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EARTH AND SOCIETY
RESEARCH HUB

CITIES WILL HAVE TO FUNDAMENTALLY TRANSFORM

TEN CLIMATE RESEARCHERS REPORT

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New Climate Stories from Hamburg

CONTENT

NEW CLIMATE STORIES FROM HAMBURG

The Fish Market underwater? As climate change progresses, torrential rains and flash floods could become more frequent in Hamburg. But cities today usually aren't well-equipped to deal with the water and associated risks. How can cities like Hamburg adapt to the changing climate? The experts at the University of Hamburg's ESRAH research center (formerly CEN) and Cluster of Excellence CLICCS are pursuing the answers to this and other questions on climate change.

You'll also learn how the next generation of roadside trees is being made climate change-resilient, what secrets are locked under the seafloor near Santorini, and how winning legal rights for the environment can facilitate climate protection.

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

Enjoy browsing.

PUTTING URBAN TREES TO THE TEST

Providing shade and cooling the air, trees are vital to the quality of human's life in Hamburg. However, our trees face challenging conditions along streets – and with climate change. In particular, freshly planted trees are thus subjected to stress, indicated by slow growth and failure to gain large canopies. How can we provide the next generation to be climate-change-proof?

In order to determine which tree species cope best with extremely dry conditions, I designed an experiment together with my team. For three years, we studied nine different species, with in 135 individual young trees, at the tree nursery Lorenz von Ehren. Thereby the soil substrate – a type of artificial soil provided for the planting of young trees in cities – is the key determinant.

Many areas along streets consist of sandy soils, often the result of construction work. Sand is coarse porous and thus cannot store much water; However, it is well suited to gas exchange. In contrast, fine soil, soft like flour, can store more water due to higher capillary forces. Nevertheless, in reverse,

fine soil is more prone to compaction, e.g. caused by traffic or construction sites.

For our experiment, we aimed to represent urban-like conditions along streets in the nursery. Therefore, we planted two-thirds of our test trees in two different types of soil: one consisted of pure sand, which composition was frequently found along streets (95% sand); and a representative for a commonly used artificial soil-substrate with 93% sand but elevated humus content. This leads to slightly elevated water holding capacity.

As a reference, we planted the final third of the trees in the natural fertile nursery's soil. Featuring even more humus and a finer structure, it offers ideal growing conditions and can hold up to four times more water compared to the sandy soil. In addition, we buried 300 sensors beneath the trees to monitor water consumption over the three years of root growing.

Our findings: Although all trees planted in the two sandy substrates survived, these conditions were found to limit growth substantially compared to the reference soil and were thus only poorly suited for dry periods. The sandy substrates measured a water availability of only six to ten percent, compared to 23 percent in the ideal soil.

We also determined that the trees in the sandy substrates weren't even able to fully tap the water available. Caused by its coarse-porous structure the water filled capillary spaces become incoherent when sandy soil dries out. As a result, the flow of water to the roots is interrupted, which is less likely, the finer the soil is structured.

As a result, trees like the small-leaved linden and sweetgum, whose roots essentially grow to follow water, coped in our experiment better when planted in sandy soils. In contrast, trees that can produce substantial negative pressure to still take up water in dry soils – like the golden rain tree and Turkey oak – proved to have the less successful strategy.

Our conclusion: no tree can grow properly under the insufficient conditions. The soils found along streets are often of low quality. Consequently, it is essential that young trees be planted in sufficiently large pits and in improved substrates capable of storing more water. Though the recommended size for these pits is twelve cubic meters: the larger, the better.

Dr. Alexander Schütt was a member of the Center for Earth System Research and Sustainability and there, he was investigating trees under climate change.

Official Warning:
Storm surge Hamburg Elbe area
Inform your neighbors

WARNING, FLOOD RISK: WHERE CITIZENS OF HAMBURG NEED MORE SUPPORT

Due to climate change, extreme weather events are becoming more frequent in Hamburg. The city is well-equipped to withstand storm surges, thanks to a system of levees. But heavy rains and flash floods can occur anywhere – not just near rivers. Since June 2021, Hamburg has also maintained a hazard map for heavy rains. The map shows how water flows through the city, and where flooding can occur.

In this regard, my focus is on how people respond to catastrophes. Are all citizens exposed to the same hazards and therefore equally at risk? Which of them can overcome crises on their own, and which can't? To find answers to these questions, together with my colleagues I'm analyzing a range of social data.

To date, in order to determine where the citizens of Hamburg are most endangered by floods, the population density has been the parameter of choice, the assumption being that


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the fewer people living in a given area, the fewer are affected when a crisis strikes. But does this approach accurately reflect citizens' vulnerability? To arrive at a more accurate picture of the reality, we supplemented further social factors. The requisite data were available at the Statistical Office of Northern Germany's Hamburg branch.

To calculate the vulnerability of the citizens in a given district, we first determined the percentages of children under the age of ten and elderly people living alone. In crisis situations, these groups often need help and can barely save themselves, if at all. Another aspect we examined: the ability to overcome crises, which reflects the percentage of citizens who receive financial support from the state, and those with no higher diplomas or degrees. Why did we include these factors? Because money can help to solve problems; a higher income offers citizens more options for improving their situation – for instance, after a flood has destroyed their home or belongings.

On this data basis, we prepared a number of social vulnerability maps. When our findings are compared with the population density map, a number of similarities can be seen. But it's worth taking a closer look. For example, our calculations indicate higher vulnerability in Kirchdorf-Süd, Steilshoop and in Osdorfer Born. Though the vulnerability is already high in these areas because of the population density, it is exacerbat-

ed by social factors. And if we look in even more detail, we can see that there are many areas in which a very high number of older citizens are living alone – like in parts of Bergedorf. Based on the population density alone, this aspect wasn't apparent before. In contrast, west of the Alster the population density is high, but the people living there can more easily respond to risks; many of them have advanced degrees and the financial resources needed.

Our calculations show in which districts improving protection from flood-related risks is especially important. In addition, examining social vulnerability reveals those areas in which the financial resources and educational opportunities are still inadequate. It's essential to make massive investments in education in these areas, so as to ensure that the people living in them can, in the long term, more readily cope with crises.

Dr. Malte von Szombathely is an urban geographer and part University of Hamburg's Cluster of Excellence for climate research CLICCS.

ADAPTING TO CLIMATE CHANGE: CITIES WILL HAVE TO FUNDAMENTALLY TRANSFORM

During heavy rainfall, when a certain amount of rain is exceeded in a short time, cities can face challenges of urban flood risk. However, this depends not only on the amount of rain, but also on the land's ability to absorb the water.

Is the surface sealed? Are there plants that can slow down surface runoff? Are there differences in elevation, and if so, where does the water flow to and accumulate? The capacity of the sewer system is another important aspect.

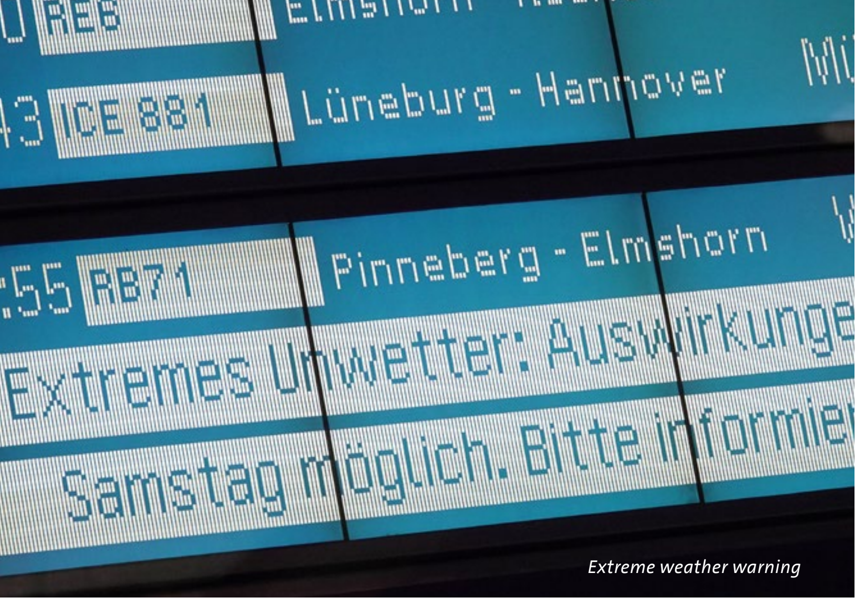
Whether a heavy rain event turns into an emergency or even a disaster also depends on a number of societal factors. For example, how well informed citizens are about risks and how they redesign their property accordingly. Efficient rainwater management can store water and prevent rapid surface water runoff.

In order to create new retention areas and to implement unsealing measures, political decisions have to be made – including those requiring a fundamental redesign of public

space. For example, by giving water more space and embedding water management infrastructures in the city.

For the case study of the city of Hamburg, my colleagues and I investigated climate risks and urban adaptation not just from a meteorological but from a holistic perspective. Together with stakeholders, we assessed how sustainable certain adaptation measures are, but also how complex and how likely it is that these will be accepted. How plausible is it that these measures will be implemented? How is the willingness to support them? Can and will the city afford them?

That's the tricky part. Unlike physical problems, societal behavior can't be precisely calculated and integrated into a computer model. For example, the frequency of heavy rainfall events has strongly increased in the greater Hamburg area. However, that doesn't automatically mean that more unsealing measures will take place, or that retention areas to catch the rainwater will be constructed. These decisions tend to depend more on whether funding will be allocated, how much time it would take to implement new measures, and whether politicians are under pressure to act. This can happen, for instance, if damage and associated losses become more frequent and expensive, through new scientific findings, or if more and better information is provided about possible risks.



Extreme weather warning

With my colleagues, I worked on a qualitative system dynamics model of the urban system. This conceptual model enables the visualization of the causes and relationships between individual components of the system and thus the identification of possible feedbacks. It is all about how the system works as a whole – whether and how different processes reinforce, dampen or cancel each other out. This could only be done in an interdisciplinary team. Each of us is an expert in a certain field: hydrology, soil science, social sciences, political science, law, urban planning, economics, or meteorology. Our goal was to identify the crucial levers that enable sustainable adaptation to climate change.

Research has shown that it is essential to focus on effective leverage points that may be less obvious at first glance, but aim at system-wide change. Something as complex as climate adaptation can only be successfully addressed by getting all actors on board – water management, urban planning, politics and the public. The integrated approach of a water sensitive city is the first step in the right direction.

Dr. Franziska S. Hanf is a climate physicist. She is working on climate adaptation in urban systems in the Cluster of Excellence for climate research CLICCS at the University of Hamburg

INDIA'S TRADITIONAL AGRICULTURE IN JEOPARDY

Climate change is impacting agriculture in regions around the globe. Things will become especially difficult in areas like the Himalayas of Northeast India, where steep slopes and nutrient-poor soils already make farming a challenge. What are the prospects for the local population?

Clear a field, sow, reap, switch to a new field. In many farming regions throughout the Himalayas, shifting cultivation is employed – a traditional farming practice used predominantly for rice, but also for other grains and vegetables. In this approach, a section of forest is cleared and burned, which serves to destroy pests and to fertilize the soil with ash. After cultivating it for one or two years, the farmer moves on to a new field. Now the old field lies fallow, grasses and shrubs spread, and a new forest slowly starts to grow as the soil recovers. My team and I are working to explore how traditional farming methods like this one will be affected by a changing climate.

Climate change hasn't just led to forest fires in Australia and dry periods in Germany – it's also affecting farmers in

Northeast India. In spring 2023, we traveled there to assess how much local agriculture was already impacted. The farmers told us that, for example, they'd been unable to plant corn in spring due to a lack of rain. And there are other challenges to be overcome: many young people are leaving their home villages, which means they aren't there to pitch in. In other regions, commercial plantations are increasingly competing with traditional types of farming. This reduces the amount of available land, which can lead to shorter cultivation cycles.

But how will climate change affect fields in the Himalayas in the future? To get a better idea, we fed information from soil samples and climate data into a computer model that simulates all processes connecting the atmosphere, plants and soil, e.g. the water cycle, plant growth and soil erosion. In addition, the model factored in when rice is sown in India, when it is harvested, and how long the fields lie fallow afterwards. This allowed us to estimate how the climate would affect Northeast India's soils by 2100.

In the future, more intensive rain during the summer monsoon will wash away more of the fertile soil. Farming on steep slopes and intensively cultivated fields – i.e., those with short fallow periods – will be particularly hard hit, as rainfall will more easily erode the soil. In concrete terms, soil erosion could increase by more than 60 percent if the planet warms by 3 degrees Celsius as opposed to 1.5 degrees. Consequently, especially toward the end of the century, soil erosion will increasingly pose a problem for traditional agriculture in Northeast India.

Given these prospects, do farmers want to continue practicing shifting cultivation? Among the younger generation, many are abandoning agriculture. In contrast, older farmers tend to cling to shifting cultivation, both for cultural reasons and due to a lack of alternatives, even if it will mean having to adapt to new circumstances.

Longer breaks between the cultivation cycles could help; less of the fertile soil would be eroded. The nature of the field also needs to be borne in mind. In this regard, the rule of thumb is: the steeper the field, the longer it should lie fallow. Planting trees can also help; their roots help to stabilize the soil.

Dr. Lea Schröder is investigating how agriculture can sustainably adapt to climate change at the University of Hamburg's Cluster of Excellence for climate research CLICCS.

SANTORINI: GLEANING VOLCANIC HISTORY FROM THE OCEAN FLOOR

Santorini is a picturesque archipelago in the southern Aegean. The islands encircle a massive volcanic caldera, which the ocean has long-since covered over. Some speculate that Santorini is all that's left of Atlantis – the fabled, highly advanced island empire that suddenly vanished. The fact that about 3,600 years ago, a volcanic eruption at the center of the archipelago destroyed a flourishing Minoan city may be one of the sources of this ancient legend.

The eruption set off a tsunami that was felt throughout the eastern Mediterranean and likely contributed to the decline of the Minoan culture. It also changed the climate: Giant clouds of ash blocked out the sun, covering the world in a two-year-long winter.

On the islands, the traces of the volcanoes reach back as far as 600,000 years. Yet the geological structures only tell part of the story; much of the volcanic field lies underwater, or even under the seafloor. My colleagues and I, together

with an international team of researchers, have created the first detailed reconstruction of the volcanic field's spatial and chronological development. Its geological history also includes the nearby Christiana Islands and the submarine volcano Kolumbo.

In the course of several expeditions led by my doctoral advisor Christian Hübscher, we gathered seismic data that can show us how the volcanic centers waxed – and waned again. To get a better picture of what is hidden beneath the seafloor, we use a method similar to medical ultrasounds: behind our research vessels, we drag underwater microphones called hydrophones through the water. With the aid of a specially designed "air pulser", we produce acoustic signals, which penetrate the seafloor and are echoed back from structures beneath. The hydrophones register the reflected signals, which we can analyze with a special software.

These signals allow us to create an image of the seafloor, and to delve a few hundred meters below its surface. In this regard, the deposits left behind by eruptions have unique characteristics that we can trace back to individual volcanoes, and they also occasionally allow us to make new discoveries – like a previously unknown volcano to the west of Santorini! Long-since dormant, it is now covered in millennia of more recent sediments.

But just how old are the different layers? To find out, we measured their thickness. On the basis of average sedimentation rates, we were able to estimate their ages and determine when individual eruptions took place. We found that the volcanic field was created in the course of four different phases and from a chain of individual volcanic centers.

The first phase began roughly three million years ago, in the Pliocene. It wasn't until the final phase, which began roughly 350,000 years ago, that the central volcano, whose deposits can still be seen today on Santorini, formed. We surmise that the phases were closely connected to the tectonic activity of the nearby rift system – a series of extended valleys in the Earth's crust. Our findings will help to reconstruct the frequency of volcanic eruptions in the region, identify hazards and more reliably assess the attendant risks.

Dr. Jonas Preine is a geophysicist and investigated the development of volcanic systems for his doctoral thesis at the Center for Earth System Research and Sustainability.

CO_2-PRICES ARE ALSO GOOD FOR YOUR HEALTH

Was the German eco-tax a flop? Since 1999, gasoline and diesel have been taxed nationwide. The initial plan was to increase the percentage every year. But in 2003, it was locked in at ca. 15 cents per liter. The tax is still at that level today, even though an additional carbon pricing was implemented in 2021. Research to date has found the eco-tax largely ineffective – but just the opposite is true.

How would Germany's emissions have developed without the eco-tax? Unfortunately, we don't have any "mirror universe Germany" where there was no eco-tax, so that we could compare. But our team found another way: We programmed a realistic "clone" of Germany, a model that represents the German transportation sector on the basis of key economic figures.

We also used datasets from other industrialized countries – ones that are as similar to Germany as possible – that did not introduce an eco-tax in the assessment period. We combined this data to make the clone, which consists e.g. in parameters like income or the number of vehicles per capita.

From Wednesday particulate matter emission warning in Stuttgart

To validate the clone, we simulated the thirty years before the tax was introduced and compared the figures with actual historical records. Since there are always minor variations from clone to clone, we made seven, just to be on the safe side. So, how effective was the eco-tax?

As the results clearly show: tremendously effective. Our comparison showed that, from 1999 to 2009, the transportation sector reduced its CO_2 emissions by ca. ten percent relative to the clone.

Why, then, has the tax previously been considered ineffective? Past studies conducted by the German Institute for Economic Research (DIW) simply compared Germany's total emissions before and after rolling out the tax. But the entire economy changed, too, regardless of the tax. Germans became wealthier, started buying different cars, and drove more kilometers. Bearing this in mind, we were now able to calculate the tax's actual effect.

And that's not the only thing we discovered: The eco-tax also reduces annual particulate emissions and harmful nitrous oxide emissions by 27 percent and 13 percent, respectively.

Unlike various types of climate damage, which predominantly concern the future, this represents a direct health benefit and reduces related costs. If we put these two factors together, the eco-tax saved us more than 80 billion euros in the course of a decade.

For our calculations, we drew on official cost estimates from the German Environment Agency (UBA). In 2012, the UBA worked on the assumption that one metric ton of CO_2 emissions translated into ca. 80 euros in subsequent costs for harm done to the environment and economy. Today, they have raised that number to over 300 euros per metric ton. As such, every liter of gasoline or diesel that we don't burn saves us much higher societal costs than previously believed. The eco-tax is hardly a flop – it's good for the climate and our health alike.

Prof. Moritz Drupp is a sustainability economist and was investigating CO_2 pricing at the Cluster of Excellence for climate research CLICCS at the University of Hamburg.

RELIABLY PREDICTING EXTREME WEATHER

Water shortages, parched fields, fire risks – the consequences of droughts, heat waves and other weather extremes can be devastating. Which makes it all the more important that human beings be prepared for such events in time. In this context, the sooner there are reliable forecasts, the better.

Therefore, as part of my doctoral studies I investigated how such weather extremes can be predicted several months in advance. To be specific, I investigated a circulation system in the Tropical Pacific between South America and Australia. The ocean currents and air circulation there are mainly constant.

However, every two to seven years the system changes: either the direction stays the same but the system is intensified; or it reverses, causing the air and ocean to flow in the opposite direction.

These events, known as La Niña and El Niño, can trigger extreme weather events around the globe. But how could I predict early on whether, and if so, where, they will cause problems like droughts?

Extreme events like this could already be predicted roughly a month in advance. My aim was to extend this forecast period. To do so, I needed three things: up-to-date ocean and atmospheric data, a climate model and a high-performance computer. If I fed the data into my model, it could predict the weather for the next several months – but how reliably?

In order to check this, I first used the model to retroactively forecast past weather conditions that I knew about thanks to various meteorological reports. When the modeling data corresponded well with the actual data, it showed me that my model realistically depicted the past – which meant that it could also provide reliable forecasts for the future. However, the datasets didn't correspond equally well in every year. On closer examination, I realized that droughts in North America could only be reliably predicted when the climate system showed a marked deviation – in other words, when a La Niña event dominated. In concrete terms: if the temperature at the water's surface in the East Pacific is colder than average, the months of December, January and February tend to be dry in southern North America and Mexico.

This isn't anything new. What is new, however, is that the model predictions during these anomalies are more reliable than in other years. In other words, in those times when the risk of drought is greatest, we can trust our forecasts the most.

Accordingly, I now keep a close eye on the temperature of the Pacific waters. At the first sign of an anomaly, I feed the data into my model. Then I can say exactly when, and over how great a geographical area, a drought can be expected, and up to four months in advance. That's a real step forward, and one that gives authorities and those working in agriculture time to mitigate the worst effects.

I'm currently transferring my findings to Europe. What climate anomalies produce heat waves over Central Europe? If I can identify which climate processes lead to high temperatures, I might be better able to predict hot summers in the future – and to warn of extreme heat several months in advance

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Dr. Patrick Pieper is an expert on seasonal climate modelling. He was a member of the Center for Earth System Research and Sustainability and at the Cluster of Excellence CLICCS at the University of Hamburg.

WHEN THE ENVIRONMENT SUES FOR SUSTAINABILITY

Everybody's talking about it, many are promising to deliver it, and few are making serious efforts: sustainability. It's a term that people around the world use for orientation, but which often serves as nothing more than a mantra.

After all, being sustainable ultimately means maintaining equilibrium between the consumption and regeneration of natural resources – which doesn't leave future generations with fewer opportunities and ensures the preservation of ecosystems. But if we take a look at our resource consumption and the climate changes on the horizon, we see just how far we are from that goal.

As a member of the Board of Directors at University of Hamburg's Center for Earth System Research and – you guessed it – Sustainability (CEN) I'm especially interested in how societies are responding to climate change and biodiversity loss. As my research shows, in practice there are three main paths for pursuing sustainability.

On the one hand, there are measures that fall into the category of “modernization.” Many favor this path. Governments, NGOs and the industrial sector support the vision of simply continuing to manufacture and grow as usual, but in a modern, “green economy” without harmful side-effects. In this approach, the plan is for a combination of innovations and CO_2 pricing to stop climate change and preserve our livelihoods. But the bottom line is sobering: biodiversity continues to decline, the mountains of garbage continue to grow, and our planet is becoming warmer and warmer.

Consequently, others call for a radical change: transformation. The growth-based logic at the core of capitalism has to be abandoned. Since our planet doesn’t have limitless resources, constant growth has to end at some point. Radically rethinking our economies could pave the way for more sustainable growth. Yet our analyses indicate that we’re still a far cry from achieving this.

The third path involves a somewhat grimmer scenario, one based on authoritarian policies and control. Conceivably, individual countries or firms could implement geoengineering measures, the EU’s borders could be fortified, or elites could seclude themselves in safety zones. Since current crises could lead to an ecological state of emergency, we actually expect to see control imposed more often in the future. Democratic processes could be suspended, allowing states to directly

intervene. From a geopolitical standpoint, a number of factors currently point in this direction.

But we won't achieve true sustainability in time with any of the three options above: from plastic litter and nuclear waste to the warming atmosphere and oceans, humanity has set off changes that will create tremendous burdens for the generations that follow us. In fact, we're already living in the age of post-sustainability. Accordingly, we should do everything in our power to keep these burdens from getting even worse.

One ray of hope – an approach from the field of law. Though it comes from modernization, it can also be transformative: in 2008, Ecuador added certain rights for the environment in its federal constitution. Ever since, individuals and groups have had the right to file claims on behalf of ecosystems whenever the latter's rights are infringed upon, e.g. through pollution or damage. In 2017, a river in New Zealand was declared a legal entity; in 2022, the lagoon Mar Menor became the first ecosystem in Europe to follow suit. In the future, the resulting court rulings could set new global precedents.

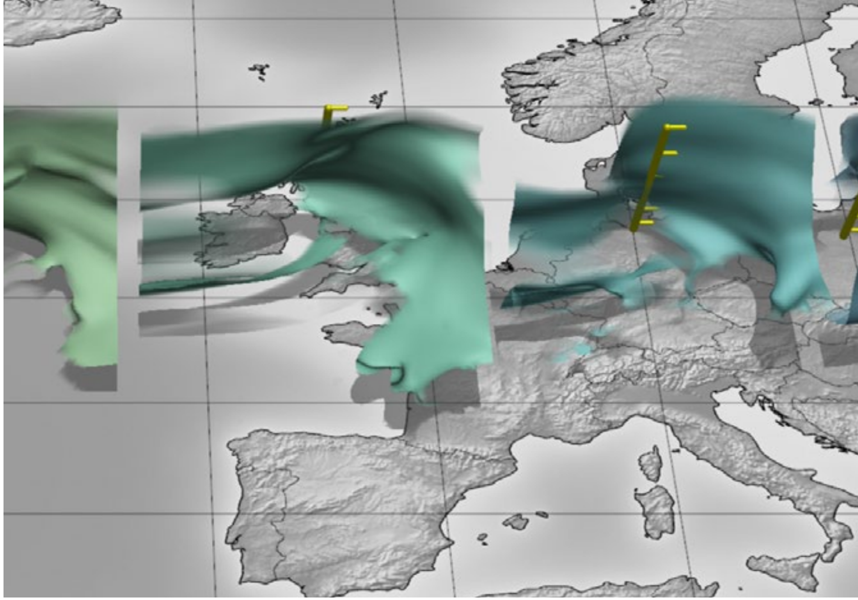
Prof. Frank Adloff is a sociologist and board member of the Centrum for Earth System Research and Sustainability and, consequently, board member of the new Earth and Society Research Hub ESRAH.

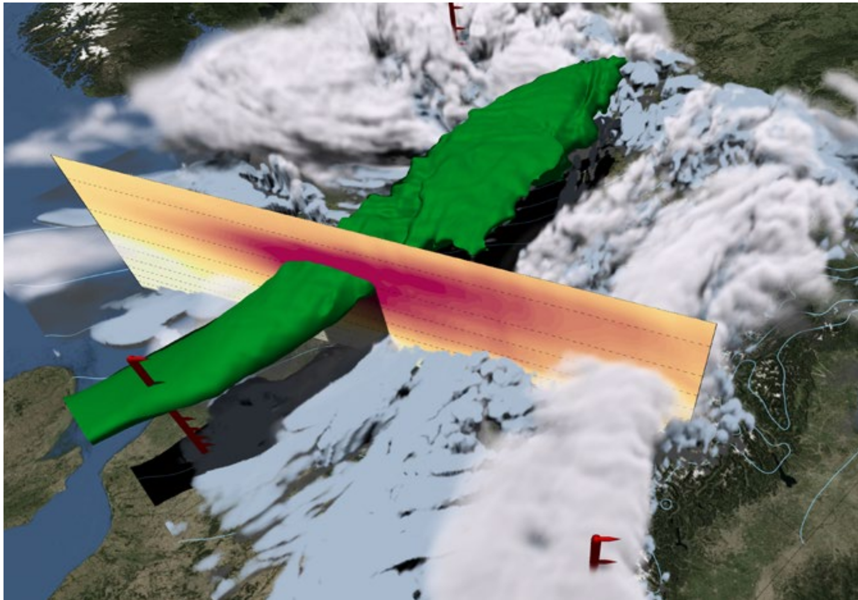
WEATHER AND CLIMATE: NOW IN 3D

What will the weather be like tomorrow, or the climate be like 20 years from now? Today, these questions are answered using complex computational models that spit out lists of numbers as long as your arm. These tremendous amounts of data often have to subsequently be transformed into graphics or maps – which are usually two-dimensional – to decipher their meaning. But what if I could explore the atmosphere hands-on, in 3D?

While I was working as a meteorologist in Munich, I often asked myself this question. There I was involved in planning research flights. My job was to determine routes with the highest probability of certain interesting meteorological phenomena occurring on them. To do so, I often had to make predictions for the upcoming flight on short notice: where would the clouds we were looking for be formed? What way would clouds of smoke from forest fires drift? I had to reconstruct these three-dimensional processes using 2D maps, which was painstaking and time-consuming work.

Other fields have made major advances in this regard. For instance, in computer games I can walk through virtual worlds





that respond to my every move. Couldn't we do the same thing with scientific data? The interface between meteorology and IT was something that had fascinated me for years.

So I started experimenting with graphics hardware from the gaming field in order to visualize meteorological data in a 3D environment. I programmed a new software package that allowed the data to be displayed interactively. At the CEN, Universität Hamburg's Center for Earth System Research and Sustainability, I'm working to refine this tool.

Thanks to graphic cards' computing power, the images are rapidly and fluidly displayed, allowing me to directly investigate meteorological phenomena. I can scroll through the atmosphere horizontally or vertically and immediately see the results in 3D. In this way, I can identify interesting or new phenomena intuitively, without the need for lengthy searches.

This represents an important step forward for the research community, since interactive 3D graphics can help to reveal even hidden processes. Normally, forecasting data is reviewed using 2D maps. Only particularly interesting parts of the data are looked at more closely in complex 3D animation at the end of the analysis. But with the new software, which I call Met.3D, all data can be investigated in 3D from the beginning.

A real limitation on the software is how much data the graphics memory can handle. Accordingly, our team was working to reduce the amount of data. This could be done, for instance, by teaching the program to automatically recognize certain atmospheric patterns like cold or warm fronts. So, if we want to take a closer look at cold fronts, we search for them in the data and filter out the results, which means we then only need to transfer this data to the graphics memory.

I am currently planning to incorporate Met.3D into teaching and at the same time research the value the program can add to education. I'm convinced that students could much more easily understand atmospheric processes if they could see the interactions for themselves and in 3D.

Dr. Marc Rautenhaus conducts research on the visualization of scientific data at the Center for Earth System Research and Sustainability and the Regional Computing Center.

CLIMATE CHANGE: COLOMBIA'S LONGEST RIVER NEEDS TO BE MANAGED

In Northern Colombia, the Magdalena River flows into the Caribbean Sea. From source to delta, this mighty river is over 1,600 kilometers long, and its drainage basin is roughly the same size as that of the Rhine. Due to climate change, droughts are now becoming longer here, while at the same time, floods are becoming more frequent.

Furthermore, the economy and the population have grown significantly – leading to a huge increase in water consumption. Agriculture, too, consumes tremendous amounts of water. In addition, today the Magdalena River supplies roughly 70 percent of the country's total hydroelectric power.

I'm interested in how the region can reconcile energy production and irrigation in the future. In order to determine how water management like this can be optimally designed, I have tested several scenarios using a computer model I created. In addition, I have combined various prognoses regarding changes in the climate and society, and taken key technical calculations into account: how full will the reservoirs be, how much

water will be available, and how high will water consumption be in the future?

My simulations show that, even within the next 20 years, at peak times water for agriculture, private households and industry will be in short supply. Therefore, the infrastructure should be expanded with dams and reservoirs in advance in order to increase storage capacity and meet water needs up to the year 2100.

And what about hydroelectric power? My findings show that conflicts between energy production and irrigation mainly arise in January, when it's especially dry. At this time, the crop fields need to be irrigated intensively. This poses a dilemma, since at the same time there isn't enough water in the reservoirs to cover electricity production when the energy demand is particularly high. In my hometown of Santa Marta, at such times there is often no power for hours at a time.

What could the solution look like? The capacity of the dams and reservoirs has to be increased by the year 2100 in order to ensure adequate supply for households, agriculture and industry alike. This will require substantial investments, but the subsequent operational and maintenance costs will be relatively low.

But how can investments be used to yield the optimal social benefit? To answer this question, I investigated e.g. a number of ways in which such decisions can be made: in the first option, the decision-maker dynamically adapts the management to compensate for changes. In the second option, a more shortsighted decision-maker makes investments based on the assumption that the current water supply and demand will also apply in the future. A third decision-maker assumes that the supply will remain constant, but the changes in demand will be similar to those in the past decade. What this tells us: skillful management is key. Here my models can help local authorities plan proactively and invest optimally in order to ensure a sufficient water supply for future generations.

As a result, the economic benefit could even increase by US$ 120 billion by the year 2100. However, dam building must not infringe on human rights, and the far-reaching consequences of changing the natural environment have to be carefully balanced against the economic benefits.

Dr. Martha Bolivar is a hydraulic engineer hailing from Colombia and was a member of the Center for Earth System Research and Sustainability at the University of Hamburg.

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