STRATEGIES

FOR FUTURE CLIMATE RESEARCH

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Edited by Mojib Latif

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Max-Planck-Institut für Meteorologie
Bundesstraße 55
D-2000 Hamburg 13

THE GERMAN CLIMATE RESEARCH PROGRAMME

By
Hartmut Graßl

In recent years many German climatologists, the German Parliament and the German Government were among those taking possible anthropogenic influence on global climate more serious than the respective groups of many other nations.

The following pages try to show for the Federal Republic of Germany how climatological research was initiated in small steps, how it developed, what has been reached and what should follow, as seen by a scientist.

1. Historical Background

Germany lies entirely in the midlatitudes within the west-wind belt under strong oceanic influence and is blessed at present climate conditions with rather low interannual and interseasonal variability. Therefore, the need for intense climatological research seemed low for the authorities and except for some individuals like Fritz Müller in Munich or Herrmann Flohn in Bonn, who were taking up anthropogenic climate change issues already in the late fifties and early sixties or even the forties of this century, no formal climate research programme did exist. This low interest is also documented in the lack of a regional general climate time series or trend analysis by the Deutscher Wetterdienst until very recently, although many time series in central Europe date back more than a century and network density is higher than everywhere else on our globe.

Since meteorology and climatology cannot be separated clearly, any meteo rological research is always a contribution to climatology. A first strong improvement of the capabilities for meteorological research was reached with the first modern research vessel METEOR, which contributed already during its first cruise to the Indian Ocean to an international programme. The funding of projects for distinct cruises was given by the German Science Foundation.

If one tries to find early meteorological research programmes - not

single projects - in the Federal Republic of Germany one will first find loosely coordinated groups also funded by the German Science Foundation (Deutsche Forschungsgemeinschaft) in socalled "Schwerpunktprogrammen", where a group of scientists carefully formulated an envelope for a distinct portion of meteorological research. All German scientists in research institutions, if accepted in a peer review, could participate in these projects which normally lasted 5 to 8 years. The first of these started in 1966 and was named Energiehaushalt und Allgemeine Zirkulation (Energy Budget and General Circulation) and was strongly devoted to the improvement of weather forecast models, then still including barotropic models. In the late sixties and early seventies the German Science Foundation started still larger projects in meteorology and oceanography so called "Sonderforschungsbereiche" in Mainz/Frankfurt, Berlin and Hamburg, initiated and pushed by Christian Junge, Walter Scherhag and Karl Brocks, respectively. The consecutive numbers given to theses specific research themes 73 in Mainz/Frankfurt, 94 in Hamburg and 39 in Berlin, tells us how many of these were proposed and that climate related disciplines were not the first to get strong and coordinated funding for a distinct university. In view of the presently started International Geosphere Biosphere Programme (IGBP) two of these "Sonderforschungsbereiche" No 73 in Mainz/Frankfurt studying atmospheric trace substances (Atmosphärische Spurenstoffe) and No. 94 in Hamburg studying the ocean (Meeresforschung) meant an extremely early start of real interdisciplinary research, combining for instance in Hamburg meteorological, oceanographic and biological research. Within the Fladenground Experiment 1976 in the northern North Sea, for example, phytoplankton dynamics as a function of physical and chemical conditions have been studied and also led to the remote detection of chlorophyll fluorescence (by Roland Doerffer), a spectral feature now discussed for the use in new satellite instruments. Thus a typical JGOFS (Joint Global Ocean Flux Study) project took place in 1976 investigating facets of the global carbon cycle.

In the Mainz/Frankfurt research programme air-chemistry investigations were initiated which then seemed to many quite academic, for example the measurement of vertical profiles of dinitrogenoxide (N_2O), however, have started studies on the sink of a quite inert trace gas, which is number four of the atmospheric greenhouse gases and whose decay products in the stratosphere, NO molecules, are - as we now know - responsible for most of the natural ozone destruction by catalytic reaction chains.

In 1972 another climate related initiative, which now can be called one

of the corner stones leading to the ERS-1 satellite launched on the 17th of July this year, was started by the main actor in the present German climate modelling scene, the cause for this volume, Klaus Hasselmann: JONSWAP (Joint North Sea Wave Project), meant to explain how sea waves are generated by wind stress, but stimulating much more, for instance the international sea wave modelling group (SWAM) and finally leading to validated global sea wave models usable together with the forecast of the European Centre for Medium Range Weather Forecasts for ship routing one week ahead.

Another level of organisation was reached, when in 1973 the German Science Foundation formed a Senate Commission for Atmospheric Sciences (Senatskommission für Atmosphärische Wissenschaften) initiated and chaired until 1989 by Hans Hinzpeter. From this time onwards new research programmes and actions by the meteorological community could be prepared on a much broader scale. Meteorology and climatology related programmes were sometimes initiated, always reviewed and eventually recommended by this commission.

A good example is the contribution of Germany to GATE (GARP Atlantic Tropical Experiment in 1974; GARP = Global Atmospheric Research Programme a forerunner of the Global Climate Research Programme, the latter initated 1979 by the First World Climate Conference) when three research vessels were sent and the intercalibration of turbulent heat flux measuring buoys was coordinated. Germany supported GATE with 6 Mio DM as well as 90 persons from 11 institutions.

A further big step, showing the importance gained by climatological research among scientists, was done in 1975 with the foundation of the Max-Planck-Institute for Meteorology in Hamburg by the Max-Planck-Society. Fortunately, Klaus Hasselmann, a theoretical physicist working in oceanography became director of this institute. The main goals of the new institute were climate modelling and process studies in the planetary boundary layer over the open ocean. Up to this foundation and into the late seventies a strong interest in climatological research from the German government was not documented. The first indication of the existence of an anthropogenic influence on global climate in official papers can be found in 1978, for example in the yearbook of the Umweltbundesamt (Federal Environmental Protection Agency), although restricted to some lines in a volume of some hundred pages. However, already in 1979 a first proposal for a national climate research programme has been accepted by the Federal Cabinet, after but in line with the first climate programme of the European Communities.

2. The Climate Research Programme of the Federal Republic of Germany

Nearly at the same time an initiative of scientists, stimulated and guided by the Commission on Atmospheric Sciences of the German Science Foundation had led to a first draft of a climate research programme following a meeting of scientists in Bad Sooden-Allendorf in 1979, the year when the First World Climate Conference did point to the possible impact of mankind on global climate and had urged governments to strengthen climate research. This first draft emphasized the need for basic climatological research, was still strongly oriented towards atmospheric processes and did not find immediate realisation in a government funded research programme. The volume of funding desired and necessary for such a complex topic as understanding climate processes was no longer within the scope of the German Science Foundation. Finally, shortly after the change in government, the Climate Research Programme of the Federal Government was started in October 1982. It was the begin of an unprecedented growth of climate research in Germany. The programme was structured for a first phase, which lasted until 1989, by another scientists meeting in Bad Sooden-Allendorf in October 1983. The following main topics were established and coordinators were named:

⊙	climate modelling and diagnostics	Hasselmann
⊙	radiation and clouds	Raschke
⊙	land surface climatology	Roth
⊙	mesoscale modelling	Fiedler
⊙	terrestrial paleoclimatology	Frenzel
⊙	marine paleoclimatology	Samthein

Although tried, a climate impact group was not established.

How does this structure and the results achieved so far relate to the pillars of climate research as seen from a present point of view?

2.1. The Pillars of Climate Research and Climate Forecasting

The nonlinear coupling at strongly different time scales, typical for the climate system components biosphere, atmosphere, hydrosphere, cryosphere and lithosphere and the dependence of the planetary radiation budget mainly on trace gases and water in all three phases, gives rise to continuous climate change at all locations. To forecast this change is extremely difficult or may - if near to a bifurcation - be in principle impossible. Climate on Earth has shown preferred states, for example recent interglacials lasting 10 to 15

thousand years with only small amounts of inland ice on the Northern Hemisphere imbedded in 7 glacials of roughly 100 thousand years duration, causing large ice-sheets to advance seven times into midlatitudes in America and Europe.

A continuous global three-dimensional monitoring in ocean and atmosphere as well as global land surface observations for years, although surely the most important pillar of climate research, do not suffice to understand the full variability of climate. We also need numerical models of the climate system components interactively coupled to each other and validated by these global observations of present climate conditions. These validated models then may be used for sensitivity studies in order to understand climate processes, especially in view of the lack of a real global observing system for the ocean. For forecasting purposes under changed conditions, however, this is again insufficient. We also need paleoclimatological data bases to test the models under strongly different conditions before they are used as a forecasting tool.

2.1.1. Observations and Process Studies

Numerical models of climate system components normally lack precision, because all processes and pheonomena not resolved by the numerical grid have to be parameterized. Therefore, model improvement is depending on new or better parameterisations and these again are derived from specifically designed process studies or mesoscale models resolving some processes. In turn the experimental studies constitute special observing periods. The national climate programme has included such process studies especially for cirrus clouds (realized as the International Cirrus Experiment (ICE) coordinate by Erhard Raschke). Also the land surface climatology group organized common experiments, which tried to show the impact of different land uses on climate parameters. The German Science Foundation, which always was stimulating basic research in climatology earlier than other organisations, supports the Sonderforschungsbereich 318 "Climate-Relevant Processes in Atmosphere, Ocean and Cryosphere", which has as its main goals the understanding of deep water formation in the Arctic and of the corresponding processes within the convective atmospheric planetary boundary layer.

2.1.2. Numerical Models

The national climate programme has put the main emphasis on climate system modelling; the advisory committee has proposed to concentrate on a single global atmospheric circulation model taken from the European Centre for Medium Range Weather Forecasting; the Ministry of Research and Technology has financed in 1984 a fast computer, a CYBER 205 at the Max-Planck-Institute for Meteorology in Hamburg, to be used by all climate modellers; the advisory committee has proposed to create a climate computing centre (foundation in January 1988 in Hamburg as "Deutsches Klimarechenzentrum (DKRZ) GmbH"); the global climate modellers at present using two CRAY super-computers financed by the Ministry for Research and Technology have not only learnt to run two coupled ocean-atmosphere models but also have developed a global carbon cycle model, dynamic ice-sheet models, global aerosol transport models for troposphere and stratosphere as well as coupled ocean-atmosphere-sea ice models.

2.1.3. Paleoclimatological Data

The first structure of the National Climate Programme contained with terrestrial and marine paleoclimatology two groups, which were asked to concentrate their studies on distinct time intervals during the last ice age cycles, thereby including the warm periods approximately 6000 and 125000 years before present. Since the interest in rapid climate changes grew during the last years the emphasis was broadened recently to these events especially for the North Atlantic.

2.2. Some Highlights of the Results

Since climate research is organized strongly international, it is difficult to name the origin of achievements. The following few major results are presented only as a subset of those results where German scientists have contributed substantially.

2.2.1. Northern Hemisphere Land Surface Paleoclimate

The terrestrial paleoclimatology group has compiled convincing evidence of a much drier and colder climate 18000 years before present at nearly all locations on all continents and a warmer and on average much more humid

climate around 125000 and around 6000 years before present. The strong increase in temperature with latitude at higher precipitation found for the warmer periods also led to a strong northward shift of the tree-line and only a minor shift of the southern forest margin, thus increasing the forested area. Since the warmer periods are often proposed to be used as an analogue, which we might reach again quite soon due to the anthropogenic greenhouse effect addition, one has to be very carefull in interpreting these results. The data compiled represent climate under a different solar radiation distribution throughout the year. Therefore, only climate model runs foreced with different Earth orbital elements and the much more rapid increase in greenhouse gases than occurring under natural conditions, after validation with the paleoclimate record, can give the desired answer.

2.2.2. Coupled Ocean-Atmosphere Models

The most important step in understanding climate processes on time scales of centuries was done during the last two years, when the first coupled ocean-atmosphere models without climate drift for present climate conditions and with the ability to handle correctly time dependent radiative forcing became available. Klaus Hasselmann's group was the first to present results for two of the scenarios of possible greenhouse gas increases proposed by the Intergovernmental Planel on Climate Change (IPCC) established by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP). These results will strongly influence the discussions on the containment of the additional greenhouse effect. Main and new points are (see also Figure 1):

- The strong delay of global warming of some decades by the oceans heat capacity only allows roughly one half of the warming, to which we are already committed, to be realised at the present increase in trace gas concentrations.
- Areas of strong wintertime mixing in the ocean are warming far less than other ocean areas and these again less than land surfaces, enhancing the land-ocean temperature differences significantly and also pointing to an intensified monsoon circulation. Also the Southern Hemisphere is thus warming less rapid.
- The global mean precipitation increase after a warming is due to enhanced rain in the inner tropics and high northern latitudes.

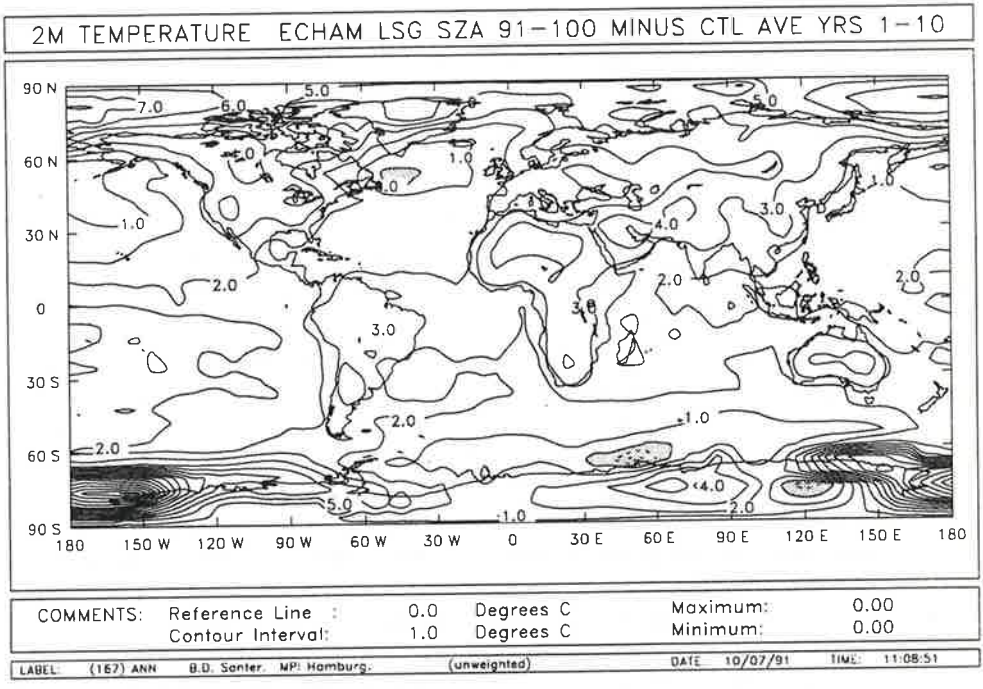

Fig. 1: Surface air temperature increase in 2085 for scenarios A (business as usual) of IPCC as calculated by a coupled ocean-atmosphere model (Cubasch et al., 1991).

2.2.3. Global Climate Sets from Remote sensing

The radiation budget of our planet cannot be measured directly, but it is derived from remotely sensed backscattered or emitted radiances. Although other global data sets are in principle accessible from direct observations, they are more easily derived from remote sensing by satellites. Together with American colleagues German climatologists have derived the yearly course of the planetary radiation budget also separated into the ocean and continent portion (see Figure 2) have derived new validated algorithms and global data sets for water vapour column content over oceans and sea surface skin temperature. These data sets are most valuable for more thorough climate model tests, which have been started now.

2.2.4. Was it a Successful Programme so far?

The concentration on global coupled models, distinct process studies and paleoclimatology was the correct approach as seen by the success of most of the coordinated investigations. The development of mesoscale models for parameterisations in global models and the measurements of land surface climatology processes for the improvement of mesoscale models, which are needed for climate impact studies, were not as successful as the branches mentioned earlier. Desirable future new branches will be named in the next section.

2.3. Further Steps of the National Climate Programme

Despite the strong increase in funding and the overall scientific success of phase I of the national climate programme some deficiencies and new questions clearly emerged:

- Concerning **numerical models** time has come to concentrate efforts for global air chemistry models and for mesoscale atmospheric circulation models in order that a community model be defined which is supported by one of the larger research organisations and which is then improved by a concerted national or international action as done for the coupled ocean-atmosphere model, which now should be developed into global carbon cycle models, i.e. should calculate carbon dioxide concentration from given emissions.

PLANETARY RADIATION BUDGET

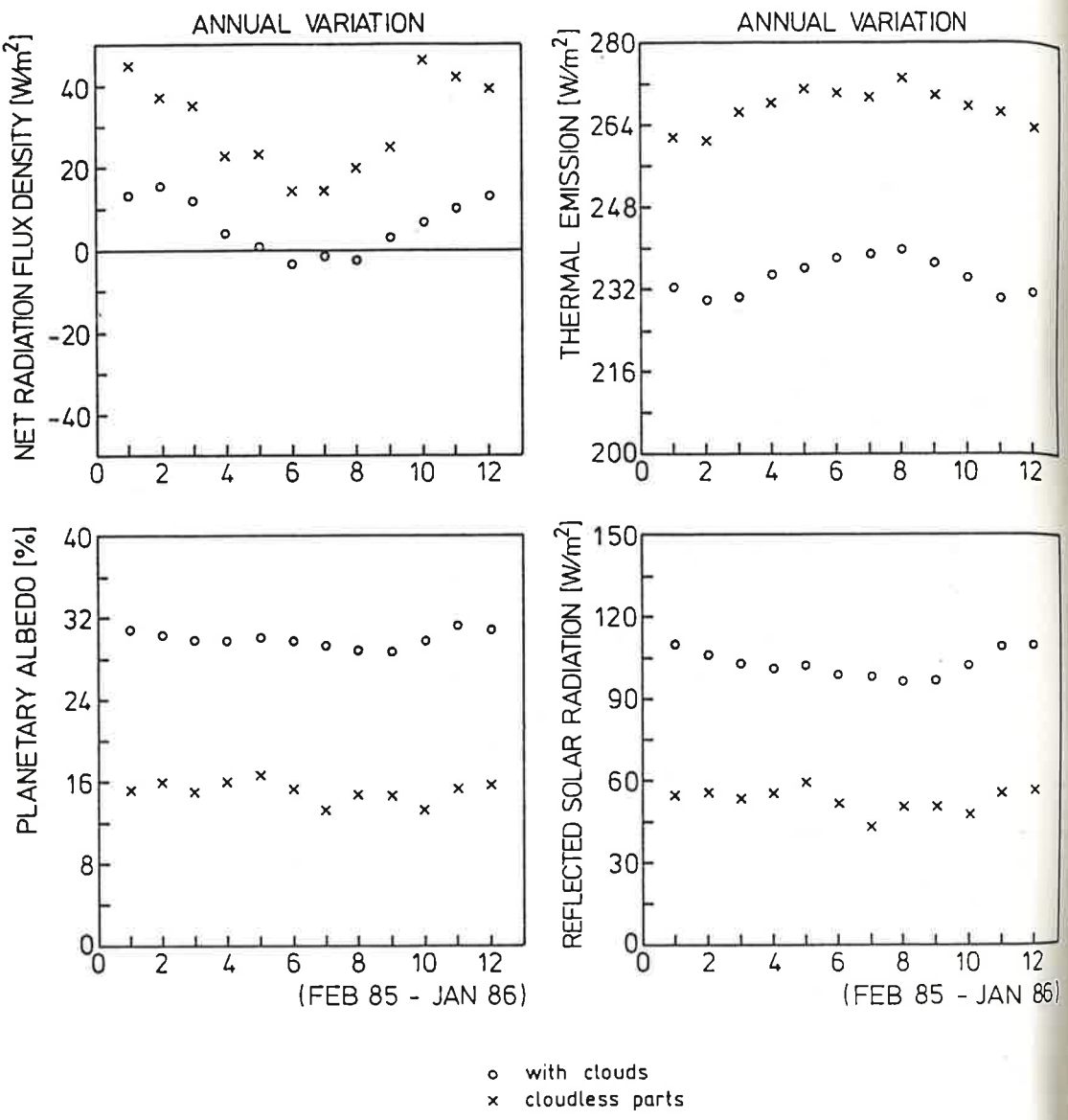

Fig. 2: Seasonal variation of the global radiation budget, also separated into the ocean and continent portions as measured by Earth Radiation Budget Experiment (ERBE) satellites (Rieland et al., 1991).

- The **climate impact** research has to become a new pillar concentrating - as already proposed by the Scientific Climate Advisory Committee to the Federal Government installed in 1988 as desired by the Bundesrat and stimulated by the Government of Bavaria (wissenschaftlicher Klimabeirat der Bundesregierung) on a few topics only but not excluding socioeconomic impacts.
- **Climate diagnosis** including climate model output and the search for new extrema should be coordinated and should include more strongly the German Meteorological Service.
- Germany has to contribute more to the **long-term monitoring** of climate-relevant trace substances and the efforts to understand sources and sinks of these substances including feedback mechanisms at changed climate.
- National climate research programmes as a whole should be reshaped according to the development of the **Global Change** Programmes. A first immediate task in this respect is the coordination of activities within the former land surface climatology group, the planned Global Energy and Water Cycle Experiment (GEWEX), the established core project Biological Aspects of the Hydrological Cyle (BAHC) within the International Geosphere Biosphere Programme (IGBP) and the upcoming German Science Foundation project "Regionalisation in Hydrology" (Regionalisierung in der Hydrologie).

Hopefully these tasks will be supported by the Federal Government at a level according to the growing importance; other authorities, the Länder for example, should also take part in national and international coordination and in funding more strongly than up to now.