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CENTER
FOR EARTH SYSTEM RESEARCH
AND SUSTAINABILITY (CEN)

WHEN RAPESEED FIELDS BECOME A BONE OF CONTENTION

TEN CLIMATE RESEARCHERS REPORT

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New Stories of Earth System Research from Hamburg

INHALT

NEW CLIMATE STORIES FROM HAMBURG

Renewable energies can protect our climate. But there are sure to be conflicts when crop fields are full of rapeseed and maize for use in biogas processing plants. What makes farmers decide in favor of or against growing these energy-producing plants? Researchers at Universität Hamburg's Center for Earth System Research and Sustainability (CEN) and Cluster of Excellence CLICCS are currently exploring these and many other questions concerning climate change.

You'll also find out which areas are best suited to enhancing nature conservation in Europe, why the vegetation in a small Himalayan village has remained unchanged despite climate change, and what measures can help reduce nutrient inputs into in the North Sea.

Once a month, our researchers discuss their work in the *Hamburger Abendblatt*. In the following pages, we have gathered ten of these articles.

Enjoy browsing!

NATURE CONSERVATION: FILLING IN THE GAPS

An apparent contradiction is what first inspired me to write my dissertation: on the one hand, the European Union is creating more and more conservation areas; on the other, flora and fauna species continue to die out, and habitats are disappearing at an alarming rate. And this trend is not just problematic in terms of wildlife conservation; the loss of biodiversity also impacts our climate – because diverse, intact habitats like moors and forests bind carbon that could otherwise escape into the atmosphere as the greenhouse gas carbon dioxide.

Where conservation areas are still lacking is an aspect I'm investigating in my dissertation. To do so, I began by researching what the EU had done to date. In the process, I realized that the EU has now reached one of its most important goals: conservation areas now account for 18 percent of Europe's land mass; that's one percent more than promised. Yet it has failed to reach a second key goal: it hasn't yet adequately taken into account every type of habitat, and hasn't declared ten percent

of each of Europe's 43 "ecoregions" as protected areas. This should have happened by 2020. The EU has agreed on this at various climate summits.

Six ecoregions could still use some improvement. They include the "English Lowlands beech forests" and the "Po Basin mixed forests" – comparatively small regions, and niche landscapes, so to speak. Surprisingly, however, another region – one that sprawls across several countries – is also on the list. Beeches, oaks and pines dominate the "Atlantic mixed forests", which stretch from the Pyrenees to the German-Danish border. Yet the massive region is hardly uniform; in addition to forests, it is also home to habitats like running waters, moors and meadows. In order to preserve Europe's biodiversity, we would need to protect at least a sliver of each habitat.

That hasn't happened yet. In the Atlantic mixed forests, for example, there are no bog woodlands, i.e. deciduous forests with moor birches or Scots pines on damp, nutrient-poor and acidic soils. Such forests can or once could be found in France, Belgium and the Netherlands – and were once common in northern Germany. But after centuries of drainage, they're now in dire straits.

So who needs to take action? Which country has to create the remaining conservation areas? Though there are no guidelines to provide answers, it would make good sense to create them where the EU's goals could be reached most affordably. That's most often possible in areas where the land isn't very fertile. If there are no major impacts on their commercial interests, landholders are more likely to accept the limitations that conservation entails. And less-farmed areas often provide a safe haven for rare plants and animals.

For my dissertation, I gathered information on land prices throughout Europe, and developed a computer program that compares them with the presence of habitats that warrant protection: no mean feat, since I had to first devise a suitable algorithm. It took a year and a half before I was able to start identifying districts, duchies, counties and comtés that would be good candidates. Some are only a stone's throw away from Hamburg, e.g. in the district of Rotenburg (Wümme) or Lüneburg.

Actually, we're very close to reaching the EU's goals. Only an additional 0.35 percent of Europe's land mass would need to be declared as conservation areas; that's 15,000 square kilometers – or 20 times the area of Hamburg.

Dr. Anke Müller wrote her dissertation in the research unit Sustainability and Global Change and was a member of Universität Hamburg's Center for Earth System Research and Sustainability.

THE NORTH SEA IN 300,000 DATA SETS

Taking up industrial and agricultural wastewater from all across the country tributaries such as the Elbe and Weser are pushing their way into the sea. Likewise, large quantities of emissions pumped into the air are dissolving into the ocean. Thus, ample amounts of additional—potentially unwanted—nutrients like phosphate and nitrogen reach the North Sea contributing to overfertilization.

Luckily, ever since phosphates were banned from detergents in the 1980s, phosphorous concentrations have declined; nitrogen levels are also dropping. The European Union Water Framework Directive sets limit values for both. Nonetheless, during peak times these maximums are far exceeded, for instance through land fertilization.

My colleague Johannes Pätsch and I share a particular interest in finding out how the North Sea will change in the future: What nutrient concentrations can be found and how will they be distributed in coastal waters and the open sea? What are the impacts of climate change and rising temperatures?

We are using a computational climate model that can provide detailed prognoses for the North Sea Region. Based on mathematical formulas it is geared to deliver simulations, as exact as possible, of the complex processes at work there. We verify our results by modeling previous time periods and comparing them with real-world data gathered at the time. The more similar the results, the better the model.

But the data set best fitting our model merely comprises measurements from the 1970s to the 1990s. It is rather ill-suited for a comparison with today, as back then the water was still full of phosphate and nitrogen. So, we needed a new data set aiming to collect and prepare all official data gathered on the North Sea Region from 1960 to date and make it available all across the world – a giant project.

Initially, I asked various oceanographic research centers for daily figure packages including times and places. These centers receive most data from research vessels, measuring buoys or coastal stations. I thus accumulated over 300,000 data sets with information on salt concentration, temperatures at various water depths, and nutrients such as phosphate, nitrogen, and silicate – all meeting different standards and quality levels.

From this we had to eliminate double mentions, identify freak values, and check data plausibility. We used the cleansed data to develop an interactive map of the North Sea with measured values for each month. Our map is freely accessible online through the Universität Hamburg's Integrated Climate Data Center (ICDC) – a treasure trove for marine biologists and climate modelers.

The new data is already helping us detect weak spots in our computational model. During simulations, for example, the phosphate value never fully drops to zero. In the sea, however, this frequently happens once all nutrients get used up in summer. We must therefore further hone our model until it gets better at simulating real conditions. It will not be fit for calculations into the future before it can simulate the past 30 years as targeted. Our next goal is to predict North Sea scenarios up to the year 2100.

Such prognoses are in high demand. What is the key to reducing nutrient loadings? New wastewater treatment plants? Nitrogen-free car fumes? Policymakers strive to comply with EU-prescribed limits. Our improved North Sea model helps devise useful countermeasures.

Dr. Iris Hinrichs is an oceanographer from the Center for Earth System Research and Sustainability at Universität Hamburg.

ENERGY TRANSITION: WHEN RAPESEED FIELDS BECOME A BONE OF CONTENTION

In the course of the energy transition, the proportion of renewable energy in Germany has increased significantly. But the wind turbines, biogas plants and solar parks have repeatedly come under criticism. Can such conflicts be avoided?

The transition to climate- and environment-friendlier energy sources is impacting our landscape: wind turbines and energy crops for biogas plants require a great deal of space – which can lead to conflicts. Accordingly, at Universität Hamburg's Center for Earth System Research and Sustainability (CEN) we are investigating what future "energy landscapes" could look like. To do so, my colleague Prof. Jürgen Scheffran and I are working with models that simulate developments over extended timeframes. For example, we use what are known as agent-based models – models that describe why, when and how stakeholders act.

Concretely, we have employed such a model in Schleswig-Holstein to investigate how bioenergy needs are

shaping land use. Here, every agricultural community is considered to be a stakeholder. We've also taken a closer look at four agricultural plants that can, in part, be used as energy crops – wheat, maize, sugar beets and winter rapeseed – and compared the size of the crop fields and the choice of plants in 2010 with the projected development through 2100.

The idea: farmers in each community make decisions about which plants to grow every year on the basis of specific rules. That means they don't act randomly, but instead take into account the current profit expectations – making them to some extent predictable. The market price, harvest size and demand can be used to calculate the potential profit for farmers.

When it comes to the price and harvest size, in the model we assume that the trends of the last 20 years will continue largely unchanged; in contrast, we vary the other factors for each respective case. In this way we can e.g. investigate how crops change when more agricultural land is available, or what happens when energy crops are actively promoted, such as through subsidies.

The results show: if communities have more available agricultural land each year, the area used for food production doesn't decline. What's more, the proportion of energy crops, including maize – which typically partly serves as an energy crop – declines and instead, above all, more wheat is planted.


BIOSPRIT
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Only external stimuli, like financial incentives, can increase the proportion of energy crops. However, beyond a certain point this development accelerates markedly – changing the landscape significantly.

Our model is unbiased: it shows which developments can arise, but not people's reactions, for example protests. We can, however, identify situations in which conflicts are likely – for instance when monocultures are created, or when commercial land competes with conservation areas. If residents respond with e.g. demonstrations, it could affect farmers' decisions for or against particular plants – and the development through 2100 would then look very different.

At the annual "Energy Landscapes North Germany" conference we bring together representatives from government, the scientific community and society at large to discuss different scenarios and issues. Together we seek to find solutions and to assess new developments. For example: What would change if bioenergy were no longer limited to local use, but could be used throughout Germany? Would more farmers opt for rapseed if there were also a demand for it as an energy crop in Bavaria?

Dr. Peter Michael Link is a geographer at Universität Hamburg's Center for Earth System Research and Sustainability.

HAMBURG-BASED “AGENTS” IN THE SERVICE OF CLIMATE RESEARCH

My agents don’t wear dark sunglasses, and most don’t even drive a car. Except for Bob: when he needs to go somewhere, he prefers to drive there. In contrast, Alfred likes to bike through the city (as long as it’s not raining), and Earl tends to use public transportation.

Day in and day out, Bob, Alfred and Earl commute to work in Hamburg’s Hoheluft district, bring their children to the daycare, or go shopping. But they don’t actually exist. They are “agents”, who move through a virtual Hamburg in a computer model. My team and I use this model to explore how agents’ typical living situations and attitudes influence e.g. their choice of commute: Bob doesn’t have much time, Earl doesn’t have much money, and Alfred is very environmentally aware. In addition, factors like the weather, gasoline and bus prices shape their decisions.

Thanks to the model, we can also estimate how the agents are affected by “environmental stresses”, i.e., by environmental factors that are potentially harmful to their health, like heat, noise, air pollution or the impacts of climate change.

In cities characterized by a high density of people, buildings and traffic, these stresses are especially dangerous: around the globe, air pollution alone is responsible for an estimated two million deaths every year. Further, because buildings store heat, extreme heat waves — which are likely to become more frequent in the future — can make cities far warmer than the surrounding countryside.

More than half of the global populace already live in cities, and that number is rising. For urban planners and politicians, making cities healthy and worth living in is a key priority. And the insights that we glean from agent-based modeling can help them achieve that goal. On the computer we can experiment to see how annoying construction sites, rising costs for public transportation, or additional bike paths affect the choices of individual citizens – and what that means for their health, and for the health of the city as a whole.

The method was made possible by the rise of computers. I first took advantage of it for my doctoral dissertation in 1989, where I used a self-programmed model to simulate the outcomes of various scenarios in the East-West conflict. Given the two main possibilities — escalation and de-escalation — my model predicted that growing trust between the two superpowers would likely produce a chaotic transitional period. And, just a few weeks after the simulation, the cold war ended with the collapse of the Eastern Bloc. Even I was amazed to see how quickly the reality caught up with my forecast.

Today, agent-based modeling has become indispensable for researchers. If our goal is to understand how a specific group will behave in a given setting, the method can offer valuable insights. It's also well suited to researching the effects of urban environmental stresses — as the test with the representative agents Bob, Alfred and Earl shows. The results produced to date have laid the groundwork for expanding the model using real-world behavioral data. We could then e.g. simulate the consequences of extreme weather events, to determine whether or not urban evacuation and supply routes actually work as they should in a crisis. Another possibility would be to apply the method to other metropolitan areas – after all, cities around the world have to adapt to climate change.

Jürgen Scheffran is a Professor of integrative geography and head of the Climate Change and Security Research Group (CLISEC) at the Center for Earth System Research and Sustainability.

TEMPERATURE EXTREMES: EUROPE IS WARMING UP, TURKEY IS COOLING OFF

In Europe, we can access temperature data established through a dense network of measuring stations since 1950 – a gigantic treasure trove of data that also reveals plenty of information about medium-term climate conditions.

One thing is for certain: Average temperatures are rising. But how exactly does this manifest itself locally? As a statistician at Universität Hamburg's Center for Earth System Research (CEN), I set out to approach measurement series from a different angle – producing astonishing results!

We normally derive averages from measured data. These provide us with a good overview. I can thus, for instance, compare the average temperature of a certain year to averages from other years. Alternatively, I can scrutinize all summers in a country or certain region since 1950, focusing on their development.

Yet, averages are only half the truth. If, for example, the nights would get colder while the days would become warmer in the same place and at the same time, the averages would not change at all – humans and nature, however, would be severely impacted. Therefore, I am particularly interested in finding out whether extreme temperatures are changing as well, for ecological systems tend to be most vulnerable under radical conditions.

But what values are extreme? In order to answer this question, I categorize 90 percent of all temperature values as "normal". Merely the coldest and hottest five percent are considered extreme – a well-known statistics method not yet applied in climate research.

We would expect global warming to work as a simple addition to "normal temperatures" with hot days getting even hotter and colder days warmer.

Even so, the results clearly show: While average temperatures, particularly in France and Germany, have generally been increasing, extreme values have been developing very differently across Europe. As expected, hot days have become even hotter in Central and East Europe over the past sixty years. In Norway and Southeast Europe, by contrast, hot days have actually cooled down. Turkey is a special case: In the past decades, both hot and cold days have gotten colder.

How does this fit into patterns of warming due to climate change? Regionally, strong natural climate variations may mask the global temperature rise, so to speak. This knowledge

is crucial to individual areas: Instead of assuming a general two-degree temperature increase, politicians can use our findings in adapting urban planning and agriculture to specific local requirements.

Hence, I have created additional profiles for individual cities. Trondheim in Norway, for instance, shows a diminishing temperature range since 1950. In the past, temperature lows averaged minus 18 degrees Celsius; nowadays, they do not drop below about minus 14 degrees anymore. Unaltered, temperatures on the warmest days do not exceed six degrees. Evidently, Trondheimers have “lost” several low temperature points in the past sixty years.

Quite differently, in Germany’s capital Berlin, colder days have stayed more or less the same, averaging about seven degrees Celsius. Hot days saw temperatures increasing by two degrees, roughly reaching 32 degrees: Berlin’s temperature profile has broadened. I am currently analyzing data from the measuring station in Fuhlsbüttel, a district of Hamburg. We will know more about temperature trends in Hamburg shortly.

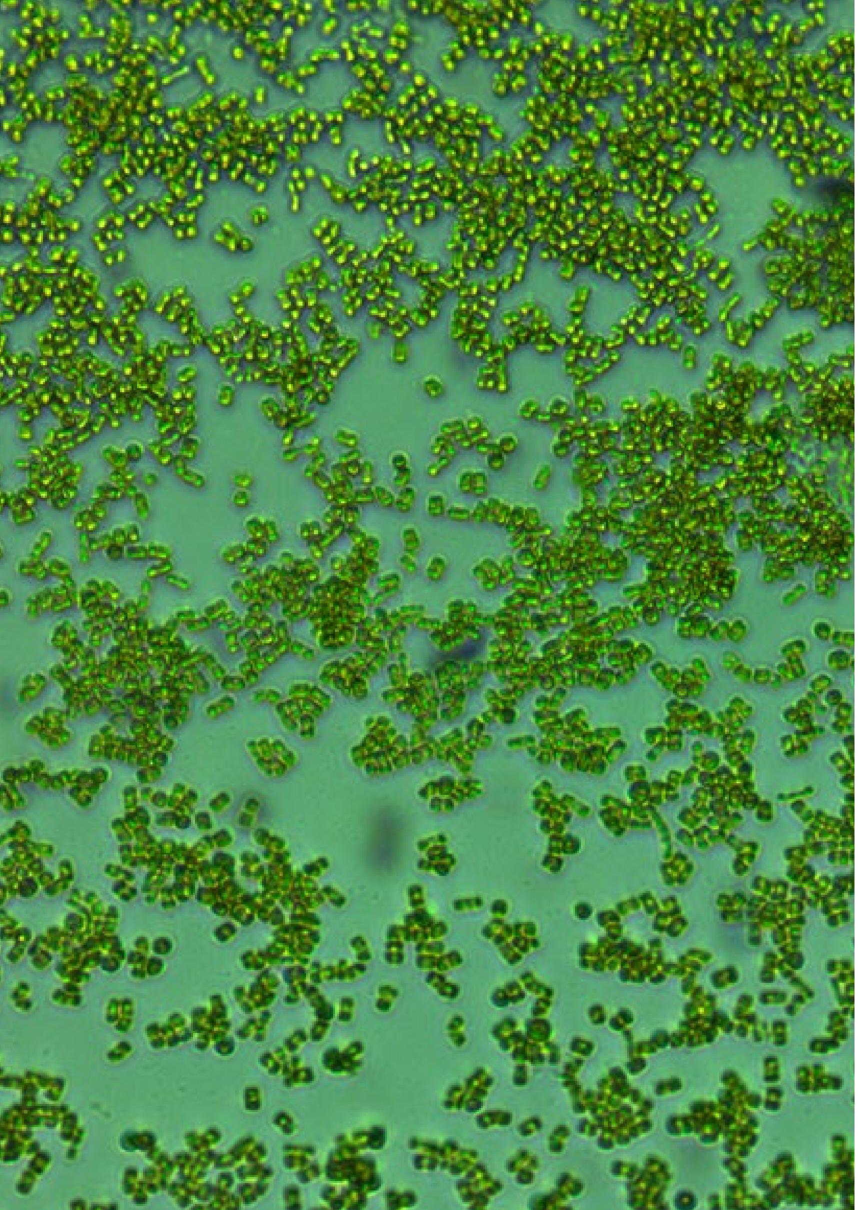
Dr. Christian Franzke has worked as an expert in climate statistics at the Center for Earth System Research and Sustainability at Universität Hamburg.

MARINE ALGAE: DEFYING CLIMATE CHANGE ON A ROLLERCOASTER

Half of the oxygen we breathe comes from the ocean. Minute algae, known as diatoms, produce this oxygen. At the same time, they are also the basis of the entire food chain in the ocean. But climate change is altering their habitat.

In the year 2100, climate change may well have altered quite a few things in the sea. That’s why I’m investigating how algae will react in the long term to new and extreme conditions. A ten-degree rise in water temperature? Significantly more CO_2 dissolved in the sea – making the water more acidic? Many of today’s algae wouldn’t be able to tolerate this, and computer models predict that the population could decrease by a fifth in the long term – with far-reaching repercussions for the oceans and the atmosphere.

But is the alga of today the same as the alga of tomorrow? Algae reproduce rapidly and their populations are enormous. A generation is replaced within one or two days – an advantage when it comes to mutation, which can lead to beneficial genetic adaptations.



We put a type of diatom known as *Thalassiosira pseudonana* in hundreds of mini aquariums at different temperatures. Their "comfort zone" is 22 degrees Celsius, but we also kept them in water that was warmer, at 26 degrees. According to the IPCC climate report, the temperature will have risen by this much on average by 2100. And this is just a mean value; peak temperatures – like those in a heat wave – will be much higher, which is why we wanted to provoke the algae still further. In another 100 containers, we are exposing them to continuous temperatures of 32 degrees.

Once an experiment has been set up, it means that my team has to monitor, clean, and feed the algae several times a week. For one to two years! Including at Christmas and during the summer vacations. Evolution may be beautiful, but it takes time! Usually, we only finish the experiment after 300 generations. And sometimes, in the end it turns out that the algae were unable to permanently adapt to the test factor and struggled to thrive.

Couldn't we get the algae to adapt in a shorter time? I wanted to try out a new method out for the first time: Instead of introducing the *Thalassiosira* to the changing conditions gradually, I put them on a rollercoaster. In a further series of experiments, I immersed them in alternating baths – warmer, cooler, warmer, cooler. Every four days I turned the thermostat up from 22 to 32 degrees, then after another four days turned it back down again. Could they tolerate this?

The surprising answer: Yes, very well! The results were impressive, demonstrating that while the algae in constant 32-degree modus were unable to cope with the heat and developed poorly for about a year, they were able to tolerate the same temperature in fluctuating modus without any problem. The population came to life – like at 26 degrees – and grew quickly. Faster even than at the usual 22 degrees. Our analyses also show that the genetic changes in *Thalassiosira* are greatest in fluctuating conditions.

An unstable environment promotes genetic adaptation in algae – a groundbreaking discovery. This means that they are better equipped to adapt to future extreme situations. A positive side effect: Our experiments can be shorter. For the moment we don't have to worry about the flexible diatoms. Instead we need to keep an eye on their predators, which may not be able to adapt as quickly. With their versatility, the algae appear to always be one step ahead.

Elisa Schaum is a Junior Professor for plankton ecology and an evolution expert at Universität Hamburg's Center for Earth System Research and Sustainability.

LIKE SMALL BLENDERS IN THE SEA: OFFSHORE WIND TURBINES

Along Germany's coast they seem to sprout up like mushrooms: offshore wind farms. Dozens of wind turbines, each over 100 meters tall, produce renewable electricity for our households. But do these farms disturb marine ecosystems? Or do they actually have a positive effect?

To answer these questions, we are currently investigating two wind farms off the north coast of Eastern Friesland. Once a year we travel through the offshore wind farms on the research vessel Heincke. During these two-week expeditions, we always have the Triaxus sensor system in tow. Equipped with various measurement instruments, it moves independently, bobbing up and down between the surface and the sea floor, measuring – among other things – the water temperature and the concentration of phytoplankton, which are minute algae.

The two wind farms cover an area greater than 10,000 soccer fields and their turbines provide enough electricity to supply over 800,000 households. Together with colleagues

from Universität Hamburg's Center for Earth Systems Research and Sustainability (CEN), the Helmholtz-Zentrum Hereon and the University of Oldenburg, we were able to collect the first data even before the wind farms were installed – since even the turbines' bases could affect the water flow.

Our data confirms that assumption: on the leeward side of the turbine bases we have observed turbulence similar to that behind bridge piers in a river. The bases act like small mixers in the sea – the turbulence increases the mixing of the water and the usual "layering" effect is weakened. Normally, in summer there is a layer of warm water at the top and a separate, colder layer below. Anyone who's ever swum in a lake knows this phenomenon: our feet are sometimes in much colder water than our torsos.

Usually there is little exchange between these two layers, and since the microalgae have already consumed most of the nutrients in the upper layer by spring, they usually only multiply slowly in summer. However, the turbulence is now transporting nutrients from the deeper water to the topmost layer, allowing the algae to multiply faster. During the expedition, we discovered veritable "plankton columns" – water masses several hundred meters in diameter with particularly high algae concentrations. Our next task is to find out exactly how these columns are formed, and what effect they have.

It’s possible, for example, that zooplankton benefit from the increased algae concentrations, since these microscopic crustaceans feed on phytoplankton microalgae. If they do, then the waters between the turbines should offer rich pickings for the fish that feed on zooplankton. This in turn would mean that larger fish – such as cod – that feed on other fish would also benefit from the increase in potential prey. The farms could become a refuge for various fish species, producing a positive effect on the ecosystem. In addition, the rotors’ slowing effect on the wind could change the layering of the water in the summer, affecting an area far larger than the wind farms themselves. To get to the bottom of these effects, we’ll soon be heading back out to sea: the next sea voyage is already planned.

Dr. Jens Floeter is an expert in fisheries science at Universität Hamburgs’s Center for Earth System Research and Sustainability.

HOW A VALLEY IN THE HIMALAYAS IS DEFYING CLIMATE CHANGE

The small village of Beding clings to the side of a cliff, roughly 3,700 meters above sea level in the untamed Rolwaling Valley – approximately 100 kilometers east of the Nepalese capital, Kathmandu.

Here, in the mountainous world of the Himalayas, climate change is progressing faster than elsewhere in the world: on-site measurements and trend calculations indicate that the average air temperature at this altitude rose by 1.5 degrees Celsius between 1991 and 2012. Yet, while rising temperatures have led the treeline to advance in other mountainous regions, in Rolwaling it hasn't budged an inch. That would seem paradoxical, since the higher reaches now offer a sufficiently long vegetation period for trees. Why, then, has the treeline remained so stable? At Universität Hamburg's Center for Earth System Research and Sustainability (CEN), my colleague Birgit Bürzle and I are investigating this question. Due to the short vegetation periods and low temperatures, the trees grow into stunted krummholz. Whereas the krummholz zone in the Alps chiefly consists of mountain pine, the

woods surrounding Beding are dominated by hardy rhododendron bushes. Only two to three meters tall, they form virtually impenetrable thickets.

The undisturbed treeline offers optimal conditions for our research; such untouched transitional zones between two different ecosystems are hard to come by; in the Alps, for example, they've all but disappeared. Since human beings cleared away trees there in the higher altitudes, and areas once used as alpine pastures were later reclaimed by the forests, the lines between climate-change-related and anthropogenic effects have become too blurred. In contrast, the northern cliffside near Beding has remained unchanged, because the Buddhists believe it to be sacred.

Here we surveyed the vegetation at four different heights – including the level of the rhododendron belt, and the areas directly uphill and downhill of it. I counted and mapped the trees, recorded the diameters of their trunks and canopies, and gathered wood samples. In addition to rhododendrons, the area is also home to birches, pines, ashes, maples and junipers.

In addition, my colleague explored all the plant communities; beyond trees and saplings, these include all shrubs, herbs and grasses. Though she found over 100 species in the survey area, she also determined that only 12 of them grow in

the krummholz belt, and the chances of new species settling there seem practically nonexistent.

Our studies show that the composition of the vegetation and the position of the treeline don't just depend on the temperature, but also on the available nutrients and topography. In addition, the evergreen rhododendrons create inhospitable conditions for other plants: since they grow together so densely, very little sunlight makes its way to the topsoil. And even if a seed manages to germinate into a plantlet, its roots will hardly be able to penetrate the hard-to-decompose leaves in the soil. There is also evidence suggesting that rhododendron leaves release growth-inhibiting toxins, allowing the plants to protect their habitat from invasion by other species. At the same time, the plants themselves form a physical barrier, preventing plants in the transitional zone from migrating up to the treeline – an obstacle that seeds can't overcome, either. In fact, this is so effective that it has prevented the treeline from shifting, despite climate change.

Dr. Niels Schwab and **Dr. Birgit Bürzle** conduct research in the field of vegetation and landscape ecology at Universität Hamburg's Institute of Geography.

NEW INSIGHTS
INTO MYSTERIOUS ICE CLOUDS

On fair days, I can study the subject of my research just by looking out my office window: cirrus clouds, which look like feathers painted on the sky with delicate brushstrokes. They can be found at altitudes of six to fourteen kilometers, are composed of tiny ice crystals, and play a decisive part in the climate system. But we're only beginning to understand just how they actually work.

To learn more about cirrus clouds, I have developed a measuring instrument that can peer inside ice clouds from the vantage point of a satellite. For the past 13 years, I've been trying to convince the European Space Agency (ESA) of the instrument's value – and now I've finally succeeded: in 2023 the "ICI" (Ice Cloud Imager) will be launched into orbit together with the weather satellite MetOp-SG, where it will observe cirrus and other ice clouds for the next twenty years from 800 kilometers above the surface.

Clouds have an enormous influence on our climate. For one thing, they reflect part of the sun's radiation back into

space; for another, they capture part of the heat produced on Earth, which would otherwise dissipate into space. As such, they help shape the temperature on our planet.

That being said, not all clouds are created equal. Low-hanging clouds composed of water droplets reflect more short-wave solar radiation and let the Earth's long-wave radiation pass through them – we can often feel their cooling effect firsthand. In contrast, cirrus and other clouds made of ice have very different physical properties: they let in more solar radiation and keep more heat near the Earth's surface; as such, they have more of a warming effect.

The ICI will measure how much of the radiation coming from the surface a given ice cloud allows to pass through. To date, researchers have only been able to gauge this radiation in certain segments of the electromagnetic spectrum: one third of it is released into space before it can be analyzed. The ICI will penetrate this unexplored area and record radiation in the "sub-millimeter range", i.e., at wavelengths of between 0.5 and 1.5 millimeters.

Thanks to various tests, we know that such measurements can be taken with the sensors available today. For example, together with British researchers we mounted a prototype of the instrument on an airplane and had the craft fly over ice clouds. We're very satisfied with the results; though there's still no guarantee that the ICI will work just as smoothly in space, but they're a promising start.

The new data this approach yields will allow us to determine the makeup of a given cloud: how much ice it contains, how large the individual crystals are, and whether there are also water droplets. We need this type of information to refine our climate simulations, which can currently only portray clouds in a very rudimentary form: that's true for today's clouds, and even more so for the clouds of tomorrow, which will be affected by climate change. But we don't yet know if there will be more or fewer ice clouds in the future, if their distribution will change, or if their composition will be altered. Thanks to the ICI we'll be able to make more accurate predictions – and to follow the first changes "live".

Prof. Stefan Bühler is a member of Universität Hamburg's Center for Earth System Research and Sustainability (CEN) and Managing Director of its Meteorological Institute.

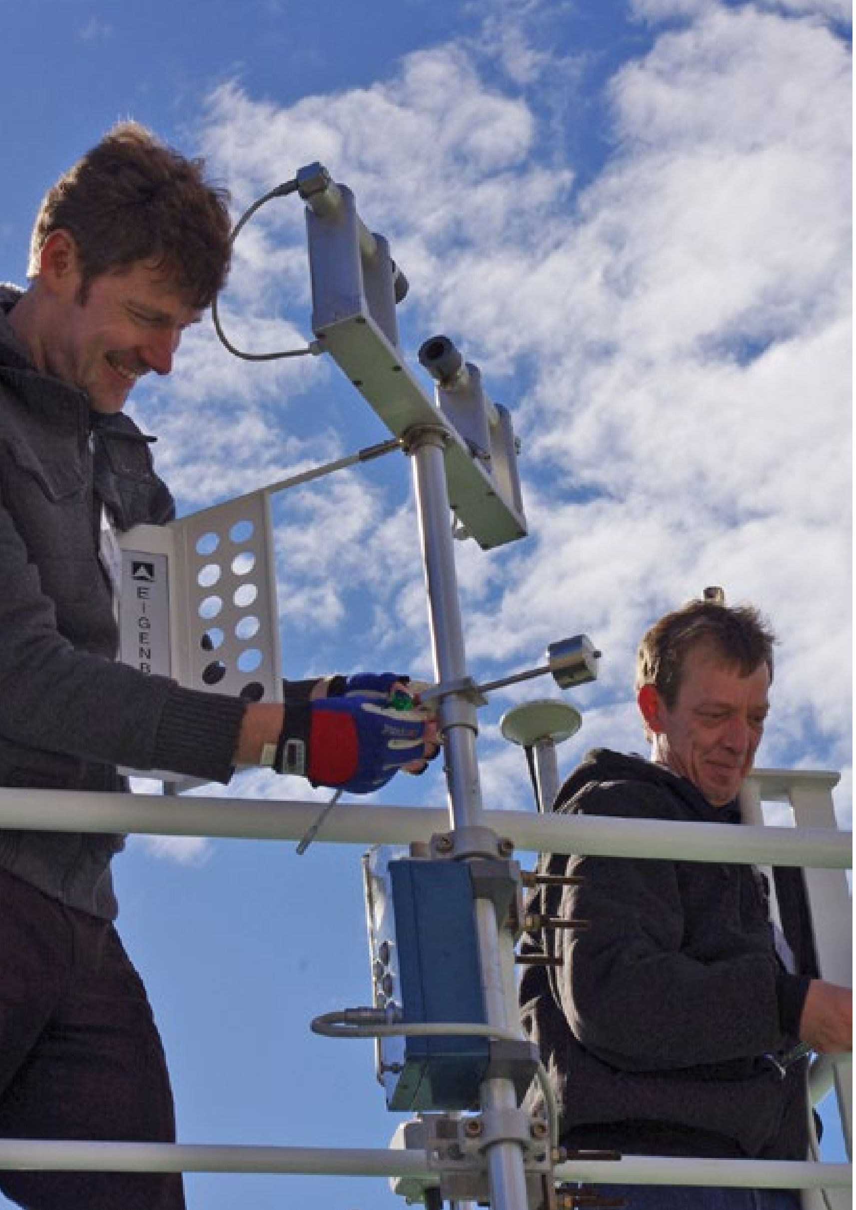
RAIN CATCHERS OUT AT SEA

"It's like a wall of water! It's raining so hard I can't see my outstretched hand." This is how a crew member of the research vessel Meteor reported a heavy tropical rain shower off the coast of Guinea.

At the time, September 14, 2015, one of my measuring devices was also on board: It recorded 40 liters of rain per square meter in just 20 minutes. It must have been an incredible cloudburst. For comparison: In Germany, severe weather warnings are issued for rainfalls of eight liters per square meter in the same time.

That extreme measurement is part of a new, world-ocean dataset that I am developing at at Universität Hamburg's Center for Earth System Research (CEN). My OceanRAIN project fills an important scientific gap, as to date precipitation over the sea has not been accurately and comprehensively measured on board ships – even though around 80 percent of all precipitation falls over the oceans. As such, the oceans play a key role for the water cycle in the climate system – including evaporation, which we also measure.

Special satellites – which indirectly determine the precip-



itation over a measured radiation field – provide a global picture. These require mathematical rules – algorithms that convert the radiation field into precipitation. Around the globe, numerous research institutes have created such algorithms, but until now they lacked high-quality, shipboard measurements of rainfall over the oceans. Now, for the first time the satellite data can be verified, calibrated and improved: If they reproduce what our equipment has measured, we know that the satellites are correctly adjusted. Climate models can also be improved in this way, and in turn verified using satellite data.

Until now there were no measurements over the oceans, because there was no suitable equipment for use on board ships. While land-based gauges collect rain – and less accurately, snow – shipboard measurements call for a different method, since here the wind often blows the rain away from the collection containers and they remain empty. On board a ship the containers are also exposed to more movement – for example stronger airstreams and more turbulence due to structures on deck.

The solution is an electronic device that allows me to determine the amount and type of precipitation: an optical distrometer. This records every individual raindrop and snowflake, creating a shaded area for each. Together with the manufacturer, I have further optimized the device for automatic operation. It offers an improvement on the previous satellite data, because it can differentiate between rain, snow and mixed phases. Using a distrometer we were able to accurately measure snowfall at minus forty degrees. It measures precipitation with 128 different particle sizes, from 0.1 to 22 millimeters in diameter.

There are now 14 ships around the globe with our distrometers on board, with the longest continuous dataset being collected by the icebreaker Polarstern: For seven years, the distrometer recorded rain, snow and mid-phase precipitation from the Arctic Ocean to the Antarctic. Before I started my project, there were only a total of about 10, 000 rain measurements collected over the world's oceans – and they were of comparatively poor quality. In the meantime we have taken more than seven million measurements, ten percent of which relate to precipitation. These are available for remote-sensing and climate research – and the dataset is still growing.

Dr. Christian Klepp worked as a geoscientist at the Center for Earth System Research and Sustainability at Universität Hamburg.

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