



TERENO – Finding local solutions to global change

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Content

FINDING LOCAL SOLUTIONS TO GLOBAL CHANGE	4
OBSERVATORIES OF THE TERENO PROJECT	6
EIFEL/LOWER RHINE VALLEY OBSERVATORY	8
HARZ/CENTRAL GERMAN LOWLAND OBSERVATORY	12
NORTHEASTERN GERMAN LOWLAND OBSERVATORY	16
BAVARIAN ALPS/PRE-ALPS OBSERVATORY	20
TAKING TO THE SKIES TO GET TO THE BOTTOM OF SOIL MOISTURE	24
GOOD OPPORTUNITIES FOR JUNIOR RESEARCHERS	25
THE WORLD'S LARGEST LYSIMETER NETWORK	26
CLOSE COOPERATION WITH CLIMATE RESEARCHERS	27
TERENO-MED: A FOCUS ON WATER RESOURCES IN THE MEDITERRANEAN	28
ADAPTING TO CLIMATE CHANGE	30
TERENO ORGANISATION	31

Finding local solutions to global change

A changing world

Global change has triggered a number of environmental changes, such as alterations in climate, land productivity, geo-resources soil and water, and atmospheric chemistry. Many areas of the Earth-Human system are affected, thereby directly impacting the lives of present and future generations. Like many countries, Germany too is faced with the threat of increased droughts and heat waves, soil degradation, winter storms, water shortages at one extreme and flood events at the other, as well as a decline in biodiversity. These changes can range across broad temporal and spatial scales and present strong regional differences. For example, in Germany summer precipitation decreased by 20% between 1900 and 2000 in the north-east, while it increased by up to 50% in the south and south-west over the same time period.



PARTICIPATING HELMHOLTZ RESEARCH CENTERS

- Forschungszentrum Jülich – FZJ
- Helmholtz Centre for Environmental Research – UFZ
- Karlsruhe Institute of Technology – KIT
- Helmholtz Zentrum München – German Research Center for Environmental Health – HMGU
- German Aerospace Center – DLR
- Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences

and research the long-term ecological, social and economic impact of global change at regional level. For example, the programme monitors changes in the hydrosphere, biosphere, pedosphere, lower atmosphere and anthroposphere over various spatial and temporal scales. The project is scheduled to run for 15 years and is supported by six Helmholtz Research Centers which provide the basis for cooperation projects with universities and other research organisations.

Uniting terrestrial research

TERENO partners have set up four regional “terrestrial observatories” in regions representative for Germany: Eifel/Lower Rhine Valley, Harz/Central German Lowland, Bavarian Alps/pre-Alps and Northeastern German Lowland (see map). Existing research stations and activities in these regions have been integrated into the observatories. All four observatories are equipped with a combination of in-situ measuring instruments, as well as ground-based and airborne remote sensing techniques. These include measuring systems for the determination of regional precipitation, micrometeorological eddy-covariance systems, sensor networks, as well as monitoring systems for the quantification of water, matter and energy flows. Further infrastructure measures include high capacity data processing and communication systems to guarantee fast access to the environmental data sets collected. Furthermore, TERENO partners are developing new sensor and monitoring concepts, as well as models that can also be applied in areas less well-equipped with measuring technologies.

The United Nations’ Intergovernmental Panel for Climate Change (IPCC) regularly publishes reports on the current state of climate knowledge. However, long-term changes that have been and will be triggered by global change cannot be assessed with any degree of accuracy as numerous environmental processes have yet to be adequately understood. In particular, we have yet to understand how individual environmental systems, key processes and feedback effects work in detail. On the one hand, local parameters affect the overall system, on the other hand global environmental variables and feedbacks play an important role in highly complex local environmental systems. In addition, there is a lack of data series collected over longer time periods. Such data are the key to recording long-term regional changes and developing regionally effective adaptation and mitigation strategies.

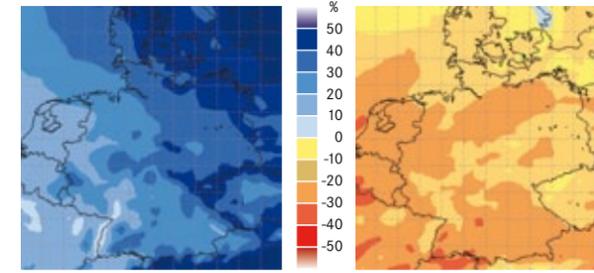
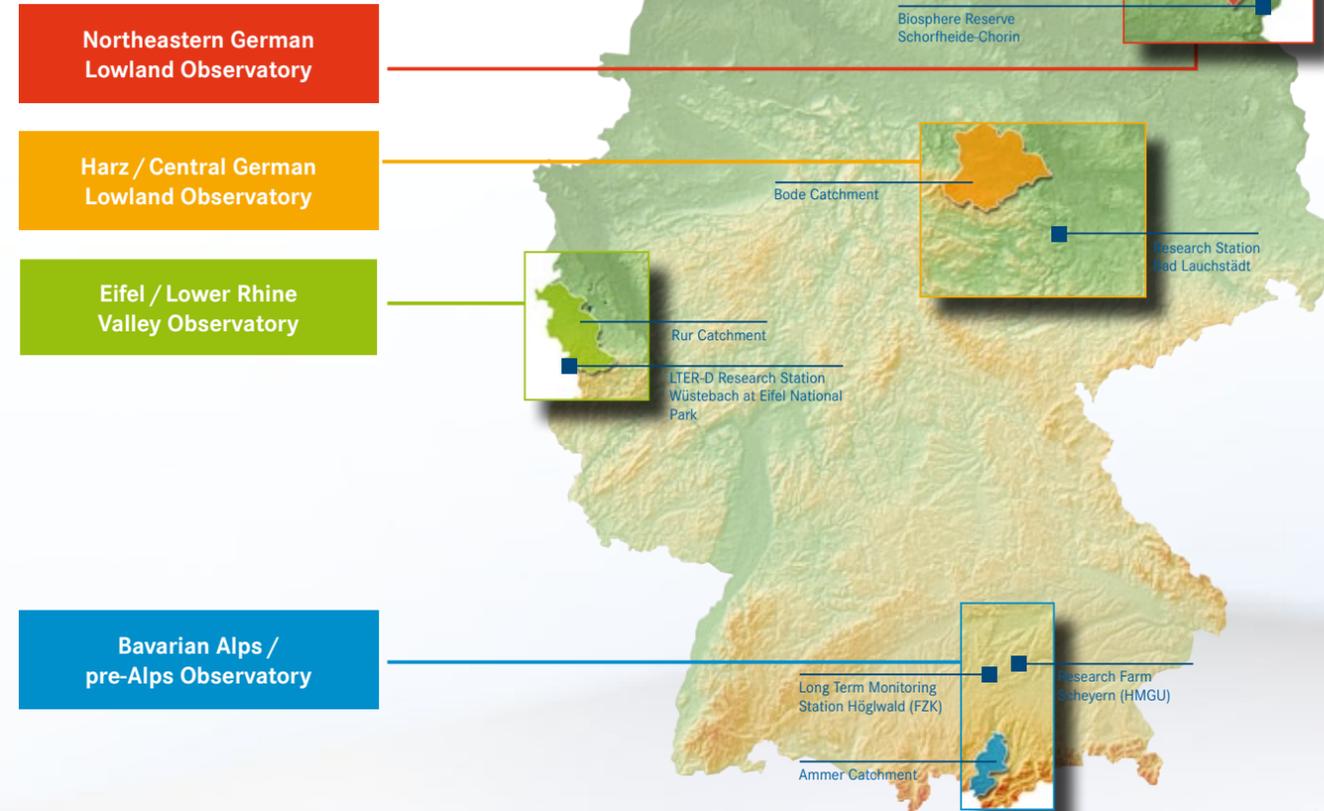
TERENO – a national Earth observation network

It is against this background that the Helmholtz Association launched the TERENO (TERrestrial ENVIRONMENTAL Observatories) initiative in 2008. TERENO spans an integrated Earth observation network of observatories across Germany that extends from the North German Lowlands to the Bavarian Alps, with a focus on particularly sensitive regions. An interdisciplinary and long-term research programme aims to catalogue

IMPORTANT SCIENTIFIC QUESTIONS

- What are the effects of global change on the terrestrial systems groundwater, soil, vegetation and surface waters, and consequently, on the development of the human habitat?
- How do feedback mechanisms affect the exchange processes of terrestrial systems (e.g. between land surface and atmosphere) as well as the terrestrial fluxes of water and matter?
- Which direct influences do changes in soil and land use (e.g. due to the EU Cross Compliance Directive, promotion of energy crops) have on the water balance, soil fertility, biodiversity and regional climate?
- What are the consequences of large-scale anthropogenic interferences (e.g. open mining, the development of water systems, forest conversion, changes in agrarian farming systems) on terrestrial systems?

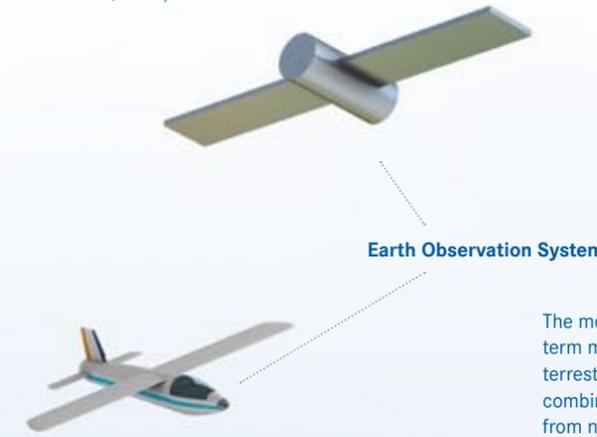
Observatories of the TERENO-Project



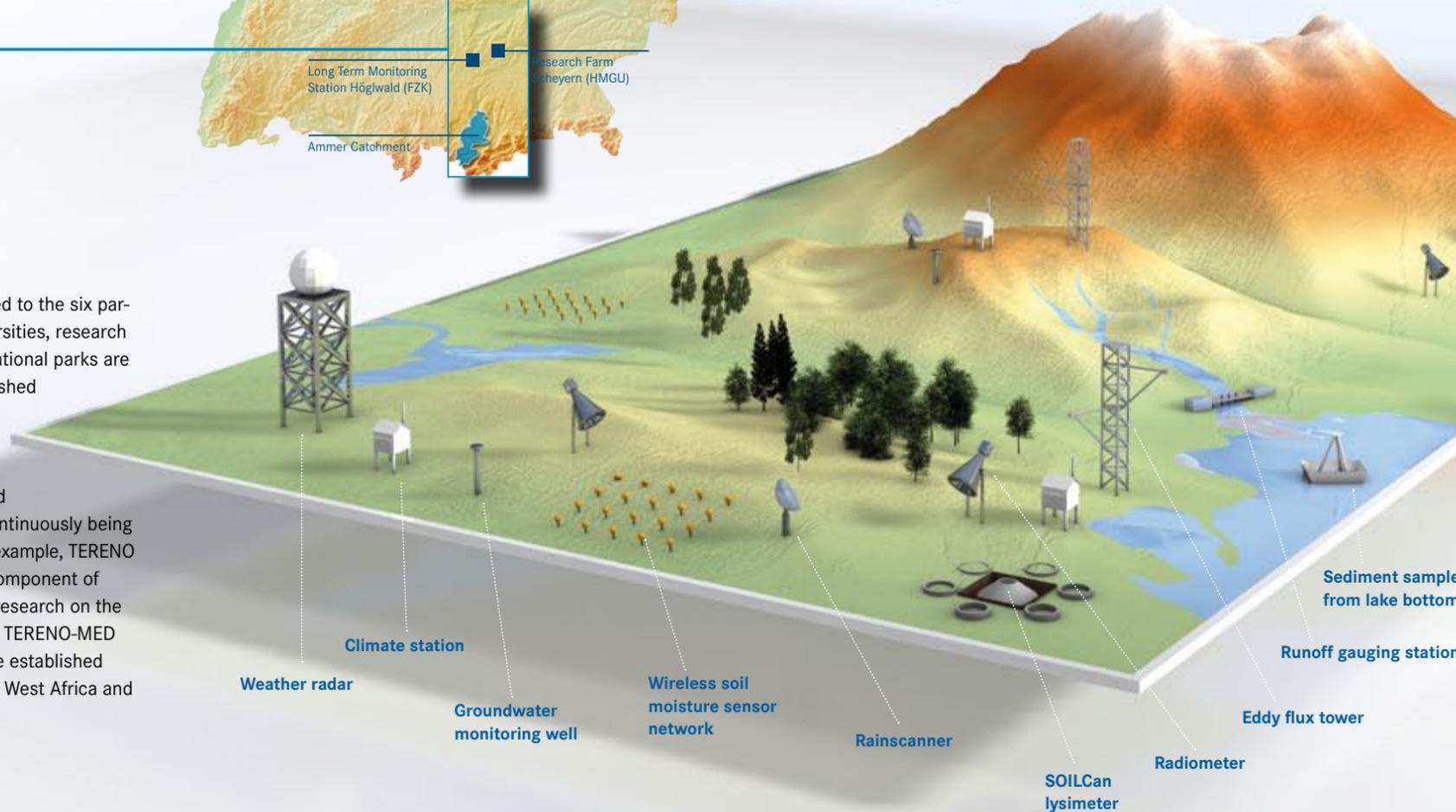
Predicted mean relative change (in percent) in seasonal precipitation in Germany for winter (left) and summer (right) for the period 2071 to 2100 compared with 1961 to 1990 (ensemble mean from 12 regional climate simulations; www.regionaler-klima Atlas.de, verified 2 July 2011, Meinke et al., 2010).

New models for better forecasts

Through work carried out at its observatories and the development of new measuring methods, TERENO provides long-term data on changes in condition and matter fluxes of terrestrial systems on an unprecedented scale. These include, for example, groundwater renewal rates, river outflow volumes, data on the leaching of chemicals from the soil into groundwater, or of the flows of organic soil substances, as well as emissions of greenhouse gases into the atmosphere. The data sets will significantly foster the validation, advancement and integration of terrestrial models (e.g. groundwater and soil water balance models, regional climate and weather prognostic models). The research community can use these models to derive efficient prevention, mitigation and adaptation strategies. Possibilities include the optimisation of irrigation systems, the development of warning systems for extreme weather events and flooding and integrated control systems of water management constructions.



Cooperation in the observatories is not limited to the six participating Helmholtz research centres. Universities, research organizations, government authorities and national parks are closely involved. TERENO has already established itself as a focus for terrestrial research in Germany, bringing together activities that have up to now been run separately. Through cooperations with other national and international networks, collaborations are continuously being extended at a European and global level. For example, TERENO is a partner of ICOS-Germany, the national component of the European observation network ICOS for research on the carbon cycle and greenhouse gas emissions. TERENO-MED and the WASCAL and DESERVE projects have established close links with the Mediterranean as well as West Africa and the Near East.



EASY ACCESS: TEODOOR DATA PORTAL

Data collected over the course of the TERENO project are made accessible in a processed form through the central internet portal TEODOOR. The portal enables scientists within the TERENO community, as well as external users, to search, view and download data by specific themes and regions. For example, data generated from runoff gauging stations, climate and soil moisture stations is available online. In addition, TEODOOR provides information on dissertations and publications that are published in connection with TERENO.

TEODOOR
<http://teodoor.icg.kfa-juelich.de/tereno-online-portal-folder/Tereno%20Online%20Data%20Portal>
TERENO Data Policy
<http://teodoor.icg.kfa-juelich.de/overview/downloads/TERENO%20Data%20policy.pdf>



Eifel/Lower Rhine Valley Observatory

Where unspoiled nature and large-scale human intervention meet

The catchment area of the Rur river is the central research area of the TERENO observatory “Eifel/Lower Rhine Valley”. It spans an area of 2354 square kilometres and is subject to a wide variety of uses: the relatively flat region in the north is densely populated and is intensively farmed.



In contrast, the low mountain ranges to the south are sparsely populated. Several important drinking water reservoirs and recreational areas are located there. The region is also home to the Eifel National Park, which serves as a reference area for a natural environment largely untouched by human hands. The observatory is coordinated by the Forschungszentrum Jülich (FZJ), and has attracted numerous partners such as universities and public authorities.

IN FOCUS

Measuring stations are located throughout the entire Rur catchment area. They cover areas with a variety of hydrological characteristics and collect information on, for example, soil moisture and groundwater levels, as well as water, material and energy flows.

The forested catchment area of the “Wüstebach” located in the Eifel National Park, is one such measuring stations. Scientists at the site employ numerous meteorological, pedological and hydrological sensors to measure the forest system’s water and matter cycles. A 34-metre high measurement tower was installed in order to record the greenhouse gas flows between the forest ecosystem and the atmosphere. Greenhouse gases in particular, such as carbon dioxide and nitrous oxide, are a main focus of this research. How much of these greenhouse gases, if at all, is absorbed by the forests or released in to the atmosphere according to environmental conditions, has a deep impact on climate change. The tower is also used to conduct research on bats and serves as a platform for a rain scanner.

The Wüstebach measuring station, along with the Selhausen und Rollesbroich measuring stations, is part of the European research infrastructure ICOS (Integrated Carbon Observation System), which aims to quantify the long-term balance of greenhouse gas flows in Europe (see page 28).

What makes the Wüstebach catchment area particularly interesting is a decision taken by the National Park’s management to convert the areas of spruce forest, which were previously used for timber production, into a more natural mixed deciduous forest. Scientists at the FZJ are co-ordinating this process together with colleagues at the universities of Bonn, Aachen, and Trier. Over a period of more than 15 years, they will evaluate the effects of the conversion on the soil, water quality and the exchange processes with the atmosphere, as well as on biodiversity.

Wireless network for measurement data

In order to monitor the effects of this change in the identity of the forest in detail, a cutting-edge wireless soil sensor network called “SoilNet” was installed. The network was developed within the framework of TERENO by scientists from the FZJ. Soil moisture and temperature are measured by over 1000 sensors at three different depths. Wireless transmitters relay the data to a receiver, which in turn sends the data on to the FZJ in near real-time. In addition, the Wüstebach site also contains six lysimeters from the TERENO-SOILCan network (see page 26). The project investigates the effects of global change on the matter and water balances in the soil, by subjecting soil samples to different climatic conditions.



Monitoring the soil from the sky

TERENO researchers measure soil brightness temperature and consequently water content of the soil in a field outside the village of Selhausen. Perched on top of a 20-metre high converted crane is an L-band radiometer. Researchers are therefore able to cover a wider research area, and additional measuring equipment can be secured to the crane rig.

One research focus is on the effects of surface structure on soil evaporation. Measurements are supplemented with a mobile radiometer that tests different areas of arable land. In addition, the measurements help to validate the data collected by the SMOS (Soil Moisture and Ocean Salinity) satellite mission, a campaign run by the European Space Agency (ESA). SMOS generates a global soil moisture map every three to four days. Selhausen is also an important site for the SOILCan network, as it is equipped with 24 lysimeters.

The TERENO test site Rollesbroich is a veritable hub for international collaborations. The soil moisture station is part of the worldwide COSMOS network, in which cosmic radiation is used to collect non-invasive soil moisture measurements. In addition, a micrometeorological station is also located at the site. It determines energy, water and CO₂ flows, and is part of the European ICOS network. 200 measurement points for the soil moisture sensor network SoilNet were also installed in Rollesbroich together with six lysimeters from the SOILCan network.

EARLIER ALERTS

The weather radar run by the FZJ is an important part of the TERENO observatory “Eifel/Lower Rhine Valley”. It is installed on a 34-metre high tower at the 290-metre high Sophienhöhe site, a slag heap from an open-cast mine which dominates the local area and as such, provides an ideal location for the weather radar. At 1.4 million euros, the station is one of the TERENO project’s most substantial investments.

The weather radar station enables researchers to monitor regional rainfall within a 100 kilometre area with greater accuracy than previously possible. They can pinpoint location to within 200 metres and what is more, they can predict whether it will rain, snow or hail. Comparable stations only indicate whether precipitation is present, but not what form it takes. Other institutions also benefit from the weather data: the station is networked with other radar stations, including the identical weather radar at the Meteorological Institute of the University of Bonn. The FZJ researchers also collaborate with the German Meteorological Service (DWD).

In addition the weather radar provides better protection against storms and flooding. In recent years the Eifel region has been particularly affected by local flooding causing significant damage. Data from the weather radar flow into a hydrological model for flood forecasting. Scientists at the FZJ work together with local water boards, the Erft Water Authority and the Eifel-Rur Water Association, who tailor their infrastructure such as sluice gates and pumping stations to the forecasts they receive.

Current images from the weather radar:

<http://teodoor.icg.kfa-juelich.de/overview-en>

CLOSE COOPERATION WITH THE TR32

The partnership between the TERENO observatory “Eifel/Lower Rhine Valley” and the Transregional Collaborative Research Centre 32 “Patterns in Soil-Vegetation-Atmosphere Systems” (TR32) at the universities of Bonn, Cologne, and Aachen is a showcase for successful collaboration. The TR32 has been run by the German Research Foundation (DFG) since 2007. The project focuses on the exchange of energy and materials between the soil and the atmosphere according to landscape pattern. For example, the exchange processes for carbon dioxide and water vapour over a flat field are different than those in a forest in the mountains, and are maintained to different heights.

Scientists from the TR32 therefore have access to state-of-the-art measuring equipment.

<http://tr32.uni-koeln.de/index.php>





Observatories

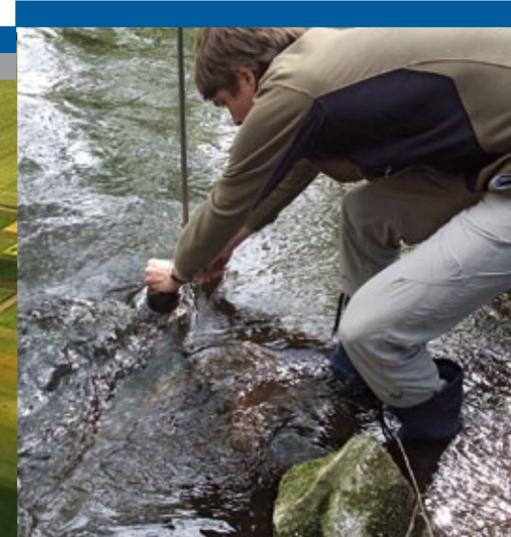
Harz/Central German Lowland Observatory



The effects of climate change and land use on biodiversity

The TERENO “Harz/Central German Lowland Observatory” covers various landscape types that are characteristic for Central Germany: from the Harz mountains in the west, to the course of the Elbe river with its flood plains in the east, from predominantly agricultural regions to large urban areas such as the cities of Leipzig and Halle. Correspondingly, there is a wide range in land use, urbanity and sensitivity to changes in climate which is captured by the observatory. In recent decades, the effects of climatic changes have begun to be observed in the region: some areas are increasingly troubled by drought, while precipitation rates have been rising during the winter months. The mean annual air temperature rose by 0.5 to 1.5 degrees Celsius. The observatory is coordinated by the Helmholtz Centre for Environmental Research – UFZ.





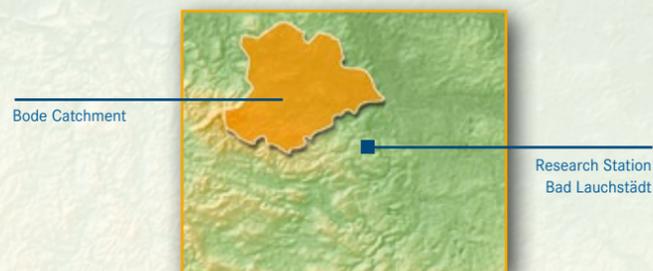
➤ Harz/Central German Lowland Observatory

IN FOCUS

Based on UFZ priority areas in environmental research, water research, soil research, biodiversity research and different social scientific aspects form the central focus of the research programme at the TERENO “Harz/Central German Lowland Observatory”. Monitoring and research activities are concentrated in four main corridors. A team of scientists is investigating the relationship between climate, land use and water balance in a hydrological observatory covering the catchment of the Bode river. The effects of changes in climate and land use on the species variety of flora and fauna are being explored along two transects: along a transect following the course of the river Bode into the Magdeburger Börde region, and in an area spanning from Leipzig via Halle to the Harz region. A special flood plain research platform covers the course of the Elbe from the border of Saxony up to Magdeburg. Studies at this platform focus on the impact of climate effects on the hydrological extremes and particularly sensitive flood plain habitats. At the Leipzig site the focus is on the interactions between the climate and urban processes.

Hydrological observatory in the Bode catchment

The catchment of the Bode river is one of the most intensively monitored catchment areas in Germany. The German Meteorological Service (DWD) and the State Agency for Flood Defence and Water Management of Saxony-Anhalt have, over a period of many decades, established a dense network to measure meteorological data as well as river discharge. The hydrological observatory of the TERENO observatory “Harz/Central German Lowland” is located here.



Working within the framework of TERENO, scientists from the UFZ have installed online measuring stations at various runoff points to monitor water quality. In addition, a rain radar and additional weather stations were installed in those sections of the catchment area that are relevant for modeling studies. To date, five intensive measuring sites are in place in selected areas, each measuring no more than a few square kilometres, in order to investigate specific hydrological issues and matter fluxes in detail.

The research focus at the forest site “Hohes Holz” is on the fluxes of energy, water and trace gases at the interface between soil and atmosphere. At a section of the Selke river, one of the tributaries to the Bode, scientists are engaged in a detailed investigation of the dynamic of water and matter at the interface between the flowing water, river sediment and groundwater. In collaboration with the University of Applied Sciences Magdeburg-Stendal, the UFZ is setting up an infrastructure for multi-scale monitoring of soil moisture dynamics within the Schäfertal catchment area. The continuous automatic measurements are complemented by regular geophysical measuring campaigns as well as airborne and satellite based remote sensing. Researchers working in the Sauerbach area of the Magdeburger Börde are focusing on water and matter flows in an intensively farmed small catchment.

Rappbode Dam Observatory

The Rappbode Dam, located in Central Germany, is the country’s largest drinking water dam, supplying water to more than one million people. The dam has three main tributaries, which are also impounded by auxiliary dams: the Bode, Hassel and Rappbode rivers. Different types of land use characterise each of the respective catchment areas. As a result, there is significant variation in the type of nutrients and in the quantities of dissolved organic carbon (DOC) flowing into the dams via the three tributaries. TERENO researchers at the dam observatory want to gain a quantitative and more detailed understanding of the complex interactions between the catchment areas and water quality in the reservoirs. There is a particular focus on the transport of carbon and nutrients from the catchment area as well as on determining the relevant parameters for these matter fluxes into the dams. A further research focus is the nutrient and organic carbon turnover in lacustrine ecosystems.

Water quality adversely affected by DOC concentration

A core research focus is the dynamic of dissolved organic materials in drinking water reservoirs. Over the past 20 years, the concentration of dissolved organic carbon (DOC) at the Rappbode Reservoir has been steadily rising.

Currently, the dynamics of various physical, chemical and biological parameters are being continuously monitored at nine sites. These measurement stations are located at each of the tributaries to the reservoir system, at the connections between the auxiliary dams and the main reservoir, as well as at the main reservoir and its outlet. Close cooperations have been initialised with the reservoir authority (Talsperrenbetrieb Sachsen-Anhalt) and the drinking water company (Fernwasserversorgung Elbaue Ostharz) leading to an active exchange of data and knowledge.

BIODIVERSITY RESEARCH

Biodiversity refers to biological diversity from the ecosystem and biocenosis level to genetic species diversity. Biodiversity research in TERENO focuses on how changes in the climate and land use impact on:

- Local adaptation of species populations based on genetic variation
- Plant population genetics
- Distribution areas of species, including changes in biocenoses
- Entire biocenosis, including knock-on effects on ecosystem functions and services, such as erosion protection, pollination and CO₂-fixation

The aim is to record biodiversity and its role in central ecosystems and landscapes in relation to environmental factors such as temperature, precipitation and land use. Based on their findings, the researchers plan to develop concepts for the sustainable use of ecosystems and landscapes. In addition, the basis for management options is to be established.

Recreating global change

The TERENO researchers can draw on a network of study areas for the observation and monitoring of species and biocenosis. The region along the course of the river Bode into the Magdeburger Börde region is one option, as is the transect leading from Leipzig via Halle to the Harz region. The experimental research facility in Bad Lauchstädt provides scientists with the opportunity to recreate climate change scenarios. For example, the Global Change Experimental Facility (GCEF) makes the targeted recording of the influences of changes in the climate and in land use on the environment possible.



Observatories

Northeastern German Lowland Observatory

Better predictions for the future using data from the past and present

The TERENO observatory “Northeastern German Lowland” spans an area of Germany which is considered one of the regions most severely affected by climate change. The impact of increased dry periods is already being felt, drying out the regions’ numerous lakes and mires. The observatory covers the catchment area of the Ucker river, the Müritz National Park, the biosphere reserve Schorfheide-Chorin and the DEMMIN calibration and validation test site run by the German Aerospace Center (DLR). The GFZ German Research Centre for Geosciences in Potsdam and the DLR Earth Observation Center (OEC) are coordinating work at the observatory and are cooperating closely with universities and other research organisations. Of particular note is the emphasis being placed on geoarchives. The aim is to acquire and combine high quality data on climate developments in the past and present to improve forecasts for the future.



IN FOCUS

In addition to elucidating climate dynamics and landscape evolution, the research programme at the observatory in the North-East German Lowlands covers three further thematic core areas: remote sensing, hydrology and geopedology. The Müritz National Park, founded in 1990, is an important research area. Spanning some 322 square kilometres it is one of the largest national parks in Germany. The landscape is young and was formed by three ice ages, the last one ending some 17,000 years. The park includes forests as well as numerous lakes and mires.

At its eastern tip, the Müritz National Park borders the catchment area of the Ucker river, the biosphere reserve Schorfheide-Chorin lies to the south. What makes these regions interesting is their differences in landscape use. Unlike the landscape of the Müritz National Park, human intervention has been greater in the other two areas. In the Schorfheide, with pine and beech forests, land use is moderate and characterised by organic farming. In contrast, large parts of the Ucker catchment area are intensively farmed.

Natural archives provide valuable information

Comparing these different areas enables researchers to better estimate whether changes can be attributed to global change, short-term natural fluctuations or interference through agriculture or forestry. For example, many lakes in the region have seen their water levels fall by over one metre over the last 30 years. Natural archives, such as lake sediments or annual tree rings provide information on how lake levels have responded to changes in environmental conditions over recent centuries to several millennia. Tree-ring widths and other physical and chemical properties reveal dry and wet periods, as well as extreme events.

1611 AD

1550 AD

The oldest trees in the Müritz National Park are some 300 years old. The trees being analysed in the Müritz National Park can be up to 500 years old. Another useful archive are first-

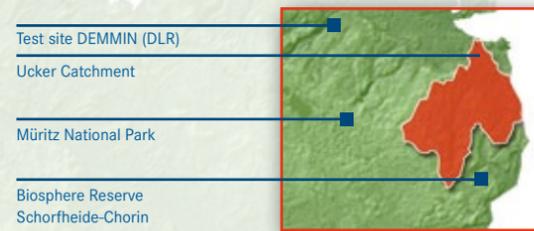
hand accounts, such as those contained in old chronicles and books, which provide details about what the weather was like in the past.

In addition to evaluating lake sediment and tree rings, researchers also collect and examine samples of archaeological and historical wood and paleosoils. Other useful archives include first-hand accounts about what the weather was like in the past as well as remote sensing databases.

The challenge lies in linking information from the past with data and processes that are currently being recorded at the TERENO observatories. Once this has been achieved, new climate models and better long-term climate forecasts will be possible. Scientists working at the Northeastern German Lowland observatory are making different long-term measurements in forest, arable and grass land soils, for example, collecting data on water evaporation through plants and the soil surface. Together with partners from universities and other research organisations they are investigating the matter and energy balance of different soils and the exchange processes with the atmosphere and hydrosphere. Within the framework of TERENO-SOILCan for example, six lysimeters were installed at the Dedelow test site, which is run by the Leibniz Centre for Agricultural Landscape Research (ZALF).

DEMMIN test site

The DEMMIN test site (Durable Environmental Multidisciplinary Monitoring Information Network) has been run by the DLR's Earth Observation Center (EOC) since 1999. Located in the northern part of the observatory, some 180 kilometres north of Berlin, DEMMIN is a test site for the calibration and validation of remote sensing missions and data, spanning an area of 50 kilometres by 50 kilometres. Joint partner is the Demmin Network (IG Demmin), an association of the region's farmers. The Demmin Network spans some 30,000 hectares. Researchers working at the site collect environmental data on vegetation, soil and exchange processes between the soil and the atmosphere in order to compare these in situ data with data from aerial images and satellite pictures collected by remote sensing. These studies can be applied to other areas which have the necessary remote sensing information, making it possible to gain new insights into the environmental data collected there.



In 2004 the DLR installed an agrometeorological weather monitoring network, which, amongst other things, allows for detailed recordings of precipitation and radiation parameters, as well as soil moisture and temperature. In addition, so-called corner reflectors enable the verification of radar signals, making it possible for researchers to study, inter alia, the exchange processes of water as a function of the weather. Within the framework of TERENO-SOILCan, six lysimeters were added to the weather monitoring network. These on-the-ground measurement devices provide the DLR scientists with local values on water and material balances. At the same time, remote sensing data can be compared with data collected simultaneously on the ground. This provides the basis for the development of remote sensing data products and their integration into environmental models.

CO₂-BALANCE WITH CARBOZALF

Only around 45% of the carbon dioxide (CO₂) produced by humans is retained in the atmosphere. The rest is swallowed up by the oceans and absorbed by soil and plants. How that happens in detail, and which landscapes are CO₂ sources or sinks, remains largely unexplained. CarboZALF, a field laboratory in the TERENO observatory "Northeastern German Lowland" run by the Leibniz Centre for Agricultural Landscape Research (ZALF) aims to address these questions. ZALF is conducting its research in close collaboration with the GFZ and the University of Potsdam. The goal is to gain an overall picture of the carbon balance for particular landscapes.

One example, which is particularly pertinent for the region around the TERENO observatory "Northeastern German Lowland": bogs release CO₂ into the atmosphere. Flooding a bog can put a stop to these emissions. However, it also releases the even more harmful greenhouse gas methane. If the factors responsible for this process are better understood, it might be possible to bypass the methane production stage. In addition, the researchers want to find out how the increased cultivation of energy crops affects the CO₂ balance.

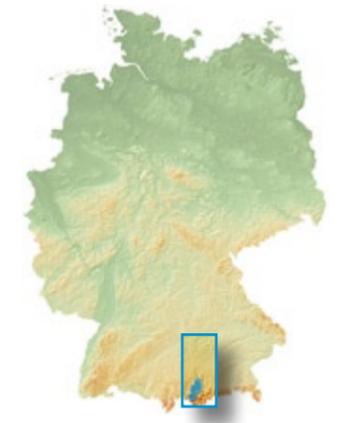
The lysimeter station in Dedelow supplies the project with important information about water and material balances. Three of the six lysimeters which have been installed originate from the CarboZALF experimental site. Making use of the absorption of laser light in the air, the scientists also want to find out how CO₂, methane and other trace gases evaporate from expanses of water or from the ground. To this end, the University of Potsdam and the GFZ are developing a new infrared absorption spectrometer.





Observatories

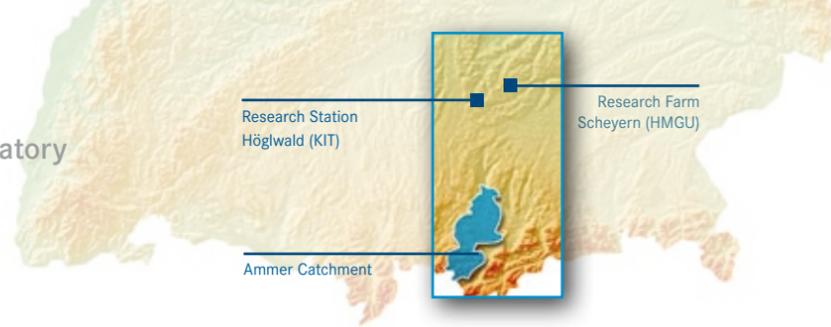
Bavarian Alps/pre-Alps Observatory



Particularly sensitive to the effects of climate change

Melting glaciers, floods and landslides are all clear signals: mountainous regions are particularly sensitive to the effects of climate change. That is not the only reason why the TERENO Observatory “Bavarian Alps/pre-Alps” is so important for climate research. The catchment area of the Ammer river in southern Bavaria is characterised by a complex topography. This diversity is reflected in the large differences in soil, climate, land use and rainfall. The research platform Höglwald and the Scheyern agricultural research farm, both in operation for more than 20 years, have valuable long-term data at their disposal. The observatory is coordinated by the Karlsruhe Institute of Technology (KIT) and the Helmholtz Zentrum München.





IN FOCUS

The approximately 709-square kilometre Ammer region provides TERENO researchers with the opportunity to study the effects of climate change on completely different landscape types. For example, the highest point lies 2185 metres above sea level, the outflow is at 533 metres. Long-term mean annual precipitation in the northern part is 1,100 millimetres a year, while the southern part with the summits of the Ammer Alps receives more than 2,000 millimetres a year. The researchers are particularly interested in the exchange processes between the soil and the atmosphere under short-term and extreme weather events. Under the direction of the Karlsruhe Institute of Technology (KIT) they have built measuring stations at three elevations along the topographical profile. The stations have been equipped with, amongst other things, climate stations, eddy covariance systems and 36 lysimeters.

Research foci include the cycles and storage of carbon and nitrogen. The scientists are investigating the relationship between the biosphere and the atmosphere – for example, of energy flows and of trace gases such as carbon dioxide, nitrous oxide and methane – and the particularly sensitive terrestrial hydrology in pre-alpine ecosystems. Vegetation, microbial biodiversity and temporal dynamics of matter turnover also play an important role. For instance, one of the questions to be addressed here is what connections exist between exchange processes and the change in biodiversity.

Instrumentation within the Ammer catchment area is supplemented by a rain scanner situated on top of the 950-metre high Kirnberg mountain. The microwave radar collects data on rainfall within a 50 kilometre radius. Next to the 16-metre high tower stands a smaller mast which records common weather

data such as wind and temperature. Similar weather stations can be found at each of the observatory's test sites. In addition, TERENO researchers benefit from long-term hydrometeorological observations collected by the mountain weather station on the Hohen Peißenberg mountain, which was founded in 1781 and is run by the German Meteorological Service (DWD).

“Höglwald Forest” research platform

The Höglwald is located approximately 70 kilometres north of the Ammer river catchment area and about 40 kilometres west of the city of Munich. A spruce forest over 100 years old, the Höglwald is part of a region characterised by a mixture of forested and intensively farmed land. With the help of the research platform which was set up in 1993, scientists are investigating the exchange of trace gases, in particular of nitrogen compounds such as nitrous oxide or ammonia. The Höglwald is known to be oversaturated with nitrogen, there is high nitrate contamination of the leachate, nitrous oxide emissions – a dangerous climate killer – are also above average.

Fully automated monitoring systems have been installed at three research areas in the Höglwald, where they monitor the exchange of greenhouse gases between the soil and the atmosphere all year round. Measuring chambers are new additions – they have been installed at the very edge of the forest next to a field. They are intended to collect data on the input of ammonia generated by agriculture into the forest. In addition, measurement equipment erected on top of a 50-metre high tower record flows of water vapour and carbon dioxide.

USING RADIO NETWORKS TO COLLECT MORE ACCURATE PRECIPITATION DATA

A new measurement technique is set to improve the temporal and spatial accuracy of precipitation data. The research project PROCEMA (“Regional Precipitation Observation by Cellular Network Microwave Attenuation and Application to Water Resources Management”) is making use of unusual means to achieve this goal: radio links run by mobile network operators.

Conventional precipitation measurement methods only provide average values, which is too imprecise for the large variations in rain and snow experienced in the Alps. While rain radars offer higher spatial resolution they are prone to error. Radio links are usually used by mobile phone network providers for communication between base station towers. The antennae exchange microwave signals in the frequency range 10 – 40 gigahertz.

The signals are attenuated by rain, snow and hail – a nuisance for network operators, a boon for the TERENO researchers. By analysing the attenuation data they can accurately determine the amount of precipitation in the direction of the radio link.

Scientists from the Karlsruhe Institute of Technology (KIT) have been making minute-by-minute recordings of the strength of microwave signals in the area around Garmisch-Partenkirchen since 2010. Mobile network operator Ericsson is a partner. A 650-metre long test track was installed at the TERENO test site “Fendt” in Autumn 2010. Researchers at the site are closely monitoring the effects of air moisture, solar radiation and other parameters on microwave signals.

Agricultural research farm “Scheyern”

Higher yields, less space – the demands on modern agriculture are huge. And yet at the same time there is also pressure for food production to be managed in an environmentally sustainable manner. At the Scheyern agricultural research farm, scientists are exploring whether this apparent paradox can be resolved, and if so, how. The monastic estate spans 150 hectares and is located approximately 40 kilometres north of Munich. Agricultural land has been farmed there for more than five centuries. The region demonstrates typical problems associated with intensive agricultural use, such as erosion, groundwater contamination and the impoverishment of flora and fauna. Scientists have been researching environmentally friendly agricultural practices at the former Benedictine monastery since 1990. The Helmholtz Center Munich has been the tenant of the estate since October 2005.

Combining climate protection and agricultural production

Scientists at Scheyern are working on a new strategy to reconcile climate protection with agricultural production, so-called agroforestry systems. Under this approach, trees and shrubs are planted on the same plot as agricultural crops and in such a way so as not to impede crop management. It has been shown that agroforestry systems allow for more efficient water use than traditional cultivation methods. For farmers, this could open up opportunities for the use of fallow land, while at the same time preserving valuable functions of the ecosystem. In addition, the researchers hope that the mixed field use will lead to additional reserves of carbon being stored in the ground. Agroforestry systems could therefore potentially help offset the greenhouse effect.





Remote Sensing

Taking to the skies to get to the bottom of soil moisture

Flight and satellite missions are an important component of TERENO

Remote sensing has long been an important and established measuring method in climate research. For the most part, ground-based equipment can only make spot measurements, whereas planes and satellites can cover huge areas. As such remote sensing has an important role to play at the TERENO observatories.

Measurement flights to all four observatories take off from the Oberpfaffenhofen location of the German Aerospace Center (DLR). Research aircraft like the Dornier Do228 take radar images of test sites at altitudes of some 2,800 metres. The real challenge is to extract actual soil moisture levels from the radar data. No easy task, as radar waves are very sensitive to rough surfaces, ploughed fields and different types of vegetation affect how the radar pulses are reflected. That makes comparisons with data collected on the ground all the more important, helping to optimise evaluation algorithms that automatically calculate soil moisture.

A digital 3-D model of the Earth

In June 2010 the DLR, in partnership with Astrium GmbH, launched the radar satellite TanDEM-X. Together with its twin "TerrarSAR-X", it will send back observations of the Earth over the next three years. This information will be used to

construct a digital 3-D elevation model of the Earth's surface. TERENO will also be able to use this model as a basis for the geographical coding of image data and as an input parameter for various hydrological models. TanDEM-X will also record information on vegetation structure, albeit in 2-D due to the use of X-band radar waves.

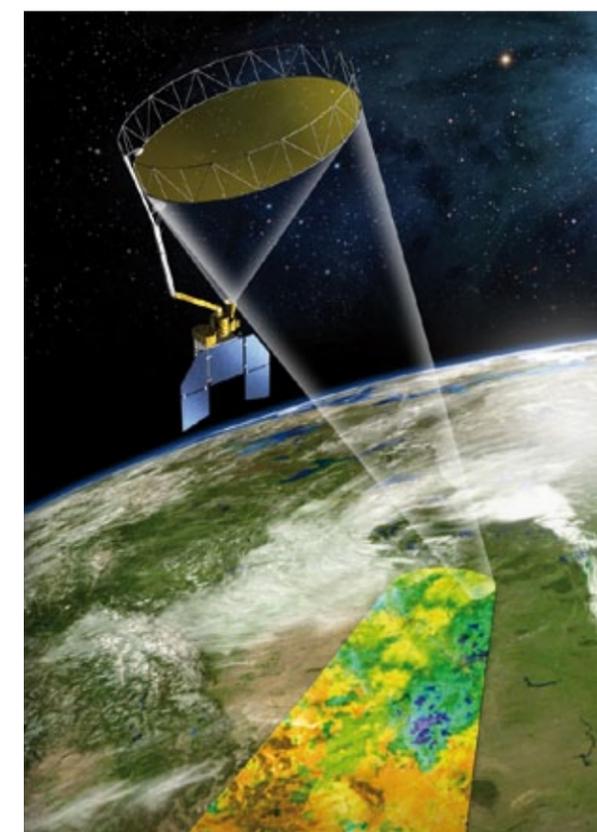
That is where the Tandem-L mission, which the DLR is planning in cooperation with NASA, comes into its own. Tandem-L is also based on two satellites flying in close formation. New advances in areas such as antenna and monitoring technologies, as well as the use of microwaves in the long-wave range, make it possible for Tandem-L to produce 3-D maps of forests and areas of ice and snow with unprecedented precision. Dynamic processes such as afforestation or the degradation of forests can therefore be monitored to a high degree of accuracy for the first time. The launch of the satellites is scheduled for 2019.

COOPERATION WITH THE ESA AND NASA

The aim of the European Space Agency's (ESA) satellite mission SMOS (Soil Moisture and Ocean Salinity) is to measure soil moisture and salt content in the upper levels of the oceans. Both play a key role in the global water cycle. Unlike Tandem-L, the SMOS satellite itself doesn't send any microwaves down to Earth. Instead, it uses a radiometer to measure the brightness temperature of the earth's surface and calculate the required values. The TERENO observatory "Eifel/Lower Rhine Valley" and the DLR test site DEMMIN in the TERENO observatory "Northeastern German Lowland" are two of the European test areas for SMOS. Simultaneous measurements on the ground are used to calibrate the instruments on board the satellite and to validate its measurements.

More accurate soil moisture measurements

NASA's SMAP (Soil Moisture Active Passive) mission is scheduled to begin in 2014. SMAP will provide measurements of soil moisture and its freeze/thaw state with unprecedented precision, resolution and coverage. To this end, the satellite is equipped with a high-resolution radar as well as a radiometer. It is hoped that these data will enhance understanding of the processes involved in energy, water and carbon fluxes. NASA has selected the TERENO observatory "Eifel/Lower Rhine Valley" as a calibration and validation site for SMAP.



GOOD OPPORTUNITIES FOR JUNIOR RESEARCHERS

The Helmholtz Research School on Mechanisms and Interactions of Climate Change in Mountain Regions (MICMoR) opened its doors at the beginning of 2012. In future, up to 25 Ph.D. students will investigate the effects of climate change at the interfaces of atmosphere, biosphere and pedo-/hydrosphere at the TERENO observatory "Bavarian Alps/pre-Alps". The programme, which is funded by the Helmholtz Association of German Research Centres, combines an interdisciplinary training with a cross-disciplinary skill-set. MICMoR is located at the Institute of Meteorology and Climate Research (IMK-IFU) at the Karlsruhe Institute of Technology (KIT).

Dr. Torsten Sachs from the GFZ German Research Centre for Geosciences in Potsdam and Dr. Matthias Mauder from IMK-IFU are already one step ahead. They are both leading their own research groups at TERENO observatories with support from the Helmholtz Association. Over the next five years they will each receive funding of 250,000 euros per year, with the option of a tenure track position in the long term. The Helmholtz Young Investigator Group led by Torsten Sachs monitors the exchange of the greenhouse gases carbon dioxide and methane with the atmosphere at the TERENO observatory "Northeastern German Lowland". The aim of the project which Matthias Mauder is pursuing in the TERENO observatory "Bavarian Alps/pre-Alps" is to record all of the scales which are relevant for the exchange between the biosphere and the atmosphere in order to solve the energy gap problem.

www.micmor.kit.edu

www.helmholtz.de/en/working_at_helmholtz/postdoktoranden/helmholtz_young_investigators_groups

One research focus is on how the radiometer and active radar might best be combined, and which special features need to be taken into account for different types of vegetation. At the TERENO Selhausen test site, scientists from the Forschungszentrum Jülich (FZJ) have gained initial experience in the combination of these systems, which NASA is now also implementing in SMAP. In addition, overflights equipped with relevant sensors have been conducted in the Rur catchment area since 2008.



TERENO SOILCan

The world's largest lysimeter network

TERENO-SOILCan investigates material and water fluxes in the soil as well as soil balances

Working within the framework of TERENO-SOILCan, researchers at the four TERENO observatories have set up 126 lysimeter systems at 13 locations according to a uniform design, making it the largest network of its kind in the world. TERENO aims to use SOILCan to collect long-term data on changes in terrestrial systems wrought by climate change. The primary research focus is on material and water fluxes as well as soil balances.

This kind of data is lacking world-wide, but is absolutely crucial for the development and improvement of models for the exchange processes between the biosphere, atmosphere and hydrosphere. The starting point for the network was preliminary work undertaken at the TERENO observatory based in the Bavarian Alps and pre-Alps region by the Institute for Meteorology and Climate Research (IMK-IFU) at the Karlsruhe Institute of Technology (KIT). TERENO has extended the climate feedback model adopted by the IMK-IFU to include all of its observatories.

SOILCAN'S CHALLENGES

- Changes in the coupled cycles and storage of carbon and nitrogen (temporal dynamics)
- Biosphere-atmosphere exchange of climate-relevant trace gases
- Changes in vegetation and biodiversity
- Changes in all components of terrestrial hydrology, such as the water balance, evaporation, precipitation variability and water-retention capacity
- Supplementary instrumentation of the experimental sites within the TERENO observatories
- Bridging the gap in scale from the point- to the field scale (up-scaling)

Soil monoliths exchanged throughout Germany

The lysimeters are made out of stainless steel, have a surface area of one meter squared and are one and a half meters long. They have been integrated into the respective research sites of the TERENO observatories as intensive measuring devices. To this end, lysimeters have been prepared at areas of land used to cultivate arable crops as well as at grassland areas.

Researchers have exchanged the soil cores in the lysimeters, so-called soil monoliths, throughout Germany along existing temperature and precipitation gradients at locations which correspond to the predicted changes in climate at the TERENO observatories. For example, soil monoliths at the installation destination are exposed to drier and warmer environmental conditions than at their original sites. Lysimeters from all four observatories were brought to the central research sites Selhausen and Bad Lauchstädt, the former characterised by an Atlantic, the latter by a continental climate.

CLOSE COOPERATION WITH CLIMATE RESEARCHERS

TERENO is working closely together with a second large Helmholtz Association research activity, the Helmholtz Climate Initiative REKLIM (Regional Climate Change). REKLIM also focuses on the regional and local consequences of climate change. Key research topics include, amongst other things, changes in atmospheric components and trace elements, changes in ice coverage in polar regions and in sea levels. Scientists are investigating processes in polar regions that impact the climate, the effects of changes in land surface, and changes in extreme weather events.

www.reklim.de/en/home

Observatory	Location	Number of networks	Annual mean temperature/ rainfall	
Eifel/Lower Rhine Valley	Selhausen	24	10°C	720 mm
	Rollesbroich	6	8°C	1150 mm
	Wüstebach	6	7.5°C	1200 mm
Bavarian Alps/ pre-Alps	Scheyern	6	7.4°C	803 mm
	Fendt	18	8.2°C	1030 mm
	Rottenbuch	12	5.5°C	1400 mm
Harz/Central German Lowland	Graswang	6	4.5°C	1600 mm
	B. Lauchstädt	18	8.8°C	487 mm
	Sauerbach	6	9°C	530 mm
Northeastern German Lowland	Schäfertal	6	6.9°C	630 mm
	Demmin	6	8.1°C	555 mm
	Dedelow	6	8.7°C	483 mm

Wireless data exchange

Every SOILCan lysimeter is attached to three highly sensitive load cells that monitor the important components of the water balance, evaporation and precipitation, with high temporal resolution. In order to collect information about the soil in the lysimeters, researchers installed various sensors such as tensiometers and dielectric probes to measure soil water content, temperature sensors and carbon dioxide gas sensors. The lysimeter systems are fully automated and equipped with cutting-edge wireless-based technology for monitoring and data communication. In order to monitor local climatic characteristics weather stations have been erected within the immediate proximity of each station.

“TERENO is important because it tackles a great unknown: the role of land surfaces in regional climate systems. There are many feedback processes between the atmosphere and land surface that we still don't understand”, says REKLIM's scientific director, Professor Peter Lemke from the Alfred Wegener Institute for Polar and Marine Research (AWI).

It is precisely these feedback mechanisms which are the focus of the REKLIM research topic “Land surfaces in the climate system”. The long-term environmental data which are being collected at the TERENO observatories are the very data which REKLIM also needs. At the same time, they are also instrumental in verifying and improving existing climate models. Accordingly, the two initiatives work closely together.



International Cooperation

TERENO-MED: A focus on water resources in the Mediterranean

Creation of a Mediterranean Observatory Network

In the Mediterranean water is often in short supply. Many countries in the region are frequently affected by droughts. However, when it does rain, it often comes as heavy rainfall causing flash floods and land-slides. In a recently published report, the Intergovernmental Panel on Climate Change – IPCC warns that droughts and heavy rain events are set to increase, particularly within the Mediterranean area. Furthermore, in many regions groundwater levels are sinking as a result of excessive water consumption. The aim of the new TERENO-partner project TERENO-MED is to set up a hydrological observation network to investigate these and other aspects of the water balance in the Mediterranean.

TERENO-MED is a collaboration between the Helmholtz Centre for Environmental Research (UFZ) in Leipzig and the Forschungszentrum Jülich, with the UFZ coordinating the project. Several international partners are also on board. Its objective is to study the effects of population development, changes in land use and economic and climate change on water resources in the Mediterranean region. The TERENO-MED network will span eight to ten observatories in representative regions of the Mediterranean. Potential locations include the South of France, Spain, Italy, Greece, Cyprus and Turkey, as well as countries in Northern Africa and the Middle East. The planning and start-up phase is scheduled to run until 2013.

6.8 million euros are earmarked for TERENO-MED, providing funding for basic measuring equipment such as weather and soil moisture stations, groundwater observation wells and runoff gauges, in order to capture important hydrological and meteorological parameters, but also more specific measurement equipment, addressing the specific problems (e.g. with regard to water quality) in the respective areas. The project will help to find solutions and develop management strategies for problem regions – thereby helping to implement the European Commission’s directive on water scarcity and droughts and the EU programme “Horizon 2020”.

INTERNATIONAL COOPERATIONS (SELECTION)

- DIGISOIL Collaborative Project
- ENTRANCE HGF-JL – ENvironmental TRANSition of Chinas Ecosystems under predicted climate change
- ENVEurope Project: Environmental quality and pressures assessment across Europe
- EXPEER – Distributed Infrastructure for Experimentation in Ecosystem Research) coordinated by L’Institut National de la Recherche Agronomique – INRA (Dr. Abad Chabbi), France
- FLUXNET
- HOBE – Center for Hydrology, Denmark
- ICOS – Integrated Carbon Observation System
- iSoil – Interactions between soil related sciences
- KLIMZUG-NORD
- LTER-Europe – European Long-Term Ecosystem Research Network
- NitroEurope IP
- PEER – Partnership for European Environmental Research
- PROCEMA HGF-VI – Regional Precipitation Observation by Cellular Network Microwave Attenuation and Application to Water Resources Management
- RSSC-West-Africa – “Regional Science Service Center for West Africa”
- SMOS – Soil Moisture and Ocean Salinity, Mission of the European Space Agency (ESA)
- WESS – Joint Research Centre Water & Earth System Science

Cooperation across borders

In France, a series of research initiatives have already joined forces around the topic “The Mediterranean Environment” to form the “MISTRALS”-Association. One of the partners is the SICMED project, which monitors changes in land use and effects on ecology and water, and has a lot in common with TERENO-MED. Both research consortia want to develop strategies to promote sustainable development within the Mediterranean region, and are therefore strengthening their collaboration.

ICOS monitors European sources and sinks of carbon dioxide

Trace gases such as carbon dioxide are released into the air by soil and plants. TERENO scientists are not alone in wanting to find out how changes in land use and climate affect these biogenic emissions, and, in turn, what consequences this effect has on the climate. Environmental researchers have come together as part of ICOS (Integrated Carbon Observation System), a European research initiative to build an extensive network of monitoring stations. The project aims to pinpoint sources and sinks of carbon dioxide and other greenhouse gases throughout the whole of Europe and bordering regions. At the same time, researchers are eager to establish the role that soil, forests and oceans play in the global carbon cycle. The TERENO observatories are making a significant contribution to this unique project through their already existing infrastructure.

www.icos-infrastructure.eu

Research at a natural landscape lab

The virtual institute ICLEA at the TERENO observatory “Northeastern German Lowland” brings German and Polish scientists together. ICLEA stands for Institute of Integrated Climate and Landscape Evolution Analyses. Together, the researchers aim to gain a better understanding of the effects of global change on the evolution of the North-East German-Polish Lowland since its formation at the end of the last ice age. They are particularly interested in finding out more about the interactions between the natural and anthropogenic processes which have an influence on how this landscape evolves. The innovative ICLEA concept integrates current hydrological and climatic data – made available through TERENO-infrastructure – with long time series taken from natural climate and environmental archives as well as historic remote sensing data.

www.iclea.de/#english

EXPEER promotes European network

The impact of climate change varies greatly for different ecosystems such as forests, meadows, fields and river landscapes. EXPEER (Distributed Infrastructure for Experimentation in Ecosystem Research) is spear-heading research at a European level. The EU project brings together research organisations that focus on terrestrial ecosystems. TERENO is one of the project partners. EXPEER is setting in place a European network that enables scientists to coordinate their research and puts all the collected data at their disposal. For example, scientists at the Forschungszentrum Jülich are developing methods within the framework of EXPEER that will make it possible for local data from EXPEER observatories to be applied to larger areas in Europe through remote sensing data and modelling.

www.expeer.fr

Adapting to climate change

International large-scale WASCAL programme provides support to West Africa and takes TERENO as an example

Climate change is a severe challenge for West Africa. Periods of drought follow on the heels of years marked by heavy floods. Germany is lending its expertise to the countries concerned so that they are better placed to counter the negative consequences of climate change. TERENO supports the international large-scale project “West African Science Service Center on Climate Change and Adapted Land Use”, in short, WASCAL.

Periods of drought in West Africa are getting longer, rainfall is becoming more variable, and extreme rainfall is also becoming more common – that poses a huge problem for agriculture. Farmers see their livelihoods under threat, hunger and poverty loom on the horizon. Large data bases related to climate and land-use are being set up; the evaluation of these data can help scientists and politicians to secure the food supply of local communities under changed climate conditions. To this end, WASCAL is working to strengthen research infrastructure in West Africa related to the environment and climate change, pool the expertise of all partners and promote networking among African researchers and at an international level.

Ten West African countries are collaborating on the project: Benin, Burkina Faso, the Ivory Coast, Gambia, Ghana, Mali, Niger, Nigeria, Senegal and Togo. In the long-term, the aim is for the partner countries to take full charge of the project. WASCAL is organised around three principle components: a joint competence centre in West Africa, a core research programme and a graduate research programme. WASCAL is

coordinated by the Center for Development Research (ZEF) at the University of Bonn, funding is provided by the German Federal Ministry of Education and Research (BMBF).

TERENO a role model

TERENO serves as a role model for WASCAL. Both initiatives are based on the concept of setting up terrestrial observatories in order to develop better climate projections and adaptation strategies with the help of long-term data. The Institute for Meteorology and Climate Research (IMK-IFU) at the Karlsruhe Institute of Technology (KIT) is helping to set up a hydroclimatological measuring network within the framework of WASCAL, while the German Aerospace Center (DLR) is taking care of the remote sensing aspect of the programme. The data management system for WASCAL will be jointly developed by the Forschungszentrum Jülich and the ZEF on the basis of the data management infrastructure setup of TERENO.

www.wascal.org

TERENO

Scientific Steering Committee

The Steering Committee defines goals and priorities, and is responsible for all strategic planning, setting priorities and making decisions regarding equipment for the observatories as well as collaborations. TERENO is coordinated by the Forschungszentrum Jülich.

Members

Prof. Dr. Harry Vereecken
Dr. Thomas Pütz
(Forschungszentrum Jülich)

Prof. Dr. Georg Teutsch
Prof. Dr. Peter Dietrich
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Prof. Dr. Hans Peter Schmid
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Dr. Eckart Priesack
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Prof. Dr. Achim Brauer
(Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences)

Prof. Dr. Irena Hajsek (ETH Zurich)
Dr. Erik Borg
(German Aerospace Center)

Advisory Board

The Advisory Board is made up of a group of international cooperation partners and independent experts, who advise and support TERENO on scientific questions.

Members

Dr. Richard P. Hooper (Chair)
Executive Director of CUAHSI

Prof. Dr. Karsten Høgh Jensen
University of Copenhagen, Coordinator of HOBE

Prof. Dr. Hangsheng (Henry) Lin
Pennsylvania State University, Coordinator of the Hydrogeology initiative and the Shale Hills Critical Zone Observatory

Prof. Dr. Sonia Seneviratne
ETH Zurich, Institute of Atmospheric and Climate Science

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University of Colorado

Prof. emeritus Dr. Hannes Flüher
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Dr. Malcolm Davidson
European Space Agency

Prof. Dr. Christiane Schmullius
University of Jena

Prof. Dr. Ulrike Tappeiner
University of Innsbruck

Prof. Dr. Bas van Geel
University of Amsterdam

Prof. Dr. Jeffrey J. McDonnell
University of Saskatchewan

Coordination Teams

TERENO Coordination Teams (CT) manage research at the observatories in different priority areas. They are responsible for implementation of the instrumentation, as specified in the implementation plan, for the collection and quality assurance of data, and for providing support to the research teams in their work on the ground.

The individual teams and their priority areas:

- CT Atmosphere
- CT Biosphere
- CT Pedosphere
- CT Hydrosphere
- CT Environmental Sensing
- CT Geoarchives
- CT Data Management
- CT Integrative Modelling

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Helmholtz Centre for Environmental Research – UFZ

Karlsruhe Institute of Technology – KIT

Helmholtz Zentrum München – German Research Center for Environmental Health – HMGU

German Aerospace Center – DLR

Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences

www.tereno.net