.5194/acp-4-2481-2004)

The synthesis of our growing knowledge about the atmosphere is advanced through computer modelling. German institutions have been at the forefront of modelling advancements, initially via the development of general atmospheric circulation models. In the last decade, coupled ocean-atmosphere-land models have progressed and can now be used to perform transient climate simulations and seasonal climate anomaly predictions. Also emerging in the last few years are the first high-resolution regional coupled models, including interactive hydrology for detailed regional climate scenario calculations. Computer models are used to analyse complex system feedback through sensitivity studies, and to predict possible states of the system. Atmospheric forecasting on short timescales of up to two weeks is optimised by assimilating observed data into the model. This limits the initial conditions for simulations and provides deterministic information about predicted weather conditions, as well as air quality and ultraviolet radiation levels. On longer timescales, the atmosphere-chemistry-climate system is "chaotic" and forecasting can only provide statistical information. While the chaotic nature of the weather system has been known for decades, only recently chemical instabilities, for instance the "bromine explosion" (sudden release of reactive bromine species on areas as large as several million square kilometres over the polar ice) could be found in the lower atmosphere.

Fig. 5: The Zotino Tall Tower Observatory (ZOTTO) in central Siberia, where long-term measurements of atmospheric composition are conducted at a remote site in the middle of the Asian continent. (Source: Max Planck Institute for Biogeochemistry, Jena)

The atmospheric research community has identified and developed work programmes for six thematic areas:

- "Atmospheric self-cleaning capacity and air quality" addresses the hemispheric and global distributions as well as sources/sinks of short- and long-lived chemical components and the changes affecting them. There is a particular need to achieve a better understanding of the role of natural trace gases, the photochemistry of the tropical troposphere, and processes in the tropopause region.

- "Lower-middle atmosphere interactions and climate" investigates stratosphere-troposphere coupling relating to the ozone layer and climate predictability and their impact on ultraviolet radiation. This area highlights the role of water vapour in the energy budget as well as the dynamics of the stratosphere, and how studies of dynamic interactions with the troposphere could improve long-term weather and climate forecasting.

- "Biogeochemical cycles and the climate system" studies atmosphere-biosphere, atmosphere-ocean and atmosphere-land exchange processes, in particular in the carbon cycle, and how they link to atmospheric composition and climate change. New aspects in this area are the role of reactive carbon species of natural origin and the coupling of the nitrogen and carbon cycles.

- "Aerosols, clouds and the water cycle" focuses on the role of aerosol particles and cloud microphysical processes, convection and cloud properties. The investigations encompass the effects of aerosols on the surface energy budget and evaporation, and precipitation formation in convective clouds.

- "Extreme weather events" is particularly concerned with the processes that lead to floods and droughts. The question is how these processes act under climate change, and how precipitation forecasts can be improved. While the overall picture is that global warming is expected to accelerate the water cycle, precipitation may become more intense in some regions and decrease in others.

- "Seasonal to interdecadal variability and predictability" analyses the earth system dynamics and its representation in coupled ocean-atmosphere-land climate simulations. Present climate models will be extended into a first generation of earth system models to be used in scenario simulations and climate forecasts. The level of detail of biogeochemical, aerosol and cloud processes in the models will be based on the thematic studies mentioned above.

OCEANS

The ocean, through its dominating influence on the global climate and its major role as a source of important natural resources and devastating hazards, plays a key role in the lives of all human beings. At the same time, the ocean is increasingly being altered by anthropogenic CO_2 emissions, fishing, pollution and other human activities. From a European perspective, the Atlantic and Arctic oceans are particularly important, and changes in the tropical conditions as well as shifts in the high latitudes are the focus of several ongoing research projects.

The North Atlantic and the embedded thermohaline circulation support a relatively mild climate in northern Europe. At the same time, the formation of deep waters sequesters significant amounts of anthropogenic CO_2 in the interior of the ocean. A number of efforts are being directed towards achieving an understanding of the variability of the current system in the northern North Atlantic. These efforts are based on a combination of hydrographic observations, moored observatories and high-resolution ocean modelling. The most prominent signal during the last decade was a well-documented warming of the water column above 2000 m over the entire Labrador Sea, caused primarily by the weakened or absent formation and deep convection of Labrador Sea Water. The ad-hoc assumption that this warming trend should be reflected in a changed intensity of circulation and outflow of the Deep Western Boundary Current at 53°N was not confirmed by moored observations between 1997 and 2010. Other issues of interest are the interior Subpolar Gyre circulation and exchanges between the Arctic and North Atlantic in the Fram and Denmark Straits (*Fig. 6*).

Changes in circulation and air-sea fluxes are being investigated in the Tropical East Atlantic at several locations between the Mauritanian Shelf, the Cape Verde Islands and the Equator along 23°W. An improved understanding of the marine biochemical changes is being sought and particular attention is devoted to the deposition of dust (*see SOPRAN*). A poorly ventilated water mass results in a zone of low oxygen concentration at a depth of 300 – 500 m below the water's surface (*see Fig. 7*).This Atlantic oxygen minimum zone is expanding in volume and its minimum values are decreasing, very probably due to anthropogenic influences. The impact of deoxigenation on marine nutrient dynamics and habitat reduction of tuna are being investigated.

Recent high-resolution ocean model studies that resolve the ocean mesoscale eddy fields in a transport sensitive region at the southern tip of Africa show that the interbasin exchange between the Indian Ocean and the South Atlantic Ocean have a similar influence on changes in the near-surface Tropical Atlantic Ocean as alterations in the thermohaline circulation in the subpolar North Atlantic.

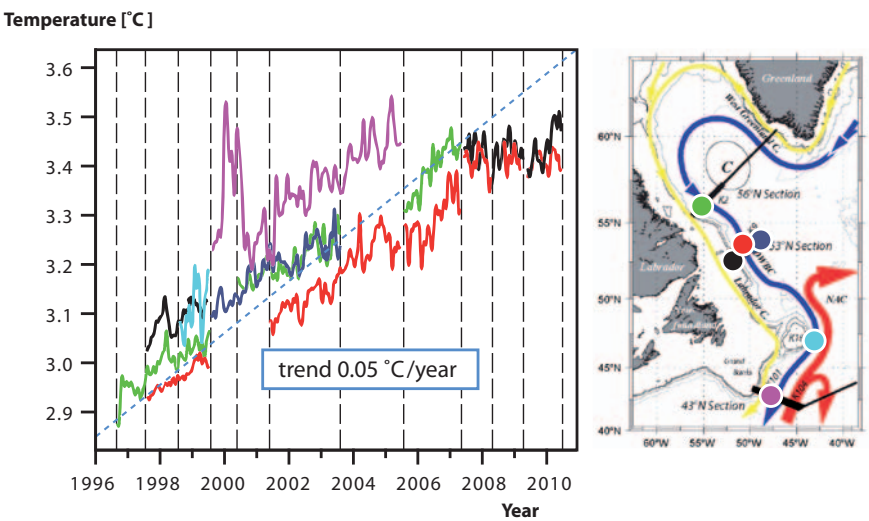


Fig. 6: Evolution of temperatures at 1500m depth along the southern path of the North Atlantic Deep Water exiting the Labrador Sea. The warming trend since the mid 1990ies seems less pronounced since 2008. (Source: Fischer et al. 2010, DOI: 10.1029/2010GL045321)

PROJECT EXAMPLES

SOPRAN – *Surface Ocean Processes in the Anthropocene*

The new, interdisciplinary "Earth system thinking" that is needed for tackling modern and future environmental problems, requires explicit consideration of the coupled nature of the earth system within global change research projects. With these needs in mind, the SOPRAN project depends explicitly on integrating the contributions and expertise of scientists trained in physics, chemistry and biology. Atmospheric chemists and physicists, chemical, biological and physical oceanographers and marine ecologists will tackle problems of common interest and relevance to human society. Therefore, as well as being an important research programme in its own right, the SOPRAN research themes provide a context within which diverse research communities, which are currently operating separately, can be joined in highly innovative research in which the next generation of scientists can be trained.

Endorsed by

Programme Duration: 2007-2013
Funding: BMBF (Cooperative Project)
HTTP://SOPRAN.PANGAEA.DE/

EXCELLENCE CLUSTER "THE FUTURE OCEAN"

The work of scientists in the Kiel cluster of excellence "Future Ocean" is aimed at examining the changes in the oceans and re-assessing the risks and opportunities for the future that will arise from the ocean. The long history of marine science research in Kiel offers a perfect background for broadening scientific horizons and taking an interdisciplinary approach to the research that urgently needs to be carried out. A large group of scientists from the most diverse disciplines has joined forces in this cluster that was established to explore the ocean of the future. The cluster encompasses not only marine researchers, but also geologists, medical scientists, economists, mathematicians, chemists, legal experts and social scientists. A total of five faculties from the University of Kiel, the Leibniz Institute of Marine Sciences IFM-GEOMAR (from 2012 on: Helmholtz Center for Ocean Research) and the Kiel Institute for the World Economy (IfW) as well as the Muthesius Academy of Fine Arts are participating in this cluster. Marine research at Kiel University is the main focus of the cluster and thus raises the University's profile as a leading centre for interdisciplinary marine studies.

Programme Duration: 2006-2012 (a second phase has been applied for)
Funding: DFG (Excellence Initiative)
WWW.FUTURE-OCEAN.DE

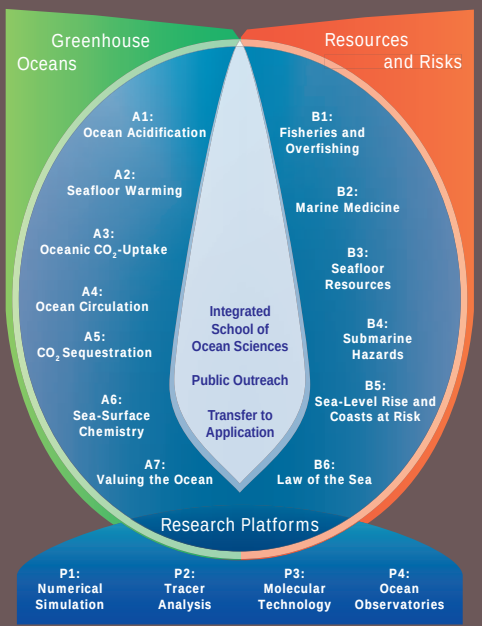


Fig. 8: Topics of "The Future Ocean".

CLIMATE – *Biogeochemistry Interactions in the Tropical Ocean*

The Collaborative Research Centre 754 is studying the physical, microbiological and chemical processes operating in these zones and is seeking to determine how sensitive the oxygen switch is to climate change. The project addresses the present-day situation (through direct observations of processes), the past (through reconstructions of the response of oceanic O2 to past climate changes) and the future (through the development of biogeochemical and physical models). The overall goal is to improve the understanding of the coupling of tropical climate variability and ocean circulation with the ocean's oxygen and nutrient balance, to quantitatively evaluate the nature of oxygen-sensitive tipping points, as well as to assess consequences for the ocean's future. Within the Collaborative Research Centre 754, scientists from the University of Kiel and the Leibniz Institute of Marine Sciences (from 2012 on: Helmholtz Center for Ocean Research) are working with colleagues from the Bremen-based Max Planck Institute for Marine Microbiology to carry out a unique multi-disciplinary study covering chemical and physical oceanography, sediment biogeochemistry, marine ecology, molecular microbiology, palaeoceanography, geology, as well as climate and biogeochemical modelling.

Programme Duration: 2008-2011 (a second phase has been applied for)
Funding: DFG (Collaborative Research Centre – SFB 754)
WWW.SFB754.DE

THE NORTH ATLANTIC AS PART OF THE EARTH SYSTEM: FROM SYSTEM COMPREHENSION TO ANALYSIS OF REGIONAL IMPACTS

The overall objective of the collaborative project is to define an observational and diagnostics system capable of determining the impact of large-scale variability on regions of the North Atlantic, its adjacent seas and the European continent itself. The intention is to improve the qualitative and quantitative prediction capabilities of application-relevant models. The cooperative project uses measurements in the Atlantic to describe its current state, as well as links to other measurement campaigns. In addition, there is a status description as a function of time via models, and an assessment of large-scale variability effects on regional social and economic conditions in Europe.

Programme Duration: 2006-2012
Funding: BMBF (Cooperative Project)
HTTP://NORDATLANTIK.ZMAW.DE/PROJEKT.724.0.HTML

Endorsed by

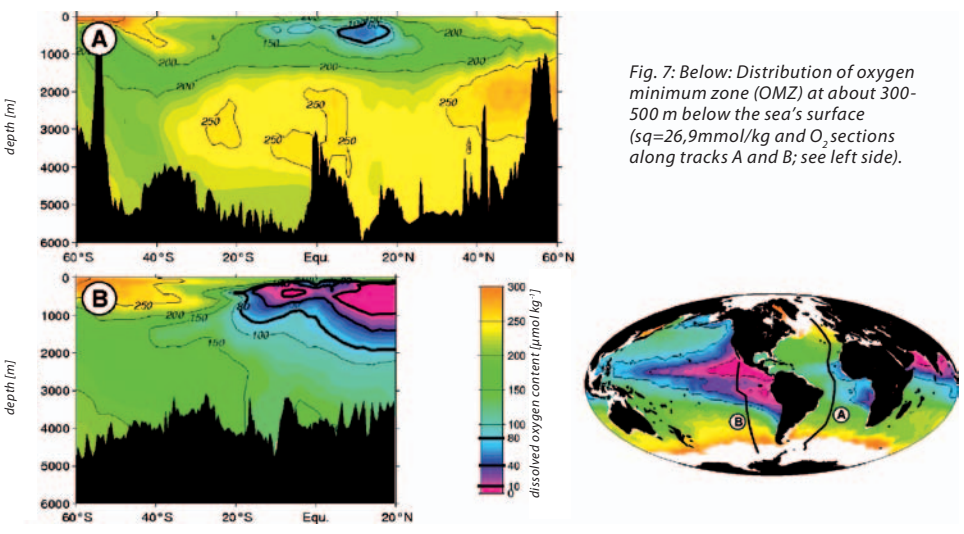


Fig. 7: Below: Distribution of oxygen minimum zone (OMZ) at about 300-500 m below the sea's surface (sq=26,9mmol/kg and O_2 sections along tracks A and B; see left side).

provided by J. Karstensen, SFB 754

CARBON CYCLE

Rising surface temperatures and changes in climatic conditions are consequences of rising CO_2 concentrations in the atmosphere. This represents a real danger that has precipitated intensive research into the natural and anthropogenically influenced carbon cycle as well as its relevance to the global society. Only about 45% of CO_2 emitted accumulates in the atmosphere, the remainder is taken up by sinks in the ocean and terrestrial ecosystems. It is not clear whether these sinks will continue to exist in the future.

About 20% of the global oceanic uptake of CO_2 enters the North Atlantic and is transported into the ocean's interior by physical processes associated with deep-water formation (*see also p. 14*). In addition to such physical processes, biological uptake and the subsequent sinking of organic carbon to deeper waters also contribute to the global oceanic carbon balance. Direct observations from "Voluntary Observing Ships" (VOS) as well as high-resolution model simulations show that there are strong fluctuations in the uptake of CO_2 from year to year (*Fig. 9*). This is mainly a result of variations in wind stress and heat flux which influences mixing and deep-water formation and thus carbon sequestration potential of oceans. Climatic fluctuations and shifts in biological production significantly alter the carbon uptake and, therefore, it cannot be assumed that the ocean is a constant sink for anthropogenic carbon.

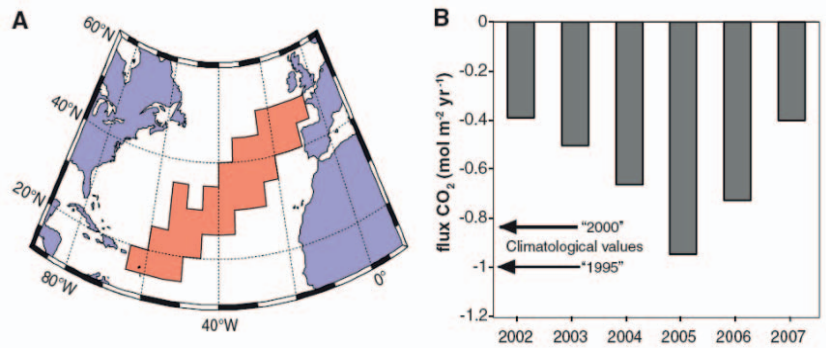


Fig. 9: Annual sea-air fluxes of CO_2 calculated from data on a shipping route between the United Kingdom and the Caribbean. (A) Mosaic of 5° by 5° tiles in which data coverage of the UK-Caribbean route is sufficient to calculate annual fluxes over the years 2002 to 2007. (B) Annual average fluxes for the enclosed area (A). The fluxes are negative (i.e., from air to sea). Fluxes calculated using "climatological" values of air-sea fCO_2 gradient in this region, referenced to 2000 (Takahashi et al. 2009, DOI: 10.1016/j.dsr2.2008.12.009) or 1995 (Takahashi et al. 2002, DOI: 10.1016/S0967-0645(02)00003-6), are also indicated. Although these may be indicative of fluxes at these earlier times, they are not strictly applicable to any given year. (Source: Watson et al. 2009, DOI:10.1126/science.1177394)

In contrast to the ocean, terrestrial carbon sinks are much more heterogeneous in space and time, and are controlled by a multitude of processes that are still poorly understood. In Europe, the carbon balance is determined primarily by fossil fuel emissions (total of 1.6 petagram of carbon per year in 2000-2004) of which approximately 15% are compensated by terrestrial carbon uptake in growing forests. At the same time, croplands are losing carbon and hence reduce this terrestrial sink (*Fig. 10*). In addition, climate variations strongly modify the terrestrial carbon balance as witnessed e.g. during the heat wave in Europe in 2003. Recent research also shows that enhanced nitrogen deposition, increased CO_2 concentrations and moisture availability play an important role in the enhanced growth of European forests.

Carbon cycle research requires a three-pronged approach: (1) Process studies in the laboratory or in the field are needed to understand the dynamics of carbon in various forms, its transformation by physical, chemical and biological processes, and their interactions with the environment and other nutrients. (2) A monitoring strategy is indispensable for quantifying and assessing changes and their drivers on regional and global scales. Recently developed new methods (*e.g. Fig. 9*) have substantially improved our observing capacity, but need to be sustained and integrated into a global observing system. (3) Finally, the process understanding and the observations must be integrated into regional and global modelling systems, which are needed to quantitatively assess the roles of individual carbon cycle factors and to investigate the carbon cycle as an interacting component of the Earth system. Several collaborative European FP7 projects with strong German participation are pursuing this research agenda. The projects include CarboChange, GHG-Europe and CARBO Extreme (*see right-hand side*). These research-oriented projects are supported by the newly established large-scale European research infrastructure, the Integrated Carbon Observing System (ICOS, *see p. 37*), which will harmonise and run high quality carbon observations over the next few decades. The expansion of the substantial German contribution to ICOS is supported by the Federal Ministry of Education and Research.

Within the United Nations Framework Convention on Climate Change (UNFCCC), the vast majority of nations have agreed to a "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Article 2). Whereas original climate policy initiatives have concentrated on

PROJECT EXAMPLES

CARBOCHANGE – *Changes in Carbon Uptake and Emissions by Oceans in a Changing Climate*

CARBOCHANGE will provide the best possible process-based quantification of net ocean carbon uptake under changing climate conditions using past and present ocean carbon cycle changes for a better prediction of future ocean carbon uptake. It will improve the quantitative understanding of key biogeochemical and physical processes through a combination of observations and models. Results will include optimal process descriptions and error margins that are as realistic as possible of future ocean carbon uptake quantifications with models developed from currently available observational evidence. The project will deliver calibrated future evolutions of ocean pH and carbonate saturation as required by the research community working on ocean acidification in the EU project EPOCA and additional projects in this field. The time history of atmosphere-ocean carbon fluxes past, present and future will be synthesised globally as well as regionally for the transcontinental RECCAP project. Observations and model results will merge into GEOSS/GEO through links with the European coordination action COCOS and will lay the foundations of the marine branch of the European Research Infrastructure ICOS (*see p. 37*).

Project Duration: 03/2011 – 02/2015
Funding: EU FP7
WWW.CARBOCHANGE.B.UIB.NO

CARBO-EXTREME – *The terrestrial Carbon Cycle under Climate Variability and Extremes – a Pan-Europe Synthesis*

CARBO-Extreme aims to improve our understanding of the terrestrial carbon cycle in response to climate variability and extreme events. It will represent and apply this knowledge across Europe with predictive terrestrial carbon cycle modelling. It aims to interpret model predictions in terms of the vulnerability of the terrestrial – in particular soil – carbon pools under different scenarios and give advice to the European Commission and other stakeholders in order to support the development and implementation of climate, soil and ecosystem protection policies.

Project Duration: 06/2009 – 05/2013
Funding: EU FP7
WWW.CARBO-EXTREME.EU

GHG-EUROPE – *Greenhouse Gas Management in European Land Use Systems*

The GHG-Europe project aims to improve our understanding of and capacity for predicting the European terrestrial carbon and greenhouse gas budget. More than 50 % of Europe's land surface is used for agricultural and forestry production. Land management directly impacts the terrestrial sources and sinks of greenhouse gases (GHGs). In view of climate change it is crucial to know the amount of GHGs released into the atmosphere by anthropogenic activities. But natural drivers such as climate variability also influence the GHG balance of European ecosystems. The attribution of GHG emissions to anthropogenic and natural drivers is the ultimate challenge being tackled in the GHG-Europe project and is the precondition for an assessment of the potential for GHG reduction from agriculture and forestry in Europe.

Project Duration: 2010 – 2013
Funding: EU FP7
WWW.GHG-EUROPE.EU

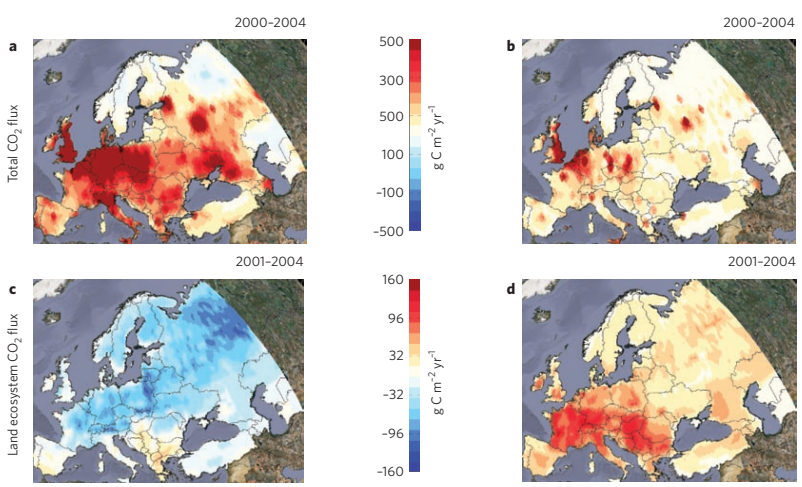


Fig. 10: Synthesis of the carbon balance of Europe averaged over the years 2000-2004 derived from a multitude of observations and methods. Positive values (red) indicate carbon losses to the atmosphere, negative values (blue) denote carbon uptake. (a) Total carbon balance, (b) estimated error (1 standard deviation), (c) carbon balance of European ecosystems, (d) estimated error (1 standard deviation). (Source: Schulze et al. 2009, DOI:10.1038/ngeo686).

greenhouse gas emission – of which CO_2 is currently considered to be the most important – it is now apparent that the complete carbon cycle and not only atmospheric emissions will need to be incorporated into carbon management. Hence, different forms of carbon sinks are being investigated. The Kyoto Protocol already takes account of the terrestrial carbon sink in the form of biomass. Sequestration of carbon in the deep oceans and in geological land formations is also part of the research considerations and a number of test projects already exist. However, there is still a considerable amount of research to be done before there is sufficient knowledge available to enable full carbon management and before policy measures are developed to make such management feasible.

Lastly, the global carbon cycle and its management cannot be studied solely from a natural science perspective. The perturbation of the global carbon cycle is closely linked to human development and the need for energy and food resources on land and in the sea. The scientific assessment of any management options thus clearly also needs to take into account the multitude of socio-economic drivers and interactions in the modern world. Addressing this in a rational, scientific way poses a huge challenge, which, however, must be met in order to steer the Earth system to within acceptable limits over the next 100 years and beyond.

LAND USE CHANGE

Land is a scarce resource. This means that its use for one purpose often excludes other uses. Major trade-offs in land use arise between climate change measures, notably in the form of renewable energy sources, agricultural production and the conservation of natural ecosystems. Total food crop yield between 1961 and 1999 increased by 106% globally, a growth that was achieved by global increases in crop and permanent pasture land of 12% and 10%, respectively. Other factors that contributed to this development are a 100% increase in land that is irrigated at the expense of rivers, aquifers and wetlands, an increase in the use of fertiliser by at least 200%, and of pesticides by over 800% (Green et al. 2005, DOI: 10.1126/science.1106049). These land use changes affect natural areas in ways that are not fully understood but that could have significant consequences for the welfare of nature and humans as well as for climate change. To better understand these impacts and to develop policies to control what are for the most part inevitable changes, the German Federal Ministry of Education and Research followed a recommendation of NKGCF and has recently launched the research programme "Sustainable Land Management" (*see right-hand side*).

The technologies used to improve agricultural productivity are thought to have a significant impact on natural systems, but the biophysical dynamics of these impacts are poorly understood and only a handful of studies have been able to meaningfully quantify these processes. One general effect of human-induced changes to the quantity and quality of natural areas is the impact on the ability of certain species to survive under deteriorated conditions. The ALARM project, which has recently come to an end, involved the development of methods to assess such risks (*see ALARM*). If species are lost, this may in turn lead to a further deterioration in the functioning of natural areas. The "biodiversity exploratories" (*see p. 21*) are an attempt to better understand the interaction between land use, biodiversity and ecosystem functioning.

Countries can avoid regional trade-offs in land use by importing resources, goods and services. Countries can use international trade to export the land use conflicts that would result from producing certain goods at home. Well-known (if inconclusive) efforts to quantify off-site effects include concepts such as the ecological footprint and virtual water. It has become clear that regional land management generates local trade-offs and global off-site effects. Sustainable land management therefore requires a global perspective which reflects the possibility that the most effective decisions on a local level impoverish welfare elsewhere. On the other hand, global targets and instruments alone are not sufficient because differences in regional and local situations need to be taken into consideration in order to develop policies that are effective on the local scale. Consideration of these cross-scale interactions requires research programmes to be set up accordingly (*see GLUES*).

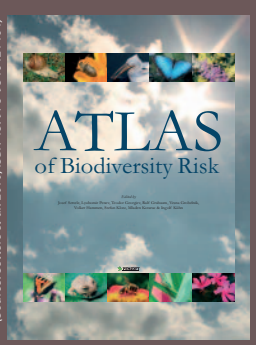
In the event that scientific answers to these questions are found, a further challenge is to ensure that the answers find their way into policymaking. This requires the dissemination of results as well as close cooperation between stakeholders and policymakers, all of whom have different interests, at multiple administrative levels. Ideally, for instance, regional groups would be involved in the scientific process from the start to ensure that research questions and solutions are adapted to local problems. Networks like these that connect relevant actors are increasingly relevant in the identification of appropriate policy responses. In Germany, the NeFo project aims to bring together national scientists and global institutions (*see p. 21*).

PROJECT EXAMPLES

ALARM

Assessing large-scale environmental risks for biodiversity with tested methods

The effects of global change on biodiversity, such as climate change, land use change and biological invasions are well understood in isolation, but it is not understood how these drivers interact. This interaction may aggravate the impact on global biodiversity. Since species distributions are partially limited by climatic conditions, climate change will affect species potential for spatial dispersal. Fragmentation and isolation of suitable areas will increasingly limit options for movement as an adaptive reaction to climate change. Available data on such processes are of insufficient quality and resolution to assess these dynamics. The ALARM project looked at these interactions and their effects on biodiversity across spatial and temporal scales, while also addressing the role that biodiversity plays in the support of important ecosystem services such as pollination. The project identified the socio-economic risk indicators that are related to the drivers of biodiversity pressure and showed how these affect risks to biodiversity under various change scenarios. These results have been picked up on by policymakers and are now used around the world for teaching students and informing members of the public about the complexities of the loss of biodiversity and ecosystems.



The Atlas of Biodiversity Risk. (Source: Settele et al. 2010, ISBN-13: 978-9546424464)

Programme Duration: 2004 – 2009
Funding: EU 6th Framwork Programme
WWW.ALARMPROJECT.NET

GLUES

Global Assessment of Land Use Dynamics, Greenhouse Gas Emissions and Ecosystem Services – Scientific Coordination and Synthesis of the Research Programme on Sustainable Land Management Modul A

GLUES supports projects within the research programme "Sustainable Land Management"and aims to synthesise their results. In order to be able to identify transferable patterns from regional projects, the number of differing regional conditions needs to be reduced and this is something that GLUES aims to achieve by creating global scenarios and a common data pool via a geodata infrastructure (GDI). These global scenarios provide a context for all the regional scenarios that remains consistent across all projects. Scenarios are being developed for the medium (2030) and long-term (2100), which will enable the study of outcomes of immediate policy actions and how they correspond to long-term goals. The common data pool allows the exchange of well-described data between the different regional collaborative projects in the research programme. To satisfy the demand for efficient communication infrastructures, networking, outreach (public relations and science policy interface) and the involvement of stakeholders and to assist in the effective implementation of results, GLUES also supports the regional projects within the research programme by managing the programme's major communication needs. An internal and external communication strategy for the research programme has been developed to effectively communicate and feed results into specific target groups. Stakeholder involvement, continuation strategies for the implementation of results throughout the life span of the projects and measures to apply scientific results to political processes are all part of the professional services offered.

Programme Duration: 2010 – 2014 (projected)
Funding: BMBF
HTTP://MODUL-A.NACHHALTIGES-LANDMANAGEMENT.DE/EN/MODULE-A

RESEARCH PROGRAMME "SUSTAINABLE LAND MANAGEMENT"

Global change poses an enormous challenge for policy, economy and society. Innovative approaches to our use of natural resources and land are needed to cope simultaneously with adaptation and mitigation of climate change, changing demographic structures, and conflicts between nourishment, our energy supply and other economic activities. Using various examples, the research projects in this programme will develop new models, technologies, system solutions and policy strategies for sustainable land management. The projects take into account integrative, interdisciplinary and regional perspectives, which enables them to address the variety and complexity of the demands placed on land and natural resources. Research is oriented towards policy development and the project scientists will work in close cooperation with regional and international stakeholders. The research programme is divided into two parts: module A has an international focus (*see figure below*) and module B looks specifically at land management options in Germany. The projects in module A address interactions between land management, climate change and ecosystem services. The main purpose is to identify key functions provided by natural resources that are indispensable to sustainable and climate-optimised land management. The projects in module B will look for ways to pursue an integrative development of urban, suburban and rural areas. The challenge here is to identify development policies that can take into account the complexities of regional socio-economic, ecological and social conditions.

Programme Duration: 2011 – 2015 (projected)
Funding: BMBF
WWW.SUSTAINABLE-LANDMANAGEMENT.NET

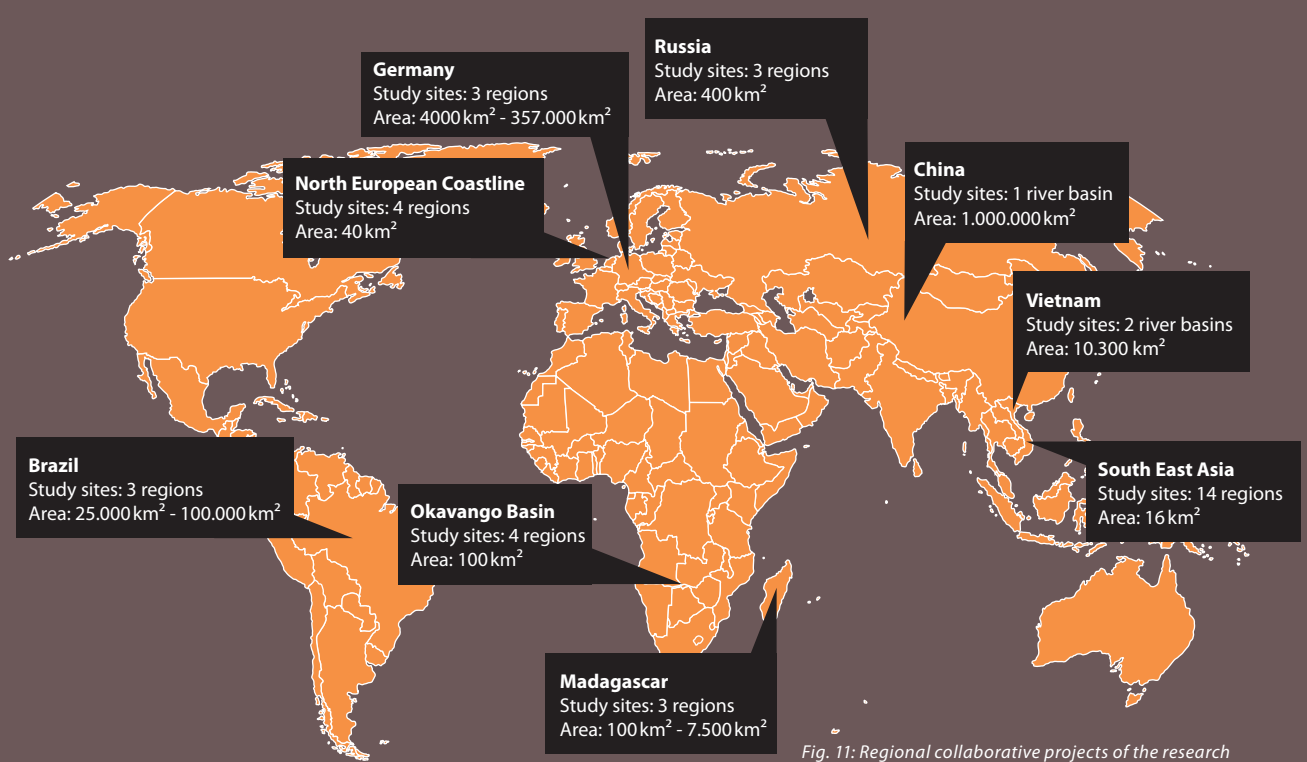


Fig. 11: Regional collaborative projects of the research programme "Sustainable Land Management" work on different topics and questions on sustainable land management in international regions. Note: This map only shows the projects in module A of the research programme.

BIODIVERSITY AND ECOSYSTEM SERVICE

Biodiversity is the fundamental base for global life support systems. The UN declaration that made 2011 – 2020 the decade of biodiversity is acknowledgement of this. When early life was established in the world ocean, photosynthesis began producing oxygen, which contributed to the conversion of the Earth's atmosphere from anaerobic to its aerobic composition. Evolution and the adaptation of organisms have turned most of the Earth into productive ecosystems that control fluxes of water, carbon, nitrogen and provide the goods and services necessary for human well-being. Therefore, the current dramatic loss of all levels of biodiversity (ecosystems, communities, species, genes) entails cascading effects and negative long-term consequences for ecosystem functions and adaptation potential within the dynamic earth system. The third Global Biodiversity Outlook report (published May 2010) has concluded that the 2010 target to significantly reduce the rate of biodiversity loss was not reached and that the drivers of loss are still increasing in strength. The main drivers include climate change, land-use change and overexploitation of resources (as for example in the case of marine fisheries, or the degradation and logging of temperate and tropical old-growth forests). Overexploitation is fueled by economic growing and by the need to provide food for an exponentially increasing human population. Understanding the interrelationship between global change, biodiversity and ecosystem services is regarded as a major scientific challenge to which Germany's biodiversity research contributes in many different ways, from taxonomic expertise to extensive data records of the distribution of organisms, from short-term experiments to large-scale earth system observatories, including long-term impact studies with ecological components, all covering continental as well as aquatic realms.

Biodiversity research is fundamental for understanding the interrelationships of global change and biodiversity, and how best to deal with the drivers of biodiversity loss, in order to slow down or even halt the decline of our living resources and consequently the ecosystem services on which we depend. Biodiversity research provides insights on very different levels of complexity. There is a need for taxonomic research to significantly expand our baseline data on species identities and phylogenetic relationships, as well as to increase our knowledge of the relevant underlying evolutionary processes that create and maintain diversity. The investigation of the spatial and temporal dimensions of past, present and future biodiversity is needed to describe the distribution of life on Earth (e.g. Census of Marine Life, **WWW.COML.ORG**), to monitor changes (e.g. *LTER programme, see right-hand side*), to understand the underlying processes and consequences (e.g. cross-cutting project "Niche evolution", Biodiversity and Climate Research Centre (BiK-F), **WWW.BIK-F.DE**) and to predict future biodiversity changes (e.g. *ALARM project, see p. 19*). In order to make such predictions it is necessary to understand the interrelation between species and ecosystems, the resilience against changes, and the risks and consequences of crossing tipping points that lead to irreversible changes (e.g. *Exploratories for long-term biodiversity research, see right-hand side*). Species as well as ecosystems have to be investigated with respect to the services they provide and the value that these services constitute, thus linking knowledge from the natural sciences explicitly with that of the social sciences, especially economics (e.g. *TEEB study, see below*). Results of all these different types of biodiversity studies of relevance to global change research are essential for the formulation of informed political decisions on how to deal with ecosystems in a responsible manner. Science-policy interfaces are a valuable tool for improving evidence-based policymaking (e.g. *Network-Forum NeFo, a project of DIVERSITAS Germany*) and will support the future Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES).

The following are examples of ongoing biodiversity research initiatives in Germany with relevance to global change issues, representing different concepts and research methods, temporal and spatial scales, and networks.

PROJECT EXAMPLES & NETWORKS

TEEB

The Economics of Ecosystems and Biodiversity

The TEEB initiative is a major global initiative to assess the economic consequences of biodiversity loss and outline the importance of ecosystem services for human well-being in economic terms. As a meta-analysis, the TEEB reports collect and summarise information about the value of nature and how economic instruments can help to better take this value into account for different stakeholders, national and international policymakers, local administrators and businesses. TEEB's scientific coordination is carried out by the Helmholtz Centre for Environmental Research – UFZ in Leipzig.

Programme Duration: since 2007
Funding: European Commission, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and ministries from six other countries
WWW.TEEBWEB.ORG

DIVERSITAS GERMANY – *A scientific network for biodiversity researchers*

DIVERSITAS Germany e. V. is a scientific network that identifies key scientific problems relating to biodiversity research, the safeguarding of biodiversity and the sustainable use of its goods and services. Acting through the German National Committee on Global Change Research (NKGCF), DIVERSITAS Germany supports the implementation of the aims of DIVERSITAS International, a partner of the ESSP, and of the UN Convention on Biological Diversity (UNCBD). The national network strengthens links with international research partners for innovative and interdisciplinary research.

Programme Duration: long-term, registered society (e. V.) since 2009
Funding: society membership
WWW.DIVERSITAS-DEUTSCHLAND.DE

NEFO – *Network-Forum for Biodiversity Research Germany, a platform at the science-policy interface*

NeFo is a DIVERSITAS Germany project that constitutes a network and forum for biodiversity researchers in Germany. It aims to build a communication structure that is supportive and complementary to existing research institutions, networks and policy advisory bodies. It focuses, among other things, on land use as a major and complex driver for the loss of biodiversity. As biodiversity is pivotal for human well-being, there is a need to identify and implement sustainable land use strategies that maintain biodiversity and ecosystem services. This is increasingly recognised by policymakers at the national and international level. Developing and implementing sustainable land-use strategies requires research that addresses both the natural and socio-economic aspects of biodiversity, as well as communication strategies that are accessible to policymakers, media and the public. NeFo provides active support in facilitating this process by communicating biodiversity-relevant information both ways, from research to policymakers and vice versa.

Programme Duration: 2009 – 2012
Funding: BMBF
WWW.BIODIVERSITY.DE

EXPLORATORIES FOR LONG-TERM BIODIVERSITY RESEARCH

In 2006, the DFG established three Biodiversity Exploratories, exemplary large-scale and long-term research sites which serve as open research platforms to address critical questions related to the understanding of the relationship between the biodiversity of different taxa and levels, the role of land use and management for biodiversity and the role of biodiversity for ecosystem processes. The three exploratories are situated at sites across Germany including the Schorfheide-Chorin Biosphere Reserve (NE Germany), the Hainich National Park and surrounding area (central Germany) and the Schwäbische Alb Biosphere Reserve (SW Germany), all of which focus on grassland and forest ecosystems.

Programme Duration: since 2006
Funding: DFG
WWW.BIODIVERSITY-EXPLORATORIES.DE

LTER-D – *Network for Long-Term Ecological Research - Deutschland*

The German network for long-term ecological research (LTER-D) is a platform for communication, documentation and collaboration between scientists in long-term, system-oriented and interdisciplinary environmental research. It covers 19 sites and platforms that carry out long-term ecological research in all relevant ecosystem types from the high mountains to the coasts and the deep sea. LTER-D is a member of the international LTER umbrella organisation ILTER and the European network LTER-Europe.

Programme Duration: since 2004 in Germany; > 20 years internationally
Funding: various national and international funding sources
WWW.LTER-D.UFZ.DE **WWW.ILTERNET.EDU** **WWW.LTER-EUROPE.NET**

BIOFRESH – *Biodiversity of Freshwater Ecosystems*

BioFresh is an EU-funded international project on "Biodiversity of Freshwater Ecosystems: Status, Trends, Pressures, and Conservation Priorities" that aims to build a global information platform for scientists and ecosystem managers enabling access to all available databases that describe the distribution, status and trends of global freshwater biodiversity. BioFresh integrates the freshwater biodiversity competencies and expertise of 19 research institutions and is coordinated by the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin.

Programme Duration: 2009-2014
Funding: EU 7th Framework Programme
WWW.FRESHWATERBIODIVERSITY.EU

BIOACID – *Biological Impacts of Ocean Acidification*

In view of the growing concern about the possible impact of ocean acidification on marine life, a national initiative for a cooperative project entitled "Biological Impacts of Ocean Acidification" (BIOACID) is funded by the BMBF to study the effects of ocean acidification on marine organisms and their habitats, the underlying mechanisms of responses and adaptations on the level of populations and communities, how they are modulated by other environmental stressors, and what are the consequences for marine ecosystems and ocean biogeochemical cycles. BIOACID employs a wide range of scientific approaches and methodologies, extending from field monitoring of OA-sensitive areas and ecosystems to mesocosm perturbation experiments, combined with closely coordinated ecosystem and biogeochemical modeling activities using parameterizations of observed biological responses and their biogeochemical implications. The proposed project is closely coordinated with the European Project on Ocean Acidification (EPOCA) funded as part of the 7th EU Framework Programme.

Programme Duration: 2009-2012
Funding: BMBF
WWW.BIOACID.DE **WWW.EPOCA-PROJECT.EU**

Photo: J. Lundälv, Sven Lovén Marine Center & A. Freiwald, Senckenberg MEFO

Fig. 12: Intact and destroyed coral reef at the Mauritanian continental slope.

WATER AVAILABILITY AND WATER MANAGEMENT

Water is a central issue in many fields of environmental research. The supply of sufficient amounts of water of adequate quality is essential for health, as well as for the cultural and economic development of societies. Yet, reducing the percentage of the human population that do not have access to adequate supplies of good quality fresh water remains a challenging task.

Climate change puts pressure on the availability of water resources through prolonged periods of drought, risking food security in many regions of the world, and threatens people's lives and goods through an increasing number of floods. The explosive growth of megacities in developing countries and countries in transition poses a challenge to supply systems, treatment technologies and management concepts with respect to exploitation strategies, allocation mechanisms and issues related to the social, economic and environmental sustainability of cities. The Guanting project develops concepts for the sustainable planning and management of water resources in the vicinity of the mega-metropolis of Beijing (*see right-hand side*).

In order to improve the basis for adequate water management, the future grand challenges in water research increasingly need to be looked at in the context of global change, i.e. climate change, land use change, demographic and economic change. This context requires the integration of all forms of water resources into management strategies – "green water", which is water stored in and moving through soils and plants to control crop growth, "blue water" is water stored in lakes, rivers and groundwater, and "virtual water" is water 'embedded' into products during their production process.

Global change and water - the grand challenge is: how to manage these issues? How can we set beneficial yet realistic and achievable targets? How can we integrate different use interests and at the same time guarantee the availability of water for generations to come and for ecosystems that are the life support system for humans and the environment? What are the right measures to take?

Modern water research needs to reinforce methodological key competences in order to achieve a profound understanding of the effects of global change on the environmental system including delay effects, feedback mechanisms and the complex interaction of the various environmental subsystems. More coordinated and long-term efforts in environmental observation and exploration are needed (*see TERENO*). These efforts need to be interlinked with the joint efforts of the modeller community to better simulate the water system across different scales, different compartments and with different conceptual approaches.

Modern water research needs a systemic approach in order to deliver competent and relevant answers to the emerging challenges and therefore needs to develop new forms of strategic cooperation between the various disciplines and across institutional borders. Such an initiative was recently launched among the different groups of the German water research community in form of the Water Science Alliance (*see right-hand side*).

In order to create a synergy between the efforts of the various projects on integrated water resources management (IWRM) that are funded through the Federal Ministry of Education and Research (BMBF), the IWRM-Networking project organises coordinated activities bringing together the strengths of the many IWRM projects that are being carried out in different parts of the world. A good example, where the applicability of solutions and the transferability of IWRM concepts is being tested, is the International Water Research Alliance Saxony (IWAS), which is committed to developing and implementing concrete IWRM solutions in five hydrologically sensitive regions worldwide. Adaptation to the effects of global change will be a

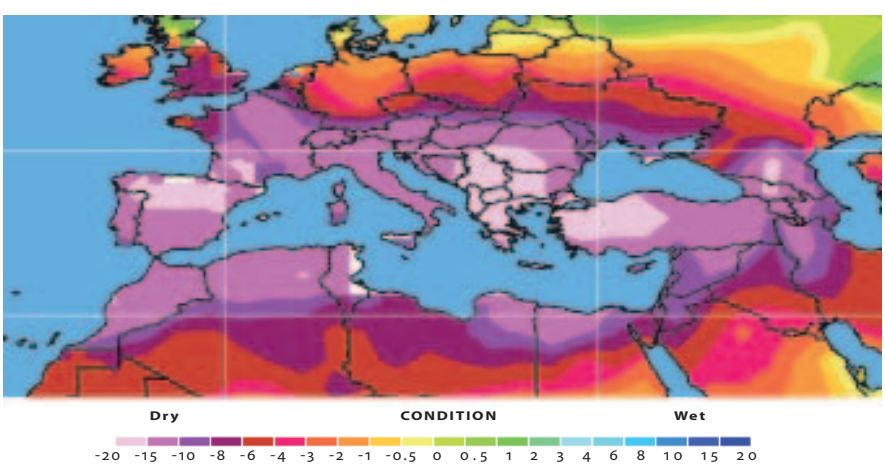


Fig. 13: Projections of climate change in the Mediterranean for 2060-2069 as laid out by the Palmer Drought Severity Index. This index determines aridity through precipitation and temperature information (particularly for long-term prognoses; < -4 = extreme drought) (Source: Dai 2011, DOI:10.1002/wcc.81).

PROJECT EXAMPLES

IWAS – *International Water Research Alliance Saxony*

IWAS develops concrete solutions to water problems in 5 hydrologically sensitive regions worldwide under the umbrella of the IWRM concept (IWRM: Integrated Water Resources Management). The regions under investigation are: Eastern Europe (Ukraine), Central Asia (Mongolia), Middle East (Saudi Arabia and Oman), Latin America (Brazil), South-East Asia (Vietnam). Its strategy is to develop concepts that are transferable between regions and may be adapted to the specific regional conditions where they shall be applied.

Programme Duration: 2008-2013
Funding: BMBF
WWW.IWAS-INITIATIVE.DE

IWRM – *Networking Project*

In order to create synergies among the various IWRM projects funded through the BMBF since 2006, the IWRM-Networking project supports the interaction between the scientists involved in the different international projects. In supporting the activities through joint thematic workshops and common thematic publications the project furthers the dialogue between science and politics, supports knowledge and technology transfer and therefore contributes to the implementation of research results.

Programme Duration: 2009-2011
Funding: BMBF
WWW.WASSERRESSOURCEN-MANAGEMENT.DE

TERENO – *Terrestrial Environmental Observatories / TERENO-MED*

In the frame of TERENO-MED the concept of TERENO on integrated environmental monitoring and modelling is to be transferred to representative sites across the circum-Mediterranean area. The initial focus will be on the analysis of water quality and quantity. The goal is to create a data and knowledge basis in order to allow for a strategic and complex water management in a partly densely populated coastal region with a growing economy, dynamic political and social developments, and an expected aggravation of already existing water scarcity.

Programme Duration: Set-up phase: 2008 – 2011 / 2012-2015
Funding: Helmholtz Association
WWW.TERENO.NET

WATER SCIENCE ALLIANCE

The Water Science Alliance aims to strengthen and bundle the existing competences in water science within the German water research community and beyond. The current situation of water science is characterised by a heterogeneous funding structure which often lacks overall coordination, and a diverse system of approximately 150 research institutes with good, yet very fragmented competences. The goal is to bring together research groups across different disciplines of water research and across institutional borders in the frame of common research goals in order to enable the national water research community to develop solutions to the complex problems related to water in a changing environment. Therefore, a White Paper was elaborated, presenting six priority research fields, with the participation of representatives from a wide range of research institutions, learned societies, National Agencies, as well as the Federal Ministry of Education and Research (BMBF), the Federal Ministry for the Environment, Nuclear Safety and Nature Protection (BMU) as well as the National Research Foundation (DFG).

Duration: Long-Term
Funding: Helmholtz Association and national and European/international funding agencies
WWW.WATERSCIENCEALLIANCE.ORG

GUANTING PROJECT - *Sustainable water and agricultural land use in the Guanting watershed under limited water resources*

The project analyses how land use practices in the Guanting watershed can be modified to guarantee sustainable availability of adequate quality water for users within the watershed and for the capital of Beijing taking into consideration the limits set by climatic, environmental and economic conditions.

Programme Duration: 2009 - 2012
Funding: BMBF
HTTP://GUANTING.PIK-POTSDAM.DE

CLIMB – *Climate-Induced Changes on the Hydrology of Mediterranean Basins*

CLIMB analyses the effects of climate change on available water resources in Mediterranean catchments. Seven catchments were chosen according to criteria of vulnerability to climate-induced changes in water availability, temporal variations/changes in the discharge regime and/or in water quality.

Programme Duration: 2009-2011
Funding: EU 7th Framework Programme
WWW.CLIMB-FP7.EU

key to the future of both humans and ecosystems. The IWRM initiatives are aimed at developing management capacities in order to enable humans to successfully adapt to global climate, land use and economic change.

The water research community in Germany will put special focus on the development of adequate solutions to water-related problems in the circum-Mediterranean region (Southern Europe, Northern Africa, Near East). This region is particularly affected by climate change on the one hand (prolonged periods of drought) and by rapid political, societal and economic changes on the other. The region plays an important role in food production, tourism, and in geopolitical issues, at the same time as having enormous potential for the sustainable production of solar energy and electricity as well as for the production of fresh water through wastewater treatment and desalination. Yet, prognoses on the future development of water resources in this region are very uncertain due to data scarcity, in particular the lack of long-term observations. The German science community is taking up the challenge of analysing the effects of climate change on Mediterranean hydrology through the CLIMB project (Climate-Induced Changes on the Hydrology of Mediterranean Basins) as well as through the establishment of a long-term network of hydrological and environmental observatories at representative sites throughout the Mediterranean (*see TERENO-MED*).

COASTAL ZONES

Coastal zones are among the most dynamic areas in the world, and are continuously changing as a result of variable influences from the land, the sea, the atmosphere and, more recently (i.e. over a period of centuries), from humans. Today, coastal zones represent one of the most important settlement areas – they are home to around 60% of the world's population and 75% of all cities with a population exceeding 2.5 million. Demographic estimates predict that these proportions will continue to increase and coastal ecosystems will therefore play an increasingly important role as a source of goods, services and income for coastal societies.

Although humans have inhabited coastal areas for many millennia, human impact has increased dramatically in both scale and rate over the last 200 years – which also contributes to global change. Nowadays, coastal zones are, more than any other area, areas of rapidly increasing socio-economic pressures in the form of harbour development and sea traffic, settlement, recreation, fisheries and aquaculture, coastal tourism, exploitation of hydrocarbons and mineral resources, and in recent years, wind energy production. In addition, coastal seas are affected by the input of environmentally harmful chemicals from industrial activities, nutrients and pesticides from agricultural activities and sediments from enhanced soil erosion. Such activities and inputs often have a detrimental impact on the local marine environment, resulting in the severe degradation of natural habitats. In addition to "direct" human impact, climate change is having a greater and greater effect on coastal zones through ocean warming, increasing storminess and, of course, rising sea level. The latter in particular might become a serious threat to coastal communities existing just above sea level (e.g., in the Maldives or along the German North Sea coast) or even below sea level (e.g., in parts of the Netherlands and the US Gulf coast).

Coastal communities inhabiting the onshore side of the coastal zone that are confronted with the effects of global change have begun to develop adaptation strategies that go far beyond the mere strengthening of existing coastal protection schemes. The major German research programme, KLIMZUG, aims to develop innovative strategies for adaptation to climate change and related weather extremes in specific regions, including coastal zones (*see KLIMZUG*).

The understanding and assessment of local effects of global change in coastal zones requires dedicated research and monitoring strategies. Compared to the state of knowledge on onshore terrestrial processes and systems, there are still many uncertainties about the offshore coastal marine environment. This lack of knowledge to a large extent reflects the logistic challenges of marine research. However, compared to many other coastal environments a reasonable database for the German coastal seas in the North Sea and the Baltic Sea exists. However, an integrated understanding of these systems that takes into consideration all forces (and feedbacks) that control energy budgets, material fluxes and ecosystem dynamics is still under development. In order to work towards such an integrated understanding, extensive synoptic data sets are needed to enable a major step forward in the validation of numerical models that can ultimately be used to describe these systems and enable assessments of future developments to be made for a variety of global change scenarios. To obtain a synoptic description of key variables of the North Sea and to feed them into numerical models, the COSYNA project (Coastal Observation System for Northern and Arctic Seas) has been set up and is running in conjunction with research projects such as WiMo (Scientific Monitoring Concepts for the German Bight) (*see COSYNA*).

A major step in the advancement of coastal research has been the realisation that human society has become a huge catalyst for changes in coastal zones. Consequently, coastal research is nowadays one of the most dynamic fields of interdisciplinary cooperation involving the social sciences (in their widest sense) as well as the natural sciences. One particular example of this is the IGBP project Land-Ocean Interaction in the Coastal Zone (LOICZ) in which the social sciences and economics are playing a decisive role – jointly with the natural sciences – in the assessment of the present state of coastal systems and the development of tools to model future developments. On a regional level, an integrative approach of this kind is currently being pursued in the Baltic Sea. BONUS (**WWW.BONUSPORTAL.ORG**) is a major international initiative aimed at integrating Baltic Sea system research into an interdisciplinary and multinational programme to support the region's sustainable development. By implementing a policy-driven, fully-integrated joint research programme based on extensive and continuous stakeholder consultations, BONUS will provide concrete scientific outputs to facilitate the implementation of ecosystem-based management of environmental issues in the Baltic Sea area. The SPICE programme (Science for the Protection of Indonesian Coastal Ecosystems) for tropical regions is also

KLIMZUG – *Managing Future Climate Change in the Regions*

Even if a successful climate protection strategy is set up in the near future, there remains an urgent societal, economic and political demand for the development of new and improved methods for climate change adaptation. KLIMZUG puts substantial emphasis on developing such strategies for German coastal regions as part of a number of regional projects:

- RADOST - Regional Adaptation Strategies for the German Baltic Sea Coast
- northwest2050 - Prospects for Climate-Adapted Innovation Processes in the Model Region Bremen-Oldenburg in northwestern Germany
- KLIMZUG-NORD - Strategic Approaches to Climate Change Adaptation in the Hamburg Metropolitan Region

Programme Duration: 2009-2014
Funding: BMBF
WWW.KLIMZUG.DE

Fig. 14: North Sea coastal landscape at risk.

*Fig. 15: FINO3 – research platform in the North Sea (**WWW.FINO3.DE**).*

COSYNA
Coastal Observation System for Northern and Arctic Seas

Programme Duration (1st period): 2010-2013
Funding: BMBF
WWW.COSYNA.DE

WIMO
Scientific Concepts for Monitoring in the German Bight

Programme Duration: 2010-2013/15
Funding: State Lower Saxony
WWW.WIMO-NORDSEE.DE

The first phase up to 2013 focusses on the German Bight in the North Sea where COSYNA is setting up an observational network implementing state-of-the-art technologies to provide data for an integrated approach linking observations and numerical modelling. In conjunction with WIMO the aims are to assess the current state of the German Bight, to develop scenarios for future developments and to contribute to decision-making processes.

focussed on providing knowledge for integrated coastal management (*see p. 49*). Since it commenced in 2003, SPICE has provided significant information on the structure and functioning of coastal ecosystems and alterations due to human interventions. The results have already found their way into management strategies that are being developed by the regional planning authorities.

Although coastal research is today at the forefront of the development of interdisciplinary cooperation between the social and natural sciences, real interdisciplinary research is still the exception to the rule, and this is often a result of the different "languages" spoken by each discipline. In order to overcome this language barrier, scientists need to learn interdisciplinary communication early on in their career. Aware of this need and thanks to the already advanced state of interdisciplinary cooperation in the field of coastal sciences, the integration of social and natural sciences is a key element of several Ph.D. training courses in Germany, especially those that have been funded by the German Excellence Initiative since 2006 and 2007. The next step will be to build upon and further develop such integrated training-based approaches on coastal systems and other areas in institutes such as the three marine science centres of excellence in northern Germany. One such development is the research-based international research training group INTERCOAST (**WWW.INTERCOAST.UNI-BREMEN.DE**) where 13 German and 8 New Zealander Ph.D. projects are focussing on integrated coastal zone and shelf-sea research incorporating marine science, social science and legal issues. It is expected that this new generation of coastal scientists, trained in interdisciplinary communication, will contribute to a major advance towards much stronger integration in coastal research in the coming decade(s).

POLAR REGIONS

The climate on Earth is to a large degree determined by the temperature contrast between the equator and the poles. Polar regions, especially in the Arctic, currently exhibit the most pronounced climate change compared with other world regions. Over the last 50 years, average temperatures north of 65°N have risen at almost twice the rate as temperatures in the rest of the world. In the Antarctic, the Antarctic Peninsula is one of the most rapidly warming regions on Earth. Understanding of the polar processes that are responsible for climate variations on regional and global scales and their impact on ecosystems is still limited. This is largely due to limitations in observing systems in those cold, remote and difficult-to-access regions. Nevertheless, several interesting results have emerged in the past few years.

The most significant change in the Arctic is the large decrease in sea ice cover, especially in summer. Important for the Arctic sea are thick ice floes that only can grow in regions of perennial ice covers. Since 2004, the thickness of the multiyear sea ice has been monitored with airborne electromagnetic induction devices, e.g. in the Lincoln Sea (Canadian High Arctic) (*Fig. 16)*. Over this period, six expeditions operated from the Canadian Forces Station Alert using helicopters and more recently research aircrafts such as *Polar 5*. Although the sea ice thickness in this area is subject to a significant interannual variability, the rate of decline of the summer sea ice cover has nevertheless been accelerating over the last three years, and has reached values close to the record minimum observed in 2007.

The large changes in the sea ice cover are partly a response to changes in atmospheric conditions, e.g. in temperature and wind systems. However, hardly any permanent atmospheric observations over wide regions of the Arctic are available. Thus, our knowledge about climate change over the central Arctic Ocean is mainly based on so-called re-analysis models representing model interpolations based on few direct observations. For example, the routine meteorological observations of R/V Polarstern are always transmitted to the WMO Global Telecommunication System (GTS) and thus contribute to the re-analysis products. This does however not mean that these observations can be perfectly reproduced, since they are adapted to and interpolated with physical models. The comparison indicates that the representation of atmosphere-sea ice-ocean interaction still has to be improved in the reanalysis models.

In 1992, a weekly ozone-sounding programme, which began in 1985 at the Georg Forster Station, was transferred to Neumayer Station II. Both stations are located within the area normally surrounded by the Antarctic stratospheric vortex. Since 2009, the programme has continued without interruption at Neumayer III. The measurements contribute to the "Global Atmospheric Watch" (GAW) as well as to the "Network for the Detection of Stratospheric Change" (NDSC). The time series is the longest record of ozone balloon soundings in Antarctica. It makes a significant contribution to the monitoring of the so-called "ozone hole". The data indicate that a significant recovery of the ozone layer above Antarctica has not been observed until now.

It is not just the sea ice but also the liquid freshwater that plays a significant role in the Arctic Ocean by insulating the warm Atlantic-derived subsurface waters from the atmosphere and thus enabling sea ice to form. The freshwater stems from river runoff, which comprises 10% of the global continental drainage, into the comparatively small Arctic Ocean. The inflow from the Pacific also has a very low salinity. Freshwater in the upper layers stabilises the water column and thus also affects the ventilation in Arctic and North Atlantic convection sites. Recently, it was shown that the amount of freshwater in the central Arctic varies considerably. Such an assessment was possible due to the joint efforts made during the IPY (International Polar Year 2007/08) involving Arctic-wide hydrographic surveys that were enhanced by data from automated platforms. In comparison to the sparser data collected during the 1990s, the 2006-2008 observations showed that in the years immediately before, the Arctic Ocean was accumulating freshwater over large central areas, particularly in and around the Beaufort Gyre. The increase amounts to approximately 20% of the

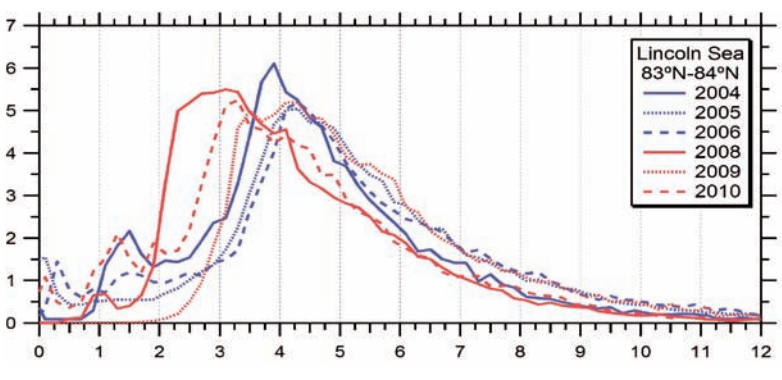


Fig.16: Sea ice thickness distribution in the Lincoln Sea taken from airborne measurements between 2004 and 2010. (Provided by C. Haas (Univ. of Alberta) & S. Hendricks (AWI))

GERMAN POLAR RESEARCH RELIES ON A SOPHISTICATED INFRASTRUCTURE FOR OPERATIONS IN POLAR REGIONS INCLUDING RESEARCH VESSELS, AIRCRAFT AND RESEARCH STATIONS BOTH IN THE ARCTIC AND ANTARCTIC.

Research aircraft "Polar 5"

Polar 5, a former DC-3, has been completely refurbished and fitted with ski-landing gear and special equipment mounted either inside the aircraft or on the wings in order to carry out investigations of the lithosphere, the atmosphere, the cryosphere and their interactions in the Arctic and Antarctica. Nowadays, aircrafts are also a necessary part of the operational logistics of the remote research stations in Antarctica. Research flights are conducted by the Alfred Wegener Institute in cooperation with other institutions and universities, and external partners.

WWW.AWI.DE/EN/INFRASTRUCTURE/AIRCRAFT/RESEARCH_AIRCRAFT

Research and Supply Vessel "R/V Polarstern"

An important tool in Germany's polar research programme is the "Polarstern". The "Polarstern" has completed a total of 25 expeditions to the Arctic and 27 to the Antarctic. The ship is equipped for biological, geological, geophysical, glaciological, chemical, oceanographic and meteorological research, and contains nine research laboratories. Additional laboratory containers may be stowed on and below deck. Refrigerated rooms and aquaria permit the transport of samples and living marine fauna.

WWW.AWI.DE/EN/INFRASTRUCTURE/SHIPS/POLARSTERN

Fig. 17: Research aircraft Polar 5 (Longyearbyen, Spitzbergen).

HAUSGARTEN - The Arctic deep-sea long-term observatory

At the HAUSGARTEN permanent station of the Alfred Wegener Institute located in the Fram Strait, the gateway to the Arctic Ocean, a shift in the plankton community occurred in the last 10 years. The abundance of diatoms, silica-shelled phytoplankton, decreased and was substituted by much smaller flagellates and coccolithophorids, which are the major global producers of calcium carbonate. Such phytoplankton produces marine snow particles (aggregates), an ideal substrate for bacteria to grow on. The challenge is to understand how far north into the central Arctic such changes occur and what the consequences will be for ecosystem dynamics.

average value. Model simulations show that this accumulation is mainly driven by a changing wind field and indicate that the Arctic Ocean recovered after a strong freshwater release to the North Atlantic in the last decades of the last century.

Over the past decade, the Arctic and adjacent regions have undergone significant and sweeping changes. This includes rapidly rising temperatures, shrinking sea-ice cover, destabilisation of land-fast ice, sediment transport by sea ice, and sea-level rise and increasing coastal erosion due to degradation of permafrost. The thawing of permafrost is responsible for dramatic landscape changes, including thermokarst lake drainage and expansion, wetland formation and slope processes. On the other hand, it is also responsible for natural hazards that threaten infrastructure such as community housing, roads, railways, landing strips, or pipelines that form a vital element of the socio-economic system in the Arctic. Warming permafrost temperatures could also potentially release large amounts of carbon as carbon dioxide or methane. A recent estimate puts the amount of soil organic carbon contained in permafrost at half the amount of the total global soil organic carbon pool, which highlights the importance of permafrost for the Earth's climate system. The environmental, socio-economic and geopolitical consequences of a sustained reduction in Arctic sea ice will be significant. For example, the continuing reduction in sea ice is very likely to extend the navigational season and increase marine access to the Arctic's natural resources. Here, polynyas (areas of open water surrounded by sea ice) play a central role as they are of major importance for sea-ice production and the ecosystem of the Arctic shelf seas. These polynyas form along the coastline between fast and drift ice and are particularly sensitive to changes in oceanic and atmospheric circulation. The wind-forced Laptev Sea flaw polynya, which are the most important location for sea-ice formation in the Arctic, turned out to be a significant element in the moisture and heat balance of the Arctic.

These changes have already clearly manifested in the Arctic shelf environments. If they continue, as projected by climate models, there will not only be consequences for the global climate, triggered by changes in ocean circulation. Drastic effects are also expected for circum-Arctic ecology, which will in turn have major implications for human activities in the high northern latitudes. Precise knowledge of the magnitude of these changes and the mechanisms amplifying or damping their consequences are essential for understanding the entire Arctic climate system and its impact on the global system in the future.

MEGACITIES

Since 2007, more than half of the world's population (3300 million people) are living in cities – an increase from 30% in 1950 to 51% in 2011, which is predicted to reach more than 60% in 2030. Urbanisation is advancing rapidly, particularly in the developing and emerging economies of Asia and Africa. Megacities, i.e. cities with more than 5 million inhabitants, are particularly significant in this world-wide process of urbanisation. Almost 60 megacities, with a total population of more than 600 million, are expected to exist by 2025 (*see Fig. 19*).

Megacities are characterised by high development dynamics, large population figures and densities as well as intense and complex interactions between different demographic, social, political, economic and ecological processes. Moreover, highly dynamic processes take place simultaneously, thereby often reinforcing each other. Megacities are subject to the manifold processes of global ecological and socio-economic-political change. Due to their strong developmental dynamics, they also co-determine these global changes. In general, megacities are globally viewed as risk areas, where environmental pollution, symptoms of capacity overload and stress, resource consumption, natural and human-made risks (e.g. floods, earthquakes, storms, water shortages, economic crises, ethnic-religious conflicts and industrial accidents) endanger the functioning of mega-urban economies and societies. Disadvantaged population groups in megacities are particularly subject to increasing poverty and vulnerability as well as socio-spatial segregation and fragmentation processes; in addition, socio-economic disparities and disintegration are getting worse. However, the positive development opportunities inherent in megacities as global junctions should also be taken into account: there is substantial potential due to the wide range of available financial and human resources as well as widely networked and interacting stakeholders, especially those who pioneer sustainable development, for instance through decreasing per capita spatial consumption, achieving efficient resource use or improved education and health care. Furthermore, technical innovations in megacities can be realised cost-efficiently and integrated into existing structures (e.g. transport systems, networks, process innovations).

Against this background, four complementary initiatives were launched during the last years focusing on the most important challenges of research on megacities. The Federal Ministry of Education and Research established the programme "Research for the Sustainable Development of the Megacities of Tomorrow" and the Helmholtz Association launched the coordinated projects "Risk Habitat Megacity" and "ClimateAdaptationSantiago" (*see right-hand side*). In parallel the DFG established the Priority Programme "Megacities – Megachallenge: Informal Dynamics of Global Change", whereas the German National Committee of Global Change Research has successfully encouraged scientific communities to combine their research efforts into large research groups. These initiatives are also in line with the International Human Dimensions Programme (IHDP) core project on "Urbanisation and Global Environmental Change", as well as with the work of the MegaCity TaskForce of the International Geographical Union (IGU) and one of the key topics "Megacities – our global urban future" emerging from the International Year of Planet Earth. All programmes are based on proven international partnerships among interdisciplinary academic communities as well as major stakeholders from local governments, private enterprises, non-governmental organisations and civil societies, particularly in the countries of the "Global South".

Major research projects at present focus on topics such as mega-urban sustainability, comprehensive environmental and social management, mobility and transportation, climate protection and energy efficiency, water and energy supply and consumption, food supply and nutrition, waste treatment, urban health and quality of life, mega-urban planning and governance: loss of governability and steering capabilities, fragmentation and social coherence, social innovation, the dynamics of informal processes, security issues, risk assessment and disaster prevention. New methodologies have to be applied for mega-urban contexts, such as high resolution satellite data, decision support systems, scenario methodologies.

Photo: F. Kraas

Fig. 18: Contrasts between history and modernity in Guangzhou/China

PROJECT EXAMPLES

MEGACITIES - MEGACHALLENGE: INFORMAL DYNAMICS OF GLOBAL CHANGE

Megacities are the result of globalisation processes and are subject to global ecological, socio-economic and political change. Reciprocally, they also dictate these changes due to their strong development dynamics. Increasingly, megacities are subject to an at least partial loss of governability – with the consequence that more and more processes are taking place informally or illegally. This informality has barely been investigated with respect to form, function and interaction.

The priority programme aims at systematic research on the increasingly important connection between highly complex and informal mega-urban processes and the form and effect of global change on the reorganisation of spatial, social and institutional relationships in the megacities. Main topics are: (1) loss of governability, new forms of governance and self-organisation, (2) dominance and differentiation of urban economies, (3) complexity and dynamics of matter and resource flow and (4) complex dynamics of informal settlement development. Two prominent mega-urban areas (Pearl River Delta/China and Dhaka/Bangladesh) have been selected as programme sites, where 11 research projects involving approximately 100 scientists from 15 different disciplines from Bangladesh, China and Germany are working together.

Programme Duration: 2006 – 2013
Funding: DFG
WWW.MEGACITIES-MEGACHALLENGE.ORG

Endorsed by UGEC

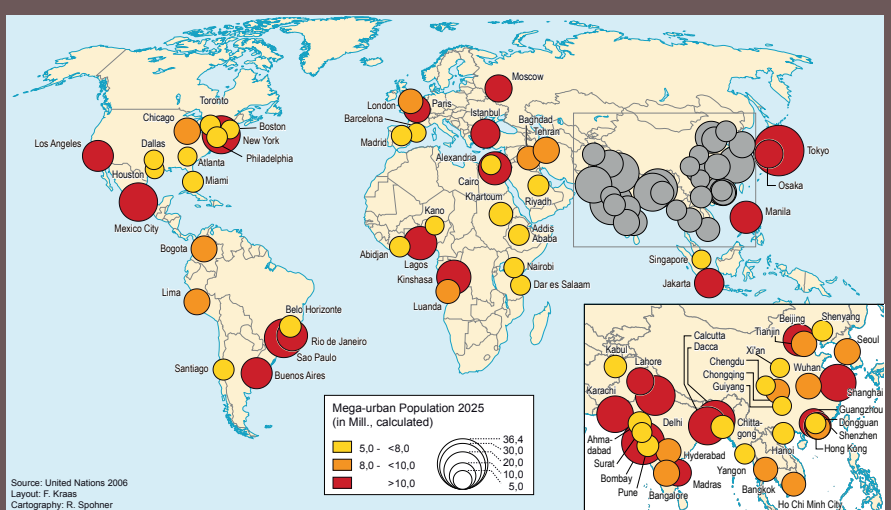


Fig. 19: Map of Mega-urban Population in 2025 (Image credit: F. Kraas).

FUTURE MEGACITIES

Energy- and Climate-Efficient Structures in Urban Growth Centers

Urban agglomerations and, in particular, megacities in developing and newly industrialising countries, contribute to three quarters of global energy consumption as well as approximately 85% of the global production of anthropogenic greenhouse gases. Many of these future megacities not only co-drive climate change, they also receive the full brunt of its consequences, not least because about a fifth of the world's population live in areas with high population densities less than 30 kilometres from the coast.

BMBF's funding priority aims to develop and implement solution-oriented and integrated planning and management concepts (best practice). Sixteen projects were set up for a pre-phase (07/2005-03/2008), taking into consideration cities in Latin America, Africa and Asia. The particular themes of the transdisciplinary project are centred on specific practical urban needs and demands as well as innovation potentials of urban living. The main phase of the programme (04/2008 -08/2013) focuses on the implementation of energy- and climate-efficient structures in urban growth centres. Thematic fields encompass: energy supply and consumption, water- and waste management, housing, mobility, urban agriculture and urban planning. Mitigation and adaptation strategies are being developed for Lima, Casablanca, Addis Ababa, Gauteng, Karaj, Ho Chi Minh City, Hyderabad, Urumqi and Hefei.

The funding priority contributes to the international dialogue as outlined in the BMBF's "High-Tech Strategy 2020 for Germany". It is also part of the "FONA - Research for Sustainable Development" framework programme run by the BMBF.

Programme Duration: 07/2005 – 08/2013
Funding: BMBF
WWW.FUTURE-MEGACITIES.ORG

CLIMATE ADAPTATION SANTIAGO

As a follow-up activity, a new project was launched that strongly builds on the work of the "Risk Habitat Megacity" research initiative and addresses climate change as an additional feature of ongoing global environmental change. The ClimateAdaptationSantiago project (CAS) aims at developing, in close collaboration with local stakeholders, adaptation measures for the Metropolitan Region of Santiago de Chile in the key topics of water, energy, land use, and related vulnerabilities. The project brings together the work of two Helmholtz centres (UFZ, KIT) and partner organisations from Latin America (Universidad de Chile, Universidad Católica de Chile, United Nations Economic Commission for Latin America and the Caribbean). The establishment of a Regional Learning Network in urban areas with scientists and stakeholders from five other Latin American megacities (Bogotá, Buenos Aires, Lima, Mexico and Sao Paulo) aims at sharing knowledge and exchanging experience in the field of climate change adaptation.

Programme Duration: 2009 – 2012
Funding: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Coordination by Helmholtz Centre for Environmental Research – UFZ)
WWW.CLIMATE-ADAPTATION-SANTIAGO.UFZ.DE

RISK HABITAT MEGACITY

Strategies for Sustainable Development and Climate Change Adaptation of Latin American Megacities

The "Risk Habitat Megacity" research initiative was established with the objective of deepening the understanding of complex urban processes, interactions and feedback mechanisms. Scientists from five Helmholtz centres and five partner organisations in Latin America generated orientation and decision-making knowledge by adopting an integrative and interdisciplinary framework to study specific environmental-related topics (energy system, water resources and services, land use management, earthquakes, waste management, socio-spatial differentiation, transportation, air quality and health).

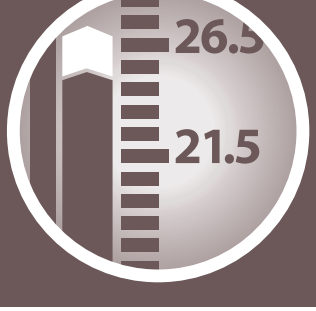
A variety of results in terms of empirical findings, methods, models, tools and measures were achieved as well as the training of more than 20 PhD students in interdisciplinary and problem-oriented research.

Geographically, the megacity research carried out by the Helmholtz Association concentrates on Latin America, which is the by far most urbanised and most inequitable developing region in the world. Santiago de Chile is the 'anchor city' and hosts the coordination and the dissemination of results.

Programme Duration: 2007 – 2011
Funding: Helmholtz Association (Coordination by Helmholtz Centre for Environmental Research – UFZ)
WWW.RISK-HABITAT-MEGACITY.UFZ.DE

Endorsed by UGEC

CLIMATE CHANGE - MITIGATION AND ADAPTATION



Although knowledge of the climate system and its complex interactions with anthropogenic greenhouse gas emissions is far from being comprehensive, the recommendations of the natural sciences are crystal clear: in order to protect ourselves against the disastrous consequences of climate change, the world community needs to limit the rise in global average temperature to 2°C above pre-industrial levels. This requires greenhouse gas emissions to be reduced by roughly 50% vis-à-vis 1990 emission levels within the next two decades. Economic cost-benefit analyses such as the Stern review (Stern 2007, ISBN: 9780521700801) support stringent emission reduction since the estimated global costs of emission mitigation is substantially less than the benefits of avoided climate damage. Despite the impetus from natural science, the global economic rationale and the United Nations' commitment to the 2°C target, the Cancún Conference showed that the prospects for cooperative emission abatement on the global level are bleak. The discrepancy between socially desirable action and perceived inaction has shifted the research focus in climate change analysis from natural science at least partially towards socio-economic research in order to carry out investigations into incentive and implementation problems of precautionary climate strategies. Given that climate change is underway and cannot be completely stopped due to climate system inertia in the short run, adaptation to climate change is the second climate policy option that is increasingly being considered. This option must be balanced against mitigation efforts and may share some of the incentive and equity problems of the first option. The challenge for socio-economic research is therefore to identify fundamental barriers to effective climate change mitigation and adaptation, but also to come up with practical strategies to overcome these barriers. From a narrower economic perspective, the fundamental challenge to climate policy resides in the global public good nature of greenhouse gas emission abatement. Another impediment to effective climate policy is the discrepancy between the perceived short-term costs and the long-term benefits of strategies to address climate change. German socio-economic research promotes insights into the challenges of climate policy design and aims at practical policy support through a variety of projects, funded by the German Research Foundation, the Federal Ministry of Education and Research, independent foundations (e.g. Volkswagen Foundation, Fritz Thyssen Foundation, MERCATOR), and the 7th Framework Programme of the European Commission. German socio-economic research increasingly contributes to the Intergovernmental Panel on Climate Change process.

Selected issues in theoretical and applied analysis include:

INTEGRATED ASSESSMENT

Integrated assessment combines knowledge from the natural sciences and socio-economic disciplines to capture cause-effect chains including responses of the climate system. It is essential to derive optimal mitigation and adaptation strategies and to assess policy instruments. One particular challenge is the assessment of damage from climate change due to major uncertainties in cause-effect chains. There is also only limited information on the costs of mitigation and adaption. Further problems are associated with time discounting and monetization. Research addresses these methodological challenges by extending standard analyses, e.g. incorporating risk (extreme events, tipping points), and determining their implications for climate policy design. In order to address these uncertainties, German scientists have developed recognised expertise in inter-model comparison. A more recent area of prominence refers to "climate security" which views climate change as a multiplier of conflict pressure within and between countries due to limited access to resources, land loss, damage to infrastructure or the increase of migration. At the more fundamental level, socio-economic research contributes to the assessment of climate change through modelling, qualitative research, the experimental analysis of preferences and the use of contingent valuation methods.

INTERNATIONAL ENVIRONMENTAL AGREEMENTS

Owing to the global dimension of climate change, a major line of socio-economic research is dedicated to the issue of how environmentally effective international agreements can be pushed forward. Game theoretical research investigates how to make agreements incentive-compatible and self-enforcing through credible sanctions in the form of either sticks or carrots (e.g. issue linkage with trade treaties, technology transfers, direct monetary transfers or liability rules). Institutional and political economy research gather experiences from environmental legislation such as the Kyoto Protocol or the EU Climate and Energy Package to draw lessons as to how to trade off the interests of multiple stakeholders and how to frame the procedural context of negotiations.

LINKS TO RESEARCH ACTIVITIES

- BMBF research funding programme: Economics of Sustainability, WWW.WI-N.ORG
- BMBF research funding programme: Economics of Climate Change, WWW.PTDLR-KLIMAUNDUMWELT.DE/DE/773.PHP
- A platform for joint studies and science-based stakeholder dialogue: The European Climate Platform, WWW.EUROPEAN-CLIMATE-FORUM.NET
- Project: The Full Costs of Climate Change (Funding: EU, Duration 2008-2011), WWW.ZEW.DE/EN/FORSCHUNG/PROJEKTE.PHP3?ACTION=DETAIL&NR=866

CLIMATE JUSTICE, EQUITY AND FAIRNESS PREFERENCES

The role that fairness and international justice play in the prospects of effective international cooperation is investigated in theoretical analysis and in experimental settings. The normative nature of equity needs to be underpinned by practical philosophy along with climate ethics as an emerging sub-discipline. For practical policy support, research comes up with combinations of alternative equity principles in order to find a compromise between extreme positions.

UNILATERAL CLIMATE POLICY STRATEGIES AND CARBON LEAKAGE

Germany and other OECD countries are under increasing pressure to go ahead with unilateral emission reductions (e.g. the EU Climate and Energy Package). However, the effectiveness of unilateral action may be seriously hampered by emission leakage: the increase of emissions in non-abating regions as a reaction to the reduction of emissions in abating regions. Reduction of energy demand by abating regions leads to a drop in international fossil fuel prices, which in turn increases energy demand by non-abating regions. Another important source of leakage stems from the relocation of emission-intensive industries from abating regions to non-abating regions. Furthermore, there is the risk that increasingly stringent climate policies serve as a declaration of expropriation as far as the owners of fossil fuel resources are concerned, inducing them to extract more resources in the present and thereby accelerate global warming (the so-called green paradox or intertemporal leakage). Besides empirical estimates of leakage rates, socio-economic research investigates appropriate response strategies such as border taxes on embodied carbon.

ADAPTATION TO CLIMATE CHANGE

Recent years have seen the rise of socio-economic adaptation research as a field in its own right in Germany. Adaptation financing for developing countries has become a cornerstone in international negotiations that is reflected in theoretical and empirical research. Adaptation governance is also addressed on the national and local levels. Since both the costs and benefits of adaptation typically occur on these levels, there is less need for global coordination of adaptation on efficiency grounds. Whether adaptation needs new policy instruments, or whether it should be 'mainstreamed' into existing institutions and organisations on different administrative levels is being investigated under the umbrella term "climate policy integration". Further research addresses the spatial planning and river management issues involved in the consequences of climate change. The role private actors or business play in adaptation is increasingly being addressed. Substantial costs are expected to arise from the adaptation of infrastructure (e.g. water, transportation, energy). This involves a complex interplay between private and public actors that may require a modification in current regulations to set appropriate incentives for adaptation and to provide the appropriate financing.

MANAGEMENT OF LOCAL AND REGIONAL SYSTEMS

Natural and urban systems are exposed to climate change at the same time as contributing to it. Managed ecosystems store or release carbon and have to react to altered seasonal cycles or weather conditions. Land-use patterns partially determine emissions, and cities exhibit an extraordinary dynamic (e.g. structural changes, social pattern, emissions) influenced by economic growth, at the same time as being also exposed to changing natural conditions (such as sea levels rise and the likelihood of more frequent extreme weather conditions). For these reasons, case studies on social-ecological systems are being carried out around the world.

OVERLAPPING REGULATIONS

Climate policy in Germany and the EU is implemented through a myriad of policies and instruments. The risk therefore exists of counterproductive overlapping regulation. A prime example is the explicit promotion of renewable energy and energy efficiency along with emissions trading. Greenhouse gas emission reduction will become more costly as too much "greenness" and too much energy savings are enforced. Applied research seeks to quantify additional benefits for composite objectives such as strategic innovation, job creation or energy security that could justify the use of overlapping regulatory instruments.

TECHNOLOGICAL INNOVATION

Technological change constitutes a central issue in climate policy as it determines the costs of mitigation and adaptation. The interaction between policies and (induced) technological change is crucial for a comprehensive assessment of the costs and benefits of climate policy. Socio-economic research investigates the sources and impacts of various forms of technological progress such as "learning-by-research" or "learning-by-doing" and provides insights into the importance of technology diffusion and technology transfer.

FUTURE ENERGY CONCEPTS

Ever since the industrial revolution, a robust relationship between GDP and the use of energy has been observed. Accordingly, following the huge growth in economic prosperity in the past decades, global demand for energy has grown to unprecedented heights, and demand continues to grow at an impressive pace.

As in the past, growth in demand is still primarily met by an increased use of non-renewable, mainly fossil fuels. Extrapolating this development into the 21st century gives rise to two key challenges:

1. How long will the various non-renewable energy sources be available to fuel the world economy at affordable prices?
2. How can the global energy system be efficiently transformed in such a way as to limit its contribution to global warming?

Growing resource scarcity and resulting price trajectories of different energy sources will continually shape the energy system in a fundamental sense. In the light of still sizeable ranges of fossil fuels and the apparent ability of the energy-economic system to adapt to increases in energy prices, the scarcity of resources per se does not seem to prompt an urgent call for action from European policymakers. Climate change research, however, is providing more and more evidence for the need for rapid and decisive reductions in greenhouse gas (GHG) emissions. However, for obvious reasons, these reductions need to be implemented on a global level, and individual measures by Europe alone can only have limited effects at best on the global scale.

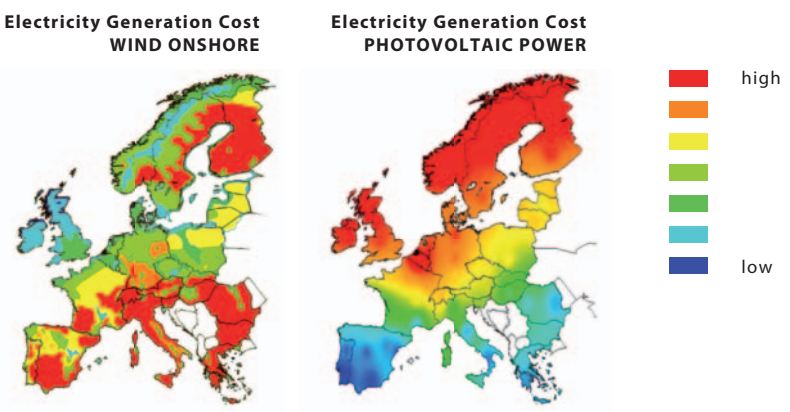


Fig. 20: The map above depicts differences in the full cost of wind and photovoltaic power generation by reflecting geographical and meteorological variations across Europe. The map has been generated for the "European RES-E policy analysis" study. This study is working on quantifying the economic value of potential RES promotion synergies across technologies and European locations.

FUTURE ENERGY MIX

An overarching question concerns the mix of energy sources used to satisfy the demand for energy. In a future, low-carbon world three likely candidates for leading technologies stand out: fossil-fueled power stations using carbon capture and storage, nuclear power, and renewable energy sources (RES). Research concentrates on developing consistent scenarios for a future low carbon energy mix under different assumptions. Key questions comprise (1) feasibility of certain objectives, (2) cost and preconditions associated with certain pathways and (3) cost-optimal solutions. (Due to Germany's political decision to abandon nuclear energy, there is no noteworthy publicly funded research on nuclear energy beyond some exclusively technical research activity in Germany at this point.)

Given their relative attractiveness from a purely ecological perspective, RES obtain a great deal of attention from policymakers and, in consequence, academic research. RES are, for the most part, still not competitive in power generation, even at current prices for CO2-emission certificates under the EU-ETS (European Union Emissions Trading System). Therefore, and because European governments nonetheless favor a rapid build-up of RES, public funding is required to make RES competitive in the short-run. An important feature of RES is a strong variability in their production costs depending on meteorological and geographical conditions (*see Fig. 20*). There is evidence that future electricity production costs could be reduced considerably if location-based synergies for RES were appropriately exploited across Europe and North Africa. In this context, the potential role of renewable energy sources in the Saharan countries (concentrated solar power, photovoltaics, wind) is the object of particular attention. For example, the so-called DESERTEC project (**WWW.DESERTEC.ORG/EN/**) is investigating the potential contribution of RES to the rapidly growing demand for energy in the Maghreb region as well as on the European market.

Biomass plays an important and special role in RES. Either as biofuel in transport, a combustible for power generation, or a substitute for natural gas in the heat sector and it will provide a sustainable option for industrialised and developing countries alike. A pertinent question with respect to biomass concerns the trade-off between

FURTHER CONCEPTS FOR REDUCTION OF GREENHOUSE GAS EMISSIONS OR ENERGY SAVING ARE:

► ***Decentralised Power Generation, Demand Side Management and Smart Grid***

The transformation of the electricity system will also see a growth of decentralised power generation in the form of small-scale applications like photovoltaic or cogeneration of heat and power in micro-turbines. The increased share of decentralized power generation will necessitate new management and market structures.

Project: "Dena Grid Study II" (Funding: DENA and others, Duration: 2007-2010)
WWW.OFFSHORE-WIND.DE;
"IRED - Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid" (Funding: EU, Project Coordination: Fraunhofer IWES,)
WWW.IRED-CLUSTER.ORG

► ***Energy Efficiency and Contracting***

Contracting particularly has the potential to overcome the problem that many economically reasonable investments are not realised due to various reasons of which low awareness of energy as a product is only one reason.

Project: "Contracting im Mietwohnungsbau" (Funding: Federal Office for Building and Regional Planning , Duration: 2007-2009)
WWW.BREMER-ENERGIE-INSTITUT.DE

► ***Future Mobility Concepts***

New fuel concepts like hybrid or battery driven e-cars will play an increasingly important role in transportation. Many segments of transportation do not easily lend themselves to electrification. Hence it is expected that other new technologies, in particular fuel cell technology could prove to be additional promising options.

Project: "Eco Cars" (Funding: BMBF, Duration: 2006-2009)
HTTP://KOOPERATIONEN.ZEW.DE/EN/ECO-CARS/HOME.HTML

► ***Coal, Carbon Capture and Sequestration***

Using coal for power generation remains a compelling option, especially in countries with high GDP growth rates. Obviously, coal-fired power plants are strong emitters of GHG. Carbon capture and storage (CCS) – technologies to store GHG emissions in deep geological formations – seems to provide a technically viable answer to this challenge. On a global perspective, CCS can fill the technology gap during the transition to emission-free power generation.

Project: "CCS Global" (Funding: BMU, Duration: 2009-2011)
WWW.WUPPERINST.ORG/EN/PROJECTS

energy use and conventional agricultural use of arable land used for biomass production (*see p. 18/19*).

INTEGRATION OF RENEWABLE ENERGY SOURCES INTO THE ELECTRICITY SYSTEM

Successful integration of a high proportion of RES into the electricity system needs to be supported by a massive extension of the network infrastructure. The geographical dispersion and the intermittent nature of most RES intensify the need for significant changes to the power grid. For example, the transport of electricity generated by RES in Northern Europe or in the Sahara region over large distances with minimal loss is likely to require the implementation of high-voltage direct current transmission technology.

Besides grid expansion, other opportunities to address RES intermittency include temporary curtailment of RES, the availability of redundant conventional capacity, or demand-side-management. In addition, the issue of electricity storage is being widely studied in order to respond to the (technical) challenges posed by RES intermittency. Today, electricity can be "stored" mainly in the form of water reservoirs in pumped storage plants. But new technologies like compressed air energy storage for example might expand the choice of storage facilities. Researchers are also rather hopeful about the concept of "power-to-gas", using electricity to produce hydrogen or methane, and about decentralised storage options from an increased use of cars propelled with electricity strored in electric batteries. However, even on longer time scales, most of these storage options appear to be economically inferior to other RES integration measures.

ACCEPTANCE RESEARCH

Taking grid expansion, onshore wind farms or the construction of CO_2 pipelines as examples, it can be seen that most energy-related projects have many easily discernable and significant local effects. In the Western world, public acceptance of energy projects has increasingly become a matter of concern for policymakers and energy companies. Communication seems to be the key to ensuring local support for infrastructure projects related to the transformation of the European energy system. Acceptance research concerning the ambitious transformation objectives appears to be still in its infancy. First results indicate, among other findings, that e-mobility stands a high chance of achieving broad social acceptance.

The energy system will undergo an unprecedented transformation. Change research is investigating the manifold interdependencies in a changing energy system as well as the interplay of technical, economic, social and political aspects. Only a deeper understanding of these complex interactions will provide a sufficient basis for economically sound and socially accepted decisions which give rise to a sustainable, efficient and secure energy supply for generations to come.

EARTH SYSTEM GOVERNANCE AND INSTITUTIONS

Governance is the key to understanding human impact on global environmental change and for developing mitigation and adaptation strategies. It comprises the manifold social structures and processes of agenda setting, decision-making, monitoring and implementation that shape the behaviour of individuals and societies. The issue of governance therefore goes far beyond formal political and state institutions and their activities: it includes informal structures, processes and actors along with economic institutions and other mechanisms for societal coordination. Consequently, in addition to law and politics, markets, economic incentives, discursive processes and moral values have to be taken into account. It is clear that the institutions, organisations and mechanisms through which humans currently govern their relationship with the natural environment are not only insufficient – they are also poorly understood.

In addressing these challenges of global change, the concept of "Earth System Governance" emerged and gave its name to an internationally coordinated 10-year research effort under the umbrella of the International Human Dimensions Programme on Global Environmental Change. This project focusses on the formal and informal rules, rule-making systems and actor networks from local to global levels of human society that are set up to prevent, mitigate and adapt to problems of environmental change.

In studying governance systems, scholars have to take into account the many formal and informal institutions and organisations on different levels – international institutions, transnational corporations, national parliaments and governments, non-governmental organisations, economic forces and other societal institutions. Research on governance and institutions has to focus in particular on the relationship between these different elements and levels of environmental governance. The goal is to identify both the potential causes of the unsustainable use of the Earth's resources and the opportunities to support a more comprehensive response by humankind to the challenges of global change. Governance for global change is a demanding topic for the social sciences and its many disciplines that range from anthropology to economics, through law to political sciences and sociology. In addressing these requirements, research in the field of earth system governance revolves around five central analytical themes: architecture, agency, adaptiveness, accountability and allocation.

1.) ARCHITECTURE

The first analytical problem concerns the architecture of earth system governance including questions about the emergence, design and effectiveness of governance systems as well as the overall integration of global, regional, national and local governance. Research studies in this field analyse how the performance of environmental institutions is affected by their embeddedness in larger institutions, such as global environmental treaties. The choice of an adequate scale is important to ensure that measures take into account the conditions and priorities of the area concerned. Many sustainable resource management schemes developed at the local level cannot easily be transferred to the regional or national level and vice versa.

The choice of appropriate policy instruments is another key question with regard to the architecture of earth system governance. The traditional command-and-control type of environmental policy measures has recently been supplemented and partially replaced by softer instruments like information, capacity building and trading systems. In this context, governance research examines which instrument or instrument mix is appropriate, and whether and under which circumstances these instruments are effective, efficient and legitimate.

Furthermore, earth system governance research examines the environmental consequences of non-environmental governance systems (e.g. the world trade regime), addresses questions concerning the relative performance of different types of multi-level governance architectures (e.g. the EU and the UN), attempts to explain instances of "non-governance", for example in the case of international forest governance, and aims to identify the overarching and crosscutting norms of earth system governance.

2.) AGENCY

Understanding effective earth system governance requires an understanding of the agents that drive governance and that need to be included in the governance process. The particular research gap that is being addressed in current research concerns the influence, roles and responsibilities of actors other than national governments, such as business actors, non-profit organisations and scientific bodies, as well as the interactions among them. When and how do these actors and non-governmental networks such as the Forest Stewardship Council (FSC) or the Global Reporting Initiative (GRI) become influential and accepted as rule-makers and implementing agencies? How can international scientific assessment bodies (such as the Intergovernmental Panel on Climate Change (IPCC) or the emerging Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)) be designed in order to be effective in decision-making processes on international as well as national and local levels?

- Database (IRD), TU Darmstadt (www.tu-darmstadt.de)
- Institute for International Law and European Law, University of Goettingen (http://inteurlaw.uni-goettingen.de/inteurlaw/index.php)
- Earth System Governance Research Centre, University of Oldenburg (www.uni-oldenburg.de/ecoeco)
- Environmental Policy Research Centre (FFU) (www.fu-berlin.de/ffu)
- German Development Institute (www.die-gdi.de)
- Institute for Environmental and Sustainability Communication (INFU), Leuphana University of Lüneburg (www.leuphana.de/en/institute/infu.html)
- Institute for Social-Ecological Research (ISOE) (www.isoe.de)
- Max Planck Institute for Comparative Public Law and International Law (www.virtual-institute.de)
- Transformations of the State, Bremen University (www.state.uni-bremen.de)
- Social Science Research Centre Berlin (www.wzb.eu)

3.) Adaptiveness

In the face of global change, governance must respond to the inherent uncertainties in human and natural systems. It must combine the stability necessary to ensure long-term governance solutions with the necessary flexibility to react quickly to new findings and developments. The resulting research challenge is thus to understand and further develop the adaptiveness of earth system governance, i.e. the ability of a socio-ecological system or a social actor to adapt to changes and maintain essential functions for its or his/her survival. What role can stakeholder participation play and where does it fail to deliver effective solutions? How can learning processes be initiated and launched with the participation of actors across different policy fields?

Research on adaptation to climate change has to deal with the specific vulnerabilities connected with climate change, in particular on an inter- and transnational level. These vulnerabilities are associated not only with changing global or regional climatic conditions (e.g. changing precipitation rates, increasing droughts), but also with societies' capacity to cope with these changes. This differs between regions (e.g. semi-arid regions or coastal zones) and different social groups (e.g. subsistence farmers or fossil fuel-dependent industrial farmers). The capacity to cope thus defines how extreme events can be absorbed and how the resilience of socio-ecological systems can be maintained. Moreover, the different timescales involved – some aspects of climate change may only become significant in a number of years' time, nevertheless, action is pressing today – and the uncertainties concerning precise scientific prognoses relating to the scope and regional impact of climate change raise additional challenges for governance strategies. The interplay of spatial and temporal scales has to be addressed along with questions relating to the effectiveness, fairness and legitimacy of new and innovative governance solutions.

4.) Accountability and legitimacy

The more regulatory competence and authority is conferred upon larger institutions and systems of governance – especially at the global level – the more we will be confronted with issues relating to how to ensure the accountability and legitimacy of governance. Simply put, we are faced with the need to understand and ensure the legitimacy of earth system governance processes. The world witnessed the emergence of a strong and active public movement in climate politics around the Copenhagen summit 2009. As is also the case in other fields, non-governmental organisations are becoming influential through their research, dissemination of information and through the active part they play in the implementation of environmental measures. These groups strengthen the international public voice, of which they are an important part. Broad acceptability of governance outcomes thus requires that the public, stakeholders, local communities and non-governmental organisations affected by environmental change have a say in decision-making.

5.) Allocation and greening the global economy

As is the case with any political activity, earth system governance is also about distribution and justice. It is in essence a conflict about the access to goods and resources and about their allocation. The novel character of global change phenomena, such as climate change or the loss of species and ecosystem functions puts issues of allocation and access in a new light.

Given that the way we use natural resources and pollute the environment is determined in large part by economic structures, appropriate pricing for natural resources and ecosystem services becomes essential for their sustainable use. To date, however, markets often fail to perform this function and many market interventions, including subsidies, often have a negative impact on resource use. Identifying areas of market failure, designing economic instruments for the internalisation of environmental effects and weighing up the equity and fairness of these solutions are thus important tasks for governance research. It is of even greater importance that research of this kind looks at the ability and awareness of regulatory bodies to properly address these issues. For instance, the question must be raised as to whether environmental concerns are properly reflected in the European Union's Common Agricultural Policy. At a global level, the intricate relationship between the World Trade Organisation (WTO) and multilateral environmental agreements are important areas of research. Bringing together economic, legal and political science approaches in this field thus can provide answers as to how equity can be reconciled with governance effectiveness.

In all these areas, German research has advanced and contributed to the worldwide discourse on earth system governance and the institutional dimensions of global change. Given the dynamics, urgency and uncertainties of all phenomena related to global change, integrated governance research is increasingly called upon to move forward on these research frontiers.

OBSERVING SYSTEMS

Measurements of earth system parameters are needed to identify the effects of global change in space and time. They contribute to our scientific understanding of the functioning of the earth system. Observing systems, together with modelling capabilities, are essential prerequisites for the development of global resource management strategies, aimed at sustainable development.

Scientific knowledge is the basis for the development of national and international policies, relating to the environment and climate change. The establishment of a measurement network for the earth system with adequate "fit for purpose" accuracy is intrinsically complex and challenging. Precise measurements having adequate sampling to provide the knowledge required to improve our understanding of the science, the prediction of models and the evidence base for policymaking. This task is demanding for both the scientific community and the global society.

Over the past decades, a wide range of short- and long-term observation facilities and networks have been established to provide services to science and society. Prominent successful examples are the global meteorological network, which forms the basis for reliable weather forecasts, and various stations for air and water quality assessments. The need for and significance of an adequate climate change observatory is now recognized. Initially this comprised one accurate measurement programme, established during the International Geophysical Year (IGY) in 1957. Today, a network of analytical stations for high precision measurements of CO_2, CH_4 and other greenhouse gases is in operation. These stations have pinpointed the continuing increase of CO_2 and other atmospheric greenhouse constituents, which is attributed to the combustion of fossil fuels and land-use change. A fleet of research ships and submarine platforms examines ocean processes and a fleet of satellites observes the Earth. Measurements include a variety of physical, biogeochemical and societal parameters ranging from trace gases, aerosols, clouds, the short-wave and long-wave radiation budget, ocean salinity, ice movements, land-use changes, chlorophyll content of vegetation to urban sprawl. A multitude of ecological research sites studies e.g. the role of vegetation in the earth system, the state of lake and river systems, or changes in coastal and open ocean habitats. However, there has not yet been an overarching integrated approach to the establishment and use of measurement networks, which have so far largely depended on pioneering individual scientists and visionary scientific communities.

As an industrialised country, Germany is a significant polluter. It contributes, for example, to the tropospheric release of chlorofluorocarbons, halons and methyl bromide, acid deposition in Europe, the release of greenhouse constituents from fossil fuel combustion and land-use change. To assess global pollution Germany is committed to expanding global earth observing capabilities by developing and supplying novel instrumentation, providing platforms such as ships, satellites, aeroplanes, ocean drifters and balloons, as well as supporting measurement infrastructures for integrated observations (e.g. ICOS – *see right-hand side*) at specific research sites, e.g. within the BIOTA-AFRICA (**WWW.BIOTA-AFRICA.ORG**), TERENO (*see p. 39*) and GLOWA (**WWW.GLOWA.ORG**) projects. Through its support of earth observation from space, e.g. through the German TerraSAR, Tandem-X, RapidEye and EnMAP satellite missions, the national development of SCIAMACHY, and the ESA development of MIPAS and MERIS (*see Fig. 22*) on the ESA flagship ENVISAT (*see Fig. 21*), it facilitates emerging technologies, required for the measurement of essential climate and land surface variables defined by the Global Climate Observing System, GCOS (**WWW.WMO.INT/PAGES/PROG/GCOS/INDEX**).

Fig. 21: Envisat is the most advanced earth observation satellite with a unique combination of sensors that improve the range and accuracy of scientific measurements of the atmosphere, oceans, land surface and ice. (Image credit: ESA/Denmann production)

CARBONSAT AND THE CARBONSAT CONSTELLATION

The Scanning Imaging Absorption Spectrometer for Atmospheric Chartography, SCIAMACHY, is a German contribution to the European Space Agency (ESA) platform ENVISAT. It has demonstrated that accurate measurements of the total dry column amounts of carbon dioxide and methane can be measured from space. Building on these low spatial resolution trailblazing results, the CarbonSat concept was developed by a scientific and industrial team led by the University of Bremen and including the Max Planck Society, University of Heidelberg and the German Aerospace Center (DLR) with the aim of providing high spatially and temporally resolved measurements of carbon dioxide and methane. After a peer-reviewed competition, CarbonSat was selected in 2010 by ESA for Phase A B1 Studies for its Earth Explorer Opportunity 8 Mission. The German team has now initiated the CarbonSat Constellation project to provide the data from space instrumentation required for the monitoring, verification reporting and transparency of the carbon dioxide and methane emissions from the local to the regional scale in the a post-Kyoto Protocol era. This initiative yields daily global estimates of carbon emissions on a scale of a few km. It yields point source emissions from power stations, urban areas and diffuse fluxes from the biosphere. Its objectives are optimally aligned with the Strategy for Space published by the German government in autumn 2010.

WWW.IUP.UNI-BREMEN.DE/CARBONSAT

ICOS–D

Integrated Carbon Observation System – Deutschland

The European Research Infrastructure "Integrated Carbon Observation System" (ICOS) aims to provide the long-term observations required to develop knowledge and understanding of the present status and future behaviour of the global carbon cycle and greenhouse gas emissions. ICOS will provide quantitative, high-resolution information of the spatial and temporal patterns of greenhouse gas sources and sinks over the European continent for at least the next 20 years. This information is indispensable for the scientific assessment of greenhouse gas fluxes and how they are modified by changes in climate and anthropogenic management. The information provided by ICOS is also crucial for monitoring and assessing the effectiveness of carbon sequestration and/or greenhouse gases emission reduction activities.

The German contribution, ICOS-D, includes five components, covering networks of measurements in atmosphere, ecosystems and oceans, together with a calibration laboratory for the entire European network and a national competence centre for data integration and dissemination. ICOS constitutes the European component of the Integrated Global Carbon Observations (IGCO) within GEOSS (Task EC-06-01). The build-up phase of ICOS is funded by the BMBF from 2011-2014; thereafter, ICOS-D will be operated for at least 20 years by national host institutions such as Deutscher Wetterdienst (DWD).

Programme Duration (Build-up Phase): 2011-2014
Funding: BMBF
WWW.ICOS-INFRASTRUKTUR.DE

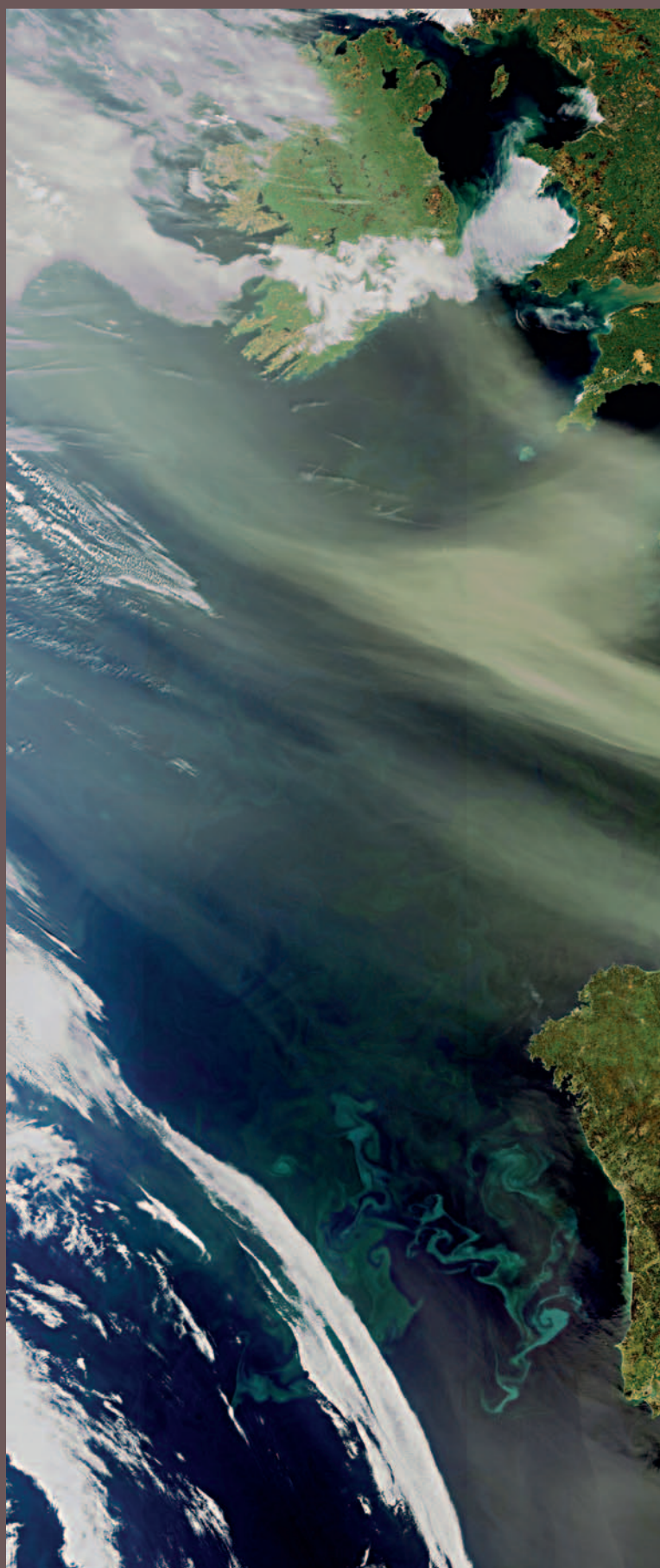


Fig. 22: The MERIS instrument (Medium Resolution Imaging Spectrometer) on ENVISAT captures dust and sand from the Algerian Sahara Desert, located in northern Africa, blowing west across the Atlantic Ocean. The dust contains many nutrients, including nitrogen, phosphorus and iron, which act as a fertiliser and stimulate the production of massive plankton blooms. In this image (published in April 2011), plankton blooms are visible in the Atlantic as blue and green swirls. Although some types of plankton are individually microscopic, the chlorophyll they use for photosynthesis collectively tints the colour of the surrounding ocean waters. This allows dedicated "ocean colour" satellite sensors to detect them from space. (Image credit: ESA)

In order to monitor the key processes and dynamics within the earth system, an overarching and integrated concept for observation in an "end-to-end" approach including both measurement and modelling is required. This ranges from the definition of the observation, which feed into global and regional earth system models, the delivery of user-related products and thereby the provision of the evidence base to decision-makers in order to facilitate the sustained management of resources. It is now accepted by the scientific community that a comprehensive, integrated observation system for global change and its manifold effects and feedback mechanisms is essential, linking observation technologies on a global level for the purpose of tracking environmental changes.

There have been a number of international efforts, which have led to the specification of earth observation systems required to accurately assess the earth system. In 2005 at its third Earth Summit, the Group on Earth Observation (GEO), which was established in 2002, inaugurated the Global Earth Observation System of Systems (GEOSS, WWW.EARTHOBSERVATIONS.ORG/GEOSS.SHTML). This has a 10-year implementation plan, which is currently being established through international cooperation. Along with new developments in monitoring, assessing and predicting environmental and hopefully climate change, GEOSS will enable the development of facilities to prepare for weather emergencies, predict natural hazards like floods, droughts and fires, better manage crop production, coastal areas and fisheries, monitor deforestation, biodiversity loss, and land-use change as well as water and air quality, support the UN's effort to help refugees in crisis regions or identify and fight epidemic diseases, to name but a few direct benefits that affect our economic prosperity and quality of life.

One major challenge in delivering GEOSS' objectives is the integration of a wide range of existing observation systems with long-term consolidated data for environmental and climate change research. This includes the development and deployment of new technologies where necessary, to consistently deliver the full range of high-quality data on all the required temporal and spatial scales and from all major fields of the natural and social sciences.
GEOSS requires measurements of earth system parameters to be combined across a broad range of disciplines and scales for the example of land surface state and process observations. The backbone of this system consists of a network of standardised terrestrial and aquatic observation sites. This delivers detailed, integrated measurements of all coupled natural and socio-economic parameters. This network of observation sites is augmented by a fleet of well adapted high- and medium-resolution instrumentation on satellite observation platforms. These platforms create a steady flow of regional and global environmental and societal data to transcend the scales. The satellite component of the system fills the gaps between the knowledge of the local impact gained from specific sites and the regional and global perspective. Observation sites and satellites provide the inputs for regional models to enhance the understanding of the earth system and to develop alternatives for local and regional decision-makers. The multi-scale observation approach is readily transferred to other components of the earth system being impacted by global change such as the oceans and the cryosphere. Besides the important observation of the land and ocean dynamics, a key element of the future observing system is the accurate measurement of both long-lived and short-lived greenhouse constituents.

A significant investment in scientific research is needed to be able to fully understand and utilize the integrated data streams that will be produced by GEOSS and to establish this end-to-end process e.g. in the following fields:

- development of integrated observation, data management and information delivery systems
- improvement of quantification of environmental parameters and processes by direct or indirect observations,
- improvement of integration of observations into coupled earth system models,
- improvement in understanding of the mechanisms underlying the observed patterns,
- validation and tests of earth system models over varying time and spatial scales with integrated observations,
- communication of results and conclusions to all stakeholders.

LTER–D

Network for Long-term Ecological Research – Deutschland

The components of global change operate on different spatial and temporal scales. Scientific analysis of this sphere, however, often works on shorter timescales, due to the typical funding duration of research projects. Nevertheless, long-term observation is indispensable for the detection of long-term processes and changes, and is the foundation needed to develop sustainable strategies. LTER-D is a member of the international umbrella organisation ILTER. LTER-D covers terrestrial and marine platforms that undertake long-term ecological research in all relevant ecosystem types from the high mountains to the deep sea. LTER-D insures that data are saved and documented and that they are accessible long after individual research or monitoring projects have been completed. This is in line with the long-term horizon of large-scale strategies for environmental protection, such as the EU Habitats Directive and the EU Water Framework Directive, which plans for time periods of over 20 years. LTER-D is an umbrella for other long-term research projects within Germany and works in collaboration with the German Biodiversity Exploratories and the TERENO initiative, for example.

WWW.LTER-D.UFZ.DE WWW.LTER-EUROPE.NET WWW.ILTER-NET.EDU

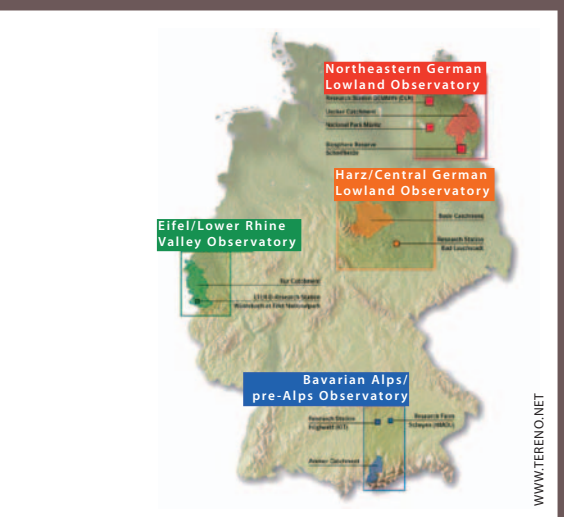


Fig. 23: TERENO sites in Germany.

TERENO

Terrestrial Environmental Observatories

Long-term observation enables assessment of the impact of climate change to be clearly distinguished from changes caused by natural fluctuations. Against this backdrop, the Helmholtz Association established and operates a network of environmental observatories for long-term observations (> 10 years) focused on the challenges of global change and the necessity of interdisciplinary research in terrestrial environmental science. While comparable environmental research networks are typically focused on specific environmental compartments and processes (e.g. carbon cycle, biodiversity) the TERENO network aims at an integral view, taking into consideration lower atmosphere, biosphere, pedosphere, hydrosphere and socio-economic interactions. In Germany, three observatories are currently in operation and will be linked with ICOS-D. A fourth observatory in Germany, as well as several for the Mediterranean region, are in preparation. Each observatory consists of different test and monitoring sites designed in a hierarchical manner to allow interdisciplinary process studies from the local to the regional scale. State-of-the-art monitoring and exploration technologies including for example remote sensing imagery as well as ground-based observation technologies allow a scale-spanning observation of the different environmental compartments. TERENO will provide a long-term series of system variables as an important input for the analysis of global change-driven processes. Strategies for prevention, mitigation and adaptation will be developed using integrated system models.

Programme Duration (Set-up phase): 2008 – 2011
Funding: Helmholtz-Association
WWW.TERENO.NET

GEO BON

The Global Biodiversity Observation Network

Members of the German National Committee on Global Change Research were heavily involved in the DIVERSITAS and NASA lead initiative to develop a global biodiversity observation system. Current scientific evidence demonstrates a continued decline in the status of biodiversity. This leads to reduced benefits for people, especially in terms of genetic resources, agricultural productivity, ecosystem services, resilience to environmental disturbance, human health and well-being. Further understanding of biodiversity change is therefore critical to shift unsustainable practices towards a sustainable use of biodiversity.

In response, DIVERSITAS and NASA are leading the early planning stages in the implementation of a global biodiversity observation system that will collect, manage, share and analyse data on the status and trends of the world's biodiversity, and regularly report its findings through GEOSS.

The BIOTA-AFRICA network (jointly invented by African and German researchers) was one of the founding members of GEO BON. In April 2008, a month before the COP9 of CBD opens at Bonn, Germany also hosted the implementation workshop of the GEO BON.

WWW.BIOOBSERVATION.NET WWW.DIVERSITAS-INTERNATIONAL.ORG

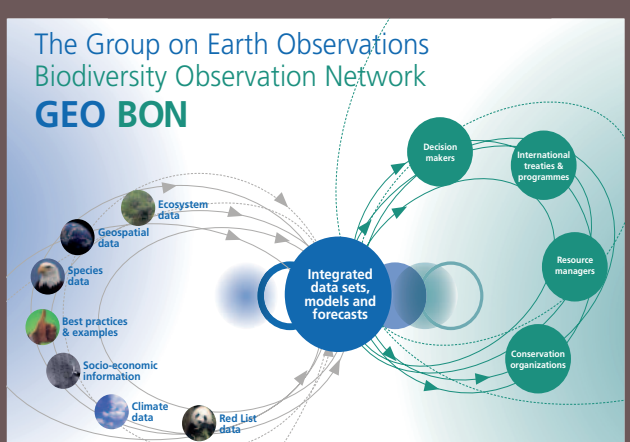


Fig. 24: Biodiversity Observation Network. (Source: WWW.BIOOBSERVATION.NET*)*

GBIF

The Global Biodiversity Information Facility

A sound knowledge base of the Earth's biodiversity is crucial for monitoring, analyzing, and responding to environmental change. The mission of the Global Biodiversity Information Facility (GBIF) is to make the Worlds biodiversity data freely and universally available for science and society via the internet. Established in 2001 as a global megascience initiative, GBIF is supported by more than 100 member countries and organizations to develop and operate a globally distributed information infrastructure. The GBIF portal today interconnects more than 12.000 biodiversity datasets containing more than 290 million records of individual organisms from all countries. The portal provides a crucial information source for research and other biodiversity initiatives (e.g., the World Database of Protected Areas, GEO BON, and the future IPBES), and GBIF has become a valuable partner for international conventions and organizations. Germany is a founding member of GBIF, and contributes significantly to the information infrastructure through a national network of eight data nodes serving more than 8 million datasets, as well as substantial financial support from BMBF and DFG.

WWW.GBIF.DE WWW.GBIF.ORG HTTP://DATA.GBIF.ORG

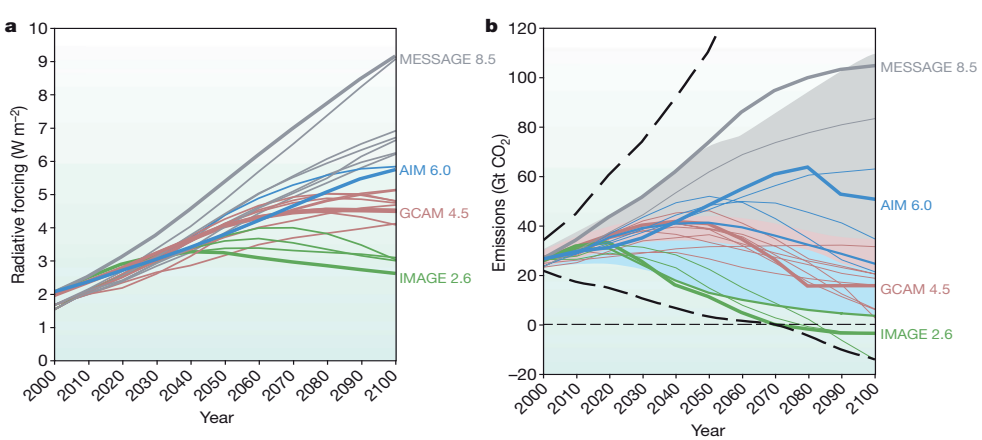
EARTH SYSTEM MODELLING

The understanding from a scientific and a socio-economic point of view any of a number of possible futures of the climate system on a global and regional level depends on research in several interconnected fields. This search for understanding is what motivates the international organisation and coordination of research. This is especially true for research related to the 5th Assessment Report of the IPCC (AR5) to be published in 2014. Three such fields of coordinated research are mentioned here:

(1) New socio-economic scenarios were developed by the integrated assessment modelling community with the goal to integrate for the first time climate policies to limit future atmospheric CO2 concentrations and hence related radiative forcing. These activities led to the so-called "**REPRESENTATIVE CONCENTRATION PATHWAY**" (RCP) scenarios, which describe mitigation actions that stabilise future CO2 concentration at different levels, implying control over direct and indirect anthropogenic CO2 emissions. Especially noteworthy is the RCP2.6 scenario (*see Fig. 25 IMAGE 2.6*), which targets a global mean warming of 2°C in 2100, for which a significant reduction in anthropogenic CO2 emissions is necessary. The timing and level of emission reduction of course depends on the effectiveness of carbon uptake by land ecosystems and the oceans, and on feedback of climate warming to the biogeochemical processes controlling natural CO2 uptake, which is one of the foci of current research.

(2) The climate modelling community has developed a new set of standard experiments targeting specific questions on the nature and functioning of the climate system and its possible future changes. In comparison to past protocols, the protocol of the new **COUPLED MODEL INTERCOMPARISION** Project (CMIP5, *see right-hand side*) includes several new types of experiment designed to address current research questions. These concern the feedback of climate warming to cloud effects on radiative transfer – a problem that is still not well understood – and the question of the feedback of climate warming on the carbon cycle, including its dependency on the nitrogen cycle, which directly relates to the abovementioned scenarios, in which CO2 emission is controlled in order to follow a targeted CO2 concentration pathway. These necessary emission reductions will depend on such feedback achieved. One pioneering study has been carried out by Roeckner et al. (2010, DOI: 10.1007/s10584-010-9886-6) within the European ENSEMBLES project (**WWW.ENSEMBLES-EU.ORG**). This study simulated the climate change and the allowable anthropogenic CO2 emissions related to the so-called E1 scenario. Developed as part of this study the E1 scenario targets a global mean 2°C warming in 2100, similar to the RCP2.6 scenario. It was shown that the higher the climate warming, the greater effect it has on the carbon cycle's ability to remove atmospheric CO2.

Another very active field of research, which prompted new kinds of CMIP5 experiments, is the issue of if, where and to



Models providing RCP:

MESSAGE: Model for Energy Supply Strategy Alternatives and their General Environmental Impact, International Institute for Applied Systems Analysis, Austria.

AIM: Asia-Pacific Integrated Model, National Institute for Environmental Studies, Japan.

GCAM: Global Change Assessment Model, Pacific Northwest National Laboratory, USA.

IMAGE: Integrated Model to Assess the Global Environment, Netherlands Environmental Assessment Agency, The Netherlands.

Fig. 25: Representative concentration pathways. (a) Changes in radiative forcing relative to pre-industrial conditions. Bold coloured lines show the four RCPs; thin lines show individual scenarios from approximately 30 candidate RCP scenarios that provide information on all key factors affecting radiative forcing from v. Vuuren et al. (2009, DOI: 10.1073/pnas.0711129105) and the larger set analysed by IPCC Working Group III during development of the Fourth Assessment Report. (b) Energy and industry CO_2 emissions for the RCP candidates. The range of emissions in the post-SRES literature is presented for the maximum and minimum (thick dashed curve) and 10th to 90th percentile (shaded area). Blue shaded area corresponds to mitigation scenarios; grey shaded area corresponds to reference scenarios; pink area represents the overlap between reference and mitigation scenarios. (Source: Moss et al. 2010, DOI:10.1038/nature08823)

CMIP5

Coupled Model Intercomparison Project Phase 5

In 2008, WCRP's Working Group on Coupled Modelling (WGCM), with input from the IGBP AIMES project, agreed to promote a new set of coordinated climate model experiments. These experiments comprise the fifth phase of CMIP5. CMIP5 will notably provide a multi-model context for (1) assessing the mechanisms responsible for model differences in poorly understood feedbacks associated with the carbon cycle and with clouds, (2) examining climate "predictability" and exploring the ability of models to predict climate on decadal time scales, and, more generally, (3) determining why similarly forced models produce a range of responses

HTTP://CMIP-PCMDI.LLNL.GOV/CMIP5

CORDEX

A coordinated regional climate downscaling experiment

The CORDEX framework aimed at improving coordination of international efforts in regional climate downscaling research. CORDEX has designed a set of regional climate domains for the majority of the globe's land areas and will coordinate the downscaling of CMIP5 RCP4.5 and RCP8.5 scenarios for the period 1950-2100. More than 20 RCM groups will contribute to CORDEX, with regional climate simulations over one or more of the CORDEX domains.

HTTP://WCRP.IPSL.JUSSIEU.FR/SF_RCD_CORDEX.HTML

Sponsored by WCRP

what extent climate is predictable (*Fig. 26*) if the initial state of the particular climate system is known, and how to optimally exploit existing climate prediction arising from observation-based state estimates of the system. If, for instance, confident predictions were possible in Europe or parts of Europe over 10 to 30 years, this would be of major interest for regional downscaling and for analysing climate change impacts and planning. However, the basic science first needs to be addressed. Ocean observations are a critical element relating to this issue, as the ocean gives rise to decadal climate variations. Early studies, that use the Hadley Centre climate model or the ECHAM5/MPIOM model indeed demonstrated skill in decadal hindcasts and generated forecasts. These kinds of experiment are now being undertaken by a larger community. They all follow the CMIP5 experimental design in order to obtain both ensemble predictions by single models, and also to generate a multi-model ensemble of such hindcasts as well as a forecast up to 2035.

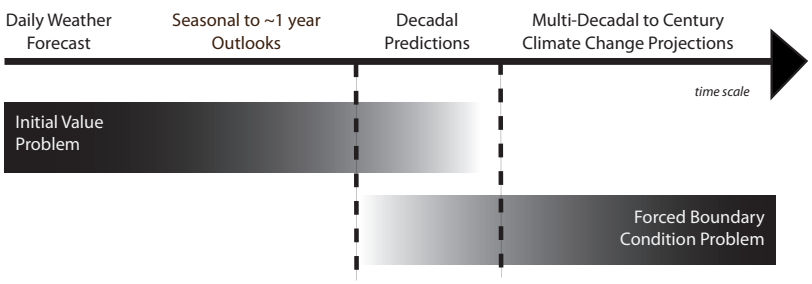


Fig. 26: Schematic illustrating progression from initial value problems with daily weather forecasts at one end, and multidecadal to century projections as a forced boundary condition problem at the other, with seasonal and decadal prediction in between. (Source: Meehl et al 2009, DOI: 10.1175/2009BAMS2778.1)

(3) **REGIONAL ASPECTS OF EARTH SYSTEM MODELLING** cover several different activities, which are briefly outlined below.

- **Development of regional earth system models (RESM):**
  The development of fully coupled RESMs is often directly linked to catchment scales for the purpose of studying water and energy cycles. Several groups in Germany are currently involved in the development of RESM for the drainage basins of the Baltic Sea and the Mediterranean Sea, for which an extension of the physical models to bio-geochemical modelling systems is also being developed. One example is BALTIMOS: a fully coupled model with components for the atmosphere (model REMO), ocean-sea-ice (model BSIOM), hydrology (model LARSIM) and for the ecosystems (model ERGOM) (WWW.REMO-RCM.DE/BALTIMOS.1318.0.HTML).
- **Production of regional climate change simulations:**
  Various global and regional modelling groups in Germany actively contribute to both CMIP5 experiment protocols by participating in either global or regional climate modelling. On the regional scale, the CORDEX initiative (*see above*) is of highest importance. On a European scale, the spatial resolution of the European CORDEX simulations will be further extended within several European projects under FP7. It is planned to carry out a number of high-resolution (5-15 km) regional climate modelling integrations, targeted in both space and time on selected case studies.
- **Analysis and interpretation of regional climate change simulations:**
  The above-mentioned simulations will build the basis for regional climate change research as well as for adaptation measures. In Germany, many scientists from universities and individual research centres are involved in regional climate change impact studies and assessments. Up until now, they have mainly been working with climate change information from global and regional climate models, which they use for regional integrated impact assessments.

  In addition to the development of global earth system models, much greater efforts are needed to develop regional subsystem models, which include not only physical processes, but also bio-geochemical ones. Due to the very different characteristics of the individual regions and due to regional adaptation to climate change, the transferability of RESMs from one region to another and the integration of human activities in the region (like land use / land covers changes) have not yet been fully explored and can clearly be seen as grand challenges for future work.

DATA CENTRES AND DATA AVAILABILITY

Observations, measurements and models are an integral part of global change research and the resulting datasets form the basis for scientific publications. Data collection, curation and access are essential for reviewers and readers who wish to verify scientific findings. Future use of data not only depends on their availability, but also on the way they are archived. Issues addressing earth system changes need to take global datasets into account. However, at present, research data are generated and stored by individual scientists and projects, which restricts the sharing of data with a broader research community. It is therefore highly desirable that such distributed data be made freely available to all users (Open Access) in a harmonised, machine-readable form that facilitates the exchange, compilation, processing and analysis of data.

Libraries are tasked with the long-term conservation and provision of access to printed publications. The Internet has added new possibilities for direct access to digital documents through publisher online catalogues, portals and search engines. However access to and distribution of digital objects is limited if the right infrastructure does not exist. The dynamic Internet and ever-changing technologies frequently lead to a "file not found (404)" error message when pages have been moved or deleted. Commercial publishers were among the first to introduce persistent identifiers in order to preserve access to electronic Web resources and ensure their availability over time. At present, more than 50 million Digital Object Identifiers (DOI®) are registered in a system operated by the International DOI Foundation. DOIs are currently mainly attributed to journal articles, and there are now global calls for primary data to also be given a persistent identifier. The "Publication and Citation of Scientific Primary Data" (STD-DOI) project, funded by the German Research Foundation (DFG), led, in 2009, to the establishment of DataCite, a partnership of leading research libraries and information providers set up to improve reliable access to research data on the Web by sustainable archiving, citation and identification of datasets by means of the DOI system (**WWW.DATACITE.ORG**).

Data centres have been in existence for around the last 50 years, during which time the archiving of and access to digital objects has suffered from constantly changing storage media and formats. Many valuable data have been lost due to defective tapes and discs in cases where no backup was available. In addition, many disciplines did not take the archiving of research data very seriously. Nowadays, new electronic data handling tools prevent the loss of data by migration from one server to another. The capacity of storage systems has been increased to the petabyte range and the recent developments provide scientists with future-proof, long-term access to digital data from anywhere in the world through the combination of archives into science-specific portals.

During the International Geophysical Year 1957/58, the World Data Center System (WDC) was established by the International Council for Science (ICSU) in order to archive and distribute data from earth system research. The WDC now includes 52 centres (*German contributions see p. 43*) in numerous countries around the world that provide online access to global change research data. The 29th General Assembly of ICSU took the decision to create a new World Data System (WDS, http://icsu-wds.org) whose objectives were to move away from current stand-alone WDCs to a common globally interoperable distributed data system and become a global "community of excellence" for scientific data. A prototype data portal is operated in Germany as a common entry point for the broad range of existing data sources. Any organisation that is in possession of relevant data is encouraged to join the new WDS. Germany will contribute to WDS with the German WDC cluster for Earth System Research and the data publisher PANGAEA (**WWW.PANGAEA.DE**).

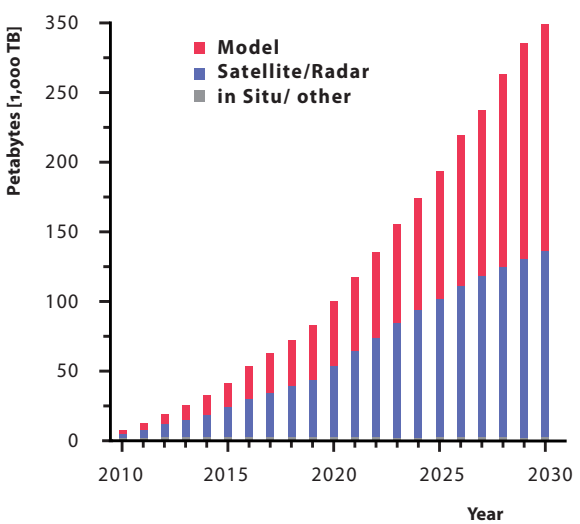


Fig. 27: Future data increase in climate research (Oberpeck et al. 2011, DOI:10.1126/science.1197869).

The ***World Data Center for Climate*** (WDCC) offers data management consulting for climate models over the lifetime of the data. In 2010, the quantity of model data available on the Web has grown to >400 TB. As a Data Collection or Production Centre (DCPC), the WDCC is part of the World Meteorological Organisation's information system. As part of the IPCC Assessment Reports, WDCC is one of three data nodes for climate model data collection that operates in cooperation with the Program for Climate Model Diagnosis and Intercomparison (PCMDI, USA) and the British Atmospheric Data Centre (BADC, UK).

WWW.WDC-CLIMATE.DEW

The ***World Data Center for Marine Environmental Sciences*** (WDC-MARE) is aimed at collecting, scrutinising, and disseminating data related to Earth system research in all fields of marine sciences. The centre also publishes WDC-MARE reports of scientific results as provided by the document centres of research institutes. Projects that use WDC-MARE for data curation purposes, deal mainly with environmental, geological, biological, physical and chemical oceanography.

WWW.WDC-MARE.ORG

The ***World Data Center for Remote Sensing of the Atmosphere*** (WDC-RSAT) provides a growing collection of atmosphere-related satellite-based datasets, information products and services. It focusses on atmospheric trace gases, aerosols, dynamics, radiation and cloud physical parameters along with complementary information. The dissemination of information is achieved either by giving free access to data stored at the centre or by acting as a portal that links up to external sources. WDC-RSAT is a member of the WMO-WDC group and serves as a management platform for the Network for the Detection of Mesopause Change (NDMC).

HTTP://WDC.DLR.DE

The ***German Research Centre for Geosciences*** (GFZ) offers geological data resulting from scientific drilling operations. Most of the data are accessible through a central portal and through discipline-specific portals, such as the World Stress Map (WSM), the Satellite Data Center (ISDC), the Scientific Drilling Database (SDDB) and the GEOFON Seismological Network. Datasets are assigned a DOI and are citeable. The new portal and the publication of data are offered as a joint service of the GFZ Centre for Geoinformation Technology (CeGIT) and the GFZ library of "Wissenschaftspark Albert Einstein".

WWW.GFZ-POTSDAM.DE:80/PORTAL/GFZ/SERVICES/FORSCHUNGSDATEN

GERMAN WDC CLUSTER FOR EARTH SYSTEM RESEARCH

Fig. 28: CryoSat will produce 50 GB of data per day. (Image credit: ESA)

Any discussion relating to the archiving of and access to research data always homes in on the huge quantity of data requiring enormous storage capacities. For example, a satellite like CryoSat (*see Fig. 28*), which was recently launched to monitor the behaviour of polar ice, will produce around 50 GB of raw data per day. Another major aspect that needs to be taken into account, but is rarely mentioned, is the variety of measurements taken in all parts of the geosphere. Data repositories are faced with the challenge of having to cope with a complex range of datasets with tens of thousands of variables produced by all the different academic disciplines involved in global change research. Smart data models are therefore required, such as the data library and publisher PANGAEA, which is able to handle this highly diverse output of geoscientific research.

Besides curiosity to find out how the Earth works, the recognition that researchers receive for their work is another major driver of scientific progress. It can therefore be safely assumed that standards for data citation that give credit to the author give researchers incentives for data sharing. Consequently, data archiving needs to become an integral part of the established scientific publication process, and most importantly needs to provide appropriate citable and reliable access to research data. To improve the current situation, scientists from Germany and the UK have initiated the journal Earth System Science Data (ESSD, **WWW.EARTH-SYSTEM-SCIENCE-DATA.NET**), the first ever journal aimed at the publication of original research data. The first publication made available an eight year time series of ozone profiles from the Antarctic station of the former German Democratic Republic (*see Fig. 29*).

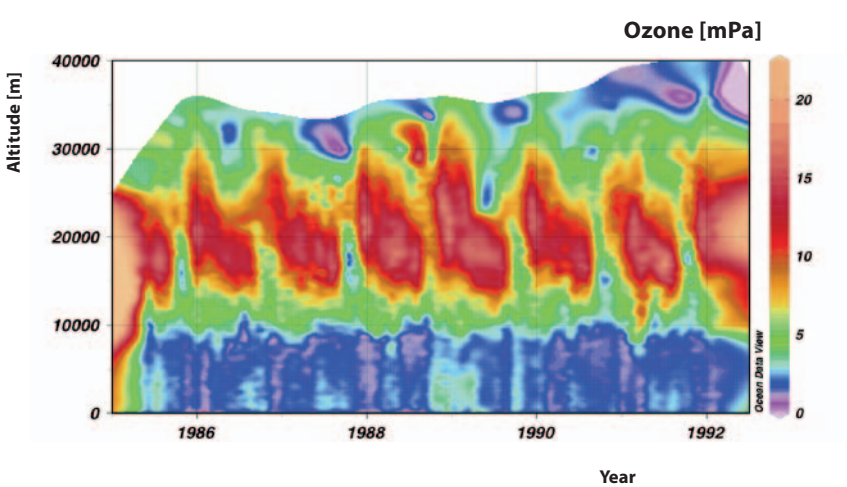


Fig. 29: Ozone time series from the Antarctic - the first publication in the data journal ESSD (König-Langlo & Gernandt 2009, DOI:10.5194/essd-1-1-2009).

CAPACITY BUILDING AND EDUCATION

KNOWLEGDE TRANSFER: CLIMATE SERVICE CENTRE, REGIONAL CLIMATE OFFICES HGF, REGIONAL SCIENCE SERVICE CENTRES AFRICA

EDUCATION

KNOWLEDGE TRANSFER

The transfer of knowledge to decision-makers in politics and economy and to the general public is essential for all climate adaptation and mitigation strategies. All institutions dealing with climate research have their own local public relations units, which undertake or organise the transfer of knowledge.

In addition to this standard outreach, specific groups and institutions coordinate knowledge transfer. Such groups and institutes include the newly established Climate Service Center Center (CSC, an institution at the Helmholtz-Zentrum Geesthacht), the Helmholtz Association's network of Regional Climate Offices (*see right-hand side*) and the Regional Science Service Centres for Climate Change and Adaptive Land Use in Southern and Western Africa (SASSCAL, WASCAL), all of which are described in this chapter.

Future climate change and its related impacts play an important role in many business and policy considerations. Although a huge amount of data is available, stakeholders responsible for the implementation of climate change adaptation strategies often lack the necessary basis to make informed decisions. They need support in assessing the quality of existing data and information, the assumptions on which they are based, and associated uncertainties.

CSC
Climate Service Center

The Climate Service Center, established by the German government at Helmholtz-Zentrum Geesthacht and funded mainly by the Federal Ministry of Education and Research (BMBF), supports decision-making in the area of adaptation to climate change by providing science-based data and information. The information provided is sector specific and tailored to customer needs. CSC's main customers are decision-makers in business, politics and administration, especially in the fields of sustainable land and forestry management, food, infrastructure (water, energy and transport), insurance, civil protection and security issues. As outlined in *Fig. 30,* the CSC is an interface between climate-related research and application in Germany. It brings research institutions, universities, climate consultants and business partners together in a joint network. CSC is currently developing partnerships with other German climate service facilities, including in particular the Regional Climate Offices of the Helmholtz Association. The CSC has four specialist departments (Climate Systems, Management of Natural Resources, Economics and Policy, Communication), which work together in an interdisciplinary way. Although CSC is primarily a German service centre, it also operates at an international level within its network in order to promote international cooperation between climate service providers. Two of CSC's departments (Management of Natural Resources and Climate Systems) are directly involved in the Southern African Science Service Centre for Climate Change and Adaptive Land Use (*see right-hand side*).

WWW.CLIMATE-SERVICE-CENTER.DE

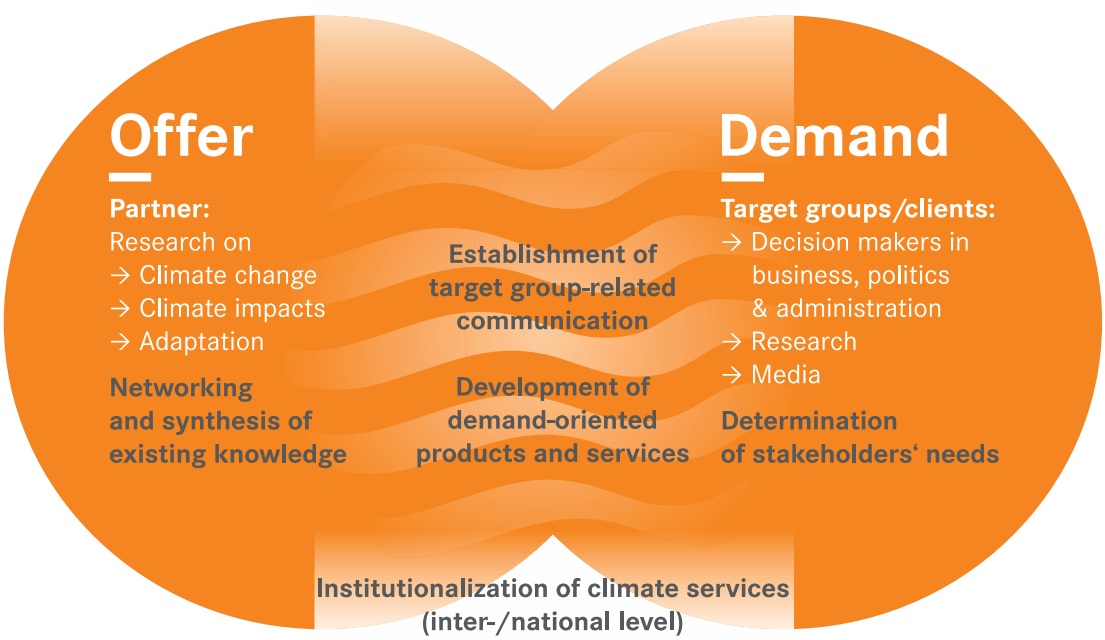


Fig. 30: The Climate Service Center as an interface between research and practice, closing the gap between offers of science-based information and the demand for tailored products and services. The five elements of the CSC strategy are shown in black.

THE NETWORK OF HELMHOLTZ REGIONAL CLIMATE OFFICES

Climate consulting: region-specific, comprehensible, solid

Global climate change varies enormously in terms of regional impact. Adaptation strategies in response to climate change have to take these differences into account in order to optimise regional and local efforts and investment. Due to the increasing need for consulting services, the Helmholtz Association has set up a network of four Regional Climate Offices. These offices work in specific fields and are also part of the Helmholtz Association's user-oriented climate research, which includes climate protection as well as climate impact and adaptation studies. Their many locations around the country along with existing technical networks enable the optimal exchange of research results related to regional climate change and its consequences. Among others, research results from the Helmholtz Centres are presented by the Regional Climate Offices in the form of comprehensible documents on specific regions and natural spaces that are available to all actors and decision-makers in politics, industry and society as well as to the general public.

The objective of the four Helmholtz Regional Climate Offices is to bring together research results on climate change for certain regions and natural spaces as well as to prepare and communicate the information in a comprehensible way. In this context, each climate office represents specific regional aspects of climate research based on the scientific expertise of the respective Helmholtz centre (*see Fig. 31*). The public demand for information concerning regional aspects of climate change is collected and integrated into the research programmes of the respective centres.

WWW.KLIMABUERO.DE

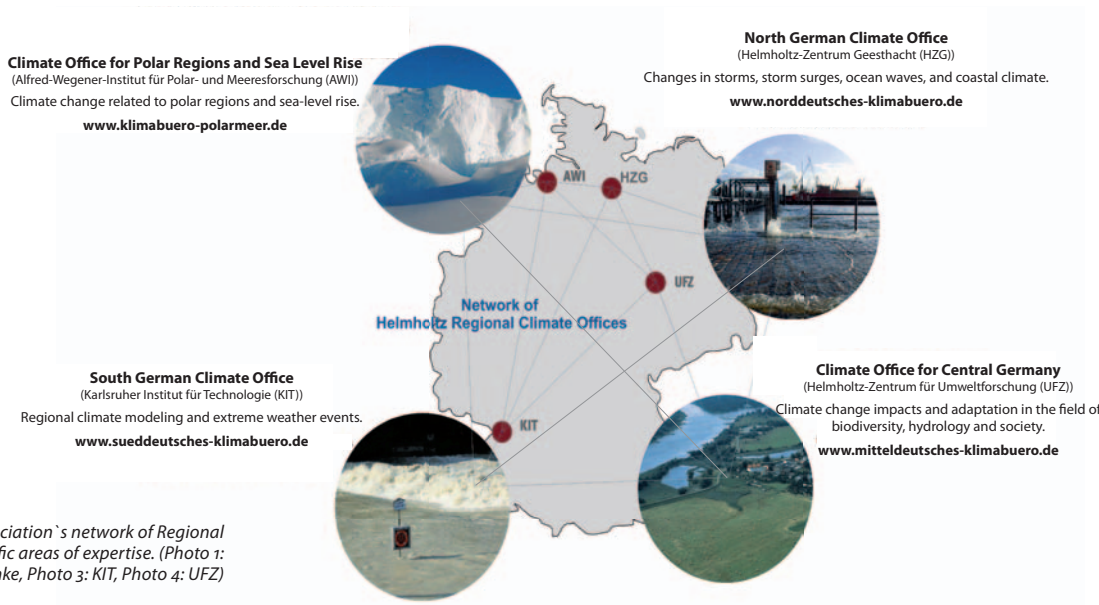


Fig. 31: The Helmholtz Association`s network of Regional Climate Offices and their specific areas of expertise. (Photo 1: R. Treffeisen, Photo 2: I. Meinke, Photo 3: KIT, Photo 4: UFZ)

REGIONAL SCIENCE SERVICE CENTRES FOR CLIMATE CHANGE AND ADAPTED LAND MANAGEMENT IN WEST AND IN SOUTHERN AFRICA

The current processes of global change, including for example, demographic change, climate change and the globalisation of economic systems, are an enormous challenge for societies worldwide, especially in Africa. Current projections on future developments indicate that there is an urgent need to develop concepts on how to adapt to these future challenges.

WASCAL and SASSCAL are two initiatives for regional science service centres in West (WASCAL) and Southern Africa (SASSCAL) to help tackle these challenges and thereby enhance the resilience of human and environmental systems to climate change. The initiatives base on a decade of successful scientific cooperation between Germany and parts of the region and aim at establishing a novel type of research infrastructure. Structures, capacities and networks were partly developed during BMBF funding initiatives GLOWA (WWW.GLOWA.ORG) as well as BIOTA-AFRICA (WWW.BIOTA-AFRICA.ORG).

In order to meet the demands of target groups such as policy-makers and governmental administration, farmers, practitioners and other regional and local stakeholders affected by climate change, the centres have three main objectives that are closely interrelated and that will be given equal priority: (1) trans-disciplinary, applied oriented research for people, (2) services and advice for policy, decision-makers and stakeholders and (3) capacity development.

One of SASSCAL's specific focus areas and mandates is the integration of information generated at a national level into an integrated regional understanding of patterns and processes. WASCAL will be organized around three principle components - a competence center, a core research programme and a graduate research programme - that will be implemented in the region together with the West African partners.

WWW.SASSCAL.ORG WWW.WASCAL.ORG

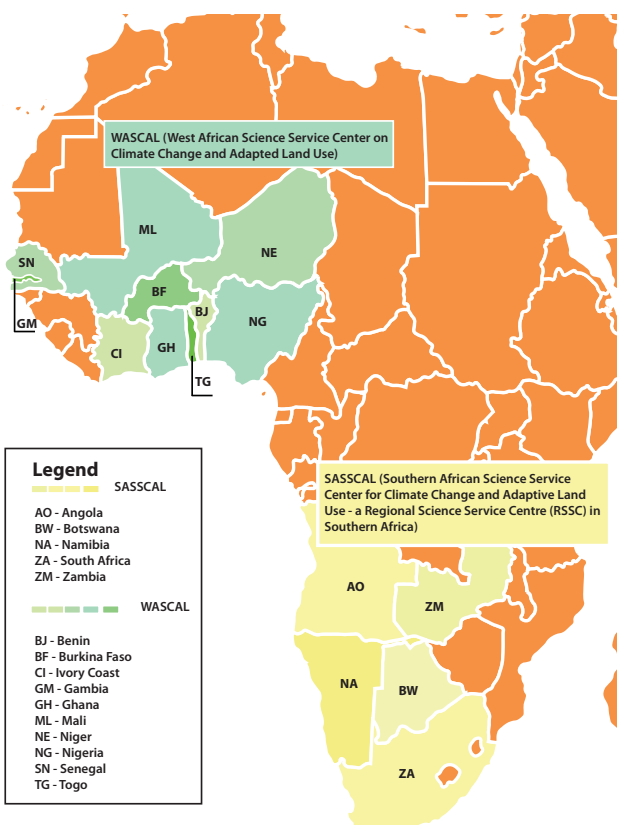


Fig. 32: The two Regional Science Service Centres of West and Southern Africa. (Source: PT-DLR)

EDUCATION

Understanding the impacts of global and climate change requires an understanding of the underlying complex human-nature relationships and this requires inter- and trans-disciplinary research approaches. It also requires professionals and academics from a variety of disciplines who have a broad range of knowledge and interests. These are challenges that go beyond conventional education programmes. Preparing the next generation of scientists in the field calls for innovative approaches that combine a firm disciplinary grounding (e.g. in physics, chemistry, economics, sociology, philosophy) and the ability and openness to work across disciplines.

Several measures are currently being taken to promote adequate education in global change science both at national and international levels. They range from the development of research and capacity building projects that promote learning by doing to innovative and interdisciplinary education programmes at universities designed to encourage young academics and to inspire the next generation of global change scientists to participate in this complex field of research.

National research institutions in Germany (Helmholtz Association, Max Planck Society, Leibniz Association, Fraunhofer-Gesellschaft) traditionally participate in postgraduate education at universities and nowadays there is a particular focus on fields relevant to global and climate change. They also contribute to the development and implementation of special courses and summer schools in cooperation with their international partners. The latter enables students to access global change education at an early stage of their careers, for example at the undergraduate level, where a strong disciplinary education is thus supplemented by involving the students in global change-related research at summer schools or through special courses e.g. ACCENT Plus for schools and students by the European Network of Excellence (funded by the EU), Future Ocean School Programmes by the German Kiel Excellence Cluster (funded by the DFG), scholarships for Ph.D., master and bachelor students provided through the SPICE programme (funded by the BMBF, DAAD).

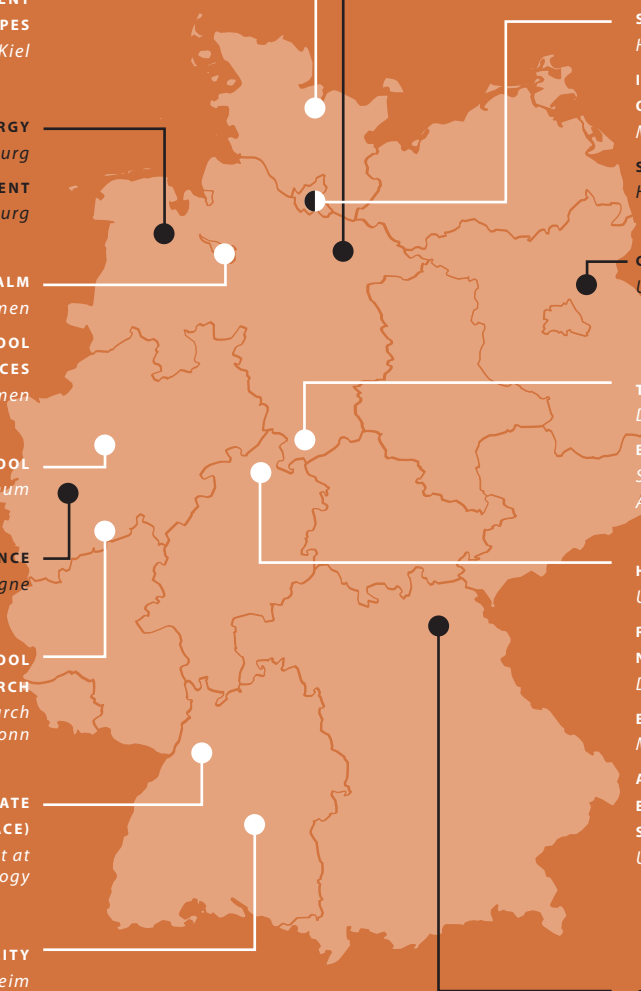
The recent drive towards internationalisation at German educational institutions has provided new opportunities for furthering global change education. Educational programmes are being developed with partners in different geographic regions of the world to address global change issues that are region-specific and also provide opportunities to foster and test a variety of approaches to tackle the societal impacts of global change. This also results in an enhanced mobility of faculty and students as well as ready access to innovative research themes related to global change.

These efforts are reinforced by support from DAAD and various foundations (Robert Bosch Stiftung, Alexander von Humboldt Foundation and Volkswagen Foundation) that provide an opportunity for the networking of academics for research and education under specific global change research themes. By contributing to the mobility of academics, such networking opportunities play a role in initiating the development of curricula, some of which are currently being implemented.

The recent Excellence Initiative of the German government and DFG has enabled universities to establish topical research clusters and graduate schools in cooperation with national research centres of Helmholtz Association, Max Planck Society, Leibniz Association and Fraunhofer-Gesellschaft. Current global change-relevant graduate schools and research training groups work in fields like oceans, landscapes, food and human security (*see selection of coordianated educational programmes*). The structured and coordinated master and Ph.D. programmes offered by some German universities with, for instance, a special emphasis on the environment (University of Kassel) or climate system science (University of Hamburg) or the oceans (Universities of Bremen & Kiel) provide for interdisciplinarity by connecting the relevant modules and offer a comprehensive learning and training package. These programmes are also open to the international community.

With their research projects and capacity building activities, German institutions make a substantial contribution towards fulfilling the international obligations and agreements to which Germany is party. In particular, the German science community works closely with and contributes to the training, education and capacity building activities of international organisations and their programmes and assessments (UNESCO, ICSU, IPCC, IGBP, IHDP, START etc.).

Much is under way to foster education in global change science, especially in training people in inter- and transdisciplinary research approaches. Today, though interdisciplinarity is widely and largely acknowledged as being the way to find answers to society's questions, traditional disciplines still receive the greatest scientific recognition. Therefore, being a part of a global interdisciplinary scientific community is not just an intellectual challenge that involves the exchange of research and the development of ideas, theories and methods in the search for new ways of integration, but it is also a personal challenge and decision. One way to ensure that there will be sufficient young minds working on global change issues is to catch them young in kindergartens and in schools, to promote awareness of global change issues and therefore sustainability at a very early stage (*see future ocean school programme*).



INTEGRATED SCHOOL OF OCEAN SCIENCES
Alexander von Humboldt Foundation and the Kiel Cluster of Excellence

INTEGRATED STUDIES OF HUMAN DEVELOPMENT IN LANDSCAPES
DFG Research Training Group Kiel

RENEWABLE ENERGY
Karl von Ossietzy University of Oldenburg

WATER AND COASTAL MANAGEMENT
Karl von Ossietzy University of Oldenburg

GLOBAL CHANGE IN THE MARINE REALM
DFG Graduate School Bremen

BREMEN INTERNATIONAL GRADUATE SCHOOL OF SOCIAL SCIENCES
DFG Graduate School Bremen

RUHR UNIVERSITY RESEARCH SCHOOL
DFG Graduate School Bochum

ENVIRONMENTAL SCIENCE
University of Cologne

BONN INTERNATIONAL GRADUATE SCHOOL FOR DEVELOPMENT RESEARCH
DAAD and Center for Development Research at the University of Bonn

GRADUATE SCHOOL FOR CLIMATE AND ENVIRONMENT (GRACE)
KIT-Center Climate and Environment at the Karlsruhe Institute of Technology

GLOBAL FOOD SECURITY
DAAD and University of Hohenheim

SUSTAINABILITY SCIENCES
Leuphna University Lüneburg

SCHOOL OF INTEGRATED CLIMATE SYSTEM SCIENCES
Hamburg University

INTERNATIONAL MAX PLANCK RESEARCH SCHOOL ON EARTH SYSTEM MODELLING
Max Planck Research School Hamburg

SCHOOL OF INTEGRATED CLIMATE SYSTEM SCIENCES (SICSS)
Hamburg University

GLOBAL CHANGE MANAGEMENT
University of Applied Sciences, Eberswalde

TRANSFORMATION OF GLOBAL AGRIFOOD SYSTEMS
DFG Research Training Group Göttingen

BIODIVERSITY AND SOCIETY
State of Lower Saxony and Georg-August-Universität Göttingen

HUMAN-ENVIRONMENTAL-SYSTEMS
University of Kassel Research Training Group

REGULATION OF SOIL ORGANIC MATTER AND NUTRIENT TURNOVER IN ORGANIC AGRICULTURE
DFG-Research Training Group Kassel

EARTH SYSTEM MODELLING
Max Planck Research School and University of Kassel

AGRICULTURE AND NUTRITION, ECONOMY AND ENVIRONMENT, ENERGY AND MATERIAL FLOW SYSTEMS, SUSTAINABLE PLANNING AND BUILDING
University of Kassel

GLOBAL CHANGE ECOLOGY
Universities of Bayreuth, Augsburg and Würzburg, with research institutions and international organisations.

● **MASTER PROGRAMMES** ● **PH.D. PROGRAMMES**

SELECTION OF COORDINATED EDUCATIONAL PROGRAMMES IN GLOBAL CHANGE SCIENCE IN GERMANY

PROJECT EXAMPLE

SPICE - *Science for the Protection of Indonesian Coastal Ecosystems*

SPICE is a research programme developed within the framework of science and technology cooperation between Indonesia and Germany in the field of marine sciences and geosciences. It takes into account the national research priorities of Germany and Indonesia in "Research for Sustainability" and addresses scientific, social and economic issues relevant to the conservation, governance and management of coastal systems which are under threat from climate and other global changes. Capacity building through research is one major component of the SPICE programme. In the first phase the programme was supported by a BMBF/DAAD-sponsored special scholarship programme on marine sciences for Indonesian students and junior scientists, which enables them to take up studies at postgraduate level at German partner universities.

Programme Duration: 2003-2010
Funding: BMBF
WWW.ZMT-BREMEN.DE/EN/SPICE_II.HTML

FUTURE OCEAN *School programmes*

The school programmes are designed to acquaint pupils with natural sciences and their fascination using Marine Sciences as an example. The students are introduced to current research through the lectures of the Kids' and Students' University on the one hand and through projects and practical work which brings them into direct contact with scientists, on the other.

Programme Duration: 2006-2012 (a second phase has been applied for)
Funding: DFG
WWW.OZEAN-DER-ZUKUNFT.DE

GLOBAL CHANGE FRAMEWORKS

THE INTERNATIONAL GLOBAL CHANGE PROGRAMMES, ESSP AND NKGCF

The German National Committee on Global Change Research (NKGCF, WWW.NKGCF.ORG) was set up in October 1996 by Germany's major research funding agency, the German Research Foundation (DFG), in close collaboration with the Federal Ministry of Education and Research (BMBF). By bringing together scientists from all fields of global change research and the four international programmes under the umbrella of one committee, Germany has shown forward-thinking in anticipating the need for close collaboration between all the scientific disciplines that carry out global change research. This organisational structure enables the national committee to efficiently support interdisciplinary research and to develop new strategies and drive forward activities in this cross-disciplinary field (e.g. in interdisciplinary joint projects of ESSP or committees such as European Alliance of Global Change Research Committees). The committee members are supported by a scientific secretariat which also acts as national contact point and coordinating office.

As a scientific advisory board to DFG and BMBF, the German National Committee plays a significant role in the process of identifying research priorities and in stimulating German contributions to the four international global change programmes and ESSP (*see right-hand side*). The NKGCF members are also involved in the strategic discussions of German contributions to international science organisations, such as the International Group of Funding Agencies (IGFA), the International Council for Science (ICSU), the International Social Science Council (ISSC) and the Belmont Forum. DFG is an ordinary member in all of these groups. While academic disciplines came closer together during the last years to meet the challenges of global change, there was also seen the need for a closer institutional collaboration between sciences and the humanities. Therefore ICSU, ISSC and DFG signed a Memorandum of Understanding in 2009.

From 2009 to 2011, NKGCF members held different scientific discussions on pressing questions related to topics such as climate-engineering, regional climate models and ecosystem services. All of these discussions included scientists from different disciplines (range from ethics to politics, law, physics, chemistry, biology, philosophy or economics) and also some stakeholders. In 2010 a national statement relating to the public criticism of IPCC was published and NKGCF members took part in several international expert discussions on research needs and challenges of the future. To exchange its experiences and knowledge, the NKGCF organises a national colloquium every three years that covers issues related to international discussions and strategies. In 2012, the 5th NKGCF colloquium "Limits of Growth Reloaded?" aims to discuss the limitedness of natural resources and its connection with the future of economic growth as well as population development. This is related to the new international strategy: the "Earth System Science for Global Sustainability: The Grand Challenges" spearheaded by ICSU in cooperation with ISSC (*see Future Research, p. 54*).

MEMBERS NKGCF 2009-2011

Prof. Gernot Klepper Ph.D. ***Chair***	**Environmental and Resource Economics**
Prof. Dr. Antje Boetius *Co-Chair, Diversitas liaison*	Marine Microbiology
Prof. Dr. Meinrat O. Andreae *Co-Chair, IGBP liaison*	Biogeochemistry
Prof. Dr. Peter-Tobias Stoll *Co-Chair, IHDP liaison*	Environmental Law and Intern. Business Law
Prof. Dr. Martin Visbeck *Co-Chair, WCRP liaison*	Physical Oceanography
Prof. Dr. Christoph Böhringer	Economic, Environment and Energy Policy
Prof. Dr. Katrin Böhning-Gaese (since 2011)	Biodiversity and Area Dynamics of Vertebrates
Prof. Dr. Hans-Georg Frede	Resource Management, Ecology
Prof. Dr. Armin Grunwald (since 2010)	Technology Assessment and System Analysis
Prof. Dr. Elisabeth Kalko	Animal Ecology
Prof. Dr. Frauke Kraas	Anthropogeography, Urban Research
Prof. Dr. Wolfgang Lucht	Earth System Modeling
Prof. Dr. Ulrich Platt	Environmental Physics, Experimental Physics
Prof. Dr. Michael Schulz	Paleoclimate Research
Prof. Dr. Georg Teutsch	Applied Geosciences, Hydrology
Prof. Dr. Wolfgang Weisser (up until 2010)	Terrestrial Ecology
	Ex Officio
Dr. Harry Lehmann	Federal Environmental Agency (UBA)
Dr. Gisela Helbig	Federal Ministry of Education and Research (BMBF)
Dr. Bettina Schmalzbauer	Scientific Secretariat NKGCF
Dr. Johannes Karte	German Research Foundation (DFG)

NKGCF ACTIVITIES

- Four regular committee meetings per year.
- National colloquia to discuss achievements and to redesign and refocus future needs of the global change research programmes.
- Scientific workshops and expert discussions to develop and discuss new methodological approaches and to develop new research initiatives and interdisciplinary research programmes; organised with the financial support of DFG and BMBF.
- Scientific conferences to evaluate the progress and achievements of German contributions to global change research. These meetings also provide the necessary background information for future development of research programmes. The discussions and main outcomes of these meetings are published either as books or as part of the committees' publication series.
- Ad hoc working groups to discuss and review new research initiatives, and to help develop new programme components.

ESSP

WWW.ESSP.ORG

The Earth System Science Partnership (ESSP) is a joint initiative of the four global change research programmes (DIVERSITAS, IGBP, IHDP and WCRP) for the integrated study of the earth system including its structure and functioning, changes that happen in the system, and implications for global and regional sustainability. The ESSP has four main types of activities:

- Joint projects on issues of global sustainability, designed to address the global change aspects of four critical issues for human wellbeing: carbon dynamics (GCP), food security (GECAFS), water resources (GWSP) and human health (GECHH).
- Regional activities, including capacity building, networking and integrated regional studies (START, MAIRS). earth system analysis and modelling approaches can also be coordinated through collaboration with existing activities of the four consteks strategic partnerships, e.g. ESSP and CGIAR jointly launched the Research Programme on Climate Change, Agriculture and Food Security (CCAFS).
- Global Change Open Science Conferences. ESSP recognises the important contribution that the broad interaction amongst scientists makes to its activities. The partnership is therefore committed to hosting major international science meetings every five years.
- Communication activities. These include the ESSP website, the science-policy dialogue (e.g. SBSTA, UNFCCC), the launch of a new interdisciplinary scientific journal ("Current Opinion in Environmental Sustainability" published by Elsevier), a report series, and features on ESSP activities in the programme newsletters.

Earth System Science Partnership

DIVERSITAS

WWW.DIVERSITAS-INTERNATIONAL.ORG

DIVERSITAS is the international biodiversity programme that promotes an integrative approach to biodiversity science, linking biology, ecology and social sciences disciplines, and providing the scientific basis for the conservation and sustainable use of biodiversity. Besides cross-cutting issues, DIVERSITAS' research focusses on (1) monitoring current biodiversity and predicting changes (bioDISCOVERY), (2) establishing a robust understanding of the ecological, economic and cultural consequences of biodiversity loss and changes (ecoSERVICES), (3) developing new knowledge to guide policy- and decision-makers (bioSUSTAINABILITY) and (4) documenting biodiversity, its diversification and the effects of human-induced changes (bioGENESIS).

IGBP

International Geosphere-Biosphere Programme

WWW.IGBP.NET

IGBP investigates the interactive physical, chemical and biological processes that define earth system dynamics, the changes that are occurring therein, and the role of human activities relating to these changes. Besides fast-track activities, IGBP's main research projects focus on the major compartments of the earth system such as oceans (IMBER and GLOBEC), land (GLP) and atmosphere (IGAC), the interfaces between them such as land/atmosphere (iLEAPS), land/ocean (LOICZ), and ocean/atmosphere (SOLAS) and a system-wide integration (PAGES and AIMES).

WCRP

World Climate Research Programme

WWW.WCRP-CLIMATE.ORG

WCRP is aimed at developing an improved knowledge and understanding of climate system variability and change, and determining the extent to which climate can be predicted and to which humans influence the climate system. WCRP is a network of core and co-sponsored projects, working groups and cross-cutting initiatives. Main core projects focus on climate and cryosphere (CliC), climate variability and predictability (CLIVAR), global energy and water cycle processes (GEWEX) and stratospheric processes and their role in climate (SPARC).

IHDP

International Human Dimensions of Global Environmental Change Programme

WWW.IHDP.UNU.EDU

Viewing global problems as social and societal challenges, IHDP fosters the integration of social science in global environmental change research to address these challenges from an interdisciplinary perspective. It investigates the interactions of humans with the environment, thereby operating at the interface between science and practice. Besides capacity development and science-policy interactions, the main projects of IHDP are: Earth System Governance (ESG), Integrated Risk Governance (IRG), Industrial Transformation (IT), Urbanization and Global Environmental Change (UGEC), and co-sponsored with IGBP Integrated History of People of Earth (IHOPE), Land-Ocean Interactions in the Coastal Zone (LOICZ) and Global Land Project (GLP).

ICSU - *International Council for Science* **ISSC** - *International Social Science Council*

IGFA - *International Group of Funding Agencies* / **BELMONT FORUM** - *Council of Principals for IGFA*

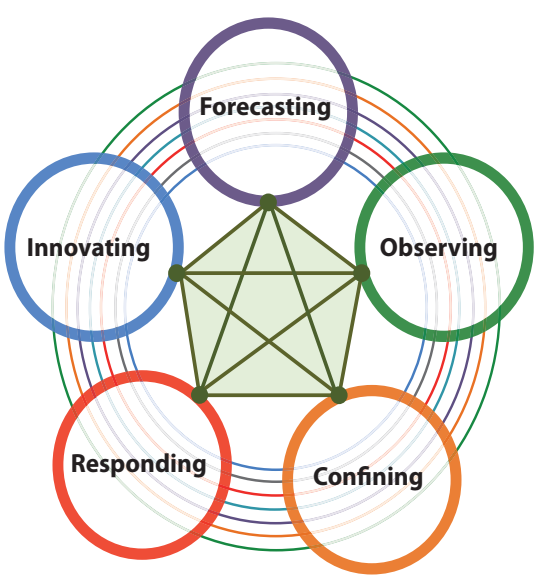
WWW.ICSU.ORG | *WWW.WORLDSOCIALSCIENCE.ORG* | *WWW.IGFAGCR.ORG* | *WWW.IGFAGCR.ORG/INDEX.PHP/BELMONT-FORUM*

The common target of the international scientific councils and their alliances (ICSU, ISSC, IGFA, Belmont Forum) is to support global change research on a global level by bringing together national funding organisations in one group. The scientific councils therefore all have the same objectives within the global change research framework from the perspective of different disciplines (such as natural sciences and social sciences) and different approaches.
To explore options for the future holistic strategy of earth system research, ICSU initiated an earth system visioning process in 2009. Together with funders and scientists from around the world the future of the earth system research was discussed and results were published in the strategy paper "Earth System Science for Global Sustainability: The Grand Challenges" (ICSU-ISSC, 2009). The new strategy promotes a stronger interdisciplinary research approach and indicates a reorganisation of global organisational structures.

FUTURE GLOBAL CHANGE RESEARCH

The study of the earth system, its components, processes and interactions with humans has come to a point of transition. Over the last decades disciplinary knowledge has enhanced dramatically in the field of climate change and its impact on hydrological cycles, land use change, biological diversity, ecosystem functions, human health, food and energy systems, or on the oceans. It became clear that the understanding of the vulnerability of the earth system and with its different compartments which is determined by human actions can only be improved by the development of coupled socio-ecological systems.

Natural science research has provided sufficient evidence about the long-term impacts of many human activities to indicate that action is urgently needed to avoid major risks of global change, in particular in highly vulnerable regions. However, we have little understanding as to what the appropriate course of action should for questions such as "How can we establish a globally sustainable society in a long term perspective? How can we change human behaviour and political direction to effectively implement strategies for the controlling of but also for living with climate change? How can societies respond most effectively and in a fair manner to the global change that is already underway?" (*see also ICSU 2010, Paris, ISBN: 978-0-930357-73-3*). These questions ask for a stronger involvement of the social sciences into global change research endeavours and their integration within the established research activities of the natural sciences. The different disciplines of the social sciences are all needed to contribute to these questions using their insight into the determinants and dynamics of among others life styles, economic incentives, institutions for governing change, or societal risk management.



In support of this stronger integration of research approaches, the international councils for natural science and social science (ICSU, ISSC) has recently published a strategy paper "Earth System Science for Global Sustainability – The Grand Challenges" (ICSU 2010, Paris, ISBN: 978-0-930357-73-3). In this strategy paper five grand challenges are categorised "Forcasting", "Observing", "Confining", "Responding" and "Innovation" (*Fig. 34*) that comprise priority research questions as for example:

- What significant environmental change are likely to result from human actions? How would those changes affect human well-being, and how are people likely to respond? *(Grand challenge "Forecasting" - Improve the usefulness of forecasts of future environmental conditions and their consequences for people.)*
- What do we need to observe in coupled social-environmental systems, and at what scales, in order to respond to, adapt to, and influence global change? *(Grand challenge "Observing" - Develop, enhance and integrate the observation systems needed to manage global and regional environmental change.)*
- How can improved scientific knowledge of the risks of global change and options for response most effectively catalyze and support appropriate actions by citizens and decision-makers? *(Grand challenge "Confining" - Determine how to anticipate, recognize, avoid and manage disruptive global environmental change.)*
- What changes in behaviour or lifestyle, if adopted by multiple societies, would contribute most to improving global sustainability, in the context of global environmental change, and how could they be achieved? *(Grand challenge "Responding" - Determine what institutional, economic and behavioural changes can enable effective steps toward global sustainability.)*

Fig. 34: The five grand challenges in earth system science: The concentric circles represent the disciplinary research needed in the social, natural, health and engineering sciences and the humanities that must be carried out alongside interdisciplinary and transdisciplinary research in order to address the challenges. The lines linking the grand challenges show that progress in addressing any challenge will require progress in addressing each of the others. (Source: ICSU 2010, Paris., ISBN: 978-0-930357-73-3)

- How can pressing needs for innovation and evaluation be met in sectors like global energy security, demands for land and water, ecosystem services, communication patterns and geo-engineering? *(Grand challenge "Innovating" - Encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy, and social responses to achieve global sustainability)*

Answering this questions with respect to scoping global change will require for instance scientific endavour in capacity building and predictions. Also robust data and information sets of natural and social sciences are needed. Finally, the grand challenges include a series of research questions that can only be answered in an interdisciplinary way.

Guided by the five grand challenges the global environmental change programmes (IGBP, DIVERSITAS, IHDP, WCRP) and its partnership ESSP will host a jointly organised conference in London in 2012. The conference aims to provide a comprehensive update of the knowledge of the earth system and the pressure the planet is now under. This "Planet under Pressure"-Conference will set a new vision for global change research (26-29 March 2012, London, WWW.PLANETUNDERPRESSURE2012.NET).

Fig. 35: „Planet under pressure" - A joint conference of WCRP, IHDP, IGBP, DIVERSITAS and ESSP.

In 2012 the NKGCF wishes to introduce and discuss ICSU's strategy paper with the German global change community at its 5th National Colloquium. It has chosen one important aspect that influences global sustainability, namely the issue of resource limits. Resources such as water, biomass, minerals and energy have long been viewed not to be a constraint on increasing prosperity. However, continued population growth paired with current and expected future global change makes resource scarcity work in two ways, there may be absolute limits to the availability of natural resources and there may be limits to the absorptive capacity of the earth system for those natural resources once they have been used. The 5th National Colloquium of the NKGCF (*Fig. 36*) will provide a forum to discuss the significance of this topic for societies and to see how the science can contribute to the understanding and to the management of these complex dynamics of natural resource use and global sustainability.

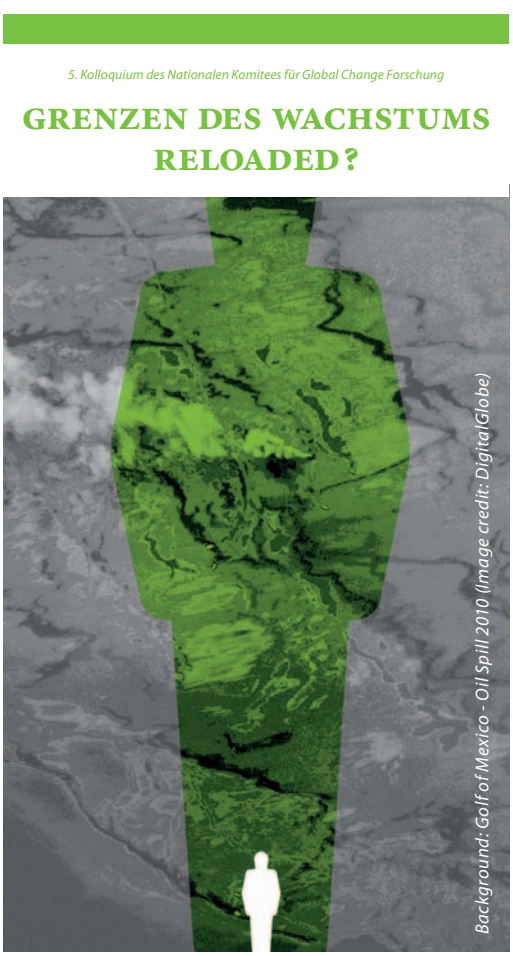


Fig. 36: „Limits to growth reloaded?" - Topic of the 5th National Colloquium of NKGCF.

GERMAN RESEARCH FUNDING AND INSTITUTIONS

FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

WWW.BMBF.DE

The Federal Ministry of Education and Research (BMBF) and the German Research Foundation (DFG) are the main contributors financing global change research in Germany.

The BMBF-Framework Programme "Research for Sustainable Development" (FONA) and the High-Tech Strategy of the Federal Government are the framework of BMBF activities in Global Change research (**WWW.FONA.DE**, **WWW.HIGHTECH-STRATEGIE.DE**). It comprises the following fields of action:

- Understanding and simulating processes in coupled natural and social systems.
- Avoiding or mitigating human induced environmental damage through innovative technologies, processes, services and policies.
- Enabling adaptation to global change through development, implementation and dissemination of innovative technologies and strategies.

The research and innovation strategy of BMBF has an integrative and comprehensive character: natural scientific research provides basic insights; social sciences and economics analyse behavioural and management trends and options; technological development provides solutions for environmentally sound growth, innovative information and consulting opportunities make complex knowledge on global change available and enhance decision making capacities throughout society. Many of the research activities are planned and implemented in interdisciplinary and international cooperation.

To implement scientific objectives in global change research BMBF has several funding mechanisms. The project oriented funding solves specific scientific questions on Global Change within the scope of short- and mid-term programmes. Moreover, scientific institutions throughout Germany receive institutional funding of BMBF and their respective federal states.

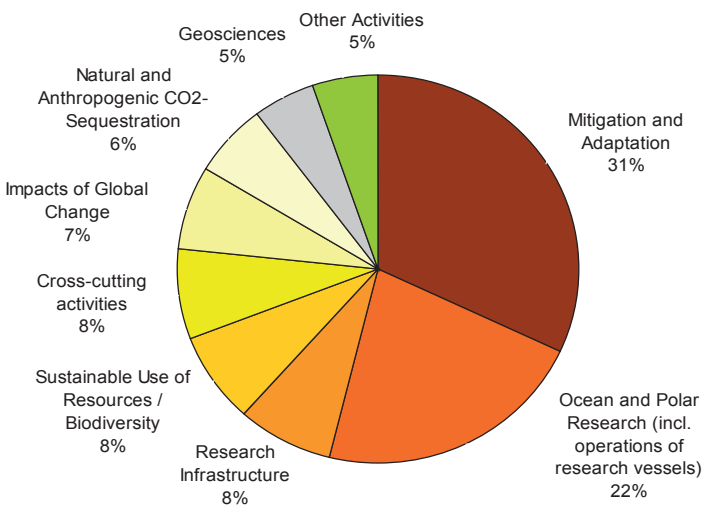


Fig. 37: BMBF project and infrastructural funding: BMBF's funding resources for project oriented global change and climate research summed up to about 152,6 million EUR in 2010, including investment costs for research technology and infrastructure. (Exact amounts for institutional funding for global change research are difficult to establish. Institutional budgets usually cover a wider range of research topics. However, global change and climate research together can be estimated between 200 and 250 million EUR in 2011, including operational cost for large scale research infrastructure.)

Recipients of institutional funding of BMBF are mainly four large scientific organisations: Helmholtz Association (HGF), Leibniz Association (WGL), Max Planck Society (MPG), and Fraunhofer-Gesellschaft (FhG). Their research facilities have a special significance in global change research because they operate instruments and systems. Research on global change relies on complex equipment (e.g. aircrafts, high performance computers, ships and observatories). Additionally, Helmholtz and Leibniz Association address questions of global change in research networks ("Earth and Environment", "Environmental Research", *see page 59, 60*).

KLIMZUG
Managing Climate Change in the Regions for the Future

BMBF's KLIMZUG funding programme aims to improve regions' competitiveness under climate change and associated weather extremes. Seven sample regions in Germany are supported with up to 83 million EUR to form productive networks of private enterprise, public administration and research, to understand and prepare for the specific consequences of climate change and also seize opportunities and potentials. KLIMZUG regions are intended to serve as examples for adaptation networks which are sustainable in the long-term and create competitive locations. In this way, the funding is intended to help integrating anticipated climate changes and the associated extreme weather events and draw consequences for the adaptation of planning and infrastructure development as well as political and economic decision making processes.

Programme Duration: 2009-2014
Funding: BMBF
WWW.KLIMZUG.DE

GERMAN RESEARCH FOUNDATION (DFG)

WWW.DFG.DE

The German Research Foundation (DFG) is the self-governing organisation for science and research in Germany and, as such, is the central funding organisation for German universities. Its membership consists of German universities, non-university research institutions (e.g. MPG), scientific associations and the Academies of Science and the Humanities. DFG has been involved in funding global change research for many decades. As an organisation responsible for funding in all branches of science and the humanities, DFG is in charge of research related to all the international global change programmes (WCRP, IGBP, IHDP, DIVERSITAS) and the Earth System Science Partnership (ESSP). Research funding is awarded through a number of individual projects and larger coordinated programmes, such as Collaborative Research Centres, Priority Programmes, Research Units, Research Training Groups (*see overview below*) which are initiated through a bottom-up process. The overall annual funding for global change research amounts to around € 80 million.

CLIMATE - *Biogeochemistry Interactions in the Tropical Ocean*

The SFB builds upon wide-ranging expertise from several disciplines and institutions including chemical and physical oceanography, sediment biogeochemistry, marine ecology, molecular microbiology, paleoceanography, geology, as well as climate and biogeochemical modelling.
The research carried out within the sixteen subprojects focuses on the following questions:

- How does subsurface dissolved oxygen in the tropical ocean respond to changes in ocean circulation and ventilation?
- What sensitivities and feedbacks link low oxygen levels, key nutrient sources and sink mechanisms?
- What are the magnitudes, timescales and controlling factors of past, present and likely future variations in oceanic oxygen and nutrient levels?

Programme Duration: 2008-2011
Funding: DFG
WWW.SFB754.DE/EN/?PROJECT

OVERVIEW OF DFG-FUNDED PROJECTS AND PROGRAMMES RELATED TO GLOBAL CHANGE RESEARCH

COLLABORATIVE RESEARCH CENTRES (SONDERFORSCHUNGSBEREICHE, SFB)

564 Sustainable Land Use and Rural Development in Mountainous Regions of South-east Asia
574 Volatiles and Fluids in Subduction Zones: Climate Feedback and the Causes of Natural Disaster
754 Climate – Biogeochemistry Interactions in the Tropical Oceans

TRANSREGIONAL COLLABORATIVE RESEARCH CENTRES (TRANSREGIO, TR)

32 Patterns in Soil-Vegetation-Atmosphere Systems: Monitoring, Modelling and Data Assimilation

CLUSTER OF EXCELLENCE (EXZELLENZCLUSTER, EXC)

80 The Future Ocean
177 Integrated Climate System Analysis and Prediction (CliSAP)
309 The Ocean in the Earth System

GRADUATE SCHOOLS (GRADUIERTENSCHULEN, GSC)

119 Global Change in the Marine Realm
208 Graduate School for Integrated Studies of Human Development in Landscapes

PRIORITY PROGRAMMES (SCHWERPUNKT-PROGRAMME, SPP)

527 (Integrated) Ocean Drilling Programme (IODP/ODP)
1158 Antarctic Research with Comparable Investigations'in Arctic Sea Ice Areas
1167 Quantitative Precipitation Forecast
1176 Climate and Weather of the Sun-Earth-System
1233 Megacities - Megachallenge: Informal Dynamicsof Global Change
1257 Mass Transport and Mass Distribution in the Earth System
1266 Integrated Analysis of Interglacial Climate Dynamics (Interdynamics)
1276 Multiple-Scale Modelling in Fluid Mechanics and Meteorology
1294 Atmospheric and Earth System Research with the "HighAltitude and Long Range Research Aircraft" (HALO)
1315 Biogeochemical Interfaces in Soil
1372 Tibetan Plateau: Formation - Climate - Ecosystems (TIP)
1374 Biodiversity Exploratories
1418 Refractories - Initiative to Reduce Emissions - „FIRE"

RESEARCH TRAINING GROUPS (GRADUIERTENKOLLEGS, GRK)

717 Proxies in Earth History
1024 Interdisciplinary Environmental History - Natural Environment and Social Behaviour in Central Europe
1070 Modelling Material Flows and Production Systems for Sustainable Resource Use in Intensified CropProduction in the North China Plain
1086 The Role of Biodiversity for Biogeochemical Cycles and BioticInteractions in Temperate Deciduous Forests
1364 Interactions between Tectonics, Climate and Biospherein the African-Asian Monsoonal Region
1565 Complex Terrain and Ecological Heterogeneity (TERRECO): Evaluating ecosystem services in production versus water yield and water quality in mountainous landscapes
1598 INTERCOAST: Integrated Coastal Zone and Shelf-Sea Research

RESEARCH UNITS (FORSCHERGRUPPEN, FOR)

510 Environmental and Cultural Changes in West and Central Africa
536 Matter Fluxes in Grasslands of Inner Mongolia as Influenced by Stocking Rate (MAGIM)
539 Saharan Mineral Dust Experiment (SAMUM)
562 Dynamics of Soil Processes under Extreme MeteorologicalBoundary Conditions
668 Dated Speleothems Archives of the Paleoenvironment
703 Rift Dynamics, Uplift and Climate Change in Equatorial Africa: Interdisciplinary Research linking Asthenospere, Lithosphere, Biosphere and Atmosphere
816 Biodiversity and Sustainable Management of a Mega-diverse Mountain Ecosystem in South Ecuador
891 The role of tree and shrub diversity for production, erosion control, element cycling, and species conservation in Chinese subtropical forest ecosystems
896 Predictability and Dynamics of Weather Systems in the Atlantic-European Sector (PANDOWAE)
995 Biogeochemistry of Paddy Soil Evolution
1070 Understanding Cenozoic Climate Cooling: The Role of the Hydrological Cycle, the Carbon Cycle, and Vegetation Changes
1095 Stratospheric Change and its Role for Climate Prediction(SHARP)
1246 Kilimanjaro Ecosystems under Global Change: Linking Biodiversity, Biotic Interactions and Biogeochemical Ecosystem Processes
1380 Himalaya: Modern and Past Climates (HIMPAC)
1451 Exploring mechanisms underlying the relationship between biodiversity and ecosystem functioning
1701 Introducing Non-Flooded Crops in Rice-Dominated Landscapes: Impact on Carbon, Nitrogen and Water Cycles (ICON)

MAX PLANCK SOCIETY (MPG)

WWW.MPG.DE

The Max Planck Society carries out basic research in the humanities, social sciences, life sciences, natural sciences and engineering sciences in its own institutes and facilities, which benefit from total autonomy in their choice of research foci. The Max Planck Society works in close cooperation with other research institutions and universities. There are currently 80 institutes and research facilities throughout Germany and in Italy, the Netherlands and the USA.

EARTH SCIENCE AND CLIMATE RESEARCH

Max Planck Institutes in Mainz, Hamburg, Jena and other partnering institutions have joined together to form the Earth System Research Partnership. The goal of the partnership is to develop an integrated approach to earth system science, focussing on the interactions between human activities, land-based ecosystems, oceans and atmosphere, and applying aircraft and ground-based measurements, remote sensing and modelling. The understanding of the earth system and its interactions are a basic prerequisite for the definition of economic and political strategies for an ideal and sustainable use of the planet's resources.

Approaches involved are threefold: measurements and in-situ experiments are required to examine processes within the components. The Max Planck Society operates long-term measurement stations and is a key partner in the acquisition and use of the HALO research aircraft.

Secondly, the Earth has to be analysed on large time- and space scales in order to achieve an understanding of regional, global and long-term processes and alterations. The use and analysis of satellite data is essential for surveying global and continental phenomena. The third main pillar is modelling. Numeric models, for example, are used as theoretical tools for investigating interrelations in the earth system. Research focuses on the following questions:

- What feedback and long distance relations of the earth system are especially important?
- What regions and components have a particularly sensitive reaction to global change?
- Are there critical thresholds that lead to abrupt changes in the earth system?
- Are there options to manage or control the earth system in the long term?

These activities are of international relevance and are hence closely linked on the international level to large research programmes, notably the International Geosphere-Biosphere Programme (IGBP). Other topics related to global change and involving research work at numerous institutes are: Fundamentals of sustainable energy supply (e.g. hydrogen) and changes in biodiversity.

IMPRS - *International Max Planck Research Schools*

- ***IMPRS for Atmospheric Physics and Chemistry***

This research school is a joint initiative of the MPI for Chemistry, Mainz, and Mainz University. Other partners are the Atmospheric Physics Department of the MPI for Nuclear Physics in Heidelberg and the Universities of Heidelberg and Frankfurt. The Research School investigates atmospheric physical-chemical processes and the human influence on global change. Improved understanding of these processes contributes to the development of atmospheric chemistry and climate models which will play an increasingly important role in the assessment of global climate change. The research topics address sensitive regions of the atmosphere that have received relatively little attention up until now, such as the tropics.

WWW.ATMOSPHERE.MPG.DE/ENID/1280

- ***IMPRS for Global Biogeochemistry***

In cooperation with the Friedrich Schiller University Jena, this Research School offers a Ph.D. programme in global biogeochemistry and related earth system sciences. Research and teaching focusses on (1) an improved understanding of biogeochemical processes with an emphasis on terrestrial ecosystems, (2) the development of observational techniques to monitor and assess biogeochemical feedbacks in the earth system and (3) the theory and model development for improving the representation of biogeochemical processes in comprehensive earth system models.

WWW.IMPRS-GBGC.DE

- ***IMPRS on Earth System Modeling***

This research school, established by the Max Planck Institute for Meteorology and the University of Hamburg, provides a high quality, modern and structured graduate education to talented and creative students from around the world who are pursuing a doctoral degree in interdisciplinary climate research. Doctoral students contribute to the understanding of the earth system through the application, evaluation and development of a spectrum of earth system models at different levels of complexity and spatial and temporal scales. Emphasizing the physical system, IMPRS-ESM comprises institutions and scientists from the broader field of earth sciences, including economics and social sciences. Our Ph.D. programme stimulates and advances the careers of young researcher through a special curriculum and an active visitor and exchange programme.

WWW.EARTHSYSTEMSCHOOL.DE

HELMHOLTZ ASSOCIATION (HGF)

WWW.HELMHOLTZ.DE

The Helmholtz Association identifies and addresses the huge challenges facing society, science and industry, in particular through its research into highly complex systems. Its 17 national research centres carry out scientific-technical and biological-medical research. Helmholtz concentrates its core competences and resources on strategic programmes aimed at increasing the efficiency, flexibility and target-oriented focus of its research. Several Helmholtz centres usually join forces to make a group application for the funding of their research programmes, which are all assigned to the six major research fields of the Helmholtz Association: Energy, Earth and Environment, Health, Key Technologies, Structure of Matter, Aeronautics, Space and Transport.

PARTICIPATING HELMHOLTZ CENTRES

- Alfred Wegener Institute for Polar and Marine Research (AWI)
- German Aerospace Center (DLR)
- Helmholtz Centre for Environmental Research - UFZ
- Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences
- Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research (HZG)
- Helmholtz-Zentrum Jülich (FZJ)
- Helmholtz Zentrum München – German Research Center for Environmental Health
- Karlsruhe Institute of Technology (KIT)
- Helmholtz Center for Ocean Research (GEOMAR) (from 2012)

EARTH AND ENVIRONMENT

The work done by the scientists is aimed at providing the most accurate description possible of the consequences of the far-reaching and complex changes to the Earth and the environment in order to enable government and society to plan ahead. The research field "Earth and Environment" brings together researchers from the natural sciences and social sciences who work in close collaboration for the benefit of science, society and government.

Their environmental research focuses on addressing the major challenges identified by national and international bodies: natural disasters, climate fluctuations and climate change, the availability of and access to clean water, sustainable use of resources, biodiversity and ecological stability as well as the socio-political dimension of global change. The research field "Earth and Environment" addresses these central challenges through four programmes: "The Geosystem Programme: The Changing Earth", "Marine, Coastal and Polar Systems Programme", "Atmosphere and Climate Programme" and "Terrestrial Environment Programme".

A further key element is the joint creation and operation of cross-programme infrastructures, such as the research aircraft HALO or the "Terrestrial Environmental Observatories" (TERENO, *see p. 23, 39*). A similar approach is being pursued with the observation system COSYNA, which involves the development of a long-term observation system to be used initially in the German North Sea and later in Arctic coastal waters to enable a synoptic description of conditions. In addition, eight Helmholtz centres are combining their resources in a project called REKLIM to study and explore the regional impact of global climate change (*see below*).

Global change research topics can also be found in the research fields "Aeronautics, Space and Transport" and "Energy". These topics address questions related to the development of innovative solutions for environmentally friendly and energy-efficient transport, renewable energies and efficient energy conversion, amongst other things.

REKLIM
Helmholtz Climate Initiative - Regional Climate Change

REKLIM is using its unique combination of competence in regional observations and process studies (in situ observations, airborne and satellite remote sensing) coupled with model simulations to improve regional and global climate models in order to provide a solid basis for climate-related decision support. Moreover, regional climate simulations are used to determine the effects of climate variability and change on the regional scale with improved modelling tools for attribution and impact studies. Conversely, process modules and parameterisations from these regional studies serve to improve global climate models. Thanks to their expertise, scientific infrastructure and facilities, the Helmholtz centres AWI, DLR, FZJ, GFZ, HMGU, HZG, KIT and UFZ have the necessary preconditions for jointly pursuing crucial research topics of this kind and achieving added value. The goal is to generate data for current and expected climate changes in various regions, to analyse these data to help improve global and regional climate models and to make the results available, through regional climate offices (*see p. 47*), to political decision-makers, local government, the business community and the general public.

WWW.REKLIM.DE/EN/HOME

LEIBNIZ ASSOCIATION (WGL)

WWW.LEIBNIZ-ASSOCIATION.EU

The Leibniz Association is a network of 87 scientifically, legally and economically independent research institutes and scientific infrastructure facilities. Leibniz Institutes carry out strategic and thematically oriented research and provide scientific services of national significance. They strive to find scientific solutions for major social challenges. Leibniz Institutes employ more than 16,000 people, 7,100 of whom are academics, including 2,100 junior scientists.

LEIBNIZ INSTITUTES AND GLOBAL CHANGE RESEARCH

The causes and consequences of global change as well as the internal processes and external drivers in earth system science are priority topics addressed by Leibniz scientists. The Leibniz Institutes cover areas ranging from the environmental and natural sciences, life sciences, economics, engineering and social sciences. For instance, the Potsdam Institute for Climate Impact Research (PIK) works in the field of coupled dynamics of the geosphere, biosphere, and atmosphere under natural and human forcing. A number of Leibniz Institutes conduct long-term measurements of atmospheric, oceanic and terrestrial provinces as well as operating ship-based mobile observation systems and modern remote sensing equipment (including radars and lidars) that provide experimental information about various physical processes and assess environmental data on the short and long-term variability of freshwater ecosystems gathered by monitoring stations.

Simulations play an important role in our understanding of the complexity of earth system science and its processes. Decision-makers, industry and public welfare all rely heavily on hypothetical situations (scenarios) and their extrapolation. For instance, PIK is heavily involved in the development of the next generation of earth system models and the Leibniz Centre for Tropical Marine Ecology (ZMT) in Bremen uses computer-based models designed to enhance knowledge about currents, circulation patterns and oscillations of the ocean province.

The reconstruction of past environmental changes at different time scales is essential for gathering evidence about past and future environmental changes. Geologists and biologists from the Senckenberg Research Station of Quaternary Palaeontology in Weimar are reconstructing Quaternary environmental history. The Leibniz Institute for Baltic Sea Research Warnemünde (IOW) focuses on changing marine ecosystems and transformation processes driven by external forces in the Baltic Sea region and other marine areas.

Large-scale environmental changes are reflected in a different way on a regional level. For example, ZALF scientists are studying the regional nitrogen and carbon fluxes as well as gas exchanges and their interactions and responses to global change in the rural landscape in the northeast of Germany.

Leibniz Institutes take an integrated approach to global change research. The "Leibniz Network on Biodiversity" (LVB) was established in 2008 to combine the competences of 28 Leibniz Institutes focusing on research into the connection between environmental change and biodiversity loss.

The search for resource-efficient technologies to reduce human impact is one of the major challenges for humankind. For example, the Leibniz Institute for Plasma Science and Technology (INP) in Greifswald is working on the development of resource-efficient technologies to reduce the impact of artificial light on animal and human health within the joint research project "Loss of the Night" (IGB). The Leibniz Institute for Applied Geophysics (LIAG) in Hannover is looking for alternatives to fossil resources in the field of geothermal energy.

Global change is of crucial importance for policymakers, society and industry. The socio-economic impact of global change is the subject of work being carried out at the Kiel Institute for the World Economy (IfW) and the Centre for European Economic Research Mannheim (ZEW), with particular emphasis on the complex interaction of energy demand, the supply of exhaustible fossil energy, and climate goals.

HABIT-CHANGE - *Adaptive management of climate-induced changes of habitat diversity in protected areas*

The project HABIT-CHANGE will identify and monitor past, recent and potential future change processes in protected areas which are driven by anthropogenic activities such as altered land use and climate change (CC). The project will develop adapted and flexible management strategies and guidelines designed to respond to these changes, thus helping to protect natural resources and heritage. The project's overall objective is to evaluate, enhance and adapt existing management and conservation strategies in protected sites in order to proactively respond to likely influences of climate change as a threat to habitat integrity and diversity. Alongside this, a monitoring concept is being developed to detect changes caused either by human activity or climate change effects. This is a very valuable tool especially for the administration of nature protected areas. Specific objectives are the identification of potential climate change induced threats, evaluation of existing conservation practices, derivation of a set of indicators reflecting local-scale effects, establishment of monitoring measures based on earth observation (EO) data, providing protected site authorities with decision support tools, fostering the awareness of the need for adaptive management. Recommendations for managing CC-induced changes on a regional, national and European level will be derived from this information.

Programme Duration: 2010-2013
Funding: INTERREG IV B CENTRAL EUROPE Programme
WWW.HABIT-CHANGE.EU

MEMBERS OF NKGCF

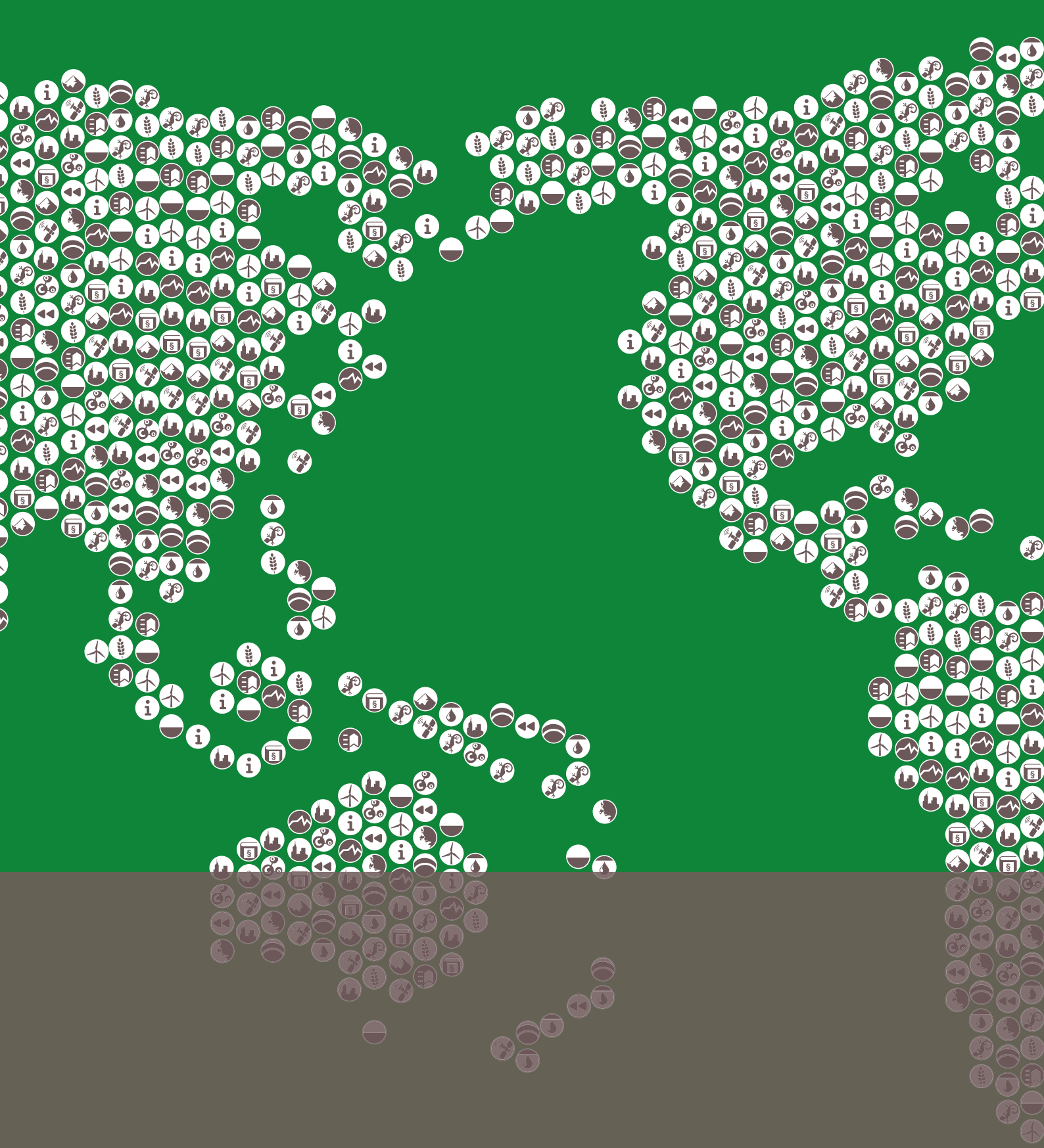
PROF. DR. JOSEPH ALCAMO (2006-2008)	University of Kassel	*Alcamo@usf.uni-kassel.de*
PROF. DR. MEINRAT O. ANDREAE (SINCE 2006)	Max Planck Institute for Chemistry	*andreae@mpch-mainz.mpg.de*
PROF. DR. WOLFGANG ANDRES (1997-2002)	Goethe University Frankfurt	*andres@em.uni-frankfurt.de*
PROF. DR. LENNART BENGTSON (1997-1999)	Max Planck Institute for Meteorology	*lennart.bengtsson@zmaw.de*
DR. NORBERT BINDER (1997- 2003)	Federal Ministry of Education and Research	
PROF. DR. ANTJE BOETIUS (SINCE 2009)	Max Planck Institute for Marine Microbiology	*aboetius@mpi-bremen.de*
PROF. DR. CHRISTOPH BÖHRINGER (SINCE 2009)	Carl von Ossietzky University of Oldenburg	*christoph.boehringer@uni-oldenburg.de*
PROF. DR. KATRIN BÖHNING-GAESE (SINCE 2011)	Biodiversity and Climate Research Centre (BiK-F)	*Katrin.Boehning-Gaese@senckenberg.de*
PROF. DR. MARTIN CLAUSSEN (2000-2005)	Max Planck Institute for Meteorology	*martin.claussen@zmaw.de*
PROF. DR. PAUL J. CRUTZEN (1997-99)	Max Planck Institute for Chemistry	*paul.crutzen@mpic.de*
PROF. DR. WILHELM DANGELMAIER (2006-2008)	University of Paderborn	*wilhelm.dangelmaier@hni.uni-paderborn.de*
PROF. (EM.) DR. ECKART EHLERS (1997-2002)	ZEF – Center for Development Research	*ehlers@giub.uni-bonn.de*
PROF. DR. HANS-GEORG FREDE (SINCE 2009)	Justus Liebig University Giessen	*hans-georg.frede@umwelt.uni-giessen.de*
PROF. DR. HARTMUT GRASSL (2000-2005)	Max Planck Institute for Meteorology	*hartmut.grassl@zmaw.de*
PROF. DR. ARMIN GRUNWALD (SINCE 2009)	Karlsruhe Institute for Technology	*grunwald@kit.edu*
PROF. DR. JOST HEINTZENBERG (1997-2002)	Leibniz Institute for Tropospheric Research	*jost.heintzenberg@tropos.de*
DR. GISELA HELBIG (SINCE 2006 EX-OFFICIO)	Federal Ministry of Education and Research	*gisela.helbig@bmbf.bund.de*
PROF. DR. DR. H.C. CARLO JÄGER (1997-2002)	Potsdam Institute for Climate Impact Research	*carlo.jaeger@pik-potsdam.de*
PROF. DR. NORBERT JÜRGENS (2000-2008)	University of Hamburg	*juergens@botanik.uni-hamburg.de*
PROF. DR. ELISABETH KALKO (SINCE 2003)	University of Ulm	*elisabeth.kalko@uni-ulm.de*
DR. JOHANNES KARTE (SINCE 1997 EX-OFFICIO)	German Research Foundation	*johannes.karte@dfg.de*
PROF. DR. STEPHAN KEMPE (1997-2002)	University of Darmstadt	*kempe@geo.tu-darmstadt.de*
PROF. GERNOT KLEPPER PH.D. (SINCE 2003)	Kiel Institute for the World Economy	*gernot.klepper@ifw-kiel.de*
PROF. DR. FRAUKE KRAAS (SINCE 2006)	University of Cologne	*f.kraas@uni-koeln.de*
DR. THOMAS KRAFFT (1997-2006 EX-OFFICIO)	NKGCF Scientific Secretariat	
DR. HARRY LEHMANN (SINCE 2009 EX-OFFICIO)	Federal Ministry for the Environment	*harry.lehmann@uba.de*
PROF. DR. PETER LEMKE (2003-2008)	Alfred Wegener Institute	*peter.lemke@awi.de*
PROF. DR. EDUARD LINSENMAIR (1997-2002)	Julius-Maximilians University Würzburg	*kelins@biozentrum.uni-wuerzburg.de*
PROF. DR. KARIN LOCHTE (2000-2005)	Alfred Wegener Institute	*karin.lochte@awi.de*
PROF. DR. WOLFGANG LUCHT (SINCE 2009)	Potsdam Institute for Climate Impact Research	*wolfgang.lucht@pik-potsdam.de*
PROF. DR. JOCHEM MAROTZKE (2006-2008)	Max Planck Institute for Meteorology	*jochem.marotzke@zmaw.de*
PROF. DR. WOLFRAM MAUSER (1997-2008)	Ludwig Maximilians University Munich	*w.mauser@iggf.geo.uni.muenchen.de*
PROF. DR. ULRICH PLATT (SINCE 2009)	Heidelberg University	*ulrich.platt@iup.uni-heidelberg.de*
PROF. DR. RAINER SAUERBORN (2000-2005)	Heidelberg University	*rainer.sauerborn@urz.uni-heidelberg.de*
PROF. DR. HANS JOACHIM SCHELLNHUBER (1997-1999)	Potsdam Institute for Climate Impact Research	*director@pik-potsdam.de*
PROF. DR. BERNHARD SCHINK (2000-2002)	University of Konstanz	*Bernhard.Schink@uni-konstanz.de*
DR. BETTINA SCHMALZBAUER (SINCE 2007 EX-OFFICIO)	NKGCF Scientific Secretariat	*bettina.schmalzbauer@ifw-kiel.de*
PROF. DR. FRIEDRICH SCHOTT (1996- 2002)	Leibniz Institute for Marine Sciences	
PROF. DR. MICHAEL SCHULZ (SINCE 2009)	MARUM - Center for Marine Environmental Sciences	*mschulz@uni-bremen.de*
PROF. DR. HANS SPADA (1997-1999)	University of Freiburg	*spada@psychologie.uni-freiburg.de*
PROF. DR. PETER-TOBIAS STOLL (SINCE 2006)	Georg August University of Göttingen	*pstoll@gwdg.de*
PROF. DR. GEORG TEUTSCH (SINCE 2006)	Helmholtz Centre for Environmental Research - UFZ	*gf@ufz.de*
PROF. DR. PAUL L. G. VLEK (2003-2008)	ZEF – Center for Development Research	*p.vlek@uni-bonn.de*
DR. INGE PAULINI (2003-2008 EX-OFFICIO)	Federal Ministry for the Environment	
PROF. DR. MARTIN VISBECK (SINCE 2009)	Leibniz Institute for Marine Sciences IFM-GEOMAR	*mvisbeck@ifm-geomar.de*
PROF. DR. ALFRED VOSS (2000-2005)	University of Stuttgart	*alfred.voss@ier.uni-stuttgart.de*
PROF. DR. DR. H.C. GEROLD WEFER (2003-2008)	MARUM - Center for Marine Environmental Sciences	*gwefer@rcom-bremen.de*
PROF. DR. JOACHIM WEIMANN (1997-2001)	University of Magdeburg	*joachim.weimann@ww.uni-magdeburg.de*
PROF. DR. WOLFGANG W. WEISSER (2003-2010)	Friedrich Schiller University of Jena	*wolfgang.weisser@uni-jena.de*
PROF. DR. GERD WINTER (2000-2005)	University of Bremen	*gwinter@uni-bremen.de*

ABBREVIATIONS AND ACRONYMS

ACCENT PLUS	Atmospheric Composition Change - The European Network
AIM	Asia-Pacific Integrated Model
AIMES	Analysis, Interpretation and Modelling of the Earth System (core project)*
ALARM	Assessing large-scale environmental risks for biodiversity with tested methods
AWI	Alfred Wegener Institute for Polar and Marine Research
BADC	British Atmospheric Data Centre
BALTIMOS	Software tool for modelling hydrological cycle
BIK-F	Biodiversity and Climate Research Centre
BIOTA	Biodiversity Monitoring Transect Analysis in Africa
BMU	Federal Ministry for the Environment, Nature Conversation and Nuclear Safety
BSIOM	Ocean-sea-ice modelling system
CARBONSAT	Carbon monitoring satellite
CAS	Climate Adaptation Santiago
CBD	Convention on Biological Diversity
CC	Climate Change
CCAFS	Research Program on Climate Change, Agriculture and Food Security
CCS	Carbon capture and storage
CD	Certificate of deposit
CEGIT	GFZ Centre for Geoinformation Technology
CGIAR	Consultative Group on International Agricultural Research
CH_4	Methane
CLIC	Climate and Cyrosphere (core project)*
CLIMB	Climate-Induced Changes on the Hydrology of Mediterranean Basins
CLISAP	Integrated Climate System Analysis and Prediction (core project)*
CLIVAR	Climate Variability and Predictability (core project)*
CMIP	Coupled Model Intercomparison Project
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon dioxide
COCOS	Coordination Action Carbon Observing System
COP 9	Ninth meeting of the Conference of the Parties
CORDEX	A Coordinated Regional Climate Downscaling Experiment
COSYNA	Coastal Observation System for Northern and Arctic Seas
CRYOSAT	Satellite for cryosphere measuring
CSC	Climate Service Center
DAAD	German Academic Exchange Service
DCPC	Data Collection or Production Centre
DIVERSITAS	International association for biodiversity research
DLR	German Aerospace Center
DOI	Digital Object Identifier
DWD	Deutscher Wetterdienst
ECHAM5	5th generation of the ECHAM general circulation model
ENMAP	German hyperspectral satellite mission
ENVISAT	Environmental satellite
EO	Earth Observation
EPOCA	European Project on Ocean Acidification
ERGOM	Ecosystem Modelling System
ESA	European Space Agency
ESG	Earth System Governance Project (core project)*
ESM	Earth System Modelling
ESSD	Earth System Science Data Journal
EXC	Excellencecluster
FP7	Seventh Framework Programme
FSC	Forest Stewardship Council
FONA	Research for Sustainability
FZJ	Helmholtz Centre Jülich
GAW	Global Atmospheric Watch
GB	Gigabyte
GBIF	Global Biodiversity Information Facility
GCAM	Integrated Model to Assess the Global Environment
GCOS	Global Climate Observing System
GCP	Global Carbon Project (joint project)*
GDP	Gross Domestic Product
GECAFS	Global Environmental Change and Food Systems (joint project)*
GECHH	Global Environmental Change and Human Health (joint project)*
GEO	Group on Earth Observation
GEO BON	The Group on Earth Observations - Biodiversity Observation Network
GEOFON	Seismological measuring system
GEOMAR	Helmholtz Center for Ocean Research
GEOSS	The Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment (core project)*
GFZ	German Research Centre for Geoscience
GHG	Greenhouse Gas
GLOBEC	Global Ocean Ecosystem Dynamics
GLOWA	Global Change and Hydrological Cycle
GLP	Global Land Project (core project)*
GLUES	Global Assessment of Land Use Dynamics, Greenhouse Gas Emissions and Ecosystem Services
GOME	Spectrometer for global monitoring of atmospheric Ozone
GRACE	Graduate School for Climate and Environment
GRI	Global Reporting Initiative
GRK	Post graduate programme
GSC	Graduate school
GTS	WMO Global Telecommunication System
GWSP	Global Water System Project (joint project)*
HALO	Research aircraft "High-Altitude Long Range"
HGF	Helmholtz Association
HIMPAC	Himalaya Modern and Past Climates
HZG	Helmholtz Centre for Materials and Coastal Research
ICOS	Integrated Carbon Observing System
ICOS-D	Integrated Carbon Observation System - Germany
ICSU	International Council for Science
IFW	Kiel Institut for the World Economy
IGAC	International Global Atmospheric Chemistry
IGB	Leibniz Centre for Water Ecology and Freshwater Fishery
IGBP	International Geo-Biosphere Programme
IGCO	Integrated Global Carbon Observation
IGFA	International Group of Funding Agencies
IGU	International Geographical Union
IGY	International Geophysical Year
IHDP	International Human Dimension Programme
IT	Industrial Transformation (core project)*
IHOPE	Integrated History of People of Earth (core project)*
ILEAPS	Land-atmosphere core project (core project)*
ILTER	International Long Term Ecological Research

IMAGE	Integrated Model to Assess the Global Environment
IMBER	Core project focusing on ocean biogeochemical cycles and ecosystems
IMK-IFU	Institute for Meteorology and Climate Research - Atmospheric Environmental Research
IMPRS	International Max Planck Research School
INP	Leibniz Institute for Plasma Science and Technology
INTERDYNAMICS	Integrated Analysis of Interglacial Climate Dynamics
IODP	Integrated Ocean Drilling Programme
IOW	Leibniz Institute for Baltic Sea Research Warnemünde
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IRG	Integrated Risk Governance (core project)*
ISBN	International Standard Book Number
ISDC	Satellite Data Centre
ISSC	International Social Science Council
IUP	Institute for Environmental Physics
IWAS	International Water Research Alliance Saxony
IWRM	Integrated Water Research Management
KIT	Helmholtz Centre for Technology
KM	Kilometre
LARSIM	Hydrology modelling system
LIAG	Leibniz Institute for Applied Geophysics
LLNL	Lawrence Livermore National Laboratory
LOICZ	Land-Ocean Interaction in the Coastal Zone (core project) *
LTER	Network for long-term Ecological Research
LTER-D	Network for Long-term Ecological Research - Germany
LVB	Leibniz Network on Biodiversity
MAGIM	Matter Fluxes in Grasslands of Inner Mongolia as Influenced by Stocking Rate
MAIRS	Monsoon Asia Integrated Regional Study
MARUM	Center for Marine Environmental Science
MEBO	A sea floor drill rig
MERIS	Medium Resolution Imaging Spectrometer
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MPCH	Max Planck Institute for Chemnistry
MPG	Max Planck Society
MPIOM	The Max Planck Institute Ocean Model
NASA	National Aeronautics and Space Administration
NDMC	Network for the Detection of Mesopause Change
NDSC	Network for the Detection of Stratospheric Change
NEFO	Network-Forum for Biodiversity Research Germany
NKGCF	German National Committee on Global Change Research
OECD	Organisation for Economic Co-operation and Development
OMZ	Oxygen Minimum Zone
PAGES	Past Global Changes (core project)*
PANGAEA	Data Publisher for Earth and Environmental Science
PCMDI	Programme for Climate Model Diagnosis and Intercomparison
POST-SRES	Stabilization scenario
RAPIDEYE	Provider of high resolution satellite imagery
RCD	Research Centers Directory
RCP	Representative Concentration Pathway
RECCAP	Regional Carbon Cycle Assessment and Processes
REMO	Regional atmosphere modelling system
RES	Renewable Energy Sources
RESM	Regional Earth System Models
RSSC	Regional Science Service Center
SADC	Southern African Development Community
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Use
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SDDB	Scientific Drilling Database
SFB	Collaborative Research Center
SICSS	School of Integrated Climate System Science
SOLAS	Surface Ocean-Lower Atmosphere Study (core project)*
SOPRAN	Surface Ocean Processes in the Anthropocene (core project)*
SPARC	Stratospheric Processes and their Role in Climate (core project)*
SPICE	Science for the Protection of Indonesian Coastal Ecosystems
SPP	Priority programme DFG
STD-DOI	Publication and Citation of Scientific Primary Data project
TB	Terrabyte
TEEB	The Economics of Ecosystems and Biodiversity
TERENO	Terrestrial Environmental Observatories
TERRASAR	German earth observation satellite
TIP	Tibetan Plateau
TOMS	Total Ozone Mapping Spectrometer
TR	Transregional collaborative research centre
UBA	Federal Environmental Agency
UFZ	Helmholtz Centre for Environmental Research - UFZ
UGEC	Urbanization and Global Environmental Change (core project)*
UNCBD	United Nations Convention on Biological Diversity
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNU	United Nations University
USA	United States of America
VOS	Voluntary Observing Ships
WASCAL	West African Science Service Center for Climate and Adapted Land Use
WCRP	World Climate Research Programme
WDC	World Data Centre System
WDC-MARE	World Data Centre for Marine Environmental Science
WDC-RSAT	World Data Centre for Remote Sensing
WDS	World Data System
WGCM	Working Group on Coupled Modelling
WGL	Leibniz Association
WIMO	Scientific Monitoring Concepts for the German Bight
WSM	World Stress Map
WTO	World Trade Organisation
ZALF	Leibniz-Centre for Agricultural Landscape Research
ZEF	Centre for Development Research
ZEW	Centre for European Economic Research Mannheim
ZMT	Leibniz Centre for Tropical Marine Ecology
ZOTTO	Zotino Tall Tower Observatory in central Siberia

*The enclosed poster gives an overview about organisation and cooperation of core projects / joints projects.



NKGCF

GERMAN NATIONAL COMMITTEE ON GLOBAL CHANGE RESEARCH