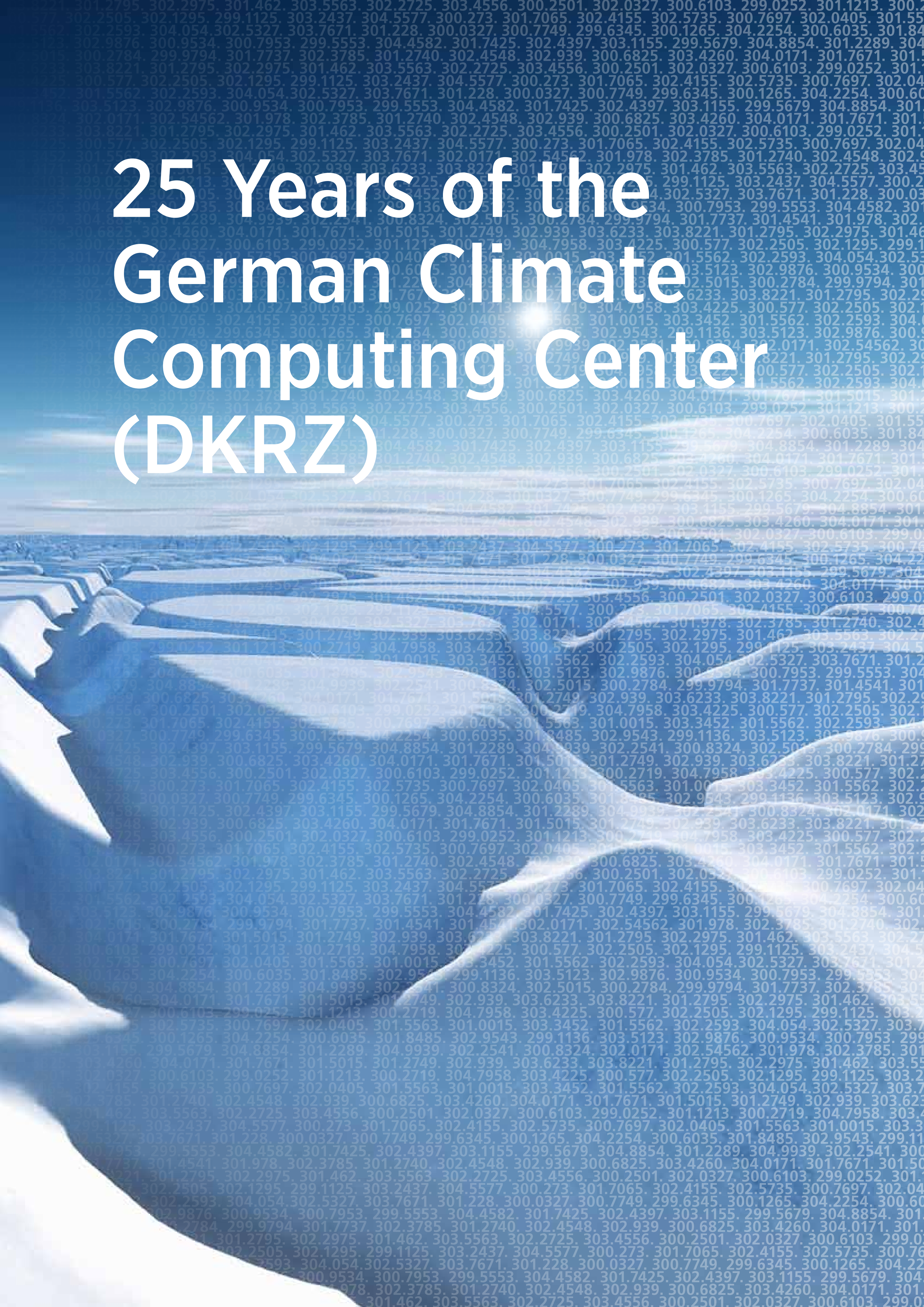
DKRZ

DEUTSCHES
KLIMARECHENZENTRUM

25 Years of the German Climate Computing Center (DKRZ)



A journey back in time through 5^2 years of the DKRZ

Dedicated to all past and present staff members

Prof. Dr. Thomas Ludwig,
Managing Director of the DKRZ

Foreword

The German Climate Computing Center was founded on November 11, 1987. Five generations of computers in 25 years. Those are the most basic facts on the anniversary we celebrated on November 11, 2012. In the span between those two dates, both the available computing power and volume of archived data literally grew a million-fold, and the size of our staff more than tripled, from 22 to 71. Our mission statement is based on three major goals: "Maximum computing power – advanced data management – expert service."

By offering services that exclusively support climate and earth system research, the German Climate Computing Center (Deutsches Klimarechenzentrum, short: DKRZ), a national facility, enjoys a unique status among major German computing centers. Our focus on this range of applications is also reflected in our choice of installed computing and storage systems: Climate research requires an enormous amount of computing power, but in relation it takes even more storage capacity in the form of hard disks and magnetic tapes. Our staff includes many geoscientists and computer specialists who provide our users with outstanding advice and support. In addition to experimentation and theory, computer-based simulation forms the third pillar of scientific progress.

Advances in climate research are largely achieved with the help of increasingly powerful computing infrastructures. The DKRZ has dedicated its efforts to effectively harnessing technological advances in computing and storage systems for the benefit of climate research. This book takes stock of the progress made in our first 25 years.

We hope you'll enjoy this trip back in time!

Thomas Ludwig

GREETINGS & CONGRATULATIONS

Dr. Georg Schütte, State Secretary, Federal Ministry of Education and Research

The 2012 UN Climate Change Conference in Doha demonstrated how difficult it is to come to a consensus on climate change. The political responses to this challenge must be formed on a foundation of sound scientific facts – information that the DKRZ has been collecting for the past 25 years. Together with only a handful of related institutions, its efforts form the backbone of global climate modeling, the basis of the IPCC's findings. The Federal Ministry of Education and Research gladly supports the vital work of the DKRZ, which provides the indisputable scientific facts needed to make informed political action possible and promote an open social discourse.

Prof. Dr. Peter Gruss, President of the Max Planck Society

Today, especially in the field of climate research, working without the help of powerful computers has become practically unthinkable. In this regard the DKRZ, which the Max Planck Society supports as the largest shareholder, provides invaluable services to international climate research and the staff of the Max Planck Institute for Meteorology (MPI-M). The climate simulations that the MPI-M contributed to the IPCC's Fifth Assessment Report required a quarter of the DKRZ supercomputer's capacity for two entire years. Thanks to the DKRZ, the MPI-M researchers' models are among the best in the world and their work enjoys an excellent reputation.

Univ.-Prof. Dr. Dieter Lenzen, President of the University of Hamburg

Modern researchers need more and more computing power. At the University of Hamburg, that's especially the case when it comes to climate research, which is what originally sparked the creation of the DKRZ. Initially a joint computing center for the Max Planck Institute for Meteorology and the University of Hamburg's Meteorological Institute, the DKRZ is now an essential part of earth system research in Hamburg within the framework of the Cluster of Excellence CliSAP. Our leading position in climate research is most certainly due in part to the contribution of the DKRZ. We'd like to thank the DKRZ for the successful cooperation and wish it all the best for the years to come!

Prof. Dr. Wolfgang Kaysser, Scientific and Technical Director of the Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research

The DKRZ provides computing power at the highest international level. In the context of our research into climate change and its impacts on coastal regions, it provides a highly reliable, indispensable basis. Furthermore, as a central instrument in German climate research, the DKRZ strengthens our ties to key research networks such as the KlimaCampus in Hamburg. We at the Helmholtz-Zentrum Geesthacht would like to offer our heartfelt congratulations on your anniversary and to thank you for the close and successful cooperation so far. We're confident that together with the other shareholders, we will rise to the challenges of tomorrow.

Prof. Dr. Karin Lochte, Director of the Alfred Wegener Institute for Polar and Marine Research

As Helmholtz Centre for Polar and Marine Research, the Alfred Wegener Institute especially pursues field research in the cold and temperate regions of the Earth. Our goal is to better understand the driving forces and mechanisms of our climate system, as climate changes in the Arctic, Antarctic and our oceans will impact the future of our planet. High-performance computers for climate simulations and a data storage profile adapted to the challenges of climate modeling are indispensable for our research. As a long-standing DKRZ shareholder, we look forward to our continued cooperation.

K. Lochte

Contents

The DKRZ – Where did it come from?

The people of Germany are environmentally aware: We know that the way we choose to heat or build our homes and the way we travel from place to place today influence the climate of tomorrow. This awareness can also be seen in the environmental policies of three Chancellors: In 1991 Helmut Kohl signed the *Einspeisegesetz*, a law that allowed electricity from private solar panels to flow into public power grids. In 2000 Gerhard Schröder passed the Renewable Energy Act, which promoted the use of electricity and fuels from regenerative sources. And in 2011 Angela Merkel declared Germany's "Energy Transition" – due in no small part to findings based on simulations from the German Climate Computing Center. As a pivotal German service center for climate modeling, it supports today's researchers in achieving vital climate-related advances.

The Hamburg-based Max Planck Institute for Meteorology and the University of Hamburg's Meteorological Institute began working closely together in the early 1980s, initially creating a small joint computing service. But the "big questions" in climate research called for high-resolution, three-dimensional, global models that combined the atmosphere and ocean – and required an enormous amount of computing power.

The idea of a supercomputer was born, and here too, it was a politician who made it possible. Franz Josef Strauß was one of the first to address environmental issues, successfully moving the federal government to create a scientific council for climate-related issues in 1987. At the same time, the Federal Ministry of Research allocated 18 million German marks for the project, presenting a window of opportunity – for the right idea and the right type of science at the right time – for the genesis of the DKRZ, the first European body to bring together the infrastructure and expertise needed to model large datasets and future projections.

DKRZ

PARTNER FOR CLIMATE RESEARCH

1987

System administrator Dr. Otto Böhringer monitors the first generation of high-performance computers at the DKRZ.

The beginning

Staff move into their offices on the 12th floor of the Geomatikum building

Our first computer has only a single processor

Resolution for atmospheric models is roughly 500 kilometers

The history of the German Climate Computing Center started with a piece of paper: On November 11, 1987 the Max Planck Society, the University of Hamburg on behalf of the city of Hamburg, and the GKSS Research Centre Geesthacht signed the shareholders' contract. The new center was to be led by a proven team: The Founding Director of the Max Planck Institute for Meteorology, Professor Klaus Hasselmann, was appointed Scientific Director, while his colleague of many years, Wolfgang Sell, assumed the technical and administrative management.

The fledgling computing center started with 22 employees and the high-performance computer "Control Data Cyber-205," which researchers in Hamburg had been using to create 3D models of climate processes in the atmosphere and oceans since 1985. The Federal Ministry of Research and Technology now agreed to finance a new computer. The shareholders would in turn be responsible for its operation and maintenance.

1988

DKRZ researchers still fondly recall the "computer with personality."

A true work of art

As the new heart of a national computing center, the successor to the "Cyber-205" had to be carefully selected. This task took Klaus Hasselmann and Wolfgang Sell to the USA, where they visited several computer companies and were impressed by the innovative spirit they saw in the American IT sector. "We heard some brilliant ideas," recalls Hasselmann, who ultimately opted for Cray Research Cooperation.

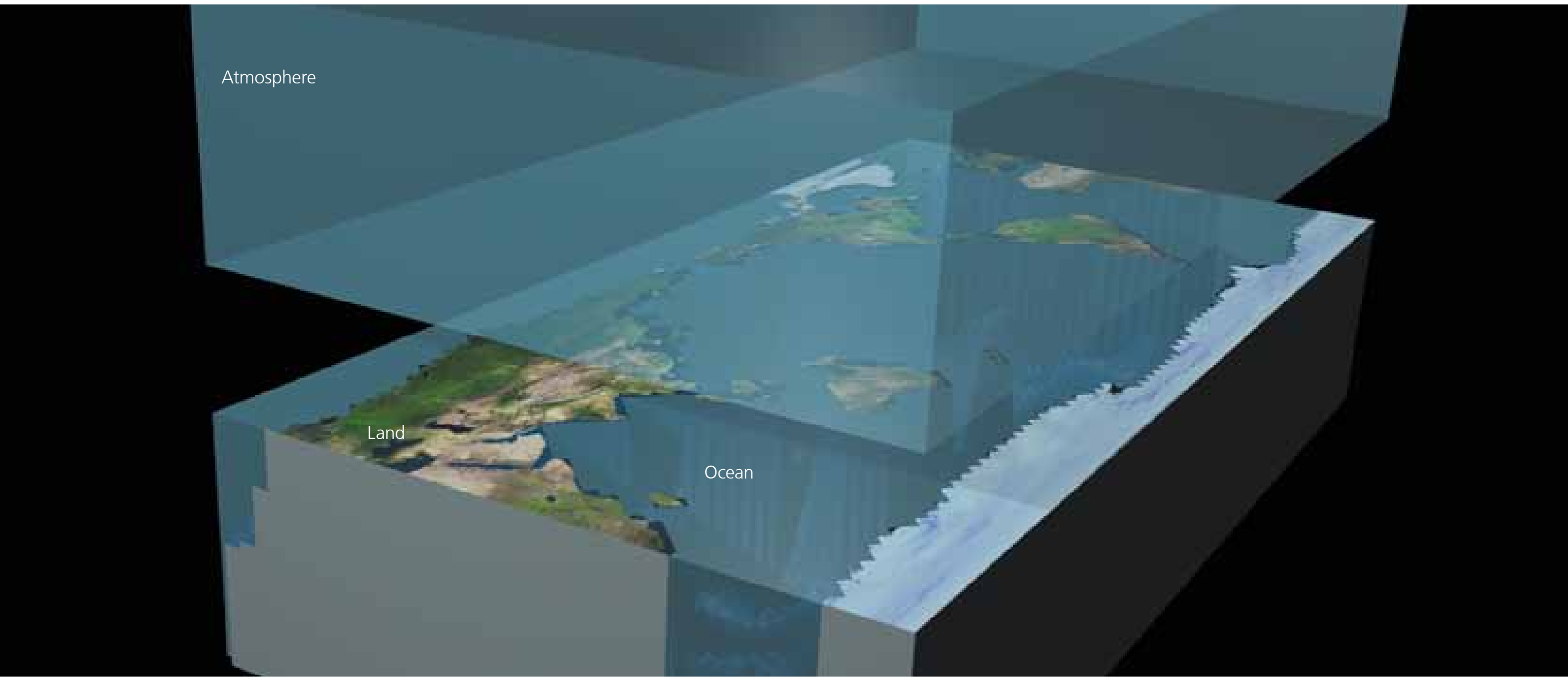
On October 31, 1988 the new "Cray 2S" supercomputer was installed, a beauty in every sense of the word. Beyond its stylish design, the Cray also delivered impressive performance: Running on four processors, it boasted ten times the computing speed of its predecessor. This speed, combined with significantly more main memory (1 gigabyte), meant much higher resolution and ushered in the first 3D coupled atmosphere-ocean models in Germany.

The DKRZ user information guide "GIGAFLOPS" is published

The Intergovernmental Panel on Climate Change (IPCC) is founded

Construction of a new building, the "Pavillion," begins

1989



Coupled climate models simulate interactions between the atmosphere and ocean such as the water cycle: Water from the ocean evaporates and rises into the atmosphere, gathers inside clouds, and then descends again in the form of rain.

Leading the way

The first robot-operated silo can store up to 1 terabyte of data on 6,000 magnetic tape cassettes

Email service is introduced

Number of DKRZ employees grows to 34

Oceanographers are engrossed in ocean models and atmospheric researchers constantly work to fine-tune their atmospheric models – in 1989, we said goodbye to these outdated demarcations. With the advent of coupled global climate models, German researchers made a major breakthrough, joining the "major leagues" in international climate research. Of the four atmosphere-ocean models worldwide at the time, two were made in Hamburg. These first realistic simulations revealed that climate changes in response to CO_2 emissions were not limited to the atmosphere, but also affected the ocean, which is essentially a global buffer for excess heat.

"These advances were only possible because we had the right computer for the job," explains Ulrich Cubasch, who assumed leadership of the DKRZ's Model Support Group in 1991 and is now a professor in Berlin. "With its predecessor, we could only simulate two years at most, but with the 'Cray 2S' we could project up to 100 years into the future." It should be noted, though, that these simulations took roughly half a year to complete.

First report on the global climate

Can we already see solid evidence of the greenhouse effect? What does climate change mean for forests, coastal areas or glaciers? What will the consequences be for agriculture, industry and our health? How can we best cope with these effects – or avoid them? In 1990, the Intergovernmental Panel on Climate Change (IPCC) first gathered the key findings of international climate research, releasing a roughly 1,000-page Assessment Report. The German contributions were supplied in part by the Max Planck Institute for Meteorology. As one of the lead authors, Professor Ulrich Cubasch presented the results of the model calculations made at the DKRZ.

The IPCC's first Assessment Report marked the dawn of a new era in climate research, as it meant that researchers from around the globe could now contribute and combine their data to arrive at an overall image of global climate change and its effects. At the same time, this created a new, herculean task: Collecting, analyzing, and clearly presenting the data now called for large data archives and massive processing power. Accordingly, thanks to its technical capacities, expertise and enormous storage space, the DKRZ would take on increasing importance in the preparation of subsequent assessments. The IPCC now produces a new report roughly every six years and was awarded the Nobel Peace Prize in 2007.

The "Cray 2S" computer now supplemented by the "Cray Y-MP"

First simulations of a transient CO_2 increase using a coupled 3D-atmosphere-ocean model

Roughly 60 German research organizations can now be reached over the internet

1991

The High Performance Storage System in use today encompasses seven libraries and over 65,000 magnetic tape cassettes.

The discovery of trees

Federal Minister of Research Dr. Heinz Riesenhuber visits the DKRZ

The Alfred Wegener Institute for Polar and Marine Research becomes the fourth DKRZ shareholder

The “Model Support” department is created

Whether they deal with the atmosphere, oceans or ice, climate models provide trillions of individual data points. How can these tremendous amounts of data be organized? At the time, they were stored on magnetic tapes – with the disadvantage that every user had to remember how many of “their” bits were stored on which part of what tape. The new, hierarchical archiving system UniTree, which the DKRZ helped to develop, meant a minor revolution: To allow long-term archiving, users now began creating treelike directories and subdirectories, like folders on an ordinary PC. The program then saved them on magnetic tape cassettes, which robotic arms sorted into a storage library and retrieved whenever they were needed – the whole process being automated and running around the clock. This approach to archiving and organization would prove to be dependable and highly effective. In fact, it remained in service until 2009, when it was replaced by the more modern High Performance Storage System (HPSS), which can save data nearly as fast as it is produced, handling up to 5 gigabytes per second.

Why does climate research need its own computing center?

"You can't have top research without top computers"

Hardly any other research area places higher demands on IT than climate modeling. Why a specialized computing center makes good sense, and what fruit it has borne – we asked Professor Klaus Hasselmann, the first Scientific Director of the DKRZ.

A computing center exclusively for climate research – is that a luxury or an essential resource?
In order to provide answers to highly specific questions on our climate system, we need specialized hardware and software. And we need highly trained professionals who know how to use the equipment properly so that we can meet the unique needs of climate research in terms of computer power, data storage and processing.

But couldn't every institute just do the same on its own?
No, experience shows that that doesn't work. First of all, different areas of expertise have to be brought together before we can develop complex climate models. And secondly, these models take tremendous amounts of computing power to run. The higher the resolution of the models – which is to say, the more precisely we want to depict climate processes –, the more powerful the computer has to be. Typically, individual institutes can't afford these high-performance computers. As such, it makes excellent sense to pool expertise and technology in a central resource available to all climate researchers, from both a scientific and a financial perspective.

How much money are we talking about?
Today a supercomputer can cost roughly 40 million euros, which is quite a bit of money. But what would it cost us if the temperature of the entire planet rose by 1 degree Celsius? Then we'd have costs on an entirely different scale.

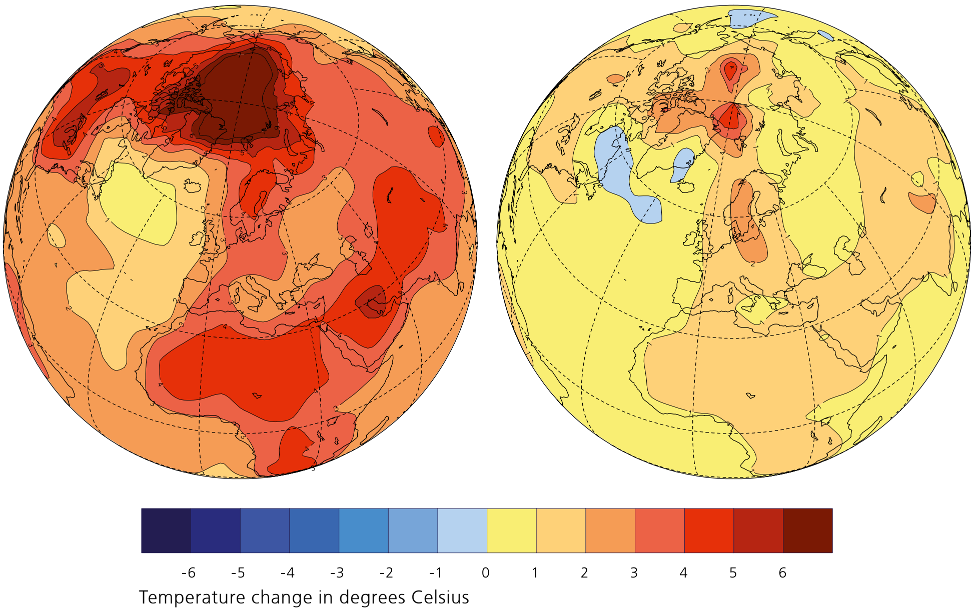
Has the DKRZ made German climate research competitive, internationally speaking?
Germany has always been home to good research. But: You can't have top research without top computers. As a specialized computing center, the DKRZ has allowed us to set a milestone or two – like being the first to prove that, with 95 percent certainty, global warming is above all due to increased greenhouse gas emissions. Today, Germany is at the forefront of climate research.

And therefore also made us competitive in international climate policy?
Our research definitely plays a part. Germany is comparatively advanced. And we can use the results of our own research to support our green stance and demands for an energy transition, which boosts our credibility.

Professor Klaus Hasselmann, Scientific Director of the DKRZ from 1987 to 2000, Director of the Max Planck Institute for Meteorology from 1975 to 1999

1992

Lost time
In preparation for the Earth Summit in Rio, the DKRZ visualized the data from the scenario calculations produced in Hamburg. In 1992 it was already clear: massive greenhouse gas emissions would raise temperatures across the planet by 2080 (left-hand globe). If the CO_2 levels in the atmosphere could be reduced, global warming could be stopped or at least slowed down (right-hand globe). However, this insight is only now producing concrete action – and even now it remains tentative.



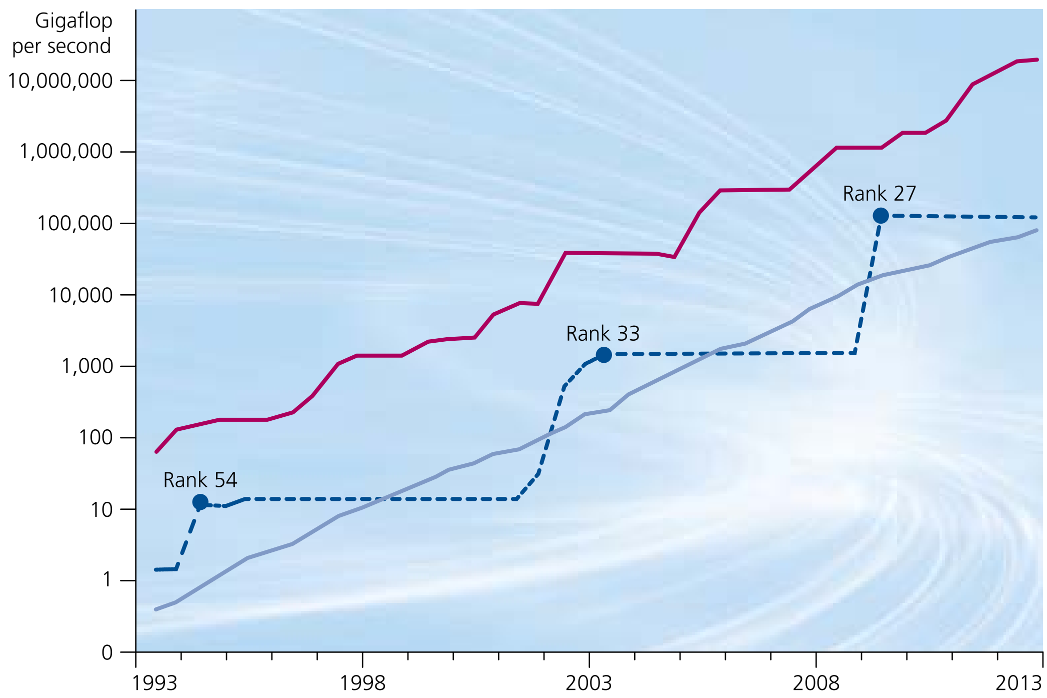
The power of numbers

The Max Planck Institute for Meteorology and the DKRZ produce the film “The Climate of the Next Century”

Addition of a second robot-operated silo doubles storage capacity

DKRZ team expands to 48 employees

Once it had published its first Assessment Report in 1990, the IPCC didn’t just rest on its laurels. On its behalf, the research groups involved in the report and others analyzed more data and worked out a diverse range of different scenarios. How will future economic developments affect the climate? How quickly will the levels of CO_2 emissions rise under different sets of conditions? The Max Planck Institute for Meteorology also began running new climate simulations at the DKRZ, involving a continuous rise in CO_2 emissions. Though this was more of a technical task than a scientific one, it was nonetheless important, namely for the 1992 United Nations Conference on Environment and Development (Earth Summit) in Rio de Janeiro. Using the findings from follow-up reports it presented at the conference, the IPCC substantiated the idea of man-made climate change – even if this wouldn’t be proven for another three years. And it worked: In Rio, politicians first signaled their readiness to protect the environment, signing the Rio Declaration on Environment and Development.



Rapid climb
Since 1993 the performance of the world's Top 500 computers, including the DKRZ, has risen by a factor of between 10,000 and 100,000.

The 500 fastest in the world

When it comes to the 100-meter dash, it's as simple as can be: Whoever runs the fastest wins the race. It's the same for the fastest computers on the planet: Whoever calculates the fastest is the winner. The judge running the stop-clock is LINPACK, a program that measures how many calculations a computer can make in one second. Since 1993, it has been used to test the world's fastest computers, the results being posted in a Top 500 list (www.top500.org). In the first year, the then five-year-old DKRZ computer "Cray 2S" came in at a respectable 187th place. Its performance of 1.4 gigaflops – or 1.4 billion individual operations per second – is roughly equal to that of modern notebooks.

However, comparative calculations using climate models are better suited to the DKRZ's work, as they place entirely different demands on computers than LINPACK – just as in sports, a solid performance in the 100-meter dash doesn't qualify you for a 10-kilometer run.

Hamburg's high-speed computer network connects research bodies in and around Hamburg at a bandwidth of 100 Mbps

Work on a climate database starts with a workshop

DKRZ archive stores 1 terabyte of model results

Changed out "on the fly": With minor assistance from a crane, the Cray 2S (left) makes way for its successor, the Cray C916 (right).

Over the rooftops of Hamburg

DKRZ goes online with its first website

CERA database stores and documents its first climate data

"Cray T3D" installed as the first parallel computer – many operations can now be performed on different processors simultaneously

What is practically the fastest computer in Germany, weighs 12 tons and is suspended 65 meters off the ground? On May 11, 1994 came the clear answer to this guessing game: the Cray C916. The DKRZ's new supercomputer is a compact unit: a two-meter-tall pillar with three side-wings. Though the wings are removable, the individual components are still too large and heavy for any elevator – just like its predecessor, the Cray 2S.

So how do you get the new computer up to the 15th floor and the old one down from there? As Wolfgang Sell, the Technical and Administrative Director of the DKRZ at the time, recalls, "Well, we took out some windows, ordered a crane and installed heavy supports in the floor. They distributed the weight so that the whole thing didn't come crashing all the way down to the ground floor." The new computer delivered a performance of up to 12 gigaflops, virtually unmatched in its day. But the climate researchers were insatiable when it came to computer power – just three weeks later, the new system was running at peak capacity. Eight months after installation it was upgraded with four additional processors, boosting its performance to 16 gigaflops and making it eight times faster than the Cray 2S.

What we had to prove

Ever since the Industrial Revolution, humanity has been pumping more and more greenhouse gases into the atmosphere. As a result, the mean global temperature has risen by 0.7 degrees Celsius – just a fluke of nature, according to the skeptics. How, then, can the effect of greenhouse gas emissions be differentiated from naturally occurring fluctuations? Thanks to the powerful DKRZ computer, researchers from the Max Planck Institute for Meteorology started work on new simulations, using higher-resolution coupled atmosphere-ocean models. At the same time, they simulated the global climate over a several-hundred-year timespan and compared their models with observational data, for example, climate data gleaned from tree rings. Like identifying a fingerprint, the Hamburg-based researchers ultimately succeeded in filtering the greenhouse gases' climate signal from the noise of natural fluctuations. In 1995 they delivered the first concrete proof that global warming was very likely a man-made phenomenon – a breakthrough that hit the field of climate research like a thunderbolt.

DKRZ now offers its users online support

Awarded the German Industry Film Prize for "Klimasimulationen – Vorhersage des globalen Wandels" (Climate Simulations – Prediction of Global Change)

IPCC publishes its Second Assessment Report

1996

Connecting to the world

"SGI Onyx 2 IR" installed for interactive 3D visualizations

IPCC proposes the creation of a global data center for climate data

DKRZ archive now grows by 500 gigabytes per month

In the early years of the DKRZ, researchers had to actually be on site to use the computers: Data was still usually transferred using magnetic tapes, a time-consuming and cumbersome affair. But the DKRZ was already hard at work to create a broadband link to the budding Internet. The center's connection to the new German broadband science network in 1996 marked a milestone: The transfer rate increased tenfold to 20 megabits per second – comparable to a private DSL connection today.

Today the broadband connection speed has reached several thousand megabits per second, allowing researchers at the other end of the country to run climate simulations and later analyze and visualize the results, all from the comfort of their office. Even so, it's still not fast enough to transmit all of the calculation data, which is produced faster than it can be sent.

What will happen if the ice in Greenland melts?

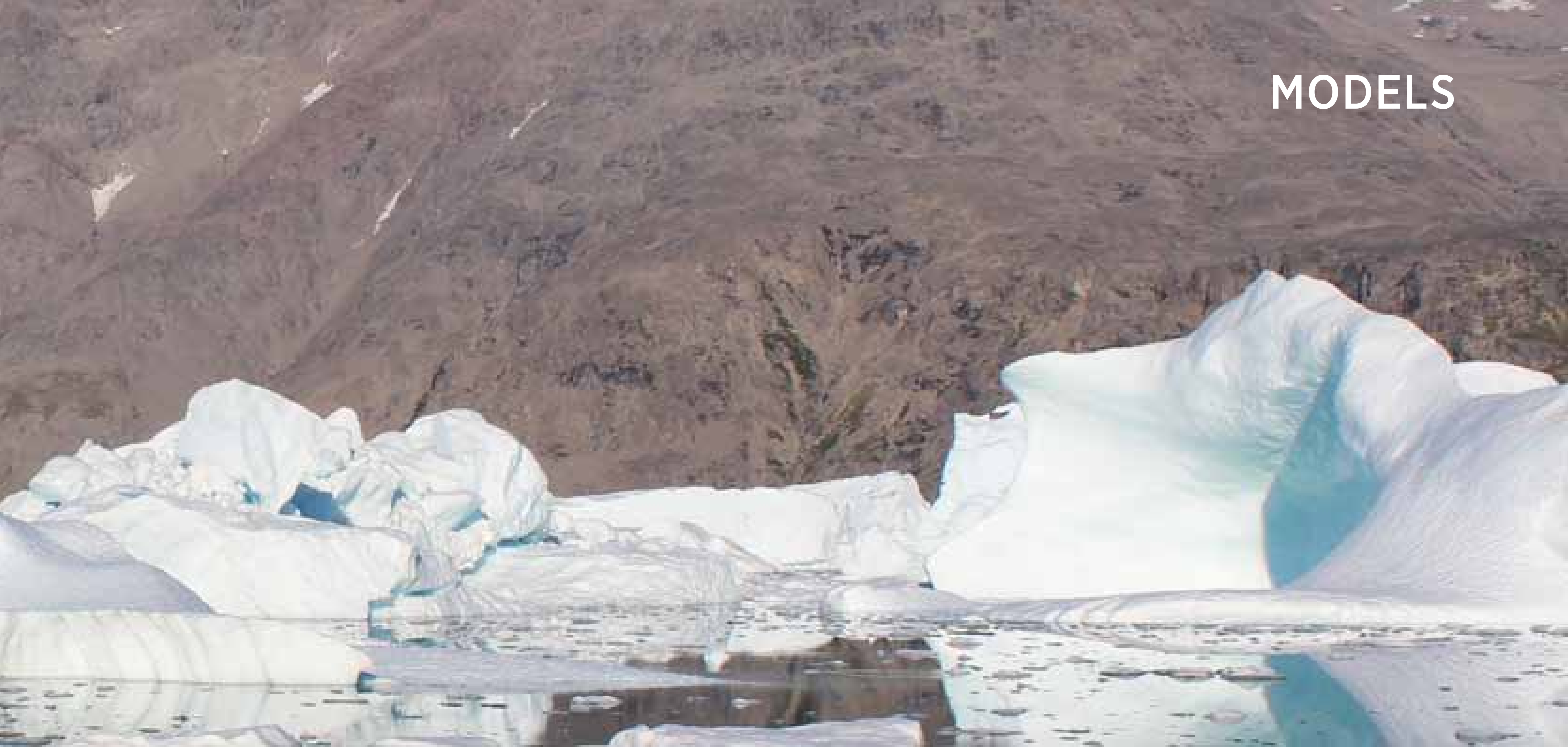
The curse of resolution

Models allow scientists to simulate changes in our climate. The quality of those models is partly a question of computer power. What's currently possible – and what's not?

In the summer of 2012 Greenland's ice sheet melted more than at any other time in recorded history. If global warming continues to intensify this thawing, sea levels will rise – but not uniformly. Further, the meltwater may significantly affect the currents in the North Atlantic; or it might have little or no effect on them. No one can say for sure, because our climate system isn't a simple formula of cause and effect – it's far more complex.

Climate researchers work with models that divide the earth into different grid cells, in which changes in certain environmental parameters are calculated. The finer the grid, the higher the resolution, and the more details can be investigated. Some processes, like the melting of ice sheets, call for simulations covering millennia to arrive at a representative view. Furthermore, researchers repeat simulations with slightly different initial parameters in so-called ensembles. According to Professor Jochem Marotzke, Director of the Max Planck Institute for Meteorology (MPI-M) in Hamburg, "Mathematically speaking, our climate is chaotic: Tiny changes can have major effects in the long run."

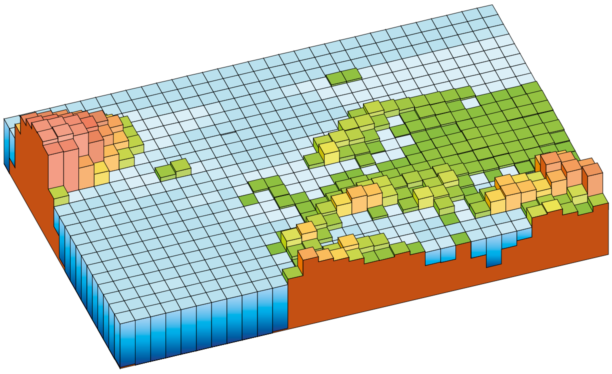
Yet the findings a climate model can produce are also a question of computer power. The IPCC's Fourth Assessment Report from 2007 was based on simulations involving global models using grid sections roughly 200 kilometers across. The calculations made by German researchers alone tied up a fourth of the DKRZ's computing capacity for over two years.



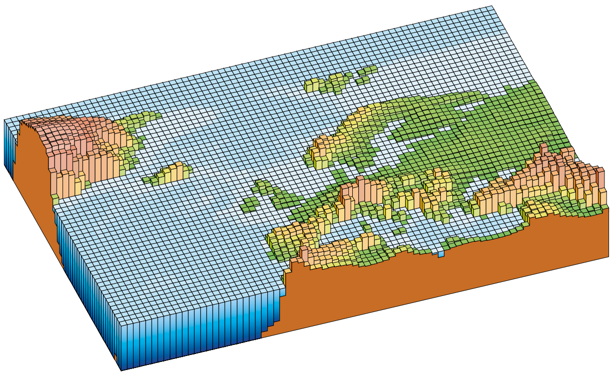
In fact, both large-scale ensembles and above all higher levels of resolution call for far more performance than today's supercomputers can deliver. "Our current climate model," explains Marotzke, "simulates the ocean at a resolution of 40 kilometers. If we wanted to boost that to 10 kilometers, or four times the resolution, it would take 64 times as much computer power." That's the bare minimum of computational power needed to even begin to calculate the future effects of Greenland's melting ice sheet. Unlike large-scale processes, small-scale phenomena, like the influx of meltwater in the East Greenland Current, cyclones and cloud formation can hardly be simulated in earth system models. And Marotzke is well aware of this: "Even with the next generation of supercomputers, we're going to hit certain limits."

The climate-modeling specialists at the MPI-M work closely together with the experts at the DKRZ, especially because of the comprehensive data services and professional consulting which the latter offer: "In some cases we work with the same data for five years, and we need to have constant access to it," says Marotzke. The DKRZ's experts also help to optimize models to ensure that no computer power goes to waste – meaning every bit can be used for the highest resolution.

Spotlight on details
The smaller a model's grid spacing is, the higher the resolution and the more details can be identified.



Grid spacing: 250 kilometers



Grid spacing: 100 kilometers

Specialized data for everyone

DKRZ supports the creation of a Hamburg-based educational server

Federal Environment Minister Dr. Angela Merkel visits the DKRZ

Exhibition "Arctic – Antarctic" in the *Bundeskunsthalle* in Bonn – DKRZ provides key visualizations

Hydrologists want to know where floods are most likely to occur, geographers focus on the climate in specific regions, and coastal planners have to decide how high to build their embankments. The data from the massive model simulations is particularly crucial when researching the impacts of climate change – but of course not all data is useful for everyone. What's more, users need to be able to grasp what the numbers mean, and what they can and cannot be used for.

One of the IPCC's goals is to promote more cooperation in science, which in 1996 led it to propose the creation of a global data center. Just one year later, the die was cast: The DKRZ and the UK's Climate Research Unit launched the virtual Data Distribution Centre (DDC), which gathered and described the most important climate-related data from the IPCC's ongoing model simulations, as well as making it publicly available: Anyone could go online and download the data. The DKRZ's Model Support Group advised users on how to best use and interpret the data, helping to ensure they drew the right conclusions. Starting in 2003, the US-based Center for International Earth Science Information Network began working with the DDC, and in 2007 the Climate Research Unit passed the baton to the British Atmospheric Data Centre.

Rapid access: The most important files are stored on the hard disks of the data management server.

Looked for – and already found

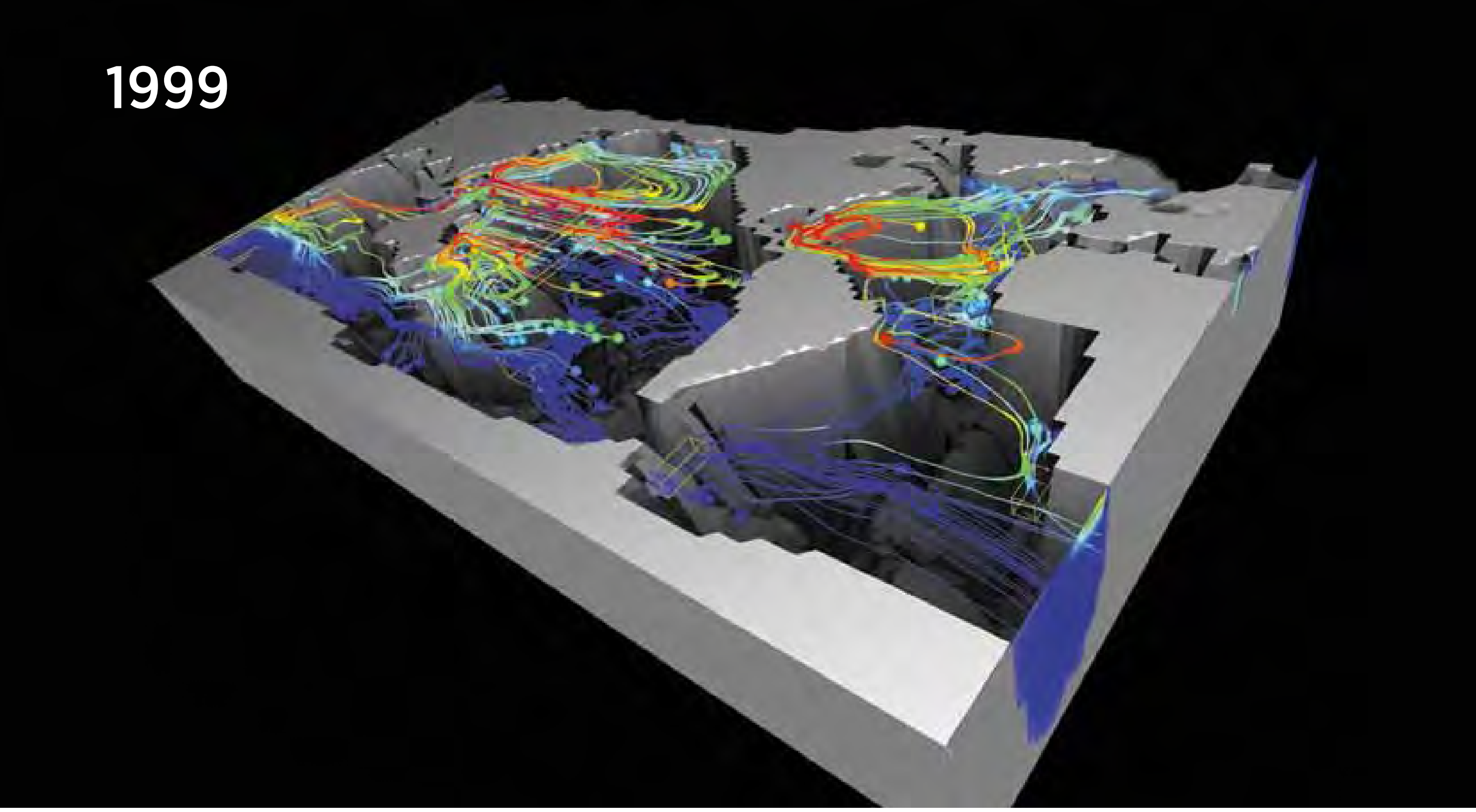
Say you were looking for the average monthly precipitation figures for 2010 to 2015 from all simulations using a certain type of climate model – in the early 1990s, you'd have needed plenty of patience. After all, these figures were buried among countless others, all stored on magnetic tapes. It soon became painfully clear that the DKRZ needed a climate database, but the virtually limitless amounts of data made even well established IT providers break into a sweat. Even the banks and insurance providers that they were used to supporting had never generated comparable amounts. Working with the company Oracle, the DKRZ developed a new system. In 1994 the first dataset was entered into the CERA database: a 2.8-megabyte simulation using the ECHAM climate model. By 1998 CERA had already grown to 1 terabyte – over 350,000 times as much memory as before. The database works like a filter: Using a search interface, researchers enter the climate parameters they're looking for along with framework conditions, like the model's time interval and resolution, and can then download the results they need. Above all, the most commonly requested data, such as mean precipitation and temperature levels, are stored in the database. The database is also home to the IPCC Data Distribution Center. By the end of 2012, CERA had grown to 650 terabytes.

DKRZ relaunches its website

Data server "SUN ES 6000" replaces the "Convex C3840"

First plans for restructuring are discussed

1999



The endless journey of water in the ocean: A visualization based on data from the OPYC ocean model shows the different paths that water follows in its course through the "big pond." Colder and deeper water is blue, warmer surface water is red (from the GEO book "Die unendliche Reise" (The Endless Journey)).

The endless journey

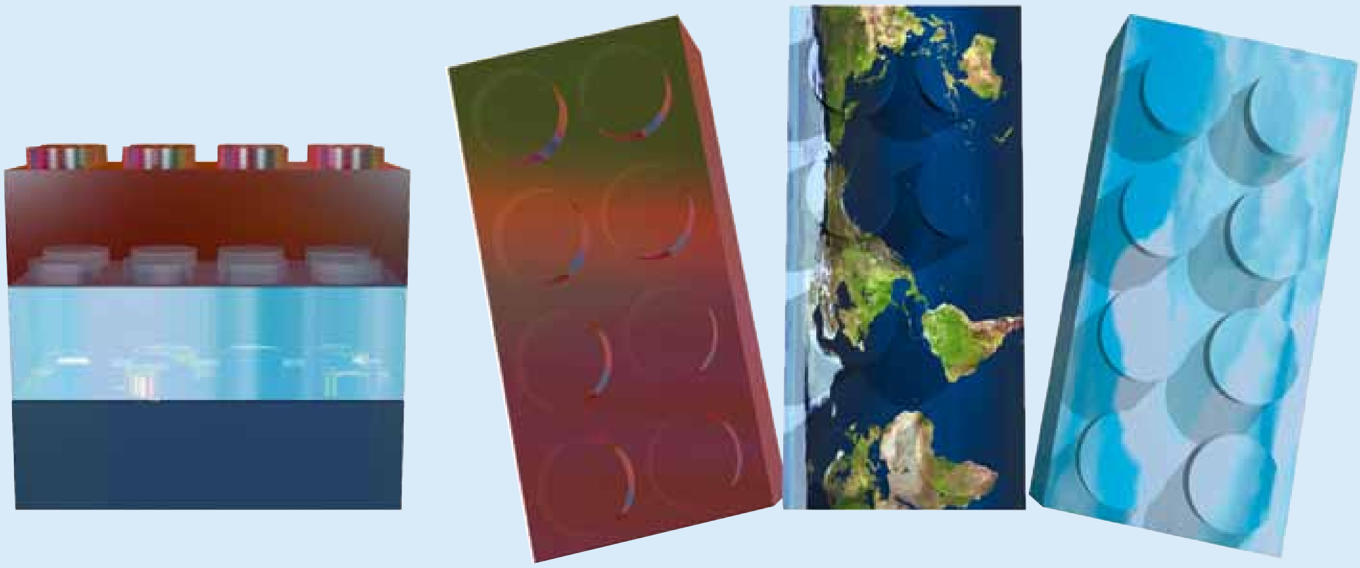
The film "Klimaänderung – Nachhaltige Strategien" (Climate Change – Sustainable Strategies) is produced

Professor Klaus Hasselmann retires

IT world is holding its breath – will we be hit by the Y2K problem?

They say a picture is worth a thousand words. And the saying also holds true for the scientific world, for example, when it comes to analyzing columns of figures, identifying trends, or determining the geographical distribution of data. The human brain can more readily grasp visualizations than raw statistics.

Scientists visualize research data in order to arrive at new insights. Visualizations can also be a tremendous help in communications with the broader public, as they can make complex interrelations clearer and more tangible. Accordingly, visualizations from the DKRZ quickly find their way into the media. In newspapers, magazines, books and on television, they are used to illustrate reports on the latest breakthroughs in climate research. In 1999 the GEO book "Die unendliche Reise" (The Endless Journey) was published, presenting "the highlights of scientific photography from GEO," which included visualizations from the DKRZ.



The building-block principle

By now, hundreds of climate researchers relied on the DKRZ's Model Support Group, though as of 2000 under new management: At this time, the Federal Ministry of Education and Research discontinued its coverage of the computing center's operating costs. In turn, however, it took the "Model & Data Group" (the former Model Support Group) under its wing, agreeing to finance its work for the next ten years. Located at the Max Planck Institute for Meteorology, the group worked to simplify the application of climate models and boost the efficiency of data flow. In the large-scale EU project PRISM, the Model & Data Group worked closely with the DKRZ to establish Europe-wide standards for simulations and the proper saving of the resultant data.

The group also standardized both the model controls and interfaces between individual models, so that climate researchers across Europe could combine model components to create coupled models tailor-made to their specific research needs. Or, in simpler terms: Just like with Lego blocks, atmospheric module A, ocean module B and component F for ice can simply be stacked up.

New Scientific Director: Professor Guy Brasseur succeeds Professor Klaus Hasselmann

Nearly 800 downloads per month from the CERA database

Scientific Steering Committee founded

In June 2004, Professor Guy Brasseur, Professor Hartmut Graßl and Federal Minister of Research Edelgard Bulmahn (l. to r.) attended the dedication ceremony for the new Center for Marine and Atmospheric Sciences in Hamburg.

The end of a dry spell

IPCC publishes its Third Assessment Report – using scenarios simulated at the DKRZ

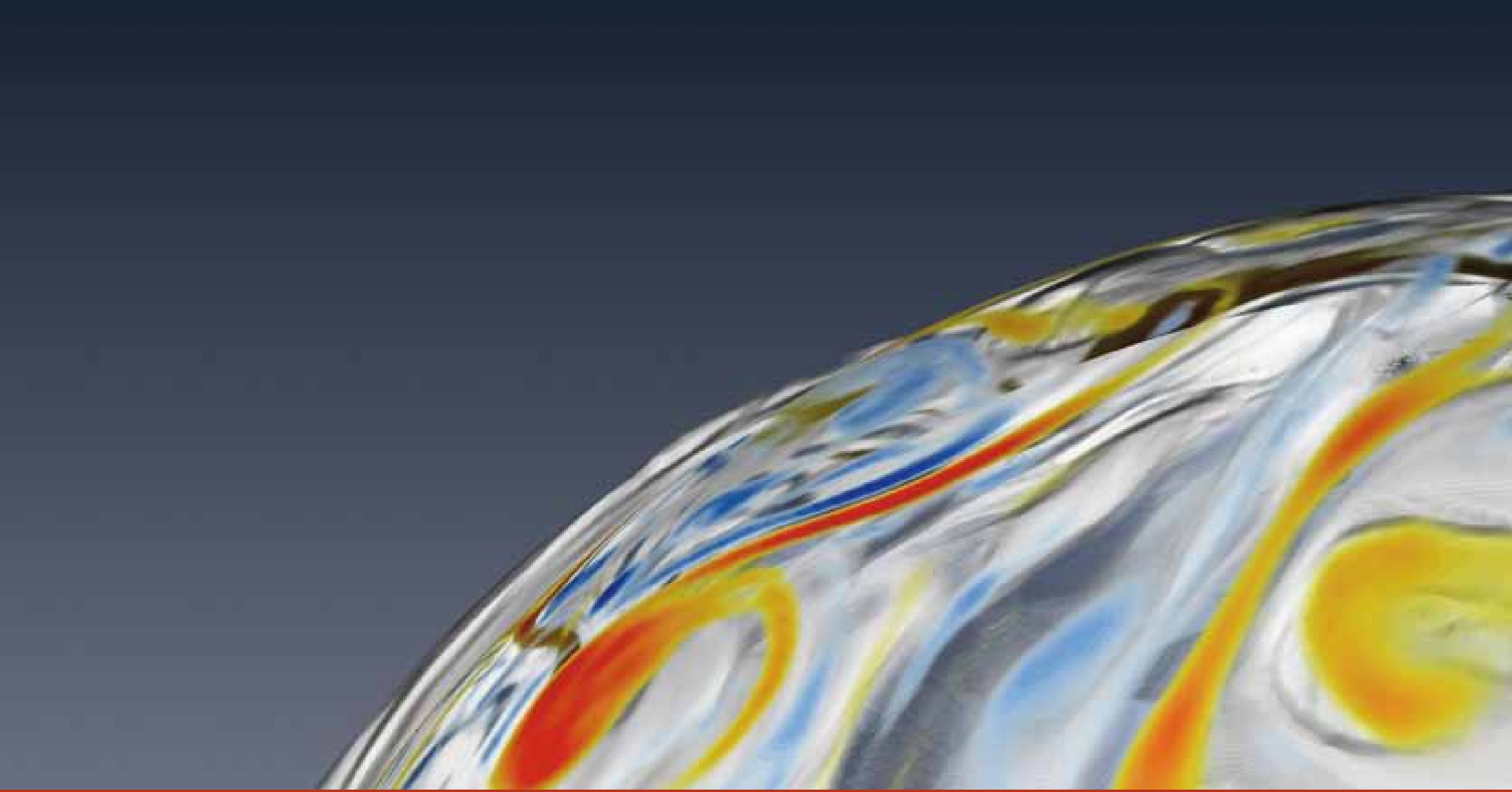
CERA database is now a web-based resource

Office space is repurposed into computer rooms for the "Hurricane" supercomputer

It's quite simple: Using an old computer means less performance, fewer experiments and therefore less top research. In 1998 the four-year-old DKRZ computer dropped out of the Top 500 fastest supercomputers in the world. And if your computer can no longer compete, it won't be long before German climate research also starts lagging behind internationally. After five years, a computer should really be replaced. But there was no rest for the "Cray C916" after 1999, as no funds for a replacement were forthcoming – a bombshell for the DKRZ and the Max Planck Institute for Meteorology.

For months on end, Professor Guy Brasseur – who had taken over as Scientific Director of the DKRZ in 2000 – doggedly negotiated with the Federal Ministry of Education and Research, ultimately securing financial backing for two further generations of computers. In 2001 the hard times finally came to an end: Starting in October, an interim system with twice the performance of the Cray brought the DKRZ closer to the competition, and finally in 2002, a new supercomputer was installed.

What are the benefits of climate research data?



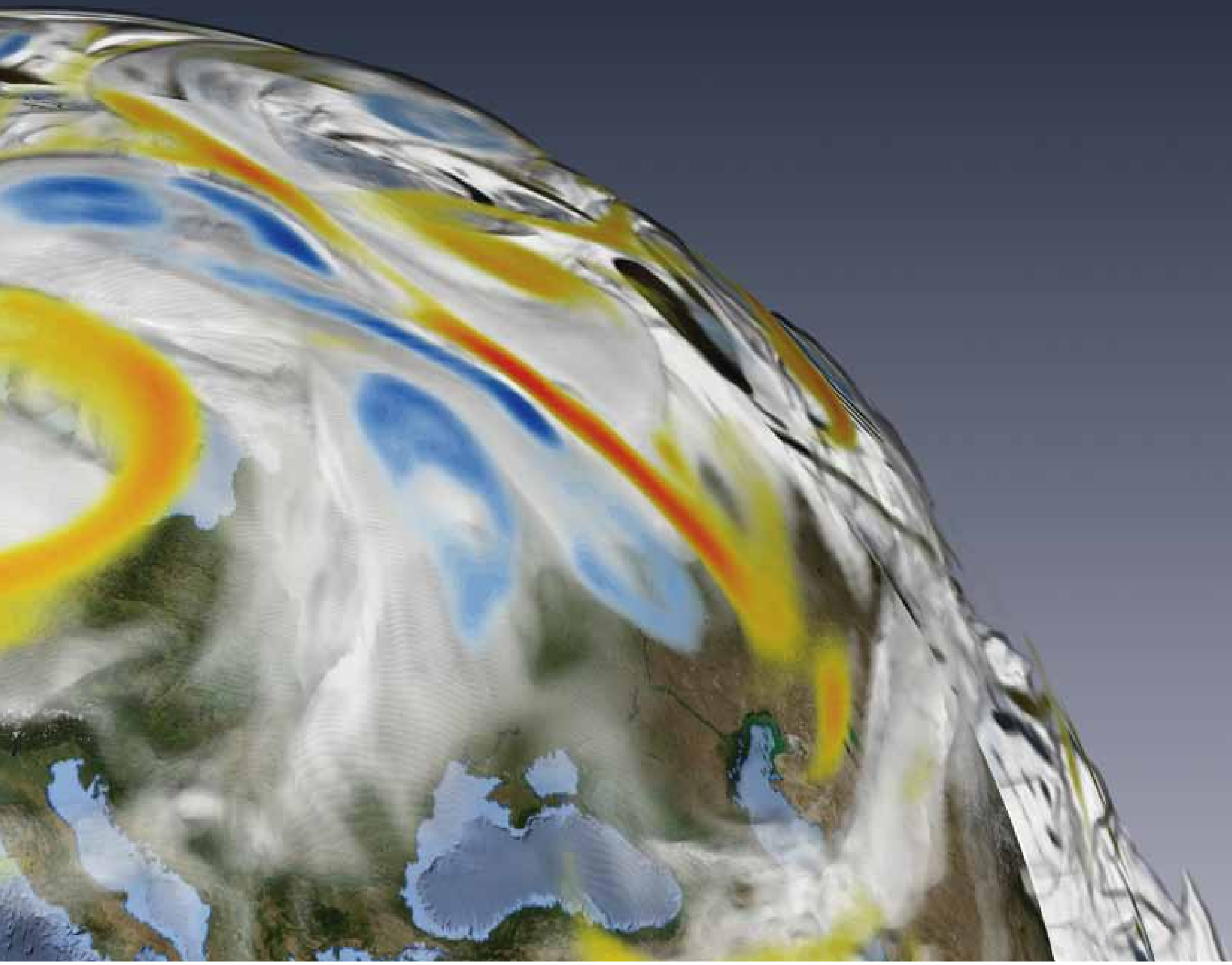
Environmentally aware today, environmentally neutral tomorrow

Severe weather, rising sea levels, loss of habitable land: Climate change isn't some abstract subject for researchers; it affects everyone on the planet. Why are research findings important for society, business, and politics, and what are their impacts?

Hamburg's embankment needs to be higher: In 2012 the City Senate decided to raise the projected flood level – the highest water level to be expected in the event of a storm surge – by 80 centimeters. Just one example of how cities are coping with climate change. "In the future, we're going to have to live differently," explains Professor Guy Brasseur, Director of the Climate Service Center (CSC) and former Scientific Director of the DKRZ. "Tomorrow's societies will need to be climate-aware societies."

Advances in research point to how we can use technology to respond to our changing environment. It then becomes the task of our economic and political leaders to decide which measures are financially feasible and which we as a society are prepared to support. That makes it all the more important that the public is as well informed as possible.

Much has been accomplished already. Citizens and the media are talking about the climate and the potential effects of climate change: for agriculture, as severe weather could become more common; for the healthcare system, because pathogens are spreading in new regions; or for tourism, because the snow on ski slopes in the mountains is melting away.



But above all, future generations will feel the effects. “We have to broaden our view to include entire centuries,” says Professor Hartmut Graßl, former Director of the Max Planck Institute for Meteorology and one of the spiritual fathers of the DKRZ. “We have to make decisions and change our policies now. But it will only be our grandchildren and great-grandchildren who can judge how much difference it made.”

Spending billions, even though we can’t be sure of success – this is a major challenge for industrialized nations, who should also serve as role models for developing countries. According to Brasseur, “We have to successfully communicate that the path we’ve taken, one of oil and coal, may very well make rapid industrialization possible, but it also has serious drawbacks.” The only options with a real future are those that are both economically viable and environmentally sustainable.

Like the decision to raise the embankment in Hamburg. Though it had been added to at different times in the past, this time something was different: Instead of responding to catastrophes that had already hit, the city now took a proactive approach – based solely on scientific forecasts.

2002

Technicians from the company NEC installing the new high-performance computer.

“Hurricane” brings a new wind

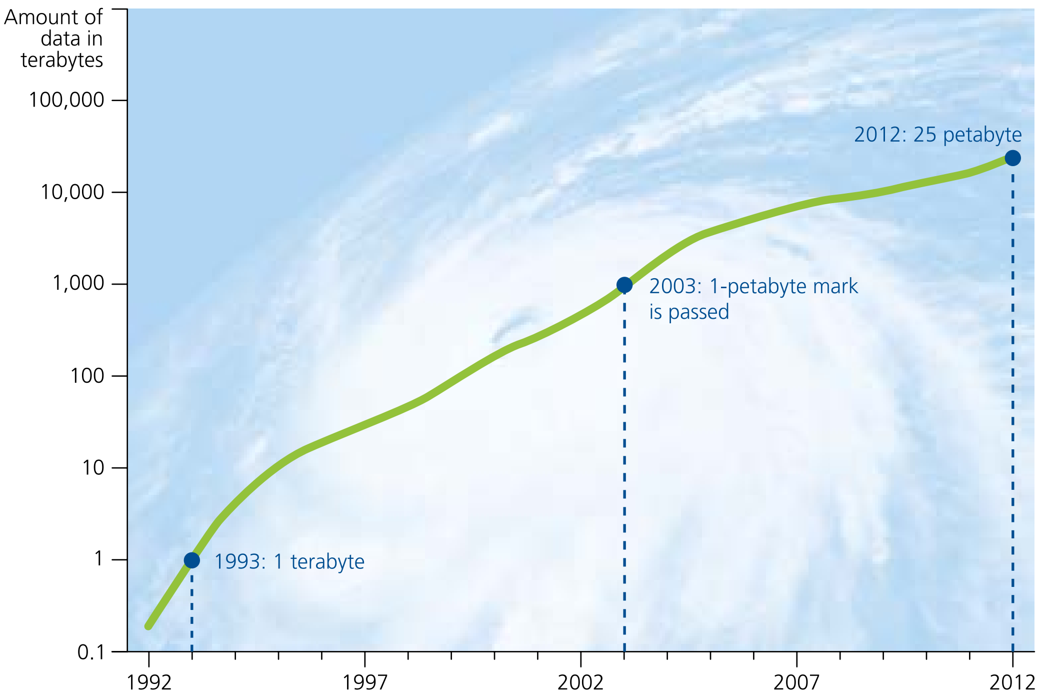
Newsletter “TerraFLOPS” published by the “Model & Data Group” and the DKRZ

User committee founded – Dr. Bernadette Fritzsch from the Alfred Wegener Institute is the first Speaker

DKRZ website is relaunched

The Federal Ministry of Education and Research (BMBF) invested roughly 35 million euros in the new computer system. In March 2002, installation work commenced for the NEC SX-6, the new high-performance computer for earth system research. Dubbed the “Hurricane,” it brought with it a fresh new wind: After four years of absence, the first stage of expansion alone catapulted the DKRZ back into the Top 500 computing centers worldwide.

On September 10, 2002, the Hurricane was christened in a formal ceremony, at which State Secretary Uwe Thomas of the BMBF claimed the flooding of the Elbe River demonstrated the “urgent need for research into its climatic causes.” The new “Hurricane” computer would allow the DKRZ to use significantly better resolution for climate models. “Until now, we could only run global simulations at a resolution of roughly 300 kilometers grid spacing; now that’s been improved to 100 kilometers,” explained veteran DKRZ user Mojib Latif from the Max Planck Institute for Meteorology, who is now a professor in Kiel. Only climate researchers in Japan have it better: Their Earth simulator delivers a resolution of 10 kilometers.



From tera to peta
Between 1993 and 2012 the amount of data in the DKRZ archive skyrocketed, rising an amazing 25,000-fold: from 1 terabyte to 25 petabytes.

Walking among giants

Covering as much area as 24 phone booths, equipped with 192 processors, and boasting a peak performance of over 1.5 trillion operations per second – the newly installed Hurricane was no lightweight. Starting in April 2003, it offered researchers 100 times the performance of its predecessor, the "Cray C916." Hurricane could store 100 terabytes of data – roughly 2,000 times as much as an average PC at the time. But even that was not enough: After only two weeks of climate simulations, its hard disks would have been full. As such, the data was transferred to magnetic tape cassettes in the "StorageTek" silos, which had a total capacity of 6 petabytes (6,000 terabytes).

The bigger the computer, the more data it produces. Whereas the DKRZ had generated 1 terabyte of climate data over its first six years in operation, an additional 10 terabytes were added in 1996 alone. By the end of 2003, the 1-petabyte mark had been reached. To put that in perspective: That's the same amount of data as on 120,000 DVDs, enough to watch movies nonstop for at least 40 years. By 2012 the volume had risen to nearly 25 petabytes.

The "Model & Data Group" co-organizes the International Climate Conference for Earth System Modeling

World Data Center for Climate Data founded

Calculations for the IPCC's Fourth Assessment Report begin

For nearly two decades, Wolfgang Sell led the DKRZ as Technical and Administrative Director.

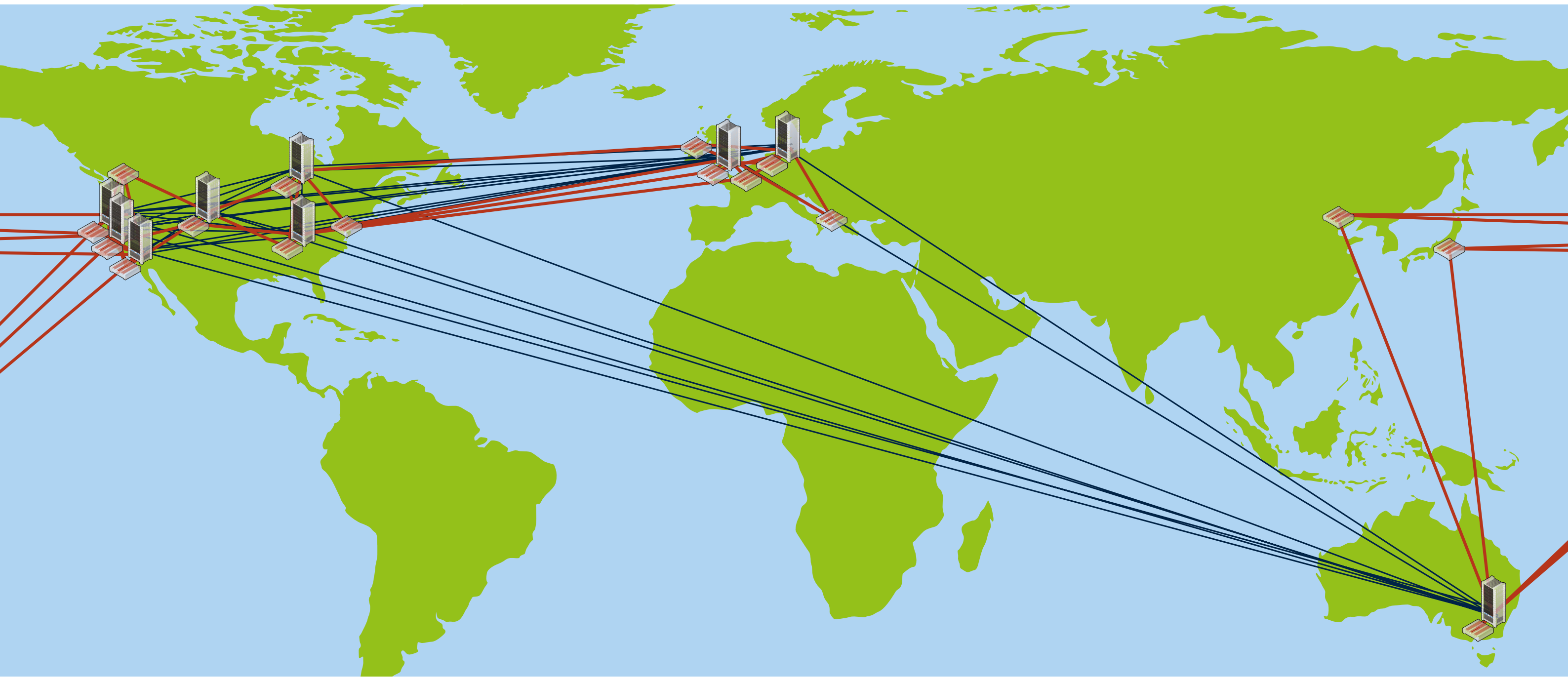
The crew chief of climate modeling

CERA database now grown to 100 terabytes

A new addition to the climate model "family" – a hydrological land model

New visualization computer "SGI Prism" delivers more graphics power for higher-resolution models

"One of my fellow students once told me I'd never be satisfied until I had the biggest computer in Germany," says Wolfgang Sell with a laugh. The physicist's focus is on numerical simulation – and his friend would prove to be right. By the early 1990s the DKRZ had become the most powerful scientific computing center in Germany, and Wolfgang Sell, its first Technical and Administrative Director, had a clear vision of the institute's role: "It's just like in Formula 1 racing: There are drivers, namely the researchers. And there are mechanics who wait at the pit and make sure the car will go as fast as possible; that's us." Sell achieved a fine balancing act, negotiating computer prices so that the DKRZ profited without alienating its distributors. He intentionally split funding between investments in computer power and in data archiving. After 17 years of service, at the end of 2004, the "crew chief" of climate modeling left the DKRZ for early retirement, secure in the knowledge that he'd left the institute technologically and structurally ready to face the future; the race was won.



The network is the computer

When researchers are faced with tasks that call for extremely high amounts of computer power, they simply get on the Internet, where they can use various geographically distributed computer systems as a virtual supercomputer. This principle is generally referred to as grid computing, and the only precondition is that the task in question has to be divisible into separate and independent sub-tasks.

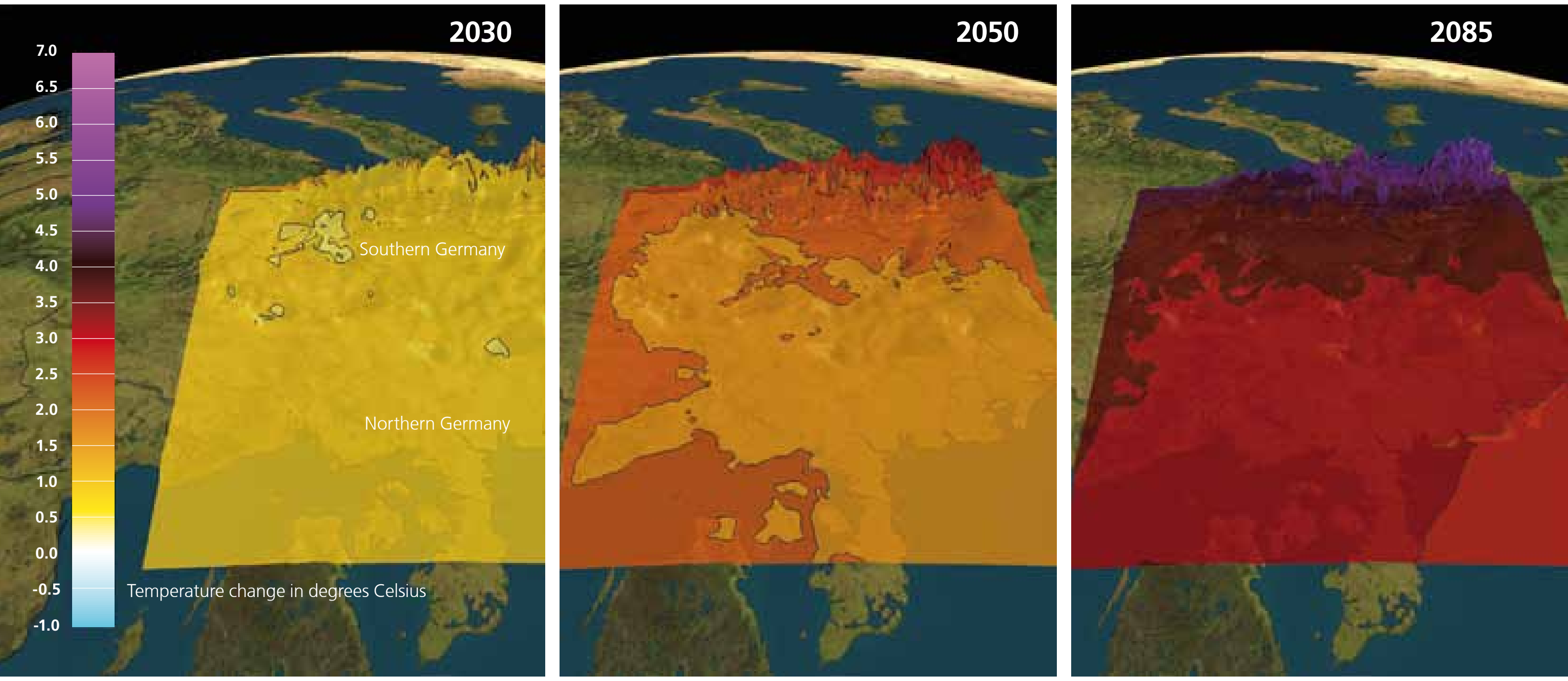
As early as 2004 the DKRZ began working together with its European partners to explore whether grid computing could also work for climate simulations. Their conclusion: No, it can't, but the idea of distributed climate data archives with uniform access was born. The transition from idea to reality began in 2005 with the Federal Ministry of Research-sponsored project "C3-Grid," which created a web portal that allowed researchers to access various climate data archives. Subsequent international projects improved the data-grid technology, which was most recently used for the global distribution of the new model simulations for the IPCC's Assessment Report for 2013 – research becomes technology.

The project "Climate Change and its Impacts" lays the foundation for networking schools and climate research

Calculations for the Fifth Assessment Report tie up a fourth of the DKRZ's computing capacity

Maximilian Prugger becomes Managing Director

2006



A warmer Germany: Assuming continued industrial growth, the rapid implementation of new and efficient technologies, and a balanced use of all available energy sources, the REMO simulation predicts that the average temperature in Germany will still rise by 2085 – by roughly 5 degrees Celsius in the Alps and by roughly 3 degrees in coastal regions.

A magnifying glass for Germany

CERA database users download 1 million files

Manfred Meinecke succeeds Maximilian Prugger as Managing Director

Linux cluster “Tornado” supplements “Hurricane”

Global climate models can only offer an imprecise view of the future. Local and regional effects are nearly impossible to portray with the large-scale grids, precluding accurate predictions for specific regions. But we all want to know what climate change would mean for us – right where we live and work. In order to find that out, scientists use a trick: Just like a magnifying glass, high-resolution regional models can zoom in on the previously calculated development of the global climate. These more precise geographic conditions and small-scale processes provide detailed regional forecasts.

On behalf of Germany’s Federal Environment Agency, in 2006 the Max Planck Institute for Meteorology used the regional model REMO to create simulations for Germany, Austria and Switzerland. With a resolution of only 10 kilometers, climate researchers were now able to analyze temperature and precipitation changes in different regions of Germany.

How much energy is climate research worth?

“We need to think farther ahead: green science!”

Actually, the electricity needed for the DKRZ supercomputer in a year would produce the same amount of carbon dioxide as roughly 7,000 cars. In the following, Professor Thomas Ludwig explains why that’s not the case, and how supercomputers’ energy consumption can be minimized.

The “Blizzard” computer uses almost 8,500 processors, and they run around the clock. How high is the DKRZ’s electricity bill?

For the computer systems and the rest of our facility, we currently use about 16 million kilowatt-hours from renewable resources per year. So the annual bill is roughly two million euros.

And will it rise for the next computer?

Not necessarily. When our new supercomputer is installed in 2014, it will deliver 20 times the performance of the one we use today – performance we need in order to make our climate models more precise. But that doesn’t mean the energy consumption will follow suit. In fact, we’ll most likely be able to keep it at the same level.

How?

Thanks to advances in semiconductor technologies, the transistors on computer chips can be made smaller and smaller. Smaller transistors take less electricity. Admittedly, this advantage is to some extent balanced out by the fact that more transistors would fit on a single chip. The big question is: How can I get maximum computer performance with minimum energy? A chip with billions of micro-transistors may “gobble up” just as much power as one with millions of larger transistors, but it delivers far better performance.

So it’s all about technology?

There’s also another aspect: Optimized programs can deliver the same scientific findings faster, which also means they need less energy. Today people are already talking about “green technology” and “green IT,” but we need to think farther ahead: green science! All researchers who work with supercomputers need electricity to get their results. The more computer power – and electricity – they use, the more findings they can produce. But with optimized programs, we can reduce that energy consumption.

Why can’t you just accelerate all of the programs?

We lack the specialized personnel. For one thing, it’s not easy to learn optimization methods for so-called parallel programs. For another, we are only allowed to invest funds in hardware; that’s a binding legal requirement. The ideal economical and ecological approach would be a different one: We could then buy a somewhat smaller computer, use the money saved to invest in personnel who can optimize our programs – and in the long run, save both energy and money.

Thomas Ludwig, Professor of Scientific Computing and Managing Director of the DKRZ

2007

The new KlimaCampus is intended to be central and vibrant. The groundbreaking ceremony is planned for the end of 2013.

Excellent: The KlimaCampus

Construction work on a new DKRZ building begins

Fourth IPCC Assessment Report released

Auxiliary Directors: Professor Jochem Marotzke (Scientific Director) and Stefan Heinzel (Technical Director)

The Federal Ministry of Research-sponsored Excellence Initiative made it possible: In recognition of the performance and expertise in climate research established in Hamburg over the course of two decades, in 2007 the Cluster of Excellence Integrated Climate System Analysis and Prediction (CliSAP) was launched with an initial mandate of five years and 31 million euros.

The alliance, bringing together the University of Hamburg, Max Planck Institute for Meteorology, GKSS Research Centre Geesthacht (as of 2010 renamed the Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research) and DKRZ, received funding for additional staff and networking was intensified – the KlimaCampus was born, finally bridging the gaps between disciplines. Meteorologists, oceanographers, geophysicists and ecologists began working closely together with experts from the social and business sciences, media studies and peace research. In 2012 the research community in Hamburg received further long-term support: Excellent research findings and the city of Hamburg's pledge to fund a new building created the ideal conditions for receiving a further five years of funding.

Earth on the screen

Computer games show us how it's done: With fluid motion and interactions, we solve riddles or problems in 3D virtual worlds. Researchers use the same 3D technology to transform climate data into images. Up to now, they had to transfer the data from the supercomputer to the personal computers in their offices to interactively visualize the model results. But climate models with higher and higher resolution produce enormous amounts of data, which means higher strains on the computers and network alike.

In 2007, the DKRZ killed two birds with one stone by simultaneously installing a central visualization server and new software for network-based 3D rendering. As a result, there was no more need for data transfers; the files never left the computing center. The only thing missing was an easy-to-use 3D visualization application. Starting in 2008 "Amira ClimateViz" (now "Avizo Green") was used to read the special data formats needed for the climate models, to essentially wrap the data directly around the 3D Earth, and to then send the finished images to climate researchers at their workstations. Input from researchers in the form of mouse-clicks and keyboard commands were sent in the opposite direction.

More than 1,000 climate researchers use the DKRZ computer

Approval procedure for Professor of "Scientific Computing" and Managing Director of the DKRZ continues

Past 1,200 years are simulated in the "Millennium Project"

DKRZ Managing Director Ludwig, Federal Minister of Research Schavan and Hamburg's First Mayor von Beust (l. to r.) push the button, symbolically starting the computations for the IPCC's Fifth Assessment Report.

At 250 square meters, the Blizzard supercomputer would fill roughly five 2-room apartments.

One hit after the other

New Managing Director Thomas Ludwig is simultaneously approved as Professor of Scientific Computing

Michael Truchseß becomes Administrative Director

First *Klimawoche* (Climate Week) in Hamburg

A new building, new computer, and new Managing Director: In 2009, changes came one after the other. The City of Hamburg authorized 26 million euros of funding to completely remodel a building to serve as the DKRZ's headquarters. In February it became home to "Blizzard," Europe's largest climate computer, and in May, the new workplace of Managing Director Thomas Ludwig. With plenty of cause for celebration, the new DKRZ was officially inducted into service on December 10, 2009. Guests in attendance included Hamburg's First Mayor Ole von Beust and Federal Minister of Research Professor Annette Schavan. Her Ministry had invested 35 million euros in the supercomputer and the new data archive – "to help Germany lead the way in climate research," according to Schavan. With the push of a button, the Minister, Hamburg's First Mayor and DKRZ'z new Director symbolically started the computations that would contribute to the IPCC's new Assessment Report in 2013. And what's more: Thanks to its peak performance of nearly 160 teraflops, scientists can now more precisely simulate regional climate phenomena like storms and small ocean eddies in global models. In the new climate data archive, the largest in the world, 56 robotic arms now juggle 65,000 magnetic tape cassettes, which can hold more than 60 petabytes of resultant data.

In the new DKRZ building, staff from the former "Model & Data Group" and the DKRZ are now once again working together under the same roof.

Reunited at last

After ten years of working separately, the technical and scientific sides of data management and model support were brought back together again: The "Model & Data Group," which had been separated from the DKRZ in 2000 and financed as an independent group by the Federal Ministry of Education and Research, jumped back on board as the DKRZ's "Data Management" department in 2010. To make this change possible, the shareholders had to make major investments, increasing the annual budget by three-quarters of a million euros.

The new department was not only put in charge of maintaining the climate database and the long-term data archiving, but also of creating a suitable infrastructure to allow it to do so. Given the rapidly climbing amounts of data, which are now approaching the double-digit petabyte range, it's increasingly challenging to develop strategies and solutions for the dissemination and archiving of climate data – two services that are indispensable for international model comparison studies and worldwide cooperation in the fields of climate and climate impact research.

DKRZ and Climate Service Center present their Climate Globe at the World Expo in Shanghai

First international conference on energy-aware high-performance computing: the EnA-HPC

DKRZ acts as a filming location for German TV thriller "Tatort"

2011

Information for everyone

Newsletter "TerraFLOPS" now relaunched as "DKRZ-Mitteilungen" (DKRZ News)

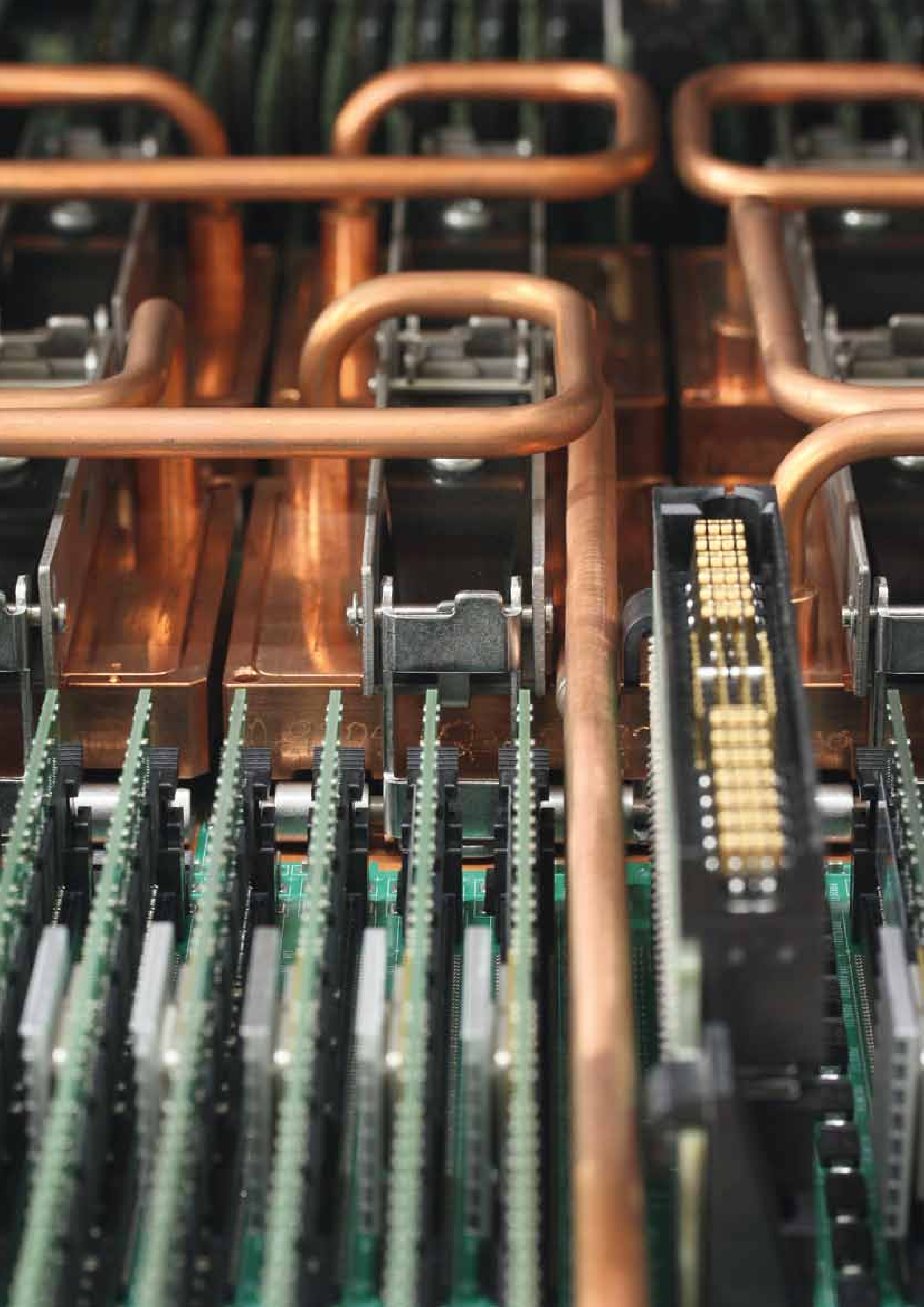
EU project EUDAT is intended to establish a European data network

Visualization server "Vision" is upgraded – and now dubbed "Halo"

How quickly information technology changes is a phenomenon the DKRZ sees not only when it comes to supercomputers. By 2011, the DKRZ website developed in 2002 was already "outdated" and completely revamped with a modern design, new organization and exciting content. At the same time, the DKRZ significantly boosted its public presence, providing information on its services and the latest climate research findings for interested members of the public, the media and experts at numerous events.

The Climate Globe proved to be a real crowd-pleaser: At events including the Hamburg Climate Week, the Extreme Weather Congress, and the Night of Knowledge, the Globe gave hundreds of visitors the chance to take an interactive journey through time and see firsthand the potential effects of climate change around the world. The DKRZ also opened its doors for Girls' Day and in 2012 for Green Day, giving young people a chance to go behind the scenes of climate research and perhaps even develop a taste for it – after all, that's how career choices start. The DKRZ also offered guided tours of its supercomputer, an opportunity that more than a thousand visitors took advantage of in 2011.

Is there a limit to what supercomputers can do?



"What we need are fast computational cores"

Every new generation of computers delivers more performance – but not without limits. Just where are the limits to this growth? We talked with computer specialist Stefan Heinzel about the current challenges IT is facing.

What sets the DKRZ apart from other scientific computing centers?
The amount of data generated. Let's take prime numbers as an easy example. If we keep going down the line of prime numbers, we'll only find one new prime number at a time. In contrast, climate models produce enormous amounts of data that have to be analyzed and archived, which is why a high-performance computing center for climate research has to be specially designed.

Computer performance isn't unlimited. Where are the technical hurdles?
In the next eight years – I don't want to predict farther than that – we shouldn't run into any major physical or technological boundaries; digital technology is still maturing. But climate research will have a harder time than other fields when it comes to capitalizing on new technologies.

Why is that?
Today computer performance is growing because hundreds of thousands of computational cores, the actual processing units, run in parallel. But time, a very important dimension for climate research, can't be handled in a parallel way. You need the results for the year 2050 before the model can calculate further data for 2051. To do this, ideally the individual cores should be extremely fast; but, since that would consume too much electricity, it's not a very reasonable solution.

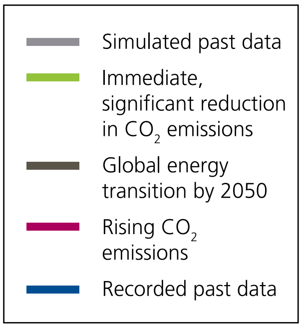
Bigger and more complex can also mean more sensitive. How stable will tomorrow's computers be?
Computers are now using more and more processors and memory modules, which makes it increasingly likely that one component or another will break down. The control system has to be capable of autonomously replacing faulty ones with functional ones. And running programs have to be able to detect interruptions so that they can continue processing right where they left off. Around the world many groups are working to make this possible for major applications.

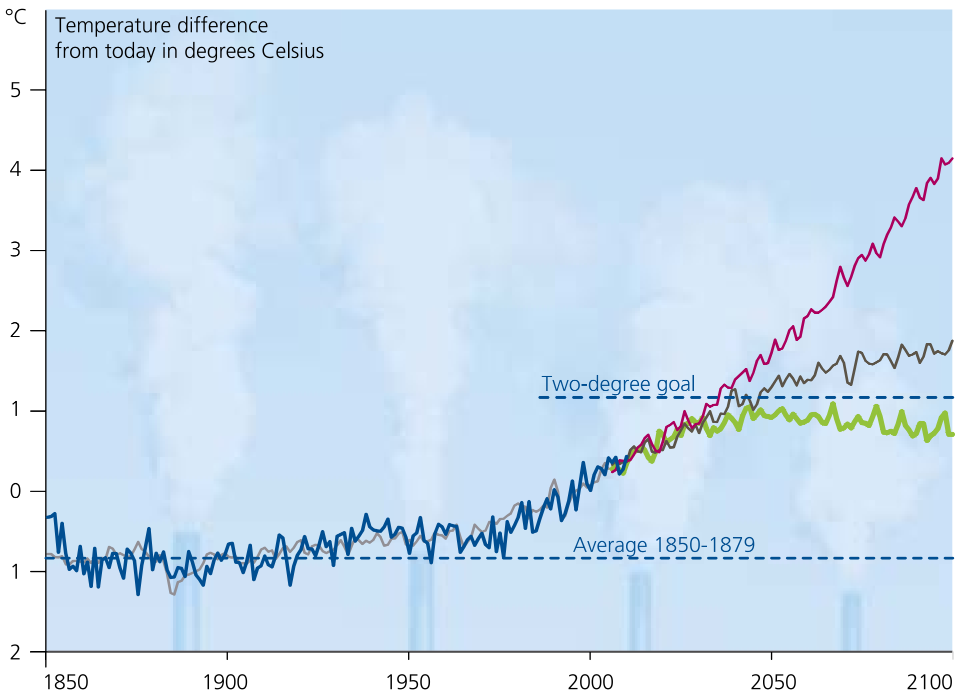
Today's digital computers work according to the laws of classic physics and IT, yet quantum mechanics could mean a major performance boom. A penny for your thoughts on the possibility ...
Well, at the moment that's still just a theoretical construct. Computing centers don't generally plan more than ten or twelve years ahead, and quantum computers won't be introduced that fast. But at some point the technology will have to proceed in one direction or the other; if not, performance will stagnate.

Stefan Heinzel, DKRZ Auxiliary Director from 2006 to 2009 and since 1993 Head of the Max Planck Society's Rechenzentrum Garching

2012

Yesterday, today and tomorrow
Since the beginning of industrialization, the mean global temperature has risen by 0.8 degrees Celsius. The different scenarios show how much it will continue to rise by 2100 – depending on how we deal with CO_2 emissions in the future (simulations with the MPI-ESM model).





The climate goal is still in sight

Federal Ministry of Education and Research grants Cluster of Excellence CliSAP an additional five years of funding

On November 11, 2012 DKRZ celebrates its 25th anniversary

DKRZ organizes a workshop on program analysis and optimization

Thanks to intensive research and new technologies, the global level of climate expertise continues to grow. Every five to seven years, researchers present the latest findings in the IPCC's Assessment Reports. For the German contribution to the Fifth Assessment Report and the international model comparison project "CMIP5," the DKRZ supercomputer "Blizzard" simulated more than 15,000 Earth years. At the DKRZ alone, a dozen specialists worked on the project.

The Max Planck Institute for Meteorology's new MPI-ESM climate model was later expanded to include two new components of our climate system: land vegetation and the biogeochemistry of the ocean, such as the development of algae. Up to that point, researchers had had to do without these important factors and their interaction with other parts of the climate system, because the calculations simply would have taken far too long. Even with Blizzard's massive performance, the simulations took two years to complete – the results were published in 2012. "According to our calculations, we can still limit global warming in this century to less than 2 degrees Celsius. But that will only happen if we can drastically reduce our carbon dioxide emissions," says Professor Jochem Marotzke, Director of the Max Planck Institute.

Vision

"The DKRZ will dependably unlock the potential of rapid technological advances for the benefit of climate research." That is our vision. Given the fact that the performance of the best computers grows roughly 1,000-fold every ten years, it also represents a challenge. More complex computer structures, increasingly complicated programming, major leaps in the amount of data involved, and a constantly growing demand for electrical power – all of these factors pose major problems for system operators and users alike. Technical solutions to these problems are developed in the field of IT. It then becomes the task of the DKRZ to translate the level of system performance achieved into scientific productivity.

More system performance also opens up new options for researchers: Models can now include a broader range of climate processes and portray changes in higher resolution, in terms of both time and space. The modern, data-intensive science of today can also glean new insights from the analysis of existent data, further boosting productivity.

The next 25 years, by the end of which mobile devices will likely offer the same level of performance as our current supercomputer, will call for more intensive collaboration between the sciences. As such, it is not only the vision but also the principal duty of the DKRZ to make the potential that technological advances offer available to climate researchers – a technical, scientific and sociopolitical challenge that the DKRZ and its staff are eager to rise to.

DKRZ

PARTNER FOR
CLIMATE RESEARCH

The DKRZ and its partners

Since the founding of the German Climate Computing Center in 1987, the number of employees has more than tripled. Today we employ 71 researchers, technicians and administrative staff – and the work of 18 project employees is currently externally funded. An additional 12 members of staff serve in Managing Director Professor Thomas Ludwig's university research group.

The DKRZ is a non-profit corporation with four shareholders.

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The DKRZ is an essential climate research partner, integrated in national, European, and international collaborative projects.

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Center for Earth System Research and Sustainability at the University of Hamburg

KlimaCampus

Max-Planck-Institut für Meteorologie

CSC Climate Service Center Germany
An institution of Helmholtz-Zentrum Geesthacht

GA Gauß-Allianz

enes European Network for Earth System Modelling

DKK Deutsches Klima Konsortium

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