The ocean is not a glass of water

Ten climate researchers report

A reader from the KlimaCampus in Hamburg

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Climate stories …

New findings from climate research? “Exciting!” say some. “Surely complicated!”, say the others – and fear long explanations and confusing diagrams. Indeed, both are right: there is hardly another branch of science that has gained as much importance in the last years. And yes, the questions are complex. It is not without good reason that supercomputers are needed for climate calculations.

Nevertheless: one need not be an expert to be interested in climate research. Together with the “Hamburger Abendblatt”, we have developed a series in which scientists from the KlimaCampus report on their work. Ten of these articles appear in this booklet – without technical jargon and easy to understand.

Did you know, for example, that sea level is not rising at the same rate all over the world? That clouds can heat up or cool the atmosphere, depending on where they are? And that climate change will help determine which fish we find on our plates in the future? You can find out about all this here.

We wish you a good read!

The "Little Climate Change" existed in pre-industrial times

Climatically prestressed: humans have been influencing the climate for centuries – not just since they started burning oil and coal en masse – by transforming forests into farmland …

Talking about climate change means talking about CO_2, since the more carbon dioxide we release to the atmosphere by burning petroleum, natural gas and coal, the more it heats up. But most of us don't realize the role played by land use. Deforestation, for example, which is presently occurring over vast expanses of land in the tropics, increases human-caused emissions by a quarter. On the other hand, plants compensate for about one third of the total annual emissions by taking up CO_2 in the course of photosynthesis. This presents climate research with two questions: Can the consequences of climate change be cushioned if we reforest large areas? What will happen when farmland areas increase and forests shrink?

A young scientist at the KlimaCampus, Julia Pongratz from the Max Planck Institute for Meteorology, recently came up with a surprising discovery. Using the supercomputer, she simulated the carbon fluxes between vegetation, atmosphere and ocean from the year 800 to 1850. In this pre-industrial period, fossil fuels were hardly burned and the area of agriculturally productive land was the only human-caused disturbance of the climate system. The need for farmland was, however, enormous, because the world population tripled during that time to around a billion people.

As a matter of fact, the calculations do show that the amount of stored carbon decreased the more the forest areas were displaced by agriculture. One reason for this is the fact that forests can store significantly more carbon than meadows or grain fields. And although the ocean takes up a portion of the carbon dioxide formed, the model shows a distinct increase in atmospheric CO_2 – quasi a "little climate change".

The increase cannot be explained by natural fluctuations, but the amount is not sufficient to account for increasing temperatures worldwide. Regionally, however, the effects of land use would have been noticeable, although partly with the opposite effect: areas with light-colored grass and grain, for example, reflect more sunlight than dark forests and therefore can often have a local cooling effect.

The fact that there was climate change already before humans had power stations, cars and refrigerators does not mean "all-clear" with regard to the current discussion. On the contrary, apparently we started the industrial age with a to a certain degree "prestressed climate". At the same time, the results show how important it is to consider such climate scenarios with a high degree of spatial and temporal resolution. In the mid and high latitudes, reforestation will cause more solar radiation to be absorbed, tending to cause a warming of the atmosphere. In the tropics, on the other hand, forests cause additional evaporation and thus tend to cool the atmosphere down. The question whether we can achieve a positive effect by reforestation must therefore be answered in a number of different ways. Fortunately, climate research has made great progress here, so that we are able to represent such effects in our models.

Prof. Martin Claussen is a professor at the University of Hamburg and a director at the Max Planck Institute for Meteorology.

The ocean is not a glass of water

Island states such as Tonga or Kiribati are the Achilles heel of climate change. Their coastlines lie only a few meters above sea level. If the ice caps in Greenland and Antarctica melt, these islands are in danger of disappearing into the Pacific.

New results from the Institute of Oceanography at the KlimaCampus show, however, that the enormous addition of meltwater would not disperse evenly throughout the world ocean. There would be regional differences, particularly evident in the short run on the coasts of northern Europe and North America. The dynamic processes in the ocean are the cause of this: contrary to a water glass, in which a calm surface appears a few seconds after water has been poured in, there is no resting state in the sea, due to the ocean currents. Our models show that the meltwater would still cause motion in the North Atlantic 50 years later, and it would reach the world ocean still later.

The conclusion: sea level is not rising uniformly; there are minimum and maximum values which can diverge considerably. First of all, there is the effect of

the incoming mass: when water flows into a basin, a propagating wave forms. In addition, the rotation of the earth causes it to deflect. The eddies resulting from this can travel far across the Atlantic. One can picture a full water bucket with an eggbeater in the middle: while the level in the middle sinks due to the rotation, the water overflows at the rim.

Effectively, the melting of ice leads to changes in the entire North Atlantic within a few years, affecting sea level rise as well as water circulation. This is due to the fact that meltwater is freshwater. Because of its lower density, it forms a layer on top of the more saline ocean water and only mixes in slowly. At the same time, global ocean currents, such as the Gulf Stream, with their heat-carrying capacity which is so important for us, get out of sync. In our climate models, this "answer" by the ocean to the freshwater input is particularly conspicuous.

Unfortunately, however, the new results don't mean that Tonga and Kiribati are less endangered. One part of the meltwater has an early influence on the Pacific. And climate change doesn't only melt the polar ice caps. A major part of the expected sea level rise will be based on the fact that the seas expand in volume as they warm. But this effect is also not of the same amplitude everywhere. It is also affected by the ocean currents which mix up the system – the proverbial "tempest in the teapot".

Prof. Detlef Stammer is a physical oceanographer and director of the Centre for Marine and Climate Research of the University of Hamburg.

Climate change: what will happen in the cities?

In metropolitan areas, the effects of climate change act together with buildings, vegetation, industry and traffic. These factors can amplify or diminish the risks. Take the example of Hamburg.

Maybe you already have noticed this: while the air in the city sometimes seems unbearable in summer, outside in the country a light, cool breeze is blowing. There are also differences in precipitation: in the southwest of Hamburg it is only drizzling, meanwhile, there is a heavy downpour in the northeast, on the lee side of the city.

This, actually, has nothing to do with climate change. Rather, it is a matter of small scale weather phenomena. But the examples show one thing clearly: cities with all their inhabitants, buildings and industrial plants influence temperature, wind and precipitation – to the point of creating a specific urban climate.

Compared with what we know about global climate change, the topic of urban climate is still in its infancy. One reason for this is that adequate measurement networks and data are lacking. This makes the newest analysis of the team around Prof. Heinke Schlünzen from the Meteorological Institute together with the German Weather Service all the more exciting. According to it, the average temperature in Hamburg-Fuhlsbüttel has increased by 0.07 degrees every ten years since 1891. If we take the last 60 years as a basis, the increase is more than twice as much. And for the last 30 years the curve rises even more steeply.

Maybe many would say it would be nice if it got a little warmer in Hamburg in the future. But it also rains more, particularly in the winter months and in June. The investigations also show that not only annual rainfall but also the frequency of heavy rainfall events has increased.

But the increase is most likely not only an effect of global change; Hamburg has changed tremendously as well. More than 100 years ago, many of the suburbs were still pastureland. Today, Fuhlsbüttel has not only heavy air traffic due to the airport, but also almost 12,000 people live in the just under seven square kilometers. It is difficult to differentiate between global and urban effects, but at the same time it is essential for predicting how things will develop in the future. And in order to plan how we can protect ourselves from the consequences.

For example, it would be conceivable to lower the

density of buildings and spread out more in order to reduce the heat island effect. But we are also investigating whether a higher and more compact building density with more green spaces in between could have advantages. Which concept is best for traffic? What are the needs of an aging society? And do we still feel well in these cities?

Urban climate = global climate change + the variable X. Climate changes tend to be felt more strongly in metropolitan areas, for example when there's a heat wave and the temperature doesn't go down enough at night. Other factors might have a buffering effect: through the close proximity of many high buildings, for example, downdrafts can form which help mix the air and equalize the temperature.

The fact of the matter is that we need to rethink our urban planning for the coming decades. It's not only a question of flood protection but also of spatial planning for buildings and green areas as well as wastewater management. Our research provides the scientific basis for this.

Prof. Juergen Ossenbruegge from the Institute of Geography is an expert on urban planning.

Greenhouse gases from salt marshes and mangroves

Climate researchers have begun to take a closer look at coastal flora in the course of their chemical investigations. The salt-tolerant plants there release greenhouse gases into the atmosphere.

The main source of human-caused climate change is too much carbon dioxide in the earth's atmosphere. But there are other compounds such as methane and halogenated hydrocarbons, including the infamous "CFCs" from spray cans and coolants. The latter were discussed in the nineties in connection with the ozone hole over Antarctica and the threat of an ozone hole over the Arctic – and in the end they were banned from the shelves.

Our latest expedition with the research vessel Meteor has revitalized this topic: plants in coastal zones, such as mangroves, or even in our own salt marshes, also produce compounds critical for the chemistry of the atmosphere – and this in far greater amounts than had been assumed previously. They produce so-called methyl halides from the fluorine, chlorine and iodine salts in their surroundings and release these into the air.

In order to determine which halide compounds are produced by plants and which are from humans, the scientist teams have used a proven trick: they analyze the weight of the carbon fractions in their air samples. Greenhouse gases of plant origin are slightly lighter, because the uptake and transformation in the plants' metabolism changes them.

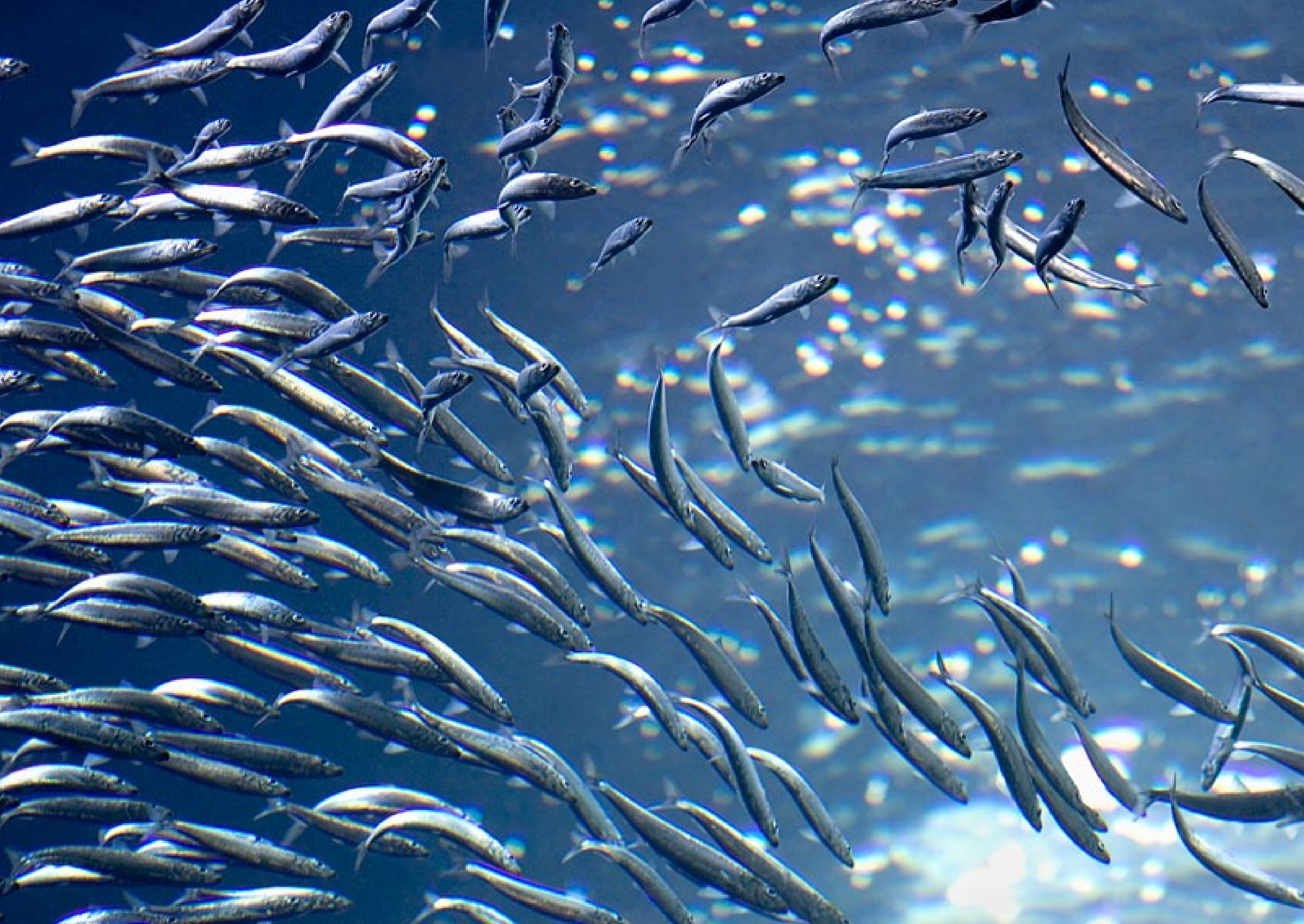
Although this process is negligible compared to the present increase in CO_2, the chemistry of our atmosphere could be altered significantly in future. What would happen, for example, if climate change made it necessary to irrigate larger areas, causing soil salinization and subsequent release of additional halogenated hydrocarbons? To what degree would the effects be compensated by the loss of a proportion of the mangroves and salt marshes due to sea level rise?

Together with our colleagues from the Meteorological Institute at the KlimaCampus, we are now developing a computer model with these if-then considerations. The expedition to the coast of Brazil, where 60 to 70 per cent of the tropical coastline is covered with plants that produce halogenated hydrocarbons, provides the basic data for this.

After all the samples have been analyzed, a mass budget will be calculated for the fluxes. Up to now, it has been estimated that the salt marshes are responsible for around one fifth of the halogenated hydrocarbon inputs worldwide. The actual amount might be quite a bit higher.

At the same time, new questions arise in this context: how much greenhouse gas from plants reaches the upper layers of the atmosphere, where it can react with other compounds? And how will this process evolve in the future? Which brings us back to the ozone hole.

Dr. Richard Seifert works at the Institute of Biogeochemistry and Marine Chemistry of the University of Hamburg.



No more cod in the Baltic Sea?

Today, most Germans buy their fish in frozen form – „à la Bordelaise“ or in small pieces in a paella. Depending on the season, it's usually coalfish or cod, both of the cod family. But climate change will determine which fish is available in the future.

On the one hand, the predicted increase in heavy rainfall will lead to more freshwater discharge into the Baltic Sea. At the same time, it is expected that the renewal of deep water coming in from the North Sea will diminish. That will lead to a decrease in salinity, which the cod does not like. As a marine species, it is already living at its lower limit in the Baltic Sea, as far as salinity is concerned. On the other hand, at first glance it seems that climate change and increasing temperature would have a positive effect on sprat, which, together with herring, is the principal food of cod. As a southern species, sprat likes it to be warm.

Does that mean no more cod in the Baltic Sea? More sprat instead? That might happen, especially since sprat eats cod eggs, which would further reduce its stock. The case is similar with herring. The feeding relation-

ships between the species are complex, but normally well regulated. Climate change, however, puts them under pressure.

In the Institute for Hydrobiology and Fisheries Science at the KlimaCampus, we have been able to integrate the interdependencies as well as the modifications that climate change will bring into a computer model. The objective: to be able to make long-term predictions about the development of cod stocks. After all, it is not only a popular food fish but also an important source of income for the fishermen in the entire Baltic region.

During our investigations we have played out several scenarios. The result: if fisheries pressure remains as high as it has been in the last decades, even without climate change, in the medium term there will only be very few cod in the Baltic Sea. If we include the effects of rising temperatures and lower salinities – which are to be expected in the coming years – in our calculations, this process will accelerate considerably.

Fortunately, the model also shows: if fisheries pressure is reduced, the stocks will tend to remain stable during the next 50 years. This is confirmed by the results of investigations in areas in which the fish stocks are already being managed prudently now.

Models which we have already developed are an important tool for this. We work closely with specialists in partner institutes in Denmark and Norway. Decisive factors are the existence of adequate protection areas for juvenile fish and effective control of the fishing quotas. Because, despite all the wonders of the modern food industry, fish fillet is still made of fish. So if we want to still be able to have fish on our plates in the future, there is no way around regulation.

Prof. Christian Möllmann, fisheries biologist, cooperates with specialists in partner institutes in Denmark and Norway.

Societies in climate stress: conflict or cooperation?

When a research submersible planted the Russian flag on the sea floor at the North Pole in August of 2007, the whole world paid attention. Was a country claiming rights to the oil and gas reserves in the Arctic? Climate change and the melting of the polar ice cap lend a new dimension to the competition for resources in this sensitive region.

Already today, there are many examples for societal conflicts brought about by climate change. Usually, it's a matter of scarce resources – water shortages, loss of productive land due to flooding, desertification or increases in fuel and food prices. Are "climate wars" therefore inevitable, as some experts claim?

At the KlimaCampus we are using computer models to investigate how such conflicts can be overcome. A study on agriculture in Illinois showed, for example, how the problem "tank or plate" can be defused. Instead of processing corn or soybeans into biofuels rather than food, organic waster or highly productive grasses were used as renewable energy sources. The result: with sustainable use and efficient production there are good chances for a lasting and economically sensible utilization.

Formulating human activity in models is difficult. Contrary to physics, in which planets follow predictable orbits, humans make decisions according to their own discretion. Despite this – or even because of it – it is worthwhile trying. The model shows us the consequences of our actions, and it shows that violence and war mean a loss for everyone in the end, while cooperative solutions often bring distinct advantages.

One example for this is the Gulf War. If the costs of the military intervention are included in the calculations, it quickly becomes apparent that the "war for oil" actually made the sought after resource more expensive. There are hidden costs for water, too: the 20 million inhabitants of the Cairo metropolitan region get their water from the Nile – and this removal serves to increase the salinization of the soil in the Nile delta, the most important agricultural production area in the country. The consequence is the necessity to import expensive food, which could be avoided through cooperative resource management.

At the climate conference in Copenhagen the main

issue was that the world population needs more and more resources – and produces more and more CO_2. An attempt is being made to establish a mode of equity between developing and industrial nations. To this end it would be conceivable that Europe could invest in technologies with which resources and fuel could be used in Africa more efficiently. It is already clear now that this would pay off for both sides.

Prof. Jürgen Scheffran from the Institute of Geography of the University of Hamburg investigates conflict situations related to climate.

Intelligent models make clouds calculable

Humans have observed clouds for millennia: artists, farmers, seafarers, meteorologists. Nevertheless, for us climate researchers it is still difficult to represent clouds exactly in our calculations.

Clouds play an important role in the climate system – and, depending on their location, they influence the greenhouse effect. Near the ground, for example, they inhibit the reflection of heat back into higher air layers, thus keeping the earth warm. During this process, the water droplets contained in the clouds heat up and the cloud rises. Further up in the troposphere, the clouds then act like a mirror. A large proportion of the sunlight is reflected off their tops and does not reach the earth – thus reducing the greenhouse effect.

In order to better understand the upward and downward motions as well as the complex systems of cloud formation and dissolution, we are presently working on a new generation of computer models at the KlimaCampus. Our results show: it is not so fruitful to meticulously investigate the more uniform cloud masses – the really important processes take place on the margins. This is where the cloud is changing form and advancing and where it is determined whether the droplets will rise and form an "anvil" or remain as a flat cloud. Here, the model has to be particularly exact, while in other areas fewer calculations are necessary.

Why is this important? Well, in spite of the most modern supercomputers, complex climate calculations still require an immense amount of time. Sometimes it takes months to achieve a result. In addition, many clouds, particularly local thunderstorm cells, are smaller than the maximum resolution of the available computer models.

Up to now, the density of the cloud cover had to be set at an average value. But locally, it could look quite different. One can imagine it to be like driving a car in fog: although the mean visibility is 50 meters according to the weather report, individual segments on the route are often completely without danger, while near damp meadows there are often thick veils. Clouds are also not uniformly distributed but are most dense in the places where the ground and the air contain the most heat and moisture.

Our goal is to create "intelligent" models that make densely meshed calculations in the important margins and have a lower resolution in the other, less important regions – at the same time automatically following the motion of the clouds. If we succeed in solving this tricky mathematical problem, it will not only save computer time but will mean a real leap in quality.

Prof. Jörn Behrens is a mathematician and an expert on climate models. At the KlimaCampus he is head of the research group "Numerical Methods".

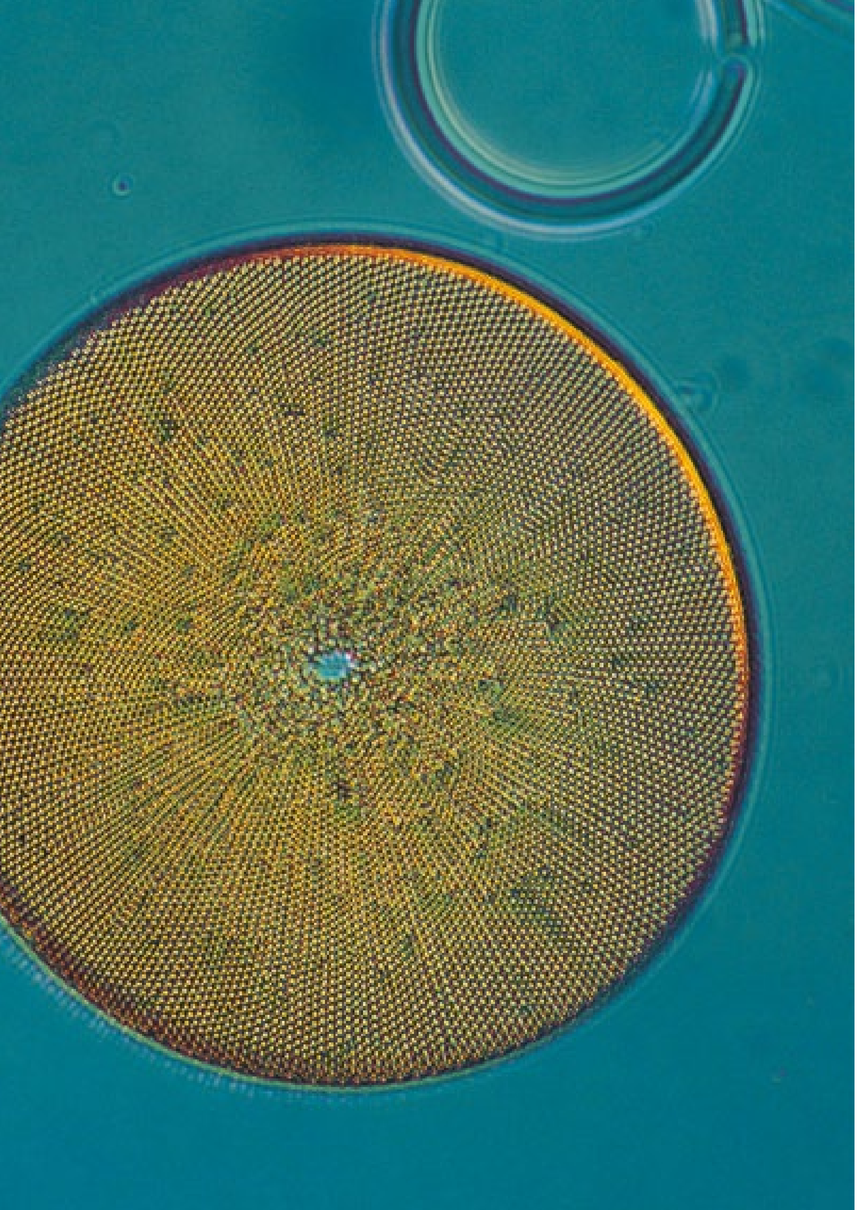
Climate change in the ocean: algae bloom or desert?

We know them as an algae carpet off Rügen or as "red tides" off the coast of Florida: microalgae, the most important primary producers in the ocean. It is unclear what influence climate change will have in future.

The ocean is the largest reservoir for carbon dioxide that we know. Not only because CO_2 is soluble in water, but also because billions and trillions of microscopic plankton algae take up the greenhouse gas in their metabolism during photosynthesis. The latter is also important because a portion of the dead algae sink to the sea floor, thus "disappearing" from the carbon dioxide balance for thousands of years. Indeed, without this buffer effect, global warming would be much greater.

There are, however, signs that the amount of algae is tending to decrease, in spite of the oversupply of CO_2 and cozy warm temperatures and that, with respect to nutrients and species, actual deserts are forming in the world ocean. Large-scale data on this are obtained from satellite observations of the chlorophyll content of the ocean.

However, the electromagnetic waves of the satellites



only penetrate to a few meters below the sea surface and therefore might not be revealing the whole truth. Particularly the germ stages of many algal species lurk in the deep and can always initiate local algal blooms – such as the carpets of bluegreen algae occurring in summer in the Baltic Sea.

Bloom or desert: how algae will react in the end to increasing temperatures and more carbon dioxide in the sea is hard to predict exactly in time and space. At the KlimaCampus we are presently trying to identify the influence of climate change on plankton using model calculations. For this, the numerous interrelationships between the physical and chemical parameters in the ocean such as temperature and nutrient concentrations and the biology of the algae have to be taken into consideration. For example, dense algal carpets at the surface block light penetration into deeper layers, thus inhibiting photosynthesis and CO_2 turnover there.

Near surface layers tend to heat up due to this mechanism, since with the light also the heat is held. Below, it gets cooler, and the light diet means that the algal growth remains lower despite sufficient nutrient concentrations. In extreme cases, the algal concentration already influences reflection at the surface so that light and heat cannot penetrate as deeply in the first place.

Up to now, computer models were not able to represent the interplay with biology adequately. A comparison with reality shows: many prognoses for the annual algal bloom are too late. We were also able to show that the development of the bloom, which varies strongly from year to year, can only be reliably predicted if the life cycles and the interrelationships between the algal species are considered.

The best comparison is with agriculture. The more seedlings the farmer plants, the better the harvest. In the sea the situation is similar: the more algal spores that have accumulated in deeper layers and that germinate under the right environmental conditions, the stronger the development of the algal bloom.

Prof. Inga Hense works to integrate biological processes into climate models and is establishing a new research group for this at the KlimaCampus in Hamburg.

Good for the climate: weathering of rocks binds carbon dioxide

Removing the greenhouse gas carbon dioxide from the air and storing it deep underground: a few years ago such a project would have been rejected as a fairy tale. In the meantime, there is serious thought about so-called CO_2 sequestration – and discussion about the risks.

The path to a “climate neutral” society is still long. And as long as we do not succeed in reducing greenhouse gas emissions, we will also have to think about the possibilities for removing greenhouse gases from the atmosphere. To somewhere where they cause less or no damage.

In the meantime, alternatives exist which are worth being taken seriously. For example, the chemical weathering of rocks extracts CO_2 from the atmosphere. During this process, carbonic acid is formed in the surrounding groundwater. At the KlimaCampus we are therefore investigating to what degree this process can be amplified in order to bind as much carbon dioxide as possible.

Unlike deep sequestration, this method does not simply involve storage of carbon dioxide underground. The carbonic acid dissolves mineral components such as calcium, magnesium or silicon from rocks. The positively charged elements, such as calcium and magnesium, attract the negatively charged carbonic acid. This binds the CO_2 to the groundwater. A security risk due to spontaneous release of gas does not develop. The groundwater with the bound carbon is transported later via the rivers to the oceans, where it can remain for millennia.

The idea: in order to boost weathering and bind more CO_2, a light, soluble mineral powder could be dispersed on a large scale over suitable spaces. Olivine, known to many mineral collectors as peridot, would be suitable for this. It is one of the most common minerals on earth, occurring for example in volcanic rocks, and it is easily obtainable.

First calculations show that a billion tonnes of carbon in the form of carbon dioxide could be caused to “disappear” each year by artificial weathering. For comparison: the yearly emissions of carbon to the atmosphere by humans amount to around eight billion tonnes. But practically speaking, not all areas are appropriate for such turbo-weathering.

For application, one of the things that are lacking is important basic scientific knowledge: how would artificial weathering affect plants and micro-organisms? The silicon released is an important plant nutrient. To what degree might grain harvests, for example, be improved?

At the same time, the increased transport of weathering products into the ocean would have a partial mitigating effect on ocean acidification, which is detrimental to species diversity.

The funding for such a gigantic global project would be less of a problem: it could be financed by the CO_2 certificate market.

Prof. Jens Hartmann works at the Institute of Biogeochemistry and Marine Chemistry of the University of Hamburg.

Storms, typhoons, polar lows: regional models help to analyze changes

Larger, faster, further? In climate research the trend is the opposite: the challenge is to be able to also calculate comparatively small phenomena such as storms or local low pressure areas. For example, up to now it has not been possible to determine whether storms in the North Sea and the North Atlantic will be more frequent in the future or might follow different tracks.

Global climate models, which scientists have been using successfully for around 40 years, divide the earth into a three-dimensional grid of boxes and calculate the weather for each one. The side length of the boxes ranges from one to three hundred kilometers. A low can be reliably represented by four to five grid boxes. The so-called polar lows, however, often only extend over several hundred kilometers, thus falling through the net.

A finer resolution exceeded the capacity of the available computers up to now. Fortunately, this has changed – not least thanks to the new supercomputer in the German Climate Computing Center. My colleagues and I from the Institute of Coastal Research at the Helmholtz-Zentrum Geesthacht are interested in finding out the advantages of regional models in comparison to global models.

As a matter of fact, some of our experiments show that the finer regional grid is not necessarily better. For example, over the open ocean a coarser grid can be used to represent relatively more uniform factors such as surface wind speeds or air pressure at sea level. A regional model brings no advantage in this case but consumes valuable computer time.

Along the coasts is another story: here, an exact analysis is worthwhile, because the form and the topography of the coastline affect the wind conditions and temperatures in a relatively small area. Typical weather phenomena over mountain ranges can also only be represented realistically by a regional model.

Every climate model is put through a thorough reality check. For this, we do not calculate forwards but rather backwards for several decades. By comparing the calculation results with data which were actually measured at the particular site and time, we can test the quality of the model. At the same time, we investigate whether frequency, magnitude and storm tracks of polar lows or typhoons have changed.

Models are also capable of compensating for errors due to different observational methods and stations. Satellite data, for example, have only been available since the seventies. By intelligently combining observational data with high resolution and global models, we can obtain specific results on the changes in regional climate phenomena.

Dr. Frauke Feser is a meteorologist at the Institute of Coastal Research at the Helmholtz-Zentrum Geesthacht and a member of the KlimaCampus in Hamburg.

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About the content

How are clouds calculated? Can carbon dioxide be made to disappear through weathering? And what do mangroves and hair spray have in common? In a series of articles in the “Hamburger Abendblatt”, scientists from the KlimaCampus of the University of Hamburg regularly give answers to questions like these. Oceanographers and meteorologists, geographers and biologists explain their research and present current results. You can read the best contributions here.