A nationwide monitoring program involving multiple TERENO sites revealed that pesticide levels exceed government thresholds in more than 80 percent of streams (p. 6).

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TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES

Newsletter 2/2021

CONTENTS

Compare and connect

Some of today's important scientific questions would be impossible to investigate without research infrastructures like TERENO. To detect differences and similarities in regional climate change, for example, it is important to be able to compare sites, to provide easy access to fellow researchers, and to work closely with other infrastructures.

200 YEARS HELMHOLTZ
Inspired by challenges.

HELMHOLTZ ASSOCIATION

TERENO site used in the eLTER PLUS project: the Hohes Holz forest tract within the Bode watershed

TRANSNATIONAL ACCESS: TERENO SITES OPEN TO EU RESEARCHERS

To help accelerate scientific progress, the EU is providing European researchers with easy access to the EU's best research infrastructures – thanks to a special research program known as the INFRAIA projects. TERENO has been a longtime participant in these projects.

"Currently, TERENO is a partner in the eLTER Advanced Community project eLTER PLUS, which the EU is funding for a five-year period starting 2020," says Dr. Steffen Zacharias from the Helmholtz Center for Environmental Research – UFZ. "Six TERENO sites are open to interested researchers, who can finance their research in biodiversity, biogeochemistry, hydrology or socio-ecology through the project." Funding is available for two types of projects: Transnational Access (TA) and Remote Access (RA). Through TA, users can conduct their own research, measurements and experiments on site. RA allows users to define measurements and experiments, which are then conducted at the sites by local personnel.

The six TERENO sites – Harz, Siptenfelde, the Bode catchment area, Wüstebach, Rollesbroich and Selhausen – are equipped with state-of-the-art instrumentation and represent typical central European climate and landscape conditions. Researchers can use all six sites for both TA and RA projects. Projects can also be conducted at multiple sites.

"With funding for both TA and RA projects, we provide European researchers with easy access to TERENO sites. This can especially benefit scientists not directly involved in the eLTER PLUS project," explains Zacharias. Both individual researchers and research groups can apply for the funding, which is then awarded following evaluation of the applications.

An effective approach

According to Zacharias, the funding is already bearing fruit: "This type of research financing has proven a very effective approach to opening the TERENO infrastructure to external researchers – as evidenced by the numerous TA and RA projects that have already been realized." Some of the research conducted so far has included: investigations of soil quality using airborne imaging spectroscopy, validation of calibration approaches on soil moisture estimates by cosmic-ray neutrons, and determining the optical characteristics of dissolved organic matter in a watershed impacted by deforestation. "All of these projects generate data, which can then be made available to everyone – thus promoting scientific progress," says Zacharias.

▶ TA and RA funding through eLTER PLUS

EDITORIAL

From political will to concrete action

Achieving climate neutrality is the only way to slow down climate change. It's certainly good that almost all member states at the UN Climate Change Conference in November committed to achieving climate neutrality within a few decades. It's also good that Germany's new government wants to gear its climate, energy and economic policy towards the 1.5 degree goal. The important thing now, however, is for this declaration of political will to be followed by concrete action measures.

In the meantime, the world needs the scientific community to continue uncovering the processes behind climate change, to assess future developments and outcomes, and to recommend adaptation measures. TERENO and its many research sites are engaged in these tasks in a number of different ways. Along with the many research initiatives investigating topics such as water and material fluxes, extreme weather events, long-term trends or biodiversity, we are also working with project partners to provide, as an example, decision-making support for agriculture. One such project is AgriSens DEMMIN 4.0, which is using state-of-the-art methods to provide data to farmers to help them adapt to climate change and make good decisions, for example, on when fertilizer or irrigation are necessary (see p. 5). We also continue to promote international exchange and cooperation through projects like eLTER PLUS (see p. 2) or events such as the international OZCAR-TERENO conference (see p. 4). And we will continue to drive progress on all of these fronts in the years to come.

I would like to wish you a very happy holiday season and all the best for 2022. And of course I hope you enjoy reading this "anniversary" edition – the 20th issue of our newsletter!

Sincerely,

Harry Vereecken
TERENO Coordinator

SCOPE MANAGEMENT IS KEY

Dr. Hank Loescher is Director of Strategic Development, Environment and Infrastructure, Battelle, as well as a NEON Architect and TERENO Advisory Board member. We spoke to him about large research infrastructures.

What are the big issues in environmental science?

Making data available not only to the researchers, but also to those not familiar with our data. By doing this, we're able to bridge and cross disciplines. Second, building better interoperability among research infrastructures (RIs) enables us to ask questions among continents. The genesis, development and migration of drought across the land in Australia, US, and Europe, for example, are quite different. What does this tell us about environmental change and its consequences for society? Lastly, there is an ongoing cultural shift in the way the natural sciences develop new understandings with RIs.

What cultural shift?

An astronomer or high-energy particle physicist, for example, are taught to use large scale RIs as part of their culture, because that is the only way to perform their research. This is unlike ecology, where you can conduct research in any ecosystem. RIs contribute to advancing the science by providing for example long term, spatially explicit, consistent data. But this brings a few challenges. We still have to improve how we define an RI, what is has to offer, and how the research community and RIs work together. New discoveries do not come from the RI data alone, but through integrating RI data with other network, RI (satellites), and PI-based research data.

What is the difference between RIs and networks?

Networks evolve through common interests and research by the researchers themselves e.g., Arctic CH_4. It is very much of a bottom-up activity. An RI tends to be top-down and is often driven by grand challenges or ambitious research questions that have a societal imperative. Such RIs like TERENO or the National Ecological Observatory Network (NEON) provide data and enable new transformative science questions. These RIs are at scale and cost that is typically beyond that of a research group, network, or university.

So RIs are a much larger effort?

Yes, larger and different means assembling the science components, but also the business and project management. Scope describes exactly what you are going to do for the budget, schedule, etc. RI designs often utilize system engineering to define the science and management scope – a process similar to a satellite or a particle accelerator. Also important is that business/management solutions are not onerous and are tailored to meet the specific RI needs and reporting requirements.

What is required for an RI to be successful?

It is important to precisely define the RI scope. The European Strategy Forum on Research Infrastructures' (ESFRI) previous annual reports have always stated: the largest problem is scope management. Whether an RI is in a design or operational phase, scope describes exactly what the RI is, how it functions, the data it produces, what are its capabilities, etc. It provides a clear means to manage budget, schedule, and deliver the RI to the research community. It also provides more robust planning horizons for sponsors and creates more inclusive opportunities. Scope management describes 'what must be done'. However, this is 180° opposite of how scientists work, where scientists ask 'what can we do?'. This scientific approach fosters huge scientific creativity, but also creates the problem of having open-ended solutions and cost overruns. No one wants to limit any scientific creativity, but in the world of large RIs, we establish a process to identify and prioritize the scientific frontiers from the user community, and a change control process to manage any new scope, budget, and effort. Managing this balance between scope and management is often foreign to researchers.

As a TERENO Advisory Board member, what do you think about TERENO?

TERENO has a great idea of what it is. But it is important to note that all large RIs have their own development path, and no two RIs are the same. There are also challenges and similarities among RIs and it's important to take advantage of lessons learned from each other. For example, some RIs develop engagement and governance at their inception. Others restructure engagement and governance through each design, construction and operational phase, since each phase has difference challenges. This is where I see the dialogue between TERENO and NEON developing, and how we may be able to provide some mutual insight from past experiences – and hopefully also contribute to the ESFRI and eLTER dialog, whose partners include TERENO and NEON.

About Hank Loescher

Hank Loescher is at Battelle, the world's largest R+D corporation, and has appointments at several universities. Battelle manages the NSF-funded US National Ecological Observatory Network (NEON) and several US National Labs. Hank managed the AmeriFlux program. His research interests include determining the biotic and abiotic controls on ecosystem-level carbon and energy balance across spatial and temporal scales.


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Conference location: Palais de la Musique et des Congrès in Strasbourg

SUCCESSFUL START

Some 200 researchers came together in Strasbourg, France in early October 2021 to take part in the first OZCAR-TERENO international conference. Roughly 100 additional participants attended the conference online. Whether in person or virtually, more than 70 oral presentations and 100 poster presentations brought participants up to date on the latest developments in Critical Zone research.

The Critical Zone is the thin, outer layer of our planet – the Earth's "skin" – from the top of the vegetation canopy down to the groundwater. The complex exchange processes in the Critical Zone – between rock, soil, water, atmosphere and living organisms – create the foundation for all life on Earth. Key to Critical Zone research are the multidisciplinary, highly instrumented observatories operated by the two hosts of the conference: TERENO and the French research infrastructure "Observatoires de la Zone Critique: Applications et Recherche", a.k.a. OZCAR. The conference program covered 17 main subject areas – from fundamental questions on exchange processes between soil, vegetation and atmosphere, to the use of data and different approaches to long-term observation, to new measurement methods and modeling approaches.

Prof. Markus Reichstein from the Max-Planck-Institute for Biogeochemistry in Jena, in his presentation "Extracting information from ecosystem time-series using a hybrid machine-learning-modelling approach" suggested that a stronger integration of observation and (mechanistic) models is needed for a better understanding of the Earth system. He proposes a fusion of machine learning and mechanistic modelling approaches into so-called hybrid modelling – a combination that could allow for better predictions and better understanding of the system, e.g. by inferring unobserved variables. In his presentation, Reichstein explained the concept using an example for the carbon cycle at site level and one for the global water cycle. In the global water cycle example, a conceptual hydrological model builds the physical basis, where e.g. partitioning coefficients are estimated spatio-temporally with a deep learning approach* and a multi-task learning approach takes into account the multiple-constraints of evapotranspiration, terrestrial water storage, runoff and snow water equivalent.

Also promising were the new insights on bedrock water storage shared by Dr. Daniella Rempe from the University of Texas (Austin) in her presentation "The bedrock component of watershed storage: Advances and insights". While dynamic water storage plays a central role in determining how watersheds respond to change, this role remains uncertain, largely because relatively little research has been conducted thus far on water storage in bedrock (as compared to research on soils and groundwater). Fortunately, this is changing thanks to recent advances in monitoring. Direct measurements indicate that bedrock water storage substantially contributes to transpiration fluxes, and also influences the timing and volume of groundwater recharge and streamflow. Furthermore, new studies indicate that plants access water stored in bedrock both within and outside of drought periods. "Together, these findings have consequences for how we conceptualize a wide array of Critical Zone processes," says Rempe.

* **Basil Kraft et al. (2021).** *Towards hybrid modeling of the global hydrological cycle. Hydrology and Earth System Sciences (preprint: status as of December 2021).*

▶ DOI: 10.5194/hess-2021-211


© Virginie Entringer

Some 200 participants were on site for the conference.


© Virginie Entringer

The conference program included an excursion to an OZCAR site: the OHGE observatory.

In her presentation "From sensor to real-time forecasts: setup of a cosmic-ray neutron sensor network for data assimilation and optimization of high-resolution real-time predictions of soil moisture", Dr. Patrizia Ney from Forschungszentrum Jülich showed how forecasts can be generated from sensor data in real time.

For their project known as ADAPTER (see also TERENO Newsletter 2021-1), Jülich researchers installed a permanent network of twelve hydrometeorological measurement systems at twelve selected agricultural field sites in Germany's state of North Rhine-Westphalia. The measurement systems are fitted with a multifunction weather station as well as with cosmic-ray neutron sensors, which provide data on current soil moisture levels. The field measurements are also fed into a land-surface hydrological model, which can generate prototypical forecasts for parameters such as plant-available water – in real time and for each specific parcel of land. The information is intended primarily to help farmers make their operations more sustainable and resilient against extreme weather, such as droughts.

The next OZCAR-TERENO conference is scheduled for 2023 in Germany.

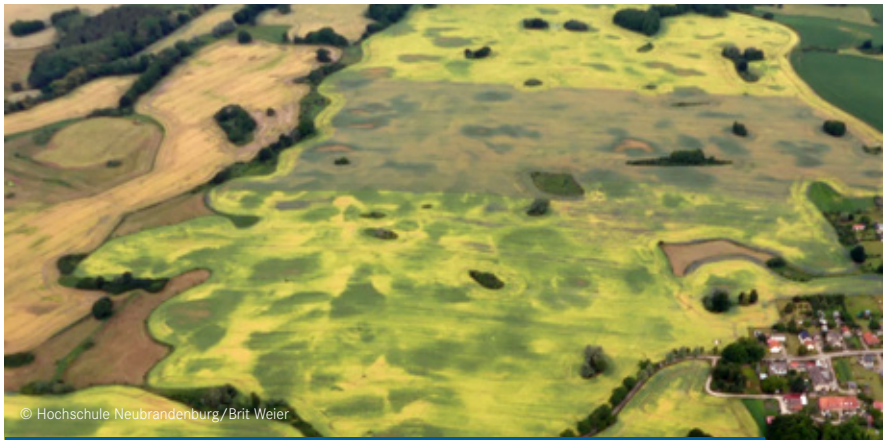
▶ OZCAR-TERENO conference

HOW FARMERS BENEFIT FROM REMOTE SENSING DATA

Modern agriculture is undergoing multiple transformation processes today. In the face of climate change, changing ecosystems and a scarcity of agricultural land, the challenge remains to secure a steady supply of food and feedstocks with agricultural products – all with an eye toward more sustainable, resource-efficient use of aids such as pesticides and fertilizer. Over the last several years, this has increasingly involved the digitalization of numerous farming processes.

Especially for a site-specific cultivation approach, with fields partitioned into multiple zones, information on soil and plant conditions in each of the zones is critical. "Data from remote sensing devices on satellites, aircraft and drones make it possible to provide farms with this data to support in their decision-making – and that is precisely our goal with the AgriSens DEMMIN 4.0 project," says Dr. Daniel Spengler from the Helmholtz Center Potsdam – German Research Center for Geosciences (GFZ), which is leading the project with funding from Germany's Federal Ministry of Food and Agriculture.

With the help of the digital experimentation field AgriSens in TERENO's Northeastern German Lowland observatory, the seven project partners want to optimize the use of remote sensing data for specific applications in crop production. These include monitoring stock development and forecasting crop yields in wheat cultivation, identifying areas with lower yields, locating rocks in fields, and integrating geodata to optimize irrigation in potato farming.


© Hochschule Neubrandenburg/Brit Weier

Airborne remote sensing data provide clues on the state of fields.

Using the datasets generated by the various systems, farmers can gain important information for their work. The information is intended to help farmers decide when certain actions – including fertilization, seeding, watering or soil tillage – are necessary. "Unfortunately, the hurdles are still much too high for many farmers to make use of this data – mainly due to data access issues, current usage in a large number of different software solutions, and a confusing array of options on the market," says Spengler. Project partners are therefore looking to provide farmers with more accessible solutions and geodata know-how. As part of an AgriSens field day held on November 4, 2021, the latest developments were presented to 125 interested participants to encourage and support them in putting these data-driven solutions into practice.

▶ AgriSens DEMMIN 4.0 project

▶ On Instagram

IMPROVING SATELLITE SENSOR VALIDATION

The number of Earth observation satellites continues to grow steadily. Along with larger space agency missions, more and more small and relatively low-cost sensors from commercial providers are finding their way into orbit. These are used for a large number of social and commercial applications. “Evaluating the radiometric performance of optical Earth observation sensors following launch is essential to being able to understand the quality and potential changes compared to initial calibration,” says Dr. Daniel Spengler from the Helmholtz Center Potsdam – German Research Center for Geosciences (GFZ). Currently, automated instruments such as AERONET-OC and RADCALNET are used to validate optical systems. “But these have only a limited spectral resolution, which sometimes means the data delivered is unsuitable for validating current and future hyperspectral sensors in orbit,” explains Spengler’s colleague Dr. Mohammadmehdi Saberioon. As part of the EU-funded HYPERNETS project, an international research consortium consisting of seven partners is looking to solve this problem with

the help of a new radiometer. By combining state-of-the-art sensor and robot technology, they have ensured that high-quality in-situ measurements in all spectral bands – and for a broad range of water and land types – are available for validation of the surface reflectance data, which are needed to derive useful information from purely optical satellite missions.

The HYPSTAR® radiometer developed as part of the project provides high spectral resolution measurements in the range of visible and near-infrared light (5 nanometers in the 380 to 1020 nanometer range) as well as short-wave infrared (10 nanometers in the 1000 to 1700 nanometer range). An integrated rotation platform allows measurements to be taken at different angles, with the added benefit of validating potential recording effects of remote sensing data. The first HYPSTAR® prototype for land applications is installed at the Demmin site in TERENO’s Northeastern German Lowland observatory and automatically collects data every day between 10 am and 5 pm, Coordinated Universal Time (UTC).

▶ HYPERNETS project

▶ Twitter

SMALL STREAMS HEAVILY POLLUTED WITH PESTICIDES

Government thresholds for pesticides have often been set too high, and even these levels are exceeded in more than 80 percent of streams. This was one finding of a Germany-wide monitoring program led by the Helmholtz Center for Environmental Research (UFZ) – and one reason project researchers are urging reform of environmental risk assessment.

The UFZ team – Philipp Vormeier, Oliver Weisner, Matthias Liess and Liana Liebmann (from left) – collecting samples at the “Launzige” stream.

Pesticides help improve agricultural yields by controlling harmful insects, fungi and weeds. However, they also enter nearby streams and cause damage to aquatic communities. “These communities are crucial for maintaining biodiversity. They are part of the food web and support the self-purification of water,” explains UFZ researcher Prof. Matthias Liess. An ecotoxicologist, Liess coordinates the Small Stream Monitoring (KgM) project, which has studied more than 100 measurement sites at streams flowing through predominantly agricultural regions in twelve federal states in Germany. Among the measurement sites was TERENO’s Holtemme site within the Harz/Central German Lowland observatory.

For more than 80 percent of the streams, measurement results revealed pesticide levels exceeding the RAC value – the concentration of an active ingredient which may not be exceeded in a body of water. In fact, 18 percent of the streams showed excessive levels for more than ten different pesticides. And thanks to the very extensive data set, the research team uncovered more important information: “Pesticides affect aquatic invertebrate communities at much lower concentrations than previously assumed by the pesticide risk assessment,” says Liess. “For sensitive insect species, the pesticide concentration in the small lowland streams is the most relevant factor that determines their survival. In contrast, other environmental problems such as watercourse expansion, oxygen deficiency, and excessive nutrient content are less important.”

According to Liess, this high degree of sensitivity is grossly underestimated – mainly because up until now, the ecological risk of pesticides in the field has been predicted based on laboratory studies, artificial ecosystems and simulation models, which do not in fact reflect reality. Liess and his colleagues therefore urgently recommend changing both the legal limits and the approval processes for pesticides and herbicides as the only way to significantly reduce the levels of pesticides entering streams.

▶ Small Stream Monitoring (KgM) project

Matthias Liess et al. (2021). *Pesticides are the dominant stressors for vulnerable insects in lowland streams. Water Research, Volume 201, 1 August 2021, Article 117262.*

▶ DOI: 10.1016/j.watres.2021.117262

UNIQUE DATA SET ON INSECT POPULATIONS

Malaise trap at TERENO site Friedeburg I

The number of insects in Germany has been on the decline for many years. This has noticeable consequences, including lower levels of biodiversity and plant pollination. In 2019, a nationwide malaise trap project was launched to collect data on insect species diversity and population development in typical habitats in Germany. The aim of the project is to help identify the processes underlying insect declines and to develop adaptation strategies.

Tent-like malaise traps are suitable for trapping a wide range of flying insect species. “The samples are quite large, so we can measure basic variables such as biomass, but require automated methods to actually identify the species, which is a prerequisite for being able to analyze species communities,” says Dr. Mark Frenzel of the Helmholtz Center for Environmental Research – UFZ, who initiated the project in 2019 together with Prof. Peter Haase from the Senckenberg Research Institute and Natural History Museum. The project is expected to run for at least 10 years and will be carried out within the German network for Long-Term Ecological Research LTER-D in cooperation with Nationale Naturlandschaften, an umbrella organization of large protected areas. “The project is unusual in that it has been running so far without basic funding, relying instead on voluntary support from Senckenberg, UFZ and the other participants,” emphasizes Frenzel. In total, about 80 traps have been set up at 28 sites stretching from Germany’s sea coast in the north to the Alps in the south – mainly in agricultural landscapes, semi-natural forests, floodplain forests and floodplain grasslands. Several sites are located in TERENO’s Harz/Central German Lowlands observatory.

Sampling takes place every 14 days during the vegetation period from the beginning of April to the end of October, resulting in about 15 samples per trap. Currently, metabarcoding is underway for approximately 2,000 samples collected in 2019 and 2020. “This genetic analysis creates a dataset that is unique for Germany, with hundreds of thousands of identifications in just a few weeks, providing information about the complete species composition of each sample,” says Frenzel. In a preliminary analysis of the biomass data, project partners found that temperature is the major factor affecting variation in the biomass of the trapped insects. Accordingly, the biomass of samples across Germany increased linearly with monthly temperature. Only in the hot months of June and July did the higher temperatures result in lower biomass levels. Further evaluation of the data is pending.

▶ Malaise trap project

Ellen Welti et al. (2021). *Temperature drives variation in flying insect biomass across a German malaise trap network. BioRxiv.*

▶ DOI: 10.1101/2021.02.02.429363v3

A BETTER UNDERSTANDING OF RADIATION FLUXES

One of the crucial variables for assessing global carbon balances is FAPAR – the Fraction of Absorbed Photosynthetically Active Radiation, i.e. the portion of electromagnetic radiation theoretically available for photosynthesis that is actually absorbed by plants. While FAPAR can be estimated over wide areas with the help of satellite remote sensing data, these data need to be validated with ground-based measurements, especially for forest ecosystems. However, few such measurements have been conducted in forests thus far; moreover, if measurement density is low, there is a large degree of measurement uncertainty due to the high spatio-temporal variability of the forest canopy.

With this in mind, researchers at RWTH Aachen University, Forschungszentrum Jülich and the University of Alberta collaborated in April 2021 to create a measurement field in Germany’s Eifel region at the TERENO Wüstebach site as part of the ComRadE project (Comparative Study of Radiative and Carbon Fluxes at Three Ecosystems in Germany, Canada and Costa Rica) funded by RWTH Aachen University’s International Research Space (IRS) program. Ten high-resolution photosynthetically active radiation (PAR) sensors and six red/far-red sensors were arranged below a Norway spruce stand - 10 meters apart in the form of two hexagons, with two additional sensors on top of the TERENO measurement tower above the canopy. All sensors are connected to TERENO’s wireless sensor network SoilNet. “This allows us to measure the spatio-temporal variability of FAPAR and the ratio of photosynthetically relevant radiation in the red range (645 to 665 nanometers) to non-absorbed radiation in the far red range (720 to 740 nanometers) in the forest,” explains project researcher Oliver Reitz from RWTH. The measurements will also be used to validate Sentinel 2 satellite-derived products. In addition, the researchers aim to use carbon flux data captured by eddy covariance measurement devices at the site to estimate light use efficiency i.e. the rate of carbon binding per amount of absorbed PAR under various temperature and moisture regimes. “These results will ultimately help us better understand radiation fluxes and their impacts on biochemical and physiological processes in forest ecosystems,” says project lead Prof. Michael Leuchner from RWTH.

Tripod with PAR sensor (blue), R/FR sensor (red) and SoilNet data logger (orange).

DETECTING AND READING CLIMATE SIGNALS FROM LAKE SEDIMENTS

Seasonally stratified lake sediments provide the ideal archive to extend the reach of TERENO climate proxy data by hundreds or even thousands of years into the past. These sediment layers have been continuously deposited in lakes over centuries, and the residues contained in the layers, such as minerals and fossils, allow scientists to draw inferences about past environmental and climate conditions.

"In order to do this, we first need to understand how exactly climate signals are transferred to sediments, and which processes affect this signal transfer. Only with this knowledge can we then correctly read and interpret proxy data in sediments," says Prof. Achim Brauer from the Helmholtz Center Potsdam – German Research Center for Geosciences (GFZ). The GFZ-administered TERENO site at Lake Tiefer See plays a central role in achieving that goal. Over the last nine years, Brauer and his colleagues have monitored climate parameters and lake water properties, and collected sediment samples on a bi-weekly basis. This allows them to analyze annual fluctuations and the impacts of extreme events, but also to identify longer-term trends.

Maintenance work on measurement buoy used for automatic water data collection

To better recognize climatic influences, the researchers teamed up with colleagues at the Polish Academy of Sciences to install a largely identical monitoring program with similar instrumentation at Lake Czechowskie in the Tuchola Forest in northern Poland, some 400 kilometers east of Lake Tiefer See. Their initial results confirm that sedimentation processes vary depending on whether the lakes froze over in winter and how much time elapsed between ice breakup in spring and summer stagnation. The seasonal sedimentation process is essentially the same in both lakes. Nutrient re-distribution during spring circulation results in diatom blooms. The algae removes CO2 from the water, which results in calcite precipitation in early summer. With the beginning of lake turnover in autumn and increasing wind and wave action, fine calcite particles and diatom shells move from the littoral zone to the lake bottom. The two lakes differ with regard to the contribution each of these deposition phases makes to the total sediment budget. This is not the result of different climate conditions, but differences in the shape and depth of the respective lake basins.

▶ Lake monitoring at Lake Tiefer See

Patricia Roeser et al. (2021). *Advances in understanding calcite varve formation: new insights from a dual lake monitoring approach in the southern Baltic lowlands. Boreas.*

▶ DOI: 10.111/bor.12506

REGIONAL CLIMATE CHANGE: THE ROLE OF LAND USE AND WATER MANAGEMENT

A new Collaborative Research Center (SFB) of the German Research Foundation (DFG) is studying the impact of land use and water management on regional climate change. TERENO is among the parties involved in the initiative.

"As part of this collaborative research center, we want to investigate how these two factors influence and thus change the regional climate. We suspect that these kinds of climate changes have already contributed significantly to the observed trends in the regional water cycle, such as heavy rains and flooding," says Prof. Harry Vereecken from Forschungszentrum Jülich, a Co-speaker for the new research center SFB 1502.

The initiative brings together a broad spectrum of disciplines, including hydrology, meteorology, geodesy, earth system modeling, remote sensing, agricultural economics and the social sciences. Working together, researchers from these various fields aim to develop a model system that will be able to map not only the dynamics of the individual components of the Earth system, but also their interactions with each other. The researchers hope the model can quantify human-induced influences on the natural regional water cycle, and that their findings can provide the basis for developing criteria for sustainable land and water use.

In addition to Forschungszentrum Jülich, partners involved in the SFB 1502 "Regional Climate Change: The Role of Land Use and Water Management" include the Universities of Bonn (speaker university), Cologne and Göttingen as well as Germany's National Meteorological Service (DWD). The DFG is funding the four-year start phase of SFB 1502 with 10 million euros.

The Rappbode reservoir within the Bode watershed

HIGH-RESOLUTION TIME SERIES HELP REDUCE NUTRIENT LOADS

For years, European landscapes and water resources have been heavily polluted with nutrients such as nitrate. In order to change this and to develop targeted management options, a better understanding of nutrient transport in catchment areas and nutrient mobilization to rivers is required. A team led by Dr. Andreas Musolff from the Helmholtz Center for Environmental Research – UFZ has now revealed important nutrient transport processes.

"New measurement techniques allow us to measure nutrient concentration quasi-continuously and to analyze processes with a high temporal resolution," says Musolff. "Thanks to these high-resolution time series, we were able to identify nutrient mobilization processes under different land use settings." Musolff and his team installed sensors at multiple sites in the Bode river catchment within TERENO's Harz/Central German Lowland observatory. The sensors measure nitrate concentration and concentrations of dissolved organic carbon (DOC) directly in the river.

"A large number of sensors means a lot of work in terms of maintenance and data management, but the data pay off with deep insights into nutrient processing," says UFZ researcher and co-author of the study Dr. Michael Rode. In more natural, forested catchments, for example, the researchers found that changes in nitrate and DOC concentrations varied significantly during runoff events. This variability was linked to antecedent conditions such as catchment wetness or temperature. In catchments with agricultural land use, the picture changes: nitrate concentrations were found to be generally higher than in forested catchments, but nitrate mobilization occurred much more uniformly. The researchers revealed a better availability and connectivity of nitrate sources during the colder and wetter seasons – which translates into higher nitrate mobilization.

These new insights – together with the in-situ monitoring of water quality – offer new operation strategies for river-fed drinking water reservoirs in the region. "This makes it possible to minimize the nutrient loading of the reservoir, which can then reduce treatment costs in drinking water production," says Dr. Karsten Rinke, the limnologist in the UFZ team.

Andreas Musolff et al. (2021). *Spatial and Temporal Variability in Concentration-Discharge Relationships at the Event Scale. Water Resources Research, Volume 57, Issue 10.*
▶ 10.1029/2020WR029442

HOW DRY AND WARM CONDITIONS CHANGE THE NITROGEN BALANCE

With climate change resulting in warmer and drier conditions in many regions, a team from Forschungszentrum Jülich, with the help of TERENO's SOILCan lysimeter network, set out to investigate the effects of such changing climatic conditions on the nitrogen balance of extensively managed grasslands. Their results indicate no risk of nitrogen pollution via drainage or gaseous emission.

Warmer, drier climate conditions will cause the growing period to start earlier and lead to water scarcity in summer. "Under these conditions we might see plants with lower nitrogen uptake efficiency and decreased yield," says lead author Mona Giraud, pointing out that earlier fertilizer input, however, could compensate for the plants' reduced uptake efficiency and yield.

"How exactly the nitrogen balance changes in response to these shifting climatic conditions tends to be highly site-specific and hard to predict with laboratory experiments, which is why long-term, holistic, and non-destructive field experiments are necessary," says Giraud. Fortunately, TERENO's SOILCan – a network of lysimeters established in 2010, with measurement instruments up to three meters high embedded in the soil – was designed with such field experiments in mind. After filling nine of the lysimeters with soil cores from the TERENO's Rollesbroich site, a relatively wet and cold site, where energy is the limiting factor for actual evapotranspiration (energy limited), the Jülich researchers then moved several of the lysimeters to Selhausen, a warmer and drier site where water is the limiting factor (water limited).

Data collected between 2012 and 2018 allowed the team to analyze and compare both sites. In Selhausen, the 19 percent lower plant nitrogen uptake – induced by water scarcity – was a main driver of significantly higher nitrogen content in the soil starting in 2014. Relatively high air temperature during the wet summer of 2014 also led to a significant spike in nitrogen concentration. But moving the soil cores from an energy-limited to water-limited location only had a very small effect on two specific kinds of nitrogen flows. First, there was an insignificant increase in nitrate concentrations in the groundwater; due to relatively low drainage in a drier climate, the elevated nitrogen concentration in the soil solution did not lead to increased leaching. And second, gaseous loss of nitrogen remained negligibly small.

Mona Giraud et al. (2021). *Soil Nitrogen Dynamics in a Managed Temperate Grassland Under Changed Climatic Conditions. Water, Volume 13, Issue 7, 931.*
▶ 10.3390/w13070931

WHEN THE FOREST CHANGES, SO DOES THE WATER BUDGET

How do deforestation and large-scale forest dieback affect the water budget of a catchment? Despite numerous studies, analysis is still lacking on whether such changes cause water to evaporate faster or drain slower, for example, over the long term. With this in mind, researchers from Jülich and Vienna conducted and submitted a runoff data analysis for TERENO's Wüstebach site.

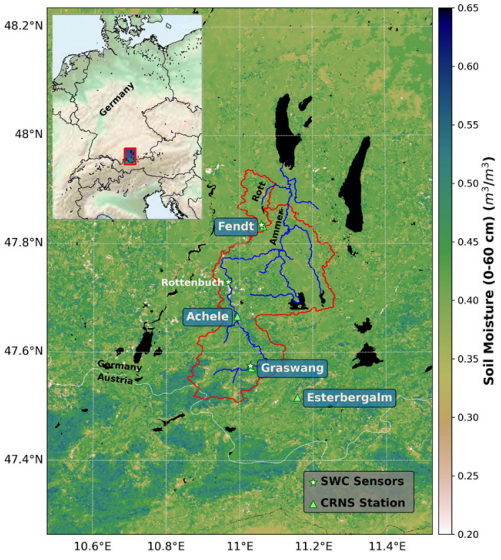
Precipitation gets distributed across the catchment area of a given river in various ways. It can drain into the river by flowing along the surface, it can infiltrate down through the soil to recharge the groundwater, or it can evaporate. "If the vegetation cover changes – as it did at the Wüstebach site in 2013, for example, when the Eifel National Park approved the logging of spruce stands to help accelerate the transition to a natural deciduous forest – it can cause precipitation to get distributed differently," explains Dr. Heye Bogena from Forschungszentrum Jülich. Such changes can be tracked by using the ratio of stable water isotopes as tracers of various water flow paths. This is because the isotopic composition of water changes during the processes of evaporation, mixing and transport.

For their data paper, the research team analyzed precipitation and stream water isotope data as well as the corresponding runoff discharge rates for the Wüstebach catchment from 2009 to 2019. "Up until the clear-cut, the stable isotopes of the Wüstebach stream water were clearly decreasing as a long-term trend. Since the cut, the trend reversed to a slight increase. This suggests that the deforestation had a significant impact on the water budget," says Dr. Michael Stockinger from the University of Natural Resources and Life Sciences (BOKU) in Vienna. The data also suggests a lower enrichment of heavy compared to light isotopes following deforestation. "One possible reason for this is that, following deforestation, a larger amount of precipitation water leaves the catchment via fast flow paths, which then reduces the isotope fractionation characteristic of soil evaporation," says Jülich researcher Dr. Andreas Lücke. The team plans to conduct additional measurements to determine the extent to which natural, longer-term changes in the water cycle have affected this isotope pattern independent of the forest conversion efforts. The researchers also hope their dataset can provide new insights into the causes of flooding.

Runoff measurement station at TERENO's Wüstebach site

Heye Bogena et al. (2020). *Long-term stable water isotope data for the investigation of deforestation effects on the hydrological system of the Wüstebach catchment, Germany. Hydrological Processes 35:e14006.*

▶ 10.1002/hyp.14006



Soil moisture in the Rott and Ammer river catchments: darker colors correspond to higher soil water content. Lakes are colored black.

IMPROVED SOIL MOISTURE PREDICTION WITH COSMIC-RAY NEUTRON SENSING

Cosmic-ray neutron sensing (CRNS) is a common technique used to determine soil moisture, and one often used in TERENO observatories. Scientists can use CRNS data to improve the soil moisture predictions generated by models. This was recently demonstrated by researchers from Garmisch-Partenkirchen and Jülich working with the widely-used land surface model Noah-MP.

"For our study we selected the combined Rott and Ammer river catchments. Both are part of TERENO's Pre-Alpine observatory, which provides extensive observation data and a lot of useful information," says the study's lead author Dr. Amol Patil, researcher at the Karlsruhe Institute of Technology's (KIT) Campus Alpine and at the University of Augsburg. The investigations showed that predictions generated by Noah-MP could be significantly improved with the help of the information gained from CRNS measurements. "We were able to reduce the root-mean-square error – a statistic for assessing prediction accuracy – up to 66 percent for the simulation of soil water content at different sites. As a result, the predictions are much closer to the real values," reports Patil.

The researchers calculated soil water content with the help of data assimilation. The soil water content dynamics and four model parameters regulating the infiltration and evaporation rates were estimated using the combined state-parameter estimation approach. "It is precisely this estimation that the CRNS data improves," explains Patil. "And ultimately this improves model physics representation across the entire catchment area."

According to the research team, just four CRNS stations were enough to effectively enhance simulations of soil water content in the vicinity of the observation stations. In regions with different land cover characteristics, they further recommended the use of mobile CRNS sensors. The study was carried out as part of the Cosmic Sense research unit funded by the German Research Foundation (DFG).

Amol Patil et al. (2021). *Assimilation of Cosmogenic Neutron Counts for Improved Soil Moisture Prediction in a Distributed Land Surface Model. Frontiers in Water, Volume 3.*

▶ 10.3389/frwa.2021.729592

A DEEPER LOOK

Measuring neutrons above the Earth's surface with cosmic-ray neutron sensing (CRNS) provides important information for quantifying soil moisture levels – but only to a depth of around 30 centimeters. Daniel Rasche (28) from the Helmholtz Center Potsdam – GFZ German Research Center for Geosciences is working on a way to use CRNS data to detect soil moisture at greater depths below the surface. A doctoral student in the DFG's "Cosmic Sense" research unit, Rasche is using various mathematical algorithms to extrapolate moisture levels at greater soil depths using data on topsoil moisture. "The goal is to be able to calculate soil moisture throughout the root zone up to a depth of about one meter," says Rasche.

To estimate soil moisture at greater depths, Rasche combines CRNS and depth extrapolation with additional measurement methods, including terrestrial gravimetry and GPS reflectometry. "Terrestrial gravimetry allows us to measure the Earth's gravity field. The more water in the soil, the heavier the Earth, and this allows us to record changes in soil water mass down to the level of groundwater," explains Rasche. Meanwhile, GPS reflectometry provides data on the top five centimeters. "When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determining a location, for example, we use the signal that enters the sensor directly. But here we use the part of signal that first enters the soil and then the sensor. The signal changes depending on how much water is in the soil, and this allows us to draw inferences about the soil moisture," says Rasche.

In addition to his permanently installed measurement instruments in the eastern part of Müritz National Park within TERENO's Northeastern German Lowland observatory, Rasche regularly uses the field campaigns at different TERENO sites to collect and evaluate data. "CRNS was completely new to me when I joined the project. But it quickly became an extremely interesting area for me," recalls Rasche, who hopes to be able to present his results by the end of 2022.

WHAT HAPPENS AFTER EXTREME WEATHER EVENTS?

While the number of extreme weather events has clearly increased over the last several years, it is less clear how such extremes, such as drought or heavy rain, impact the natural world over the longer term. Felix Pohl, a PhD candidate at the Helmholtz Center for Environmental Research – UFZ, is investigating the impacts of such extremes on the hydrogen and carbon cycles. "These cycles are closely linked," says Pohl. "I am interested in learning how the interaction of different ecosystem variables is disrupted when a lot of water disappears, for example, due to a drought – and not just the short-term impact, i.e. at the time of the water shortage, but also the long-term consequences." Pohl's research is part of UFZ's PhD project "MOMENT" which investigates material fluxes at three different sites in TERENO's Harz/Central German Lowland observatory (see TERENO Newsletter 21-1). Pohl analyzes various measurements from the three ecosystems, including soil moisture and temperature measurements, but also data on the exchange of trace


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gases such as CO2 between atmosphere and ecosystems, the flow of sap in trees, or the amount of water running down the bark of a tree during rainfall. His first round of analysis indicates that CO2 exchange following the extreme drought in 2018 was impaired not only in 2018 but in the subsequent years as well. "Of course we would need longer time series to learn whether a forest reduces its activity just temporarily or whether its productivity is affected over several years," explains Pohl (27), whose studies in Geography at the Julius-Maximilians-Universität (JMU) Würzburg led to an interest in climate models. A regional project exploring the effects of climate change on the tree population of a forest piqued his interest in climate impacts – an area he would like to continue investigating after completing his doctoral work.

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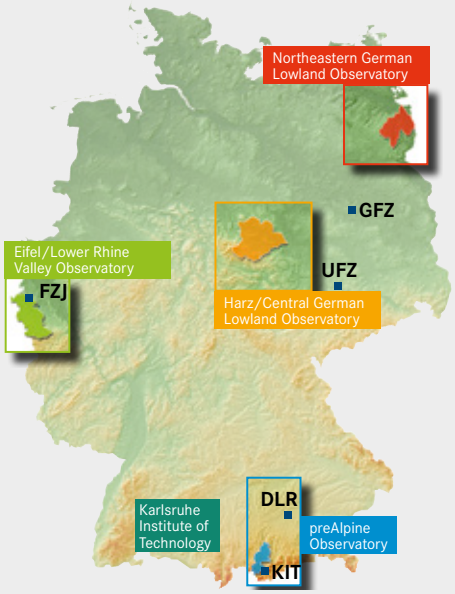

FZJ Forschungszentrum Jülich (Coordination)

DLR German Aerospace Center

KIT Karlsruhe Institute of Technology

UFZ Helmholtz Centre for Environmental Research

GFZ Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences

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