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WILL CLIMATE CHANGE FERTILIZE THE SAHARA?

TEN CLIMATE RESEARCHERS REPORT

WILL CLIMATE CHANGE FERTILIZE THE SAHARA?

TEN CLIMATE RESEARCHERS REPORT

Stories of earth system research made in Hamburg

CONTENT

THE LATEST NEWS FROM CLIMATE RESEARCH

Will climate change turn the Sahara Desert into a green paradise? This seeming paradox—as climate change is mainly associated with droughts and extreme weather—may become a reality due to increasing carbon dioxide levels. Researchers from Universität Hamburg's Center for Earth System Research and Sustainability (CEN) are investigating various climate phenomena and developments. Across the world, the many faces of climate change and its ramifications differ greatly—often taking rather unexpected turns. This compilation provides an insight into work at the CEN. It explains, for instance, how old snow impacts the Arctic and elucidates the role of climate change in the Syrian conflict.

Once a month, our researchers' guest contributions to the *Hamburger Abendblatt* take you on an intriguing journey into climate science. Ten of these articles can be found on the following pages.

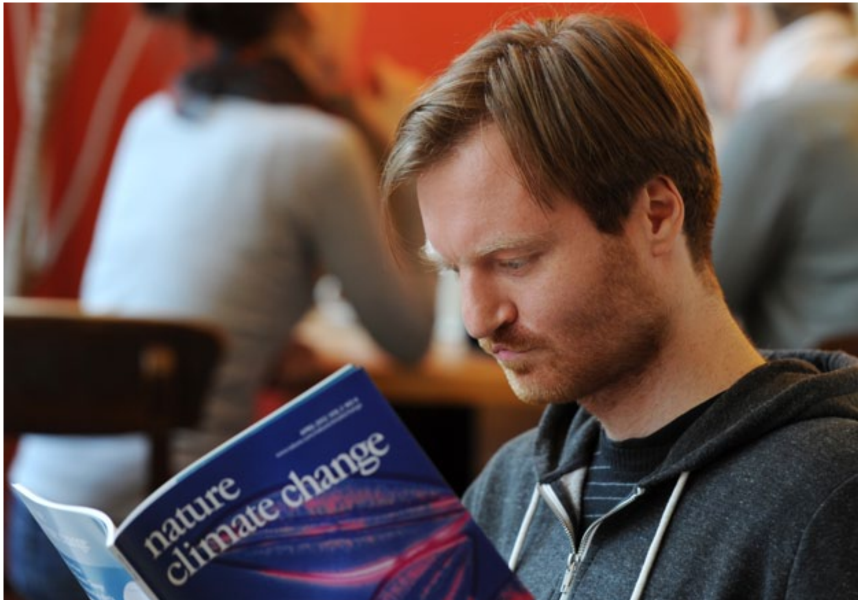
Enjoy our selection!

PARENTS, THE MEDIA OR AL GORE – WHO SHAPES OUR IDEAS ABOUT THE CLIMATE?

The IPCC's Fifth Assessment Report has turned the media's attention back to climate change. Almost every newspaper and countless magazines and television and radio stations covered it, not to mention all the discussions on the internet. But how does the media affect people's attitudes towards climate and their behavior?

To find this out, we conducted over 40 detailed interviews with citizens of Hamburg as part of a project of Universität Hamburg's Cluster of Excellence CliSAP. We chose our interviewees to cover as broad a range of attitudes on climate change as possible. It was also important to have a cross-section of Hamburg's populace: young and old, men and women with various levels of background knowledge of the subject and from different neighborhoods.

The interviews show that different experiences affect our understanding of and attitude towards climate change.



Most of those interviewed consider the media to be the most important source of information for learning about climate change. According to our findings, however, the media is less important when it comes to behavior and awareness of the issue. Interpersonal communication has a far greater influence—especially discussions with parents, friends or at school. In addition, personal experiences affect whether or not people consider climate change to be a problem. Extreme events such as heat waves and flooding were frequently mentioned.

Our interviews showed a clear pattern, enabling us to identify various types characterized by their media use and communication behavior. The most common type uses a wide range of media and formats to obtain information on climate change and discusses the topic with friends and family. They are convinced that humans are responsible for climate change, and so they are climate-aware in their actions.

There are three other types who share this view and whose behavior is also climate-aware: The first group are those who read specialist media and watch science programs and who do internet research and discuss the topic. The second group gets their information from social media platforms like Facebook and also uses them to communicate, while the third group includes people whose awareness of the problem has been heightened by an environmental disaster or by a film which has prompted them to make their behavior more climate friendly. One film that was often mentioned was Al Gore's "An Uncomfortable Truth".

The other types all doubt that humans are to blame for climate change and as such do not exhibit climate-aware behavior. On the one hand, these are people who use traditional media, who aren't interested in the subject and don't look for information on it. They are often older people who hardly use the internet. But the group also includes those who are skeptical of the mass media and mistrust newspaper, radio and television reports. They look for alternative sources of information such as internet forums and blogs. We are currently carrying out a survey of over 1,000 people to look at how often the individual types occur in the community.

Ines Lörcher conducts research on climate change reception and communication at Universität Hamburg's Cluster of Excellence CliSAP.

SCIENTIFIC MODELS HELP EVACUATE FLOODED AREAS

Flood warning! In the event of a storm surge warning, people living in at-risk coastal areas may have to be evacuated. But who can stay, and who needs to go? Misjudging the impacts could have serious consequences.

My new computational model could soon help to more accurately predict which areas will actually be flooded. This could be especially important in the future, since rising sea levels could make major storm surges a more frequent occurrence.

Ordering an evacuation is a radical step. Nevertheless, since safeguarding human lives has to remain the top priority, no area is too small to be evacuated. At the same time, an evacuation is a costly affair, and the larger the area, the higher the costs. Further, if a predicted surge ultimately turns out to be comparatively harmless, "needless" wide-scale evacuations can breed frustration among those affected. If this happens more than once, they may lose their faith in flood warnings in general. As such, predicting the affected area as precisely as possible is extremely important.

At Universität Hamburg's Center for Earth System Research and Sustainability, my colleagues and I are working to develop mathematical models that will allow us to accurately simulate these extreme scenarios. The shallow water equations, mathematical formulas that describe the physical movements of water under simplified conditions, form part of the basis of our models. But for the constantly changing processes on coastlines, they aren't sufficiently precise, which means I also need to take the length of the inbound wave into account. Shorter waves disperse more slowly; longer ones do so more rapidly. In order to more realistically simulate when the waves will hit the coast and how large they'll be when they get there, I want to add this aspect to the calculations.

There are two different formulas that can help me describe the influence of the wave's length: The Boussinesq approximation and a more recent correction. Since each has its own strengths and weaknesses, which one is better suited to my model? The Boussinesq approximation is definitely the safer bet: First proposed in 1872, it's been frequently used ever since and does a good job of describing the relevant physical processes. On the other hand, its depiction of the influence of the wave's length is so complex that there's no way it could be flexibly integrated into my model.

In contrast, the correction takes a different approach to the wave's length, so I could add it to my computational model fairly easily. That being said, it's also relatively new and therefore not as established as its predecessor – and its depiction of physical phenomena is less precise.

To compensate for this problem, I have adapted the correction so that it can better describe physical processes. The results of an initial comparison for a simple scenario were amazing: My "new and improved" correction yielded exactly the same results as the Boussinesq approximation. That means in the future, we'll have a more flexible mathematical tool that promises more accurate predictions of coastal flooding.

Anja Jeschke is investigating equations for shallow water waves at Universität Hamburg's Center for Earth System Research and Sustainability.

WILL CLIMATE CHANGE FERTILIZE THE SAHARA?

A few thousand years ago, the Earth's climate was quite different. Some regions were warmer and moister—and the Sahara was considerably greener. A lush canopy of plants drew water from the soil and "sweated" it back out, which produced monsoons on a regular basis.

But, over the course of millennia, the Earth's orbit changed, and with it the sun's influence on the climate. This also impacted the Sahara: the monsoons ended and the vegetation gradually disappeared. Today the Earth is growing warmer again. The cause: the greenhouse effect, which has been intensified by our use of fossil fuels, releasing more and more CO_2 into the atmosphere. The increased CO_2 levels are warming the Earth—and far more than thousands of years ago. The question is: with a warmer climate, will vegetation return to the Sahara?

My colleagues at Universität Hamburg's Cluster of Excellence CliSAP and I have explored this question with the help of three different climate models. The projections indicate that,

through the end of the 21st century, the central and western Sahel, as well as the southern edge of the Sahara, actually will become greener. Nevertheless, the equation “warm climate = green desert” doesn’t really work, because the increased vegetation is not only a result of the higher temperatures; two of our three models indicate that it is primarily due to the higher CO_2 concentrations in the atmosphere.

Plants need carbon dioxide: they “breathe” it in and, with the help of sunlight and water, convert it into building materials for their cells. In theory, then, more CO_2 should promote more vegetation in the Sahel zone. But our calculations show that major sections of this region will also become more arid in the wake of climate change. This will harm the plants, which need water in order to process the CO_2. So we see two opposing effects: more CO_2 “fertilizes” plants, but higher temperatures dry them out.

In order to better grasp this interaction, we examined the two factors again separately—unfortunately with mixed results. In some models CO_2 is the decisive factor for increased vegetation growth at the edges of the desert regions; in others, only those regions in which the precipitation and temperature conditions were conducive from the outset will become greener.

In this regard it’s important to know that plants take in carbon dioxide through tiny pores in their leaves. When plants have plenty of water, these pores are wide open, allowing them to absorb a great deal of CO_2. At the same time, some water is released through the pores and evaporates, which cools their immediate vicinity. In contrast, plants surrounded by CO_2-rich air only need to open their pores slightly; higher CO_2 levels mean less evaporation. The effect: the air close to the ground grows warmer. Further, vegetation is darker and absorbs more sunlight than bright desert sand. This intensifies the warming—bad news for heat-sensitive plants.

Even if the different models portray this complex interplay in different ways, we can say the following: it’s quite possible that the “ CO_2 fertilization” will lead to the formation of a green belt in the Sahara. But if so, it most likely won’t last for long; at some point, the heat and lack of water will gain the upper hand and the vegetation will dwindle once again.

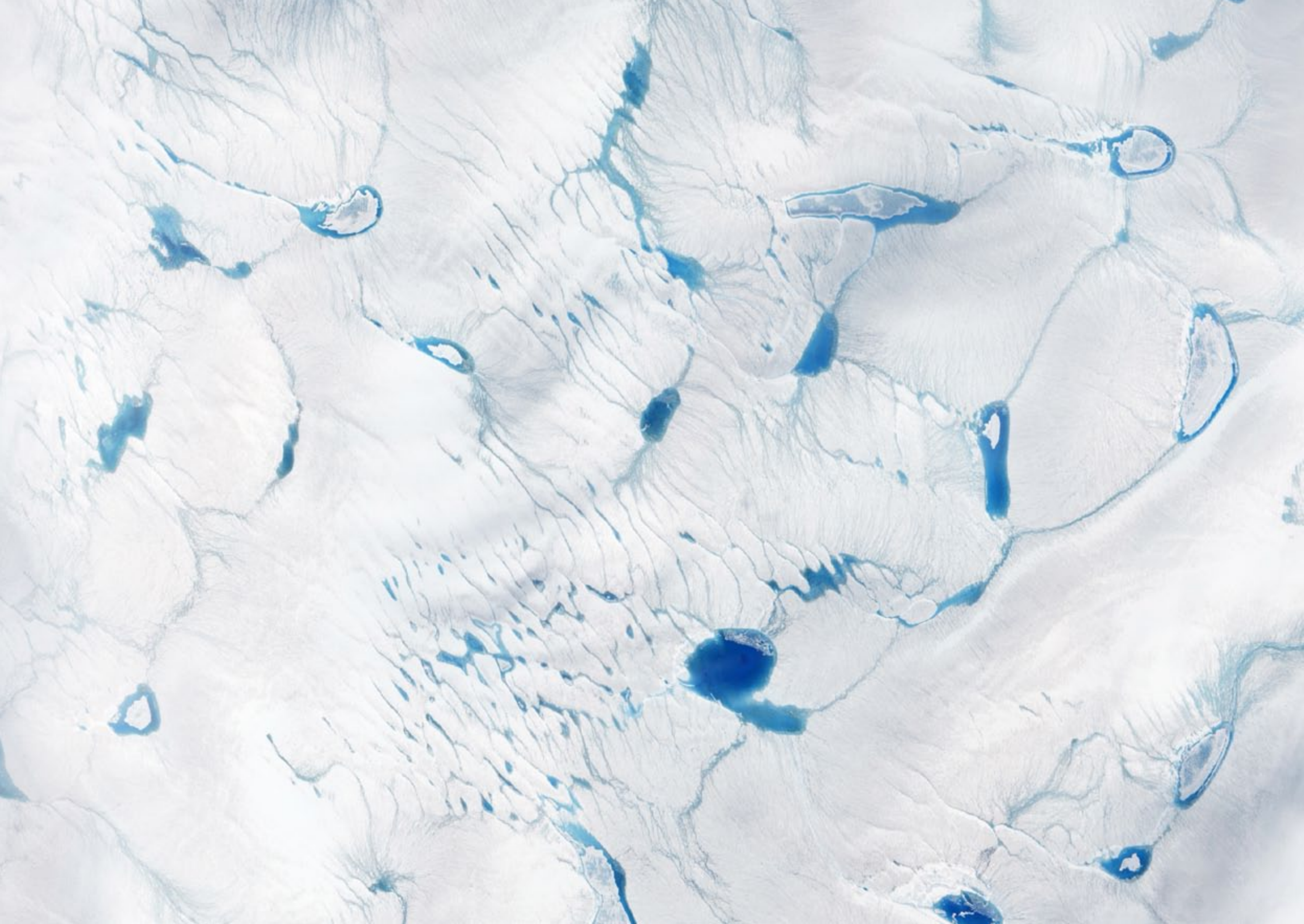
Prof. Martin Claußen is a meteorologist at Universität Hamburg and Director of the Max Planck Institute for Meteorology.

OLD SNOW OBSTRUCTS ARCTIC SEA ICE MEASUREMENTS

Twenty-four hours a day, satellites survey the Earth, providing tremendous amounts of data. Hidden in these mountains of figures lies a wealth of information. Yet before that information can be put to use, climate researchers need to first uncover and decode it.

In the course of this work, we sometimes stumble across a “mother lode”—just like we did in my recent discovery concerning Arctic ice. Changes in the ice cover of the Arctic Ocean are an important indicator of climate changes. For years now, the area covered by ice has steadily declined, and many researchers fear this trend can no longer be reversed—which would have far-reaching consequences for our climate system. As such, this region has been monitored by satellites for more than 35 years. But how thick is the ice we see? After all, the thickness of the ice tells us more about its total volume, and therefore about its longevity, than its area does.

Since late 2010 we at Universität Hamburg’s Center for Earth System Research and Sustainability have been able to



measure ice thicknesses of up to one meter with the help of the SMOS research satellite, marking a major advance. The satellite can sense and measure the natural radiation produced by all bodies — including the ocean and the sea ice on its surface. In the course of its long journey into space, this radiation is constantly diverted and reflected. As a result, only part of the energy reaches the satellite, which receives a modified signal. This effect is most prominent at transition points, e.g. at the transition from ocean to ice, or from ice to air. First we use computer models to describe the physical processes at the respective boundaries; we then use the values to determine the distance between those boundaries — e.g. to arrive at the thickness of a layer of ice.

SMOS also gets a helping hand from the CryoSat-2 satellite. Whereas SMOS's "visual depth" of up to one meter can be used to accurately measure the thinner edge areas of the sea ice, the CryoSat-2 is the expert when it comes to thicker ice. Unlike SMOS, it uses radar to measure how far the ice protrudes out of the water. Since we know that only ten percent of sea ice is above water and the remaining ninety percent is underwater, we can then calculate the total thickness. However, this method can only work if the current snow conditions are also taken into account; masses of snow can weigh the ice down to such an extent that the normal 90:10 ratio no longer applies. But how can we measure snow cover? Until now, researchers have had to resort to outdated maps and could only make rough estimates.

While integrating a formula for the snow cover into our computer model, I discovered an unexpected solution in the SMOS data. At exactly the point where SMOS runs into its limitation — namely, for thick ice — the formula delivers values for the thickness of snow cover. The expeditions with observational flights over the Arctic so far have confirmed these values — a real success, as now for the first time I will be able to create comprehensive and up-to-date snow-cover maps. The next challenge will then be to determine whether or not these maps can actually be used for the CryoSat calculations, which would allow us to more accurately monitor and comprehend changes in ice volume in the Arctic.

Dr. Nina Maaß investigates how to best measure Arctic sea ice via satellite at Universität Hamburg's Center for Earth System Research and Sustainability.

“Deep waves” affect ocean currents and the climate

If you look at a quiet sea on a warm summer evening, it’s hard to imagine that our oceans are actually never at rest. Three factors keep them in constant motion: the wind that the water produces on its surface; differing temperatures and levels of salinity in the ocean, as a result of which the colder, heavier water masses sink deeper and warmer water takes their place; and lastly the tides, which are created because the Earth’s rotation and the gravitational forces produced by the sun and moon keep the seas in motion.

All three movement patterns help to shape our climate, as ocean currents are important “conveyor belts” for heat and energy. For example, the Gulf Stream moves heat from the Gulf of Mexico to Europe’s North Sea, ensuring we enjoy mild temperatures. Unlike the wind, which merely mixes up the upper layers of the seawater, or sinking masses of colder water, which can only be found in certain regions, tidal movements affect the ocean as a whole—and they can be felt all the way down, to ocean depths of several thousand meters.

The nature of the ocean floor is what makes it so difficult to predict these movements for the purposes of climate models—our oceans not only display different depths, but are also riddled with countless trenches, ridges and slopes. When a tidal wave encounters one of these obstacles or simply sweeps along the ocean floor, it is slowed, divided, redirected or in some cases even accelerated—e.g., when the water has to pass through a narrow chasm.

The range and energy of these “deep waves” and their interaction with the ocean floor represent important parameters for climate research, as they have a considerable influence on currents and heat transfer in the ocean—and the climate in the process. At the same time, they are also connected to rising sea levels. The very first climate model ever developed in Hamburg (in the 1950s) was a tide model for the North Sea. Nevertheless it wasn’t until the 21st century that international research groups were able to develop models to simulate these processes on a global scale.

At Universität Hamburg’s Center for Earth System Research and Sustainability we have now for the first time systematically compared and assessed these global tide models. The result: global maps that show where and how different tidal patterns overlap, and where the energy input is especially high or low. In a second step, we used our HAMTIDE model to calculate the associated energy dissipation. The results tell us how tidal energy is distributed across the ocean, which routes it follows, and whether climate-relevant ocean currents are tending to grow stronger or weaker.

We’ve come a long way since the 1970s: With very few exceptions, we now have comprehensive data on the topography of the ocean floor, coupled with detailed tidal observations on the surface. At the same time, today’s models are sufficiently powerful to combine these two types of data, allowing them to represent the complex patterns of energy distribution and movement in the ocean better and better. If we can successfully integrate these findings into global climate calculations, it will mean a major step forward.

Prof. Detlef Stammer is an oceanographer and Director of Universität Hamburg’s Center for Earth System Research and Sustainability.

1.5 MILLION SYRIAN PEASANTS DISPLACED DUE TO DROUGHT

Northeastern Syria used to be one of the most productive agricultural regions in the Middle East. From 2006 until 2010, however, the area endured one of the most devastating droughts in recorded weather history. Water scarcity caused crop failures and increasing food prices.

Mostly subsisting on small-scale family-run farms, the traditional population was unable to cope with these problems. Yet, the people were left to their own devices as the autocratic government had hardly taken any precautions and offered no suitable disaster response and contingency plan. In science such situations are associated with a lack of resilience. This particular case exemplifies the inability to adapt to climatic and economic change. Due to the drought 1.5 million peasants and livestock breeders lost their livelihoods and migrated to less affected regions of the country. Numerous refugee families have settled in southern Syria for now. In March 2011, the first voices against the regime of Syria's president Baschar al Assad were raised there. These protests grew into a full-blown

civil war that continues today. A large number of northern migrants have thus been fleeing further towards Jordan, Turkey, and Lebanon—this time as war refugees.

As a peace researcher at Universität Hamburg's Center for Earth System Research and Sustainability I aim to find out what factors geared these Syrian migration waves; in particular if and to what extent environmental refugees participated in protest activities. The results may explain why climate change and its impacts should generally be assessed as driving forces behind conflicts. In 2014, I spent four weeks in Jordanian refugee camps and interviewed thirty Syrian families, some comprising up to thirty-five individuals. Among other things, I inquired whether water supplies and crops underwent changes during the drought years and how this influenced the families' decision to flee. Moreover, I asked if environmental refugees dared to engage directly in the uprising. Accordingly, facing a major predicament and experiencing tremendous anxiety, the refugees did not protest themselves. Nonetheless, recurrent drought periods combined with a severe lack of political support have fuelled social unrest.

Many Syrian refugees are planning to return to their native land and resume farming as soon as the rioting ends. But the Intergovernmental Panel on Climate Change (IPCC) warns against climate change ramifications in the Middle East. Although drought periods have always formed part of the local climate, observations prove that Mideastern winters have been significantly drier in the past twenty years than in the eighty years before. Researchers expect precipitation in northern Syria to decline by a further twenty percent, and the mean temperature to increase by four degrees centigrade until the end of the century.

Resources and an improved infrastructure are necessary to effect successful returns of Syrian smallholders to their homes. Efficient water use and alternative sources of income would help returnees adapt to climate change. One thing is certain: whoever will reign in Syria after the war will also have to tackle the repercussions of global change.

Dr. Christiane Fröhlich is a researcher at Universität Hamburg's Center for Earth System Research and Sustainability. Her main topics are climate change, migration and conflicts.

FLOODING THREATENS SOUTHERN CHINA'S PEARL RIVER DELTA

In southern China's Pearl River Delta, eleven cities are currently merging to form one huge megacity. But as a result of investments from Hong Kong and Taiwan, over the last three decades the once rural area has been transformed into a booming factory for export goods—and an area about the size of Lower Saxony is now home to a population as large as Great Britain's.

Today, the monsoon climate is already hard on the people living there. Compared to Hamburg, there is more than twice as much rainfall, most of which is concentrated in the six monsoon months. The damaging effects of regular flooding are further exacerbated by paved surfaces and channelized riverbeds. In addition, recurring typhoons lash the land with meter-high waves of seawater.

Will climate change worsen these threats? What adaptation strategies are available? This is the subject of my research at Universität Hamburg's Cluster of Excellence CliSAP. Using historical measurements from the delta and a simulation model from the Max Planck Institute for Meteorology in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Hamburg, I determined future scenarios for temperature, precipitation, sea level and tropical cyclones. According to these scenarios, the average temperature in the delta will rise by up to three degrees in the 21st century. Precipitation will become more extreme, i.e., more often unusually light or heavy. If greenhouse gas emissions go unchecked, the sea level could rise by up to a meter compared to the 2005 mark.

The result: The delta will experience more frequent and more severe flooding from the river, but also from the tides in the South China Sea, since almost eight percent of the area is three meters above sea level or less. And it is precisely here—in the flatlands—that the major industry and cities are located. The new coastal zones created through land reclamation are particularly at risk.

But floods will have different impacts in different places. Depending on their location and structure, cities vary in terms of their vulnerability. On the basis of statistical data, I first estimated the likelihood of flooding, which depends, for example, on an area's height above sea level. In order to rate a city's susceptibility to flooding, among other things I analyzed data on the population structure. The young, the elderly and the unemployed are especially at risk. I then considered the ability of cities to adapt to the flood risk. This can be determined on the basis of social aspects like per capita income. Hong Kong is a particularly interesting example. The peninsula faces serious risks—but as a business and financial metropolis also has the resources to take suitable preventive measures.

How will flood protection in the delta have to be adapted? Apart from conventional solutions like levees, the region above all needs "soft measures" that promote awareness of the dangers: A jointly developed climate strategy, more reliable weather forecasts, and official recommendations on what to do in case of a flood. Last but not least, social media could be used to provide real-time flood information.

Dr. Liang Yang is a geographer at Universität Hamburg's Cluster of Excellence CliSAP.

HIGH LEVELS OF CO_2 EMISSIONS REDUCE COMPANY VALUE

Since the introduction of the European emissions trading, CO_2 has had its price: Companies with particularly high emissions have to buy emissions certificates—that is the right to emit CO_2. Climate-friendly companies, however, can sell certificates, thus making additional profits.

But does emissions trading really change anything for companies? Theoretically, CO_2 certificates are meant to provide an incentive for more climate-friendly production. However, this only works when they prove to be a profit or a loss—if emission allowances are too cheap, the incentive gets lost. It is also a problem if the companies simply pass on their increased CO_2 costs to consumers. Then, the customers pay the price for excessive emissions. As scientific studies have shown, this is the case in the energy sector.

At CEN, my colleague Nicolas Koch and I have examined for the first time whether CO_2 emissions do influence the value of companies. In contrast to annually published balance sheets, the company value also reflects expectations for the

future. If the company is well-prepared for future challenges, which may arise from climate policy, this allows for good conditions for a high value. In order to calculate this, we have looked at several major providers: What kind of electricity mix does the company produce? Carbon, gas or renewables? How modern are its power plants? We were particularly interested in the question whether investments in low-emission technologies would pay off.

As a matter of fact, electricity providers are now forced to tackle this question themselves, for numerous power plants are aged and call for modernization. Designed for long life spans new plants are very cost-intensive, so investment decisions require careful planning.

Also, it is essential to control the future distribution of free energy certificates while fostering certificate auctions. The so-called grandfathering has already been abolished. A company's eligibility for free certificates is no longer assessed based on its past emissions, but rather on benchmarks corresponding with CO_2 emissions of the most energy-efficient plants in the respective European sector. The more CO_2 emissions, the more energy certificates plant owners must buy—clearly, CO_2 mitigation through climate-friendly technologies is the key to the best deal. This will certainly boost CO_2 certificate prices.

In our study, we have analyzed data from more than 450 power plants and simulated two scenarios: What happens if providers replace their old plants with plants of the same type? And what happens if they invest in low-emission technologies instead?

The companies' self-defined emission targets served as our calculation basis. Additionally, we have incorporated some further factors into both scenarios, such as commodity prices, plant life and increase in CO_2 prices. The result: the company value suffers clearly when emissions are too high. In 2020, the value of companies who take their emission targets seriously will be 26 percent higher than when failing to reduce emissions, due to the expected price development for CO_2 certificates. In other words: investments in low-emission power production are not only climate-friendly, but make good economic sense, provided that the statutory provisions continue to be stable.

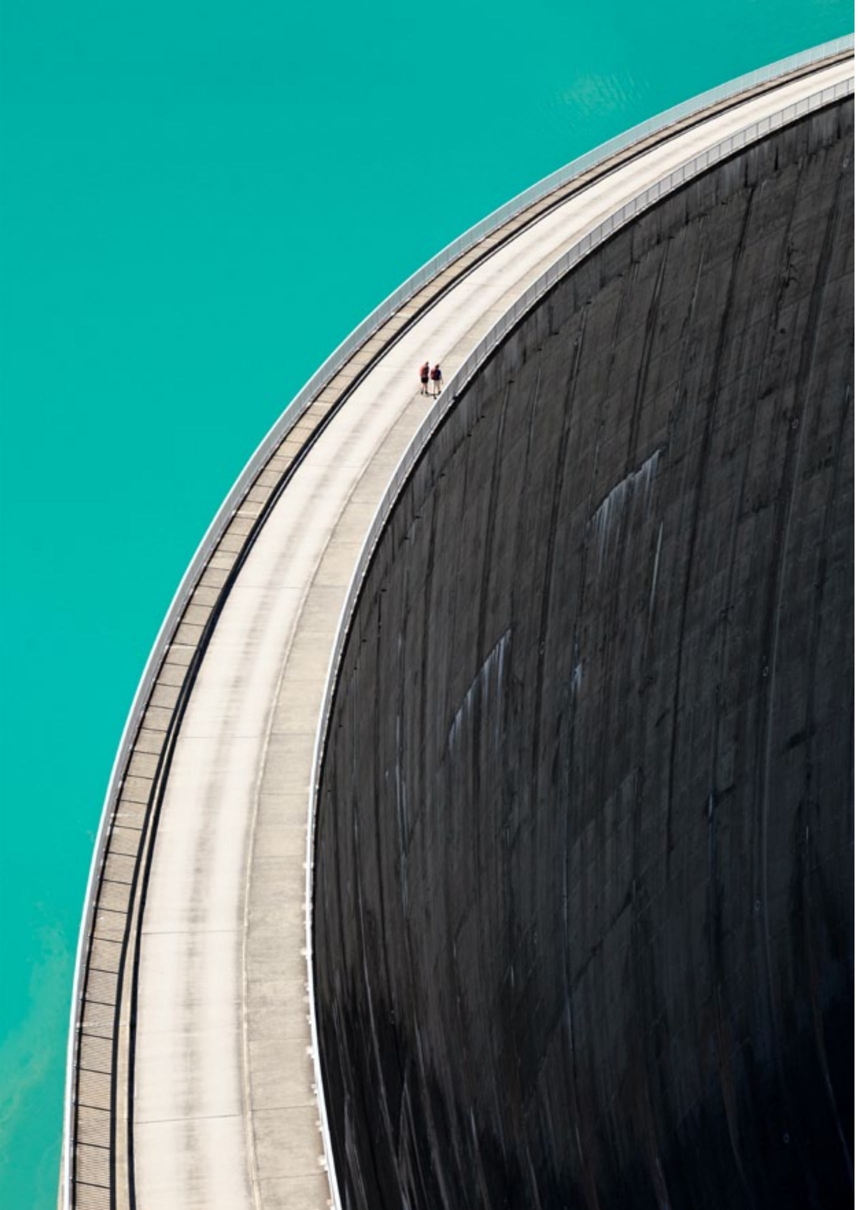
Prof. Alexander Bassen investigates how climate change relates to society at Universität Hamburg's Center for Earth System Research and Sustainability.

CLIMATE FORMULAS: EVEN EXTREME WEATHER FOLLOWS RULES

Extreme weather phenomena like disastrous monster waves, typhoons, and 100-year floods seem unpredictable. In order to make them foreseeable, climate researchers aim to translate them into strict mathematical formulas.

This goal is part of my research focus in applied mathematics and theoretical meteorology at Universität Hamburg's Cluster of Excellence CliSAP. Extreme weather events share three common characteristics: They are rare, deviate significantly from mean values, and have tremendous ramifications for nature and societies. In a nutshell, extremes are atypical which makes them difficult to trace. Thus, statistics are crucial.

There are two approaches to determining extreme values such as regional flood risks. One method focuses on pinpointing the record water level per decade. This allows us to analyze one single value for each time unit. Hence, other aberrant high water levels occurring during the investigation period remain unconsidered. The second method, by contrast, takes into account all extreme values that exceed a



certain limit. As a result, ten-year periods may indicate a random number of flood events or none at all. The outcomes of both approaches can be converted into curves depicting the frequency of certain extreme water levels.

Interestingly, all probabilities thus determined match one of four long-known standard curves—each named for the scientist who discovered it: Gumbel, Fréchet, Weibull und Pareto. So, even extremes are ruled by laws that enable us to establish the probability of future events. This is of great interest not only to climate researchers, but also to engineers, insurers, or finance experts. How high must dams be built to withstand floods within the next one hundred years? What financial losses due to major fires must be expected? How likely is a stock market crash?

A fundamental shortcoming of the above methods is their basic assumption that our climate system is invariable. Quite the contrary, our global climate depends on numerous external factors and is undergoing constant change. Therefore, I am collaborating with colleagues in France, Portugal, and Great Britain in order to find out how to incorporate climate change data into our extreme value distribution formulas. It is an incontrovertible fact that, as regards frequency, intensity, and spatial distribution, even the most chaotic weather follows universal laws. Researchers specializing in extremes examine these patterns as if through a magnifying glass. Events are more forceful and visible during unusual weather conditions. Thus, extremes are highly useful to climate research. They elucidate how a system—in our case the climate—behaves in principle.

Prof. Valerio Lucarini is a theoretical meteorologist who worked at Universität Hamburg's Cluster of Excellence CliSAP from 2011–16.

CSI CLIMATE CHANGE: IN SEARCH OF CO_2 RIVALS

The temperature curve for the Baltic Sea region shows a clear trend. It indicates a rise by up to two degrees Celsius over the past thirty years. How did this happen? Looking for clues, climate researchers must focus on the recent past.

In doing so, we proceed just like criminal investigators facing a tricky case: The wealthy Countess Celsius is lying dead on the floor. Did she die of natural causes or was she murdered? Similarly, climate change detectives will ask if the Baltic Sea area's temperature increase is due to natural fluctuations or external factors.

In collaboration with my colleagues from Universität Hamburg's Cluster of Excellence CliSAP, I start this climate murder investigation by analyzing all temperature measurements since 1980. We document the scene and collect potential evidence. If our data can merely be attributed to regular variations, we do not have a case, meaning that the Countess simply died from decrepitude. But as it turns out, the summer and fall as well as the average annual temperatures are freak values calling for clarification. Hence, we post a "Most Wanted" notice.

A prime suspect has already been identified. The relentless rise of the greenhouse gas CO_2 may explain the warming effect throughout the year. But how do we prove this? Computer-generated climate models can lead us onto the right track. These simulations provide suggestions as to what increases in temperature may derive from higher CO_2 levels. In the current case our modeling reveals that—regarding the winter and spring months—CO_2 may indeed be the sole culprit.

Nonetheless, we cannot close our case yet. The established rise in summer and fall temperatures since 1980 is too high. According to CO_2-driven computer models it ought to be lower; ergo we must conclude that CO_2 cannot be held responsible alone. It still remains a mystery what other factors contributed to those unusually warm months.

For that reason, we go on tracing further evidence. We suspect that tiny dust and dirt particles in the air may also play a major role. These so-called aerosols reflect the sunlight and block out incoming light like sunshades, thus cooling the bottom layers of the Earth's surface. Moreover, the particles facilitate the formation of clouds—a way of cooling by obscuring. So, aerosols act as a brake on temperature. Presumably, this mechanism is particularly efficient in summer and autumn.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In the course of the massive industrialization of the Baltic Sea region, the aerosol concentration in the air had increased significantly. We can therefore deduce that up until the 1980s, aerosols mitigated the warming effect in the Baltic area. Apparently, the pollution of the environment reduced regional climate change impacts for a while. Things changed, however, when the clean air policy became effective in the eighties. As manufactured aerosols became less used, their summer and fall cooling effects decreased as well. This revelation demystifies the immense rise in temperatures over the past decades.

Our murder case seems solved now. Carbon dioxide has been found guilty of warming the temperature in the Baltic region. We proved the following: until the 1980s, Countess Celsius could still rely on servants that, at first glance, appeared ill-suited to compensate any temperature-related predicament. Rather paradoxically, abundant aerosols alleviated our fragile lady's heat exhaustion by cooling the air, especially in the summer and fall. As soon as they started diminishing, she grew increasingly defenseless...

Prof. Dr. Hans von Storch is a researcher at Universität Hamburg's Cluster of Excellence CliSAP. Until 2015 he was Director of the Institute of Coastal Research at the Helmholtz-Zentrum Geesthacht (HZG).

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