



EARTH SYSTEM  
RESEARCH  
PARTNERSHIP



MAX-PLANCK-GESELLSCHAFT



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## Imprint

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Antarctic ice cores, which effectively record the history of the air's composition and temperature, can serve as a 'Rosetta stone' of the Earth system (Fig. 2). Over the last 400,000 years Earth's temperature has fluctuated in lockstep with the concentrations of the trace gases methane ( $\text{CH}_4$ ) and  $\text{CO}_2$ , even though these gases are regulated by quite different biological processes. However, externally driven temperature changes cannot explain the fluctuations of these biogenic trace gases, nor are these fluctuations sufficient to cause the observed changes in climate. This leads to the hypothesis that the biosphere along with its geophysical and geochemical environment constitutes an inextricably linked system with multiple and complex feedbacks that must be approached as a whole. Previously, Earth scientists had believed that biological processes were subordinate to the physical-geological climate system and that they adapted through evolution to the external physical conditions. While it remains vitally important to research the processes within the components of the Earth system – the circulation of the ocean, the composition of the atmosphere as well as their regulating mechanisms, for instance – it is increasingly necessary to analyse the interrelatedness of the components. How, for example, do we understand the ocean-atmosphere interactions in the context of mantle convection, volcanisms, and other long-term Earth processes? Additionally, the enormous human impact on the environment means that humans must be factored into our systemic approach to the whole.

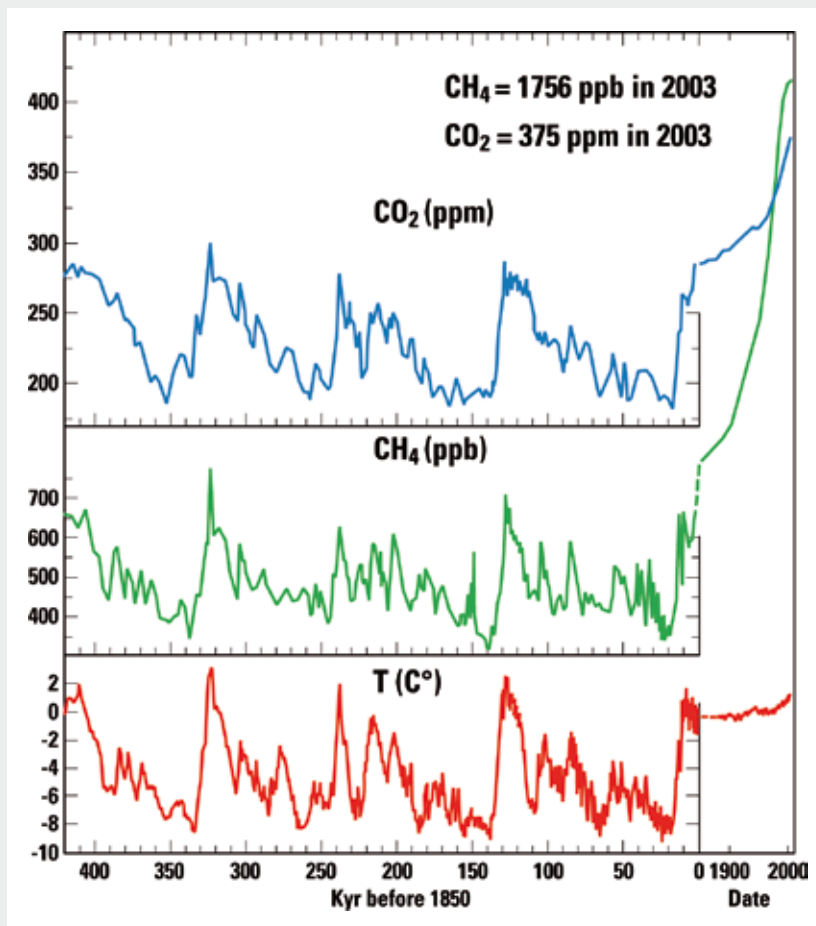


Fig. 2 (from Hansen, *Clim. Change*, 68, 269-279, 2005). Record of atmospheric carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), and temperature change extracted from Antarctic ice cores by Petit et al. (*Nature*, 399, 429-436, 1999) and from in situ and other data for the past century. The mean temperature for 1880-1899 defines the zero level of temperature. These curves show the intricate and unexplained interplay of variations in physical climate parameters and the composition of the atmosphere.

# Earth System Research Partnership

Successful Earth system research requires a combination of three methodologies. First, field measurements and experiments must be carried out, primarily to investigate processes within the system components, such as chemical reactions in the atmosphere, factors influencing ocean circulation, gas exchange between plants and air, formation of precipitation in clouds, or emission of lava, gas and dust from volcanoes. Here the observational approach, mostly in the form of field campaigns, and controlled experiments, in the laboratory or the field, complement each other.



*Fig. 3. The Terracotta Army of Xian (China) serves as an allegory of the interplay between the human population and the natural Earth system.*

Second, it is necessary to analyse the Earth on large time and space scales to understand regional, global and long-term processes and variations. The use and analysis of remote-sensing data from satellites is essential for the measurement of large-scale phenomena. The long time scales and high levels of natural variability in the Earth system call for long-term measurements at carefully selected locations and the analysis of natural archives, such as ice cores or sediment profiles.

The third pillar of Earth system research is numerical modelling. It is the fundamental theoretical tool with which we investigate the interrelationships in the Earth system. Modelling is the only 'language' in which the complex processes in the Earth system and its components can be qualitatively and quantitatively expressed. The multiple interactions and feedbacks in the Earth system often mean that the consequences of 'perturbations' (for example increase in greenhouse gas concentrations, land use change or slash-and-burn agriculture) cannot be found through linear or intuitive analysis, and seemingly paradoxical effects are frequently observed. These many interactions can only be studied properly with the help of models. We do not, however, anticipate a 'supermodel', capable of representing the entire Earth system, in the foreseeable future. Rather, models with different levels of complexity are developed, as well as models of separate parts of the system that can be coupled together in a modular fashion.



*Fig. 4. This image from the 'SeaWiFS' satellite shows many of the features currently under investigation by atmospheric and Earth system scientists – clouds, dust emanating from the Sahara desert, and industrial pollution.*



*Fig. 5. The Mauna Ulu cone. Volcanoes epitomize the interaction between the solid Earth and the Earth's fluid envelope.*

## Core scientific questions of Earth system research

In the following we present a selection of the core questions and topics being investigated now or in the foreseeable future by the Earth System Research Partnership of the Max Planck Institutes and their partners.

### 1) How is the Earth system organised?

- Systems analysis of our global environment
- Feedbacks and teleconnections
- Bifurcations, non-linear behaviour, abrupt changes, critical thresholds
- Biosphere-climate interactions
- The role of biodiversity
- Fluxes of energy, matter and information in the Earth system
- Short- and long-term interactions between the solid Earth, the ocean and the atmosphere.

### 2) Which processes regulate the distribution and availability of water?

- Interactions between aerosols, clouds and the water cycle
- Climate and the water cycle in future scenarios

### 3) Which paths lead to useful models of the Earth system?

- Theoretical foundations for new model approaches
- A spectrum of models of varying complexity
- Modular structures in Earth system models

### 4) How can Earth system models and their components be evaluated?

- Observational strategies
- Palaeo-science
- Data assimilation
- Other planets

### 5) Which regions and components are particularly sensitive to global change?

- What role do the tropics play in the Earth system?
- The role of the rapid socio-economic development in the tropical regions (megacities)
- How stable are the boreal and arctic zones?
- The oxidation capacity of the atmosphere
- Atmospheric circulation dynamics, monsoons and the hydrological cycle
- The thermohaline circulation and deep water formation in the North Atlantic
- The opening and closing of ocean passages.

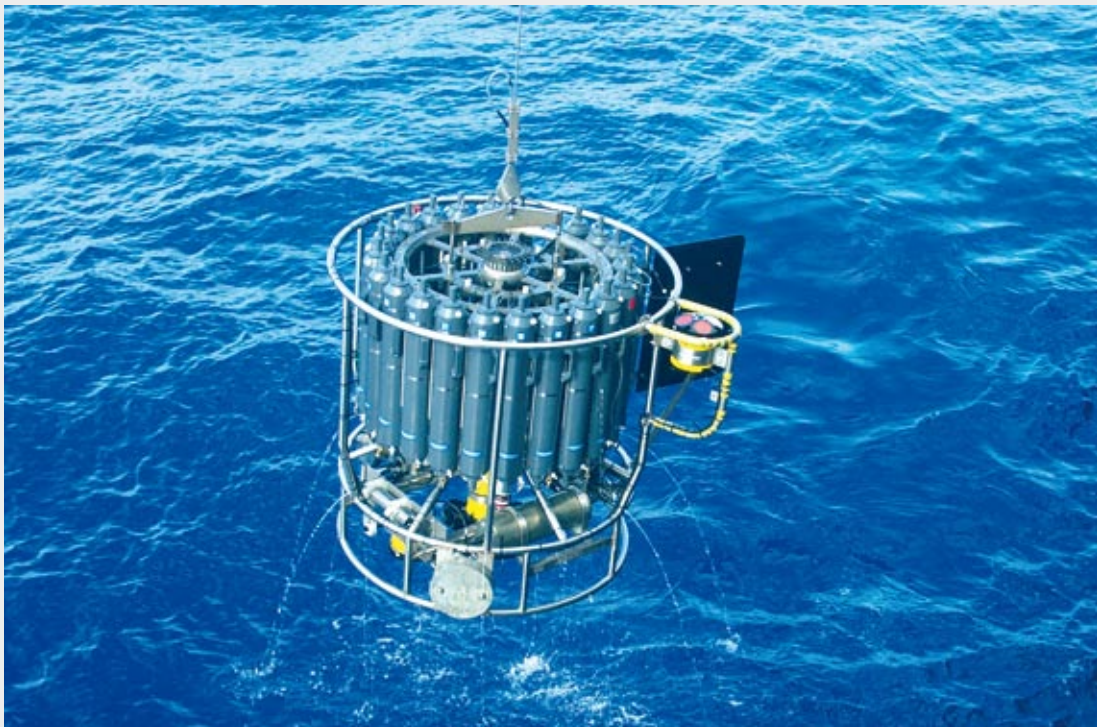
### 6) Is it possible to 'manage' the Earth system in the long-term?



## Implementation strategies

Researching all the issues listed above is well beyond the capabilities of any one Max Planck Institute. There are, however, three Max Planck Institutes dedicated to research on components of the Earth system (MPI for Chemistry in Mainz – MPI-C, MPI for Meteorology in Hamburg – MPI-M, and MPI for Biogeochemistry in Jena – MPI-BGC). In addition, divisions and groups at a number of other institutes also carry out research relevant to the Earth system (MPI for Nuclear Physics in Heidelberg, MPI for Terrestrial Microbiology in Marburg, MPI for Marine Microbiology in Bremen and MPI for Solar System Research in Katlenburg-Lindau). Starting with the institutes in Mainz, Hamburg and Jena, these institutes and research groups are now in the process of placing their work in the context of Earth system research and coordinating their strategies. The Potsdam Institute for Climate Impact Research (PIK), the German Climate Computing Centre (DKRZ) and the universities co-located with the participating Max Planck Institutes are also part of this research group.

The work described here is closely linked to major international research programmes, in particular the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP). The next section briefly describes collaborative projects that are either currently being pursued or planned for the near future by the Earth System Research Partnership. Work that is mainly located at a single institute, but which nevertheless represents an important contribution to the joint approach, is also included.



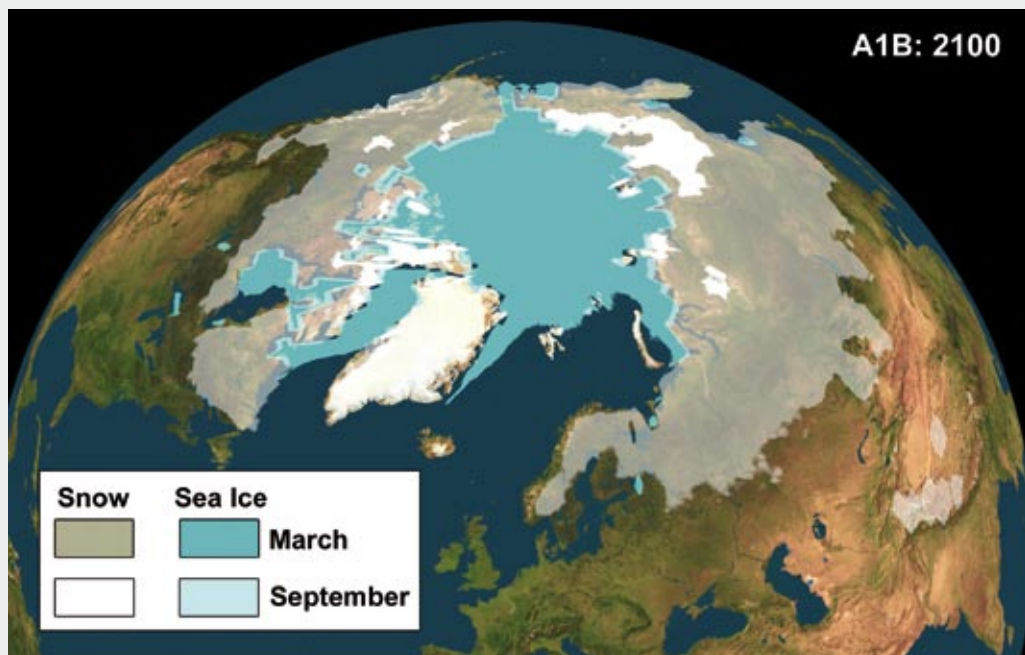
*Fig. 6. High-resolution Earth system models require a wide variety of remote sensing and in situ data for their evaluation. Here, a probe is being recovered in a project to continuously measure the strength of the thermohaline circulation at 26.5°N in the Atlantic.*

## Observations of the Earth system

- 1) Collaborative field measurement programs in critical regions of the Earth
  - Joint work between MPI-C/MPI-BGC investigating the flow of trace substances in the Amazon Basin, Europe and Siberia
  - Collaborative development and operation of a measurement tower for the study of the carbon cycle and flows of other substances in Siberia (MPI-BGC, MPI-C)
  - Studies with the new research aircraft HALO in selected regions of the Earth, e.g., China, North Atlantic, the tropics and Siberia (expected 2008, all partners)
- 2) Earth system observations through satellite remote sensing
  - Development of a working group, later a department, at MPI-C
  - Collaboration in the use of remote sensing data
  - Constructing global climatologies, e.g., the precipitation and energy fluxes over the ocean (MPI-M)
  - Establishing regional and continental inventories
- 3) Interaction of solid Earth, ocean and atmosphere (MPI-C, University of Mainz, MPI-M, MPI for Solar System Research)
  - Short-term effects, e.g., from the emission of volcanic ashes and gases
  - Long-term exchange processes (e.g., influences of hydrothermal processes on water chemistry, change in ocean circulation by tectonic plate motion and changed continent-ocean configuration, influence of weathering on the CO<sub>2</sub> budget)

## Experimental research on processes in the Earth system

- 1) Eco-physiological and biogeochemical studies on the flow of substances in the Earth system (MPI-BGC, MPI-C)
- 2) Chemical processes in the atmosphere (MPI-C, MPI-M, MPI-BGC)
- 3) Interactions of aerosols and cloud particles (MPI-M, MPI-C)
- 4) Biodiversity (MPI-BGC)



*Fig. 7. Results from the “moderate” IPCC Scenario A1B, obtained with the climate model of MPI-M. The figure shows Arctic sea ice and snow cover for September and March, in 2004 and by year 2100. According to this scenario, the Arctic Ocean will be almost completely ice-free in summer by the end of this century.*



*Fig. 8. Images of Ellesmere Island in the Canadian Arctic, taken by the 'ASTER' satellite on July 31, 2000. Big: Dobbin Bay is at the bottom of several glaciers. The detail (small image) of the leading edge of the Eugenie Glacier's 'floating tongue' reveals surface cracks and extensive calving of icebergs.*



## Modelling of the Earth system

- 1) Development of an 'Earth System Model', i.e., the coupling and further development of existing models using new numerical methods. Component models comprise:
  - Lower and middle atmosphere (MPI-M, MPI-C)
  - Ocean, sea-ice and land-ice (MPI-M)
  - Marine and terrestrial biogeochemistry (all partners)
  - Vegetation and land surface (all partners)
  - Earth system Models of Intermediate Complexity (EMICs, by PIK, MPIs)
  - Geodynamical-geochemical convection in the solid Earth (MPI for Solar System Research, MPI-C)
- 2) Regional modelling of the water cycle (MPI-M)
- 3) Assimilation of satellite and other data to improve weather and climate forecasts (MPI-M, MPI-C)

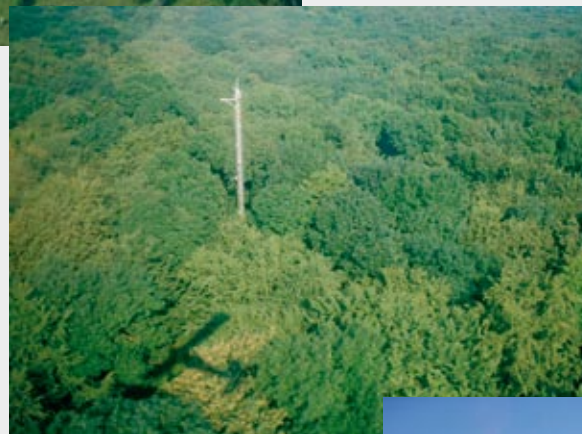


## The contribution to international programmes

The Earth System Research Partnership is closely integrated with the international research community. The current major programs, the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IDHP) and Diversitas, are joined together to form the "Earth System Science Partnership" (ESSP). Directors and scientists from the institutes of the Earth System Research Partnership contribute to these programmes as chairmen, members of Scientific Steering Committees and chairmen of core projects. They thus significantly influence the international development of these programmes. Furthermore, they play a leading role in a large number of European research projects. They also make important contributions to the periodic statements by the Intergovernmental Panel on Climate Change (IPCC).



*Fig. 9. In the Jena Experiment in the Saaleaue, interactions between plant diversity and ecosystem processes are studied on more than 80 plots with mixtures of one to 60 plant species and one to four plant functional types.*



*Fig. 10. Observation tower in the Hainich German National Park (northern Thuringia) with continuous measurements of the vertical fluxes of CO<sub>2</sub> and water vapour between atmosphere and terrestrial vegetation.*

*Fig. 11. Tall towers can be used for large-scale and long-term measurements of CO<sub>2</sub> and other atmospheric constituents. Shown is ZOTTO (Zotino Tall Tower Observatory), a new observation mast of 300m height that is currently under construction in central Siberia (near 60N, 90E) in a joint cooperation with the three MPI's and the Russian Institute of Forest, Krasnoyarsk (Photo: Y. Kisilyakhov).*



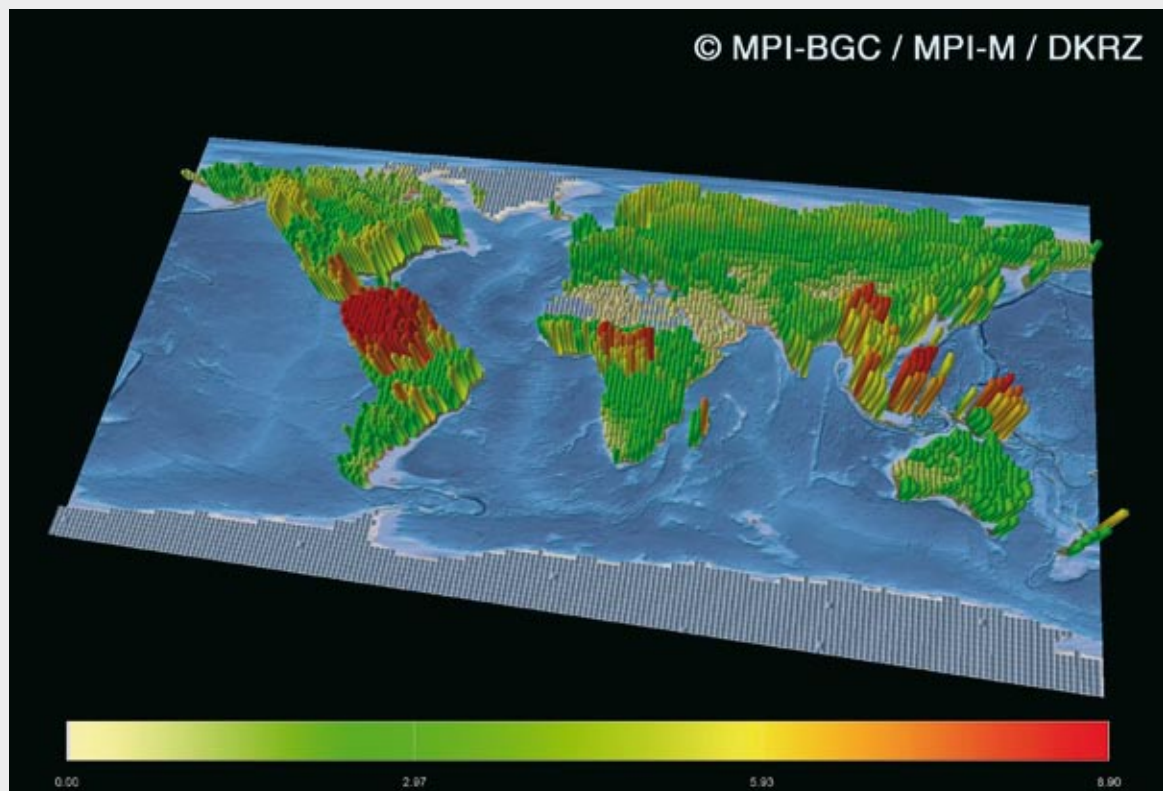
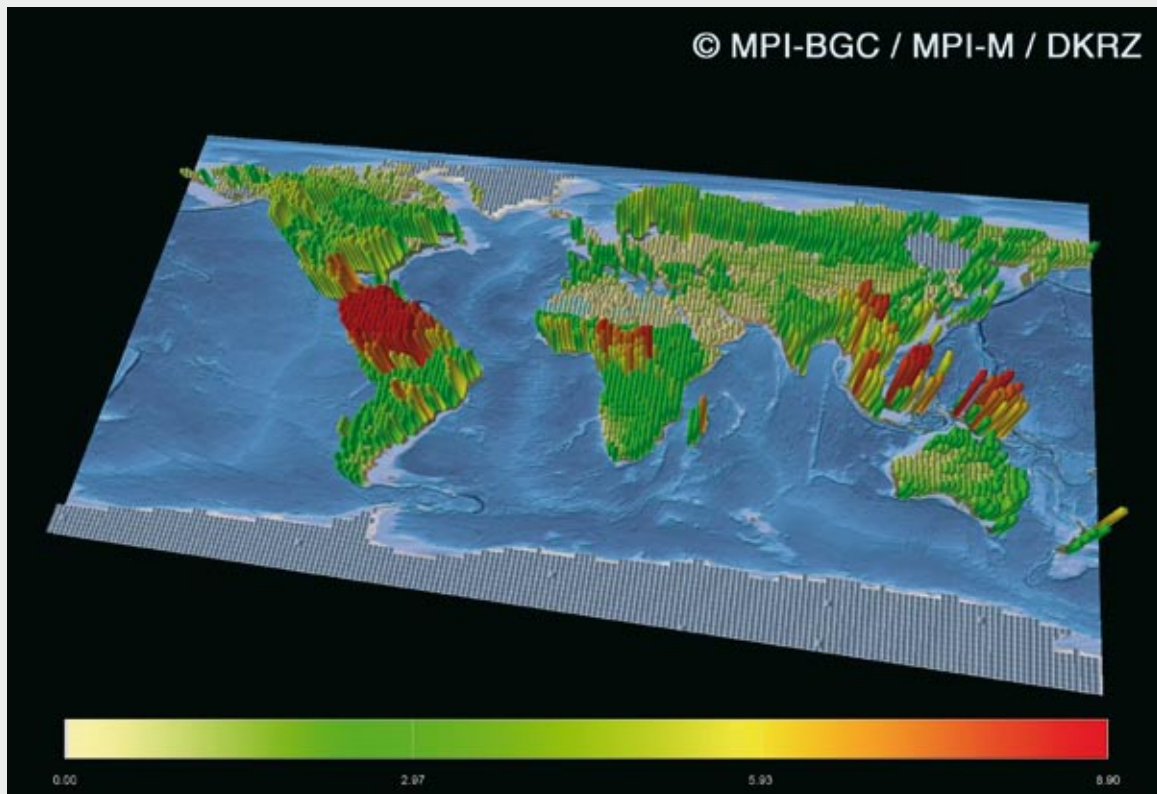
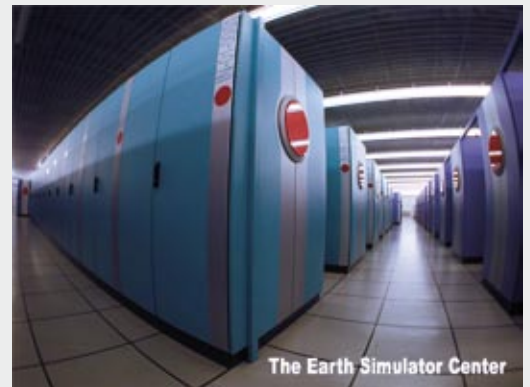


Fig. 12. Simulated vegetation intensity (leaf area per  $m^2$  of ground) for January (top) and July (bottom). Note the summertime activity in northern hemisphere mid-latitudes, the austral winter activity in Australia, and the shedding of leaves in the Siberian larch forests in winter.



## Infrastructure

A number of infrastructure components that go beyond the 'normal' infrastructure of the participating MPIs and PIK are available at present or expected in the near future. These provide important facilities required for Earth system research. The German Climate Computation Centre (DKRZ) and computational facilities at the other institutes enable the deployment of state-of-the-art model components (climate, chemistry, carbon cycle, vegetation, etc.) of the Earth system models that are currently being developed (COSMOS, MESSy). These models are made available to the international research community. A 300m high tower, under construction in Siberia, will measure the composition of the atmosphere. The research aircraft HALO, with essential financial and scientific contributions from the institutes of the Earth System Research Partnership, will represent Europe's most advanced airborne measuring platform of the next decade.



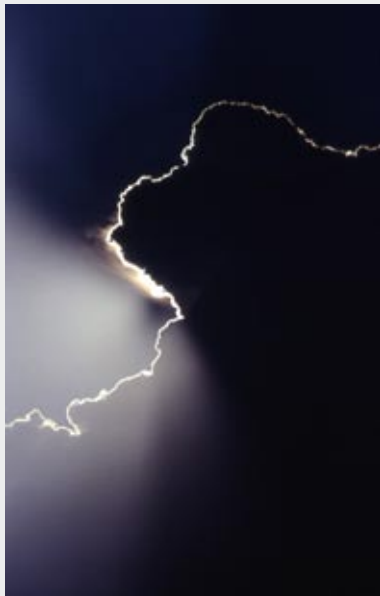
*Fig. 13. Supercomputers are indispensable in Earth system modelling. The German Climate Computing Centre (DKRZ) owns one of the most powerful computers dedicated to Earth system research in Europe (left). However, the Earth Simulator in Japan (right) is more powerful by a factor of 25.*



*Fig. 14: Artist's impression of the new research aircraft HALO (High-Altitude Long-range).*

## Outlook

It is the long-term goal of this research to develop an understanding of the Earth system that allows us to comprehend the changes in the world around us and to respond to them in an informed manner. This is the only way to find out which political and economic measures are urgent and critical for the protection of the Earth system, and how the natural resources of our planet can be used both optimally and sustainably. A solid scientific understanding of the interrelationships in the Earth system is also a basic prerequisite for convincing politicians and society at large of the necessity of difficult and far-reaching measures, such as a drastic reduction in CO<sub>2</sub> emissions. At the same time it is important to develop technological and economic alternatives, an area in which collaboration with other research establishments will be sought. These alternatives will themselves have implications for the Earth system, which we can only study through experiments with Earth system models.



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