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CENTER
FOR EARTH SYSTEM RESEARCH AND SUSTAINABILITY (CEN)

STREET TREES UNDER STRESS

TEN CLIMATE RESEARCHERS REPORT

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New Stories of Earth System Research from Hamburg

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NEW CLIMATE STORIES FROM HAMBURG

Cities without trees? Hard to imagine! They offer shade, cool the air and produce oxygen. But dryness, exhaust fumes and sealed surfaces are making their lives harder. How can we provide better living conditions for oaks, lindens and maples, so that we don't lose our "green lungs"? 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 what revived dinoflagellates can reveal about climate change; how greenhouses gases can be reduced in agriculture; and why, when looking for sites to store nuclear waste, we should keep the next ice age in mind.

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!

PLANKTON FROM 1920 – REVIVING TINY ALGAE FROM THEIR LONG SLUMBER

Phytoplankton is simply amazing: despite its small size, it forms the nutritional basis for all marine life and produces half of our planet's oxygen. Accordingly, we marine biologists are keeping a close eye on how climate change is affecting these small algae.

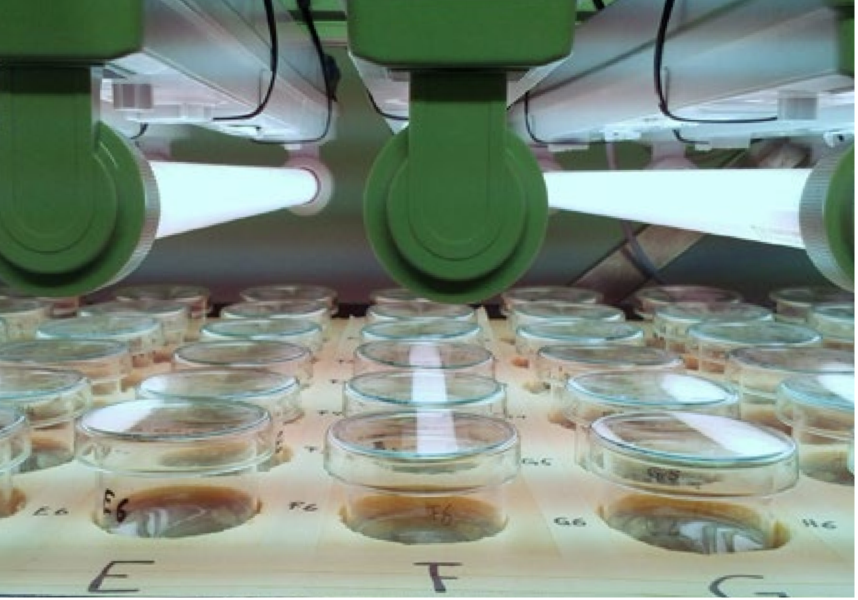
Are they successfully adapting to the higher temperatures? To answer that question, for the first time I revived the ancestors of a plankton species that can survive for years in sediment. What does the comparison with its modern counterparts tell us?

At the Center for Earth System Research and Sustainability (CEN), my work involves tiny organisms known as dinoflagellates. My "dinos" came from the seafloor off the coast of Helsinki, and their lives are mostly shaped by temperature. If it gets too warm for their taste, they go into stasis and sink to the ocean floor. Once in the sediment, they can survive for great lengths of time without oxygen. When the sea ice thaws in the spring and the first sunbeams hit the water's dark surface, they

can become active again. Further, springtime storms can stir up the sediment, exposing the sleepers to oxygen and light; as a result, they generate new cells and rise to the surface. Their favorite temperature range is between zero and six degrees Celsius. They consume massive amounts of nutrients, double their mass every three days and, together with other species, form enormous algal blooms.

Yet the time of year when the dinos typically bloom has already shifted: for the past 30 years, it has come roughly ten days earlier – a clearly recognizable change! Does that mean the dinos have adapted to the new conditions? By comparing them with their ancestors, I hoped to find out.

We were able to date the samples from Helsinki with the help of radioactive methods, and found they actually were 100 years old! During that time, the local waters had warmed by roughly 0.8 degrees Celsius, a major change for the algae. In the next step, we gently cleansed the centenarians and kept them in fresh 3-degree-warm water, always with one question in the back of our minds: would they really wake up and create brand-new dinos? And it worked! Suddenly I could see tiny, living creatures from 1920 floating in my Petri dish. Using a micropipette I then removed single cells, one by one, and allowed them to multiply separately. For comparison, I took dinos from today that were in stasis, and subjected them to the same pro-



cedure. Then I monitored their behavior at different temperatures for several weeks.

This allowed me to quickly rule out a few factors: the modern dinos didn't multiply any faster than the old ones; the pace was the same. They also became active at the same water temperatures as they did a century ago, and both groups went into stasis once the temperature reached 14 degrees – meaning their temperature range hadn't changed. Nor had their size.

Yet then I noticed that many of the new algae were much slower to go into stasis. Whereas many of the older dinos did so at between seven and nine degrees, this was true for only a handful of the new ones. That could be a strategy: the water now grows warm earlier in the year. If the dinos followed their old pattern and went into stasis en masse, they wouldn't have enough time to form algal blooms. But these blooms are vital for their reproductive cycle.

It would seem that today's dinos have adapted their rhythm to the warmer temperatures. Plus, we've learned another valuable lesson: the sediment could hold the answers to further questions on climate change adaptation.

Dr. Jana Hinners is a marine biologist and did her doctorate at the Center for Earth System Research and Sustainability at Universität Hamburg.

URBAN CLIMATE: HOW CAN WE FIND THE MOST COMFORTABLE SPOTS?

Newly paved, new benches, a handful of trees – yet the large plaza is usually empty. Another spot, just around the corner: here all the benches are full, the people enjoy spending time there. What is the difference? It could be the great view or the historical buildings – or the "thermal comfort" factor.

As an urban climate researcher, one of my goals is to identify when a place is considered to have a comfortable temperature – and the role of architecture in this regard. Whenever a place is renovated or redesigned, the local meteorological conditions change – and with them, the thermal comfort for visitors. At the Center for Earth System Research and Sustainability (CEN) we have developed a computer model that can precisely simulate cities, allowing us to test the potential effects of planned changes in advance. For example, the model can portray a given part of Hamburg three-dimensionally. It's so accurate that it can calculate the wind at a given corner, or the temperature of a specific house front. New buildings, walls or trees can be fed into the model, so as to predict their effects.

But how do I assess whether or not these effects feel good for people? The first step is to factor in humans' sense of temperature, together with the complex heat balance of the human body. Around the world, 165 indices have been developed for this purpose. In Canada, for instance, the Humidex is frequently used; combining humidity and temperature, it's best suited for dealing with heat. But what I'm looking for is an index that can cover temperatures from -5 to +35 degrees Celsius – so that it can be used worldwide as far as possible.

Other indices have been designed for working in blast furnaces or mines, but can't be used outdoors because, for instance, they don't consider the effects of sunlight. In short, a total of eleven criteria have to be met in order to accurately calculate the subjective temperature in a city using a computer model. So which indices are up to the task? To find that out, I conducted the first-ever systematic assessment of all 165 of them.

First of all, it's important that the index in question is able to accurately depict the heat balance of the human body: because whether we feel warm or cold doesn't depend on the air temperature alone. When we move from the shade into the sun, we immediately feel the warmth, because our bodies directly absorb the radiation. But air can't do that; it is warmed indirectly by the warm soil and heat from the outer walls of houses – and therefore much more slowly. The difference between the air temperature and our own "felt" temperature can be as much as ten degrees – a major effect! Other elements include wind, humidity, what clothes we're wearing, and how we're moving. The ideal index has to include all of these factors.

My analysis has considerably narrowed down the number of suitable indices – and could be a real help for other researchers working on this topic: of the 165, only four are good candidates when it comes to thermal comfort.

And under which conditions do people feel the most comfortable? For us meteorologists, the following rules of thumb apply: there shouldn't be any strong gusts of wind, though a mild breeze can be pleasant, especially on warm days. Deciduous trees are ideal sources of shade in summer, though they naturally block less sunlight in winter. A given place is optimally designed when it offers as many different thermal conditions as possible in a comparatively small space. With the right index, this can now be calculated for cities worldwide.

Dr. Jana Fischereit received her PhD in urban climate from the Center for Earth System Research and Sustainability at Universität Hamburg.

STRESSED STREET TREES: LINDENS, OAKS, OR MAPLES FACING PREMATURE DEATH IN THE FUTURE

Rambling through Hamburg and its environs, you will discover a landscape sculpted by the ice ages. Glaciers of the past pushed large amounts of scree shaping today's hilly countryside northeast of the City. Meltwater leached the glacial Elbe valley and wind-blown sand deposits piled up into dunes such as the Boberg Dunes nature reserve.

From glacial materials and recent sedimentation—for instance, due to the Elbe's tidal conditions—about 30 different soil types have developed, representing almost all soils occurring in Germany. Very few people have heard their names: Regosol, for example, is a plain, carbonate-poor soil, whereas Podzol is acidic and sandy, and Gley groundwater-saturated.

Together with my team from the Center for Earth System Research and Sustainability (CEN) at Universität Hamburg I am exploring how the various soils react to climate change and how their roles in the ecosystem and human well-being

are altering. The rising temperatures and longer dry spells in summer predicted for North Germany will dry out local soils with poor water storage and transmission abilities such as the sandy areas of the Lüneburg Heath. Dehydration will also make them susceptible to wind erosion. More extreme rainfall may effect waterlogging in the less permeable soils in northeast Hamburg — plus water-induced erosion.

These changes will also impact the City's vegetation, particularly urban trees. They are already forced to withstand difficult conditions: A warmer local climate than in the countryside, higher pollution levels, and sealed, compacted soils. Currently, 60 percent of urban Hamburg are covered by settlements and areas constructed for traffic, more than one third is sealed.

My team and I collected soil samples across the city and analyzed them. In 9 out of 10 places we found substances dumped by humans, mostly mineral-poor sand that can scarcely store any water. Almost every third sample contained building rubble, waste, slag, and ashes.

Young trees can hardly grow roots in such soils. Thus, street tree seedlings are often placed into pits with a planting depth of 1.5 meters. But these pits will soon be too small; after all, a tree root system requires about as much space as its visible part, its crown. If tough conditions worsen on account of

climate change, future street trees will be prone to short life spans. We expect newly planted trees to last no more than 40–50 years.

This would be tragic for Hamburg. No prospect of regrowing a well-established stock of trees; a dramatic loss, as ancient and mighty linden, oak, or maple trees help humans thrive by producing oxygen, providing shade, and cooling their surroundings through evaporation.

Hence, I am investigating how we can improve living conditions for trees in urban settings. We need, for instance, suitable growing mediums for planting holes which can store or drain water as needed. Assigning specially trained soil guards to roadside construction sites might help, too. We should all learn how to better protect and value soils; they are the bread and butter of plant life and animals aplenty—an all-too-exhaustible resource.

Annette Eschenbach is a Professor of soil protection and soil technology and a member of Universität Hamburg's Center for Earth System Research and Sustainability.

THE CLIMATE-CONSCIOUS FARMER

In agriculture, there are various sources of greenhouse gases: tractors emit carbon dioxide, while cattle produce methane. The nitrogen in their liquid and dry manure is an effective fertilizer, but can also transform into nitrous oxide, which is 300 times as harmful to the climate as carbon dioxide.

Around the world, whenever someone clears a forest, turns grasslands into pastures, or reduces the amount of humus in their crop soil, they harm the climate. In addition, aspects that may seem trivial can have real consequences: how often farmers till the soil, which crops they plant in which order, and whether they fertilize their soil when it's wet or dry.

That's why the government has also obliged the agricultural sector to cut emissions in the Federal Climate Change Act. This is necessary because more than ten percent of all emissions caused by humans come from agriculture. But who's going to measure the emissions? Every field, every stall and sty is different; every management decision counts, and not even the farmers themselves can keep track of all the consequences. They do, however, consider the issue to be

an important one: this was confirmed in the first survey of German farmers, which we conducted in connection with our research into greenhouse gases in agriculture at the Center for Earth System Research and Sustainability (CEN) at Universität Hamburg.

The majority of the 254 farmers surveyed rated their own level of knowledge in this area as comparatively low and wanted to receive further information. What's more: the majority claimed they were willing to do their part to reduce emissions. We were surprised to see just how willing: 70 percent of those surveyed claimed that societal recognition would motivate them to run their farms in an environmentally friendlier manner. 40 percent even considered an emissions tax to be a good thing, most likely because it would affect all farms equally and therefore seemed fair to them. In return, the farmers expected to receive compensation, such as subsidies or a label for climate-friendly products, which could be used to justify charging higher prices.

Yet a tool that could show farmers exactly where the greenhouse gases come from, and how their individual choices affect emissions production, would also be an important aspect. It would need to be straightforward, lightweight and deliver results fast. And that's exactly where we come in. We're currently working to modify software that farmers already

use – and to calculate emissions by drawing on data that they already collect. For example, sensors on their farm machinery already measure plant growth and indicators of crops' nutrient supply. Using this data, the management software monitoring the sensors automatically measures the amount of fertilizer distributed, down to a scale of one square meter. If a mathematical model were added, the software could also calculate the amount of greenhouse gases produced. We're now exploring the feasibility of this option at selected farms. Our vision is that, in the future, every farmer will have access to this additional software feature: first in Germany, and later throughout Europe.

Once that happens, farmers will be able to decide for themselves how to run their farms, where they can reduce emissions, and whether potential crop losses can be compensated for by financial remuneration. In turn, it will also be possible to define, review and implement climate targets for farmers.

Prof. Uwe Schneider is an agricultural economist at Universität Hamburg's Center for Earth System Research and Sustainability.

GLOBAL CLIMATE CHANGE CONFERENCES: SENDING AN IMPORTANT SIGNAL

Following the failure of the 15th United Nations Climate Change Conference (COP 15) in Copenhagen in 2009, the negotiations seemed to have reached a standstill. However, a new climate agreement was produced in Paris in 2015, which was hailed as a major victory. The COP 23 in Bonn finally drew to a close, without a binding agreement but with a sea of happy faces. How can we measure the success of climate conferences?

Together with international colleagues, in 2015 I closely followed the negotiations for the COP 21 in Paris and analyzed them from a sociological perspective. With more than 30,000 participants and 150 heads of state at the opening ceremony, the conference was characterized by many superlatives. Our focus wasn't on the outcome, the Paris Agreement, but on the negotiations and the diverse events that took place during the conference.

The main work done at the conference in Paris was surprisingly unspectacular: in groups, the text was broken down

clause by clause. Every suggested amendment was discussed and subsequently implemented in the text – or wasn't. Given the diverse range of interests, this was a lengthy undertaking. And the resulting Paris Agreement is fundamentally different from its predecessor, the Kyoto Protocol from 1997. First of all, it defines two common goals: helping poorer countries adapt to the impacts of climate change, and limiting global warming to less than two degrees Celsius. Yet it leaves the question of how to achieve these goals up to the individual states, relying on voluntary commitments and regular progress reports. In contrast, the Kyoto Protocol clearly delineated the required emissions reduction for each respective country.

Yet, as important as they are, the resulting agreements alone don't make for successful conferences. The effects produced by climate conferences also concern the negotiating process itself: different countries work together to find a mutually acceptable text, while vying with NGOs, environmental protection and business associations over whose interpretation has the most weight. As a result, year after year a large community sends governmental and business actors a clear signal that they'll need to adjust their future plans accordingly. Ideally, this promotes climate-friendly developments. For example, some of the countries that met in Bonn have now announced plans to abandon coal energy.

The most important outcome of our analysis: it's only when thousands of people with disparate backgrounds come together to discuss and work on new resolutions that a meaningful basis is formed for identifying shared problems and potential solutions. Climate conferences serve to network the relevant actors, and to reinforce the importance of climate change in our collective awareness. At these events, we can witness the first steps toward forming a global society.

But is that enough? Of course not. The Paris Agreement shows a potential way forward, but is based on voluntary participation. And we can quite readily see from lessons recently learned in Germany – e.g. with plans for sustainable mobility or phasing out coal-based energy production – that such plans can provoke major resistance. Major changes like making our economy a more sustainable one clearly can't just be dictated "from the top down"; without constant grass-roots pressure, global pledges will remain nothing more than empty promises. As such, if we hope to mitigate climate change to a tolerable level, it's civil society that has to now step up to the plate.

Stefan Aykut is a Junior Professor of sociology at Universität Hamburg. He conducts research in the Cluster of Excellence CLICCS and at the Center for Earth System Research and Sustainability.

WATER SHORTAGES!
WHEN CLIMATE CHANGE DRIVES ELEPHANTS TO THE VILLAGES

The rumbling could be heard for miles. A herd of African elephants was headed for the small Namibian village that I stayed at during my research visits. Elephants normally avoid the villages, but we could guess what they were searching for on that afternoon. They could pick up the scent from far away: water.

Elephant herds are now descending on villages in the Kunene region more and more frequently. But why? As an ethnologist I investigate questions like this together with my colleague Richard Dimba Kiaka. To do so, we regularly spend extended periods living under conditions that are as similar as possible to those of the Damara families in the region: in simple huts without electricity or running water. I can now speak and understand the language my neighbors use – with its characteristic clicks – relatively well.

The people here are mainly livestock farmers, and they build large water reservoirs for their goats and cattle – which are like magnets for the desperate elephants. Namibia is in

the far south of Africa and is one of the continent's most arid countries; several months can pass without a drop of rain. There are only about 60 days a year with any precipitation at all – compared to Hamburg, which has 180 days on average. Actually, the elephants are used to these conditions and search for water in dried-up riverbeds, digging down to depths of up to three feet, where they often find seeped water.

But in recent years, the water table has sunk, and the elephants are unable to find enough water. Moreover, an unusually long drought between 2013 and 2017 exacerbated the water shortage, forcing the animals into the villages. Like on that afternoon when we had no choice but to barricade ourselves in our huts. We could hear the destruction going on for several hours before the herd finally moved on. They had torn open the village reservoir, since the baby elephants' trunks couldn't reach over the edge. The pumps and troughs, water cans and vegetable plots were destroyed – the entire village infrastructure had suffered serious damage.

Is climate change to blame for the increased number of "elephant invasions"? That would fit to the forecasts issued by the Intergovernmental Panel on Climate Change (IPCC), according to which the African continent will be hardest hit by climate changes. The average temperature will rise there more than in the rest of the world. And while precipitation could

increase in central Africa, in northern and southern Africa it is likely to decrease further. But that's only half the picture.

Around the globe, elephants are an endangered species. In 1900, there were estimated to be several million – today there's only a fraction of that number. But the story is very different in the Kunene region: The number of elephants has doubled in the last 20 years – good news for wildlife conservationists. The government created nature conservation areas where elephants are protected from hunters, allowing them to reproduce undisturbed. The exotic animals also attract tourists – and the industry is booming. However, the money mainly goes to businesses in the capital, Windhoek. The state profits from tax revenues; but very little money makes its way to the rural population. As a remedy the state could e.g. tax tourism more heavily in order to compensate the locals for damages. This would be a first step toward ensuring that, in an era of climate change, nature conservation doesn't further worsen inequalities.

Prof. Michael Schnegg is an anthropologist and member of the Cluster of Excellence CLICCS at Universität Hamburg, where he is currently investigating the impact of climate change on rural regions in Africa.

SEARCH FOR NUCLEAR WASTE DISPOSAL SITES: WHY THE NEXT ICE AGE PLAYS A ROLE

Where do we put nuclear waste that remains radioactive for more than a million years? Some experts are in favor of storing the waste in salt deposits, since salt offers a number of special properties: under high pressure it behaves almost like a liquid – so that, even in the event of powerful ground motion, the waste would be gently and gradually enveloped.

That's the theory – but there's no guarantee. A look at geological history shows us that movements in the Earth's crust can have an enormous impact on salt deposits. My students and I are investigating how salt is deposited in the Earth's crust, the structure of the surrounding rock, and what processes were responsible for creating and distorting the massive layers. Since 2001, every year a group of geophysics students has travelled to the Baltic Sea to study the Earth's crust beneath the seabed. We then use the recorded measurements to create cross-sectional images that show us the stratification of the bedrock and in which areas there are cracks, fissures and distortions. Until now we have assumed that faults and fractures in the rock were the result of tectonic plates colliding several million years ago, making them geologically very old.

One day, however, when I was looking at the data with my students, I stopped short. Together with my PhD candidate Mu'ayyad Al Hseinat I took a closer look at the cross-sections. The uppermost and therefore youngest one to two kilometers – in other words, the layers with the most salt deposits – seemed to have been shaped by other processes, since the distortions we found in them didn't match with the tectonic movements of this time. So which forces were the culprits?

We immediately made plans for further research, and soon thereafter we launched an expedition to the Baltic on board the research vessel Maria S. Merian, towing a three-kilometer-long "sock" full of recording equipment behind us. The equipment measured sound waves that we had fired toward the seafloor – since boundary layers, faults and fissures reflect these waves back to the surface, this approach provided us with a detailed image. After carefully analyzing our results, we were certain: In the past 400,000 years, the glaciers from Scandinavia during the glacial periods kneaded the uppermost one to two kilometers of the Earth's surface like a giant pie crust – leaving behind immense distortions in

the Baltic Sea Basin and the North German Plain. Strata collided, sediments mixed with ice, and valleys and hills were formed. And we can still see the effects today: For example, since the melting of the last great glaciers, northern Scandinavia has continued to rise, no longer burdened by the ice's tremendous weight.

The same phenomenon affects older layers, which have also partially been pushed upward over millions of years – like the numerous salt domes to be found in northern Germany. As such, we assume that a future glaciation of northern Germany would also produce major changes in the domes.

In the course of the next 100,000 years, northern Germany and the Baltic region as a whole will only remain ice-free for a few tens of thousands of years. That makes it important that we understand the processes that can release the weight of the ice from the Earth's crust – especially since salt domes are currently being investigated as potential candidates for safely storing radioactive waste for the next million years.

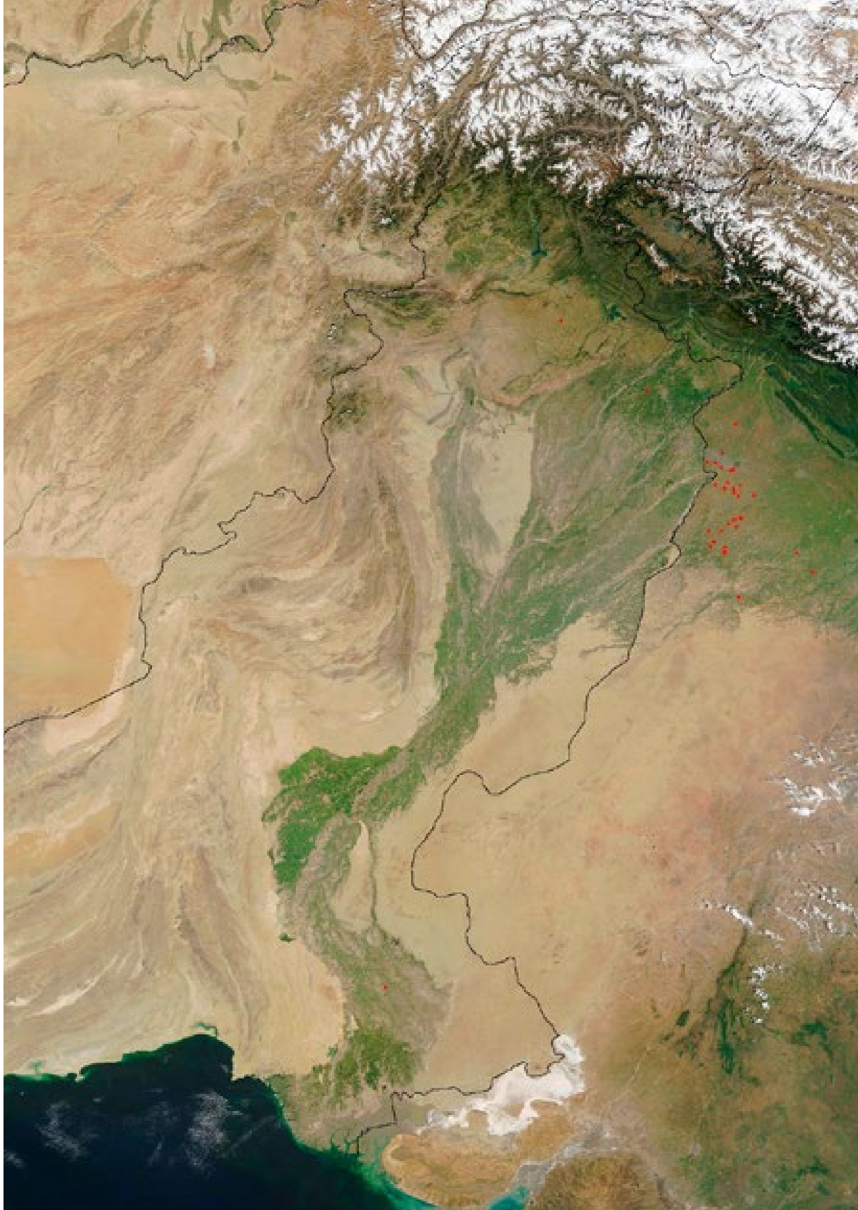
Prof. Christian Hübscher is a geophysicist at Universität Hamburg's Center for Earth System Research and Sustainability.

WEATHER FORECASTS FOR PAKISTANI FARMERS

In Pakistan a sophisticated irrigation system supplies the lush green Indus River plain with water from the Himalayas. Measuring 60,000 kilometers, it's among the longest of its kind in the world. Agriculture is both a major source of income in the region and an important livelihood.

In winter, known as Rabi, cereal and pulses thrive. They are sown in November and harvested from April to May, while cotton and sugarcane grow in summer, or Kharfi, which is characterized by monsoons. However, the difference between seasons is becoming less and less marked, with sowing and harvesting times shifting – but these aren't the only consequences of climate change.

80 percent of Pakistan's farmers own less than two hectares of land. They suffer from the effects of drought, floods, storms and extreme temperatures and increasingly have to deal with pests and diseases. Severe flooding in 2010 resulted in many farmers losing their crops and even their land. That's why at Universität Hamburg's Center for Earth System



Research and Sustainability (CEN) I'm investigating which regions are especially at risk and how farmers can adapt to the changes. To do so, I interviewed 450 farming households in Punjab – a highly populated province also known as the country's granary because of its fertile conditions.

Firstly I was interested in how the farmers perceive climate changes and the resulting risks. Have they noticed changes in rainfall or growing periods over the past 20 years? What real damage has been done, i.e., were harvests poorer due to soil erosion, pests or plant diseases? How endangered do they consider their existence to be? I also investigated the extent to which farmers themselves have taken measures to mitigate climate risks, which factors limit their ability to adapt, and whether they are supported by the local government.

The initial findings clearly reflect the prevailing environmental conditions, the availability of resources like water and fertile soil, and worsening poverty. As such, in the west of the province, insect plagues, diseases in animals and humans, and soil erosion were most commonly mentioned. This jibes with the climate records for the last 30 years: more rainfall and two major floods that washed fertile soil from the fields and at the same time provided ideal conditions for pathogens. In central and northern Punjab, where records show that temperatures have risen and less rain has fallen, farmers complained about drought and smaller harvests.

About two-thirds of farmers are aware of climate change itself, and roughly half are already attempting to adapt their seeds and their planting and harvesting times. But not all of them are succeeding. Many failed farmers are migrating to the cities to look for work – often in vain. If they were given help adapting, many of them would remain in farming – as my findings clearly show. Above all, there is a lack of tangible services and communication channels, which is something local governments could provide – and stop the rural exodus in the process. Making regional weather forecasts and early warning systems for extreme events available to farmers would be a significant first step.

Dr. Muhammad Abid did his doctorate at the Center for Earth System Research and Sustainability at Universität Hamburg and works as an agricultural economist at the University of Islamabad (Pakistan).

THE NORTH SEA TAKES UP TWICE AS MUCH CO_2 AS PREVIOUSLY THOUGHT

We have a powerful ally against climate change: the oceans. The world's oceans take up a third of the greenhouse gases that humans pump into the atmosphere as a result of industry and traffic, curbing their effect and buffering climate change. But they are paying the price – the oceans are becoming more acidic, and this is happening on our doorstep, in the North Sea.

My colleague Maybritt Meyer and I wanted to investigate how much carbon dioxide (CO_2) the North Sea absorbs in a year. To do so we needed two main pieces of information: firstly the concentration of CO_2 in the air compared to that in the water. If the levels are the same, nothing changes. However, the greater the difference – e.g. a high concentration of carbon dioxide in the air and a low concentration in the water – the higher the "pressure" on the CO_2 to dissolve in the water. An international team collected this data during several excursions.

At the same time, wind plays an important role – something we also investigated closely. The more strongly the

wind blows, stirring up the water's surface, the greater the exchange with the atmosphere. By mixing the sea like a whisk, it allows CO_2 to be more effectively absorbed. However, there is no comprehensive data from all points in the North Sea, so how can the wind be incorporated into the calculations?

To date, we have relied on data from a relatively coarse resolution global model that describes the wind speed at one grid point every hundred kilometers. We used this information to calculate how quickly or slowly the water is able to absorb carbon dioxide. But at the coasts, the wind is particularly changeable, which means that this data hardly reflects the reality.

Our partners from the Helmholtz-Zentrum Hereon are investigating the coasts with higher resolution models. Using what is known as downscaling – a complex computer simulation – it is possible to meaningfully fill the gaps in the data for regions for which there is little information. The Center calculated a new wind data set for us with a grid spacing of five to ten kilometers for the entire North Sea.

We compared this data with measurements from four stations – two near the coast and two on drilling platforms in the open sea. The results show: the wind at the coasts has previously been greatly underestimated! The high-resolution data paints a much more accurate picture. For the open sea, the measurements correspond well with the older wind data.

We recalculated the CO_2 balance – with astounding results: along the coasts more than twice as much carbon dioxide is absorbed as previously assumed. In a year, the entire North Sea took up 34 percent more of the greenhouse gas than thought.

But what does that mean? We don't know when the marine carbon dioxide storage will be full. But the more CO_2 an ocean absorbs, the more acidic it becomes. In the North Sea, acidification is in full swing, and the changes in the water's pH can have a detrimental effect on the plants and animals there: their metabolisms have to adapt, while mussels and crabs can have problems forming their shells.

Using refined methods, we can provide increasingly accurate predictions, many of which demonstrate the dramatic impacts of our actions. Therefore I would like to call on the German Federal Government to adhere to the climate goals agreed in Paris in 2015 and effectively curb greenhouse gas emissions.

Dr. Johannes Pätsch is a computer scientist and North Sea expert at Universität Hamburg's Center for Earth System Research and Sustainability.

WHEN THE TUNDRA CHASES THE TAIGA

Like in the "The Lord of the Rings" movies, trees occasionally make their way to faraway lands. Whether tropical rainforests, evergreen coniferous forests or treeless steppes: our planet's vegetation zones are constantly changing.

At the end of the last glacial period, around 11,000 years ago, the Sahara was considerably greener than it is today, while northern Germany was a tundra – an open landscape characterized by mosses, grasses and small shrubs. When plants migrate, it almost always has something to do with the climate. Either it's too hot or too cold, too dry or too wet. Plants are then unable to thrive in their original habitat and "move", albeit very slowly – over several centuries – to neighboring regions. In the process, they provide a record of climate history.

Together with an international research team at the Center for Earth System Research and Sustainability (CEN) at Universität Hamburg and the Max Planck Institute for Meteorology, I have investigated how past climate changes affected vegetation in Asia. The climate was unusually stable from the mid-Holocene around 6,000 years ago to the dawn of industrialization; only changes in the Earth's orbit around the Sun – something that occurs in regular cycles – led to several regions cooling slightly during this period.

In order to investigate the changes in vegetation, we used five different models, which we then supplied with data on the changes in the Sun's irradiation of the Earth and the slight increase in carbon dioxide emissions. Climate models use the laws of physics to describe processes like cloud formation, ocean currents, evaporation, ice melting and storms, and help us predict how the climate will develop.

We then fed these results into a vegetation model, which calculated how plants spread across the planet. Though precipitation and temperature have a major influence on plant growth, numerous other processes are also involved: higher levels of carbon dioxide in the atmosphere promote growth, tornadoes and fires destroy forests, and entire plant communities migrate, displacing established species.

This can lead to climate change feedback. For example: when the northern latitudes become colder, the treeless tundra pushes the extensive coniferous forests – the taiga – southward. Because the snow can fall between the branches, the forests remain dark even in snowy months. This means they absorb more sunlight, and they become warmer. In contrast, the treeless tundra remains completely covered in snow for several months at a time. It reflects the Sun's warmth back into space, causing temperatures to drop even further.

Our findings show that during the study period, the tundra in Asia migrated up to 500 kilometers southward due to the cooling climate in the far north. In the transition zone between the forest, steppe and desert in northern China and Mongolia the climate has become dryer, and the Gobi Desert has expanded eastward in the last 6,000 years, displacing the steppes and forests.

We weren't able to identify any abrupt changes in the vegetation in Asia; plants migrated in keeping with the climate changes brought about by the regular changes in the Earth's orbit. The findings make it clear just how sensitively the vegetation reacts to even the slightest climate changes.

Martin Claußen is a Professor of meteorology at Universität Hamburg and Director of the Max Planck Institute for Meteorology.

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