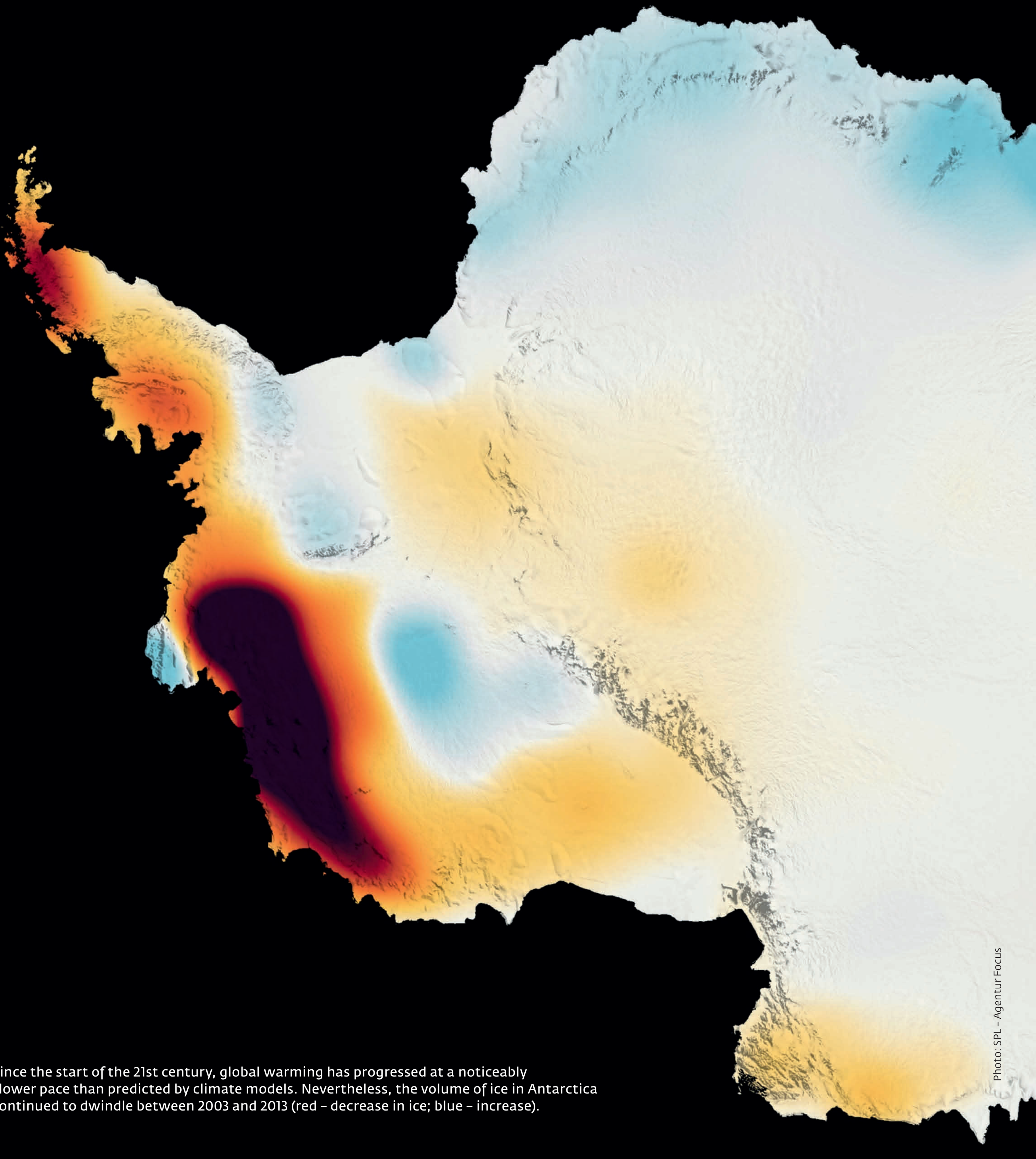
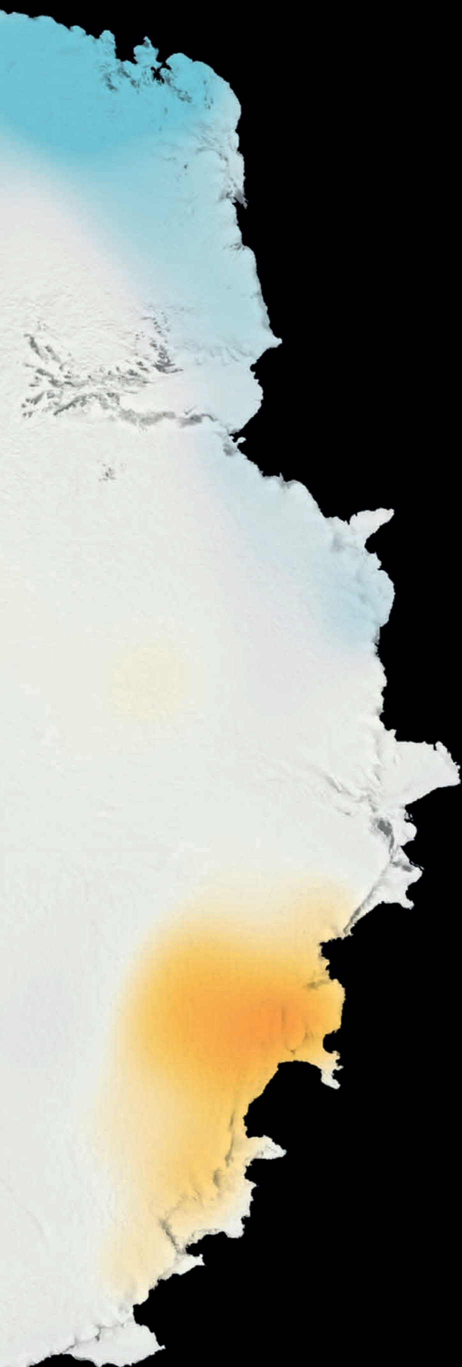


Photo: SPL – Agentur Focus

Since the start of the 21st century, global warming has progressed at a noticeably slower pace than predicted by climate models. Nevertheless, the volume of ice in Antarctica continued to dwindle between 2003 and 2013 (red – decrease in ice; blue – increase).



… and now for **tomorrow's climate**

What will the Earth's climate be like 10 or 15 years from now? Researchers have yet to find a satisfactory answer to this question – especially as random changes that occur in such medium-term periods play a significant role. Natural fluctuations are probably also the reason why global temperatures have hardly risen at all in the past 15 years. **Jochem Marotzke** from the **Max Planck Institute for Meteorology** in Hamburg and his colleagues all across Germany are working intensively on a system designed to generate reliable forecasts for the coming years.

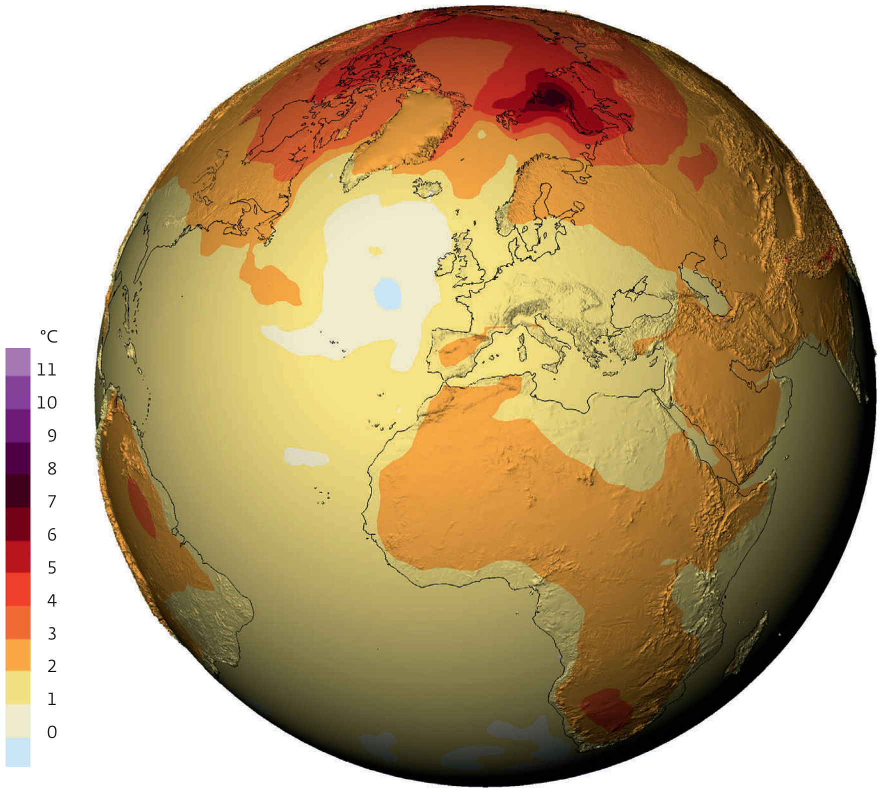
TEXT **UTE KEHSE**

In the autumn of 2005, Jochem Marotzke discovered a research topic that has been his primary focus to this day. Just a few weeks prior, Hurricane Katrina had razed New Orleans. The inspiring idea came to Marotzke at an event in Hamburg, where he presented the results of climate simulations that the Max Planck Institute for Meteorology had computed for the Fourth Assessment Report of the International Panel on Climate Change (IPCC).

This topic doesn't normally draw large crowds, yet this time, the auditorium was bursting at the seams. "All of a sudden there was this mind-blowing level of interest in any and all topics related to climate change," Marotzke recalls. After Marotzke had finished his presentation on what simulations predicted the world's climate would be like by the end of the 21st century, a man in the audience stood up and said: "You're telling us a lot of things about climate change in the year 2100, but nothing about the year 2015. Why not? That would be much more useful for us!"

Jochem Marotzke, who at that time had already been appointed Director at the Max Planck Institute in Hamburg, was caught off guard by this question: "I thought to myself: this guy is absolutely right. Why aren't we doing that?" The answer he ultimately provided was somewhat unsatisfactory in his eyes, and his listeners probably felt the same way: "Because it's more difficult to create forecasts for ten years than it is for 100 years." What he actually meant was: Because we aren't able to do that yet.

This experience gave Marotzke the first impetus to focus on predictions for medium-term climate change. Another driving force was a phenomenon that



Climate change is only taking a break: Scientists expect that by the year 2090 the Earth will have heated up particularly at the poles, as depicted in this simulation created by researchers from the Max Planck Institute for Meteorology. And this prognosis is unlikely to change to any significant extent merely because climate models failed to predict the current temperature plateau.

Graphic: MPI for Meteorology/German Climate Computing Center (DKRZ)

emerged toward the end of the last decade and that has perplexed climate researchers ever since: the temperature plateau. It appears that global warming, which was in full swing during the 1980s and 1990s, has gone into hiatus since the beginning of the new millennium. Global temperatures have been stagnating (albeit at an elevated level) since around 1998.

MEDIUM-TERM FORECASTS FOR POLITICS AND INDUSTRY

"Inevitably, climate researchers were faced with the question: Why aren't the temperatures continuing to rise as rapidly as they did in the 1980s and 1990s?" says Marotzke. He and his colleagues weren't able to provide a satisfactory answer – because virtually all climate models predicted a further increase in temperatures for the period from 2000 to 2015.

Today, approximately ten years later, promising scientific advances have been made with regard to decadal climate predictions. From 2011 to mid-2015, the German Federal Ministry of Education and Research funded the national MiKlip project (from the German *Mittelfristige Klimaprognose*, or mid-term climate forecast), which was initiated and is now headed by coordinator Jochem Marotzke. The application for the second phase has already been filed. This program is a joint effort of 22 German research institutions collaborating closely to generate more reliable information about the evolution of climate change over the next few years.

Ultimately, the researchers are seeking to develop a global prediction model that can be used by such agencies as the German Meteorological Service (DWD), and that functions in a manner similar to regular weather forecasts. This model currently exists as a prototype.

"Policy makers and stakeholders in the industry need medium-term forecasts in order to better prepare for changes," explains Marotzke. Predictions that focus on a single decade are sometimes more important than those that span an entire century, he believes. "If you know that something is going to happen ten years from now, you're more likely to do something about it than if it were to happen in 20 or 30 years."

However, such forecasts are still in their infancy. "We have our work cut out for us," says the Max Planck researcher in Hamburg. Medium-term climate predictions have one fundamental drawback: the climate system's inherent chaos. Because – just like the weather – the Earth's climate (as a mean value of the weather) is subject to natural fluctuations that occur more or less randomly. That is why no two summers are alike, for example – one can be cool and rainy, the next tropically humid, and the one after that hot and arid.

These more or less random fluctuations are what climate researchers call spontaneous or internal variability. They can, in fact, cause average global temperatures to vary by 0.2 or 0.3 degrees Celsius from one year to the next. In the eyes of the researchers, these fluctuations are "noise" – a sort of superimposed signal that interferes with the actual signal produced by global warming.

When it comes to long-term climate predictions, meaning forecasts spanning a period of 100 years, the noise has no significant impact. "We expect temperatures will have risen by two or three degrees Celsius by the year 2100," explains Marotzke. "This change is much greater than the internal variability, meaning that the latter is negligible."

When focusing on a period of just ten years, however, the temperatures increase by the same magnitude as the natural fluctuation – around 0.2 degrees Celsius. "In this case, I can't ignore the noise," says the climate researcher. In order to be able to make predictions for a single decade, he and his colleagues must therefore model not only global warming, but also the random changes. As Marotzke puts it: "The noise becomes my signal."

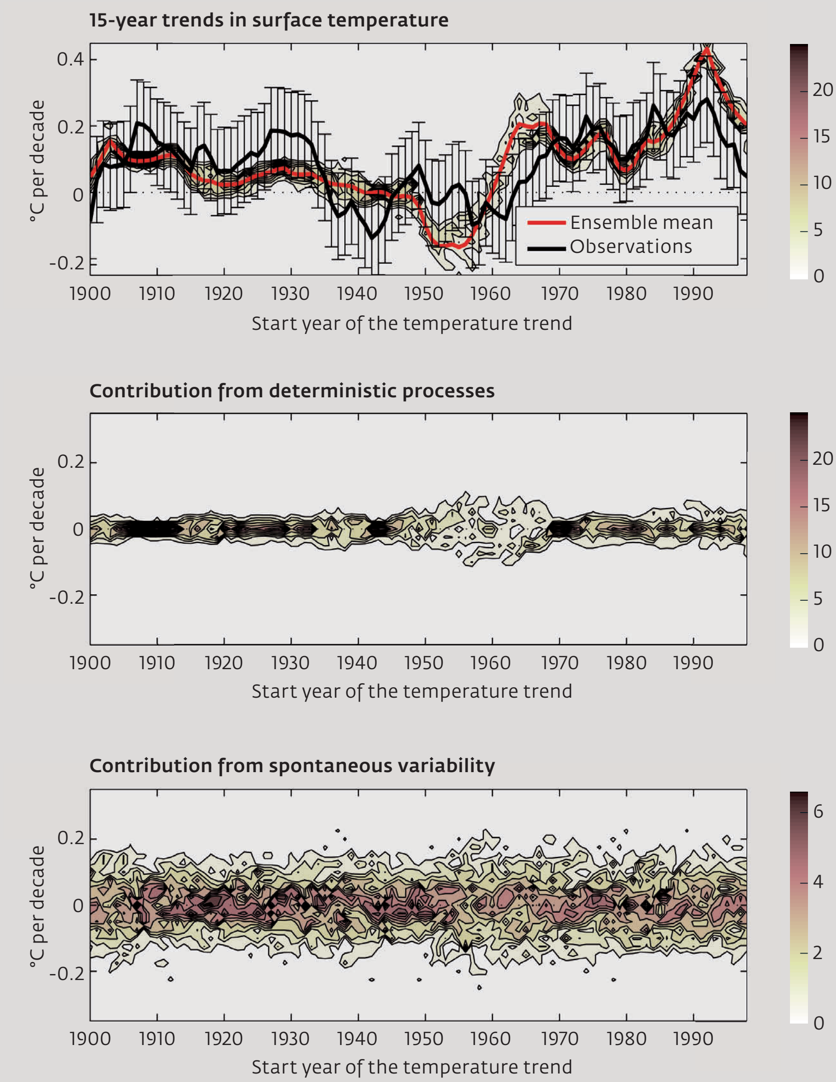
The operating principle of medium-term climate predictions is essentially very similar to that of common weather forecasts. The prerequisite for both is that the initial state be determined as precisely as possible. "You input today's climate, let the model perform the calculations, and then you can use the resulting data to look several years into the future," says Marotzke. That is how the researchers hope to at least temporarily control the chaos – it is "deterministic," after all, meaning that it obeys the laws of physics, which in turn can be described using equations.

Weather forecasts are proof that this method works. The quality of these predictions has improved continually over the past few decades, thanks to more advanced observation techniques and faster computers. Today, meteorologists are able to make five-day predictions that are as reliable as three-day predictions were back in the 1990s. Yet the randomness can't be fully tamed. "What we also know is that weather forecasts can't look beyond two weeks into the future. That's when the atmosphere loses its memory," explains Jochem Marotzke.

MODELS ARE TESTED USING OLD DATA

That's why the atmosphere isn't the only part of the climate system that researchers need to rely on when making medium-term predictions. They also need information about the oceans, as it is the state of the world's seas that will determine the climate in the coming years. In other words: decadal climate forecasts are basically ocean weather forecasts.

The MiKlip team is composed of researchers from all across Germany working on different tasks. One module, for example, focuses on developing methods for determining a forecast's initial state as precisely as possible, while another studies the climate processes that play a role in medium-term predictions. Jochem Marotzke is head of the "Synthesis" module, in which scientists generate and further develop global forecasts. >



Coincidences affect the climate: The top graphic depicts the development of the average global temperature for every year and ensuing 15-year period since 1900. The red line represents the mean of 75 simulations, while the black line and error bars stand for the observed temperatures. In the middle graphic, the narrow bandwidth of values reveals that deterministic processes such as atmospheric feedback loops cause only slight changes in the trends. The bottom graphic shows the wide scattering of trends attributed to random fluctuations in the climate system, which also explains the hiatus in global warming observed in recent years.

Medium-term climate forecasts are based on the MPI-ESM, the current Earth system model developed by the Max Planck Institute for Meteorology – the same climate model used by the Max Planck researchers to compute the long-term predictions for the reports published by the IPCC.

"It is important and useful for us to use one model for everything. This allows us to compare our results with those produced by other groups, and we all benefit from each other's improvements," Marotzke emphasizes. The MiKlip team has since developed three generations of this model, and the powers of prediction have improved with each new version. The researchers test the quality of their forecasts using data that reflects past states. They enter the initial state of 1980 into their model, for example, to see whether the simulated climate fluctuations that occurred up until 1990 match their observations.

In the first model generation, the quality of these hindcasts was rather poor for tropical regions, for instance, but it has since improved. The prognoses relating to the North Atlantic were more accurate from the start. Among other things, the current model version allows the scientists to predict such results as the average temperature of the next five summers in Europe or the occurrence of cyclones in mid-latitude regions with a certain degree of accuracy. "Although that's still not much of a concrete forecast," says Marotzke, "it's the first proof we have of our ability to make predictions about certain climate values in these time spans with relative accuracy at all."

NO SYSTEMATIC ERROR IN THE CLIMATE MODELS

The main problem with decadal forecasts, the oceanographer believes, is the fact that the models aren't yet sophisticated enough: The net of data points that the researchers lay over the ocean in their climate simulation is still too wide-meshed. As a result, some processes run a different course in the simulated oceans than they would in reality. Sometimes the Labrador Sea completely freezes over in the model (which it never does in the real world!), and at other times the Gulf Stream turns in the wrong direction off the North American coast. The scientists hope that these shortcomings will be remedied by the mainframe computer that is due to go into operation at the German Climate Research Center (DKRZ) in June.

One question that Jochem Marotzke and his colleagues still haven't been able to answer using the MiKlip model is what triggered the mysterious temperature plateau that appeared at the start of the millennium. "I would like to be able to say that it was already present in the 1997 state – just like you can link rain to a low-pressure system over the North Atlantic two days prior," he says. "But so far, this hope hasn't been fulfilled."

The researcher therefore opted for a different approach to tackle this tricky problem. Together with his colleague Piers Forster, a professor at the University of Leeds, he examined whether the climate models contain a systematic error that causes all models to compute a rise in temperature that exceeds the values observed in the real world. In late January 2015, the two scientists presented the result of their study in NATURE

Photo: NASA Earth Observatory – Robert Simmon

Left: Lake Powell, which lies near Las Vegas and resembles a river with its many twists and branches, has experienced very low water levels on several occasions since the year 2000. Medium-term climate forecasts could help with preparing for such global-warming-related events.

Top: Jochem Marotzke wants to fine-tune the climate models even further to be able to make reliable predictions for trends as short as 10 or 20 years.

magazine, concluding that the temperature plateau was most likely caused by the internal variability of the climate system. In other words, the Earth's atmosphere hasn't heated up further due to a random natural fluctuation.

In their study, Marotzke and Forster not only compared observations and model data pertaining to the period of the temperature plateau from 1998 to 2012, but to all 15-year trends with a start date between 1900 and 1998. This allowed them to determine whether the average temperatures predicted by the models for these time periods were higher than those observed in reality. It turned out, however, that the majority of the simulations were either above or below the observed values. The researchers therefore ruled out any systematic error.

The second step was to separate the influence of three factors that could potentially cause the discrepancy between the modelled and the observed temperatures. One possibility is that the driving force of climate change is falsely reflected in the models – that is, the amount of additional radiation energy that either is trapped in the climate system due to the rise in atmospheric carbon dioxide concentration or is reflected back into outer space due to air pollution. The values that the different models compute for this factor fluctuate significantly.

Another possibility is that the models overestimate how sensitively the climate reacts to the rise in CO_2 levels. Some models assume that the average global temperature will increase by two degrees Celsius only if the CO_2 value doubles. Others believe that the Earth's temperature will rise by more than 4.5 degrees.

RANDOM FLUCTUATIONS CURB GLOBAL WARMING

The third possibility entertained by Marotzke and Forster is that the gap between simulation and reality isn't caused by errors inherent in the models, but by a random fluctuation in the climate system.

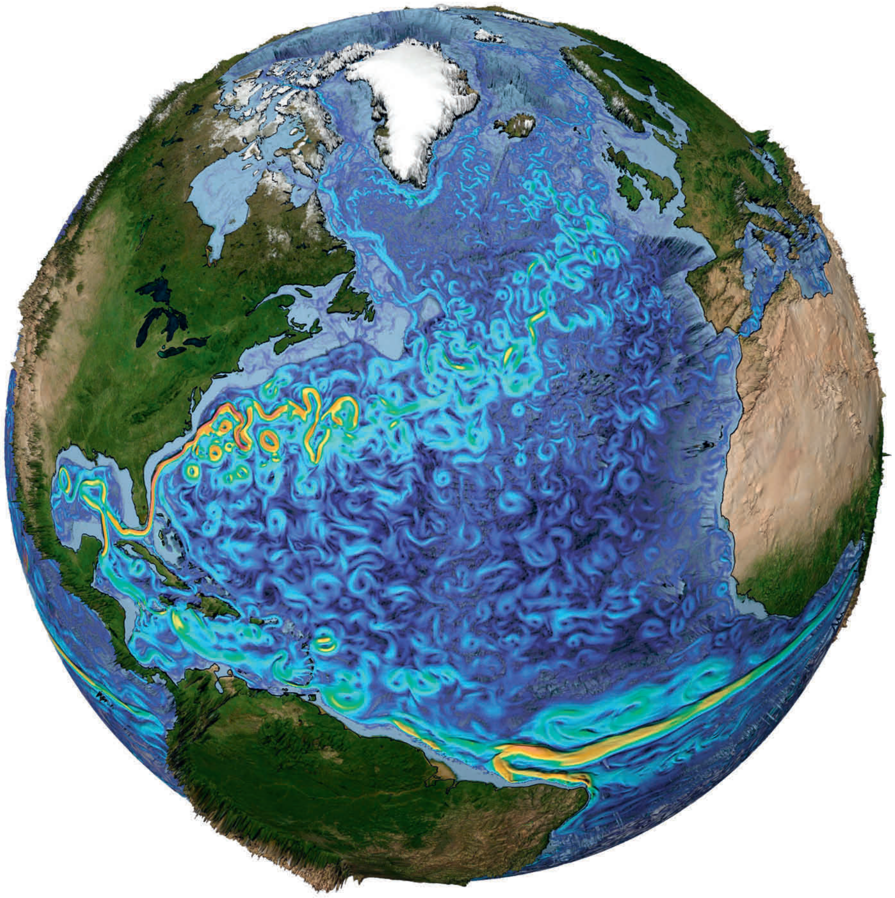
According to their analysis, virtually all the signs now point toward this third hypothesis. Marotzke also has a hunch about which coincidences must have occurred simultaneously over the past few years to seemingly bring global warming to a standstill. "I now believe that it was an extreme event that naturally is difficult to model," he says.

First, since the 1990s, the trade winds over the Pacific Ocean have grown stronger than ever since records began, according to a 2014 study conducted by Matthew England from the University of New South Wales and his colleagues. As a result, the cold water from the depths of the Pacific rose to the ocean's surface, while warm water descended into the deep – in other words, the Pacific probably absorbed a significant amount of heat.

A second unusual development was a series of extremely cold winters in Eurasia. And there were two additional, external factors: Between 2006 and 2010, the Sun receded into a phase of exceptionally minimal activity, and some volcanic eruptions spewed aerosols into the air, thus reducing solar radiation. "Everything you could possibly imagine coincided," says Jochem Marotzke.

Therefore, the temperature plateau can't by any means be used to support claims that man-made climate change doesn't exist. After all, even though the

Photo: David Ausserhofer



Snapshot in time: The Earth's climate is significantly affected not only by the atmosphere, but also by the oceans. Major currents such as the Gulf Stream, depicted here in light blue and yellow off the American coast, play a particularly important role. In order to generate reliable forecasts, climate researchers lay a fine-meshed net of data points over the ocean to make even the more subtle turbulences of maritime currents visible.

temperatures on the Earth's surface have hardly risen since the beginning of the new millennium, climate change is by no means taking a break. Other changes in the world's climate persisted regardless. The sea level continued to rise, for example, and the glacial and polar ice caps actually melted faster than ever before. The excess energy that continued to be pumped into the climate system due to the sustained increase in CO_2 concentration levels ended up in the oceans.

FEEDBACK DETERMINES LONG-TERM WARMING

The study also reached another conclusion that even Marotzke himself found highly surprising. He and Piers Forster conducted a second round of calculations, comparing the observed and the modeled trends for the average global temperature across different time periods between 1900 and 2012, each spanning 62 years. Once again, they tried to identify the main cause for the diverging results produced by their models.

Their research showed that, unlike in the 15-year trends, the internal variability is no longer the dominant factor in these longer time periods. Instead, it was especially the differently computed values for the radiative forcing that affected the simulated results. The climate sensitivity (that is, the variable showing the extent to which a doubling in CO_2 concentration levels heats up the Earth's surface), however, remained irrelevant even for these longer-term trends – even though this value differs between the various models, in some cases by a factor greater than two.

"Initially even I couldn't believe my eyes," Marotzke admits. Because in the long run, the climate sensitivity will be the decisive factor in determining the extent to which global temperatures will rise. According to this study, however, it appears that, over the past 100 years, the degree of sensitivity with which the climate reacted to rising CO_2 levels didn't yet have such a profound impact on global warming. "If we were to ask how important the climate sensitivity is for modeling temperatures in the 20th century, the answer would be: not very," says Marotzke.

Climate sensitivity is determined by various feedback loops that exist between global warming and the climate system. When temperatures rise, they trigger a number of different processes that in turn amplify global warming: more water vapor – a greenhouse gas – is trapped in the atmosphere; the Earth's surface becomes darker and absorbs more heat; and there will presumably be fewer clouds to reflect sunlight back into space. These feedback loops are crucial for long-term global warming, yet it appears that this wasn't the case in the past.

THE TEMPERATURE PLATEAU WILL END SOON

The authors' analysis rebuts accusations claiming that climate models react too sensitively to an increase in carbon dioxide concentration levels and have therefore been overestimating the rise in temperatures over the past 15 years. Because if this were in fact true, the models that show higher degrees of sensitivity would be expected to compute a greater increase in temperatures than the others. Yet that isn't the case.

After the scientists published their study, this surprising result was massively contested in a blog. Jochem Marotzke and Piers Forster were accused of having committed grievous methodological errors: critics claimed the researchers used circular reasoning to ar-

Graphic: DKRZ – Michael Böttinger

rive at their result, therefore rendering the latter null and void. Due to the complex scientific arguments surrounding this topic, the publication also caused confusion among the scientific community for a while. “Within just a few days, NATURE magazine and the IPCC approached us and inquired whether there was any truth to these allegations,” Marotzke reports.

He and Piers Forster therefore couldn’t simply return to business-as-usual and ignore the criticism. They replied in another blog and explained in great detail why their research work is conclusive and their methodological approach justified. “That convinced our colleagues in the scientific community. After a few days, the storm died down again,” says Jochem Marotzke.

The temperature plateau, however – and most climate researchers agree on this – will end sometime in the next few years. The Earth’s surface will thus probably soon start heating up at a faster pace once again. At the latest when the trade winds grow weaker over the Pacific, the breather will be over. ◂

TO THE POINT

- **Scientists only recently began focusing on medium-term climate forecasts. One such research endeavor is the MiKlip project, funded by the German Federal Ministry of Education and Research, that has been running since 2011.**
- **The climate system’s inherent chaos complicates the process of making predictions. Yet it obeys the laws of physics, which in turn can be described using equations – similar to weather forecasts.**
- **Scientists have developed a model with which they can predict such values as the average temperature of the next five summers in Europe or the occurrence of cyclones in mid-latitude regions with a certain degree of precision.**
- **It appears that global warming has gone into hiatus since the start of the new millennium. Climate models aren’t yet able to account for this development. Jochem Marotzke and Piers Forster suspect that the Earth’s atmosphere stopped heating up for now due to a random natural fluctuation.**

GLOSSARY

Earth system model MPI-ESM: The workhorse of the Max Planck Institute for Meteorology in Hamburg was developed and improved over a five-year period. It is the successor of the ECHAM5/MPIOM climate model, the main innovation being that it is now coupled to the carbon cycle, allowing the scientists to also study the feedback loops that link climate change with the Earth’s carbon concentration levels.

Gulf Stream: The Gulf Stream is a swift current in the Atlantic Ocean. It’s part of a worldwide system of maritime currents known as the global ocean conveyor belt. As it heads toward Europe, the Gulf Stream becomes the North Atlantic Current, which is part of the western boundary current and influences the climate of Northern Europe.