

This snapshot shows the ocean currents at a depth of 75 meters, as simulated by the global ocean model MPI-OM TP6M. The very high resolution with grid spacing of 10 kilometers enables good resolution of the swirling turbulence of the Gulf Stream, an important part of the Atlantic Overturning Circulation. This simulation was performed as part of the STORM project.

# Climate Memory

A gigantic heat pump is at work in the Atlantic Ocean, pushing tropical waters north and supplying Europe with a pleasantly warm climate. **Jochem Marotzke**, Director at Hamburg's **Max Planck Institute for Meteorology**, analyzed this current, laying the foundation for an improved climate model.

TEXT **NICOLA WETTMARSHAUSEN**

**U**pon hearing the word “ocean”, most people think of diving or sailing, of beaches and vast expanses. Jochem Marotzke, however, sees something very different in his mind’s eye: an enormous current of water. It starts at the equator, where warm masses of water roll off to high northern latitudes, then cool down, sink and flow slowly south once more as cold deep water.

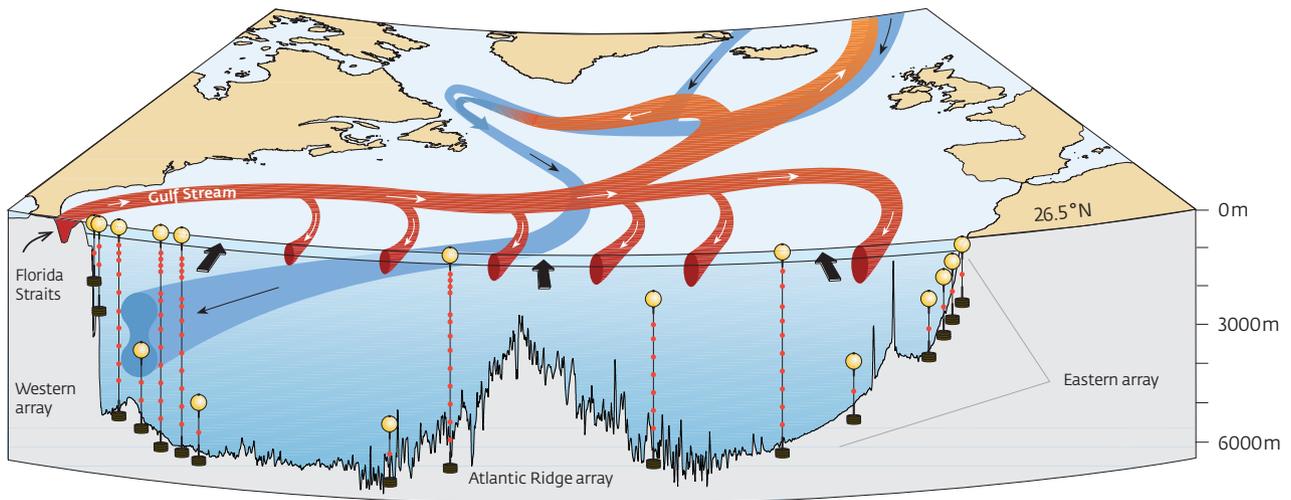
The Atlantic Meridional Overturning Circulation (AMOC), as scientists call it, is part of an enormous band of currents that flow through all of the world’s oceans. As they travel, the ocean currents convey huge amounts of heat from one region to another, thus significantly influencing the climate.

Jochem Marotzke’s research revolves around these ocean currents. The Director at Hamburg’s Max Planck Institute for Meteorology has been working for years on AMOC prediction, with an ultimate view to creating a perfect climate model.

“If we don’t understand the processes in the ocean, we won’t succeed in modeling the climate,” he says, and describes the atmosphere as a “transient something” that can’t conserve states over long periods of time. Temperature and pressure can change at breakneck speed in the air. However, since water has a high heat capacity, it can store heat for longer. As a result, the ocean reacts much more sluggishly to change than the atmosphere. This is why physicist Jochem Marotzke refers to it as “climate memory.”

## CURRENT FLUCTUATIONS INFLUENCE THE CLIMATE

The AMOC is an enormous phenomenon, with an average of 18 million cubic meters of water per second circulating through the 7,000-kilometer-wide Atlantic basin. However, its strength can fluctuate hugely in the course of a single year, sometimes transporting more than 30 million cubic meters of water, and sometimes just 10 million. >



Measuring probes are positioned in the Atlantic along the 26.5 degrees north latitude line (RAPID/MOCHA project). Some of the probes measure the entire vertical profile to a depth of 6,000 meters, while others measure only the deeper layers of current.

This is due to seasonal winds, whose impact on the sluggish ocean currents is delayed by several months. But the current can also vary considerably within a single month or even a day. These strong fluctuations make it difficult to determine the strength of the AMOC.

Scientists have long been trying to predict the changes in the AMOC, and thus the climate itself, for five to ten years into the future. All these attempts have had little success, but Jochem Marotzke’s team wants to change that. The fact is, the AMOC is important not only for Europe; its fluctuations also influence droughts in the Sahel and hurricane activity in the North Atlantic, even more than previously thought.

In order to make scientifically sound predictions, the researchers first needed

real data to check whether their model correctly simulates reality. But how does one measure currents in an ocean that is 7,000 kilometers wide? Jochem Marotzke has a solution: “We simply break down the AMOC at 26.5 degrees north into three different components.”

### OLD PHONE CABLES MEASURE CURRENTS

To start, the scientists consider the 100-kilometer-wide Gulf Stream, which runs north through the Florida Straits. This is the fastest-flowing current. The second component is the Ekman current in the top 100 meters of the ocean, dominated by the wind and the Coriolis force. Most important, however, is the mid-ocean current, which lies be-

low the Ekman current at a depth of 100 to 1,000 meters, and extends across the entire width of the Atlantic basin. “First we measure all three components separately, and later we add the values together,” explains Marotzke.

The latitude of 26.5 degrees north was not chosen by chance – some data series are already available here. Changes in the wind-driven Ekman current, for example, have been recorded directly by *QuikSCAT* since the 1990s. This satellite scans the surface of the ocean using microwave technology, yielding information on surface waves and wind strength.

Data is also available on the Gulf Stream in the Florida Straits; the Gulf Stream is measured using old telephone cables that lie on the ocean floor. “It’s a clever method,” finds Daniela Matei, a researcher in Marotzke’s department. “The procedure is based on the fact that the salt ions in the water flow downstream, moving through the Earth’s magnetic field and thus generating an electrical field. This field induces in the submarine cables a voltage that is logged at regular intervals.” American scientists have been gathering this data since 1982 and making it available to their colleagues all over the world.

So far, it’s all relatively simple – were it not for one small problem. For now, there are no long data series for the large mid-ocean current; only sporadic

### STRESS-TESTING THE CLIMATE MODEL

The only way to determine which climate model is best is by comparing them, so the international climate research community has initiated a comparison project for coordinated experiments. The Coupled Model Intercomparison Project Phase 5 (CMIP5) is intended to support the Intergovernmental Panel on Climate Change (IPCC). Experts hope to use it to investigate current questions on the mechanisms and characteristics of climate change, generating climate projections for the period up to 2300, examining the role of the carbon cycle in climate change and developing decadal predictions. Some 20 groups around the world, including scientists from the Max Planck Institute for Meteorology in Hamburg, are using standardized experiments to examine these issues.

measurements taken by ships. "The ships took six weeks to cross the Atlantic just once," says Jochem Marotzke. "The crew took measurements several times a day during the crossing, but of course no data is available for the period before or after that." Besides, he adds, such research expeditions are extremely expensive and therefore not regularly undertaken.

### DEEP CURRENTS THROUGH DENSITY DIFFERENCES

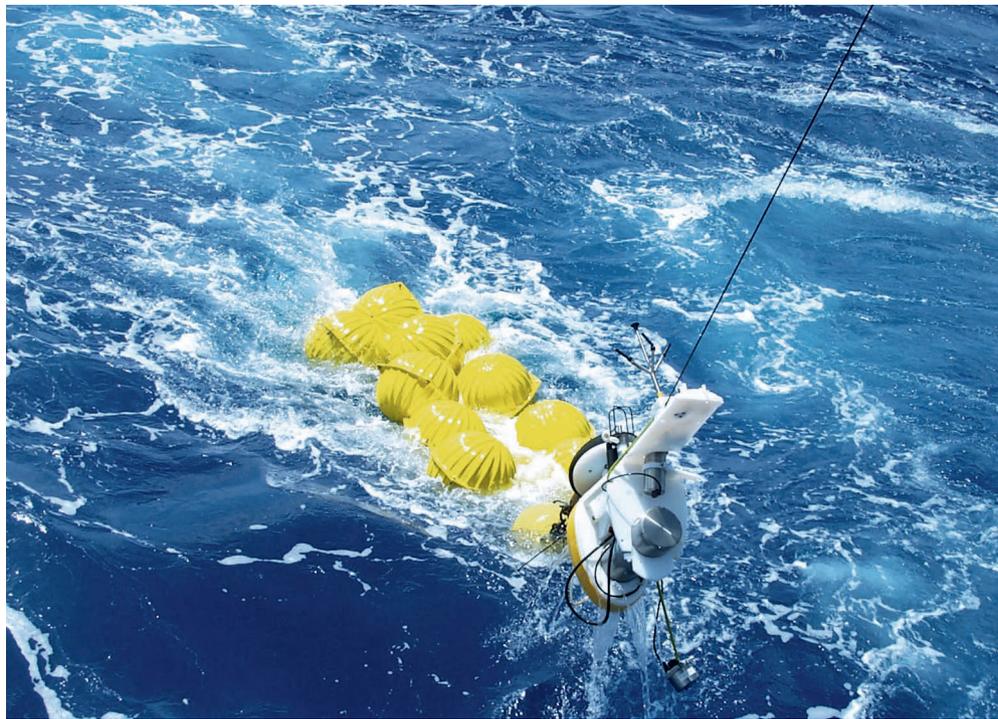
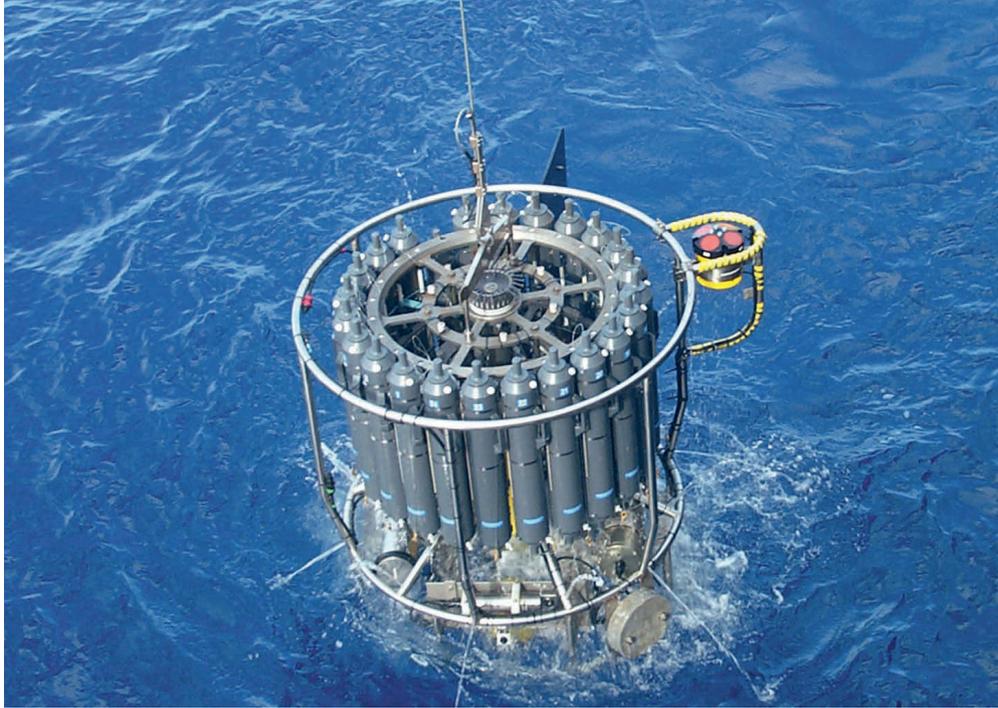
At that time, Marotzke, as a climate modeler and theoretician, found himself with no other option than to gather the necessary data himself. With this in mind, he started the RAPID/MOCHA project with British and American colleagues in 2003, when he was working at the National Oceanography Centre, Southampton (NOCS). "I wanted not only to collect data on an ongoing basis, but also to develop the prototype for a new monitoring system," explains Marotzke. "Only by doing this can we truly scrutinize the AMOC in the next ten years."

He put out to sea as early as 2004, and on the first voyage, he and his colleagues anchored 19 measuring probes along the 26.5 degrees north latitude line in the Atlantic basin. At depths of up to 5,000 meters, the probes recorded temperature, salinity, and current speed and direction. They now record a vertical profile of density right across the ocean depths, thanks to the four-year campaign. >

top: A measuring device is lowered into the sea and sends information on conductivity, temperature and pressure back up through the cable. The gray flasks collect water samples for determining salinity.

middle: This can happen, too: The probe has to be salvaged because the enormous pressure in the ocean depths caused it to implode. Under normal conditions, the cable is held in place by the yellow floats, and the probe moves up and down this cable in order to obtain a continuous vertical profile.

bottom: Scientists onboard the research vessel place a one-and-a-half-ton mooring on the seafloor. The yellow float keeps the cable with the measuring probes upright.



“Now we had a good stock of basic data,” says Johanna Baehr of the University of Hamburg, who has been working on the analysis with Jochem Marotzke and Daniela Matei since 2008. The team used the density measurements to calculate the strength of the AMOC. “Seawater has different densities depending on the temperature and salinity of the water,” explains Baehr. This leads to differences in density, and thus pressure, in the ocean. Since water always tries to flow toward a point of

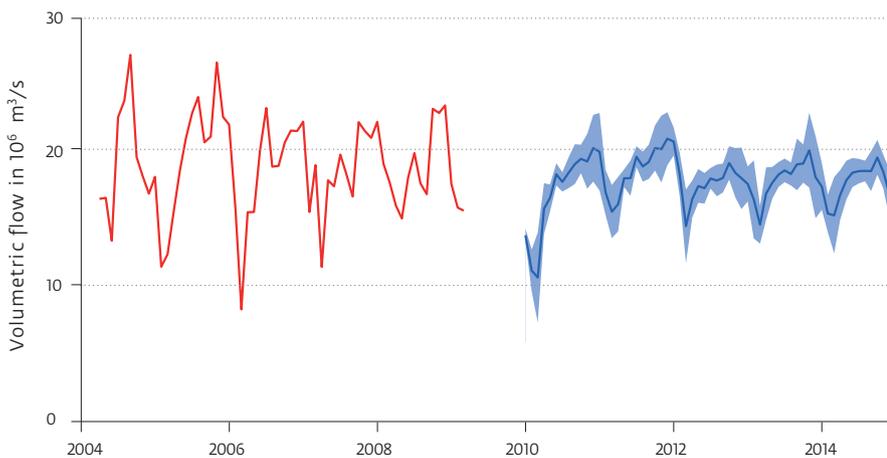
lower pressure, the pressure differences generate a current. The team was able to calculate the velocity of this current using the measurements taken from the whole width and depth of the Atlantic, from the Bahamas to the coast of Africa, at 26.5 degrees north. This gave the scientists an accurate picture of the fluctuations in Atlantic circulation between 2004 and 2008.

They then calculated the AMOC fluctuations for the same period in a computer simulation and compared

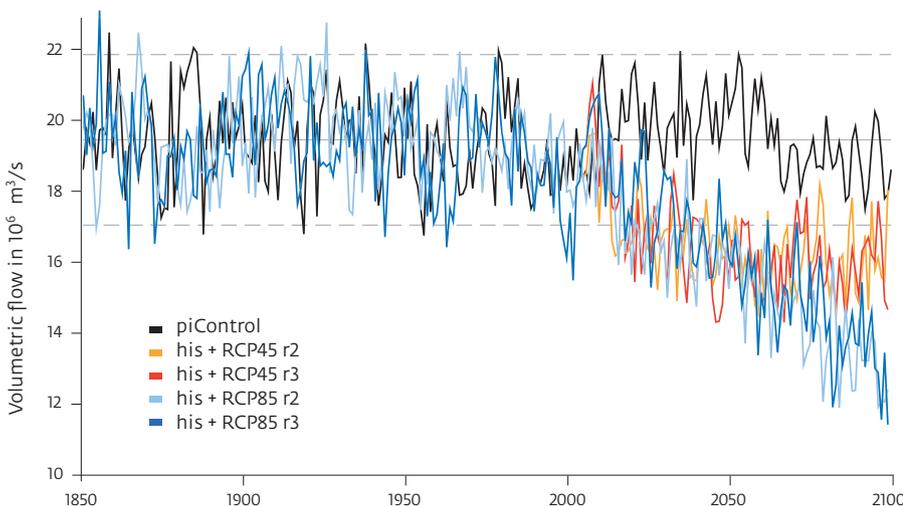
these results with the real measurements. This yielded a “hindcast” – a retrospective prediction that is used to test the quality of a model.

The researchers used the coupled atmosphere-ocean-climate model ECHAM5-MPI-OM for their simulation. It was developed at the Max Planck Institute for Meteorology and used for the climate scenarios of the Intergovernmental Panel on Climate Change (IPCC). Scientists use ECHAM5 to simulate processes in the atmosphere, and MPI-OM to simulate processes in the ocean. The two models are usually coupled together so that the simulated atmosphere influences the behavior of the ocean model and vice versa.

The red line shows the measured flow volume of the Atlantic Meridional Overturning Circulation (AMOC). The prediction (blue) shows that the AMOC will remain stable until 2014 (light blue: ensemble of several calculations; dark blue: mean value).



In the long term, global warming will weaken the AMOC. The red and orange lines represent its development if human influence on climate is moderate, while the blue lines reflect strong human influence. The black line predicts how the AMOC would develop in the absence of any human impact on climate.



**REAL DATA MAKE THE MODEL MORE PRECISE**

However, Daniela Matei modified the program and fed real atmospheric data into the ocean simulation on an ongoing basis, with wind and air pressure values gathered by the National Centers for Environmental Prediction (NCEP) over the course of 50 years. This showed that integrating real wind values does bring the ocean simulation much closer to reality – but is the newly programmed model really so good that it can look into the future?

In the German Climate Computing Center, the processors worked away for weeks and months, finally revealing that the improved ocean-climate model is sound and delivers on its promises. “There is very reasonable agreement between the measured data and the calculated data; the hindcast comparison looks good,” announces Jochem Marotzke with pride. “These new climate model calculations enabled us to predict the North Atlantic circulation accurately for the first time, and that for short periods of up to four years into the future.” Such short forecasts are much more difficult to generate than longer-term prognoses stretching toward the year 2100, because values are averaged out for long-term prognoses, so the curves become smoother. This permits the detection of longer-term trends, such as the weakening of the AMOC described by the Intergovern-



Keeping an eye on the near future: Johanna Baehr, Jochem Marotzke and Daniela Matei are interested in climate change over the next ten years.

mental Panel on Climate Change (IPCC). If, however, researchers focus in on a period of just a few years and zoom in on the curve, major natural fluctuations become increasingly clear – and overlay any trends.

So what is the prediction for the AMOC? “Despite all the naysayers, the strength of the Atlantic Overturning Circulation will remain stable,” says Marotzke. “We can also now say with confidence that the weakening of the Atlantic circulation in March 2010 was only a short-term phenomenon.”

Some people saw that weakening as an omen of a lasting reduction in the AMOC’s strength, which is still discussed as a possible consequence of climate change. A scenario such as that seen in Roland Emmerich’s film *The Day After Tomorrow*, in which the AMOC peters out entirely and the Northern hemisphere freezes under a thick layer of ice, will not happen, Marotzke is certain – “at least not before 2014.” ◀

### TO THE POINT

- The Atlantic Meridional Overturning Circulation (AMOC) conveys huge amounts of heat from one region to another, thus significantly influencing Europe’s climate.
- Understanding the AMOC is vital for reliable climate modeling.
- Max Planck scientists accurately predicted this North Atlantic current, concluding that it will remain stable until at least 2014.

### GLOSSARY

**Coriolis force:** The Coriolis force plays an important role in physical oceanography. Water masses operate in a rotating frame of reference, due to the rotation of the Earth. Those located in the northern hemisphere are deflected toward the right, and those in the southern hemisphere toward the left. The influence of the Coriolis force also gives rise to areas of high and low pressure in the atmosphere.

**German Climate Computing Center (DKRZ):** The DKRZ is the virtual laboratory of all German climatologists who use climate modeling as the basis for their research. The accuracy of a climate model depends on the performance of the supercomputer, but is also limited by it. This is partly due to the complexity and dynamics of climate, and partly to the enormous quantity of data that must be calculated and analyzed. The DKRZ is one of the world’s most important computing centers for climate simulations. Its data archive currently holds a volume of 20 Petabytes, and this increases with each new generation of computers.

**RAPID/MOCHA project:** Following the first phase from 2004 to 2008, the AMOC is being monitored under the RAPID-WATCH project until 2014. The continuous monitoring over the course of ten years is important for the constant adjustment and improvement of the MPI Ocean Model.