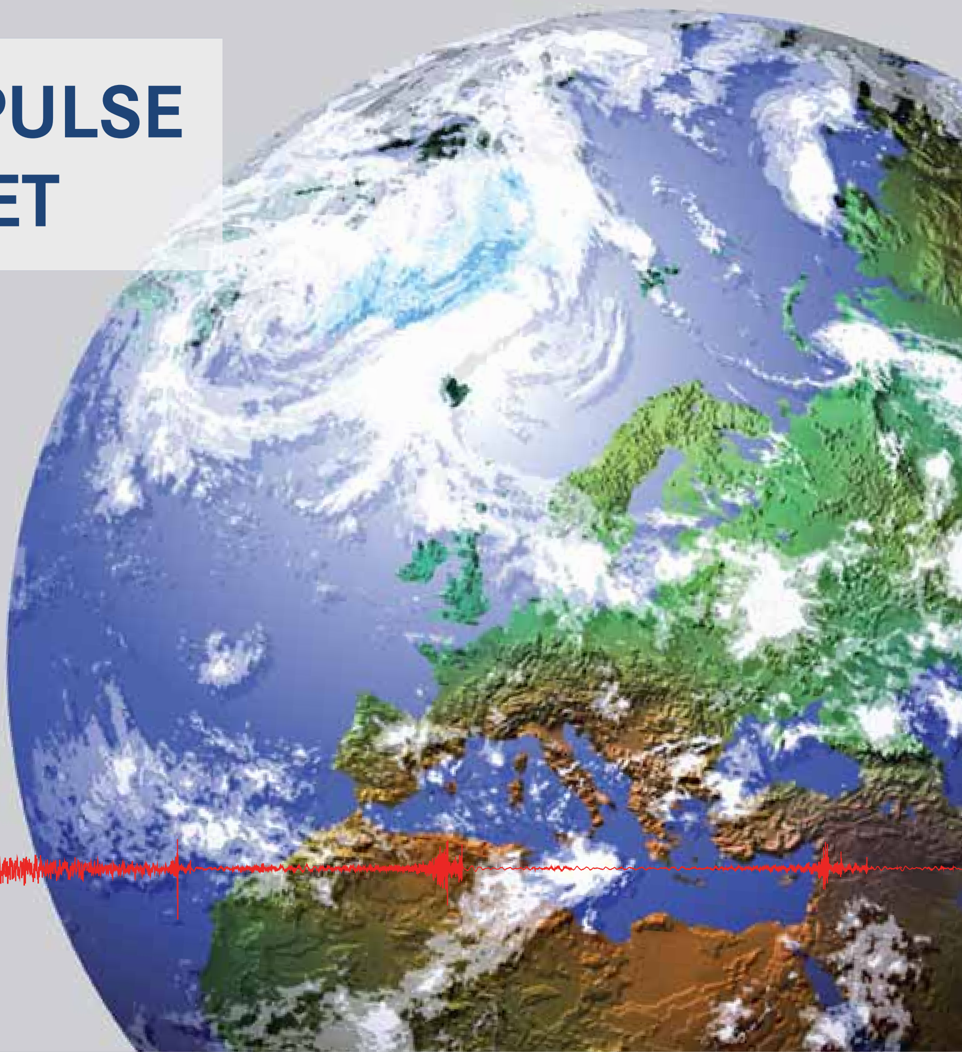
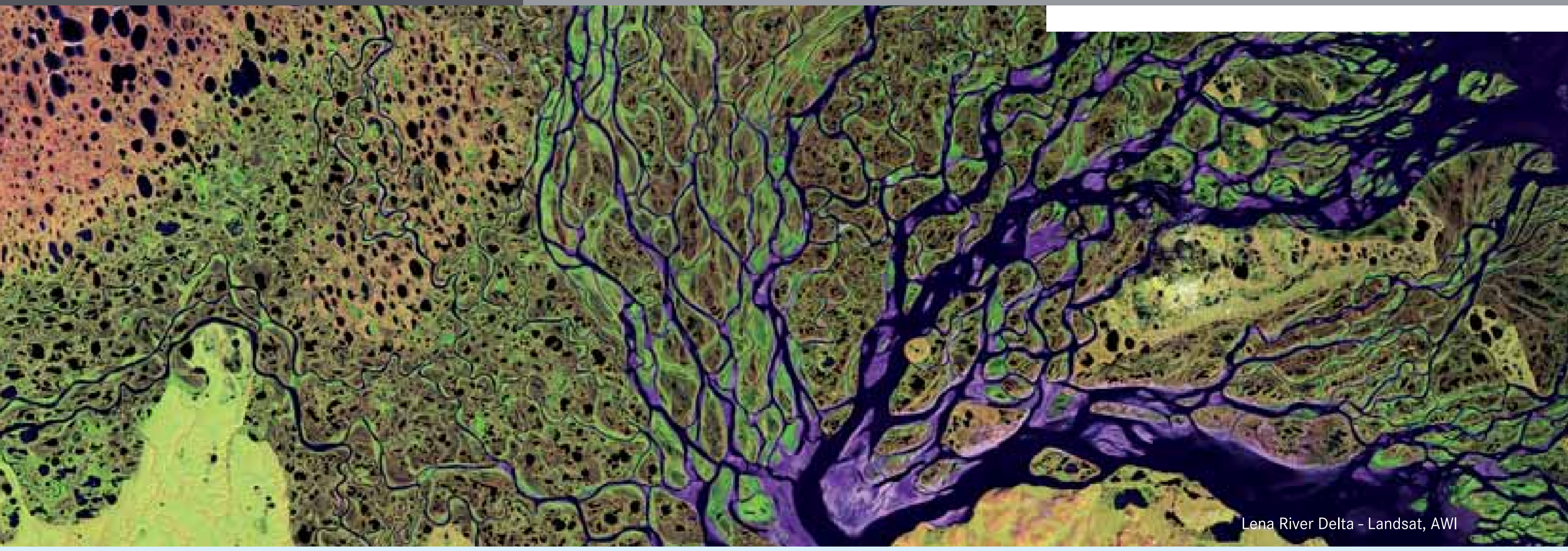
TAKING THE PULSE OF THE PLANET



The Helmholtz Association Earth Observatory Network

HELMHOLTZ ASSOCIATION



Lena River Delta - Landsat, AWI

Introduction

Long-term observations are the key to assessing global change. The Helmholtz Association combines advanced methods for monitoring the Earth system: remote sensing and observatories. Our observatories are located on land, in the air and at sea. The Helmholtz Association takes collaborative efforts to link observatories in order to enhance their benefits. Field experiments complement the network of observations in space and time.

The Earth is a constantly changing planet. Some processes that characterise the face of the planet take place at a scale of micrometres or even nanometres. Others only become perceptible at the global scale. By linking measurement programmes and observatories, the Helmholtz Association keeps an eye on all scales – from the microscopic range to the entire planet.

Satellites, ships, buoys, moored systems, radar stations, aircraft, balloons, and other types of platforms of the Helmholtz Association record critical parameters of the Earth system for all scientific disciplines the Association engages in. However, remote sensing data needs to be compared with data measured on site.

Observatories on the ground, in the air and on water are important for this purpose. If their sensors are networked, observatories can also record large-scale interrelationships. At the same time they permit a look at the fine details since their sensors are also able to observe small-scale processes down to the microscopic level. In addition, observatories support the validation of remote sensing technologies. They can be set up to gain insights into areas of our planet that are inaccessible from space, such as subsurface soils, ice sheets and aquifers, and the Earth's and oceans' interior.

For researchers of the Helmholtz Association and their national and international partners, our observatories are a key tool for understanding the Earth system, monitoring natural hazards, and assessing global change. Data from the observatories are incorporated into information infrastructures, including models to simulate the future development of the Earth system on global and regional scales. Hence, the Helmholtz Association aims at integrative, interdisciplinary approaches in Earth observation.

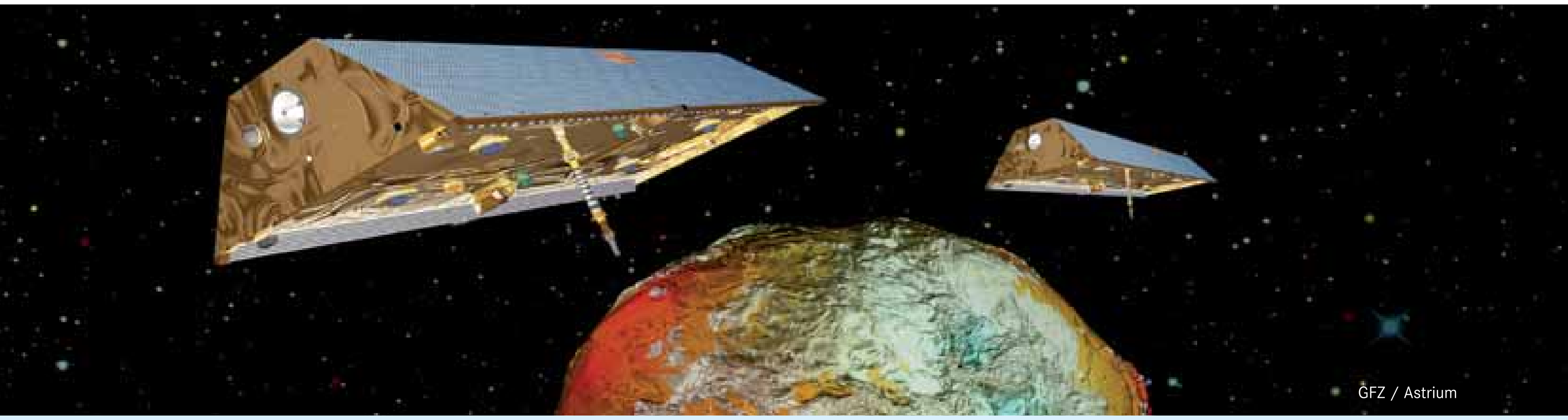
Up to now many observatories have concentrated on a certain part of the Earth system. For instance, they record individual physical variables, such as seismic waves or they monitor a certain ecosystem. However, in recent years, scientists have found that seemingly independent parts of the Earth system are linked to each other via complicated interactions.

Desert dust swept away by the wind, for example, may trigger algal bloom in seas thousands of kilometres away. Another example of far-reaching interaction concerns oceanic currents: They are not only influenced by processes in the atmosphere, especially wind, but also by events on land, such as the water volume that rivers or glaciers discharge into the ocean.

To identify interrelationships that to date have remained hidden, it is necessary to use a more holistic approach that also considers the interfaces and interactions between the various parts of the Earth system, including its living resources. A major future challenge will be to link the existing Helmholtz observatories and achieve common standards to make data available to the research community within integrated data platforms. Especially long-term time series monitoring of the interfaces of the Earth system at present should be strengthened. Long-term records play a key role in assessing natural dynamics and global change processes over many years. Helmholtz researchers will provide a conceptual framework to develop long-term programmes that can be adapted to altered circumstances and new questions that arise. This means, for example, uniform standards have to be specified for data storage and IT infrastructure.

The objective of the Helmholtz Association is to expand its platforms into intelligent multidisciplinary observatories linked to information infrastructures that support the interpretation and extrapolation of measurements. Networking measurement platforms offer an opportunity to consistently bundle knowledge from different areas of the planet.

Within the research field "Earth and Environment", satellite missions and observatories in key compartments of the Earth system already operate successfully. In addition, new initiatives are being planned or currently being established. These platforms are presented in more detail in the following sections and are organised along satellite platforms and observational platforms in the various compartments of the Earth system.



GFZ / Astrium

Satellite Missions

Potential fields of Planet Earth, such as the gravity field and the magnetic field, are a direct fingerprint of the dynamic processes acting in the Earth's interior, on the Earth's surface, and in near space. For many years GFZ has designed and operated dedicated satellite missions focused mainly on observing the Earth's main potential fields at high spatial and temporal resolution. These developments continue a more than 100-year long tradition of gravity and magnetic field observations initiated and performed by the geoscientific institutions in Potsdam.

GRACE – Gravity Recovery and Climate Experiment

The GRACE (Gravity Recovery and Climate Experiment) twin satellite mission was launched in March 2002 and is operated by the National Aeronautics and Space Administration (NASA) and the Deutsches Zentrum für Luft- und Raumfahrt (DLR), the Center for Space Research (UTCSR) at the University of Texas at Austin, the German Research Centre for Geosciences (GFZ), and the Jet Propulsion Laboratories (JPL) in Pasadena.

GRACE time-varying gravity measurements are used to study very diverse phenomena. These embrace changes in groundwater storage, variations in soil moisture, and the amount of water stored in large lakes, ice loss from the polar ice sheets and mountain glaciers, or changes in the distribution of solid earth mass associated with large earthquakes and the postglacial rebound of continents after the last ice age. The monthly determination of polar ice sheet mass loss has also allowed the determination of one of the principal contributions to the oceans' mass increase and therefore enabled the separation of the temperature and mass components of global sea level change. Finally, the GRACE GPS occultation co-experiment has provided a unique contribution to the suite of satellite measurements of atmospheric water vapour and temperature. This data provides important contributions to current weather model predictions.

The end of the GRACE mission is expected for 2014/15. It will be succeeded by the recently agreed GRACE-FO (GRACE-Follow On) mission again to be conducted in a close U.S.-German partnership and scheduled to be launched in August 2017.

Swarm

The primary aim of the ESA Swarm mission is to provide the best survey ever of the Earth's magnetic field and the first global representation of its variations on time scales from an hour to several years. Primary challenges include the study of the Earth's core dynamics, the mapping of magnetisation of solid Earth's outer shell and its geological interpretation, the determination of the 3-D electrical conductivity of the Earth's mantle, and investigations of electric currents in the magnetosphere and ionosphere.

In addition to the above sources, ocean currents produce a contribution to the measured magnetic field. Finally, the magnetic field also exerts a direct control on the dynamics of the ionised and neutral particles in the upper atmosphere and possibly even has influence on the lower atmosphere. This leads to the identification of secondary research objectives, such as monitoring the ocean circulation by its magnetic signature or quantifying the magnetic forcing of the upper atmosphere, both for the purpose of observing climate change.

Swarm, a constellation mission, will simultaneously obtain a space-time characterisation of both the internal field sources in the Earth and the ionospheric-magnetospheric current systems. Analyses of the Swarm data will greatly improve existing and provide new models of the near-Earth magnetic field at high resolution and authenticity compared with a single-satellite mission. The Swarm mission will be launched in March 2013.

EnMAP – Environmental Mapping and Analysis Program

EnMAP (Environmental Mapping and Analysis Program) is an imaging hyperspectral spectrometer under construction, designed to globally record biophysical, biochemical and geochemical variables of the Earth's surface. Global analysis of recorded data is dedicated to increasing our understanding of biospheric/geospheric processes and ensuring the sustainability of resources. EnMAP will greatly enhance our abilities in the fields of exploration and energy resources, in monitoring erosion and land degradation, in observing pollution and ecosystem stability, and to develop appropriate quantitative process models with predictive capacities for assessing our human environment.

The EnMAP Project is a joint venture with GFZ having the scientific lead. DLR acts as the project manager, and several industrial companies – i.e. Kayser-Threde GmbH and OHB-Systems AG - are involved in the sensor design and manufacturing. As a new and innovative satellite system, EnMAP is already well-recognised by more than 600 registered partner institutions worldwide that show major interest in the future diagnostic data to be provided. The mission is planned to be launched in 2017.

Ocean Observatories

The oceans contribute more than 70% to our planet's surface. They are vital for our climate, the storage of carbon dioxide and heat, a major driver of Earth's hydrological cycle, and the source of food and resources. Their sensitivity to global climate change, in particular in the Arctic, as well as the fact that more than 60% of global population inhabit the continental boundaries next to the world's oceans makes them a key area of concern. Hence, monitoring change and the ocean's way of functioning at sites of particular sensitivity is a central task.

Labrador Sea MOC Observatory

The meridional overturning circulation (MOC) originates in the subpolar North Atlantic. It is here that the cold and dense deep water masses enter the open Atlantic through the gateways of the Greenland-Scotland Ridge. On their way southward into the open North Atlantic they sink deeper and entrain ambient water with the final products called 'Lower North Atlantic Deep Water'. Additional deep water sources provided through direct ventilation from the surface to the deep ocean are located in the Labrador and Irminger Seas. All three components of the deep MOC vein merge in the Labrador Sea and exit from there into the subtropical gyre and in turn into the global conveyor belt.

From this short list of processes (overflow, entrainment and convection) of which each one is of major importance for global circulation and heat transport, it becomes immediately clear that this is one of the key locations of global circulation. What also becomes clear is that successful monitoring, or more precisely, process observations at long-time scales (seasonal to multi-decades) require a coordinated international effort, in which the individual national contributions are already a challenge in terms of equipment, manpower and due to the harsh environment. It is vital to enhance the quality of long-term measurements by simultaneous measurements at a high data rate.

The latter is one of the reasons why robotic methods are preferable when winter storms prohibit shipboard observations – here moored stations with autonomous instruments and freely profiling vehicles as Argo drifters or Gliders are the preferable observational method to overcome seasonal biases in the core measurements. Located at the exit of the Labrador Sea at 53°N, the Deep Water Export Array is used for long-term measurements of the fluxes of volume, freshwater, and heat. This array plays a role in international cooperation as part of the global OceanSITES Program.

The array in the subpolar gyre is maintained with partners from European, Canadian and U.S. institutions and is a vital ingredient of cross-basin MOC monitoring. The objectives of the Helmholtz Association (GEOMAR) observatory are as follows:

- To provide information regarding process variability (convection and water mass formation) on time scales ranging from weeks to decades in the Labrador and Irminger Seas;
- To determine the export of NADW from the Labrador Sea to the open Atlantic by a variety of moored autonomous stations off the Labrador Shelf, i.e., the 53°N-Array;
- To contribute to the international northern Overturning Array – an attempt to directly measure the MOC in the subpolar regime from the Labrador coast at 53°N to Greenland and across the NA to Scotland;
- To validate products from the modelling / assimilation efforts on both national (in and outside of Helmholtz) and international bases;
- To evaluate/calibrate remote sensing products and to support the international Argo programme through reference data.

Early morning deployment of a Moored CTD/Velocity Profiler (MVP) in the Labrador Sea MOC Array. This instrument is motor-driven for climbing the mooring wire up and down. The internal battery has sufficient energy for traveling 1 Million Meters (i.e., 1000 profiles of 1000m length).

Deployment of the central deep sea mooring in the Labrador Sea MOC Array with the global ocean Research Vessel "Meteor". Bouyant glass spheres capable to withstand the immense pressure of the deep ocean are used to keep the mooring wire upright and the instruments in their target depth. This operation is repeated bi-annual.

CVOO – Cape Verde Ocean Observatory

The subtropical Northeast Atlantic Ocean hosts a suite of processes which are of key relevance to the interaction of climate and marine biogeochemistry, e.g.:

(1) The region is home to one of the major and most productive coastal upwelling systems which represents a biodiversity hotspot that is under growing human pressures (climate change, fishery).

(2) The region features one of the ocean's natural oxygen minimum zones, which has been shown to expand and intensify in recent decades. This has major long-term implications for marine life.

(3) The region is characterised by strong emissions of radiatively (CO_2, N_2O, CH_4) and chemically active (oxygenated and halogenated) trace gases which have significant implications for atmospheric properties.

(4) The region is the world oceans' most prominent deposition region for mineral dust of terrestrial origin, which has major implications for marine productivity, making it highly sensitive to climate change.

From this short and by no means exhaustive list of highly relevant biogeochemical ocean processes that have the potential to both sensitively respond and feed back to climate change, a strong mandate for high-quality long-term ocean observation arises. This mandate has been met by establishing the Cape Verde Ocean Observatory (CVOO; http://cvoo.geomar.de), which has been operated since 2006 by GEOMAR in cooperation with the Cape Verdean partner INDP (Instituto Nacional de Desenvolvimento das Pescas).

The CVOO observational programme rests on three pillars:

(1) a multifunctional long-term mooring which has been operated continuously since 2006 measuring a suite of physical and biogeochemical properties;

(2) a ship-based monthly sampling programme for the collection of discrete samples for an extended suite of biogeochemical properties (This component is carried out by the R/V Islandia which belongs to the partner institute INDP);

(3) intense field campaigns (e.g., ship-, float-, glider-based) for the focused investigation of specific processes and properties to improve system understanding. This combination of observational approaches has synergistic effects and provides deeper insight into the scientific problems at hand. In order to improve the infrastructural basis of the multi-facetted research programme carried out at the CVOO, GEOMAR plans to establish the Mindelo Ocean Science Centre.

The major objectives of the work carried out by the Helmholtz Association (GEOMAR) at the Cape Verde observatory are the following:

- To establish a long-term time series of key hydrographic properties (physical, chemical, biological) at the CVOO as a benchmark to identify and evaluate future ocean change;
- To observe und mechanistically understand the phenomenon of ocean de-oxygenation;
- To determine the net ocean-atmosphere flux of CO_2 and O_2 at the CVOO (this product is part of the official German contribution to ICOS, the European Integrated Carbon Observation System);
- To validate products from modelling and/or assimilation efforts on both a national and international basis;
- To validate and/or calibrate remote sensing products and support the international Argo project with crucial reference data.

A Sediment trap to investigate chemical and biological processes at the Cape Verde Ocean Observatory.
This Trap is incorporated in the moored CVOO-station which is serviced (recovered and deployed) in an annual to bi-annual rhythm. This station measures a suite of physical and biogeochemical parameters.

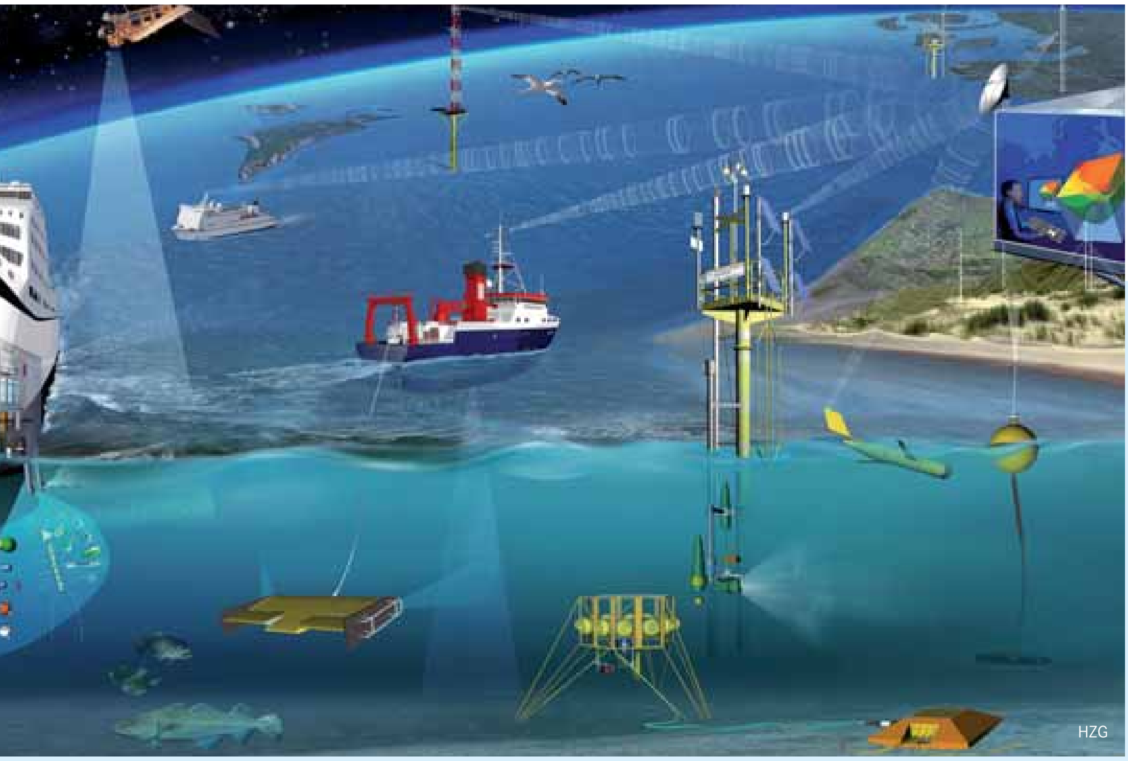
HAFOS and Hausgarten Observatory

The response of the Arctic to global climate change is influenced by heat and salt exchange between the North Atlantic and the Arctic Ocean and their impact on the Arctic Ocean circulation, heat and freshwater budgets. This mass exchange conditions deep water formation in one of the key regions of the global overturning system and thereby impacts the ocean as heat and carbon capacitor. This will affect the future of Arctic productivity as well as its biodiversity, food web structure, and the biogeochemical budgets from the surface to the deep basins. AWI and its international partners host two polar ocean observatories to cover these aspects of deep-sea oceanographic and biological processes in the West Spitsbergen Current and the East Greenland Current, the North Atlantic Current and the Transpolar Drift.

Since 1997 AWI and the Norwegian Polar Institute are observing transport processes in Fram Strait with an array of 16 moorings containing 40-60 instruments. These capture the exchange of Atlantic and Arctic waters and track variations of the physical conditions across this important deep-water connection to the Arctic. The array provides year-round, quasi-continuous time series of physical variables, such as temperature and salinity, in order to identify the strong seasonal to inter-annual variations which are superimposed on long-term trends. These variations need to be understood to assess the consequences of climate change, e.g., in water freshening and heat transport. The Helmholtz program HAFOS (Hybrid Arctic/Antarctic Float Observing System) supports this important task as a contribution to GOOS (Global Ocean Observing System) and to SAON (Sustaining Arctic Observing Networks). In addition to information obtained at fixed-point moorings, the deployment of HAFOS drifters provides observational data from a much larger oceanic volume.

Since 1999, the oceanographic array was complemented by a deep-sea long-term ecological observatory, the LTER site HAUSGARTEN. This site comprises 17 deep-water stations between 1,000 m and 5,500 m water depth in an area of 60x60 nautical miles west of Svalbard. The LTER site is operated on the basis of annually repeated sampling and the deployment of moorings and different autonomous benthic systems, which act as continuous stationary pre-programmed observation platforms. Long-term experimental platforms and field sampling campaigns are supported by deep-water work-class remotely operated vehicles (ROV). Continuous remote sensing estimates of primary productivity by satellite and a 3,000 m depth-rated autonomous underwater vehicle (AUV) are further examples of the present sensing and sampling capacities at HAUSGARTEN. These installations form a unique deep-water observatory allowing the synchronous multidisciplinary observation of oceanographic and ecosystem variables in an area under high pressure from climate change and increasing anthropogenic use. Data obtained from HAFOS and HAUSGARTEN are available to the scientific community via the Argos system and the Publishing Network for Geoscientific & Environmental Data, PANGAEA.

Under-ice multidisciplinary research at the Helmholtz Association's marine observatories in Fram Strait, HAFOS and LTER HAUSGARTEN.



Sketch of observational platforms used for COSYNA, including satellites, hydrographic radar, fixed platforms, ferryboxes, underwater nodes and frames, wave buoys, gliders and research vessels.

COSYNA – Coastal Observation System for Northern and Arctic Seas

The North Sea hosts unique ecosystems, is influenced by significant matter fluxes with profound impacts on regional water quality, and is affected by global climate change and sea level rise. In particular, the extensive use by fisheries, shipping, or windparks requires an understanding of the natural state and multidisciplinary processes to assess the impact of human influence. A key question is how the numerous interactions between physical, biogeochemical and ecological parameters of coastal seas can be best described and how they will evolve in future.

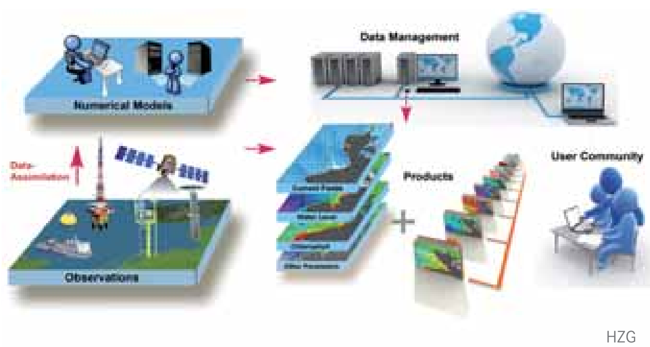
The mission of the Coastal Observing System for Northern and Arctic Seas (COSYNA) is to develop and test analytical systems for the operational synoptic description of the environmental status of the North Sea and Arctic coastal waters. COSYNA aims to provide knowledge tools that can help authorities and other stakeholders in industry, public, or science to manage routine tasks, respond to emergency situations, or evaluate trends.

COSYNA is an operational, integrated observing system in the North Sea that comprises an extensive network of remote and in-situ observations maintained over a long period of time. Numerical models are required to estimate ocean state variables at times and locations for which observations are not available. Of particular importance for COSYNA is the ability to provide forecasts for the various parameters indicating the status of the North Sea. Linking observation and forecast systems in a systematic way is the foundation of the COSYNA products. The data are transmitted in near-real time to shore and are assimilated in a high-resolution coastal model to provide routine short-term forecasts of temperature, salinity, currents, and wave conditions in the North Sea every 6 hours.

Additional observations provide various key physical, biogeochemical, sedimentary, and biological parameters observed at high temporal resolution in the water column and at the water-sediment and water-atmosphere interface. Observation platforms include satellites, hydrographic radar, fixed platforms, ferry boxes, underwater nodes and frames, wave buoys, gliders and research vessels.

COSYNA has an open data policy, providing free near real-time data and model forecasts to the public via internet. Data streams between the observation sites and central storage systems situated at the partner institutions are organized by a data management group that also ensures quality control and data documentation. The COSYNA data portal (cosyna.de) provides a comprehensive graphical presentation and download interface for all measured and modeled COSYNA data and metadata.

COSYNA is financed and coordinated by the Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research GmbH. The scientific work is carried out in partnership with the Alfred Wegener Institute (AWI), Bundesamt für Seeschifffahrt and Hydrographie (BSH), and various universities and monitoring authorities (ICBM, HPA, ZMAW, MARUM, NLWKN, BAW, LKN, FTZ).



Sketch showing how combined observations and models are integrated in data and ocean forecasting products that serve end users in society, politics, industry, or emergency services.

Auroras above Antarctic base Neumayer III, AWI

Polar Observatories

Polar regions are deficient in infrastructure, a fact that allows long-term observations of the variability of geophysical as well as general Earth system parameters. Hence, the existing observatories play an important role not only by filling global observational gaps but also by providing data series for regionally relevant process studies as well as for long-term trend analysis in the Polar Regions, the regions that most sensitively react to global change.

Antarctic Observatories

Taking advantage of this situation, AWI is operating three observatories at its Neumayer Antarctic Base that were initiated in 1982 and since monitor the weather, geophysical properties and atmospheric chemistry.

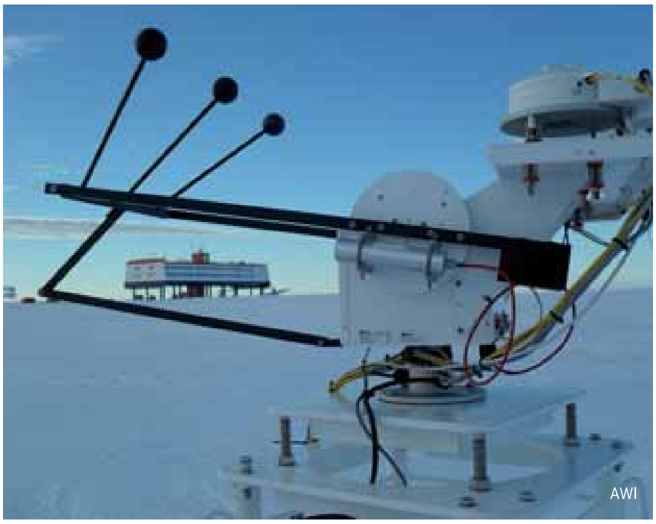
The meteorological observatory serves as one of the few global nodal points in the Baseline Surface Radiation Network. In addition to its normal routine observations it performs daily radio echo soundings. Since 1992 weekly ozone soundings to altitudes of greater than 30 km have monitored the yearly ozone concentration cycle and its vertical distribution.

The geophysical observatory monitors local, regional and global seismicity using a local network of three broadband stations augmented by a short-period 15-element array. Data are telemetered to the base, preprocessed and transmitted via satellite link to global network data streams, in particular GFZ's GEOFON network. Together with the South African Antarctic Programme, an additional broadband station is operated at Sanae Base. This seismometer network is unique to Antarctica in the sense that by its regional spread it opens a window into the Earth's crust and upper mantle in the region of Dronning Maud Land.

Geomagnetic observations are also carried out in line with the INTERMAGNET standard. An interesting feature of this geomagnetic observatory is that every day the austral auroral oval passes overhead.

The atmospheric chemistry observatory provides continuous, year-round as well as long-term data records for important gaseous and particulate trace components of the troposphere. Furthermore, the measuring programme is also concerned with some aspects of the chemistry of snow and firn as well as the stratosphere and upper troposphere. It is obvious that the atmosphere above Antarctica is the cleanest part of the Earth's troposphere and can be employed as a large clean air laboratory to study natural conditions comparable to atmospheric processes that prevailed elsewhere in preindustrial times. The Antarctic continent is largely free of aerosol and trace gas sources so that the lion's share of atmospheric trace compounds have to be advected by long-range transport to Antarctica or originate in the surrounding Southern Ocean. The low background concentrations allow precise monitoring of the effectiveness of the Montreal Protocol, for example.

Both the meteorological and atmospheric chemistry observatories are part of the Global Atmospheric Watch (GAW) station network. Since 2003, the IS27DE infrasound array has been operational with a data availability of over 99.9 %. This infrasound recording station is part of the international monitoring system (IMS) of the Comprehensive Test Ban Treaty Organization (CTBTO), with operational responsibility shared between AWI and BGR.



AWI

Antarctic base Neumayer III and instrumentation for measuring surface radiation balance.

“LIDAR" Laser and Polar Lights above the dome of the AWIPEV Observatory, Ny Alesund.

Arctic Observatories

AWIPEV

The chemical perturbation of the stratospheric ozone layer in the polar regions is one of the strongest signals for a changing atmosphere. Increasing concentrations of water vapour, other greenhouse gases and aerosols as well as changes in global ozone distribution are a direct measure of the anthropogenic share of global climate change. Hence, ozone and climate studies in the polar tropo- and stratosphere focus on understanding the regional and global forcing driving climate change.

In Ny Alesund, Svalbard, AWI has operated a meteorological and upper atmosphere observatory with particular focus on ozone depletion processes, surface radiation, and aerosol variability since 1992. Since 2003 when the original AWI-KOLDEWEY base was merged with the French Polar Institute’s RABOT base, it has been jointly operated by AWI and IPEV and appropriately named AWIPEV.

Observation is based on a variety of optical instruments. An infrared spectrometer measures the type and quantity of trace gases in the troposphere and stratosphere. A photometer, which uses the sun and the moon as light sources, measures the optical depth of atmospheric aerosols throughout the year. The vertical distribution of the concentration of ozone and aerosols in the atmosphere is determined by means of a LIDAR. In addition, balloon-borne sensors record temperature, humidity and air pressure, as well as ozone-profiles on a daily or weekly basis.

An automatic climate and soil observing system has been installed in an undisturbed area outside the settlement, which records climate variables together with data of temperature and soil moisture in different vertical profiles. This system provides unique insight into processes related to climate-induced changes in permafrost and in particular quantitative estimates of the ensuing methane and CO_2 balance by way of an installed eddy covariance system. Furthermore, local infrastructure facilitates coastal marine observatory functions, including the possibility of scientific diving and the installation of a COSYNA ferry box system.

SAMOYLOV

Since 1998, automated soil and meteorology stations located on Samoylov Island in the Lena River Delta in Siberia have produced high-quality data series of climate variability, the changing permafrost top layers, and the related changes in trace gas imbalance. This facility, which is presently greatly enhanced by the construction of a much larger base by our Russian partners, the Permafrost Research Institute in Yakutsk and the Russian Academy of Sciences, will allow year-round process studies in the future.

Both AWIPEV and SAMOYLOV are already well-equipped but will be enhanced with more integral components and the Arctic components of the TERENO network in the future. They already serve an important function in ACROSS (see below).

The new research station Samoylov in the Lena Delta, Siberia.



TERENO

Terrestrial Observatories

The consequences of global change and of natural hazards are the most immediate impacts we experience in the human habitat, reaching from gradual long-term change to rapid natural disasters. Determining the hazard potential and its predictability, assessing the impact of global change, and developing resilience via mitigation strategies is a key challenge. Its solution relies on continuous observation of the response of our environment to natural as well as man-made change and of the spatial as well as temporal distribution of risk.

TERENO – Terrestrial Environmental Observatories

Climate change and land use change are key factors of global environmental change which have to be managed by society in the coming decades. The changes take place on different spatial and temporal scales and many important ecosystem functions are expected to be affected. Steady long-term trends in temperature, precipitation, and other climatic gradients affect most of the environmental compartments exhibiting very complex feedback mechanisms. However, a comprehensive consideration of multi-compartment interactions and scale-dependencies remains a major scientific challenge of current terrestrial environmental research in order to predict the behaviour of the terrestrial system in response to changing environmental conditions.

To address this challenge, the Helmholtz Association initiated the infrastructure activity TERENO. This is a network of long-term integrated observation platforms, jointly coordinated and operated by six Helmholtz Centres in close cooperation with external partner institutions (overall coordination office at FZJ).

This network aims at investigating effects of global change on terrestrial ecosystems. Within TERENO, regional terrestrial observatories have been established in four regions selected to provide a representative cross-section of biogeoclimatic zones:

- Eifel/Lower Rhine Valley Observatory (lead coordination by FZJ)
- Harz/Central German Lowland Observatory (lead coordination by UFZ)
- Bavarian Alps/pre-Alps Observatory (joint coordination by KIT & HMGU)
- Northeast German Lowland Observatory (lead coordination by GFZ)

The objectives of TERENO are the following:

- Integration of existing research stations and activities including dedicated new infrastructure for long-term integrated environmental monitoring and observation.
- Provision of real-time access to instruments and open access to long-term environmental data in a multi-scale and multi-temporal mode, based on the data portal TEODOOR (www.tereno.net).
- Implementation of catchment-scale hydrological sensor networks, covering several 1,000 km≤, micrometeorological flux stations to measure energy and trace gas exchanges, lysimeter clusters (SoilCan), as well as lake and forest monitoring sites to study climate signal transfers into geoarchives.
- Analyses of precisely dated and seasonally resolved geoarchives, such as lake sediments and tree rings as natural data loggers, which will extend instrumental data records back to several millennia.
- Accomplishment of biodiversity studies within the framework of LTER sites.
- Dedicated airborne platforms and satellite-based remote sensing.
- Collaboration with other environmental measurement networks in Germany and all over the world, such as FLUXNET, LTER and ICOS, and will contribute to global Earth system science observation systems, such as GEO/GEOSS.
- Providing quality-controlled long-term data sets for analysing the range and variability of hydrological and ecological processes in relation to climatic and anthropogenic (management) forcings.
- Validation and advancement of integrated climate-Earth-system models and space-borne remote sensing data.

KIT

Lysimeter installation for analysis of precipitation, evaporation, variation of water storage, and seepage water formation.

One of the ten GCEF blocks for climate manipulation under multiple land use scenarios. Picture taken during the construction phase 2012, experiments will start in 2013.

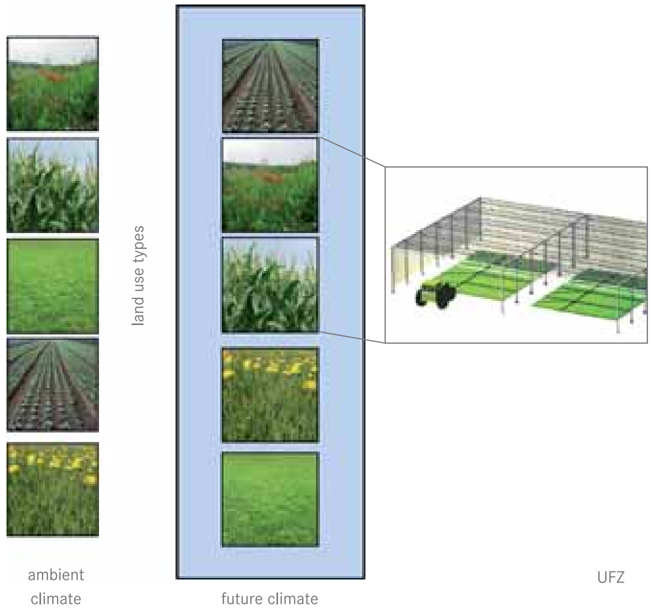
GCEF – Global Change Experimental Facility

Both, changes in climate and land use, will influence the structure and dynamics of ecosystems and, as a consequence, ecosystem functions and the provisioning of ecosystem services. Hence, apart from empirical studies and modelling approaches, manipulative field experiments are urgently needed to understand the underlying processes, to deduce indicators, to develop strategies for sustainable land use and to manipulate some of the key processes.

Previous experimental approaches have often considered individual global change factors (such as temperature or precipitation) separately, and the few multi-factorial experiments were conducted so far on rather small spatial and temporal scales. These experiments therefore necessarily ignore important mechanisms of ecological change, e.g. microevolution and species interactions. Moreover, none of the previous experiments explicitly considered different land use options in combination with climate change scenarios. Therefore, we designed the GCEF as a field-based experimental platform to assess the simultaneous effects of climate change under different land use scenarios on the functioning of ecosystems and the provisioning of ecosystem services by ecological communities.

The GCEF is located on the fields of the UFZ field station in Bad Lauchstädt near Halle. Fifty large field plots of 16 m x 24 m are grouped in 10 blocks with 5 plots per block. Half of the blocks are subjected to a climate change scenario whilst the other half remains untreated (ambient climate). On the climate change plots, mobile roofs and side panels as well as an irrigation systems allow the manipulation of temperature and precipitation regime. The different land use scenarios represent a land use intensity gradient consisting of conventional agriculture, organic agriculture as well as extensively and intensively used grasslands.

The GCEF provides a platform for interdisciplinary research projects at the UFZ and the basis for co-operations with external partners (e.g. universities, the German Centre for Integrative Biodiversity research – iDiv).



In the GCEF, five plots representing different land use scenarios are randomised in blocks with manipulated or ambient climate respectively. There are five replicates of each treatment combination resulting in ten blocks (climate treatment) consisting of 50 plots (land use treatment).

Application of direct push-technologies in the field for investigation of contaminated aquifers.

MOSAIC – Model Driven Site Assessment, Information and Control

The Helmholtz-Centre for Environmental Research - UFZ has established the research platform MOSAIC for the purpose-oriented, rapid site characterization that is a prerequisite for the understanding and the solution of environmental and hydrogeological problems. MOSAIC stands for „Model Driven Site Assessment, Information and Control" and comprises mobile modular data acquisition units for adaptive and modelling-based field investigations. The emphasis is laid upon the multi-scale observational design that allows measurements from high resolution point to field scale. Through this unique design, MOSAIC serves as a link between the different observatories. Therefore it is deployed on mobile vehicles containing geophysical measuring techniques, borehole logging, hydrogeological and geotechnical equipment, as well as mobile field analytical devices.

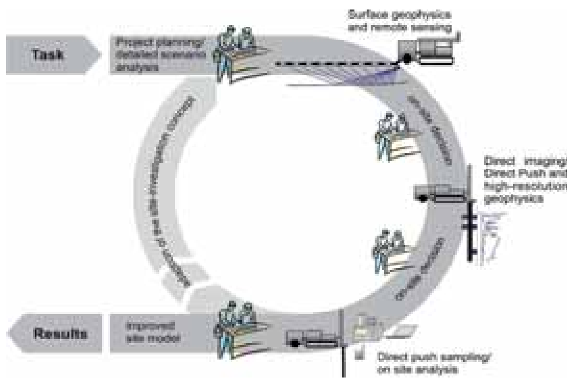
The identification of relevant system parameters and detailed knowledge of the geometry of subsurface structures are the basis for the development and evaluation of models for the description of natural systems. Against this background, exploration and monitoring technologies must be addressed to meet the challenges which arise from the discrepancy between process scale and exploration scale, the temporal variability of process, the deterministic and stochastic heterogeneity of natural systems, and the dimensions of the investigated system.

The major objectives and aims of the MOSAIC research platform are the following:

• MOSAIC provides a state-of-the-art and beyond combination of mobile exploration and monitoring systems for the characterization of environmental and hydrological systems. Application examples are water resources management, the management of contaminated megasites, the geotechnical evaluation of building ground, as well as upcoming challenges triggered by land use changes and use of the shallow subsurface for energy storage in the framework of the energy transition.

• MOSAIC can be applied for the high resolution 3D characterisation of the shallow subsurface of sites with a size of up to square kilometres. Examples include the combination of methods with different spatial resolution, development and evaluation of adaptive problem-oriented site investigation strategies as well as of new technologies, and the development of effective methods for the determination of site specific soil parameter relationships.

• MOSAIC is a broad research platform for model supported, near surface assessment and forges a connection between scientists from different fields. The platform is open to other Helmholtz institutes as well as universities in order to integrate technologies into research projects. It fosters and supports interdisciplinary research as well as technology development and transfer.



UFZ

Dynamic work plan for adaptive and modelling-based field investigation. Real time analysis of results and on-site decisions offer clear advantages compared to traditional site investigation approaches, especially when combining geophysics and direct push-technologies. A prerequisite for the application of an adaptive site investigation is the availability of a pool of methods and technologies.

Installation of a Creepmeter station of Chilean plate boundary observatory IPOC in the Atacama Desert, Northern Chile.

Earth System Observatories

The solid Earth system is as complex as the Earth's atmosphere, hydrosphere, and surface. Interaction among these components dominates the processes underlying hazards or changes in our environment across a range of scales. Events such as earthquakes and tsunamis manifest themselves in seconds to hours but are the result of stress built up over hundreds of years deep within the crust at distant locations, of the interaction with fluid and volcanic systems, surface mass flux, etc. Hence, quantifying the speed and extent of change controlled by the deep Earth requires integrated instrumentation that collects high-quality continuous data at a high spatial resolution and provides rapid data processing, information and public access.

In 2006, GFZ in cooperation with national and international partners started a series of integrated multiparameter observatories, each embracing an area of several 100 square kilometres with high spatial coverage. Their goal is the acquisition of long series of high-resolution measurements of geophysical and geochemical properties and state variables of deep Earth systems and their interaction with near surface processes. Our motivation is to improve our understanding of the processes shaping the Earth system at the regional scale, to explore the interaction and coupling of processes, to provide more reliable forecasts, and to contribute to the development of efficient observation technologies and sensor systems.

Our Earth system observatories have been selected to be optimally suited for a systematic study of coupling and interaction of Earth processes and their impact on the human habitat. By combining instrumental observation with high-resolution geological archives and proxy data, we expand the time scales to assess the temporal variability of processes, their rates and amplitudes beyond the instrumental time scale.

Three of the below Earth system observatories form test beds for the Helmholtz initiative ACROSS. Together they will form a cornerstone of the future Helmholtz observatory initiative GEMIS (see below).

• IPOC, the Integrated Plate Boundary Observatory Chile, is a European-American network of institutions and scientists (GFZ, GEOMAR, IPG, CALTECH, several Chilean and German universities) organising and operating a distributed system of multiparameter observatories (seismology, GPS, creep and tilt, electrical conductivity, weather) and projects at Chile's convergent plate margin, a global hotspot of natural hazards. IPOC is dedicated to the study of large earthquakes, deformation of the Earth's crust, magmatism, surface processes, and the associated hazards and provides data to the community (www.ipoc-network.org).

• The Plate Boundary Observatory Turkey focuses on the observation of earthquake mechanisms, the plate-scale interaction of seismicity, and complex deformation processes occurring at the North Anatolian Fault. This continental plate boundary fault neighbours Istanbul, Europe's most vulnerable megacity, and is observed in a German-Turkish-US collaboration in the framework of a fault observatory supported by ICDP (International Continental Drilling Program) and coordinated by GFZ.

• The Dead Sea Observatory is embedded in the new Virtual Helmholtz Institute (VI) DESERVE (DEad SEa Research VEnue). In a joint endeavour by the Helmholtz Centres KIT, GFZ and UFZ and their Middle Eastern partners it addresses three grand challenges: environmental risk, water availability and climate change by combining the long-term monitoring of geophysical parameters (stations are identical to IPOC), studies of coupled processes in the atmosphere, hydrosphere, pedosphere, and lithosphere as well as models for predicting and remediating strategies of geogenic risk management.

• The Central Asia Global Change Observatory studies the interaction of earthquake- and climate-controlled hazards and their impact forming a unique geohazard-georisk observatory. Several national and international institutes operate a network of instruments observing earthquakes, landslides, hydrology and interaction with variations in regional climate in this climatically highly sensitive and geodynamically active area.

Multiparameter station (seismology, GPS, magnetotelluric sounding, weather) of Chilean plate boundary observatory IPOC in the Atacama Desert, Northern Chile.

Atmospheric Observatories

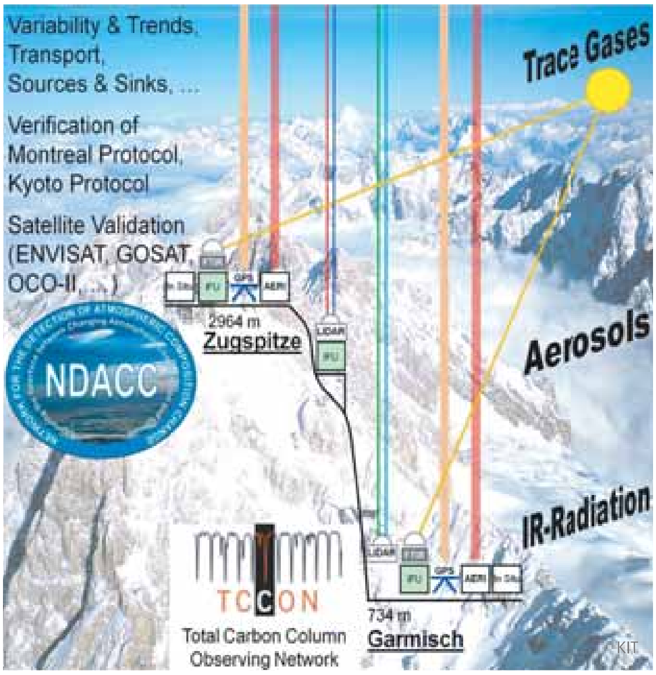
The atmosphere is the primary driver of climate change, affecting living conditions on Earth, and in turn, it is strongly affected by climate change effects in the Earth system. Changes of climate, natural atmospheric hazards, and air quality represent major challenges to humankind over many generations. The scientific knowledge derived from atmospheric monitoring thus forms an essential prerequisite for developing resilient strategies to abate or mitigate the impacts of atmospheric and climate change.

Zugspitze – Schneefernerhaus Observatory in the network of Alpine Observatories

Climate change is driven by changes in the amount of greenhouse gases, including water vapor, aerosol particles and clouds in the lower and upper troposphere and in the lowermost stratosphere. The overall occurrence of these trace species is strongly influenced by anthropogenic activities, e.g., fossil fuel combustion, and by subsequent feedback mechanisms like enhanced evaporation of water vapor in a warming climate, or by the impending release of methane from melting marine clathrates. Clouds remain the largest source of uncertainty in predicting future climate and at the same time constitute an important element of the fresh water cycle.

Major challenges faced by KIT at the Zugspitze/Schneefernerhaus/Garmisch super site are:

- To quantify long-term trends and the spatio-temporal variability of column-integrated and tropospheric mixing ratios of CO_2, CH_4, water vapor and of aerosol particles by ground-based remote sensing methods.
- To understand the reasons for the observed trends and distributions of CO_2, CH_4, water vapor, and aerosols by quantifying their sources and sinks on regional to continental scale using inverse modeling of global atmospheric measurements (e.g., Total Carbon Column Observing Network TCCON, Greenhouse Gases Observing Satellite (GOSAT) and the Orbiting Carbon Observatory OCO-2).
- To reduce major uncertainties in current climate projections which result from the in–accurate parameterization of infrared water vapor absorption properties within radiation codes.
- To correlate cloud- and aerosol properties to understand how anthropogenic and natural aerosol particles influence clouds.



Zugspitze/Schneefernerhaus/Garmisch as one of the world leading super sites for optical remote sounding of the atmosphere.

KITcube Mobile Observatory for probing the atmosphere

Atmospheric desasters, like intense thunderstorms, may cause severe damages by heavy precipitation and accompanied flooding. Operational weather models often fail to predict the location and timing of the initiation and intensification of severe weather phenomena, because the cloud and turbulent processes are not well represented in models. Therefore, temporal and spatial high-resolution measurements are required to derive good parametrizations of subscale processes.

The KITcube of the Karlsruhe Institute of Technology (KIT) comprises an excellent equipment of modern measurement instruments for experimental study of the atmosphere.

KIT

KIT performs lidar vertical soundings of water vapor above the research station Schneefernerhaus.

The instruments for ground-based remote sensing of the atmosphere (radar, lidar, microwave profiler, sodar) and the instruments for in-situ measurements (energy balance-, turbulence-, and radiation measurements, mobile met. towers, radiosondes, dropsondes) are used worldwide in large international field programs like HyMEx (Hydrological Cycle in the Mediterranean Experiment) in 2012 with a deployment in Corsica, and the DESERVE (Helmholtz Dead Sea Research Venue) in 2014.

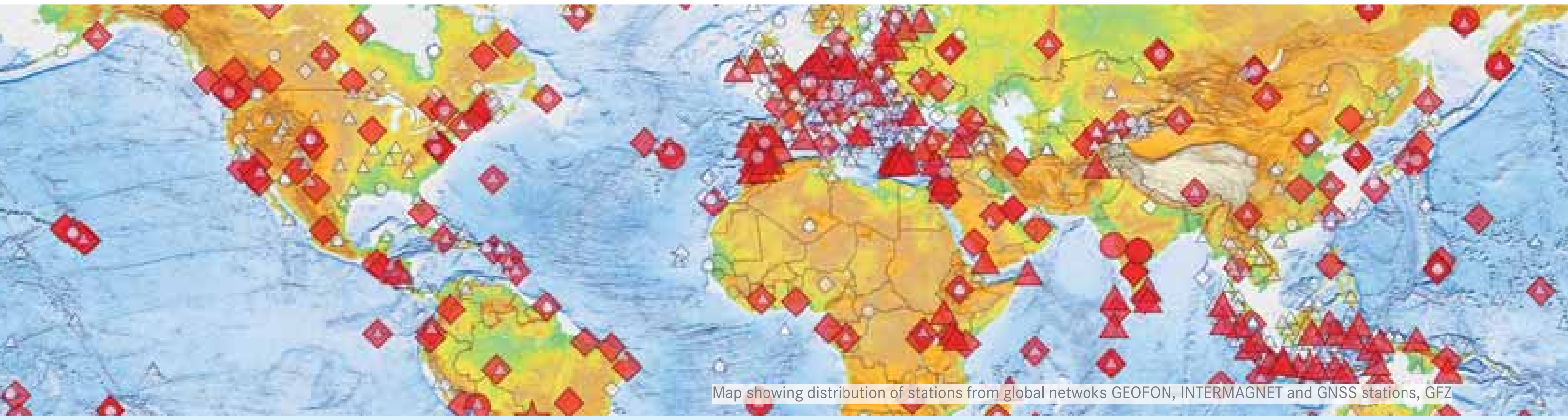
The KITcube is an overall observation system that consists of different instruments to probe the atmosphere. It can survey an atmospheric volume of about 10 km side length with different scanning devices and thus allows a complete monitoring of all relevant atmospheric processes. The KITcube is characterized by high operational flexibility. It can be operated as mobile platform at arbitrary measuring locations as well as in continuous operation for atmospheric monitoring. The different systems are centrally controlled, the data are stored in a common database and an online visualization is realized in central office space in containers platform can make a contribution for example to determine the radiation and energy balance at the Earth's surface or in combination with air chemistry observations to characterize atmospheric aerosols.

ATMONSTAT Atmospheric Monitoring Station Network

Ground based measurements for monitoring the state of the atmosphere are maintained at various locations on Earth. They complement the operational station networks of national meteorological and hydrological agencies for specific research and monitoring essential climate variables. They also important for validation/calibration of satellite missions, which are used to calculate many atmospheric and surface properties from these space based measurements. The results are then distributed in the worldwide weather network. The reliability of the data must be ensured over the entire lifetime of a satellite system, i.e. for more than a decade. For example, KIT set up validation stations within the field of view of METEOSAT in representative landscapes in Portugal, Senegal and Namibia. Within the NDACC (Network for the Detection of Atmospheric Composition Change) and TCCON (Total Carbon Column Observing Network) networks ground-based measurements are performed in Kiruna (Sweden), Karlsruhe (Germany), Izaña (Tenerife Island, Spain), Altzomoni (Mexico), and Addis Ababa (Ethiopia). Fourier Transform Infrared Spectrometers (FTIR) are used to measure the concentration of atmospheric constituents such as CO_2, CH_4, N_2O, O_3, HF, HCl, $ClONO_2$, HNO_3, among others. The data are used to determine trends of atmospheric trace gases, to analyse sources and sinks of greenhouse gases and to validate satellite data.

Other stations operated for several decades are the highly instrumented 200 m-Mast in Karlsruhe and the C-Band precipitation radar. They are used for wind energy estimation and for deriving thunderstorm statistics. The ATMONSTAT Network actually comprises long term measurements in Kiruna/Sweden, Teneriffa, Karlsruhe, Garmisch-Partenkirchen, Zugspitze, Israel, Cyprus, Portugal, Mongolia, China, South Africa, Senegal, Namibia and Mexico. All stations already measure purpose-specific atmospheric and land surface parameters, such as temperature, near surface air temperature, shortwave and long-wave radiance balance and the vegetation index ("greenness") for several years and they will remain operational for at least another 5 years. Currently, the KIT stations are the only permanent validation stations of this type.

Observatory Schneefernerhaus / Zugspitze, KIT



Map showing distribution of stations from global netwoks GEOFON, INTERMAGNET and GNSS stations, GFZ

Global Networks

Earth is subject to the dynamics of its interior as expressed in earthquakes, plate motions, and the Earth's magnetic field. Destruction from ground shaking or tsunami inundation, perturbation of satellite communication systems, as well as motions of the land surface and many more processes emanating from the solid Earth dynamics require international efforts on monitoring and early warning. To this end, we operate a series of global station networks observing individual signals of the solid Earth system.

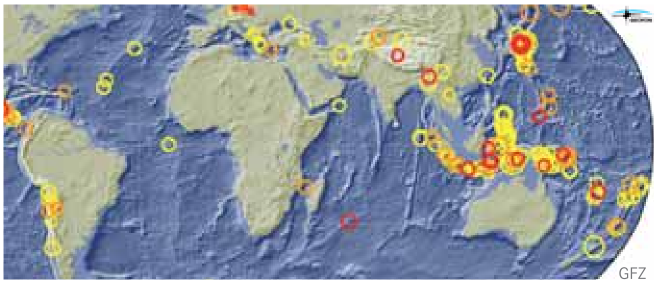
GEOFON - Global Seismological Network and Earthquake Service

Observing earthquake activity at the global scale, informing public agencies, providing early warning for tsunami generation, understanding deep Earth's interior – these are among the key challenges faced by seismology. To address these, GFZ has developed GEOFON (GEOFOrschungsNetz), a global seismological broadband network operated jointly with more than 50 international partners. It is the second largest research network within the Federation of Digital Seismograph Networks (FDSN) of IASPEI after the American IRIS network. At present it consists of 89 permanent stations on all continents and is a technically well-advanced and cost- and labour-efficient global network.

Today the GEOFON network plays a leading role in global real-time seismology. The data from all GEOFON stations is transmitted in real time to Potsdam via Internet or VSAT links. In addition, real-time data streams from a further 800 stations worldwide operated by partner institutions (GEOFON Extended Virtual Network (GEVN)) are gathered simultaneously. All data is jointly processed and source parameters of worldwide earthquakes are automatically derived and published within a few minutes. Quick and reliable GEOFON global earthquake information is available on a website (http://geofon.gfz-potsdam.de/eqinfo/list.php), via e-mail alert lists and SMS messages to other seismic centres, governmental offices, disaster managers, news media, and the general public. GEOFON provides its earthquake service also as a key node to the European Mediterranean Seismological Centre (EMSC) and as a background data centre to the North East Atlantic and Mediterranean Tsunami Warning System (NEAMTWS of UNESCO/IOC) as well as other tsunami warning centres and earthquake services in Europe, the Indian Ocean and worldwide.

Magnetic Observatories

Driven by dynamic convection in the Earth's core, our planet's magnetic field protects the Earth's surface from the solar particle wind, a fundamental requirement for the maintenance of life.



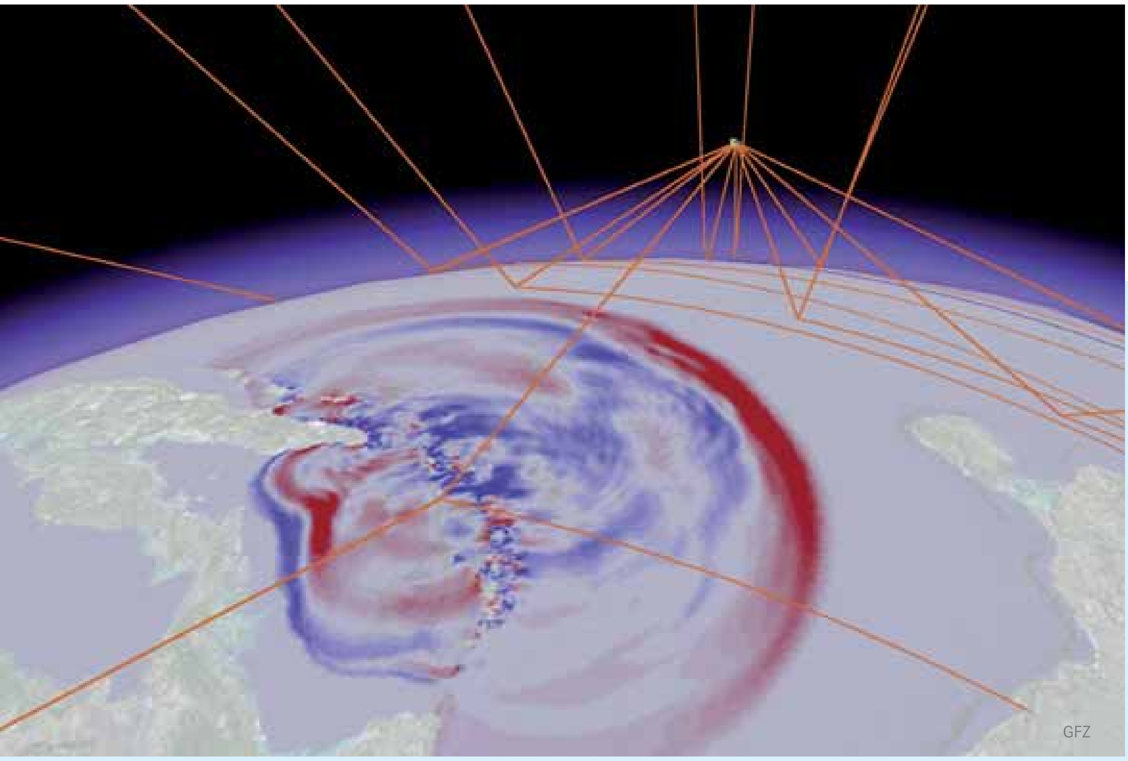
GFZ

Automatic GEOFON global seismic monitor provides near realtime information on seismic events.

Observing temporal and spatial variations in the magnetic field strength on time scales ranging from hundreds of years (variation of the main geomagnetic field) down to seconds (space weather) therefore is another key requirement. To this end, in an international effort a globally distributed network of geomagnetic observatories (INTERMAGNET - INTERnational Real-time MAGnetic Observatory NETwork) was established in 1987 to ensure the provision of high-quality data transmitted in near real time. At present, this global network consists of 123 observatories.

GFZ operates the Niemegk geomagnetic observatory and 12 associated observatories. The data series of the Niemegk observatory south of Potsdam goes back to 1890. The Wingst observatory near Hamburg with its data going back to 1938 was taken over by GFZ in 2000. Both observatories are among those with the longest records worldwide and belong to the group of 13 mid-latitude observatories used for deriving the global Kp index which represents solar particle radiation as determined by its magnetic effects. Since 1997 the Niemegk observatory has calculated this index for the International Service of Geomagnetic Indices (ISGI) of IAGA (International Association of Geomagnetism and Aeronomy).

New observatories have been established by GFZ on the islands of St. Helena and St. Maria (Azores) in 2007 and 2010, respectively, and in Keetmanshoop, Namibia, in 2005.



Tsunami detection and monitoring in near realtime employing space based GPS reflections from the sea surface.

Other observatories are now run in cooperation between GFZ and local institutions in Villa Remedios (2000) in Bolivia, Panagjurishte (2005) in Bulgaria, Yakutsk (2007), Magadan (2007) and Paratunka (2009) in Russia, Hyderabad (2007) and Alibag (2007) in India, and Surlari (2008) in Romania. Two new observatories are under construction in Pantanal, Brazil, and on Lombok Island, Indonesia, in cooperation with local institutions. Following stepwise integration of these observatories into the INTERMAGNET network (www.intermagnet.org) global monitoring of our currently weakening magnetic field will be operational, providing key information on space weather needed for example for the stability of satellite communication systems and power transmission systems.

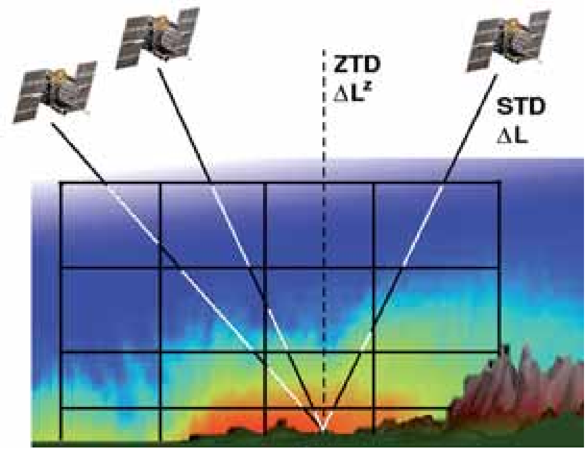
Permanent GNSS Network

Global navigation satellite systems (GNSS) have developed into one of the most important technologies for the investigation of Earth system dynamics. Beyond their original purpose of navigation they now contribute to the observation of plate motions and Earth deformation, to observation of unstable mountain flanks and hazard, to tsunami propagation, or to meteorology and the monitoring of the hydrological cycle to just name a few. Hence, globally distributed and permanently operating GNSS stations have become of critical importance for the derivation of GNSS data products, irrespective of whether the solid Earth, oceans, ice covered regions or the atmosphere are under study.

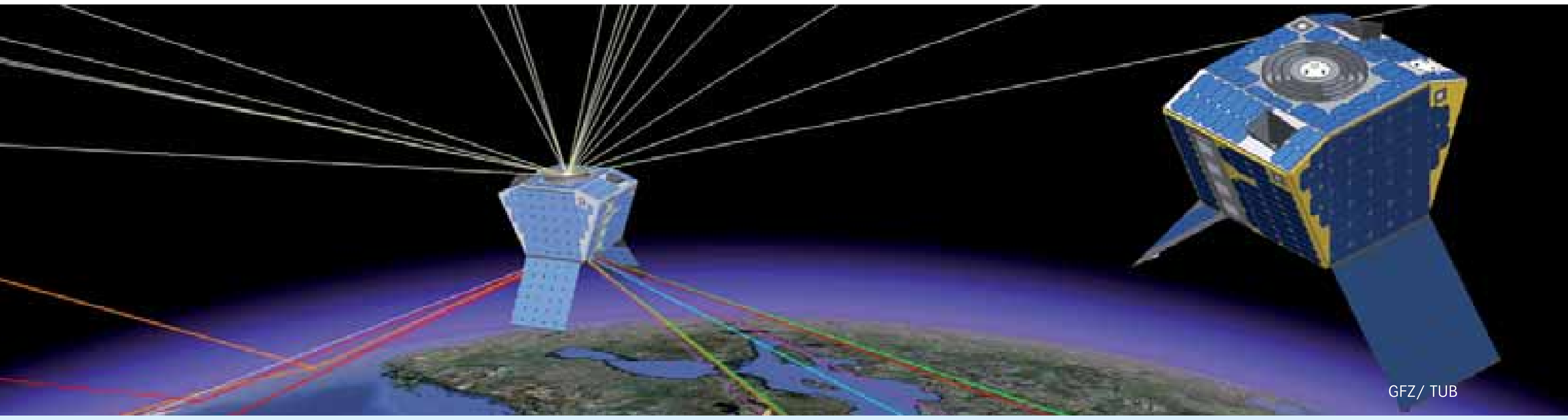
Presently, GFZ operates 40 permanent geodetic GNSS stations worldwide with strong support by its local partner organisations. The stations serve different projects, acting as a backbone of a large number of scientific investigations. 27 globally distributed stations with 1 Hz sampling provide data in real time and support various satellite mission operations (e.g., GRACE, GRAS Metop). Most of these stations are integrated into the IGS (International GNSS Service) network that now consists of about 350 stations.

Currently, a major upgrade is in process to extend the globally distributed GPS stations to multi-GNSS capability to provide data from all major navigation satellite systems like GPS, GLONASS, Galileo, QZSS, Beidou as well as meteorological data for atmosphere correction and sounding. At four sites, GFZ hosts ESA-operated tracking stations supporting the European Galileo mission and manages the data transfer from these sites to the Galileo facility centre.

Ten GNSS stations in Germany are permanently operated by GFZ, mainly on synoptic sites of the German Weather Service (DWD) in conjunction with more than 300 stations of the SAPOS network of German land survey agencies and the GRef network of the Bundesamt für Kartographie und Geodäsie (German Federal Agency for Cartography and Geodesy). A major application of this combined network in Germany is the provision of water vapour distribution over Germany in real time, which is used by forecast centres in Germany, France, and the U.K. for weather prediction.



Integration of ground and space based GNSS technologies provides high resolution sounding of atmospheric water vapor and temperatures.



Planned New Platforms

In spite of the efforts put forward for observing critical components of the Earth System as reflected by the above described existing observatory systems we face additional challenges. Important gaps in our observational strategy exist that require, in a first step, the design and deployment of additional dedicated observatory components. These embrace surface based systems enlarging our environmental monitoring in regions particularly sensitive to ongoing global change as well as associated space based satellite systems.

ATMO-SAT

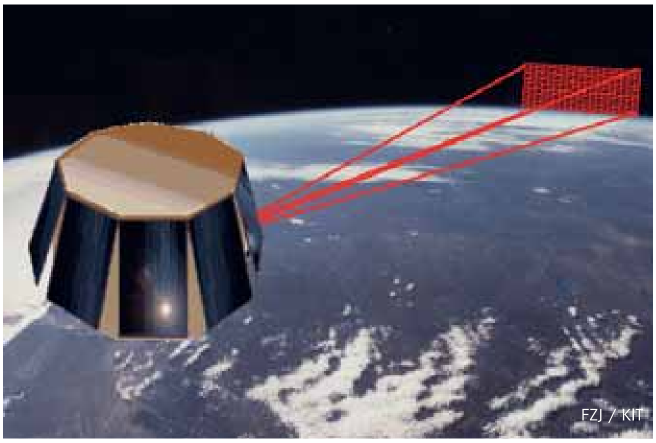
Numerous studies have shown that the upper atmosphere has a crucial influence on regional climate and weather (IPCC 2007). This occurs through vertical coupling (e.g., wave dynamics, radiation, and transport of chemical species, which, inter alia, affect the average distribution of ground pressure and associated phenomena, such as NAO and ENSO). In contrast, the underlying mechanisms are still poorly understood and represent a main source of uncertainty. The role of natural (e.g. sun-induced) variability has also been insufficiently quantified in relation to anthropogenic effects.

The ATMO-SAT satellite mission is envisioned to provide unique information about the impact of natural (e.g. sun-induced) variability on regional climate and weather. A significantly improved understanding of the underlying processes will lead to considerable improvements in regional climate forecasts and seasonal weather forecasts. The scientific targets require the monitoring of three-dimensional distributions of atmospheric temperatures and selected trace gases at a previously unachieved spatial resolution. To this end, the new 2D-imaging spectral measurement technique developed by the submitting Helmholtz Centres will be used for limb imaging of the atmosphere (demonstrated using GLORIA-AB mounted on the HALO research aircraft) from a satellite platform. ATMO-SAT is based on the long-standing expertise of the Helmholtz Centres involved in previous CRISTA and MIPAS space-based measurements as well as in the PREMIER and MACE satellite projects.

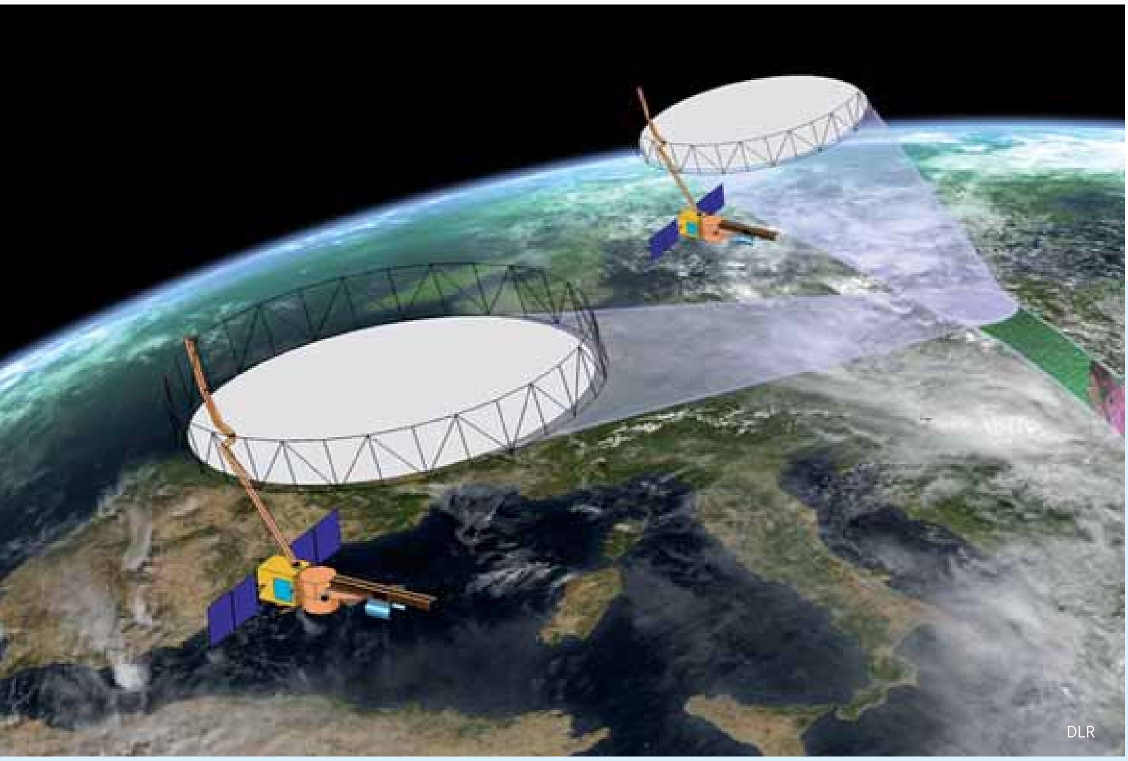
Global change is jeopardising the foundations of human life and the development opportunities of future generations. ATMO-SAT will make an important contribution to the quantitative forecasting of regional climate and weather changes, one of the greatest social challenges of the 21st century. These contributions are urgently required as clearly stated by major international initiatives in this field (e.g., IPCC, WCRP, GEOSS, GCOS, CEOS). On the national level, the Helmholtz Climate Initiative “Regional Climate Change” (REKLIM, in the “Earth and Environment” research field) will be the most important community for ATMO-SAT. This project is also of very high scientific interest to the national research initiative ROMIC (“Role of the Middle Atmosphere for Climate”) where many leading institutes of the Leibniz Association, the Helmholtz Association, the Max Planck Association, and a number of German universities are involved. An economically highly relevant field of application of ATMO-SAT is medium-range weather forecasting (world-wide).

Schedule:

- Construction: 2015-2020
- Launch: 2020 or 2021 (depending on launch opportunities)
- Operation: up to 5 years (minimum 3 years)



Atmosat - the planned atmospheric sounding satellite. Sketch illustrating the limb-imaging viewing geometry (Riese et al., ASR, 2005).



Tandem-L, the mission proposal for Monitoring Dynamic Processes on the Earth's Surface.

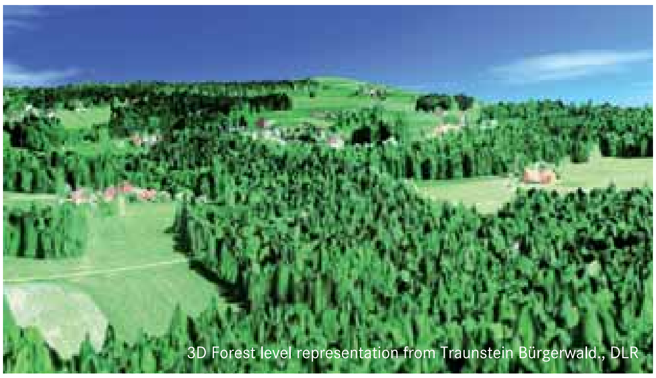
Tandem-L – Monitoring Dynamic Processes on the Earth's Surface

An important future challenge is the global measurement of Earth surface change. This embraces the quantification of forest biomass for a better understanding of the Earth's carbon cycle, the systematic recording of deformations of the Earth's surface with millimetre accuracy for earthquake research and risk analysis, the quantification of glacier movements and melting processes in the polar regions, the large-scale observation of ocean currents and the high-resolution measurement of variations in soil moisture close to the surface. Hence, in a time of intense scientific discussion about the extent and effects of climate change, global satellite-based monitoring is required providing important, currently missing information needed for improved scientific forecasting and related socio-political recommendations.

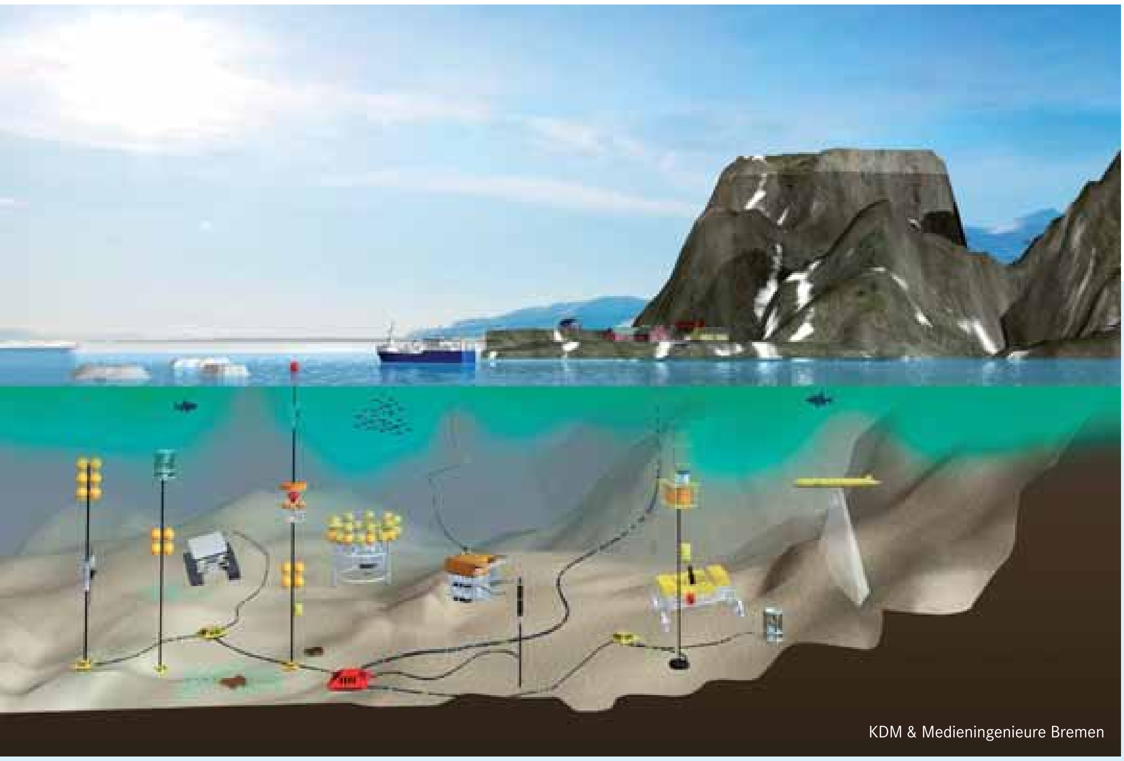
Tandem-L comprises a proposal for a highly innovative satellite mission for the global observation of dynamic processes on the Earth's surface at hitherto unknown quality and resolution. Thanks to novel imaging techniques and its vast recording capacity, Tandem-L will provide urgently needed information for solving scientific questions in the areas of the biosphere, geosphere, cryosphere, and hydrosphere.

The Tandem-L mission concept is based on the use of two radar satellites operating in L-band (23.6 cm wavelength). Application of the special synthetic aperture radar technique (SAR) facilitates high-resolution imaging of the Earth's surface independent of the weather and time of the day. It therefore offers the ideal basis for the continuous observation of dynamic processes on the Earth's surface. Moreover, the long wavelength compared to X-band (3.1 cm) fulfils the requirements of a tomographic measurement of the three-dimensional structure of vegetation and ice regions, as well as of the large-scale surveying of deformations with millimetre accuracy. The goal of Tandem-L is to image the land mass interferometrically once a week. Above and beyond the primary goals of the mission, the data set generated by Tandem-L has immense potential for developing new scientific and commercial applications. Moreover, Tandem-L is distinguished by a high degree of innovation with respect to methodology and technology. Examples include polarimetric SAR interferometry for measuring forest height, multi-pass coherence tomography for determining the vertical structure of vegetation and ice, utilisation of the latest digital beam forming techniques for increasing swath width and imaging resolution, as well as close formation flying of two cooperative radar satellites with variable adjustable spacing.

The mission concept was developed in detail in a two-year pre-phase study together with NASA/JPL. Tandem-L can be implemented within an international cooperation or on a purely national basis. According to current planning, the Tandem-L satellites could be launched in 2019. Tandem-L offers a unique opportunity to closely mesh with the multifarious activities of the Helmholtz Association (HGF) spanning across various research areas fused in a joint interdisciplinary project. The expertise of the relevant HGF research centres with their specific modelling techniques is imperative for producing highly aggregated information products. The use of Tandem-L data or products is currently being investigated in the HGF Alliance "Remote Sensing and Earth System Dynamics".



3D Forest level representation from Traunstein Bürgerwald., DLR



The FRAM Observatory "Frontiers in Arctic Marine Monitoring" for earth system sciences in the key region Atlantic-Arctic Ocean. Near-surface observational components for autonomous under-ice measurements will expand existing observation capacity in Fram Strait. For high-resolution investigations of surface gradients, biogeochemical sensors will be integrated to profile between a few hundred meters depth and the ocean surface by anchored winch systems. This new functionality plays an important role in the German contribution to the international ESFRI programs „Integrated Carbon Observing System" (ICOS) and Svalbard Integrated Arctic Earth Observing System (SIOS).

FRAM – Frontiers in Arctic Marine Monitoring

The FRAM autonomous ocean observing system is planned as a new submarine infrastructure to enable year-round multidisciplinary time series observations with near real-time data access to the main gateway between the Atlantic and Arctic Ocean. FRAM will integrate already existing Helmholtz observatories in Fram Strait, such as the LTER site HAUSGARTEN and the HAFOS oceanographic array. Technological innovations focus on continuous ocean observation in polar seas with year-round measurements directly under sea ice, with adequate resolution of the ocean surface. This will considerably expand the existing facilities towards a next-generation ocean observation infrastructure, including continuous physical, biogeochemical and biological measurements from surface to depth.

FRAM would be a major contribution to international efforts towards comprehensive global Earth observation in polar regions. It will serve national and international tasks to improve our understanding of the effects of change in ocean circulation, water mass properties, and sea ice retreat on Arctic marine ecosystems and their main functions and services. Products are long-term data at appropriate resolution in space and time and ground truth for ocean models and remote sensing, serving numerous national and international programmes. The FRAM Ocean observing system is unique in its combination of stationary and drifting system components as well as remotely navigated systems working under ice, in open water, and on the deep-sea floor. It includes an innovative e-infrastructure platform to provide data and data products to a wide range of users. It would complement the COSYNA coastal observing system by focusing on the open ocean and deep waters of the Arctic and represents a critical contribution to the Integrated Carbon Observing System and the Svalbard Integrated Arctic Earth Observing System (ESFRI ICOS and SIOS). This new Helmholtz research infrastructure could be an essential contribution to a larger submarine infrastructure, including cabled observatory platforms currently evaluated within the national roadmap pilot phase of the German Federal Ministry of Education and Research (BMBF).

Key scientific challenges include:

- Influence of Arctic freshening and warming on ice formation, stratification and the availability of nutrients for productivity
- The role of the ocean as heat and CO_2 capacitor (including acidification)
- Atlantification of the Arctic system, including shifts in biodiversity, food web structure, and biogeochemical budgets and their interactions
- Future and past of Arctic productivity and carbon export in relation to climate change
- Adaptation of life cycles and habitat ranges for plankton and benthos
- Bioindicators for ecosystem assessments
- Impact of increasing traffic and other forms of human use of the Arctic

Observing life in and under the ice-covered regions of Earth. Helmholtz research infrastructures help assessing the future of the Earth's cryosphere.

Rivers sediments in the Cinca catchment, a sub-catchment of the Ebro basin, Spain. High sediment deposition from the extensive badlands leads to a severe reduction in reservoir storage capacities.

TERENO-MED – Terrestrial Environmental Observatories in the Mediterranean Region

The Mediterranean region is one of the most imperilled regions in the world concerning present and future water scarcity. The region is delicately positioned at the crossroads between East and West, interlinking Europe, Asia and Africa. Societal and economic changes causing population growth, industrialisation and urbanisation lead to significant increases in food, water and energy demand. Hence, natural resources, such as water and soils, as well as ecosystems are put under pressure and water availability and quality will be severely affected in the future. At the same time, climate and extreme event projections from climate models for the Mediterranean are, unlike for most regions worldwide, consistent in their trends based on various scenarios. This consistency in the model predictions shows that the Mediterranean will face some of the most severe increases in dryness worldwide (based on consecutive dry days and soil moisture), and indicate a decrease of up to 50 % in available water resources within the next 50-100 years.

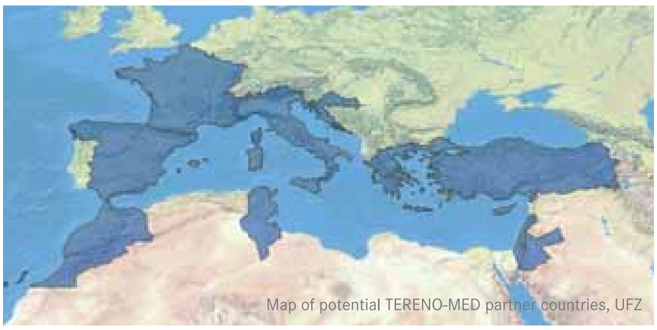
These developments are accentuated by the fact that in many of the Mediterranean countries, natural renewable water resources are fully exploited or over-exploited already today, mainly due to agricultural irrigation, but also touristic activities. At the same time, the Mediterranean region is a global hot spot of freshwater biodiversity, with a high proportion of endemic and endangered species. While trend projections for water availability and climate change derived from global studies are consistent, regional patterns and heterogeneities, as well as local adaptation measures will largely determine the functioning of societies and the health of ecosystems. However, a lack of environmental data prohibits the development of sustainable adaptation measures to water scarcity on a scientific basis.

Building on the experiences gained in the national TERENO network, a Mediterranean observatory network will be set-up, coordinated by two Helmholtz Centres and jointly operated with local partners across the Mediterranean region. In a number of Mediterranean mesoscale hydrological catchments TERENO-MED will investigate the long-term effects of global change on the quality and the dynamics of water resources in human-influenced environments under water scarcity.

The Helmholtz Centres UFZ (overall coordinator) and FZJ have therefore initiated the set-up of a network of global change observatories in 5-10 Mediterranean river catchments.

The TERENO-MED observatories will:

- investigate societally relevant water problems in the context of 'typical' Mediterranean environments,
- provide long-term and quality-controlled data available to the scientific community,
- be operated and maintained through local research institutes and universities,
- establish common monitoring platforms and foster synergies between research organizations,
- provide solutions to pressing local and regional water problems by building partnerships between scientific partners and regional authorities.



Map of potential TERENO-MED partner countries, UFZ

The biggest facility for satellite communication in Raisting, Bavaria, Germany. Photo: Richard Bartz

Towards an Observatory Network

The limitations exerted by employing individual observatory systems to observe the complexity of Earth's systems, their interactions and scales calls for the next steps: integrating ground-based and space-based observation for the improvement of spatial coverage, temporal resolution and data validation, and providing rapid information to the science community as well as to public organizations. To this end, we plan an integrated Earth observation system comprising several steps from cross-scale validation of observations to a global infrastructure network.

ACROSS – Advanced Remote Sensing – Ground Truth Demo and Test Facilities

In the past ten to fifteen years, satellite-based Earth observation technology has made enormous progress. Today's satellite-based sensors provide a wide range of spatial and temporal resolutions as well as highly valuable data sources to feed complex regional or global environmental model systems. Despite the immense progress in the use of satellite data, there are still several obstacles preventing effective use. The primary problem arises from the fact that the exact relation between the remotely sensed proxy (e.g., radiometric or spectral signal) and the environmental quantities and qualities of interest is very often not or only poorly known. As a consequence, substantial uncertainties exist in the inter-pretation of such remotely sensed data. Therefore, new approaches in satellite data analysis based on comprehensive verification concepts are necessary in order to better translate satellite signals for essential environmental variables of the Earth system.

The Helmholtz Association operates several multi-objective observatories for environmental monitoring and research in Europe and its periphery (e.g., TERENO, OceanSITES, COSYNA, GCO-CA, PBO Turkey). These observatories provide long-term data for different environmental compartments at different spatial and temporal resolutions, including the geosphere, cryosphere, hydrosphere (including oceans), pedosphere, biosphere, and atmosphere. Through the extension of these Helmholtz observatories, the new ACROSS infrastructure will significantly contribute to close the satellite data validation gap and the observatories will serve as robust validation and calibration sites at different temporal and spatial scales.

At these extended sites ACROSS will:

• Continuously collect data up to the landscape level which i) specifically refers to relevant surface processes and ii) relates to the signal recorded by the satellite, i.e., spectral and radiometric information;

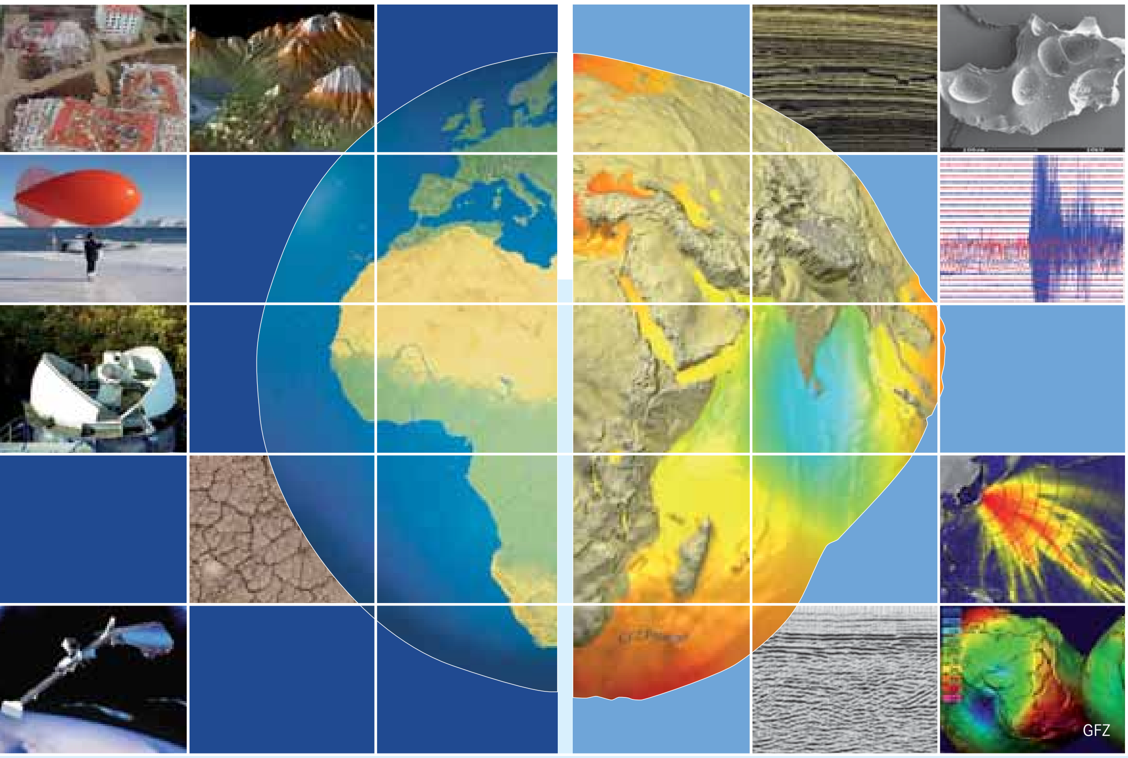
• Develop, test and approve innovative and transferable monitoring concepts and novel algorithms for the extraction of essential environmental parameters;

• Provide high-quality data series to validate existing and newly developed concepts (e.g., inverse modelling, stochastic data fusion approaches) and upscaling theories to estimate effective parameters, fluxes, and state variables at various scales;

• Support the development of forecasting and early warning systems in order to minimise the impact of extreme events (extreme weather events like floods and droughts, freshwater quality, desertification, earthquakes, landslides, tsunamis, etc.).

By relating ground truth data with satellite data, ACROSS will lay the foundations for overcoming technological and methodological challenges for the transfer of proxies remotely sensed by satellites into environmental parameters. Furthermore, the ACROSS infrastructure will be deployed to develop, improve and validate monitoring concepts which are likely to facilitate the future usage of satellite data. By closely linking the already existing observatories, ACROSS supports a better integration of Helmholtz activities across different marine, coastal and terrestrial systems. By combining the efforts, expertise and capabilities of nine Helmholtz Centres and their partners under the coordination of Helmholtz-Zentrum für Umweltforschung – UFZ and Forschungszentrum Jülich GmbH, we will create conditions to overcome still existing limits in integrated environmental monitoring and research, e.g., coupling of Earth surface ecosystems and atmosphere, connection between terrestrial hydrosphere and estuaries/marine systems. Short-term products of ACROSS are innovative monitoring concepts, novel algorithms, and models for the interpretation of remotely sensed information and the prediction of key parameters and states of the Earth system.

In the medium to long term, ACROSS will generate highly integrated multi-scale data sets as a solid basis for the validation of scientific concepts and models. Thus, ACROSS serves as an important basis for GEMIS, the global integrated multi-parameter Earth monitoring and validation system planned by the Helmholtz centres organized in the research field “Earth and Environment” (see below). The recently approved ACROSS initiative will start its operations in 2013.



GEMIS - Observing Earth, its dynamics and change from core to space.

GEMIS – Global Earth Monitoring and Validation System

ACROSS is the first step towards a global initiative forming the proof of concept at the European scale. All nine Helmholtz Centres participating in the research area “Earth and Environment” are currently involved in developing a follow-up concept for a Global Earth Monitoring and Validation System (GEMIS). This concept will provide guidance to Helmholtz institutions as to their role in the context of global and regional Earth observation and the demands entailed. Five goals have been identified to guide the establishment of a dedicated Earth observation infrastructure:

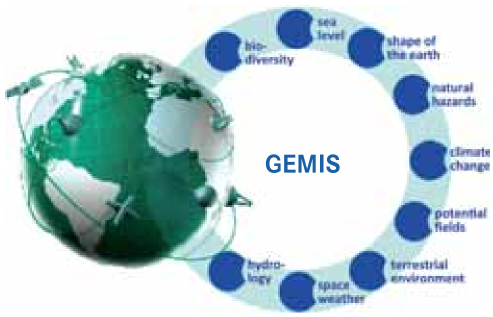
- To obtain long-term and consistently high-quality series of measurements of critical parameters for use as input for assessment, models and simulation;
- To collect data in regions that are most sensitive to hazards and global change;
- To ensure a high degree of integration of remotely sensed and in situ data series to facilitate joint information products;
- To strive for multiparameter measurement series at the same locations/regions;
- To resolve key parameters and critical processes through dedicated short-term deployments of high-resolution enhanced networks.

The aim of a globally integrated multiparameter Earth observation system lies in the spatial and temporal high-resolution mapping of relevant environmental processes, the monitoring of current states and trends in the Earth system, the measurement of critical abiotic and biotic parameters as well as long-time records of global and regional changes. These will allow us to gain a better understanding of the processes taking place in the Earth system, to improve our models and to deliver more reliable forecasts and scenarios for the future. Of particular importance here is the gathering of homogenous data series of consistent quality around the globe in order to minimise input uncertainties in models and scenarios and thereby to improve forecasts and decision-making bases. Therefore, it is mandatory to establish in situ observatories to serve as the urgently needed scientific ground segment for all types of Earth observation satellites for calibration and ground truthing. GEMIS will define the Helmholtz association’s contribution to the global systems of Earth observation as outlined, for example, in the Global Earth Observing System of Systems (GEOSS), the international Group on Earth Observations (GEO) and their European counterparts such as GMES (Global Monitoring for Environment and Security).

The Earth observation system GEMIS is to consist of three components:

- In situ multi-parameter observatories;
- Extensions of remote sensing capabilities for global near real-time coverage;
- Centres for infrastructure operations, data distribution, and capacity development.

The GEMIS concept has been developed on the basis and experience of several multi-objective observatories for environmental monitoring and research (see above described observatories) which are already operated by the Helmholtz Association, and which have in part been recently linked to the new integrated ACROSS infrastructure. The concept has been included in the national roadmap for large-scale research infrastructure of the Ministry for Science and Technology.



GEMIS contributes to the Global Earth Observing System of Systems (GEOSS).

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