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TerraFLOPS
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Supercomputing, IPCC and COSMOS

(by Joachim Biercamp) Two decades ago it was realized that the rapidly increasing demands on computing resources involved with realistic climate and environmental simulations could not be met by a single institute or university.

In 1987 DKRZ was founded as a national facility in order to provide the necessary computing power for quantitative simulations of the climate system with sophisticated numerical models. Since then DKRZ has been enabling many scientific projects which contributed to the internationally recognized standing of the German climate research.

Funded by BMBF and by its shareholders, DKRZ was able to maintain a leading position in supercomputing. The completion and acceptance of our latest system, the „HLRE“, which provides a peak performance of 1.5 TeraFlops and hosts more then a PetaByte of data (Figure 1), is a good occasion to review the history of supercomputing at DKRZ on the next pages.

Availability of state-of-the-art supercomputing resources is still indispensable for climate research today. A German contribution to the next IPCC report requires to dedicate up to one third of DKRZ‘s resources for more than a year to this task. The German plans for upcoming IPCC simulations are described on page 6.

In the near future complex Earth System Models will become increasingly important. These modelling systems which go beyond the scope of conventional climate models will even more rely on the availability of advanced supercomputers. COSMOS, the German initiative towards such an Earth System model is introduced on page 4/5.

A Short History of Supercomputing at DKRZ

1987 The first high performance computer of DKRZ was a **CDC Cyber 205** – a huge system (Figure 2) with a single processor, two vector units and a main memory of 32 MBytes, which reached a peak performance of 250 MFlops. The CDC Cyber 205 already was equipped with advanced processing units: *vector processors*. The execution time of vectorized (i.e. “data parallel”) code was drastically reduced compared to conventional scalar CPUs.

1988 By the end of the year the Cyber 205 was replaced by the **CRAY 2S**, at that time one of the world’s most powerful systems, with a spectacular design (Figure 3). The 4 vector processors of the system reached a sustained performance of more than 1 GFlops (theoretical peak performance: 2 GFlops), and its 1 GByte fast SRAM memory permitted much higher model resolutions compared to its predecessor. These upgrades allowed the first *coupled* 3-D-models of atmosphere and ocean to be run,

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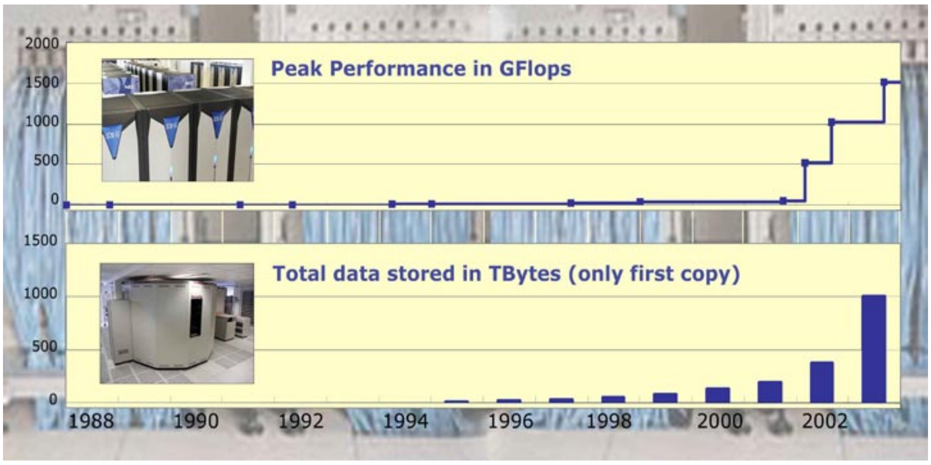

Figure 1: Development of the computing power and the amount of stored data at DKRZ. The computer performance is measured in GFlops (FLOPS = floating points operation per seconds). The amount of total data stored is given in TBytes (1 TeraByte = 1.024 GBytes)

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***Figure 2:** The first supercomputer at the DKRZ in 1988 - the CDC Cyber 205. Note the "ontop" manuals which were used instead of online manuals at that time.*

putting Germany on a par with the world leaders in climate modelling.

1990 A first robot operated silo for magnetic tape cassettes with a capacity of 1200 GBytes was installed, offering the great advantage of a 24 hour access to the mass storage system. The first transient greenhouse gas simulations with coupled atmosphere ocean models were carried out with respect to the first IPCC report (published in 1991), allocating a substantial share of the whole system. By this time the CRAY 2S was working at full capacity, and a second supercomputer, a **CRAY YMP** with 3 processors, mainly used for interactive work and model development, was added to improve the situation.

1991-92 With the installation of an additional silo the mass storage capacity was doubled. Another milestone: the hierarchical storage management system UniTree was introduced, permitting a file based access to the archive – in contrast to the previous tape based access, where the users themselves had to keep track of the organisation of files on their tapes.

1993 Even 5 years after its installation, the CRAY 2S system was still on rank 190 of the *Top500*, the list of the 500 fastest computer systems of the world (*www.top500.org/*) Nevertheless, the demand for computing time was increasing more and more and the waiting queues were rapidly getting longer. A replacement had to be found urgently!

1994 The new **CRAY C916** supercomputer (Figure 5) replaced the CRAY 2S. It was not as nicely designed as its predecessor, but, more importantly, with its 16 vector processors it reached a peak performance of 16 GFlops, pushing DKRZ up to rank 57 of the Top500. The physical exchange of the systems was a spectacular event: The computer fragments were too spacious for the lift and had to be moved in and out of the computer rooms (located in the 15th floor) with a crane (Figure 4).

At that time many high performance computer centres had installed massively parallel processor (MPP) systems with distributed memory in order to provide the required computing capacity. Could such MPP systems better satisfy the computational needs of the climate research community compared to vector supercomputers? A **CRAY T3D** with initially 32 processors, and 128 processors since 1997, was installed at DKRZ in order to evaluate this new architecture.

1995 In the first years after the installation of the new systems, the German scientific community was able, with the help of DKRZ, to defend its role as one of the world leaders in climate research. Consistently more

***Figure 3:** The successor of the CDC Cyber 205 - the CRAY 2S*

***Figure 4:** Means of transport on arrival and removal of the CRAY 2S*

and more data were produced. The total amount of data stored at DKRZ during the five years from 1988 to 1993 added up to 1 TByte, whereas in 1995 alone more than 10 TBytes were produced.

1996 DKRZ was world leader in terms of data storage and retrieval. 200 GBytes simulation data per day were transferred to or from the mass storage system, the highest transfer volumes of all UNITREE installations world wide.

1998 The CRAY C916 supercomputer was not anymore listed in the Top500, but DKRZ users were constrained to settle in with it for further three years.

2001 In preparation for the installation of the HLRE (Höchstleistungsrechnersystem für die Erdsystemforschung) a NEC SX-4 with 16 processors and 32 GBytes memory was installed as an interim system, already doubling the computing capacity at DKRZ.

2002 The installation of the HLRE began. In March, the first eight NEC SX-6 nodes with 64 processors and 512 GBytes memory in total were made available. With its 500 GFlops peak the system was able to process climate simulations up to 40 times faster than the Cray C916.

Figure 5: *The CRAY C916 at DKRZ.*

The system was ranked at position 87 of the Top500 list. Within the second phase of the HLRE installation in November, another eight SX-6 nodes were added, totalling the number of CPUs to 128 (Top500 rank 49).

2003 The system was upgraded to its final configuration (Table 1). In April the HLRE system had reached its ultimate position in the Top500: rank 33 worldwide and rank 14 in Europe. Taking into account that the *sustained* performance achievable with the majority of todays Earth System Modelling applications is much higher on architectures like that of the HLRE (e.g. parallel vector processor SMPs with high memory bandwidth and a high speed interconnection) than on MPPs, the HLRE system would even get a much better ranking: No. 2 in Europe.

In September the amount of data stored in the mass storage system reached the one PByte (1 PetaByte = 1.024 TBytes) mark.

A new shared file system between the NEC SX-6 Supercomputer and the NEC TX-7 data servers was introduced. This newly developed technology has some great advantages: it offers a very high bandwidth for transfers between both subsystems (500 MBytes/s) and it simplifies the end user access to the mass storage system.

[Michael Böttinger]
[Jana Meyer]

Table 1: *List of the supercomputers at DKRZ, their operation times and configuration.*

Computer	Manufactor / Vendor	Operating time	Number of CPUs	Peak Performance [GFlops]	Main memory [GByte]
CDC Cyber 205	Control Data Cooperation	01/1988 – 03/1989	1	0,2	0,032
CRAY 2S	CRAY Research Cooperation	11/1988 – 05/1994	4	2	1 (SRAM)
CRAY YMP		05/1991 – 05/1995	3	1	0,512
CRAY C916		04/1994 – 06/2001	16	16	2 + 4 SSD
CRAY T3D		09/1994 – 09/1995 04/1997 – 06/2000	32 128	4,8 19,2	2 8
NEC SX-4	NEC High Performance Computing Europe	10/2001 – 03/2002	16	32	32
NEC SX-6		03/2002 – 10/2002 11/2002 – 03/2003 since 04/2002	64 128 192	512 1024 1536	512 1024 1536

Towards the COSMOS Modelling System

[Guy P. Brasseur, Marco Giorgetta and Daniela Jacob,
Max Planck Institute for Meteorology, Hamburg]

http://www.mpimet.mpg.de/

COSMOS = Community Earth System Models
http://cosmos.enes.org/
http://prism.enes.org/

A major enterprise conducted at the international level, and specifically in Europe (Max Planck Society in Germany, Hadley Centre in the UK, Institut Pierre Simon Laplace in France), in the US (NSF/NCAR, NASA, DOE, NOAA) and in Japan (Frontier Program), is the development of complex Earth System Models (ESM). Such models integrate our knowledge regarding the atmosphere, the ocean, the cryosphere and the biosphere, and account for the coupling between physical and biogeochemical processes in these components of the Earth System (Figure 6). ESMs are needed to understand large climate variations of the past and to predict future climate changes. International programs, including the World Climate Research Program (WCRP) and the International Geosphere-Biosphere Program (IGBP), coordinate Earth System Modelling initiatives through their WGCM and GAIM projects, respectively.

COSMOS is an initiative of the Max Planck Institutes for Meteorology, Chemistry and Biogeochemistry, and several national and international partner institutes and scientists (*http://cosmos.enes.org* → People) to build a community ESM based on the expertise with models of Earth system components. The project is overviewed by a Steer-

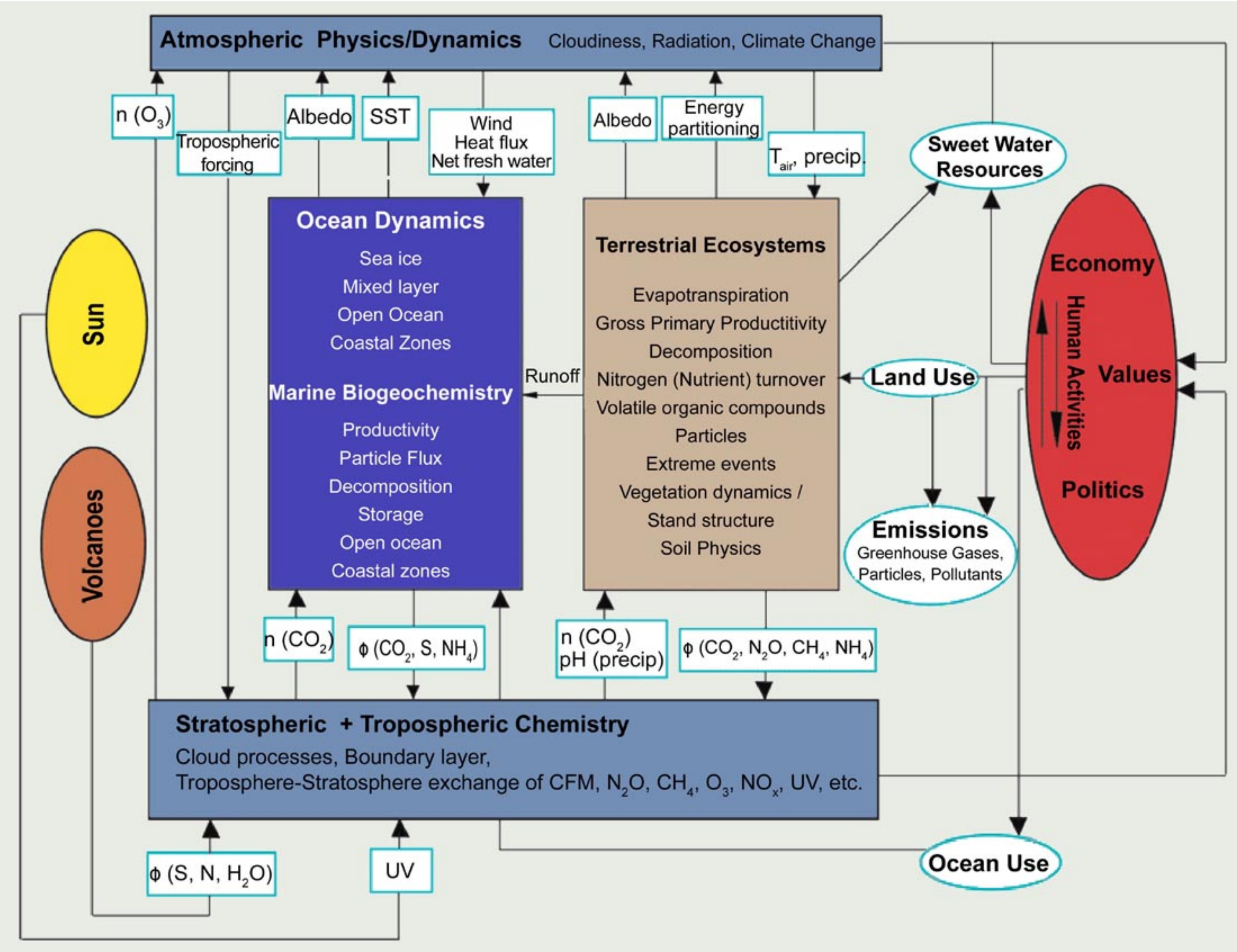

Figure 6: *Bretherton diagram of the Earth system showing the different spheres and coupling processes to be described in an Earth system model.*

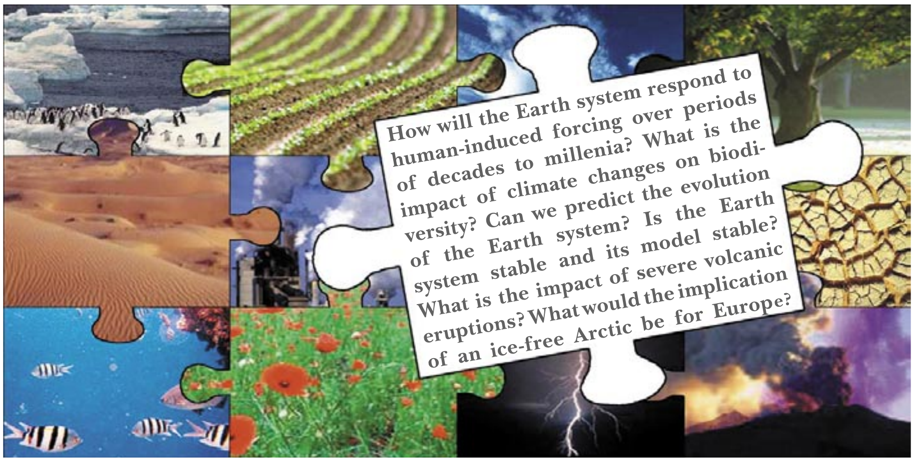

Figure 7: *COSMOS attemps to develope a complex Earth System Model (EMS) to give an answer to integrative questions as mentioned above.*

ing Committee with members of the BMBF, DFG, DLR, DMI, DWD, EC, FMI, INGV, MPI-B/C/M, PRISM, Repower Systems, SMHI, and WLA who will decide on the allocation of resources for COSMOS. Scientific guidance is given by a Scientific Advisory Group (***http://cosmos.enes.org*** → Organization).

The COSMOS project aims in the short term to create an ESM built on existing components and coupled sub sets of a full ESM, and in the longer term to obtain a flexible system with specified coupling interfaces giving freedom to exchange components. The PRISM specifications will be exploited as much as possible. During the COSMOS meeting in October 2003 the components of the first COSMOS version have been chosen. This first version will include dynamical, physical, chemical and biogeochemical processes of atmosphere, land and oceans, and will include the carbon cycle. Component models of the human activity are not yet available. Therefore anthropogenic forcing has to be imposed externally. The first version includes the following components:

- atmospheric dynamics and physics (ECHAM5)
- aerosols (HAM/M7)
- atmospheric chemistry (MECCA)
- land vegetation (JSBACH)
- land atmosphere exhange (XTSURF)
- hydrology, lateral/vertical (HD/multi layer)
- ocean/ice (MPI-OM/embedded)
- ocean biogeochemistry (HAMOCC + Dyn. Green Ocean Model)
- coupler (OASIS3)

It is planned that the first version of the complete system will be tested in summer 2004. Subsets of these models, which are already coupled, include for example [ECHAM5-HAM/M7]-[OASIS3]-[MPIOM-HAMOCC], [ECHAM5-MECCA-XTSURF], or [ECHAM5-JSBACH], where brackets denote executable units. Clearly, the development of an ESM is as much a scientific as a software engineering task, and will require substantial resources both in human power and in computer power.

The HLRE has been chosen as the host of the COSMOS model. This follows the good experience which has been gained during the last few years, when the COSMOS components have been developed and tested. In addition it is very clear that the requirements on memory, performance,

COSMOS Working Groups and co-Chairs (March, 2004)

Integration and Project Leadership	M. Giorgetta (MPI-M, Hamburg) D. Jacob (MPI-M, Hamburg)
Atmosphere: *Physics and Dynamics*	E. Manzini (INGV, Bologna, Italy) E. Roeckner (MPI-M, Hamburg)
Atmosphere: *Chemistry*	J. Damski (FMI, Helsinki, Finland) B. Steil (MPI-Chemie, Mainz)
Atmosphere: *Aerosols*	J. Feichter (MPI-M, Hamburg) R. Sausen (DLR, Oberpfaffenhofen)
Ocean: *Physics and Dynamics*	J. Haapala (FIMR) U. Mikolajewicz (MPI-M, Hamburg)
Ocean: *Biogeochemistry*	C. LeQuere (MPI-BGC, Jena) E. Maier-Reimer (MPI-M, Hamburg)
Land: *Vegetation and Hydrology*	L.Ganzeveld (MPI-M, Mainz) S. Hagemann (MPI-M, Hamburg) W. Knorr (MPI-BGC, Jena)
Regional Modelling	E. Kjellström (SMHI) D. Jacob (MPI-M Hamburg)
Data and Model Validation	E. Schaller (U. Cottbus) U. Ulbrich (U. Köln)
Data Assimiliation	H. Elbern (U. Köln) M. Heimann (MPI-BGC, Jena)

The German Contribution to the Fourth IPCC Assessment Report (AR4)

An important item on the agenda of WLA meeting in January 2004 was the German contribution to the Fourth Assessment Report (AR4) of the Intergovernmental Panel of Climate Change (IPCC). The discussion focused on the priority of experiments, the involvement of M&D and the resources needed for the simulations.

It was estimated that for the execution of the scenario runs asked for by IPCC, several hundred thousand CPU hours on DKRZs NEC SX-6 would be needed. It was decided that up to one third of the computing resources managed by WLA will be dedicated to this task, and a request for a comparable amount of CPU hours was made to the shareholders of DKRZ.

Two coupled models were considered as candidates to perform the experiments: ECHAM5/MPI-OM of the Max Planck Institute for Meteorology (MPI-M), and its predecessor ECHAM4/HOPE, which was proposed by the FU Berlin. Until May both models will be tested to assure that they fulfil the requirements for the IPCC experiments and comply with the predetermined time schedule.

At a workshop scheduled for May, 13th in Bonn (see announcement at the next page) the results of the preparatory experiments will be discussed and decisions on the model versions to be used for IPCC will be taken.

A short introduction to AR4:

The Intergovernmental Panel on Climate Change (IPCC) plans to release its AR4 in 2007. The existing working groups as well as the general structure of previous assessment reports will be maintained. The working programme for the AR4 „Climate Change 2007“ is carried out by three working groups:

- **WG I:** The Physical Science Basis
- **WG II:** Impacts, Adaptation and Vulnerability
- **WG III:** Mitigation of Climate Change

Further information on the WGs can be found on:

http://www.ipcc.ch/activity.../ar.htm#outline

The global and regional climate simulations for AR4 consist of two types of experiments: *Reference experiments* forced with past and future greenhouse gas concentrations that form the scientific base for AR4, and *sensitivity experiments* that investigate the sensitivity of climate models to CO_2 forcing (like CO_2 doubling).

The main changes of the requirements for AR4 with respect to the previous reports can be summarized as follows: The set of scenarios that will be integrated consists of A1B, B1, and A2. For each scenario and each model, an ensemble of at least three members is strongly recommended. The minimum horizontal resolution in the atmosphere should at least be T42 or 3 by 3 degrees. It is now mandatory to include the sulfate aerosol distribution (calculated interactively if possible) in the

The **A1B** scenario describes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technology. The emphasis of the technological change in the energy system is based on both non-fossil and fossil intensive energy sources, but not relying too heavily on one particular energy source on the assumption that similar improvement rates apply to all energy supply and end use technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interaction, with a substantial reduction in regional differences in per capita income.

The **A2** scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than in other storylines.

The **B1** scenario describes a convergent world with the same global population that peaks in mid-century and declines thereafter, and the rapid change in economic structures towards a service and information economy, with reduction in material intensity and the introduction of clean and resource-efficient technology. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

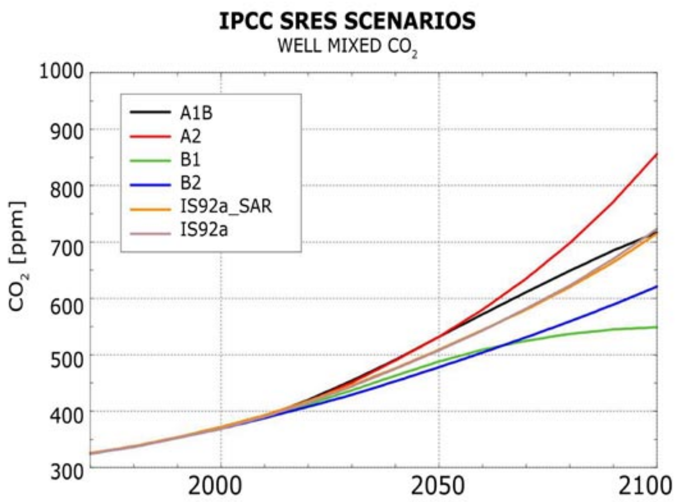

Figure 8: *Projections of the atmospheric CO_2 concentrations from year 2000 to year 2100 are based on the four illustrative SRES scenarios and the two IS92a scenarios (for comparison with SAR).*

atmospheric radiation code, and to provide estimates of radiative forcing for all greenhouse gases and aerosol components.
Other changes result from the improvements of the coupled models: The resolution has generally been increased, e.g. from T42L19 to T63L31 for the ECHAM5/MPI-OM model, and the individual model components have been improved so that flux correction is generally no longer required to avoid unrealistic climate drift.

In December 2003 WG I asked selected climate modelling centres to calculate multiple runs of the SRES (Special Report on Emission Scenarios) scenarios A1B, B1 and A2 from year 2000 to year 2200 (from year 2100 onwards with constant concentrations; see box below and figure 8). The deadline for the completion of these runs is March 2005.
The IPCC reference experiments include:

- Climate of the 20th century using observed greenhouse gases forcing from year 1860 to 2000
- SRES Scenarios A1B, B1, A2: 2000 – 2100
- SRES Scenarios A1B, B1: 2100 – 2200 with constant 2100 forcing

Additional requirements for each model are:

1. a control experiment (at least 300 years) with constant pre-industrial concentrations of greenhouse gases
2. participation in the WCRP (World Climate Research Program) Project 20C3M (20th Century Climate in Coupled Models): 1860 - 2000 experiment including observed forcing (natural and anthropogenic)
3. an experiment: 2000 – 2050 with constant (2000) concentrations

Two additional CO_2 sensitivity experiments of the WCRP Project CMIP (Coupled Model Intercomparison Program) have to be run. A 1% per year increase of CO_2 up to 2xCO_2 and up to 4xCO_2 plus 150 years with constant concentration for each experiment.
Finally, for estimating the climate sensitivity, a CO_2 doubling experiment is requested using the atmospheric model component coupled to a mixed-layer ocean.

[Jana Meyer]

Workshop

Upcoming: On May 13th 2004 a Workshop on the strategy of the German Contribution to the Fourth IPCC assessment report will be held in Bonn. It will be overseen by Martin Heimann.

The workshop focuses mainly on three topics: 1) SRES scenarios as reference experiments, 2) IPCC contributions to specific issues and 3) discussion and résumé.

Please register as soon as possible via email to M&D:
<*mad_office@dkrz.de*> or
<*luthardt@dkrz.de*>

For further information please refer to the article on the preceding page and to:
http://www.mad.zmaw.de → News → Conference and Workshops.

Majordomo list

The Model and Data Group (M&D) has set up a majordomo mailing list „mad_info“ to distribute all its upcoming news such as announcements of workshops and conferences, new models, changes in accessing M&D etc.

How to subscribe: Send an email containing subscribe mad_info in the message body to:
<*majordomo@dkrz.de*>.

You will then receive a message asking for confirmation of your subscription request which will contain a line like the following: auth 47e0268b subscribe mad_info <your_email_address>.

In order to finalize your subscription you have to resend this confirmation line to:
<*majordomo@dkrz.de*>.

News from WLA

At its 8th meeting on January 8 at the Zuse Institute in Berlin, the Scientific Steering Committee of DKRZ and M&D (WLA) thanked Prof. Dr. Hartmut Graßl and Prof. Dr. Jürgen Sündermann, who have both retired from the committee, for their valuable contributions. Two new members were introduced to the WLA. Thenceforward the Max Planck Society is represented by Prof. Dr. Martin Heimann from the MPI for Biogeochemistry in Jena and the University of Hamburg is represented by Prof. Dr. Detlef Stammer from the Institute of Oceanography.
Further information on the WLA and its past meetings are found on:
http://www.mad.zmaw.de/de/Allgeminformation/WLA/

DKRZ on *deutschland.de*

Since December 2003 the DKRZ-website has been listed on the official portal of Germany that compiles the 2000 most important, links to German tourism, economics, science, sport, culture and state and gives a short comment to each websites. The DKRZ-website is found in the categories Tourism → Weather and Climate as well as in Science → Research.

http://www.deutschland.de/

OUR SERVICES

- **Community climate models:**

  M&D provides numerical models and diagnostic software as well as user support for their application and carries out comprehensive climate model runs.

  Information: *http://www.mad.zmaw.de/ClimateModels*
  Email: *model@dkrz.de*
  Responsible: *Michael Lautenschlager (ext -297)*

- **Data Support:**

  Provision, maintenance and easy access of climate research relevant data of different research groups as well as post-processing tools and the support of users of the climate data base.

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  Responsible: *Michael Lautenschlager (ext -297)*

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- **Computer Time For Earth System Modelling:**

  Top level computing ressources and archive capacity are available to all interested research groups working on climate and earth system modelling. DKRZs scientific steering committee (WLA) selects admissible projects.

  Information: *http://www.dkrz.de/projects*
  Email: *projects@dkrz.de*
  Responsible: *Joachim Biercamp (ext -314)*

- **Support for users:**

  Support for porting models to DKRZ computers, support for model optimization, visualisation services and general user support to all users.

  Information: *http://www.dkrz.de/support*
  Email: *beratung@dkrz.de*
  Responsible: *Help Desk (ext -275)*

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