

Computer models anticipate the climate of the future

The climate experts





Global climate models indicate that a significant warming of the earth's atmosphere will occur over the coming decades. But how are these models constructed? And how accurate are their predictions?

One thing is for sure: climate researchers easily aren't put off when it comes to expeditions to uninviting places. From the Arctic's icy desert and the Patagonian steppe to the ocean deeps, scientists are searching for evidence of past climatic variations in the furthest corners of the world - because traces of the weather in the past will help them to predict the climate of the future. To that end, they collect vast amounts of data and feed them into elaborate climate models. Their common aim is to be able to describe the very complex "System Earth" as accurately as possible in mathematical terms. Highly-efficient supercomputers are run for days on end, using the resulting formulae to predict how the earth's climate might change over the coming decades as the result of mankind's activities. It has long been known that the earth's climate has tended to swing between colder and warmer periods over the millennia: the question is now, how strongly is mankind influencing the course of this cycle?

There is every reason to pursue this question. The earth's "fever temperature" started rising noticeably in about 1950. Regular measurements of the earth's surface temperature began in 1850: ten of the twelve warmest years recorded since then have occurred during the period 1995 to 2006. The overall global average for air temperature at soil level has risen by 0.74° Celsius over the last hundred years.

Weather balloons provide climatologists with data on the composition of the earth's atmosphere.



Powerful computers are needed to capture and process complex weather and climate data. One example is the German Weather Service's super-computer at Offenbach.

The composition of the earth's atmosphere has also changed markedly. We all depend on this protecting layer of gases and water vapour: without it, the earth would be buried beneath a thick layer of ice. "Calculations suggest that the average global temperature at ground level would be about -18° Celsius, rather than the current $+15^{\circ}$ Celsius", explains climatologist Joachim Namyslo of the German Weather Service.

Changes in the composition of the atmosphere influence its ability to "capture" solar energy and to convert it into heat. Measurements show that the concentration of carbon dioxide (CO_2) in the atmosphere has increased by about a third since the arrival of industrialization. But the proportion of nitrous oxide in the atmosphere has also increased significantly, and the concentration of methane has in fact more than doubled. The United Nations Intergovernmental Panel on Climate Control (IPCC) attributes the rising CO_2 -concentration mainly to the burning of fossil fuels such as oil, gas and coal. When it comes to methane and nitrous oxide though, agriculture is one of the major sources of emissions.

Glimpse into the past

To help them to make accurate predictions about future climatic patterns, climatologists first look into the earth's far-distant past. An example is the work of German climate experts who took a small research vessel to the Laguna Potrok Aike, a crater lake in the Patagonian steppe. The boat was converted into a drilling platform, allowing the scientists to bore into the sediment below the 100 meter-deep lake and to

recover a 19 meter-long profile. The finely-layered deposits of pollen, algae and fossils it contained allow them to piece together parts of the climatic history of the Southern Hemisphere over thousands of years. In the Western Antarctic, the Alfred Wegener Institute has participated in another international programme, this time to drill beneath the ice shelf. A research group led by Dr. Frank Niessen and Dr. Gerhard Kuhn was able to use microorganisms found in the sediment to create a picture of the pattern of climate change over the last five million years. Their investigations showed, among other things, that the ice-cap of the Western Antarctic melted completely on a number of occasions during the period lasting between three and five million years ago. "The worrying thing is, that the Western Antarctic ice withdrew particularly strongly during periods in which the earth was only about 3° Celsius warmer than it is now, with a higher CO_2 -content in the atmosphere than at present", explains Dr. Niessen. If the ice cap melts again, the global sea level will rise by five to seven meters.

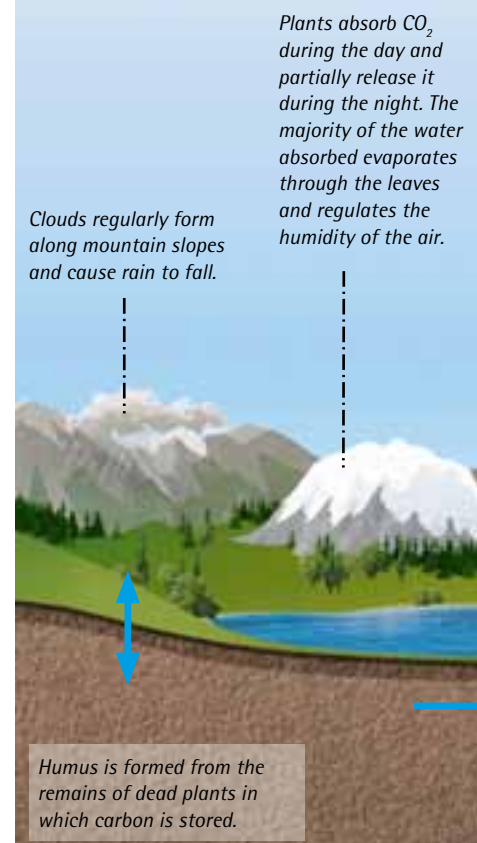
Other useful archives of information on climate available to scientists include coral reefs and limestone caves. Climatic patterns in more recent times can also be read from the annual rings of trees, and of course they can be inferred from contemporary descriptions. Current data is collected using weather balloons and satellites. At the moment, a lot of effort is being put into understanding the major ocean currents better. To this end, special buoys are used that travel with ocean currents at considerable depths, measuring water temperature and the speed of the ocean currents, and climbing to the surface at regular intervals in

order to transmit their measurements to research stations.

Climatologists use these manifold data sets as mosaic stones to create as complete a picture as possible of the global climate over the last few million years. Extreme events such as volcanic eruptions and meteorite hits help to align the various data packages.

In order to be able to deal with the mass of data, scientists subdivide the earth into several Systems and Sub-systems, for example land and ice masses; the oceans; and the atmosphere. They also split up the entire globe into equal, smaller cuboid slices: nowadays, this is mostly done with a grid size about 200 kilometers in length and 1,000 meters in height. The climatic pattern from the deep ocean to the upper layers of the atmosphere is calculated for each of these slices using mathematical equations. This requires that air- and water temperature, ocean currents, wind, precipitation, plant growth and many other elements are bound together in formu-

How the clima



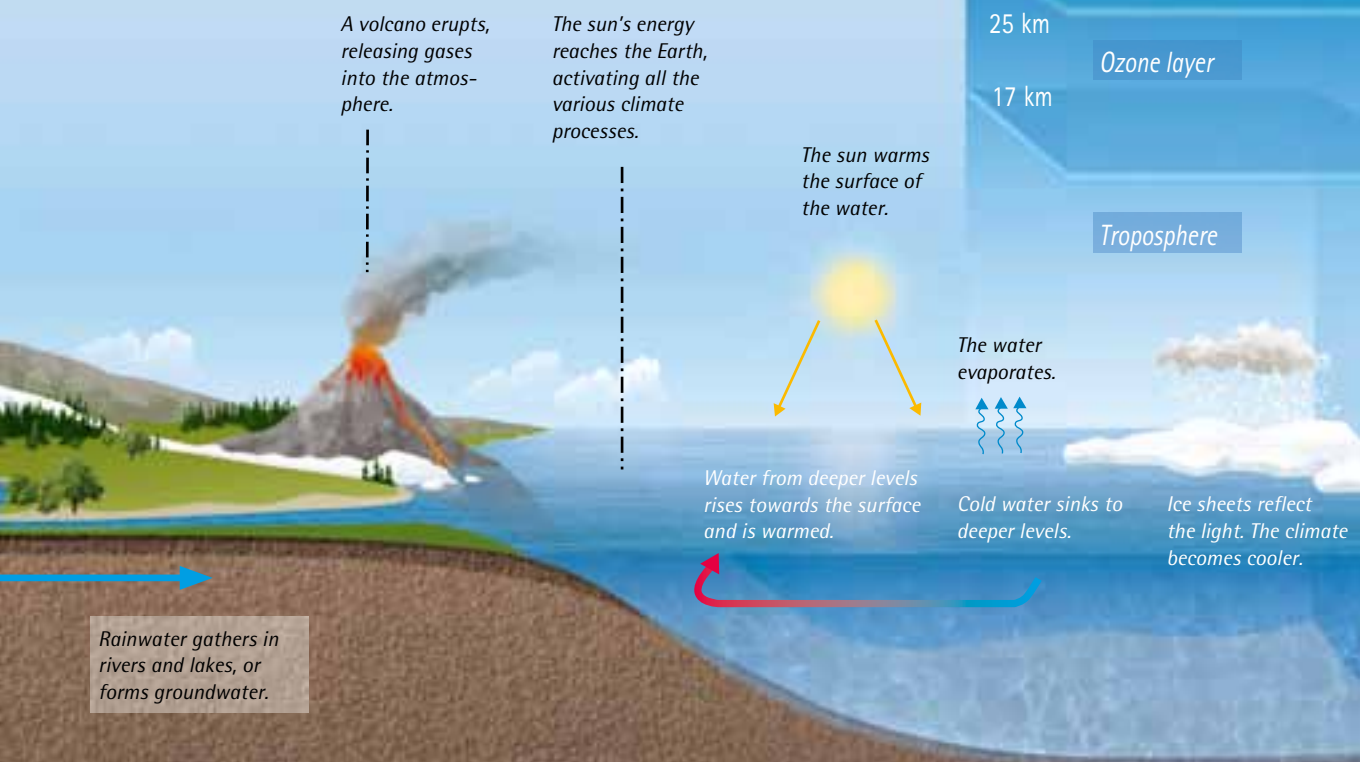
lae. As these factors influence each other in feedback loops, the modeling becomes extremely complicated. This means that very sophisticated computers are required for the calculations. The more exact and comprehensive the model, the greater the computing power needed.

Scientists around the world have developed more than 20 global climate models in recent years. But before they start calculating various future scenarios, they check the reliability of their models by calibrating retrospective calculations for past periods against the available historical weather data. In this way, they can show how precisely their models reflect reality. If the deviations are too great, the formulae are adjusted. Only when the simulations yield results that are close enough to reality are the scientists ready to start looking into the future. The layman likes to refer to this as predicting climate change: however, this is not particularly appropriate. For example, to calculate global tempera-

ture variations over the next 50 years, the scientists must initially feed the model with certain assumed values.

These assumptions include: how the CO₂-concentration of the atmosphere is likely to change; how quickly the human population is likely to increase; and the probable extent of future global industrial growth. The models then calculate future climatic patterns on the basis of these assumptions. Scientists therefore prefer to talk of Scenarios and Projections, but not about predictions. Because as soon as the underlying assumptions change, so do the results. The 4th IPCC Status Report thus indicates an average global temperature increase of between 1.8° and 4.0° Celsius by the end of the 21st century, depending on the emissions scenario. This is a considerable range. So global climate models only allow rough estimations of the influence a reduction in emissions of CO₂, methane and other greenhouse gases through human activities might have on the future temperature of the earth. But the

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scientists do not make statements about the relative likelihood of a particular climate projection, because each depends equally on the assumptions underlying it becoming reality. However, in view of the incontrovertible warming of the earth over the last 60 years, the models nevertheless provide valuable information as the basis for political decisions. They simulate the global climate on a what if? basis.

Global, regional and local climate

Given the relatively coarse grid size of 200 km, global climate models cannot make any estimation in terms of the local or even regional effects of global warming. More locally-applicable models that cover a given area in much finer detail are required for this purpose. For Germany e.g., four regional climate models have been created – CLM, REMO, WETTREG and STAR – that can be used to simulate how a global warming scenario might affect, say, the distribution of rainfall in Eastern Germany or the depth of snow cover in the Alps. Even more local models break down the scenarios to areas of a square kilometer. This means that they are able to support

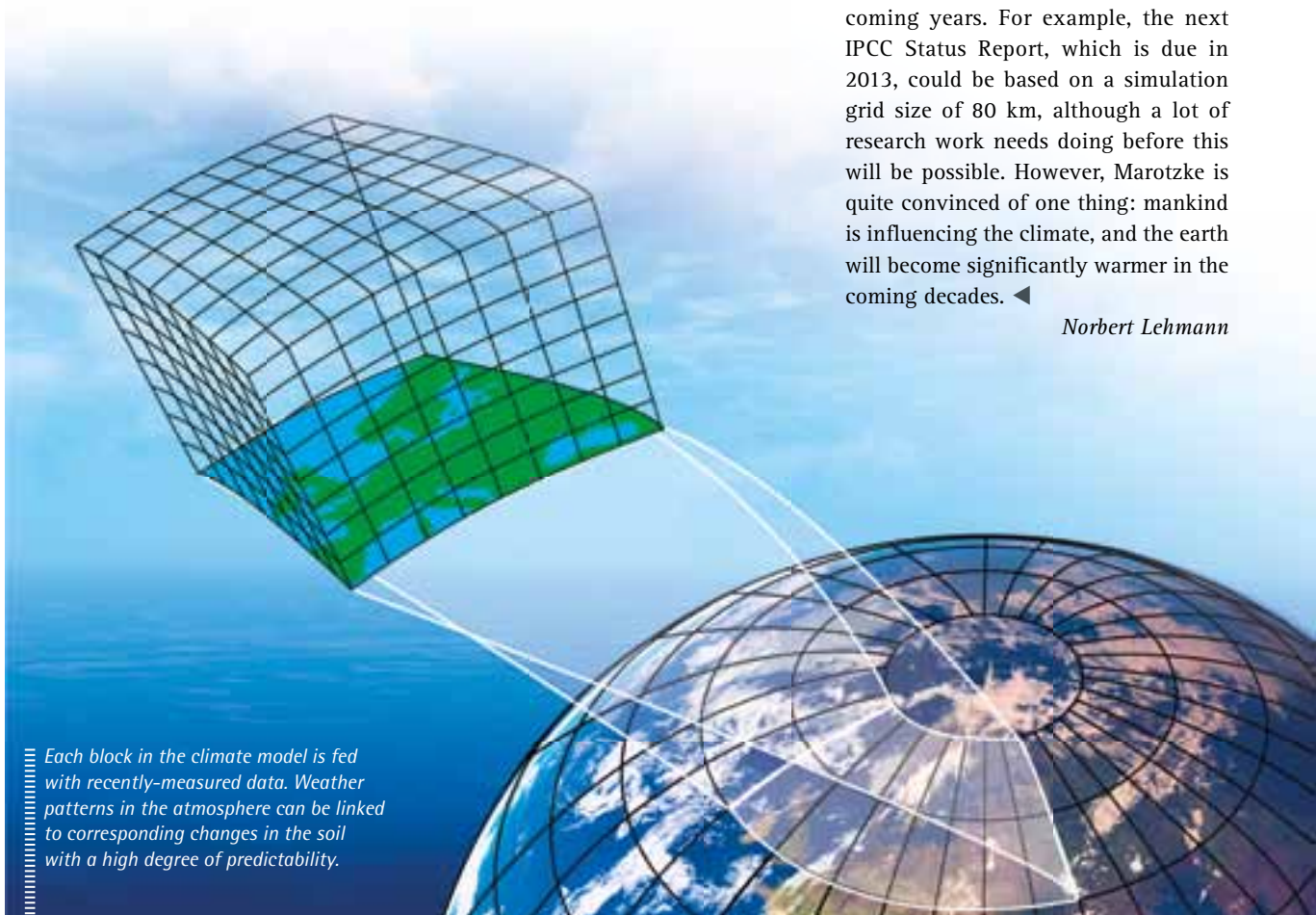
the adaptation of agriculture to local shifts in rainfall patterns or temperature changes. But one thing has to be borne in mind: local climate models depend on output from regional climate models, which in turn depend on results from global models. If calculations are to predict the seasonal distribution of rainfall in a specific area, then the local model must work with definitions determined by larger-scale models. This means that there are up to three simulation layers behind the prediction – which increases the degree of uncertainty.

“There is still a considerable degree of uncertainty about the details, but one thing we’re quite sure about: there will be a significant amount of global warming in the coming decades“ says Professor Jochem Marotzke, Business Director at the Max-Planck Institutes for Meteorology in Hamburg. Here, the global climate model ECHAM5 was developed. This coupled atmosphere-ocean model has a reputation as being one of the best in the world. ECHAM5-simulations also contributed to the 4th IPCC Status Report. Marotzke is convinced that the scientific community has now understood the processes behind global warming and is able to reproduce them accurately in models. However, “the

most significant weaknesses of current models lie in the representation of cloud formation and the temperature dynamics of the oceans”, explains the climatologist.

The warmer the air, the more clouds form: these have a cooling effect during the day, but a warming effect at night. Clouds can thus alleviate the greenhouse effect, but also strengthen it. Characterizing temporal and spatial changes in the cloud cover remains a problem for the researchers. Moreover, too little is known of the temperature dynamics and CO₂-binding capacity of the oceans. This is a significant drawback. If you imagine the climate system as a row of swinging pendulums, the oceans would be very lethargic pendulums because of the massive amounts of water they contain. But should they be set in motion, they would transfer the decisive impulses to the other, more sensitive elements of the system. Marotzke estimates that a third to a half of all CO₂ emissions are currently being bound by the oceans. But more research is needed to understand how this binding capacity would change if warming continues. Marotzke expects that climatologists will continue to make small but steady improvements to the accuracy of their models in the coming years. For example, the next IPCC Status Report, which is due in 2013, could be based on a simulation grid size of 80 km, although a lot of research work needs doing before this will be possible. However, Marotzke is quite convinced of one thing: mankind is influencing the climate, and the earth will become significantly warmer in the coming decades. ◀

Norbert Lehmann



Each block in the climate model is fed with recently-measured data. Weather patterns in the atmosphere can be linked to corresponding changes in the soil with a high degree of predictability.